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The Precautionary Principle in the Information Society

Effects of Pervasive Computing on Health and Environment

Lorenz Hilty, Siegfried Behrendt, Mathias Binswanger
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Zusammenfassung

Pervasive Computing ist eine zukünftige Anwendungsform von Informations- und Kommunikationstechnologien (ICT), die durch Miniaturisierung und Einbettung von Mikroelektronik in andere Objekte sowie ihre Vernetzung und Allgegenwart im Alltag gekennzeichnet ist. Anders als die meisten heutigen ICT-Produkte werden Komponenten des Pervasive Computing mit Sensoren ausgestattet sein, über die sie ihre Umgebung erfassen, ohne dass der Benutzer dies aktiv veranlasst.

Eine so weitgehende Vision der Durchdringung des Alltags mit mikroelektronischen Komponenten, die immer und überall eingeschaltet und weitgehend drahtlos vernetzt sind, wirft Fragen nach möglichen unerwünschten Nebenfolgen dieser Technologie auf. Den erwarteten Vorteilen sind die teilweise ungeklärten Risiken gegenüberzustellen, die in der Verwirklichung dieser Technologievision liegen. Bei der Abwägung von Chancen und Risiken stellt sich die Grundfrage der Technikethik: „Mit welcher Technik wollen wir in welcher Welt leben?'

Diese Frage kann nur im gesellschaftlichen Diskurs beantwortet werden. Ziel der vorliegenden Studie ist es, einen sachlichen Beitrag zu diesem Diskurs zu leisten, indem sie mögliche Chancen und Risiken des Pervasive Computing aufzeigt. Dabei liegt der Schwerpunkt auf Risiken für die menschliche Gesundheit und die Umwelt.

Schon die Identifikation und Unterscheidung von Chancen und Risiken setzt indessen die Orientierung an Wertgrundlagen voraus und kann nicht innerhalb der Wissenschaft allein entschieden werden. Diese Studie orientiert sich bei Bewertungen an den Prinzipien der traditionellen Ethik (Achtung der Menschenwürde, Fürsorgeprinzip und Gerechtigkeit), ergänzt um das *Vorsorgeprinzip* und die Leitidee *Nachhaltige Entwicklung*. Der gemeinsame Kern von Vorsorge und Nachhaltigkeit ist die Erweiterung des Gerechtigkeitsprinzips auf zukünftige Generationen im Sinne einer intergenerationellen Fairness: Heutiges Handeln soll die Freiräume für zukünftiges Handeln möglichst nicht einschränken.

Die eilige Leserin und der eilige Leser können sich über die Ergebnisse der Studie wie folgt informieren:

- über politischen Handlungsbedarf und weitere Empfehlungen in Kapitel 9
- über die untersuchten Chancen und Risiken und deren Bewertung in Kapitel 8
- über Fachbegriffe und Abkürzungen im Glossar

In jedem Fall empfiehlt sich zusätzlich die Lektüre der Einleitung (Kapitel 1), die Gegenstand, Zielsetzung, Methode und Aufbau der Studie erläutert. Es folgt eine Kurzfassung der Kernaussagen der Kapitel 2-9.

Kapitel 2: Das Vorsorgeprinzip dient dem Umgang mit Risiken in Situationen, in denen keine akute Gefährdung gegeben ist. Es hat den Zweck, auch solche Risiken zu minimieren, die sich möglicherweise erst langfristig manifestieren, und Freiräume für zukünftige Entwicklungen zu erhalten. Das Leitbild „Nachhaltige Entwicklung' besagt, dass sowohl eine *intra-* als auch eine *inter*generationelle Gerechtigkeit Ziel der gesellschaftlichen Entwicklung sein sollen. Vor diesem Hintergrund identifiziert und bewertet diese Studie Chancen und Risiken des Pervasive Computing. Neben Gesundheits- und Umweltaspekten im engeren Sinne kommen dabei auch Wirkungsfelder in Betracht, die im ICT-Bereich seit längerem diskutiert werden: Datenschutz,

Sicherheit, die Folgen unbeherrschbarer Komplexität technischer Systeme, die zunehmende Abhängigkeit von solchen Systemen, Auswirkungen auf die Gleichstellung der Geschlechter und die „Digitale Spaltung'.

Kapitel 3: Die Miniaturisierung der Mikroelektronik wird noch ca. 10 Jahre ohne Technologiebruch voranschreiten. Sie ist eine wesentliche Triebkraft für die Realisierung der Vision „Pervasive Computing'. Eine entscheidende Rolle wird die weitere Entwicklung der drahtlosen Vernetzung durch Mobilfunk, aber auch durch lokale Netzwerke (W-LAN) spielen. Die Energieversorgung mobiler Komponenten wird bei zunehmender Anzahl (hunderte Komponenten pro Person) nicht mehr primär über zu wechselnde oder am Netzteil aufzuladende Batterien geschehen können. Andere Energieversorgungskonzepte wie Solarzellen, Brennstoffzellen oder die Nutzung von Körperenergie werden sich stärker verbreiten. Viele Komponenten werden auch nur durch Kontakt oder durch ein Versorgungsfeld aktiviert werden, wie das heute bei Chipkarten bzw. 'intelligenten Etiketten' (Smart Labels) der Fall ist. Pervasive Computing wird sich nur dann auf breiter Basis durchsetzen, wenn Fortschritte im Bereich der Benutzerschnittstellen gemacht werden, etwa bei der Steuerung durch gesprochene Sprache. Eine wesentliche Neuerung gegenüber der heute verbreiteten ICT ist die Kontextsensitivität: Die Komponenten reagieren auf ihre Umgebung und können daher auch ohne Aufforderung durch den Benutzer aktiv werden. Im Softwarebereich werden so genannte Agententechnologien an Bedeutung gewinnen. Dabei delegiert der Benutzer Entscheidungen an Programme, weil er den Informationsfluss anders nicht mehr bewältigen kann.

Kapitel 4: Von den ausgewählten Anwendungsfeldern Wohnen, Verkehr, Arbeit und Gesundheit ist im Verkehr die rascheste Entwicklung zu erwarten. Das Auto ist durch seine Geschlossenheit und stabile Energieversorgung eine Testplattform für Pervasive Computing und wird in den kommenden Jahren immer „intelligenter' werden. Das „intelligente Haus' wird sich dagegen eher langsam durchsetzen, wenngleich die heutige Verkabelung für Computer, Telefon usw. weitgehend drahtlosen Verbindungen weichen wird. Unter den Querschnittstechnologien digitale Informations- und Unterhaltungsmedien, Wearables und Smart Labels (die hier alle unter Pervasive Computing gefasst sind) werden die Smart Labels den Alltag am schnellsten durchdringen. Es wurden drei Szenarien mit einem Zeithorizont von 10 Jahren entwickelt, die drei möglichen Entwicklungspfaden des Pervasive Computing entsprechen: Ein zurückhaltendes, ein mittleres und ein „Hightech'-Szenario. Sie unterscheiden sich hauptsächlich im angenommenen Durchdringungs- und Vernetzungsgrad, den Pervasive Computing in den verschiedenen Anwendungsfeldern erreichen wird.

Kapitel 5: Informations- und Kommunikationstechnologien werden häufig in der Absicht eingesetzt, Vorgänge zu beschleunigen und damit Zeit einzusparen. Diese Effizienzsteigerung ist zwar nicht das einzige Motiv für den Einsatz von ICT, aber historisch betrachtet das wichtigste und zugleich ein gemeinsamer Nenner der vielfältigen Anwendungen. Alle bisherigen Erfahrungen mit zeitsparenden Technologien (darunter ICT und Verkehrstechnik) haben jedoch gezeigt, dass durch die Beschleunigung kein absoluter Rückgang der Belastung des Menschen durch die jeweiligen Tätigkeiten eintreten muss. Die Belastung kann absolut betrachtet sogar zunehmen. Beispielsweise haben schnellere Verkehrsmittel nicht dazu geführt, dass wir durchschnittlich weniger Zeit im Verkehr verbringen. Vielmehr haben die zurückgelegten Entfernungen zugenommen. Obwohl E-Mails schneller geschrieben sind als Briefe, verbringen wir heute mehr Zeit mit E-Mails als früher mit der konventionellen Korrespondenz. Dieser so genannte Rebound-Effekt kann mit ökonomischen Modellen erklärt werden. Es gibt keinen Grund anzunehmen, dass der Rebound-Effekt bei Pervasive Computing ausbleiben wird. Ein Leben mit mehr Zeit für angenehme Tätigkeiten und weniger Stress gehört deshalb nicht zu den Vorteilen, die man von Pervasive Computing erwarten kann. Vielmehr werden mit der technisch ermöglichten Effizienz auch die generellen Erwartungen an die Leistungsfähigkeit des Einzelnen steigen, und zwar sowohl im Arbeitsmarkt als auch im Privatleben.

Kapitel 6: Große Chancen bietet Pervasive Computing für die medizinische Behandlung und Pflege. Besonders die Lebensqualität von chronisch Kranken, Rehabilitations- und Risikopatienten lässt sich verbessern. Ihre Abhängigkeit von stationären Einrichtungen wird durch neue Möglichkeiten der Fernüberwachung des Gesundheitszustandes (Personal Health Monitoring) und der aktiven Implantate abnehmen. Den medizinischen Chancen stehen Risiken gegenüber, darunter unvorhergesehene Nebenwirkungen von aktiven Implantaten und mögliche psychische Folgen einer neuen „Apparatemedizin', die die Patienten stärker überwacht.

Unter Gesundheitsaspekten ist besonders die heutige Kontroverse um nichtionisierende Strahlung (NIS) der Mobilfunknetze zu beachten. Pervasive Computing wird nur unter sehr weit reichenden Annahmen zu einer Stabilisierung oder Abnahme der alltäglichen NIS-Exposition führen. Wahrscheinlicher ist eine Zunahme, weil sich zusätzlich zu den Mobilfunknetzen drahtlose lokale Datennetze (W-LANs) ausbreiten werden. Diese werden zwar mit schwächeren Sendeleistungen betrieben, haben aber doch zur Folge, dass eine zusätzliche Infrastruktur mit NIS-Quellen aufgebaut wird. Mögliche Gesundheitsrisiken, die von Strahlungsintensitäten unterhalb der thermischen Wirkungsschwelle ausgehen, sind nach wie vor ungeklärt. Bestimmte biologische Effekte sind nachgewiesen und geben Anlass zur Vorsicht. Gerade vor dem Hintergrund, dass Pervasive Computing das Tragen von Strahlungsquellen am Körper (Wearables) oder sogar im Körper (Implantate) vorsieht, besteht weiterhin dringender Forschungsbedarf. Die Strahlungsexposition kann auch bei Quellen mit niedriger Sendeleistung sehr hoch werden, wenn der Abstand zum Körpergewebe sehr klein ist.

Kapitel 7: Pervasive Computing wird sowohl zusätzliche Umweltbelastungen als auch Entlastungen für die Umwelt mit sich bringen. Ob in der Summe die positiven oder die negativen Auswirkungen überwiegen, hängt hauptsächlich von den energie- und abfallpolitischen Rahmenbedingungen ab, unter denen sich Infrastrukturen und Anwendungen in den kommenden Jahren entwickeln. Direkte (primäre) Wirkungen von ICT auf die Umwelt sind Material- und Energieverbrauch in der Produktions- und Nutzungsphase sowie Schadstoffbelastung bei der Entsorgung dieser Produkte. Pervasive Computing wird die Ökobilanz dieses Lebensweges nicht grundlegend verändern. Die fortschreitende Miniaturisierung wird mit hoher Wahrscheinlichkeit durch größere Anzahl und kürzere Nutzungsdauer der Komponenten mengenmäßig kompensiert oder überkompensiert werden. Der Energiebedarf der Vernetzung, die für Pervasive Computing benötigt wird, kann einige Prozent des gesamten Stromverbrauchs erreichen, wenn keine Anreize zur Nutzung technischer Energiesparpotenziale gegeben werden. Mit einem zunehmenden Eintrag von mikroelektronischen Wegwerfprodukten einschließlich Batterien in andere Abfallströme (Verpackungen, Textilien) ist zu rechnen.

Diesen primären Umweltwirkungen stehen die Chancen gegenüber, durch die Anwendung von Pervasive Computing material- und energieintensive Prozesse zu *optimieren* oder durch reine Signalverarbeitung zu *substituieren* (Dematerialisierung). Die Entlastungspotenziale solcher Sekundäreffekte sind hoch und können die Primäreffekte bei weitem übertreffen, etwa wenn durch die zunehmende Ortsunabhängigkeit von

Tätigkeiten Verkehr vermieden wird. Diese Entlastungspotenziale werden jedoch nur dann realisiert, wenn ausreichende Anreize zu einem ökonomischen Umgang mit natürlichen Ressourcen bestehen. Anderenfalls wird ein Wachstum der Nachfrage (Tertiäreffekte) die Einsparungen kompensieren. Bisherige Erfahrungen mit den Auswirkungen von ICT haben gezeigt, dass dieser Rebound-Effekt in den meisten Fällen eintritt.

Kapitel 8: Gesamthaft betrachtet zeigt sich das folgende Bild der Chancen und Risiken des Pervasive Computing.

Auf der Seite der Chancen sind die Möglichkeiten der medizinischen Prävention, Behandlung und Pflege und das generelle Angebot an neuartigen Dienstleistungen hervorzuheben, die auf Basis des Pervasive Computing möglich werden.

Die zunehmende Ortsunabhängigkeit von Aktivitäten hat vielfältige Auswirkungen. Unter Umweltaspekten sind besonders die Auswirkungen auf den Verkehr zu beachten, die in der Bilanz positiv oder negativ sein können. Unter sozialen Aspekten kann eine bessere Vereinbarkeit von Berufs- und Familientätigkeiten (v.a. Kinderbetreuung) für Personen beiderlei Geschlechts resultieren.

Für die Wirtschaft ist von Bedeutung, dass erst lokale Inhalte und Dienste dem Pervasive Computing den entscheidenden Nutzen verleihen. Nicht globale Einheitsangebote, sondern nur lokal differenzierte Produkte können von der Kontextsensitivität des Pervasive Computing Gebrauch machen: Abhängig vom exakten Aufenthaltsort und individuellen Präferenzen werden Informationen bereitgestellt und Dienstleistungen angeboten.

Auf der Seite der Risiken wurden nach Anwendung der Kriterien *Irreversibilität, Verzögerungswirkung, Konfliktpotenzial* und *Belastung für die Nachwelt* folgende Problemfelder als die wichtigsten (jedoch nicht die einzigen) identifiziert:

- Nichtionisierende Strahlung: Die durchschnittliche Exposition wird voraussichtlich zunehmen. Hier besteht Konfliktpotenzial, weil Nicht-Benutzer von Pervasive Computing sich ähnlich wie Passivraucher einer von anderen verursachten Belastung ausgesetzt sehen werden. Es besteht dringender Bedarf, mögliche Gesundheitsrisiken weiter zu erforschen.
- Stress: Pervasive Computing kann aus mehreren Gründen Stress auslösen, darunter schlechte Benutzbarkeit, Störung und Ablenkung der Aufmerksamkeit, das Gefühl des Überwachtwerdens (Datenschutz), möglicher krimineller Missbrauch sowie steigende Anforderungen an die Produktivität des Einzelnen. Stress ist ein wichtiger Einflussfaktor für die Gesundheit.
- Unfreiwilligkeit: Ein Teil der Konsumenten und Patienten könnten durch die Entwicklung in Richtung Pervasive Computing in eine Lage gebracht werden, in der sie diese Technologie unfreiwillig anwenden müssen (z.B. weil Alternativen nicht mehr angeboten werden) oder unfreiwillig mitfinanzieren (z.B. über steigende Krankenkassenbeiträge).
- Ökologische Nachhaltigkeit: Der Verbrauch seltener Rohstoffe durch die Produktion von Elektronik und der Stromverbrauch durch die stationäre Infrastruktur könnten stark zunehmen. Wenn die Entsorgung von Millionen sehr kleiner Komponenten als Elektronikabfall nicht adäquat geregelt werden kann, gehen wertvolle Rohstoffe verloren und gelangen Schadstoffe in die Umwelt.

- Verursacherprinzip: Die Ursachen von Schäden, die durch das Zusammenwirken mehrerer Komponenten aus Computerhardware, Programmen und Daten in Netzwerken entstehen, sind in der Regel nicht aufzuklären, weil die Komplexität dieser verteilten Systeme weder mathematisch noch juristisch zu beherrschen ist. Da mit Pervasive Computing die Abhängigkeit von solchen Systemen zunehmen wird, ist insgesamt ein Anstieg des durch unbeherrschte technische Komplexität entstehenden Schadens zu erwarten. Die Folge ist, dass ein wachsender Teil des Alltagslebens sich faktisch dem Verursacherprinzip entzieht.

Kapitel 9: Zur Vorsorge gegen die identifizierten Risiken empfiehlt die Studie unter anderem folgende Maßnahmen:

- Handlungsbedarf besteht auf Seite der *Politik*, die beiden Strategien „Informationsgesellschaft' und „Nachhaltige Entwicklung' besser zu koordinieren. Es ist ferner zu prüfen, ob Haftungsnormen, Datenschutz und Schutz vor Direktwerbung für die neuen Herausforderungen des Pervasive Computing ausreichend gewappnet sind. Damit der Verbraucher seine Verantwortung besser wahrnehmen kann, empfehlen wir die Einführung einer Deklarationspflicht für technische Daten von NIS-Quellen und einer Energie-Etikette für ICT-Produkte. Um die Weichen in Richtung einer energieeffizienten ICT-Infrastruktur zu stellen, ist die konsequente Verstärkung ökologischer Anreize im Steuersystem notwendig.
- Eine kontinuierliche Technologiefolgenabschätzung (TA) für zukünftige ICT und ihre Anwendungsformen erscheint aufgrund der weit reichenden Auswirkungen dringend angezeigt. Partizipative TA, die alle gesellschaftlichen Gruppen frühzeitig in die Diskussion einbezieht, kann als „Frühwarnsystem' zur Minimierung von Risiken beitragen.
- Bildungsinstitutionen aller Stufen wird empfohlen, einen kritischen und mündigen Umgang mit ICT in die Lernziele aufzunehmen, weil die sozialen Risiken von Pervasive Computing am wirkungsvollsten minimiert werden, wenn sich die Benutzer der Möglichkeiten und Grenzen dieser Technologie bewusst sind.
- Den Unternehmen der Telekommunikations-Branche empfehlen wir, sich der „Global e-Sustainability Initiative' (GeSi) anzuschließen und eine freiwillige Selbstkontrolle zu etablieren, die ethische Mindeststandards für das Inhaltsangebot der vermittelten Dienste verlangt.
- Den Unternehmen des öffentlichen Verkehrs empfehlen wir, eine gemeinsame, langfristig orientierte Strategie zum Einsatz von ICT durch die Unternehmen selbst und durch ihre Kunden entwickeln, besonders in Hinblick auf die Konkurrenz mit dem Individualverkehr.
- Den Betreibern von Kehrichtverbrennungsanlagen wird empfohlen, ihr Monitoring auf eine allfällige Zunahme von Elektronikanteilen im Hausmüll einzustellen, um bei absehbaren Problemen andere Akteure der Elektronikabfall-Entsorgung (Branchenverbände, Gesetzgeber) frühzeitig auf ungünstige Entwicklungen aufmerksam zu machen.

Weitere vorgeschlagene Maßnahmen zielen darauf ab, den Missbrauch von Pervasive Computing zu verhindern und die Freiwilligkeit seiner Nutzung aufrecht zu erhalten.

Resumé

L'informatique omniprésente (Pervasive Computing) fait référence à une application des technologies de l'information et de la communication (TIC) se caractérisant par une miniaturisation et une intégration de la microélectronique dans divers objets de la vie quotidienne en mesure de communiquer les uns avec les autres. Contrairement à la plupart des produits TIC actuels, cette nouvelle technologie sera pourvue de capteurs capables de saisir automatiquement leur environnement sans que l'utilisateur n'ait à intervenir directement.

L'idée d'un quotidien pénétré de composants microélectroniques constamment et partout en service – sur des réseaux sans fil pour la plupart – soulève la question des effets secondaires indésirables que pourrait engendrer cette informatique omniprésente. Il est donc indispensable de confronter les avantages attendus aux risques – encore partiellement inconnus – qui pourraient résulter de la concrétisation de ces visées technologiques. L'appréciation des avantages et des risques amènera immanquablement à la question primordiale de l'éthique de la technique: «Avec quelles techniques voulons-nous évoluer dans quel monde?»

Seul un large débat de société permettra de trouver une réponse à cette question. La présente étude aspire à contribuer de manière concrète à cette discussion en démontrant les chances et les risques éventuels de l'informatique omniprésente. L'étude se concentre sur les risques pour la santé et l'environnement.

L'identification et la différentiation des chances et risques présuppose de se baser sur des jugements de valeur que la science, elle seule, n'est pas à même de fixer. Cette étude s'appuie sur des principes de l'éthique traditionnelle (respect de la dignité humaine, non-malfaisance, bienfaisance, équité), en y ajoutant celui de la *précaution*, ainsi que l'objectif de *développement durable*. Le noyau commun de précaution et de durabilité est que les deux étendent le principe d'équité aux générations futures: Les actions d'aujourd'hui ne devront pas gêner les actions entreprises à l'avenir.

Les lectrices et lecteurs pressés pourront s'informer vite

- sur des propositions d'action au niveau politique et autres recommandations au chapitre 9
- sur l'analyse des chances et des risques, ainsi que leur appréciation au chapitre 8
- sur des termes techniques et des abréviations au glossaire.

Il sera en tout cas utile de lire également l'introduction (chapitre 1) qui informe sur l'objet, les buts, la méthode et la structure de l'étude.

Un aperçu des constatations essentielles faites dans les chapitres 2 à 9 suit.

Chapitre 2: Le principe de précaution sert à traiter les risques dans des situations sans danger urgent. Il prévoit de minimiser des risques qui peuvent se déclarer à longue échéance et de préserver la liberté d'actions futures. Le concept de développement durable signifie que les buts du développement social doivent inclure autant l'équité entre les générations actuelles que celle d'une génération à l'autre. C'est dans ce contexte que la présente étude identifie et évalue les avantages et inconvénients de l'informatique omniprésente. Outre les aspects de santé et environnementaux au sens étroit du terme, d'autres aspects, débattus dans les milieux des TIC depuis un certain

temps déjà, sont pris en considération: protection des données, sécurité, conséquences d'une complexité incontrôlable des systèmes techniques, dépendance croissante qu'engendrent de tels systèmes, retombées sur l'égalité des sexes et le fossé numérique sont abordés.

Chapitre 3: La miniaturisation des systèmes microélectroniques que nous connaissons actuellement devrait se poursuivre encore pendant 10 ans. Elle représente une force motrice essentielle pour concrétiser la vision d'une «informatique omniprésente». Le développement continu de réseaux de téléphonie mobile, mais aussi des réseaux locaux sans fil (W-LAN) aura également un effet décisif. Enfin, avec leur nombre croissant (des centaines de composants par personne), l'approvisionnement en énergie des composants mobiles ne pourra plus seulement reposer sur des piles jetables ou rechargeables par des adaptateurs secteur. D'autres concepts d'alimentation en énergie tels que cellules solaires ou électrochimiques, ou l'utilisation de l'énergie corporelle se diffuseront. Beaucoup de ces composants seront uniquement activés par contact ou par un champ d'alimentation, comme cela est le cas aujourd'hui pour les cartes à puce ou les «étiquettes intelligentes» (smart labels). La percée de l'informatique omniprésente dépendra cependant des progrès faits dans le domaine des interfaces utilisateur, en matière de commande vocale par exemple. La sensibilité au contexte s'impose comme une innovation essentielle pour l'informatique omniprésente: les composants devront réagir à leur environnement et pourront donc être actifs sans l'intervention de l'utilisateur. Dans le domaine des logiciels, les technologies dites «des agents» gagneront en importance. L'utilisateur «déléguera» ainsi des décisions à des programmes, puisqu'il ne pourra plus contrôler le flux d'informations par lui-même.

Chapitre 4: On s'attend à ce que l'informatique omniprésente se développe avant tout dans le domaine des transports, tout en perçant dans d'autres secteurs tels que l'habitat, le travail et la santé. L'automobile représente une plate-forme d'essai idéale pour l'informatique omniprésente car elle offre un système indépendant avec une alimentation stable en énergie; son «intelligence» croîtra dans les années à venir. Les «maisons intelligentes», quant à elles, seront plus lentes à progresser, et ceci malgré le remplacement régulier des câblages actuels (câblages informatiques, téléphoniques, etc.) par des réseaux sans fil. L'informatique omniprésente se réalisera aussi à travers des technologies transversales, telles que les médias numériques, les «habits digitaux» (wearables) et les «étiquettes intelligentes» (smart labels). Ces dernières seront les plus rapides à percer la routine quotidienne. Trois scénarios ont été développés sur un horizon temporel de 10 ans chacun, illustrant trois voies d'évolution possible pour l'informatique omniprésente: un scénario «prudent», un «moyen» et un de «haute technologie». Ils se distinguent notamment par les taux de pénétration et de connexion que l'informatique omniprésente est censée atteindre dans ses différents champs d'application.

Chapitre 5: Les technologies d'information et de communication sont fréquemment utilisées dans le but d'accélérer les processus et de gagner ainsi du temps. Une telle augmentation d'efficacité – bien que n'étant pas l'unique raison – fournit, historiquement parlant, le motif principal pour l'utilisation des TIC et devient, en outre, un dénominateur commun pour ses multiples applications. Or, toutes les expériences faites jusqu'ici avec les technologies destinées à gagner du temps (y compris les TIC et les moyens de transport) ont démontré que l'accélération des activités ne saurait soulager avec certitude le stress individuel. A vrai dire, le stress peut même augmenter. A titre d'exemple, les moyens de transport plus rapides n'ont pas abaissé le temps que nous passons en moyenne dans la circulation, car les distances parcourues ont augmenté. Bien qu'un message électronique soit bien plus rapide à rédiger qu'une lettre, nous consacrons, à l'heure actuelle, beaucoup plus de temps au courrier électronique qu'à la correspondance conventionnelle d'avant. Cet effet dit «de rebond» peut s'expliquer par le biais de modèles économiques. Il est peu probable qu'il n'y ait pas d'effet de rebond avec l'informatique omniprésente. Dès lors, la perspective d'une vie avec plus de loisirs et moins stressante ne fera pas partie des avantages auxquels on pourrait s'attendre avec l'informatique omniprésente. Au contraire, l'efficacité technologique obtenue engendrera des exigences de rendement plus élevées, autant sur le marché du travail qu'en privé.

Chapitre 6: L'informatique omniprésente offre de grands avantages pour les traitements et soins médicaux. En particulier, la qualité de vie des malades chroniques, des patients dans des centres de réhabilitation ou à risque pourra être considérablement améliorée. Ils dépendront moins des installations hospitalières grâce à de nouveaux systèmes de télésurveillance contrôlant l'état de santé des patients (Personal Health Monitoring) et grâce à des implants actifs. Mais ces avantages médicaux peuvent être contrebalancés par des risques, comme par exemple l'apparition d'effets secondaires imprévus dus à la présence d' implants actifs dans le corps, ou encore des conséquences psychologiques suscitées par une surveillance rapprochée rendue possible par une «médecine instrumentalisée».

En ce qui concerne les aspects de santé, la controverse contemporaine sur le rayonnement non ionisant (RNI) des réseaux de téléphonie mobile est particulièrement révélatrice. L'hypothèse que l'informatique omniprésente pourrait amener à une stabilisation ou à une diminution de l'exposition quotidienne au RNI ne saurait être considérée que sous des suppositions étendues. Il est plus probable que celle-ci augmentera, étant donné qu'en plus des réseaux de téléphonie mobile, les réseaux locaux sans fil (W-LAN) tendent à se propager. Malgré leur plus faible puissance d'émission, leur fonctionnement nécessitera la mise sur pied d'une infrastructure complémentaire avec des sources de RNI. La question des risques éventuels pour la santé pouvant découler du RNI au-dessous du seuil de l'effet thermique n'a toujours pas été éclaircie. Certains effets biologiques démontrés incitent à la prudence. En tenant compte du fait que l'informatique omniprésente prévoit le port de telles sources de rayonnement sur le corps (par exemple intégrées aux habits), voire dans le corps (implants), il est urgent d'approfondir les recherches. Une exposition au rayonnement non ionisant peut devenir importante pour des sources de faible intensité si elles se trouvent très près des tissus corporels.

Chapitre 7: L'informatique omniprésente entraînera aussi bien des effets bénéfiques pour l'environnement que des charges supplémentaires . Que les effets négatifs ou positifs fassent pencher la balance dépendra essentiellement des conditions de base régissant la politique énergétique et de traitement des déchets. C'est en effet en fonction de ces conditions que les infrastructures et les applications de l'informatique omniprésente se développeront dans les années à venir. Les effets directs (primaires) que peuvent avoir les TIC sur l'environnement proviennent de la consommation de matériel et d'énergie dans les phases de production et d'utilisation des produits, ainsi que de la pollution générée par leur élimination après usage. Il est peu probable que l'informatique omniprésente modifie de façon significative le bilan écologique de ce cycle de vie. Plus nombreux, avec une durée de vie plus courte, les composants vont vraisemblablement anéantir les avantages de la miniaturisation progressive. Sans incitation à utiliser des potentiels d'économie énergétique, les besoins d'énergie des réseaux nécessaires à l'informatique omniprésente pourraient atteindre plusieurs pour-cent de l'ensemble de la consommation d'électricité. Il faut compter sur une présence accrue de produits microélectroniques jetables, piles comprises, dans d'autres flux de déchets (emballages, textiles).

Ces impacts environnementaux primaires peuvent être contrebalancés par le fait que l'informatique omniprésente permet d'*optimiser* des procédés consommant de grandes quantités de matériaux et d'énergie ou encore par le fait que des actions peuvent être *substituées* par le traitement des signaux (dématérialisation). Des effets secondaires de ce genre offrent des potentiels en faveur de l'environnement qui peuvent être considérables et surpasser de loin les effets primaires si, par exemple, le nombre croissant des activités non attachées à un lieu précis permet de diminuer les déplacements et, partant, la circulation routière. Mais la mise en pratique de ces potentiels ne pourra se réaliser que s'il existe des incitations encourageant à un comportement compatible avec la préservation des ressources naturelles. Sinon, la demande accrue (effets tertiaires) annulera à nouveau le bénéfice de ces économies. Les expériences faites jusqu'ici avec les répercussions des TIC ont révélé que cet effet de rebond se produit dans la plupart des cas.

Chapitre 8: Vu dans l'ensemble, les avantages et inconvénients de l'informatique omniprésente s'illustrent de la manière suivante:

Du côté des avantages, relevons tout d'abord ceux offerts par l'informatique omniprésente au niveau de la prévention, du traitement et des soins médicaux, ainsi que des innovations dans les services en général.

Diverses activités pourront se dérouler en tous lieux, ce qui aura des conséquences diverses. Concernant les aspects environnementaux, on mentionnera principalement les répercussions sur le trafic, puisque leur bilan peut s'avérer positif ou négatif. Du point de vue social, hommes et femmes pourront jouir d'une meilleure compatibilité entre leurs activités professionnelles et domestiques (notamment pour s'occuper des enfants).

Pour l'économie, seuls des contenus et services locaux pourront prêter une utilité décisive à l'informatique omniprésente. Les avantages de la sensibilité au contexte de l'informatique omniprésente favorisent uniquement des produits qui tiennent compte du lieu où se trouve l'utilisateur, et non pas des offres globales: sur la base d'un lieu de résidence précis et de préférences individuelles, les données informatiques sont mises à disposition et les services adéquats proposés.

Quant aux risques, diverses problématiques ont été identifiées en utilisant les critères *irréversibilité*, *effets de retardement*, *potentiels de conflit* et *effets négatifs pour les générations à venir*:

- Rayonnement non ionisant: L'exposition moyenne tend à augmenter. Il y a là un potentiel de conflit, car les non-utilisateurs de l'informatique omniprésente se verront exposés à des inconvénients par des tiers, comme dans le cas des fumeurs passifs. Cette situation impose une recherche plus approfondie sur les risques éventuels pour la santé.
- Stress: l'informatique omniprésente peut être stressante pour de nombreuses raisons comme, par exemple, une utilisation trop compliquée, de nombreuses distractions, la sensation d'être surveillé (protection des données), l'abus éventuel à des fins criminelles, ainsi que des exigences accrues sur le rendement individuel. Le stress a un impact considérable sur la santé.

- Situation de contrainte: L'utilisation accrue de l'information omniprésente peut précipiter une partie des consommateurs et patients dans une situation qui les force à utiliser cette technologie contre leur gré (si d'autres alternatives ne sont plus proposées, par exemple) ou à contribuer à son financement (par le biais du renchérissement des primes d'assurance maladie, par exemple).
- Durabilité écologique: La surexploitation des matières rares pour la production de produits électroniques et la consommation d'énergie par des infrastructures fixes pourraient s'intensifier encore. Si aucune solution adéquate en matière de traitement des déchets électroniques, déchets générés par les millions de composants minuscules, ne devait être trouvée à brève échéance, de précieuses matières premières seront perdues et de nombreux polluants émis dans l'environnement.
- Principe de causalité: En règle générale, il ne sera pas possible de clarifier les causes des dommages dus à l'effet concomitant de plusieurs composants provenant de matériaux d'ordinateurs, de programmes et de données dans les réseaux. La complexité de ces systèmes distribués ne pourra en effet plus être maîtrisée ni sur des bases mathématiques ni du point de vue juridique. Étant donné que l'informatique omniprésente contribuera à une dépendance croissante vis-à-vis de tels systèmes, nous devrons nous attendre à une augmentation globale des dommages occasionnés par cette complexité technique incontrôlable. Dès lors, une partie grandissante de la vie de tous les jours échappera de fait au principe de causalité.

Chapitre 9: Afin de prévenir les risques identifiés, l'étude recommande, entre autres, les mesures suivantes :

- La *politique* est appelée à mieux coordonner ses stratégies en matière de société d'information et de développement durable. En outre, il est urgent de vérifier si les normes de responsabilité, la protection des données ainsi que la protection contre la publicité directe ont des bases suffisamment solides pour répondre aux enjeux de l'informatique omiprésente. Afin d'inciter l'utilisateur à mieux percevoir ses responsabilités, nous recommandons l'introduction d'une déclaration obligatoire des données techniques pour les produits TIC et d'une étiquette renseignant sur leurs besoins énergétiques. . Par ailleurs, il sera indispensable de revoir le système fiscal pour y intégrer des incitations écologiques poussées destinées à favoriser une infrastructure des TIC économe en énergie.
- Eu égard à l'étendue des répercussions, une évaluation technologique continue sous forme de «Technology Assessment» nous semble urgente pour l'avenir des TIC et ses formes d'utilisation. Une évaluation technologique dite participative qui fait participer tous les groupes sociaux en temps utile à la discussion pourra servir de «système d'alarme précoce», afin de limiter les risques.
- Les institutions scolaires de tous les niveaux devront inclure dans leurs objectifs d'enseignement une approche critique et mûrie des TIC, car des utilisateurs bien renseignés sur les possibilités et limites de l'informatique omniprésente sauront minimiser les risques sociaux que pourrait susciter cette technologie.
- Les entreprises de télécommunications auront intérêt à adhérer à la «Global e-Sustainability Initiative» (GeSi) et à introduire des contrôles mutuels volontaires qui requièrent un standard minimal d'éthique pour la teneur des services proposés.
- Quant aux entreprises de transports publics, elles devront développer ensemble des stratégies orientées sur le long terme . Ces stratégies devront porter à la fois sur

l'usage des TIC au sein de l'entreprise elle-même et sur les services offerts aux clients, le but étant de rester compétitif face au transport individuel.

- Les concessionnaires d'incinérateurs de déchets sont appelés à être organisés en vue de l'augmentation éventuelle du portion d'éléments électroniques dans les ordures ménagères, afin de pouvoir alerter au plus tôt les autres acteurs en matière de gestion des déchets électroniques (associations professionnelles, législateurs) sur une évolution défavorable.

D'autres mesures sont proposées dans le but de prévenir les abus et de garantir le libre choix des utilisateurs.

Summary

Pervasive Computing refers to visionary new ways of applying Information and Communication Technologies (ICT) to our daily lives. It involves the miniaturisation and embedding of microelectronics in non-ICT objects and wireless networking, making computers ubiquitous in the world around us. Unlike most of today's ICT products, Pervasive Computing components will be equipped with sensors enabling them to collect data from their surroundings without the user's active intervention.

If our daily life is to be pervaded in such ways by microelectronic components, running all the time with most of them wirelessly networked, one must ask whether these technologies might not have undesirable side-effects. The expected benefits need to be weighed against the potential risks involved in implementing such technological visions.

When comparing opportunities with risks, we will have to answer the basic question of the ethics of technology: 'Which technologies do we want in our lives, and what kind of a world would that be?'

Only a public discourse can provide answers to this question. The purpose of the present study is to make a contribution to such a discourse by striving to present objectively the opportunities and risks of Pervasive Computing. The study focuses on the risks for human health and the environment.

The identification and assessment of opportunities and risks, though, require value judgements, which cannot be decided by science alone. This study is based on values derived from the principles of traditional ethics (respect for human dignity, welfare principle and justice), supplemented by the precautionary principle and the paradigm of sustainable development. The core values found both in the precautionary principle and in sustainability expand the principle of justice to include explicitly future generations: act today in such a way that you do not restrict others' scope to act in the future.

For quick reference:

- Our advice to politicians and others is in Chapter 9,
- The opportunities and risks that we investigated and how we evaluated them are in Chapter 8,
- Technical terms and abbreviations are in the Glossary.

We recommend that all readers have a look at the introduction (Chapter 1), which presents the object, goals, method and design of the study.

The rest of this summary gives you the main findings of Chapters 2-9.

Chapter 2: In addition to preventing risks from becoming dangers, one should also minimise risks in situations with no pressing threat. The precautionary principle deals with the latter, including long-term risks. It is intended to preserve the potential for future developments. The paradigm of sustainable development says that the development of society should be aimed at both intra- and inter-generational fairness. Based on these values, the present study identifies and assesses the opportunities and risks of Pervasive Computing. Although this study focuses on health and environmental impacts, it also addresses other issues that have persisted in discussions of ICT ethics, such as privacy, security, unmastered complexity in technical systems, our increasing

dependence on these systems, the impacts of ICT on gender equality, and the 'digital divide'.

Chapter 3: Miniaturisation of microelectronics is bound to continue for about another 10 years without breaking the trend. It is an essential driver for implementing the vision of 'Pervasive Computing'. Further development of wireless communications by means of mobile phone networks and wireless local area networks (W-LAN) will play a decisive role. The number of mobile components per person will rise so fast into the hundreds, that it will no longer be practical for the energy supply to be provided in the form of batteries that have to be replaced or recharged using AC adaptors. Other energy supply technologies such as solar cells or fuel cells, or the use of body energy will become more common than today. Many components will only come on when brought against a contact or into a field supplying energy, as can be seen with today's chip cards or smart labels, respectively. Pervasive Computing will only gain acceptance if progress is made in user interfaces, i.e. voice controlled systems. A major innovation over current ICT applications will be context sensitivity: Components will react to their environments and thus will operate without being activated each time by the user. On the software level, so-called agent technologies will gain in importance. Thus, technology and the information it makes available will demand so many additional decisions from us that we will need to delegate decisions to technology to be able to cope with them.

Chapter 4: The application areas chosen for the study were 'housing', 'transport', 'work' and 'health', of which the most dynamic one is transport. As an independent system with a stable energy supply, the car represents a suitable test platform for Pervasive Computing and it will acquire more 'intelligence' in the years to come. 'Smart homes', however, are catching on at a much slower rate, in spite of the fact that wireless connections are already being substituted for present-day computer, telephone and other wired connections. Among the cross-sectional technologies digital media, wearables and smart labels (all taken here as part of Pervasive Computing), smart labels will be the fastest to become part of our daily life. Three scenarios were developed, each set for a 10-year time horizon, corresponding to three possible development paths of Pervasive Computing: a 'cautious', an 'intermediate and a 'high-tech' scenario. They differ mainly in penetration rate and the degree of connectivity supposed to be reached by Pervasive Computing.

Chapter 5: Information and communication technologies are frequently used with the intention of speeding up processes in order to save time. Such efficiency enhancement is the main reason for using ICT – although not the only one – and can be observed in all their application areas. All the experience gained thus far with time-saving technologies (including ICT and transport technologies), however, has shown that acceleration does not necessarily imply that people's stress level will be reduced. Strictly speaking, work pressure is even expected to increase. To take one example, faster means of transportation have not shortened our average time spent in traffic, but instead have caused the distances travelled to increase. Although e-mail is much quicker to write, we are spending more time today on it than we used to in the past on conventional letters. This so-called rebound effect can be well explained by economic models; there is no reason to believe that the rebound effect will not apply to Pervasive Computing. Hence, a lifestyle with more time for leisure activities and less stress is not an advantage to be expected from Pervasive Computing. Instead, the expectations placed on individuals' performance will grow as a consequence of technologically improved efficiency, both on the labour market and in private life.

Chapter 6: Pervasive Computing offers great opportunities for medical treatment and care: in particular, the quality of life for patients who are chronically sick, undergoing rehabilitation or at high risk can be improved. Their dependence on hospital facilities will be reduced by new remote methods of personal health monitoring and by active implants. These medical opportunities will be accompanied by the risk that active implants might have unexpected side-effects or that an 'over-instrumented' medicine might have a negative psychological impact on patients subjected to close observation.

Regarding health effects, the current controversy on the non-ionising radiation (NIR) of mobile phone networks is an important issue. Only under far-reaching assumptions might Pervasive Computing make possible a stabilisation of, or decrease in, our daily exposure to NIR. An increase is more probable, as wireless local area networks (W-LANs) are being built in addition to mobile phone networks. In spite of their lower transmission power, they will add to the total exposure, unless they are used as a substitute for existing networks. Questions on possible health hazards caused by NIR below the threshold of thermal effects are still open. Certain proven biological effects do give grounds for caution. Considering the fact that Pervasive Computing involves wearing radiation sources on the body (wearables) and even inside the body (implants), we see a need for further research. Even sources of low transmitting power may cause high exposure to radiation if they are very close to body tissues.

Chapter 7: Pervasive Computing will bring about both additional burden on, and benefits for, the environment. The prevailing balance of positive and negative effects will depend on how effectively energy and waste policy governs the development of infrastructures and applications in the coming years. Direct (primary) effects of ICT on the environment will result from material and energy consumption in the production and use phases, including pollution caused by disposal of the resulting waste. Pervasive Computing is not expected to change radically the environmental impact of this life cycle. Greater quantities and shorter service lives of components will most probably counterbalance or even outweigh the benefits from progressing miniaturisation. The energy demand of the network infrastructure needed for Pervasive Computing might be as large as several percent of total power consumption if there are no incentives for using the technical energy saving potential. More and more microelectronic throw-away products, including batteries, will be found in waste streams outside that of electronic waste proper (packaging, textiles).

These primary environmental impacts of Pervasive Computing are to be seen in opposition to the secondary effects it provides in *optimising* material and energy intensive processes, or in *substituting* pure signal processing for such processes (dematerialisation). The potential environmental benefits from such secondary effects are considerable and can even outweigh the primary effects if, for instance, the increasing independence of activities from defined locations reduces traffic. But using these potential environmental benefits requires sufficient incentives to manage natural resources more economically. Otherwise, the growth in demand (tertiary effects) will counterbalance these savings. The experience gained thus far with ICT effects has shown that such a rebound effect occurs in most cases.

Chapter 8: All things considered, the opportunities and risks associated with Pervasive Computing can be summed up as follows.

The most significant opportunities come in the form of medical prevention, treatment and care, and in general on innovative services, all of them enabled by Pervasive Computing.

The increasing independence of activities from defined locations has various consequences. Among the environmental aspects, the effects on transport are foremost, as the bottom line can turn out to be either positive or negative. As far as social aspects are concerned, an improved compatibility of professional and domestic activities (namely caring for children) may result in gains for persons of either gender.

Pervasive Computing becomes interesting for business and consumers when it is filled with local contents and services. The context sensitivity of Pervasive Computing favours locally differentiated products: Information is made available and services proposed according to one's precise position and individual preferences.

We used the following criteria to evaluate risks: *irreversibility*, *delay effect, conflict potential* and *negative impacts on posterity*, and identified the following issues as the most important:

- Non-ionising radiation: Average exposure is expected to increase. There is a conflict potential, as non-users of Pervasive Computing will see themselves exposed to impairments caused by others, as in the case of passive smokers. It is imperative to do further research on the possible health risks.
- Stress: Pervasive Computing can generate stress for various reasons, such as poor usability, disturbance and distraction, the feeling of being under surveillance (privacy issues), possible misuse of the technology for criminal purposes as well as increased demands on individuals' productivity. Stress has a considerable impact on health.
- Restrictions on individual freedom: The trend toward Pervasive Computing may drive some consumers and patients into a situation in which they are compelled to use such technology (if, for instance, alternatives are no longer available) or to co-finance it against their will (as for example with rising mandatory contributions to health insurance).
- Ecological sustainability: Consumption of scarce raw materials for the production of electronics and the energy consumption of stationary infrastructure may increase sharply. Furthermore, if no adequate solution is found for the end-of-life treatment of the electronic waste generated by millions of very small components, precious raw materials will be lost and pollutants emitted into the environment.
- Causation principle: As a rule, it is not possible to isolate the cause of damage due to the combined effects of several components from computer hardware, programmes and data in networks, as no one can cope with the complexity of such distributed systems, neither mathematically nor legally. As society's dependence on systems of this kind will grow with Pervasive Computing, a net increase in the damage derived from unmastered technical complexity has to be expected. As a consequence, a growing part of day-to-day life will, virtually, be removed from liability under the causation principle.

Chapter 9: The study recommends taking the following precautionary measures against the identified risks:

- Switzerland has a strategy for an 'Information Society' and one for 'Sustainable Development'; we call upon *policymakers* to coordinate the two more closely. They should also monitor and where necessary harmonise the strength of liability standards, data security, and protection from direct marketers under the conditions of Pervasive Computing. In order to enlighten users, we recommend making compulsory a declaration for technical data from NIR sources and an energy label for ICT products. Ecological incentives should be included in the tax system to point the way to an energy efficient ICT infrastructure.
- Considering the far reaching effects of future ICT and its application forms, continual technology assessment (TA) appears urgent. Participatory TA including all social groups in good time in the discussion may serve as an 'early warning system' to minimise the risks.
- Educational institutions of all levels are requested to include critical, sophisticated treatment of ICT in learning objectives, as the social risks from Pervasive Computing can be minimised best when users are made aware of the possibilities and limits of this technology.
- Companies in the telecommunication sector are advised to join the 'Global eSustainability Initiative' (GeSi) and to initiate self-regulation to establish ethical standards for the content of the services provided.
- Public transportation services ought to develop jointly long-term oriented strategies for the use of ICT by themselves and by their clients, in particular in order to remain competitive against private transport.
- We recommend to the operators of incinerators that they prepare their monitoring procedures for a possible increase in electronic components in domestic waste, in order to make other actors in the disposal of electronic waste (business associations, legislators) aware of unfavorable developments early enough whenever problems arise.

Further proposed measures aim to prevent the abuse of Pervasive Computing and to maintain the voluntary character of its use.

1 Introduction

Lorenz Hilty

Mobile phones, electronic organisers, chip cards and digitally controlled household appliances herald a new way of using electronic information and communication technology: Pervasive Computing. Pervasive Computing describes the penetration by computer technology into areas of our everyday life in which it has not previously been present and in which it may not even be recognised as computer technology at all. A dictation machine in ballpoint pen form or the operating panel of a coffee machine are not what is generally thought of as computers. However, they contain highly miniaturised computers and are all based on the same digital data processing technology.

Computer technology makes any object into which it is integrated a potential part of an information and communication system. Together with the trend towards wireless digital networking, which was introduced with mobile radio communication, the vision of ubiquitous, but almost invisible computers exchanging data and discreetly assisting us in all areas of life is coming closer to fruition. This will transform not only work, transport and media information services, but also the home and medical treatment.

IBM predicts that in the next five to ten years more than a thousand million people will be using more than a trillion (10^{12}) networked objects across the world.

Does society want these 'electronic brownies' to become part of its daily life? How could the technological vision for Pervasive Computing be made reality? What are the opportunities and risks to health and the environment of this trend?

The aim of this TA study is to help to clarify these questions based on current knowledge and to draw up recommendations for precautionary measures. The main focus of the study is on assessing the potential risks of Pervasive Computing to human health and to the environment. It thus concentrates on the *Environmental Issues* aspect of the Proposal for the TA-Swiss Basic Study on IT Assessment (Kündig, 2002). Ethical and legal aspects and further-reaching issues relating to philosophy and the social sciences can only be touched upon. The study was conducted in the period from April 2002 to January 2003.

1.1 Initial situation: Pervasive Computing as technological vision

Pervasive Computing (abbreviated to 'PvC') is technological vision, or more precisely: *a vision for new ways of using information and communication technologies (ICT).* Hence, this is not a new technology, but a greater penetration of everyday daily life with existing technologies, although these technologies will continue to develop even more rapidly.

According to this vision, ICT components will perform their functions at any time or place. Articles of daily use, vehicles, buildings, clothing and, to some extent, the human body will be equipped with components that can store, process and transmit data.

The base technology for present and future[1] ICTs is microelectronics. Even though the PvC vision could actually be realised using current technology, the further development of that technology and the resulting ongoing miniaturisation and price reduction will make an important contribution to the feasibility of PvC under market conditions. Microelectronics will be supported and complemented by advances in nanotechnology, e.g. in sensor technology (see Fig. 1-1).

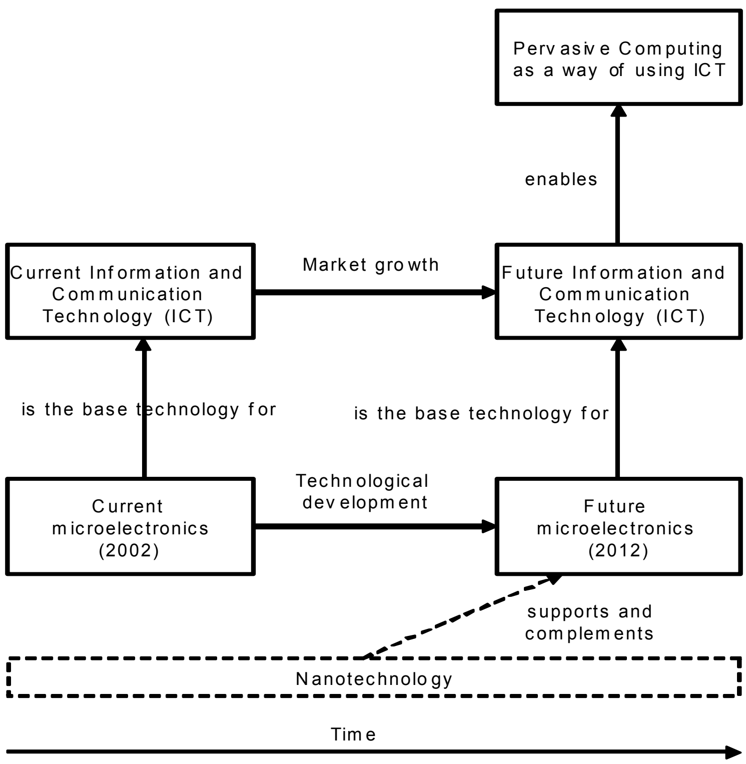

Figure 1-1: Connection between microelectronics, nanotechnology, ICT and Pervasive Computing

[1] With regard to technological development, this study has in view a period of 10 years.

> 'In the next five to ten years the computer will be erased from our consciousness. We simply will not talk about it any longer, we will not read about it, apart from experts, of course.'
>
> Joseph Weizenbaum (2001).

PvC has the following characteristics:

- Miniaturisation: ICT components become smaller and therefore more portable than today's common devices.
- Embedding: ICT components become more frequently embedded in other devices and objects of daily use ('smart objects').
- Networking: ICT components are generally networked with one another and data exchange is mainly wireless.
- Ubiquity: ICT becomes ubiquitous and increasingly inconspicuous or even invisible.
- Context sensitivity: ICT components can obtain information about their environment through wireless data exchange and using sensors.

We are interpreting the idea of Pervasive Computing as broadly as possible. In particular, we are including such concepts as 'Ubiquitous Computing', 'Ambient Intelligence', 'wearable computers', the 'Invisible Computer' and 'Anytime, Anywhere Computing'. We also consider the MIT Media Lab 'Things That Think' initiative to be part of the broad PvC Vision. This initiative brings together 40 companies and 20 research groups to pursue the aim of inventing a future of digitally augmented objects (Holt, 1999; MIT Media Lab, 2003).

It can be assumed that the current 'PC era' will be superseded by the 'PvC era' by 2012. PvC could therefore become the predominant form of ICT from the user's perspective. Users will become accustomed to things in their everyday environment becoming more 'intelligent'[2] and will be aware that they are using a 'computer' only rarely. Even though at present 98% of all programmable CPUs are embedded and are not perceived by users to be computers, e.g. in household appliances, vehicles and toys (Broy/Pree, 2003), an entirely new situation will be created with PvC, as these invisible components are networked (Bohn et al., 2002; Mattern, 2003).

The extent to which this will actually happen will not depend solely on technical possibilities and the vision of manufacturers, but will also be contingent on whether future supply is matched by sufficient demand to manufacture the millions of units that are necessary in microelectronics production. A 'critical mass' of users is also a prerequisite for the supply of attractive PvC-based services and content.

It is difficult to predict whether the need for PvC and the acceptance of the possible associated risks will be sufficient to achieve that critical mass. In this study we will therefore outline three scenarios for the period up to 2012:

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[2] We always place the adjective 'intelligent' in quotation marks where it does not refer to humans in order to distance ourselves from the far-reaching claims of 'strong artificial intelligence', which have so far not even begun to be proven. The advocates of 'strong AI', like Marvin Minsky (MIT), proceed from the controversial assumption that machines can match and surpass human intelligence.

- a ‘cautious’ scenario, where restrained growth is assumed;
- a ‘high-tech’ scenario, based on the assumption that everything that is technically and economically feasible will be achieved;
- an ‘intermediate’ scenario, which lies between the two others and which we consider to be the most likely at present, without making a forecast.

It would not be appropriate to attempt to make a forecast because we consider that developments can be *influenced*. The basic questions of the ethics of technology – ‘Which technologies do we want in our lives and what kind of a world would that be?’ – would be meaningless if the ability to influence developments was rejected out of hand. The future will therefore also depend on whether and how society can agree on the role that this technology should play in our lives.

1.2 Objectives and methodology of this study

The objectives of this study are:

1. to identity the prospective trends in information and communication technology in the direction of Pervasive Computing;

2. to assess and conduct a risk management comparison of the benefits and risks from these trends with respect to health and the environment;

3. to identify ways of clarifying the precautionary principle in the information society and of inferring potential measures specifically for Pervasive Computing.

The outlook for the study in relation to technological and market trends was limited to 10 years and is divided into a near-term perspective (2007) and a long-term perspective (2012).

The assessment of developments and the opportunities and risks arising from those developments is based on the following methods:

- Evaluation of literature:
  The statements made in this study are based primarily on the evaluation of current specialist literature,[3] and in the case of the health effects of non-ionising radiation in particular on reviews and reports by experts.
- Extrapolation of trends:
  Some technological trends will continue into the future, unless there are particular grounds to assume that the trend will be reversed.
- Scenarios:
  Possible future situations are described in scenarios based on different assumptions about the propagation speed and prospects of Pervasive Computing. In the light of the scenarios, possible effects of technology are identified on the basis of known or assessable facts.
- Survey of experts:
  The statements on opportunities and risks are based, in addition to the available specialist knowledge, on surveys of experts providing specialist support for the project team.
- Expert workshops:
  In the course of the project, three workshops were conducted.
  - A first workshop at the beginning of the project served to validate and fine-tune the questions and identify the most important problem areas.
  - Two further workshops in the second phase of the project served to discuss the initial findings in groups of experts who represented a broad range of specialist perspectives and interests.

[3] Specialist articles, books, Internet sources

1.3 Definition of the object of the study

1.3.1 Definition of the technology

The object of the study is information and communication technologies based on microelectronics which can help to make the Pervasive Computing vision a reality, as described in Section 1.1. Not all the characteristics of Pervasive Computing (miniaturisation, embedding, networking, ubiquity, context sensitivity) have to be fulfilled at the same time.

1.3.2 Selected areas of application

The study considers four selected areas of application:

- housing
- transport (focusing on motor vehicles)
- work
- health

Consideration is also given to developments in three fields that may have an impact on several areas:

- wearables (ICTs worn on the body)
- digital information and home entertainment media (excluding games)
- smart labels and other automatic identification systems.

1.3.3 Selected areas of impact

As the fields of action of the applications under consideration, emphasis is placed on the effects on human health and on the ecological environment. Because of the high importance of social and economic effects – not least for the first two areas of application – social and economic aspects are also taken into consideration, although they are studied with less depth.

The reason for focusing on health and the environment is that

- the debate on possible health effects resulting from non-ionising radiation and the *great uncertainty in this area* suggest that a wide-ranging discourse is necessary before a new way of using wireless networked ICTs becomes a reality.
- the effects of ICT on the environment have previously been discussed by experts, but, despite their high relevance, have barely entered the public consciousness. Electronic waste, rising energy consumption as a result of ICTs and standby losses are becoming environmental problems.

1.3.4 Ethical implications

The Pervasive Computing vision also calls for reflection on ethical and legal aspects. It must be examined in the light of the fundamental question underlying technology ethics and policy: 'Based on the way we see ourselves, what technologies do we want in our lives?'

However, the study restricts itself – without any claims to completeness – to *highlighting* the most important problems and aspects that should be dealt with in a further step from an ethical perspective.

In this connection it is guided by traditional ethical principles:

- the autonomy principle (self-determination principle), based on respect for human dignity and freedom,
- the welfare principle (do not harm, offer assistance),
- the principle of social justice.

We understand social justice as fairness in the sense advocated by John Rawls (1971) and in the spatial and temporal extension that forms the core of the idea of 'sustainable development', including fairness in a global perspective and *vis-à-vis* future generations.

The third point in particular – the principle of justice extended along lines of sustainability – is reminiscent of the ethics of responsibility put forward by Hans Jonas (Jonas, 1979). However, we do not go as far as adopting Jonas' position, which would amount to a maximum ('strong') precautionary principle and 'strong sustainability'. The conclusions of this study do not require nature to be accorded an intrinsic value (i.e. they are part of an anthropocentric value system), nor do they rely on an absolute 'primacy of the worst-case scenario', suggested by Jonas.

A wider-ranging discussion of the precautionary principle, the idea of 'sustainable development' and the normative framework of this study can be found in Chapter 2.

1.3.5 Acknowledgements

The interdisciplinary project team for this study has been advised by an interdisciplinary support group, led by Prof. Albert Kündig, whose advice and suggestions have had a significant influence on the results. In addition to the team leader, Prof. Beat Sitter-Liver, Prof. Peter Leuthold and Dr Jürg Baumann have played a crucial role in the formulation of this document with their detailed comments on the drafts. We must thank Dr Mirjana Moser for important advice and the entire support group for the fruitful discussions in Berne. At TA-SWISS Dr Danielle Bütschi and Dr Sergio Belucci have supported the project and provided us with much expert advice.

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1.4 Structure of this TA study

Figure 1-2 shows the chapters of this study with their function and their interdependencies. Chapters 5, 6 and 7 can be read independently, i.e. they are not based on one another. For readers in a hurry, Chapters 1, 8 and 9 should give a sufficient understanding of the findings.

The abbreviations used and the most important technical terms have been compiled in a combined list of abbreviations and glossary.

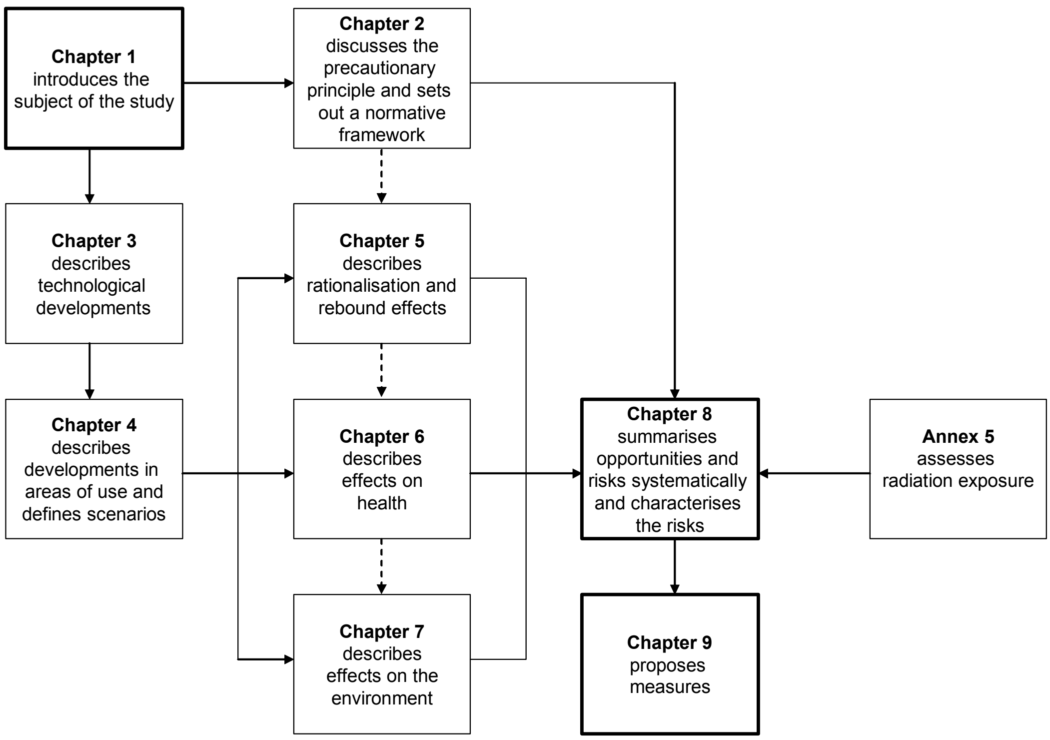

Figure 1-2: Structure of the study

2 The precautionary principle, sustainability and ethical aspects of the information society

Lorenz Hilty, Claudia Som

The precautionary principle (PP) is a very broad principle that needs to be interpreted and clarified in the context of the information society. We set out our understanding of the precautionary principle in Sections 2.1 and 2.2.

In addition to the PP, we require criteria on the basis of which to assess the possible effects of Pervasive Computing (PvC). In this connection, traditional ethical principles are supplemented by the idea of sustainable development (Section 2.3).

The two central ideas of the information society and sustainable development are directly related (Section 2.4).

In order to avoid restricting our focus to direct effects on health and the environment at too early a stage in the identification of the opportunities and risks of PvC and in order to begin our examination with a broader understanding of the issue, we will first consider the wide spectrum of social effects of information and communication technologies that have been discussed thus far as ethical issues of the information society. Some of these prove to be highly relevant to Pervasive Computing (Section 2.5).

These considerations form the basis for the normative framework (the value system) to which this study relates (Section 2.6).

2.1 Precautionary principle

Although the *precautionary principle* is formulated and construed very differently in the current international discussion, an attempt is made here to identify a common denominator:

The *precautionary principle (PP) is used for dealing with risks in situations where there is no acute danger. Its purpose is also to minimise risks that may become evident only in the long term and to maintain a margin for future developments.*

The *precautionary principle* therefore differs from the *principle of danger aversion* (*prevention principle*), which is applied where there is acute danger. A risk must be proven and must be sufficiently high to be regarded as a *danger* in the legal sense.[4]

Köck and Hansjürgens highlight the special nature of the PP: 'Precaution means creating a reserve of security' (Köck/Hansjürgens 2002, p. 42).

[4] The scale of a risk is assessed on the basis of the primary criteria of extent of damage and probability of occurrence. In so far as these variables are quantifiable, the scale of the risk corresponds to the mathematical product of the two primary criteria.

2.1.1 History of the precautionary principle

After a long period of trust in technology, awareness was raised in the 1970s of the risks of technology. It became clear that technical development not only means progress, but can also lead to damage to human health and the environment. The term 'risk society', coined by Ulrich Beck and given tangible form by the Chernobyl reactor accident, symbolises a turning point (Beck, 1986).

In the course of early environmental policy, most industrialised states began in the sixties to set limits on harmful impacts in order to prevent damage to health and the environment. It was clear that a limit could be adopted only where there was a danger in the legal sense, i.e. a proven and sufficiently high risk (cf. Reich, 1989; Köchlin, 1989; Rehbinder, 1991; Beyer, 1992; Wiedemann, 2001).

On the other hand, *potentially high* risks were mainly classified in case-law as unavoidable residual risks where the level of knowledge was insufficient and, as such, ignored (Reich, 1989).

As time passed, the limits of danger aversion became apparent. A first reference to the precautionary principle can be found in the 1976 Environment Report by the German Federal Government: 'Environmental policy does not amount only to the aversion of imminent dangers and the elimination of damage that has occurred. Precautionary environmental policy also demands that basic natural resources are protected and used sparingly' (Umweltbericht, 1976; p. 2).

Since then, the PP has been incorporated into various pieces of national legislation and into international agreements. The discovery of the hole in the ozone layer played a significant part in the acceptance of the PP in policy-making (Cavender-Bares, 2001).

In the 1983 Swiss Law on Environmental Protection, the PP is established as follows:

- Article 1(2): 'Precautionary measures shall be taken at an early stage to limit impacts that could become harmful or onerous.'
- Article 11(2) 'Irrespective of existing environmental pollution, precautionary measures shall be taken to limit emissions in so far as is technically and operationally possible and economically viable.'

The Law on Environmental Protection therefore requires the risk to be kept as low as possible even for harmful effects *that are only suspected.* It is not necessary to prove actual damage. It is sufficient if, on account of their characteristics, the impacts are likely to produce harmful or onerous effects. Avoidable emissions must be avoided, irrespective of the pollution that already exists. A margin for future developments is therefore preserved.

2.1.2 Purpose of the precautionary principle

Why should it be necessary to avoid impacts even where they pose no acute danger?

In legal literature, two theories of the precautionary principle are discussed (Köchlin, 1989; Beyer, 1992):

- The *ignorance theory* justifies a precautionary limitation of pollution on grounds of the limited knowledge (uncertainty) about future effects. The PP is intended to assist with sensible management of *uncertain risks*, whilst danger aversion applies to dealings with definite, that is to say sufficiently proven risks.

- The *free space theory* says that the PP is intended to preserve free space for the activities of future generations. This applies for example to future activities that pollute the environment in that the permitted environmental pollution (according to the risk limit) is not exhausted. However, the free space may also be applied to a modified assessment and evaluation, since values, laws and risk acceptance change in society and new scientific knowledge is acquired (‘risk of change’). Things that are regarded as unobjectionable today may be seen as unacceptable damage tomorrow.[5]

In formulating the Law on Environmental Protection, parliament took both of these aspects into consideration.

One of the expected benefits of the PP is that even minor – individually harmless, but cumulatively harmful – effects can be avoided. The PP also complements the principle of danger aversion in cases where insidious effects lead to health disorders that are latent, indefinite or associated with non-specific symptoms (Köchlin 1989).

According to Van den Daele (2001), the PP is used to bring technological development more firmly into the sphere of influence of politics and society. This appears necessary because technical progress not only brings natural risks into the ambit of human decisions, but at the same time creates new risks. New technologies can have unacceptable side-effects for society. The PP is intended to guarantee that society is able to make a conscious decision for or against entering into such risks, even where there is uncertainty over the existence and extent of a risk.

2.1.3 Scope and characteristics of the precautionary principle

The PP is not only an important principle in national and international environmental policy, but it is now also being extended to consumer protection policy (Köck/Hansjürgens 2002).

According to Van den Daele, the areas of damage associated with the notion of risk (originally health and the environment) have now been further extended to include social problems or changes in moral principles (Daele, 1991, quoted in Wiedemann/Brüggemann, 2001). With the extended scope of the PP, even the possibility of a change in applicable values would have to be treated as a risk and minimised. The question therefore arises whether, on the basis of current values, a possible change in those values can be regarded as an opportunity or a risk. Certainly such processes should be given over to a social discourse more than others (Habermas 2001), since it is obvious that society is redefining its value coordinate system and takes decisions on new technologies not just within the framework of such a system. It is not acceptable for technology to establish ‘faits accomplis’ and thereby stipulate moral standards without any reflection on the subject.

However, it would be beyond the scope of this study to undertake a closer examination of these fundamental questions. It should merely be pointed out that Pervasive Computing has the potential to change moral standards in society, for example the standards representing the boundaries between the private and the public spheres.

[5] The free space theory is directly linked to the idea of *intergenerational fairness* in the principle of sustainability.

The precautionary principle now forms part of numerous pieces of national legislation and international agreements. The notion of the precautionary principle is interpreted very differently in its various formulations, however. As the two extreme points on a scale, it is possible to distinguish between a weak and a strong version of the precautionary principle (cf. Sandin 1999, Van den Daele 2001, Rogers/Wiener 2002, Rippe 2003).

In the weak version of the PP, precautionary measures are taken only where major, irreversible risks could occur and their scientific level of proof is high. In addition, only precautionary measures that have low costs may be taken.

On the other hand, according to the strong version of the PP (the other extreme), precautionary measures should be taken even where there is speculative evidence of risks. The risks do not have to be high and irreversible. Precautionary measures are taken irrespective of their costs (e.g. losses resulting from not using a technology).

The versions of the precautionary principle laid down in laws and international agreements lie somewhere between the two extremes. The central question is still: what level of knowledge (or proof) for a risk is sufficient to implement what precautionary measures?

Table 2-1: Strong and weak precautionary principle as two extreme versions.

	Weak PP: Precautionary measures are taken only where…	**Strong PP:** Precautionary measures are also taken where…
Extent of threat	major, irreversible risks might exist	minor, reversible risks might exist
Extent of lack of knowledge	the scientific level of proof is high	only speculative evidence exists
Extent of action	the costs for precautionary measures are low	the costs for precautionary measures are high
How mandatory is the application of the precautionary principle?	Action may be taken	Action must be taken

The range of precautionary measures runs from careful monitoring of the development of a technology and the reversal of the burden of proof to a ban.

In this situation of uncertainty, Hans Jonas (1979) gives precedence to the worst-case scenario and argues that the likelihood of successes in technological development, as in evolution, is rather small. On the other hand, evolution can make numerous mistakes, since, unlike technological development, it moves forward in small steps. In addition, Jonas refers to the inherent dynamic of technical developments and poses the question whether the existing situation is suifficiently undesirable that one would accept any risk to improve it (Jonas, 1979, p. 75).

We take the view that the answer to the central question is highly dependent, first, on the potential *extent of the threat*. Secondly, however, society must be able consciously to weigh up which risks it would like to take. This is possible only through participatory approaches to technology assessment.

Based on experience with uncertain risks in the past (EEA 2001), we also believe that it is important for *minority scientific opinions* to be regarded and appreciated as possible early warning systems.

We will apply this interpretation of the PP in this study.

2.1.4 International trends

The European Environment Agency sees growing social acceptance of the PP as a response to the growing tension between two aspects of modern science (EEA, 2001):

- growing innovative power
- limited ability to predict the consequences of innovations.

Furthermore, enormous advances in communications technology have fostered a growing public sensitivity to the emergence of new risks, before scientific research has been able to fully illuminate the problems (EU, 2000). At EU level and in many Member States, the PP is currently continuing to gain importance (Ammann/Vogel, 2001).

As a reaction to the scepticism towards new technologies and to the uncertainty and inequality in modern society, there is a trend internationally to employ more participatory methods in technology assessment (TA) (EUROPTA, 2000, Joss/Bellucci 2002). Risks are reduced by factoring in various perspectives and experiences: 'Both in the knowledge production process and in the introduction of new technologies [...] broad participation by actors from civil society can reduce risks' (WBGU, 1998, p. 315).

Even though we have not been able to employ any participatory methods in the narrowly defined scope of this study, we take account of these ideas by considering minority opinions in the chapter on health and by holding wide-ranging expert workshops with representatives not only of various scientific disciplines, but also of different interest groups.

2.2 The precautionary principle and the information society

The precautionary principle, as incorporated into environmental protection legislation, revolves around the emission-transmission-immission causal chain (see Fig. 2-1). An important idea of the PP, thus interpreted, is to limit harmful impacts *at source*, i.e. to minimise emissions, thereby acting as far forward in the chain of effect as possible.

The question arises whether this approach is also suitable for problems that may be posed in connection with the wide use of ICT or whether it needs to be expanded for that purpose. We will discuss this question with reference to three examples.

Figure 2-1: The emission-transmission-exposure causal chain

Examples

Example 1: Standby electricity consumption by home entertainment electronics

With the advent of remote controls for televisions, stereo systems etc., devices have become considerably more widespread that, without special countermeasures by the user, require a constant supply of electricity. By 1990 the standby losses from electronic devices amounted to just under 2% of total Swiss electricity consumption (Bachmann, 1993). What precautions could have been taken to prevent this problem? The PP under the Law on Environmental Protection would be aimed at measures at power stations as sources of harmful impacts.[6] Based on an intuitive understanding of precaution, however, it would not only be expected that electricity is produced in as environmentally friendly a manner as possible, but also that avoidable consumption is eliminated, especially where technical solutions exist (as in this example).

Example 2: NIR exposure with the increasing number of wireless networked devices

In case non-ionising radiation (NIR) might cause damage to health, Switzerland has adopted measures including precautionary emission limitations for fixed systems in the 'Regulation on protection against non-ionising radiation'. The exposure to which a user is subjected from the mobile terminal (cell phone) is many times higher for the user themselves than exposure from the fixed systems. People who do not use the terminals themselves are exposed to a lesser extent. However, under the hypothetical assumption that the number of mobile terminals is multiplying (and this is necessary for Pervasive Computing), *exposure for non-users* could also increase, despite the Regulation on protection against non-ionising radiation. The awareness of risks could develop along similar lines to that of passive smoking and result in a similar response. Unlike smoking, however, it would be significantly more difficult for those concerned to identify the perpetrators.

6 These measures could already have been taken.

Example 3: Everyone feels they are being watched

Amongst other things, Pervasive Computing offers the possibility of using almost invisible microphones and cameras. Visionaries are even talking about ‘surveillance dust’. Because of the desired ubiquity of networked electronics, it would be practically impossible to distinguish unwanted surveillance systems from other components that provide desired services. If it is assumed that a few sensational cases of spying become known, this could lead to a general climate of mistrust, the social and health effects of which can hardly be predicted. What precautionary measures could society take to counter such developments?

Conclusions from the examples

In all three examples, the *decisive step* on the way to causing (possible) damage is the *propagation of a technology* together with the *nature of its use.* We will therefore extend the causal model, as shown in Figure 2-2. The original causal chain now forms the last section of a longer chain and there are additional new social effects (as illustrated in Example 3). The use of a technology that has been propagated interacts both with the behaviour of users and with the use of other technologies.

The propagation of a widely used technology is *reversible in theory,* but *irreversible in practice*. Once a technology has been propagated, the costs to the national economy of adjusting the course of the trend would be very high, if the legal requirements for such an adjustment are satisfied at all. In such cases, we talk about *socioeconomic irreversibility.*

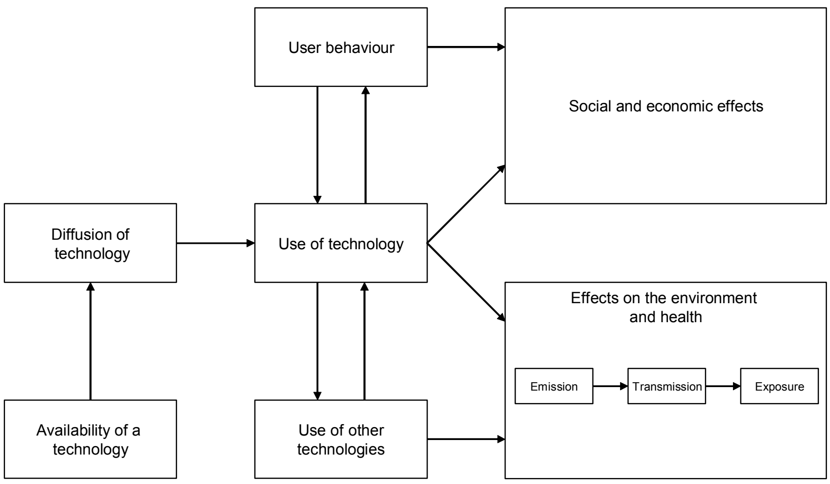

Figure 2-2: Extended causal model for the effects of new technologies

For this reason, precaution must be exercised in the case of technologies such as ICT which are very widely used in respect of the development and diffusion of technologies. Whilst an important starting point for measures is user behaviour, such measures are more in the nature of aftercare than precaution.[7]

[7] This is illustrated by Example 1. It is perfectly reasonable to recommend that users turn off equipment at the mains switch or – if there is no switch – to unplug it. However, this could hardly be seen as a precautionary measure.

In summary, it must be stated that there are three reasons why in the context of the information society the PP can be construed not only in terms of the 'Emission-Transmission-Exposure' arrangement:

1. The diffusion of very widely used technologies (mass market products) such as ICT currently in use is socio-economically irreversible.
2. A high number of emission sources can lead to unwanted exposure even where emissions are limited at source. In addition, those affected have little opportunity to react to such ubiquitous risks.
3. Precaution against social effects of a technology is not covered by the concept of 'avoiding harmful impacts'.

These reasons also apply to some other widely used technologies and are therefore not only relevant in the context of the information society. However, they are particularly pertinent in the case of PvC because the widespread use of this technology, its ubiquity and its penetration of all areas of life are an express part of the vision.

This observation raises a dilemma regarding the precautionary measures that may become policy as a result of a technology assessment:

- If the problem is tackled in a broader sense 'at source' and the development and diffusion of technologies are regulated, there is a risk of inefficiency and of conflicts, since the measures may, for example, infringe international agreements (WTO) as technical barriers to trade.
- If, on the other hand, measures at the front of the causal chain are not taken, no precautionary action is possible in the case of mass technologies, but only aftercare of more or less irreversible conditions.

Ropohl (1996) therefore puts forward the idea of 'innovative technology assessment', which is used where a technology is linked to a utilisation idea. 'This would have the advantage that they can become effective even in the early stages of technical development and, in addition, at the place where there is the most extensive technological knowledge' (Mehl, 2001, p. 112f). According to Ropohl (1996), however, this also has a disadvantage in that a forecast is difficult at this early stage. He therefore suggests that technology assessment goes hand-in-hand with technological development in an ongoing learning process. 'Whilst innovative technology assessment also needs scientific and political institutions, it is also and equally dependent on the constructive participation of industrial corporations and on the expert competence of the individuals working in those corporations' (Ropohl, 1996, p. 269f).

The advantage of this kind of approach is undoubtedly that developers of a technology can be involved in the social discourse and take responsibility at an early stage. However, it must also be borne in mind that the independence of the technology assessment is called into question.

2.3 Sustainable development

Sustainable development as a political idea has its origins in the Brundtland report by the World Commission on Environment and Development (WCED, 1987). According to the notion of sustainability in that report, the aim of economic development should be both *intra*generational and *inter*generational fairness. The needs of people living today must be met throughout the world without this being to the detriment of future generations. This has been at the heart of the principle of sustainability up to now.[8] Strictly interpreted, this principle would be 'revolutionary', as Meyer-Abich observes. For this very reason it contains 'an inherent guarantee that there will be no consequences' (Meyer-Abich, 2001, p. 293).

In the 1990s two extreme interpretations of the sustainability principle emerged.

- *Strong sustainability:* The total natural capital must be preserved, i.e. industry, as users of nature, may live only off the 'interest' of the natural capital. The use of non-renewable resources would therefore be ruled out and renewable resources could be used only within the scope of their regeneration rate.[9]
- *Weak sustainability:* The total anthropogenic *and* natural capital must be preserved.[10] This means that natural capital can be reduced at will if, in return, human-created capital is increased.

In the political discussion it has been apparent time and again that a possible consensus lies *between* the two extremes and has to be found again and again. Sustainability is therefore a future-oriented social process of learning, searching and structuring, characterised by considerable ignorance, uncertainty and a variety of conflicts, a 'regulative idea' (Minsch et al., 1998).

In Switzerland sustainable development has constitutional status:

- In its preamble, the new federal constitution of 1999 includes the people and the Cantons in responsibility towards future generations.
- The overriding purpose of the Confederation (Article 2) is, amongst other things, 'to secure the long-term preservation of natural resources and to promote a just and peaceful international order'.
- Under Article 73 (Sustainability), the Confederation and the Cantons must strive 'to establish a durable equilibrium between nature, in particular its capacity to renew itself, and its use by humans'.

In its 'Sustainable Development Strategy 2002', the Federal Council defined six guidelines and a number of action areas and measures for sustainable development policy (Strategie Nachhaltige Entwicklung, 2002).

We will base our evaluation of the effects of Pervasive Computing on these guidelines. However, not all the guidelines and not all statements on the individual guidelines are relevant to the subject of this study. Table 2-2 therefore shows in the right-hand column

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8 Here we are influenced by Meyer-Abich (2001), who construes sustainable development as *a principle* under the Brundtland report. We consider it to be irrelevant whether we should in fact talk about a collection of principles, which later formulations of sustainable development in some cases suggest.

9 The strong principle of sustainability would rule out a scenario where, through the consumption of finite resources, 'an economic upturn is created, associated with such great technical advances that economies can subsequently be made once again with renewable resources' (Meyer-Abich, 2001, p. 297).

10 'Extensive substitutions of the latter by the former are therefore compatible, e.g. seashores by swimming baths, historic regions by leisure parks, cross-country runs and walks by fitness centres.' (Meyer-Abich, 2001, p. 296)

those aspects that will be of importance for our further reflections for the reasons set out below.[11]

- The precautionary principle (Guideline 1) has a special place in this study as part of the objective.
- The polluter-pays and liability principles (also Guideline 1) are affected by PvC in so far as establishing a cause or attributing liability may be influenced significantly by future ICT developments. At various points in this study we will return to this fundamental problem (Sections 3.5, 8.7.2).
- It is clear that the three dimensions referred to in Guideline 2 are affected by the future development of a key technology like ICT, particularly where the development follows a vision consisting in the penetration of all areas of life. However, we do not accept the idea that the three 'dimensions' have equal status, because they are three mutually inclusive systems: economics is a functional system of society (alongside politics, law, science, religion etc.) and human society is part of the ecological system (alongside other populations). It is not logically possible, however, to place side by side and balance two things that are mutually inclusive.
- Guideline 3 mentions the problem of irreversibility as a characteristic of the environmental dimension and cites climate change, biodiversity and the ozone layer as examples. We will give a slightly broader interpretation to this criterion and also classify social developments that are difficult to reverse and that can cause lasting environmental pollution as irreversible risks ('socioeconomic irreversibility').

Guidelines 4-6 will be taken into consideration in selecting the measures recommended by the study.

[11] The table is no substitute for the original version of the guidelines – which we have not reproduced here because they are generally available (www.johannesburg2002.ch) – but merely an overview of selected aspects that are affected by Pervasive Computing.

Table 2-2: Aspects of the guidelines in the Sustainable Development Strategy 2002 affected by PvC.

Guideline	**Aspects mentioned in the guideline**
1. Fulfilling our responsibility towards the future	• precautionary principle • polluter-pays principle • liability principle
2. Equal consideration to the environment, economy and society	• environmental responsibility (consumption of resources, impact of emissions) • economic efficiency (income, employment, competitiveness, innovative capacity) • social solidarity (health, safety, education, equal rights and legal certainty)
3. Recognising the individual characteristics of the dimensions of sustainable development	• particular caution with regard to the irreversible destruction of environmental goods
4. Integrating sustainable development into all policy areas	*These three guidelines do not serve to assess opportunities and risks, but will be taken into consideration in selecting the measures recommended by the study.*
5. Improving coordination between policy areas and enhancing coherence	
6. Achieving sustainable development on the basis of partnership	

The connection between the precautionary principle and the sustainability principle

Because of the long-term orientation of the PP and the ‘free space theory’ there is a direct connection with the sustainability principle’s aim of intergenerational fairness. The PP can therefore be regarded as one of several instruments that implement the sustainability principle.

Rausch (1985) and Rehbinder (1991) also recognise the sustainability and precautionary principles as having the same intention: not just to delay the overexploitation of nature, but to prevent it permanently.

Norton (1992) sees the precautionary principle as a way of protecting the sustainability principle from the feared ineffectiveness.

The final declaration from the ‘United Nations Economic Conference for Europe’ back in 1990 stressed the role of the PP as a necessary prerequisite for sustainable development: ‘In order to achieve sustainable development, policies must be based on the precautionary principle [...] Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.’ (Bergen Declaration, 1990).

2.4 Sustainability and the information society

Sustainability in the information society is a more recent field of research, which concentrates on the consequences of information and communication technology (ICT) for the objective of sustainable development. This covers both the hope for largely dematerialised net product through ICT and the ecological consequences of ICT production, use and disposal, as well as rebound effects[12] from efficiency increases (Heiskanen et al., 2001; Herring, 2002; Hilty, 2002a, 2002b; Türk et al., 2002).

Sustainable development in this field is considered primarily from the *ecological* perspective, because that is where most ground has to be made up. Up until a few years ago, positive or negative ecological effects of ICT were barely discussed at all (although social effects have been discussed since the 1970s[13]). This is surprising, because the economic structural change driven by ICT entails great changes specifically in the ecological field.

Recently, questions of sustainability in the information society have been raised by the growing problem of technotrash (BAN, 2002) and by reports on major materials consumption in the production of PCs and high energy requirements for the Internet (cf. Türk et al., 2002).

Aside from these effects of ICT, however, the idea of sustainability in the information society is characterised by hope in: the prospect of an extensive dematerialisation of the value chain from the use of ICT. Dematerialisation describes a reduction of the material and energy intensity of economic processes (production, transport, consumption, waste disposal). The need for dematerialisation was recognised in the 1980s, when, after micrograms of toxic substances, the megatonnes of the regular mass flows became the focus for environmental protection: ‘Considering the fact that for every person in the United States we mobilise 10 tons of materials and create a few tons of waste per year, it is clearly important to gain a better understanding of the potential forces for dematerialisation. Such understanding is essential for devising strategies to maintain and enhance environmental quality, especially in a nation and a world where population and the desire for economic growth are ever increasing’ (Herman et al., 1990, p. 346).

Since the mid-nineties, estimates have been discussed in the debate on sustainability according to which the material intensity per service unit must be reduced by a factor of 4 to 10, if the lifestyle of the rich North is to be applied across whole globe. A *necessary requirement* for the compatibility of the two core postulates of sustainable development, inter- and intragenerational fairness, is therefore dematerialisation.[14] By and large, there are no doubts as to the technical feasibility of this aim (Von Weizsäcker et al., 1995).

Such dematerialisation can be considerably assisted or facilitated by ICT (Heiskanen et al., 2001; Hilty/Ruddy, 2002):

- optimisation of processes and products with respect to material and energy efficiency

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12 With regard to the rebound effect see also Chapter 6.

13 Social aspects of ICT and information technology have been the subject of research since the 1970s and dominate the discourse on ethics and ICT (cf. Section 2.5 und Hilty, 2002c).

14 However, it is not a sufficient requirement. This means that without dematerialisation there will not be any sustainable development, but other requirements have to be satisfied. These include overcoming the enormous social injustice both in individual countries and globally. On this point see also Radermacher (2002).

- organisation of innovative services and growing contribution of information services to the net product
- avoidance of transport by telecommunication.

The very idea of selling, instead of material goods, the use of those goods, i.e. services (pay per use) only becomes practicable in many cases with PvC (Bohn et al., 2002).

However, these aims are not achieved simply through the existence of technical feasibility; these are merely potentials. For these potentials to be realised, a number of non-technical requirements must be met. These include, for example, organisation of technology in accordance with human requirements and overall policy control of developments in the general situation.

In conclusion, it should be noted that if the sustainability principle is interpreted in the context of the information society, a '*maxim of dematerialisation'* can be inferred: *Information and communication technologies should be used in such a way that their potential for dematerialisation (reduction of material and energy conversion for the same utility) is realised.*

At present this maxim is still largely ignored or ineffective. The dematerialisation potential of ICT is not being realised; the path taken by the industrialised countries into the information society is still a path of rising materials and energy sales per head of population. We will return to this point in Chapter 7.

2.5 Other ethical aspects of the information society

In addition to the question that was discussed above concerning the way in which the sustainability principle is to be interpreted in the context of the information society, there are a number of problem areas in the information society, which have been discussed for some time. These include, in particular, the traditional ethical principles that are touched on by certain applications of ICTs: respect for human dignity, welfare, social justice.

In the 1970s, the professional associations with ICT connections (primarily information technology organisations) opened up the discourse on 'ethical aspects of computing'. With the influence of the Internet, this discourse has formed offshoots, such as 'cyberethics' (Spinello/Taviani, 2001), but has also led to more comprehensive approaches, such as 'information ethics' (Floridi, 1998; Nethics 2001; Kuhlen, 2002).

In 1976 the International Federation for Information Processing (IFIP), the global umbrella association for information technology organisations, formed a Technical Committee to deal with 'The Relationship between Computers and Society' (IFIP TC 9), which gave the many national organisations the impetus to discuss the social responsibility of ICT professions and to draw up ethical guidelines for their members. A milestone was the adoption of the ACM Code of Ethics and Professional Conduct by the Association for Computing Machinery (ACM) in 1992.

> ‘Since our way of communication and information handling is **the** outstanding characteristic distinguishing us from other beings, significant changes in the apparatus (viz. organs) and the mechanisms of perception, thinking, feeling, memory and communication are bound to have a profound impact on our civilisation and culture.’
>
> Albert Kündig (Kündig, 2002).

The IFIP Ethics Task Group analysed 30 codes of ethics or codes of conduct and formulated a framework for the development of such ethical guidelines by professional associations. An attempt was deliberately not made to pursue the idea of aiming for a uniform, globally applicable code (Berleur/Brunnstein, 1996).[15] After the Internet had raised new ethical issues, the IFIP drew up the report on ‘Ethics and the Governance of the Internet’ (Berleur et al., 1999).[16]

There are five subjects that repeatedly crop up in these discussions because of their ethical implications and the disagreements to which they give rise:

1. Privacy: Where does individual freedom to collect data end, in conflict with the right to information self-determination (which stems from the principle of autonomy)?
2. Security: What level of security for an information system needs to be guaranteed for it to be responsible to use the system? Who is responsible for security flaws? Is it a criminal act or a service to society to identify and publicise security flaws?
3. Unmastered complexity:[17] In the case of complex, and particularly distributed, information systems, it is generally not possible to give a formal guarantee of certain properties of such systems. Does the increasing dependence on such systems result in a loss of decision-making responsibility (‘the problem of incontinence’)?[18]
4. Free speech: What are the limits of the right to free speech with respect to the use of electronic media, when it comes into conflict with other fundamental rights? May or should there be censorship of Internet content?
5. Intellectual property: Where is the boundary between information as public property, which must be available to everyone for reasons of social justice, and intellectual property, over which the owner has autonomous control?

Other problems of the information society which have ethical implications have been discussed only for a few years or have not yet been discussed in comparable depth (see also Kündig, 2002, and Hilty, 2002c):

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15 The codes and additional information are available through a website (Lee, 1995).

16 Swiss information technology organisations have not developed any ethical guidelines, but there is a Working Party on Information Technology and Society in the SI. The German Information Technology Organisation ‘Gesellschaft für Informatik’ (GI), which represents 25 000 members across the whole German-speaking area, is currently revising its ethical guidelines with a view to incorporating collective ethical implications alongside individual ethical implications.

17 The term ‘unmastered complexity’ was coined by Dijkstra (1982).

18 This expression can be attributed to Mitcham (1986).

6. Digital divide: The jeopardisation of social justice through the division of society into those who have access to the information society and those who are excluded, e.g. low-income households, the elderly, those with disabilities (also known as the ‘global digital divide’: the gap between north and south).
7. Education: Changes to the education process through the use of ICT and the implications for social justice.
8. Gender issues:[19] How does the use of ICT in the workplace and in private life change social justice between genders?
9. Cultural diversity: What effect does ICT have on social justice between different cultures (e.g. dominance of the English language)? Will cultural diversity be preserved for future generations?
10. Cultural heritage: Will future generations still be able to share in our knowledge if today’s digital storage media are no longer readable in the future?
11. Dependability and trust: Does the increasing dependence on ICT infrastructures threaten the autonomy of the individual? Will we be forced, because of the complexity of structures, to trust without having sufficient verification facilities?[20]
12. Sustainability in the information society: dealt with separately in Section 2.4. above.

These twelve problem areas have entered the consciousness of the (specialist) public as information technology has developed from the mainframe computer era to current ICTs, dominated by PCs and the Internet. The following question therefore arises: what specifically will change as a result of PvC? Table 2-3 shows the project group’s assessment of this issue. Without calling into question the relevance of these twelve problems per se, in this study we will continue to examine only those where a specific change can be expected as a result of PvC. This follows from the definition of the object of the study. They will be incorporated into the synopsis of opportunities and risks in Chapter 8 and dealt with further there.

Although a specific change in the situation regarding ‘intellectual property’ and ‘cultural diversity’ can be expected as a result of PvC, those subjects will not be examined any further, since this would extend far beyond the bounds of this study.

[19] In 2000 the IFIP TC 9 formed a Working Group on Women and Information Technology.

[20] See also the quotation from K. Brunnstein in section 8.5

Table 2-3: Assessment of the potential change brought about by Pervasive Computing in comparison with current ICT applications in the ethically relevant problem areas.

Problem area	**Potential change with PvC**	**Reasons**
Privacy	very high	High degree of networking, ubiquity, invisibility, context sensitivity (sensors)
Security	very high	Higher dependence, higher degree of networking (network vulnerability), complexity
Unmastered complexity	very high	Higher degree of networking, new functions, decentralised structures
Free speech	low	The step to the Internet was crucial; PvC will not bring anything substantively new
Intellectual property	medium	The step to digitalisation and the Internet/WWW was crucial; PvC extends the problem to ‘smart’ objects
Digital divide	high	User interfaces and ICT propagation will change as a result of PvC
Education	low	The same questions arise as at present with regard to the role of PCs and the Internet as learning aids
Gender equality	medium	Greater freedom to undertake activities anywhere makes it easier to combine work and family
Cultural diversity	medium	The step to the Internet/WWW was crucial; PvC continues the trend [21]
Cultural heritage	low	The step to digitalisation was crucial; PvC will not bring anything substantively new
Dependability & trust	very high	Higher penetration of everyday life, higher complexity, verifiability is reduced markedly
Sustainability in the information society	high	Higher dematerialisation potential (see Section 2.4 and also Chapter 7).

[21] Everyday objects will become media, which may undoubtedly have far-reaching cultural effects that are difficult to predict. (An issue that would require a study of its own). The threat to cultural diversity stems primarily from global networking, however, a step already taken with the Internet.

2.6 Conclusion: A normative framework for this TA study

On the basis of the above considerations, it is possible to devise the following normative framework for assessing the consequences of PvC as a future new way of using ICTs:

1. Precautionary principle: In accordance with the precautionary principle, risks that have not been proven on the basis of the current level of knowledge are also taken into consideration. In characterising the risks and deriving measures, the 'socioeconomic irreversibility' of technology propagation is also taken into account, that is to say the section of the causal chain under examination does not begin with the technical product.
2. Sustainability: Possible effects are assessed according to their positive or negative contribution to the objective of sustainable development. In practical terms, the study is based in this respect on the guidelines set out in the Federal Council's Sustainable Development Strategy 2002 and on the dematerialisation maxim.
3. Special problem areas: Some of the problem areas from the ethical discourse on information technology that have been identified as specially relevant will be included in the further reflections, even though they do not relate to effects on health or the environment in the narrower sense. These are social and higher-ranking aspects: data protection, security, unmastered complexity, the digital divide, gender equality, dependability and trust.

3 Technological developments

Siegfried Behrendt, Lorenz Erdmann, Felix Würtenberger

The Pervasive Computing (PvC) trend is being driven by technological developments. The main influencing factors, which are described below, include the constantly improving performance of microelectronics. Advances in microsystems technology, and increasingly also in nanotechnology, create the technological preconditions specifically for context sensitivity, which was introduced as one of the five characteristics of PvC (see also Section 1.1). In communications technology, developments are emerging that will enable everyday objects to be networked in the future. Alongside fixed networks, wireless networks are also important, both local and large-scale. There are also network protocols for distributed systems or for ad hoc networks, which allow spontaneous networking of objects in close physical proximity. Also important are new forms of human-machine interaction which allow ever smaller computer technology to be used without using monitors, keyboards or mice.

3.1 Microelectronics: more powerful, smaller and cheaper

The advances in microelectronics lead to a permanent performance improvement and a simultaneous price drop for ICTs. According to ‘Moore’s Law’, the storage capacity of microchips quadruples every three years. The miniaturisation and reduction in the cost of electronic circuits mean that it is increasingly possible to integrate microprocessors ‘invisibly’ into other products. Even simple household devices are made ‘intelligent’ and capable of communication by being networked with other devices.

In addition to the performance improvement, there have also been advances in processor design, which are required in particular for mobile applications. These include more efficient power management, which regulates the clock frequency and the core voltage[22] according to the situation. New design ideas make it possible to switch parts of the CPU on and off depending on the operations being carried out.

Experiments are already being carried out with wireless networked minicomputers with dimensions of 4 x 4 x 2mm, ‘e-grains’ (already referred to, with some exaggeration, as ‘smart dust’). Energy is to be supplied in future by means of infrared radiation or through the use of temperature gradients. A sensor-actuator system and an HF antenna are the external interfaces of the e-grains, which form ad hoc networks. Consideration is being given to the idea of using them as ‘intelligent wall paint’, which will network all the objects in a room with one another (Reichl, 2001).

This vision shows the close connection in the thinking of the developers between miniaturisation and the use of large numbers of microchips. This must be concluded from the fact that development expenditure increases with miniaturisation. Thus, if the number of units remained the same, the unit costs would rise, which would mean that the market would not accept them. Miniaturisation will therefore make progress only if

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[22] CPU core supply voltage. Pentium III processors, for example, work at 1.65 V.

the sales market expands accordingly, either geographically or as a result of new applications, of which the vision of 'intelligent wall paint' is perhaps an extreme example.

In roughly ten years, silicon technology could reach its limits. Whilst in 1995 the structural size of microchips was around 35 micrometers (µm), by around 2011 it will be 50 nanometres (nm) (SIA, 2002). This is a reduction in size by a factor of 700 in 16 years.

With these increasingly delicate structures in microelectronics, the traditional description of electron movement does not apply below 50 nm and the wave characteristics of electrons become increasingly noticeable. If the development of electronic components includes this range, quantum mechanical effects must also be taken into consideration. This represents a problem for the silicon technology that has been introduced, but it will in future offer the possibility of developing fundamentally new functional elements. With 'quantum computers' quantum effects are to be made usable for future computer models.

Pervasive Computing needs above all memory chips that do not really play a role as a cost factor. An important impetus is expected to be provided by polymer electronics. For several years, technologies have been tested for applying and structuring polymers in order to manufacture and encapsulate components. There is a focus on the manufacture of low-cost plastic chips. The advantage of polymer memory chips is the much simpler manufacturing process compared with silicon-based memory chips. Rewritable memory chips using this technology have the further benefit that the contents of the memory are preserved even without a supply voltage.

In addition to major development tasks in the field of materials research and the optimisation of production processes, research is being conducted into full polymer transponders in roller-to-roller production technology. These transponders can be imprinted as universal data media (smart labels). Polymer technology could thus further the possibility of 'intelligent packaging' at very low cost (see also Section 4.7).

Plastic chips will compete with silicon chips only to a small degree; instead, synergy effects are expected: 'The combination of thin silicon chips, sensors and actuators with polymer-based construction and connection technology and polymer electronics at different substrata make it possible to embed electronic systems in nearly any conceivable object.' [23]

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[23] Polytronic: Chips von der Rolle, no author credited, 2001 in Fraunhofer Magazin 4/2001

3.2 Networking of devices and objects

A feature of PvC is the networking of a large number of components. Among the networks, the Internet will continue to play an important role in the 'PvC era', since it has developed into a global information and communication infrastructure. In future it can be expected that the Internet will encompass more and more applications and will be 'extended' right inside everyday objects.

In principle, the whole spectrum of communications infrastructure can be part of the ubiquitous networking, from satellite-based networks and fixed and mobile phone networks to short-range wireless networks (see Figure 3-1).

A central role will be played by wireless technologies, in particular where non-stationary objects are networked.

Depending on the distance to be covered, a distinction should be drawn between:

- WANs (Wide Area Networks), distances of up to 100 km.
  In the wireless sector, these are mainly cellular phone networks.
- W-LANs (Wireless Local Area Networks)
  Wireless Local Area Networks are used primarily for networking in office buildings, homes or 'hot spots' like airports and hotels and typically have a range of 100 m.
- W-PANs (Wireless Personal Area Networks)
  These cover applications such as networking of portable devices, wearable computers, 'intelligent objects' etc., with a range of 10 m.
- BANs (Body Area Networks), sometimes also called (W-)PANs.
  Networking of components worn on the body (wearables) by radio or by making use of the body's conductivity, with a range of 1 m.

Many of these radio communication networks are cellular, which means there is a distinction between the mobile terminals and the stationary access points (or base stations), which switch and relay communication between the terminals and also allow access to umbrella networks. Direct communication between terminals (peer-to-peer) is not possible in infrastructures of this kind.

Recently, 'ad hoc networks' have been gaining importance. For example, the Bluetooth standard supports ad hoc connections. Unlike cellular systems, in ad hoc networks there is no distinction between base stations and terminals. Two or more devices that have access to the same channel form a 'pico network', a network formed solely for this specific communication situation. In these pico networks, the participating terminals can communicate without the need for a stationary base station. The idea of non-cellular mobile radio communication is based on a similar principle.[24] Special mobile telephones will act as both terminals and base stations and thus form a peer-to-peer mobile radio communication network without a stationary transmission mast. Data packages are 'passed on' from terminal to terminal until they reach their recipient. However, such ad hoc connections can be established only where the physical density of connected devices exceeds a critical value.

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[24] One example is DIRC (Digital Inter Relay Communication).

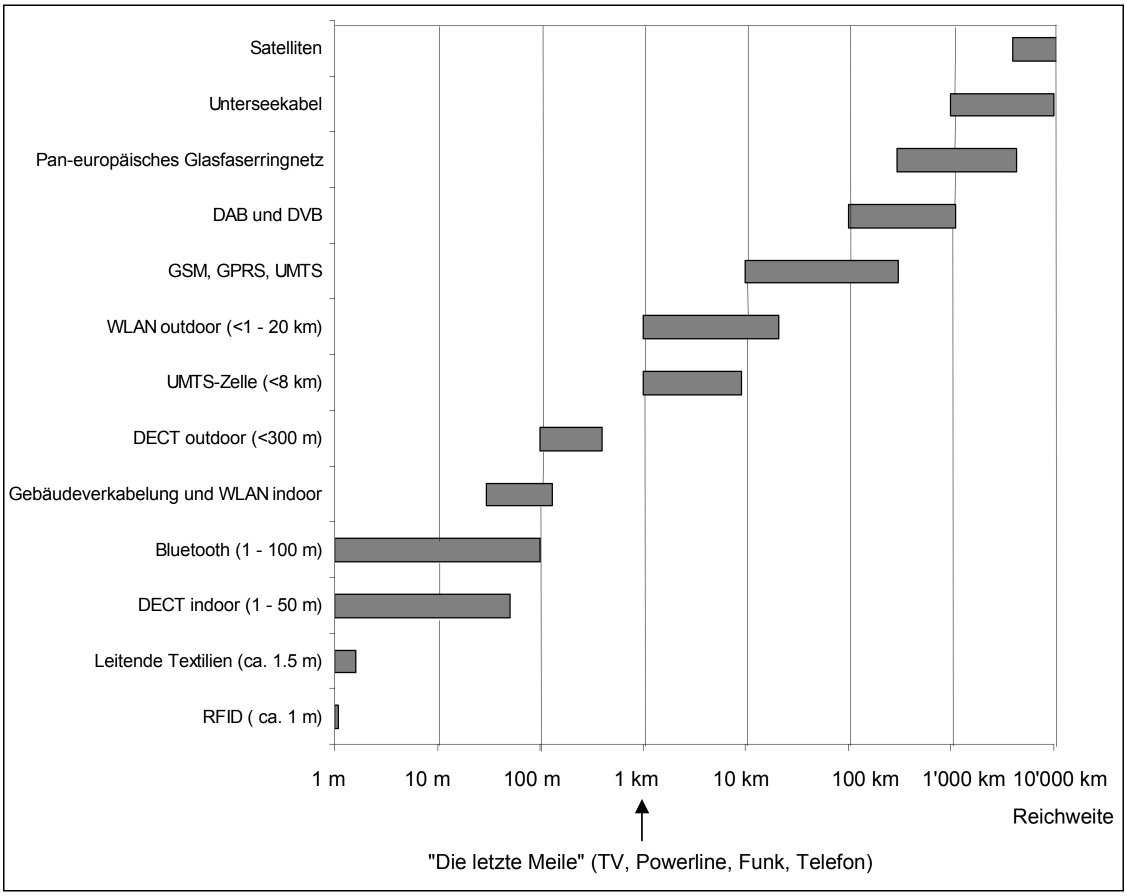

Figure 3-1: Overview of network levels and ranges of cable and radio-based transmission infrastructure (for abbreviations see glossary).

Translator's note: For legend see p. 293 below

A forecast of the wireless standards that will dominate Pervasive Computing (PvC) is uncertain for several reasons:

- Many PvC components do not yet exist and, consequently, no clear requirement profiles for data transmission can be identified yet.
- New radio communication technologies such as UMTS, IEEE 802.11 or Bluetooth are just beginning to conquer the market. It is difficult to predict their importance in ten years.
- In addition, new standards are constantly being developed.

The development of the networking potential of devices and objects also depends on further standardisation of network protocols. Many PvC devices will presumably support the Internet protocol (Ipv6). For applications in which interconnected devices or objects form a network, however, network protocols for distributed architectures are needed. In this respect there are a number of sophisticated systems and systems in development such as HAVI[25], UpnP[26] and, more broadly speaking, CORBA[27]. Hitherto,

25 Home Audio Video Interoperatibility

26 Universal Plug 'n' Play

however, these systems have been proprietary and not interoperable. Generally accepted, cross-manufacturer standards have not yet been developed, which has prevented the relevant systems from breaking through (Huhn, 2002). One example is the field of home networking (smart homes), where many different network access points exist. As soon as generally accepted standards exist, network-ready components will be a possibility for a mass market.

An attempt is made below to narrow down these uncertainties and to arrive at plausible assumptions and assessments.

WANs

For many Pervasive Computing applications, access to umbrella networks (for mobile telephony, Internet access etc.) is essential. This may be done either by connecting over a local network (W-LAN Access Point etc., see the following section) or over cellular phone networks. Mobile radio communications in Europe are clearly dominated at present by GSM networks.[28] In the medium term, however, UMTS networks[29] will also be important, and in the long term fourth generation mobile communications (4G) technologies.

Normally, mobile radio communications network have to cover radio distances from a few hundred metres to several kilometres to the next base station. Table 3-1 shows a comparison of the characteristics of GSM and UMTS technologies.

Table 3-1: Characteristics of GSM and UMTS networks

	Carrier frequency	**Pulse frequency**	**Channel access**	**Maximum range**	**Maximum transmission power**
GSM	0.9 – 1.8 GHz	217 Hz	TDMA (pulsed)	35 km	2000 mW
UMTS	2 GHz	100 Hz [30]	CDMA	8 km	125 – 250 mW

Some technical data for GSM and UMTS that are important for subsequent assessments in connection with non-ionising radiation (NIR) are set out below.

GSM

GSM uses the TDMA channel access mode. The base station and the mobile radio communications device exchange data packages on a certain carrier frequency; several calls may be transmitted on one carrier frequency. Data is divided by ‘time division’, i.e. by allocating time slots that are periodically repeated. The individual mobile phone

27 Common Object Request Broker Architecture

28 Global System of Mobile Communications. This was the first digital standard and the second generation (2G) for mobile telephony.

29 Universal Mobile Telecommunications System, the third generation (3G) for mobile radio communication networks.

30 Applies only to TDD operation, used primarily within buildings. In the case of FDD operation, the transmitter is not pulsed (BAKOM, 2000).

receives a new data package exactly every 4.615 ms. This results in a pulse frequency of 1 / 4.615 ms = 217 Hz.

The maximum transmission power of a GSM mobile is 2 W in the 900 MHz band and 1 W in the 1 800 MHz band. The transmission power of the base stations is in the order of magnitude of 1 to several hundred watts per high frequency carrier. Normally, several high frequency carriers are operated for each base station.

UMTS

UMTS uses the CDMA channel access mode.[31] Unlike TDMA[32] the data packages pertaining to different calls are not divided by time, but by different coding. First of all, this mode does not lead to pulsed radiation. However, two modes are available for the division of the go and return channels: FDD[33] and TDD[34]. The use of TDD results in a pulse frequency of 100 Hz.

The maximum transmission power of UMTS mobiles will typically be 125 to 250 mW, around 8 to 16 times less than a GSM mobile. Simulations by manufacturers have revealed that the average transmission powers of UMTS devices will be even as low as around 7 mW in the country and around 0.6 mW in the city (BAKOM, 2000).

In addition to Internet-ready mobile UMTS generation telephones, a large number of other devices and everyday objects could also be made capable of online operation (refrigerators, washing machines etc.). This should not only create further online access points in order to make the Internet ubiquitously accessible; it should also facilitate remote access to devices by owners or customer service departments for control or remote maintenance.

Prospective trends in the WAN sector

The current development band for PvC in the wireless communication sector is characterised by the GSM mobile radio communications standard (with the extensions HSCSD[35], GPRS[36], EDGE[37] and UMTS). Other technologies such as the 'DIRC'[38] system for ad hoc radio communications networks or the monodirectional DAB[39] and DVB[40] standards could be used in PvC. The latter allow only one-way communication, but could be used to disseminate information that is intended to be ubiquitously available for PvC components, e.g. weather data.

Mobile radio communication operators have high hopes of UMTS, the third generation of mobile communications, which, as a new standard, will permit higher data transmission rates, better speech quality and higher network capacities. However, following the previous technical and economic problems with the introduction of GPRS

31 Code Division Multiple Access

32 Time Division Multiple Access

33 Frequency Division Duplex

34 Time Division Duplex

35 High Speed Circuit Switched Data

36 General Packet Radio Service

37 Enhanced Data Rates for GSM Evolution

38 Digital Inter Relay Communication

39 Digital Audio Broadcasting

40 Digital Video Broadcasting

and the development of the UMTS infrastructure, it must be assumed that these ambitious aims will not be achieved for the time being.[41] Whilst UMTS has not been introduced comprehensively, the next mobile radio communication generation (4G) is already being developed. With that technology, transmission rates of up to ten megabits per second are initially possible, but, for economic reasons, will not be available across the entire network, but only at 'hot spots' with many users in a small area. These include, for example, airports and office complexes in cities. Outside conurbations, customers will share the bandwidth of a UMTS base station or they can set up their own wireless network at home, connected with the provider by TV cable, microwave radio or DSL[42]. The underlying vision is one of full integration of mobile and fixed network technologies and standardisation of service functions.

W-LANs

PvC is reliant on wireless local communication technologies (Wireless Local Area Networks). In the typical range for local networks there are a number of common standards such as the IEEE-802.11 family and HomeRF. Their most important characteristics are compiled in Table 3-2. For the sake of completeness and for comparison of transmission power, the digital radio standard for DECT cordless telephones is also shown.

Table 3-2: Characteristics of technologies in the W-LAN sector

	Carrier frequency	**Pulse frequency**	**Typical range**	**Maximum transmission power**
IEEE 802.11b	2.40 - 2.48 GHz		up to 120 m	35 mW
IEEE 802.11a	5.15 - 5.35 GHz		50 – 300 m[43]	160 – 800 mW
- " -	5.72 - 5.82 GHz		**- " -**	**- " -**
HomeRF	2.4 - 2.5 GHz		50 m	100 mW
DECT	1.85 GHz	100 Hz	50 - 300 m	250 mW (on average ~ 10 mW)

For networking in office buildings or for bandwidth wireless Internet access in hot spots such as hotels or airports, the IEEE 802.11 standard has become much more widespread in recent times.

Wireless LAN technology, which can be used in businesses and in small offices and homes, is suitable for extending hardwired LANs and for setting up Internet POPs, thus allowing greater mobility. Wireless networks are of particular interest for use at trade

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41 It is clear that, against the background of falling margins in the mobile voice communication sector, the high investment in UMTS cannot be justified solely by mobile telephone services either; new applications, based on the extended performance characteristics of the technologies, are the critical factor for the amortisation of these costs and the success of future generations of mobile communication. Data security (for example in mobile payments) and health protection ('electrosmog' from UMTS base stations) will influence developments.

42 Digital Subscriber Line

43 Depending on data transmission rate.

fairs or in conference rooms, at airports, in waiting rooms or in libraries. Depending on the distribution of *access points*, however, even large urban districts can be provided using this technology. The range is 30 to 100 m, depending on the system used, in office environments, up to 1 km in the open air, and even more than 20 km in the directional radio variant. At present the transmission power is mostly 1 to 2 Mbit/s. According to a survey by the IZT (2001), 36% of all IT firms in the United States are already using wireless LANs.

Prospective trends in the W-LAN sector

Up to now nearly all Wireless LAN products have operated in the 2.4 GHz range also used by Bluetooth, which is less susceptible to errors, since small data packages are sent on different frequencies. However, according to Frost & Sullivan, growth can also be expected in the 5 GHz range. One advantage compared with 2.4 GHz is the lower susceptibility to errors, since this frequency band is not shared by microwave ovens, Bluetooth and HomeRF.

The extent to which Bluetooth and Wireless LANs are in competition or complement one another is currently under discussion. (We will deal with Bluetooth, on account of its lower range, under the heading W-PANs in the next section). For 2006 Frost & Sullivan predict that airports, railway stations and hotels will increasingly be fitted with wireless radio communication networks based on W-LAN *or* Bluetooth technology. It is forecast that there will be more than 37 000 such 'hot spots', with the proportion for Bluetooth being estimated at 35%, whilst 20 to 50% of hot spots will have both technologies.

Excursus: Free Networks

The IEEE-802.11b standard allows a licence-free facility for wireless data transmission on the 2.4 GHz frequency band which can be used by anyone. The maximum permitted transmission power of 100 mW limits the physical range of a radio cell to a few hundred metres. As a result of the data transmission speed of W-LAN, which is very high compared with GSM – up to 11 Mbit/s (in future up to 54 Mbit/s with IEEE-802.11a) – it is conceivable that a decentralised network infrastructure will be created. The IEEE-802.11g standard, which has similar performance characteristics, could gain similar importance.

Using a peer-to-peer concept, operators of W-LAN nodes can come together in an umbrella network, which they operate and control themselves. *Free networks* like this are being developed in some cities (e.g. London, Berlin) and are beginning to be networked together. Visions of a self-promoted growth in networks are being given new impetus by W-LAN technology.

Furthermore, this does not allow profit-making groups to network with each other and to influence the telecommunications market. In addition to sharing bandwidth and costs, *free networks* can also put an end to the user's existing dependence on commercial providers. In principle, it is possible to substitute centrally operated radio communications networks such as GSM or UMTS partially with decentralised W-LAN-based networks. However, non-technical problems, e.g. problems relating to liability or data protection, could be an obstacle to this development.

In countries with weak telecommunication infrastructures, *free networks* are the obvious choice for any sort of Internet access. Both the problem of inadequate or unreliable telecommunication networks and the often high infrastructure costs can be avoided by setting up wireless *free networks*. The necessary technology is simple and can be implemented in local initiatives. In conjunction with *open source* software, such networks could help to overcome the *global digital divide* (Thaler, 2002). There have been positive experiences in non-profit projects relating to development cooperation with African countries (wire.less.dk, 2003).

There has not been a satisfactory solution to the problem of the security of open data networks of this kind against abuse by net hackers. If the networks are operated without encryption, the operators have virtually no protection under criminal law from attacks by hackers and data theft.

Further problems that must be resolved include charging for access to other services over a free network, liability in the event of failures, and rules for name-forming and addressing on the network.

Furthermore, in the light of the decentralised operation of W-LAN base stations, the question arises as to how the polluter-pays principle might also be applied to cases of health risks caused by non-ionising radiation (NIR). Unlike the GSM base stations used by current cellular phone networks, for which a manageable number of operators is responsible, in a free network both NIR emissions and responsibilities are shared among a very much larger number of small W-LAN cells with lower transmission powers and their operators.

W-PANs

The most important standards for wireless networking over a range of a few metres (Wireless Personal Area Network) are IrDA, Bluetooth, and ‘high-rate W-PANs’ under IEEE 802.15.3. Their most important characteristics are shown in Table 3-3.

Table 3-3: Characteristics of technologies in the W-PAN sector

	Carrier frequency	**Pulse frequency**	**Typical range**	**Maximum transmission power**
IrDA	infrared	–	< 5 m	–
Bluetooth	2.402 - 2.480 GHz	1600 Hz	10 /100 m	1 – 100 mW
IEEE 802.15.3	2.4 – 2.5 GHz	–	10 m	–

The different technologies have specific advantages and disadvantages. For example, the greatest disadvantage of IrDA (on which remote controls for home entertainment electronics, for instance, are based) is the need for a line of sight. With Bluetooth, however, communication can take place even through walls and thus between several rooms or offices. On the other hand, the omnidirectionality of Bluetooth can be detrimental in certain situations: if, for example, two participants at a meeting wish to exchange electronic visiting cards without bothering the others at the table, IrDA with a directional infrared beam, allowing point-to-point communication, is an advantage.

Bluetooth is an existing, open standard, which creates a cordless connection between mobile devices such as mobile phones, handheld computers, organisers or other electronic devices. Bluetooth can be implemented on a single chip. The transmission power is up to one megabit per second, whilst the range is low, at 10 to 100 metres.

A great future has been predicted for this technology. Since using series production the price of chips could fall from the current level of € 40 to below € 5, they could become a frequently used component. The market research company Forrester forecasts that 235 million Bluetooth-enabled wireless devices will be on the market in Europe in 2006. By this time, according to the same forecast, 44% of PDAs and 73% of mobile telephones in Europe will be Bluetooth-enabled.

Technologies from the W-LAN sector (see above) can theoretically also be used in the W-PAN sector. However, Bluetooth is superior to IEEE 802.11 technologies, for example, because it is less complex (and therefore less expensive) and has a lower power consumption and therefore a longer battery life.

Excursus: Bluetooth

Since Bluetooth is at present considered by experts to have the best prospects of becoming the dominant radio communication standard, we will take a more detailed look at Bluetooth technology here, dealing in particular with technical characteristics that are relevant to assessments in connection with non-ionising radiation (NIR).

Bluetooth is operated in the licence-free ISM (Industrial-Scientific-Medical) band at 2.45 GHz and is therefore exposed to interference sources such as garage door openers, baby listeners, etc. This problem is resolved with frequency hopping. The transmission frequency hops up to 1 600 times per second. Between 2 402 and 2 480 MHz 79 frequency channels, each with a channel width of 1 MHz, are available for this purpose.

According to range, there are two performance categories for Bluetooth: devices with 1 mW power (‘Pico-Bluetooth’ in technical jargon) for a range of 10 metres and devices with 100 mW power (‘Mega-Bluetooth’) for a range of 100 metres. Bluetooth is optimised for low energy consumption and is therefore particularly suited to mobile applications.

In addition to transmission mode, the Bluetooth standard offers three power-saving operating states:

- In the ‘Hold’ and ‘Sleep’ states, power consumption is 50 μA,
- in Standby mode 300 μA,
- at maximum transmission power 30 mA,

each at 2.7 V. The power consumption in the Standby modes is therefore lower than that the in transmission state by a factor of at least 100. The receive sections have a sensitivity of –70 dBm (=10^{-7} mW).

In future, the comparatively low data transmission rate could prove to be a limiting factor in the propagation of Bluetooth. In particular for multimedia applications or video communication, which will also play a growing role in short-range communication, Bluetooth is too slow.

For a higher-rate transmission in the PAN sector, there is already a new IEEE 802.15.3 standard (‘high-rate W-PANs’). This standard is being treated by experts as a promising medium and long-term successor to Bluetooth. Since higher data transmission rates generally also require higher radiated power, it must be assumed that ‘high-rate W-PANs’ will have a higher transmission power than Bluetooth.

Prospective trends in the W-PAN sector

At present, it is difficult to make a prediction of which standard will shape short-range networking of devices or ‘intelligent objects’. In general, Bluetooth is seen as having the best prospects in many areas. The propagation of Bluetooth has in fact fallen behind initial expectations. However, a large number of Bluetooth-equipped mobile terminals are currently coming onto the market. In the opinion of many experts it can be assumed that Bluetooth will dominate the W-PAN sector in the next two to three years at least. On the other hand, it can be assumed that the different radio communication technologies will be in competition only in some cases and that they can reasonably complement one another in some areas.

For *stationary* devices in homes or offices there are various cable-based variants for networking and Internet access: DSL over telephone lines, Powerline (Internet from the wall socket), Ethernet etc. For household devices which are often moved about or for ‘intelligent objects’ and ‘intelligent furniture’, on the other hand, wireless networking is needed. Options are offered by Bluetooth in particular, but also W-LANs. For specific applications, such as the exchange of virtual visiting cards, however, IrDA is an attractive option.

For networking in *motor vehicles* it is not necessary to cover any great differences. Bluetooth is therefore particularly suitable. On the other hand, there are efforts to utilise existing current-carrying cables in motor vehicles for data communication. To that end Infineon, BMW and Audi formed the *DC-BUS* consortium in 2001.

In the *wearables* sector too, existing technologies are based mainly on Bluetooth. For example, there are already wireless headsets that exchange data with a pocket computer using Bluetooth.

BANs

Body Area Networks are sometimes also called Personal Area Networks (a second meaning of the term used above). They are used for wireless networking of components worn on the body (wearables).

As a result of miniaturisation, an increasing number of devices are suitable for wearing on the body, either as accessories or embedded in clothing. Manufacturers are working (for the time being in design studies) on devices where the display is integrated into glasses and microphones and earphones are integrated into jewellery and can be controlled by speech. The individual components, communicating via wireless, form the BAN (or PAN), which will surround the wearer like an ‘aura’.

Prospective trends in the BAN sector

The Fraunhofer Institute for Integrated Circuits has developed a wireless transmission technology in the 400 MHz range for the medical sector. Using this technology, several sensors on the body can send their measurement results to a belt-mounted receiver. Because of the short range needed, average transmission powers of 0.4 mW are sufficient.

The Japanese telecommunications group NTT and its mobile radio communications subsidiary NTT DoCoMo are working on exploiting the conductivity of the body of the person wearing the wearable for a BAN. The active components, which are worn directly on the body, emit weak currents (in the order of nanoamperes) through the body in a frequency range below 1 MHz. These are also suitable in principle for transmitting information from body to body. In this way, in future two people wearing a BAN could automatically exchange their electronic visiting cards by shaking hands.

3.3 User interfaces

The current user interface for computer hardware essentially consists of a keyboard and mouse for input and a monitor for visual output. If the vision of Pervasive Computing is to become a reality, fundamental changes will be needed. On the one hand, the widely used input and output devices will continue to be developed, while on the other the propagation of new forms of human-computer interaction can be expected.

Even today, the miniaturisation of terminals means that the keys of many devices can no longer be operated using the fingers, but only with a stylus. Touch screens, which are both input and output devices, have high market potential. This trend runs counter to miniaturisation: prototypes for wall-sized touch-sensitive screens (or 'roomware') already exist.

Flexible displays can be expected in less than a decade. These include 'electronic paper', currently being developed by Xerox, and IBM's concept of 'electronic ink' (or 'e-ink'). OLED[44] technology is regarded as particularly pioneering. Since, unlike LCD[45] technologies, these organic light emitting diodes emit light themselves and do not therefore require backlighting, extremely thin displays with low weight and energy consumption can be produced. Furthermore, the high brightness that can be achieved makes this technology ideal for use in daylight, where other display technologies are detrimental because of the reflection. These advantages over other display variants mean that OLED is of interest for portable applications in particular. As a result of the integration of new microdisplay generations, head-mounted displays are becoming smaller and lighter. The display resolution will increase in order to be able to represent more complex user interfaces. 'Retina displays', which project images onto the eye's retina, are still at the research stage.

Three-dimensional images (3D) for mobile applications can also be expected on the market in the next few years. At CeBIT 2002 Siemens presented a mobile phone with shutter glasses on which 3D multiplayer interactive games can be played. 3D displays are also suited for applications in medicine and architecture.[46]

In conjunction with hand movements, 3D glasses open up completely new possibilities. Recognition of hand movements, which relate to a virtual object (the user looks through 3D glasses and sees, for example, a object hovering in space and tries to touch and distort it), is relatively advanced. Free-hand manipulation of objects in an augmented reality could therefore become a new form of interaction. For example, any controls for devices can be merged into the visual field of the user, who then uses the controls as with a real device, e.g. touching buttons, even though the device does not really exist.[47]

Other areas to which possible advances in PvC user interfaces will be relevant are speech processing and biometric authentication.

Speech processing

With the increasing computing power of microprocessors, voice input of data is becoming easier. Up to now, however, the only voice recognition systems that have

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44 Organic Light Emitting Diode

45 Liquid crystal display, the technology used for today's common flat-screen monitors.

46 http//www.w4.siemens.de/FuI/en/archiv/pof/

47 Das Vordringen des Virtuellen. No author credited. Fraunhofer Magazin 1.2003, p. 8-12

proven successful are those that have been restricted to the recognition of individual words, for example so that the user can enquire about the status of a bank account by telephone.

The recognition of continuous spoken text meets with some fundamental difficulties. For example, reduction into phonemes causes major problems. There are also difficulties with filtering out background noises and with distinguishing which sounds made by the user are directed to the voice recognition system and which are not.

In principle, concepts of acoustic input and output hold great potential for the future design of user interfaces. However, because of problems on the input side that are still unresolved, developments are slower than expected.

Biometric systems

User authentication, i.e. the determination of a user's identity, is an important prerequisite for the security of future systems. Conventional procedures are based on inputting a user name and a password (as with Internet applications or operating systems) or a Subscriber Identification Module (SIM), consisting of a chip card and a Personal Identification Number (as with mobile telephones). These procedures will no longer be practicable for the large number of small PvC components.

For those wireless networked components to recognise authorised users or even other objects, the only practicable option appears to be the transmission of a radio or infrared signal (which is critical from a security point of view, however). The user would take a certain component with them as an electronic key, in the same way as is done today with car keys or alarm systems. Procedures and data structures tailored to PvC would still have to be developed and standardised. The problem cannot be resolved using existing smart labels (RFID labels), because they require a relatively expensive reading station.

It is conceivable that biometric identification methods will play a greater role in the future. These are based on the identification of personal features (such as fingerprints, facial features, voice, hand geometry or iris patterns). In the medium term, authentication could be carried out by means of fingerprint, voice and possibly even signature. At present, these systems are not sufficiently reliable. Systems that are reliably able to identify people on the basis of iris patterns, facial features or gestures are still some way off (Burkhardt, 2001). In the case of distributed processing of visual signals that are received by sensor networks, PvC could in principle allow further steps to be taken in this direction.

However, biometric systems are prone to fraud unless they are securely encapsulated and communicate solely on secure channels. A further risk lies in malfunctions in the comparison between the characteristics of a user collected using the sensors and the stored reference values. Experiences with existing systems also show that great damage may occur if an authorised person is erroneously refused access. For example, a speaker recognition system may fail because the speaker's voice is hoarse or a fingerprint identification because the finger is dirty or injured. The use of biometric systems is therefore limited to applications that allow appropriate handling of such errors (Burkhardt, 2001).

In addition to the optical and acoustic possibilities that have been described, there will be haptic user interfaces in the future. One example is the data glove, which builds up pressure on the surface of the hand and thus produces a tactile sensation. Systems that can give a haptic impression of surfaces, e.g. textiles, are still not sophisticated. The actuators necessary for that purpose are still at an early trial stage.

Linking humans and machines

With advances in neurological knowledge a direction connection between humans and machines is entering the realms of possibility. One possibility is converting muscle contractions into control commands using EMG (electromyogram). Using this method initial successes have already been achieved; for example, it allows paralysed people to control a wheelchair.

Understanding the function of nerve signals allows the development of interfaces which directly measure biological nerve signals and forward them to technical systems. Implantable biocompatible microchips onto which nerve endings grow and which can derive signals are being developed. Initial important areas of use are primarily in prosthetics (neuroprotheses).

The most ambitious vision concerns brainwave-based interface systems (Brain-Computer Interface – BCI). These convert certain EEG signal patterns into control signals for the computer. At present it is possible to move a cursor on a computer screen to the left and to the right in this way. Although this technology is still at an early stage of research, it has been possible to introduce the first successful applications in medicine (Felzer, 2002).

Interfaces that convert technical signals into biosignals and feed them directly into the nervous system are more part of the long-term perspective for PvC (if at all). However, successes have already been achieved in medicine, for instance with artificial retinas or cochlear implants, the first routinely used sensory implant. This is an implantable hearing aid which converts acoustic signals and directly stimulates the auditory nerve.

3.4 Identification, location and context sensitivity

The interaction between microelectronic components and their local environment is a feature of Pervasive Computing. In principle, there are three possible purposes of this interaction:

- An object is to be recognised from its environment (identification)
- The exact position of an object is to be determined (location)
- An object is to detect characteristics of its environment (context sensitivity)

Location by the object itself can also be seen as a special case of context sensitivity if the coordinates are seen as fundamental characteristics of the local context.

Identification

A simple possibility of identifying an object is offered by smart labels (RFID[48] labels). These are very thin (300-400 µm) transponders, which are suitable for affixing or

[48] Radio Frequency Identification. The label emits short-range radio waves and thus transmits a small quantity of data (in the order of 1 kbit).

laminating between two surfaces, e.g. made of paper or plastic. A transponder is a microelectronic circuit consisting of a transmitting and receiving antenna, a control logic circuit and data memory.

There are transponders which can be written only once (pre-programmed transponders) and transponders that allow the stored information to be overwritten (programmable transponders).

Active transponders draw the energy needed for information transmission and data retention from a battery. *Passive* transponders take all the required energy from the electromagnetic field emitted by the writing/reading terminal. Passive transponders are generally used in smart labels.

For self-adhesive labels the price currently stands at between € 0.2 and € 1. As prices for smart labels continue to fall, they have the potential to replace traditional bar code labels for the identification of goods in many areas. 'The main advantages are that a line of sight to the reading device does not have to exist (as has been the case up to now with laser scanners at supermarkets), that individual products and not just whole product groups can be distinguished and that an electronic label can be used several times and be written with different information' (Mattern, 2002, p. 7).

In addition to the identification of objects, electronic markers that can be remotely queried offer the possibility of real-time Internet connection, through which 'ultimately any objects can be attributed specific information and methods for data processing. If objects can be clearly identified remotely and contain information, however, this opens up possible applications that go far beyond the original purposes of automatic stock management or a cashless supermarket.' (Mattern, 2002, p. 8)

Location

Navigational aids based on GPS data are widespread. Such systems are used in the motor vehicle sector in particular and provide the vehicle occupants with location-related information en route. Many such *location-based services* are conceivable: hotels, sights, advertising, etc.

With regard to the location of mobile phone users, suppliers are expecting further progress by utilising the delay differences between the signals from, for example, a mobile phone and different base stations or through a combination with GPS. It is expected that future GPS receivers, including antennas, will be only the size of a credit card (Huhn, 2002).

Many possible applications are still at the development stage. These range from cyberguides, which will be used as tourist guides, and memory aids, to the 'intelligent pen', which writes on normal paper, but at the same time digitalises what is written.

Context sensitivity

'Context sensitivity' or 'context awareness' describes the capacity of technical systems actively to acquire data from the environment and to process that data, e.g. regarding location, orientation, temperature, light conditions or available network resources. Having greater autonomy, the technology will provide content and services that the user (probably) wants in the situation in question. These include predefined actions when someone enters a room. A simpler example is the automatic adjustment of the volume of a bell tone depending on the noise level in the surrounding area.

With a view to the miniaturisation and microintegration of sensors and actuators, new materials such as piezo-electrical ceramics, specialised semiconductors and biological materials are being developed and tested.

The idea of so-called ‘emotion awareness’ shows just how far the developers’ vision extends. The systems are to record the emotional state of the user on the basis of several external indicators and then deal with them accordingly (Huhn, 2002).

Information retrieved from databases according to context can be passed to the user in order to augment their direct perception, e.g. by merging it into their visual field by means of cyber glasses (augmented reality). In this system, the user’s head and eye movements are evaluated. The industry sees applications in areas such as computer games, surgery and Computer Aided Design (CAD) simulations. For example, new furniture can be inserted into a real room by augmented reality, before it is made. A further application of augmented reality could be maintenance and repair. For example, a car mechanic can be provided visually with additional information on the vehicle parts at which he is looking.

3.5 Software agents

Software agents are programs that perform a predefined task relatively autonomously, in particular through exchanges with other agents or users over the Internet. In future such agents will know the wishes and preferences of their user and assist the user in making decisions.

The difference between traditional computer programs and software agents is that agents can accept a user profile or behavioural rules defined by the user, become automatically active and in some cases adapt to changing conditions. The aim is for agents to be able to perform more complex tasks, e.g. planning travel or taking part in auctions, without the need for constant detailed instructions from the user. ‘Shopping agents’ will be able to compare products offered by different suppliers on the Internet on the basis of predefined quality requirements.

The use of a large number of networked and context-sensitive PvC components is reasonable only if they act ‘more autonomously’ than a current PC or PDA. If they could not adapt to the information acquired from the network or from sensors and react, within certain limits, without confirmation from the user, they will continue to be of very limited benefit. For this reason, it can be expected that agent systems will be of central importance as software technology for PvC.

According to Bohn et al. (2002), PvC will allow the creation of a *perfect market*, a trend that has already begun to emerge with the Internet. This means, among other things, that market participants have full information on supply and demand and prices are fixed dynamically. In extreme cases, all goods would be handled in the same way as is currently only the case for the trading of stocks and shares on the stock exchanges. If, for example, milk is in short supply at the supermarket before closing time on Saturday, it becomes accordingly more expensive.

Even if only small steps were to be taken in the direction of the ideal of a perfect market, it is clear that, because of the dynamic pricing, the consumer will have to process significantly more information and constantly take new decisions. This is not really practicable without delegation of decisions to agents,[49] both by buyers and by sellers. In the simplest case the agents are merely given maximum and minimum prices at which they are to buy or sell, but of course it is conceivable that they will be given much more detailed information on the user's own preferences and then allowed to act autonomously on the market.

The diversity of system platforms currently restricts the commercial implementation of software agents. Several international bodies are working on standardisation, including the Foundation for Intelligent Physical Agents, founded by industry and research, and the Object Management Group (OMG), which has developed the CORBA interoperability standard.

In addition, the introduction of 'intelligent' autonomous agents raises new questions of security, data protection and liability. One problem which goes beyond the familiar security problems of the Internet arises because users entrust an agent with personal data, which the agents disclose in certain situations in the interest of their 'master', but keep secret in others. With regard to autonomous agents, the question arises whether and to what extent, after they have delegated a task to an agent, users can cancel its actions and who is liable for any damage that occurs.

These problems relate to technical framework conditions such as secure communication protocols and cryptographic requirements, but also fundamental questions of data protection and liability for actions and decisions that have been 'delegated' to technical systems.

3.6 Power supply systems

The development of new means of power supply for mobile devices is one of the most important peripheral conditions for the realisation of the PvC vision.

In principle, there are the following options (some existing, some newly developed) for power supply for microelectronics:

Continuous power supply from the mains

This option applies to stationary devices, e.g. personal computers or servers that are integrated into the PvC network environment. The electrical power requirement for these devices does not restrict their availability and is often higher than is technically feasible.

Power supply from external power supply units

A common alternative to battery operation. Very widely used for smaller stationary devices like modems. The power supply units are often inefficient and often remain connected to the mains even when the device is switched off.

[49] Even today it is very expensive for customers to cope with the moderately dynamic prices of telecommunications suppliers or Swiss health insurance funds.

Power supply with batteries

Rechargeable batteries or batteries that have to be periodically changed are suitable for mobile devices, such as mobile telephones and PDAs (Personal Digital Assistants). An important factor in the usability of these devices is the period between battery changes or recharges. If the interval is too short, then usability suffers; consequently, no reduction in battery mass is possible for the time being. In order to charge an accumulator battery, a special charging device or at least a power supply unit is needed as an additional component.

Types of rechargeable batteries that can generally be used for PvC components:

- Nickel cadmium: at present the most widely used type of battery for electronic devices, contains the heavy metal cadmium, energy density 45-80 Wh/kg (for comparison: lead battery up to 40 Wh/kg) with a cell voltage of 1.2 volts, life of up to 1 000 charge cycles, memory effect can significantly reduce the life of the battery.
- Nickel metal hydride: comparatively high energy density of 60-120 Wh/kg with a cell voltage of 1.2 volts, and good cost-effectiveness, cadmium-free, relatively high outlay on charging control.
- Lithium ion: very high energy density with low weight (110-160 Wh/kg) and a cell voltage of 3.6 to 3.8 volts, can be charged at any time, total of around 1 000 charge cycles, sensitive to overvoltage and undervoltage, so an expensive protection circuit is required, poor cost-effectiveness.
- Lithium polymer: unlike electrolyte-based batteries, this plastic-like material can be formed into any shape and allows extremely flat structural forms. Energy density of around 150 Wh/kg with a cell voltage of 4.2 volts. Solid electrolyte is non-toxic, so this battery is environmentally friendly. Disadvantage: batteries of this type have to be calibrated at regular intervals.
- Quinone high-performance battery: this battery, which is still being developed, with an energy density of around 300 Wh/kg and cell voltages of 1 or 2.4 volts, is based on an organic material (quinine). The advantage of this battery lies in its adaptability, according to the developers. This allows flexible structural forms, such as thin-film batteries. By eliminating heavy metals, the problems of waste disposal are simplified, although any release of toxic quinine into the environment must be prevented (Grote, 2001).
- Sodium sulphur battery: batteries of this kind only work in a high-temperature range of 300-350°C and are poorly suited to mobile applications.

Power supply with batteries that are not replaced during the envisaged life of the device

Is an option for components with minimal energy requirements, such as wristwatches at present. In the absence of better technical solutions, could become more widespread for PvC and encourage the trend towards disposable electronics.

Power supply from regenerative energy sources

This includes electricity generation through photovoltaics, from mechanical energy (like the 'wind-up radio') or from temperature gradients. In general, an energy storage device (rechargeable battery) is needed in order to use these energy sources.

Energy supply through external energy sources

The energy is obtained from an electromagnetic field (supply field). Examples include smart labels and the RF tags used in contactless chip cards.

Power supply from low temperature fuel cells

Because of their high efficiency, fuel cells are regarded as a technology of the future, but are still at the development stage. Initial prototypes in the 10 W power range for use in camcorders have been developed by Fraunhofer ISE (Fraunhofer ISE, 2002).

Technical options envisage energy supply from hydrogen or methanol, which is supplied to the device in fuel cartridges. At present this cannot be widely introduced onto the market above all because of the costs, which are still too high. Fuel cells promise a greater efficiency per mass/volume unit and allow more compact and light designs. In addition, they are more energy efficient (up to 60% for AFC[50] and PEMFC cells[51]) than most batteries and could be supplied with fuel from regenerative sources. One positive factor from the ecological point of view is that fuel cells contain little or nothing in the way of problematic substances and are therefore easy to dispose of.

Conclusion on power supply systems

The points set out show that the miniaturisation of mobile devices is limited by energy requirements. Unlike semiconductor technology, where Moore's Law has led to significant miniaturisation, the energy capacity of batteries has increased by just 20% in the last 20 years. At present, the power supply unit is the main obstacle to further miniaturisation. This could halt the PvC vision.

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[50] Alkaline fuel cells

[51] Proton exchange membrane fuel cells

3.7 Conclusion: What is new in Pervasive Computing?

Chapter 3 has described a number of developments in the fields of microelectronics, networking and software that are relevant to the realisation of the 'Pervasive Computing' vision. Questions of power supply have also been dealt with because they could become a bottleneck for this development which is firmly focused on tiny, portable components.

If we consider the transition to PvC in connection with the *ways in which the Internet has been used* since it came into being, it is apparent that a change has taken place in several stages, as shown in Figure 3-2 (cf. Mattern, 2003).

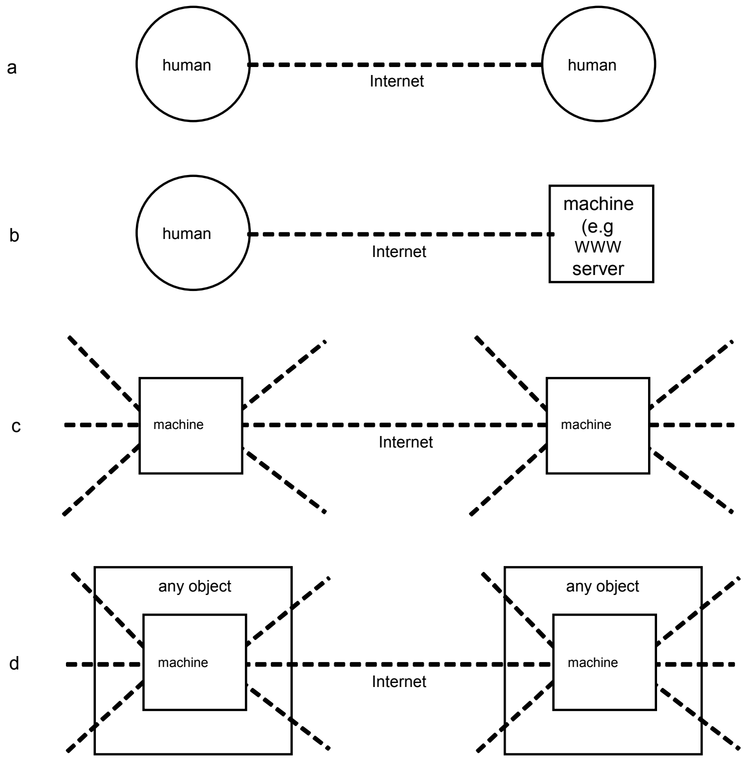

Figure 3-2: Four stages in the development of technical communications from the emergence of the Internet to Pervasive Computing.

In the 1970s, the Internet was used primarily by researchers to access remote computer resources (remote login and file transfer). At this stage, data transfer over the Internet was negligible. Only with the arrival of *e-mail* in the 1980s was there a breakthrough. The Internet was now used primarily as a *person-to-person* communication medium. This corresponds to case (a) in the figure.

The 1990s and the WWW brought a completely new way of using the Internet: 'Now people, on the one hand, were communicating using browsers with machines, namely WWW servers, on the other. This was accompanied by a multiplication in the volume of data traffic; at the same time, this was the precondition for the rapid commercialisation and popularisation of the Internet.' (Mattern, 2003, p. 2). This is represented by case (b).

According to Mattern, there is now a further qualitative leap. In the near future, the Internet will be used predominantly for communication from *machine to machine*. This corresponds to case (c) and (d) in the figure, where in case (c) the machines still appear as such ('devices'), whilst in case (d) they are embedded in other objects ('intelligent objects').

All four cases will be part of Pervasive Computing, but (c) and (d) will probably result in a further multiplication in the volume of data traffic, with corresponding demands on infrastructure. Worldwide, thousands of millions of PvC components can exchange data over the Internet without human assistance. This prospect of a world in which 'things talk to one another' is the key new aspect of the Pervasive Computing vision.

4 Developments in selected fields of application

Siegfried Behrendt, Lorenz Erdmann, Felix Würtenberger

Not everything that is technically feasible in the ICT sector will establish itself on the market. In addition to the prediction of an imminent 'second wave of the Internet economy' (Fichter, 2001), sceptical voices are also being raised, pointing out that in the Pervasive Computing (PvC) sector up to now visions have merely been set out and individual projects carried out, but many problems are still unresolved.[52]

This chapter therefore develops scenarios for the growth of ICT in various areas of everyday life, which envisage the realisation of the PvC vision to varying degrees over a period of 10 years.

It is difficult in the context of a TA study to investigate the prospects for realisation and the effects of a technological vision that is avowedly intended to affect *all areas of life*. Ubiquity, the penetration of ICT into all areas of everyday life, is the central idea behind the PvC vision.

Nevertheless, because of the limited resources for this study, we can only look at examples and conduct a closer examination of selected fields of application in which more generalised developments may take place. In addition, we will consider the future prospects of a few technological fields which are expected to play a role in PvC and will have a horizontal effect across several fields of application.

Figure 4-1 shows these focuses for the study. Of the nine fields of application (housing to leisure), we have chosen four (vertical grey bars):

- housing
- transport
- health
- work

We will also consider three horizontal technological fields:

- wearables (ICT products worn on the body)
- digital information and home entertainment media (excluding games)
- smart labels (electronic labels)

[52] '[It] has become apparent that the theme of 'Pervasive Computing' or the [...] very closely related theme of 'Ubiquitous Computing' have made headway into large companies, including Sun, Hewlett Packard and Microsoft, and into smaller companies and a large number of specific projects are already in progress. However, the results are still rather scarce at present. Quite often visions or problems have merely been recognised, and not yet resolved, e.g. security in Pervasive Computing. If, after the euphoria, no results are forthcoming, there is a danger that the terms 'Pervasive Computing' and 'Ubiquitous Computing' will just be fashionable for a short time and then will no longer be popular, at least generally' (Schoch, 2001).

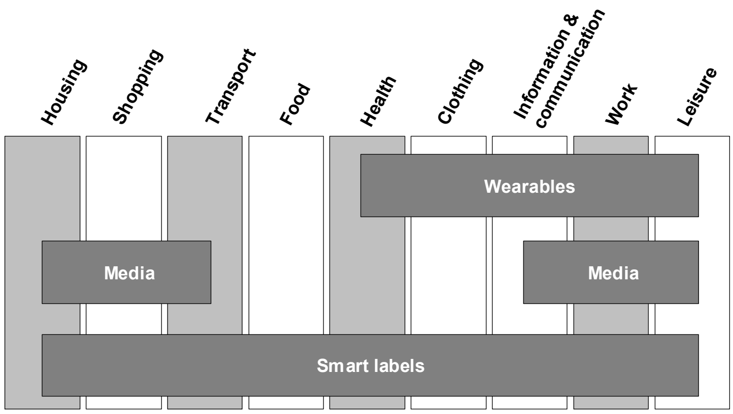

Figure 4-1: Focuses for the study

These seven focuses for the study were selected, because they are

- development priorities for industry *or*
- of importance in terms of risks to health and the environment.

The reasons are set out in detail below.

Housing

The home is the most important place that we spend time in and is therefore of prime importance from the perspective of radiation exposure. We spend most of our time in the home. Starting points are the ‘intelligent house’, ‘intelligent household devices’ and ‘home area networks’, which integrate different communication technologies.

Transport

The ‘intelligent car’ has now, to a large extent, become reality and will be introduced onto the market shortly. Transport, specifically motorised private transport, can therefore be regarded as a ‘test bed’ for acceptance and the limits of PvC. Findings from this field of application can assist the assessment of developments in other areas.

Work

Information and communication technologies are increasingly transforming the working environment. Central efforts are the ‘intelligent office’, mobile working and computer-aided collaborative work. The importance of the commercial sector lies in its pioneering role vis-à-vis consumption. This will provide impetus for the permeation of private everyday life with computer technology.

Health

Pervasive Computing will support health maintenance and medicine with a large number of applications.

Wearables

Wireless networked ICT products worn on the body are radiation sources immediately next to body tissue.

Digital information and home entertainment media

Technological development leads to a progressive convergence of media. New technologies such as rewritable paper-like displays (e-paper) are in development. The representation of media content will be one of the most important functions of PvC.

Smart labels

Electronic labels could soon give many objects an electronic identity. The spectrum of applications ranges from logistical support and electronic washing instructions in textiles to the cashless supermarket.

4.1 Housing

The 'intelligent house' vision has been present in the media for several years. The networking of home technology, a central web server and the networking of everyday objects are the central aspects of model projects Hünenberg (CH) and Duisburg (D).

4.1.1 Areas of use

Table 4-1 shows the areas where ICT are used in the housing field. Current technologies are gradually bringing closer the PvC vision – in this case the 'intelligent house' – through the increasing degree of penetration and networking and some innovations.

Cabling for ICT devices is now becoming an increasingly important part of building and modernisation work with the growing need for electricity, telephone and television sockets. In the commercial sector, the need for cabling is often eliminated by W-LANs, but wireless networks are also replacing and complementing the 'cable spaghetti' in private homes. For short-range networking the Bluetooth standard is also used. At present ICT applications in private homes are only partially networked with one another.

For a few years, work has been done in experimental houses with varying focuses on the networking of home technology (heating, air conditioning, lighting, security systems), ICT devices and 'intelligent' objects. These houses provide a good illustration of the opportunities and limits of PvC in the home.

Experimental houses as illustrative examples

As part of the 'Futurelife' project in Hünenberg (CH), a house has been constructed with various future-oriented technologies. Important features are the integration of different communication technologies, the accessibility of control functions through a single operating panel and the use of new products to provide inhabitants with more comfort and security. 60 firms – from small start-ups to major concerns like Siemens – have incorporated their products into the project. The house serves as a test laboratory in which a real family lives and in whose development the general public can participate.[53] The technical systems include:

- Security system with intruder alarm, room surveillance, wireless emergency call system, voice control, remote alarm warning system, fire alarm and fingerprint access control;
- 'SkyBox' three-level refrigerator, electronically secured external access for suppliers and e-mail notification of delivery of goods;
- Equipment control through fixed monitors like the large touch screen in the kitchen and the cordless 'Simpad' in A4 format with Internet access, virtual keyboard on the screen and handwriting recognition.

[53] www.futurelife.ch; 3 July 2002

Table 4-1: Developments towards Pervasive Computing in the housing field

	Building technology	**Information & communication**	**Smart objects**
vision for 2012	Digitalised supply and waste disposal, water and waste water, heating, lighting, decentralised power generation	*e-grains or similar technology:* 'intelligent wallpaper'	Full networking: management of all 'intelligent objects' in homes by a central server
ready for production by 2007	Context-sensitive lighting and air conditioning technology for residential buildings. Remote control over the Internet	Universal large display for PCs, television and games; Digital radio and digital television are state of the art	'Intelligent objects': e.g. ballpoint pens Networked devices: e.g. alarm clocks and coffee machines
currently on the market	*Microchip-controlled home technology:* Climate: heating, air conditioning Lighting: automatic for shutters and lighting Security technology: motion detectors, alarm systems	Cordless telephones at home Internet-ready PCs: home office and 'Infotainment' Digital television: set-top boxes and first digital televisions LAN and W-LAN	Coffee machine with automatic timer Programmable washing machine: optimised use of resources, displays, memory function

All household devices are networked with one another and connected to the Internet. As a result, the devices can be monitored, programmed and controlled even from outside. All sensors, switches and equipment controls are based on the European Installation Bus (EIB), which provides uniform control for systems such as heating, air conditioning, ventilation, lighting, blinds or wind and weather protection. The other devices communicate with one another via Powerline technology. In future it is also planned to network the house with the car and to install voice control (Wippermann, 2000).

The aim of the Duisburg (Germany) Intelligent House Innovation Centre, the 'inHaus project' for short (Miller 2001), is to make it possible to begin production of smart homes (networked, partially automated and remote controlled homes) within five years. Smart home technology will lead to energy savings and increase security and comfort. The newly researched applications will also allow existing houses to be retrofitted (Scherer 2003). The property is divided into four areas: the 'living laboratory', 'home office', 'car' and 'intelligent garden'. In a workshop research is also being carried out into the bathroom, kitchen and DIY basement of the future. The technology will be user-friendly and hidden out of sight in the background, under plaster and inside devices. In this connection, cabled and wireless networks are being tested. Televisions, telephones and computers can be used in any room thanks to a multimedia cable network. All electrical elements and the heating system can be controlled automatically, by touch button operation, by remote control, telephone or over the Internet. The external and Internet networks are connected by a ‘Residential Gateway’.

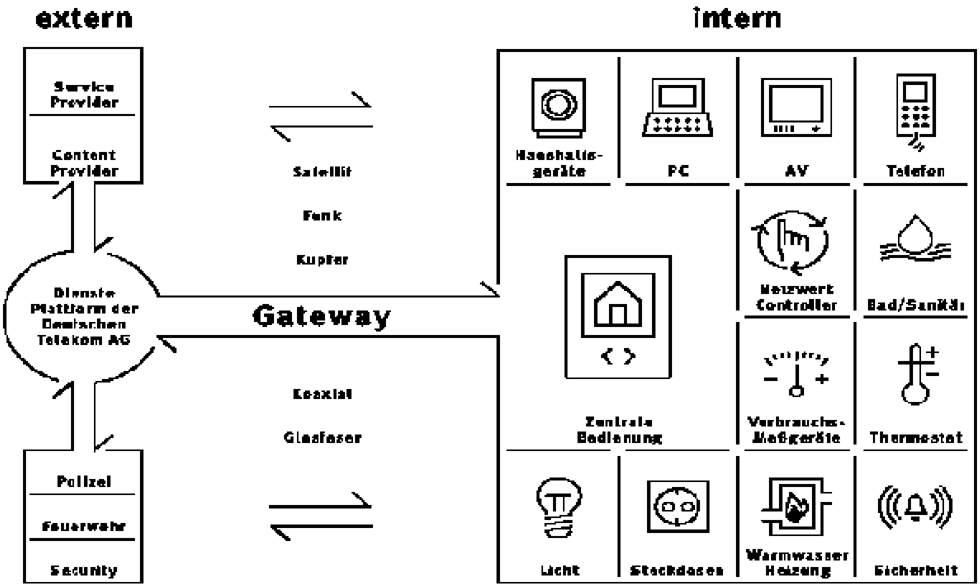

Figure 4-2: Network structure of the Duisburg inHaus project.

Translator’s note: For legend see p. 293 below.

Watering of the garden, lighting and in particular room temperatures are centrally regulated. Windows are automatically controlled by sensors for temperature, humidity and air quality. The heating output is automatically reduced when the occupants leave the house. Heating and hot water account for more than 80% of domestic energy consumption, so there are great potential energy savings. There is, as yet, no documentary evidence that the automation measures in the Duisburg experimental house have resulted in savings (Scherer 2003). Energy costs are intended to be saved by active load control, e.g. switching on the washing machine at night. The usage statistics are constantly monitored and therefore provide a basis for changes in behaviour. Predefined scenarios such as ‘breakfast’ adjust blinds and lighting and play suitable music. Figure 4-2 shows the network structure of the project.

In another project ‘The intelligent house – multimedia living in prefabricated housing developments’, the aim is to clarify whether equipping large housing developments with multimedia devices can be a ‘breakthrough innovation’ for the markets of the future. The services include an infotainment centre, home teleservices (maintenance, control, e-government) and security services.[54]

[54] The project is promoted by the German Ministry for Education and Research in the ‘Interregional Alliances for the future markets of tomorrow’ programme.

4.1.2 Market trends

In the view of many experts, home networking is 'Internet-driven', i.e. only external networking provides the customer with the desired added value. Promising applications include e-commerce and teleworking. In 1998 51.1% of Swiss households had at least one PC. In 2001, the narrower Internet user group[55] was 37.4%, while the wider user group was 52.1% (Bundesamt für Statistik, 2001).

The computerisation of home technology has seen steady, but slow growth, although the networking of 'white goods'[56] is not yet under discussion.

One niche product is the *Internet refrigerator* made by LG Electronics. A 15" LCD screen, a modem and an LAN port serve as interfaces. The refrigerator is operated using touch screens or voice commands. The refrigerator combines traditional information and communication functions like television and e-mail with cooking-related services. These services include product price comparisons between different supermarkets, recommendations for healthy nutrition and recipes for the food stored in the refrigerator.

Home owners that have invested in home automation mention enthusiasm for technology, aesthetics, comfort and prestige as motivating factors, as well as new services such as surveillance, monitoring and regulation (Aebischer/Huser, 2000). The possible time savings from bringing together the world in which we work and the world in which we live could speed up market diffusion. The test inhabitants of the Futurelife house also cite time savings and functionality as benefits. Facilities such as the big screen promote the sense of well-being. 'The networked home will become a mini-factory from which you can work when you want, but also for example order groceries online.' (Wippermann, 2000).

There are few market forecasts for the 'intelligent house', even for only parts of it, such as building technology. The Yankee Group (1999) assumed that in 2003 more than 4 million households in the United States would be networked by telephone lines, 1.5 million would be wireless networked, and fewer than 300 000 would be networked by Powerline. The market research institute Strategy Analytics predicts for 2005 that 15% of European households will have private radio communication networks, linking a total of 88 million devices, an average of 2.5 devices per household.[57] According to a forecast by Datamonitor, more than 20 million European households will be equipped with 'smart home' technology between 2001 and 2005 (Miller, 2001).

In Switzerland the transition will generally be slower. The reasons cited are the long-lasting building fabric (longer renovation and new building cycles than in the United States, for example), the high proportion of rented housing and the high proportion of institutional investors on the property market (Aebischer/Huser, 2000).

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[55] People who use the Internet more frequently at home than at work.

[56] Domestic appliances like refrigerators, washing machines, cookers.

[57] Quoted in Aebischer (2000)

4.1.3 Prospects

Whether the more or less futuristic-looking applications in the housing sector develop from niche products into mass market products depends primarily on the following factors:

1. health risks of non-ionising radiation (NIR)
2. acceptance of a technical living environment
3. compatibility of networks and terminals
4. cost-benefit ratio for owners and inhabitants.

As is clear from the Futurelife project, in an automated home many life activities have to be re-learnt. If the 'intelligent house' is also to allow ageing western European societies to enjoy the benefits of time savings and possibly to avoid going to an old people's home, the systems suppliers must attach particular importance to user interfaces that are suitable for senior citizens.

Challenges for the development of the 'intelligent house' are the connection of different devices, components and infrastructures with an umbrella system and the user-friendly, ergonomic organisation of human-machine interaction. Standardisation efforts include the 'Open Service Gateway Initiative' (OSGi)[58] introduced by the telecommunications, computer, home electronics and domestic appliance industries, the 'Home Phoneline Networking Alliance' of hardware manufacturers like Hewlett Packard and telecommunication service providers like AT&T, the 'European Telecommunications Standards Institute' (ETSI), the 'DECT Multimedia Consortium', with companies like Ericsson Mobile Networks and Canon, the 'Bluetooth Promoter Group', which includes IBM, Toshiba and Microsoft, and the 'Infrared Data Association' (IrDA), representing more than 160 companies in the computer, semiconductor and communications industries (Aebischer/Huser, 2000).

[58] The industry has set up the 'Open Service Gateway Initiative', which represents an open standard for the connection of Internet-enabled devices. Based on Java and Jini technology, OSGi is compatible with communications systems like Bluetooth, USB and WAP. The OSGi Gateway is intended to enable access to all motor vehicle electronics and sensor mechanisms and communicates data to a back-end system, which then informs the driver about critical conditions, for example. Telephone calls and Internet access will also be via the OSGi Gateway.

4.2 Transport

4.2.1 Areas of use

Transport is an information and communication-intensive process. Current ICT has already been incorporated into nearly all means of transport:

- In road transport, traffic control systems aim to improve traffic forecasting and control. Other focuses of ICT use are the comprehensive coverage of current traffic data, navigation systems, optimisation of traffic safety through driver assistance systems and reduction of energy consumption and toxic emissions through adaptive drive management.
- In rail transport, it is necessary in particular to introduce further automation of train operation. Procedures used will range from electronic positioning to remote monitoring and remote diagnosis for vehicles and track.
- For public transport in general, new types of payment system are being developed and tested, for example based on contactless smart cards. Other ideas are geared to energy-saving or automatic operation of vehicles, for example trams and underground trains.
- In air transport, developments are well advanced; they include automated landing procedures with GPS positioning, state-dependent remote maintenance, management systems for flight safety, etc.
- In maritime and inland waterway transport, ICT systems are used, for example for tracking hazardous goods, identification of ships, port logistics and traffic control assisted by radar information.

Through Pervasive Computing (PvC) people and goods that are in circulation can become locatable objects whose routes can be planned dynamically[59] across transport operators on the basis of current information. This may encourage cooperation between different transport operators and help to optimise the capacity of the transport system in general.

In the goods transport sector, PvC technologies can be used for transport telematics. Through logistics without any discontinuity of media (e.g. form -> database), they allow operational processes to be optimised and save time. In particular the following forms of use can be expected:

- mobile communication and data exchange between dispatchers and drivers or vehicle and load allows up-to-date information on current traffic conditions and route changes.
- GPS for positioning and remote queries on current location and movement status of vehicles or freight containers.
- object identification by means of smart labels and data scanners for contactless individual identification of freight and packages.

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[59] i.e. it is possible at any time to re-plan the proposed route if the capacity of routes or means of transport or even the destination change.

- sensors allow constant monitoring of the condition of cargoes of perishable goods (temperature, air humidity, vibrations etc).
- wearable computers – their functions include collection, storage and visualisation of freight data and wireless communication with databases via the Internet. Augmented reality facilitates operational loading logistics by visualising object-related freight and cargo information.
- Internet: Exchange of electronic freight documents (customs forms, delivery notes, invoices, etc.).

The advantage of these new technologies stems from the combination of the individual components in an overall system that can be based fully on existing ICT solutions.

Table 4-2 outlines the areas in which ICT is used at present and is expected to be used in 5 to 10 years, although not all applications can be classified as PvC. A general trend is the support of cross-carrier (intermodal) services. Services range from Personal Travel Assistants (PTAs) to mobility agencies, which offer mobility services covering all carriers.

Table 4-2: Developments towards Pervasive Computing in the field of transport

	Private transport	**Public transport**	**Intermodal transport**
vision for 2012	Drive by wire	Driverless transport	Comprehensive real-time mobility services by mobility agencies
ready for production by 2007	Bluetooth replaces data cables in cars Virtual safety belt Chip-controlled car battery Remote maintenance	Electronic payment system based on smart cards or mobile telephones Arrival times can be consulted in real time	Personal Travel Assistant (PTA)
currently on the market	*Control of units:* digital motor electronics *Safety:* ABS, ESP, airbags, service-interval reminder *Navigation and telematics:* navigation systems, traffic control systems *Comfort:* automatic drive *Driver information:* e.g. on-board computer *Entertainment:* digital radio, first TV on-board monitors	Controls systems geared to current traffic conditions Electronic route information Electronic tickets Public transport connection information system SMS/WAP information	Road traffic management systems WAP-supported transport information, timetables, recommended parking, intermodal travel services

There is a closer examination of present and future uses of ICT in cars below, because the car appears to have developed into a test platform for PvC for manufacturers.

Excursus: The car as a test platform for Pervasive Computing

The digitalisation of in-car electronics can be seen by any driver today from the electronic displays on the instrument panel. A luxury car contains more than 30 microprocessors, interconnected by a bus system (Burkhardt et al., 2001). In future they will be able to communicate not only with one another, but also with their environment.

The virtual safety belt

Perhaps the most ambitious vision is the virtual safety belt for cars. With the help of *Short Range Radar (SRR)* and video sensors, a virtual safety belt will surround the car at a radius of 0.2 to 20 metres. Video cameras record road signs that are further away and other road users. A display in the instrument panel warns of hazards.

Internal networking

The vision of the 'intelligent car' as an intra-networked computer platform is already well advanced. The former 'spider's webs' of on-board electronic are now being replaced by bus systems, which offer benefits in terms of assembly, weight, standardisation and upgrading (Knausenberger, 2001). Motorola's *Mobile GT* 'Infotainment' concept integrates digital car radio, mobile radio communications, GPS and other components such as smart card readers.

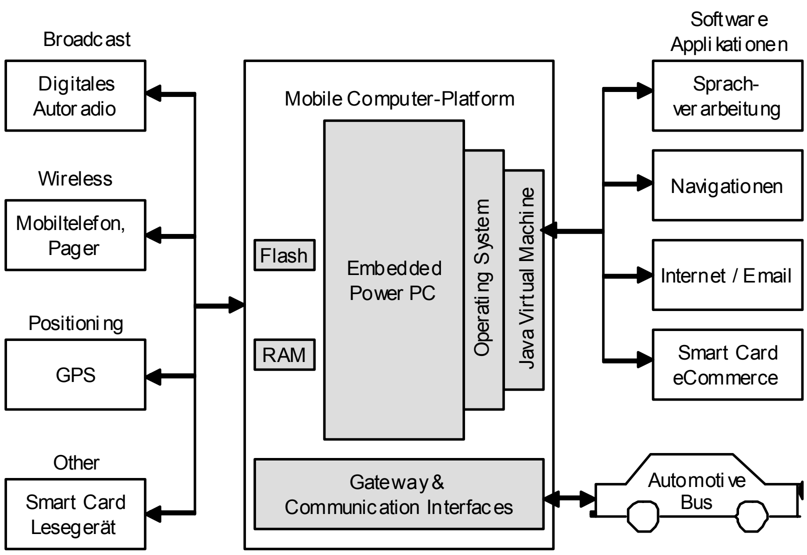

Figure 4-3: Possible network architecture for cars (Source: Motorola).

Translator's note: For legend see p. 294 below

External networking

Over the last few years, the car has been transformed from an isolated means of locomotion to a mobile network node with satellite navigation and mobile radio communication connection.

The manufacturer can monitor critical parameters such as oil temperature, update software or send out recall information. Other ICT applications with a promising future are fault diagnosis, communication with service facilities and automatic emergency calls.

The basic conditions for the integration of the Internet, digital radio and television into the car are currently being created. One aim of this development is to create an adequate mobile workstation for passengers. The first products for in-car PCs offered on the market also include DVD drives and a Bluetooth interface. The displays are integrated either into the front seat neck rests or into the central console or they are fastened to the sun visor or the headliner. In order to speak to the driver without distracting him from the traffic, speech input and output systems are being developed.

Navigation systems

Navigation systems link the information from digital cards with positional data. Location is determined with the aid of the Global Positioning System (GPS). Traffic information is transmitted to the vehicle by SMS or WAP. Data can also be transferred to the navigation system by the Traffic Message Channel (TMC); the radio broadcasters send information on traffic jam lengths and traffic flows, together with possible speeds on alternative routes that can be considered in route planning.

In addition to pure navigation, it will be possible in future to retrieve information on local tourist, cultural and gastronomic destinations and a wide variety of infrastructure systems, and to use other services, such as location in the event of breakdown (location-based services).

Conclusion

The car is an example of the way in which we can move closer to the Pervasive Computing vision in small steps. The number of *embedded* components that are invisible to users is rising and their internal and external *networking* is being extended. Aside from navigation, location and sensors enable *context-sensitive* functions (like local information and services, and the virtual safety belt). New forms of user interface are being tested.

4.2.2 Market trends

The market for PvC in transport is dominated by the car. The use of ICT in cars is growing rapidly. According to estimates, in 2010 an eighth of the value of a vehicle might be accounted for by computer programs alone.[60] However, major growth is also forecast for technologies and services that support *intermodal transport*.

Whilst transport telematic systems that are aimed at commercial users have already become widespread, demand among private end users has been rather low thus far, particularly with regard to traffic information and route guidance.[61]

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[60] Study for HypoVereinsbank, cited in Schöne (2002).

[61] In a study for TA-Swiss the ASIT/econcept/ETH Zürich/TA-Akademie working party developed scenarios for transport telematics (Mühlethaler 2002). They were discussed at an expert workshop inter alia from the point of view of influences and determinants for diffusion.

According to a Roland Berger study, as a result of satellite-controlled navigation (GPS), mobile radio connection (GSM, GRPS, UMTS) and the Internet on transport (cars, buses and trains, aircraft), in 2010 there will be a potential global market for services amounting to € 25 billion, including around € 2 billion in Germany.[62] Market potential studies indicate that by 2006 almost 50% of all new vehicles (and 90% of all luxury cars) will have an Internet connection (Burkhardt et al., 2001). The annual growth rate for purchases of flat-screen displays by the automotive industry is forecast at more than 30%.[63]

The market in car navigation systems is divided into initial installation and retrofitting. It is set to grow from 1.6 million items in Europe in 2001 to 2.9 million items in 2003 with a market volume of € 3.5 billion. By way of comparison, in 2003 around 2.6 million items will be sold in Japan and around 1.5 million in the United States (Grab, 2000).

The proportion for Germany in relation to Europe, where every tenth automobile with a navigation device is supplied, is around 60%. 'In five to six years, more or less all cars in the mid and upper class in Germany will be equipped with a navigation system'.[64] A similar trend can also be expected in Switzerland on account of the comparable purchasing behaviour.

4.2.3 Prospects

Great potential for the future use of ICT in transport can be seen above all in the areas set out below.[65] The trend towards PvC and these applications could be mutually complementary, because PvC has a close affinity with the transport sector on account of the portability of components, wireless networking and context sensitivity. The applications are:

- reduction in the number of journeys by transport (e.g. by teleservices);
- increased customer comfort on public transport;
- improvement of transport safety, e.g. through enhanced assessment of the vehicle environment by means of sensors or through increased use of track monitoring systems;
- setting up of networked transport infrastructures that are intermodally effective;
- more 'intelligent' dynamic traffic control for road, rail and waterways (already more advanced in air transport) with the aim of reducing capacity bottlenecks;
- satellite-based positioning applications;
- in-vehicle collection of traffic data;
- use of network agents for optimal planning and organisation of the journey before and/or after it has started;

62 http://www.deutsche-leasing.de/zukunft/body_analyse.html

63 Deutsches Flachdisplay-Forum: Strategie zum Ausbau der Deutschen Position auf dem Flachdisplay-Weltmarkt, Frankfurt M. o.J.

64 Klaus Meier (Noritel), cited in (Grab, 2000)

65 According to a prospective analysis by DLR and TÜV Rheinland (1999).

- mobile information services for transport users, having regard to data protection problems;
- communication platforms and terminals, for which an effort should be made to implement Europe-wide uniform standards.

Public and intermodal transport

High expectations are currently being placed in the networking of different transport operators by ICT. Priorities are optimising public transport, increasing safety levels and promoting cooperation between transport operators.

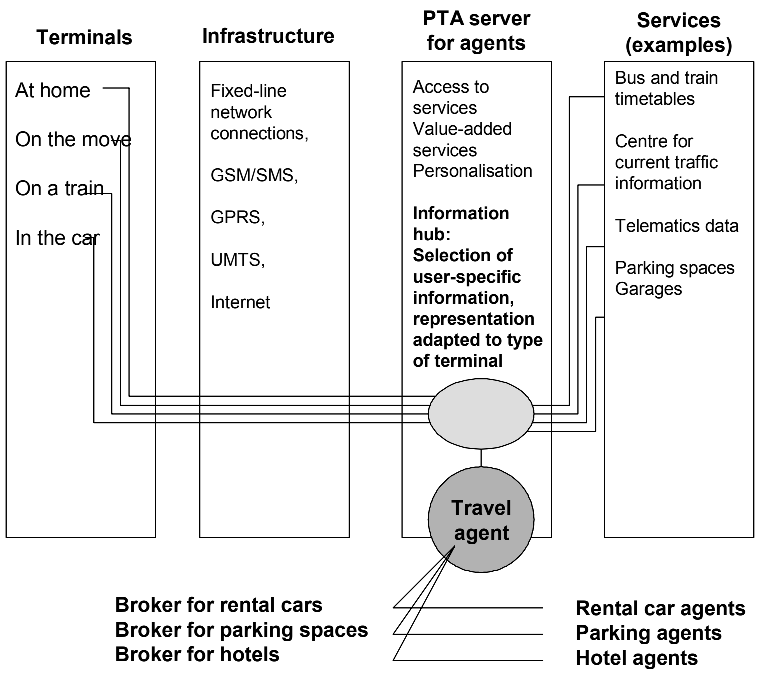

Figure 4-4 Personal Travel Assistant (Source: Tsakiridou, 2001, p. 53)

One example that illustrates intermodal networking for passenger transport is the concept of the *Personal Travel Assistant (PTA)*. Information on available means of transport and data on hotels, parking alternatives, etc. is brought together through various agents and services, so that the user will be guided on the optimum route from A to B based on his preferences (Tsakiridou, 2001).

Despite the technical feasibility, developments in intermodal applications have been slow up to now. One particular obstacle is the expenditure on cooperation between the actors involved in developing more effective services, which is still high. Moreover, the possibilities of access to the required data are still limited in some cases.

Private customers are expected to accept mobility services when integrated systems are available that offer real-time services other than traffic information and take individual user requirements into consideration as a major factor (Steinicke/Meissner, 2000).

Excursus: The car as an indicator of incidental effects and acceptance of Pervasive Computing

Because of its pioneering role, the car may also become an indicator for undesired incidental effects and for acceptance of PvC. At present, attention must be paid to three aspects that could act as a considerable brake on development:

1. conflict of aims between comprehensive information and driver's attentiveness
2. technical shortcomings and other reasons for limited acceptance

Attentiveness and safety

Increasingly high levels of attentiveness are required of drivers, for example as a result of higher speeds, higher traffic densities and the 'forest' of traffic signs. Digital aids are intended to ease the workload on them. These include distance sensors, cruise control or the abovementioned 'virtual safety belt'. But there is also limited receptivity among people to information via displays and speech output. Too high information density (in terms of space and time) is therefore a safety risk. There is also the question of acceptance given that the electronic aids take away from drivers tasks that they may like to carry out themselves.

Research departments in the automotive industry are experimenting with techniques for projecting safety information onto the windscreen. The problem of the dead angle in the rear-view mirror and the need for drivers to look over their shoulder when changing lanes have also led to thoughts of using rear-facing wide-angle cameras rather than reflection. It is not yet clear what effects such technologies will have on traffic safety.

Technical shortcomings and acceptance issues

Even now automobile computerisation is encountering technical limitations. The first 'in-car PCs' have to be expensively encapsulated so that the sensitive vehicle electronics are not disturbed. In general, the susceptibility of cars to faults is increased considerably by microelectronics. Vehicle electronics are becoming less and less transparent to maintenance personnel because of their complexity.

In general, the majority of automobile customers in central Europe are willing to pay for a high-quality vehicle. In some segments, however, some technologies are restricting the development of others. For example, the number of battery-related breakdowns is rising, because battery development has not been able to keep pace with the growing demands of electronic consumers.

There have also been shortcomings up to now in voice control systems, which are intended to allow the driver to control devices (radio, telephone, navigation, online services) during the journey. Dialects, noise interference and the general problems of speech recognition have precluded sufficiently convenient solutions so far.

The current low bandwidths and the high costs of second generation mobile radio communications networks are holding back the propagation of multimedia in cars.

A countermovement can be observed in the growing sports utility vehicle segment, where analog dials adorn the instrument panel and manual five-speed gears are used.

Hitherto, it has been difficult to assess radiation exposure (NIR) in cars. The large number of radiation sources in an internally and externally wireless networked car and the interior radiation reflection create a situation that is difficult to assess. Fears of ‘electrosmog’ could limit acceptance of the ‘intelligent car’.

Conclusion

The move towards the Pervasive Computing vision, as exemplified by the car, highlights a number of problems that may also be relevant in other fields of application.

Because of the high degree of networking, there is an availability of information that suggests that users (drivers) and their limited capacity for attentive information processing are a bottleneck in the system. The distraction of their attention by technology becomes a safety risk. As a result, the technology takes away from drivers tasks that they formerly carried out themselves, whilst the consequences for safety and acceptance are still unclear for the time being.

Contrary trends are emerging, such as the return to analogue instruments and manual gearshift.

This development can be seen as a sign that similar countertrends might also occur in other areas.

4.3 Work

The variety of changes in the working environment, some of which are having effects even today, and some of which are only just becoming apparent, are mostly lumped together under the notion of flexible working. They are made possible to a large degree by ICT:

- Place of work: changing places of use, non-territorial office, teleworking, mobile working on business trips
- Working hours: flexible working hours, constant accessibility
- Work content: project work, frequently changing teams
- Employment relationship: decline in normal employment relationships, more frequent change of employer, new forms of self-employment

The main causes of this change relate to economic growth: globalisation, outsourcing, dynamic innovation and intensified competition are crucial driving forces. However, current ICTs, in particular the Internet, have created the necessary conditions for these changes.

4.3.1 Areas of use

In the areas where ICTs are used, it is possible at present to identify three objectives that are connected with Pervasive Computing:

- rationalisation of traditional office work by a person at a workplace (‘intelligent office’)
- support of groupwork
- greater freedom to work at and between numerous locations (mobile working[66])

The ‘intelligent office’

The vision of the ‘intelligent office’ seeks to relieve users of routine activities, so that they can concentrate more on activities for which they are specifically qualified.

IBM, in cooperation with the American office equipment company Steelcase, has developed a prototype for the office of the future, called ‘BlueSpace’. This system recognises employees when they enter the room and notifies their colleagues that they are back in the office. At the same time, the air conditioning system creates the office climate favoured by the individual, the coffee machine is automatically activated and newly received e-mails are projected onto the wall.

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[66] This includes home-based teleworking, but is not restricted to it. Teleworking can be done at present without Pervasive Computing by setting up a home office with an Internet connection. The new aspect of PvC is portability and wireless networking of components and thus the greater opportunity to work at almost any location and on the move.

Table 4-3: Developments towards Pervasive Computing in the field of work

	'Intelligent office'	**Team work**	**Mobile work**
vision for 2012	Interactive rooms: fully networked office technology responds to speech and gesture Augmented reality: in medicine and maintenance	Wearables with translation software for direct communication with foreign-language-speaking colleagues	Mobile video conferences via wearable computers and augmented reality
ready for production by 2007	Document management with bar codes/smart labels Virtual secretary: Software agents for many secretarial activities Sophisticated speech technologies	Interactive furniture: networked chairs, tables, walls and doors with interactive displays Virtual conferencing: avatars in virtual meeting rooms etc.	Radio connection via UMTS, DVB, DAB etc. Mobile platforms on the basis of mobile agents Wearables in specific occupations with sophisticated speech recognition
currently on the market	PCs, network printers Company networks and intranets E-mail Simple speech recognition Software agents: search engines on the network	LANs or W-LANs for work meetings: networking of participants' laptops Teleconferencing: video and telephone conferences Virtual workspaces for global project teams	Mobile terminals: laptops, PDAs, organisers, handhelds, smart phones Radio connection via GSM, GPRS and W-LANs

Alongside such ambitious visions, efforts are being made to resolve individual problems of everyday office life:

- With the aid of electronic identification, analog work materials, i.e. traditional documents, are to be made accessible to *digital management*. In a networked office, documents equipped with smart labels and data management systems could notify users when they are looking for a document.
- The idea of human-machine interaction without keyboards or screens is based on the hope that input will be by speech recognition and output by electronic paper. Office work could be carried out by 'talking' to the paper.

With regard to speech recognition, however, a distinction must be drawn between the recognition of a few simple control commands (e.g. 'delete paragraph') or stored names ('call Mr Müller') and the dictation of free text. The latter does not function sufficiently well at present and in some cases is encountering fundamental unresolved problems.

Speech recognition could be part of a broader plan for an interactive room, which responds not only to speech, but also to non-verbal expressions like pointing gestures, which are captured by cameras or sensors. Progress has recently been made on the recognition of gestures (see Section 3.3).

Information flow management and the accompanying document management are becoming increasingly time-consuming, not least as a result of e-mail. It is hoped that *software agents* will help ease the workload on employees (see Section 3.5). They will filter, sort and manage incoming information (e-mails, telephone calls, etc.) and prioritise it.

Recent developments aim to delegate traditional secretarial activities to 'virtual assistants'. For example, work is being done at the Fraunhofer Institute for Computer Graphics Research on a 'virtual secretary' that can automatically take telephone calls, manage appointments and search for and compile documents on the basis of predefined criteria. Attempts are also being made to simulate non-verbal expressions on the output side. The virtual secretary will be represented on the screen by an avatar (a visually simulated person), which assumes a 'concerned' or 'relaxed' facial expression depending on the appointment.

Computer-aided group work

Current PCs are geared to individual work. They are not really suited to processing digital documents in a team. Collaboration with colleagues therefore regularly leads to a *discontinuity of media*. Documents are printed out for a meeting, flipcharts and handwritten notes have to be laboriously typed up after a meeting. Pin boards are photographed using a digital camera, sent as huge e-mail attachments, and then forgotten, because they cannot be processed any further.

There are various approaches and products that are better suited to traditional forms of team interaction.

- Even today local networks, in particular W-LANs, offer possibilities for networking and easy data transmission between meeting participants' laptops. However, up to now this option has not really been used because networking alone does not provide the functions that are actually required, such as co-editing (joint editing of a document.
- Interactive furniture highlights completely new possibilities for paperless work meetings and conferences. The German research and development consortium 'Future Office Dynamics' has for years been working on so-called Roomware®. This covers interactive tables, chairs and walls, including the 'CommChair', an office chair with TFT screen and pen-based data input, the 'DynaWall', an interactive electronic whiteboard with a touch-sensitive surface, and the 'InteracTable', a table with a horizontal, interactive PDP screen[67] as a shared work surface. This furniture exists in prototype form at present.

  An important factor for these developments is the creation of new display technologies with pressure-sensitive surfaces. For example, the DynaWall is based on a plasma display with a touch-sensitive layer on top. The interactive wall is written on directly with the finger, rather than chalk or pen. With appropriate software data can be transferred from one item of 'intelligent furniture' to the next. The commands are based on an alphabet of gestures. All Future Office Dynamics devices have a wireless Internet and fax connection and are linked to an LAN. Wireless networking and battery power supply make it possible to arrange 'intelligent furniture' freely around the room.

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[67] Plasma display panel

In view of the growing importance of virtual organisations and spatially dispersed project teams, alongside optimal on-the-spot electronic support for work meetings, technologies for telecooperation are becoming increasingly important. For some time it has been possible to hold videoconferences. The development of inexpensive wall displays could create a more realistic conference situation than current TV/video-based systems and interactive furniture could allow joint discussion and processing of documents.

Work is being done in the EU ‘Avatar Conference’ research project headed by the Fraunhofer Institute for Industrial Engineering in Stuttgart on a completely new form of virtual conference. A virtual conference environment will allow multimedia meetings, conferences and presentations over the Internet. Participants can meet in a virtual room, hold discussions, share information and take joint decisions.

Mobile computing

An almost inevitable consequence of increasing mobility requirements in the working environment and the growing importance of ICT-aided activities in nearly all professions is the trend towards mobile computing.

This concerns both ICT support for mobile activities in specific occupations with a high proportion of field staff and performance of any office work on business trips (‘white-collar mobile computing’). In this connection, aside from offline activities like text processing or spreadsheet analysis, a growing role is played by online applications such as data exchange with the company or WWW searches.

In the last few years, there has been a marked increase in the range of *mobile terminals*. In addition to ‘traditional’ mobile terminals like laptops or notebooks, there are now an increasing number of more compact devices like handhelds and smart phones (mobiles that can also be used as computers). Their functional diversity and computing power improves with each product generation. ‘Ultraportable’ notebooks with a weight of around one kilogram and a height of 15 millimetres are coming onto the market.

Occupations that are exercised in the open air place higher mobility requirements on devices. In the building industry, wearables are already used occasionally (e.g. helmets), in particular where ICT-aided work has to be done without the aid of hands, e.g. bridge inspections.

In occupations with a high proportion of field staff, such as the insurance sector and many technical professions, mobile ICT solutions are becoming more widespread on the basis of PDAs and handhelds.

For mobile office work, a fast data connection to the Internet and to the company’s backend is necessary, so that access to the same documents is possible without a long waiting time. In addition to UMTS und GPRS, possibilities here, depending on location and equipment, also include short-range networks like Bluetooth und W-LAN. As well as the data transmission rate, security aspects are a crucial factor in mobile work.

4.3.2 Market trends

According to a report by Handelsblatt,[68] installation of technology in a 'Bluespace' office would cost around € 25 000 at present. Such expensive 'intelligent' office systems will not establish themselves on the market, especially since the short-term operational benefit is unclear.

The outlook is different for individual applications. For example, voice recognition technologies are seen as having great potential by market researchers, despite the abovementioned difficulties. In 1998 the global turnover in this sector was $ 155 million; it has doubled since then. The US market research company Frost & Sullivan expects a turnover of US$ 1 700 million in 2005.[69] The Gartner Group is more sceptical and warns against excessively high expectations for the near future. In a recent study, it is predicted that speech recognition will break through onto the market in two to five years (Grass, 2002).

Software agents are one of the fastest growing software markets. According to a study by the IDC market research company, the market volume two years ago was US$ 112.3 million and it is set to rise to US$ 873.2 million by 2004 (Hoffmann, 2002).

The market in mobile computing terminals is continuing to grow strongly. According to the Dataquest market research institute, the worldwide PDA market grew by around 18% in 2002. Around 13 million PDA devices were sold in 2001 and this figure should be around 15.5 million in 2002.[70] In Switzerland, the PDA market in the last year was around CHF 125 million (Weiss, 2002). This corresponds to growth of 14.7% on the previous year. This growth is occurring despite declining numbers of units produced. This is because of higher unit prices for colour devices, which are in high demand.

4.3.3 Prospects

The introduction of flexible work process and the growing volumes of information that have to be processed in day-to-day work call for new technical solutions. In future mobile terminals will be an essential item in field work because work documents will probably exist only in digital form.

The 'intelligent' office of the future, be it mobile or stationary, is based on the vision that, despite the ubiquity of ICT, working methods will once again be as intuitive and natural, and work documents as accessible, as before the introduction of PCs. Everything will be networked and have computing capacity, but users will write with their hands again (on an interactive table or with an 'intelligent pen') and issue instructions to their computers by speech and gesture. The computer will disappear and make way for 'intelligent objects'.

In certain workplaces there is an acute need for new technical solutions. In medical professions, for example, great hopes are being placed in effective speech recognition technologies to reduce the growing expenditure on work at the computer. In general the clear ability to recognise factors that make work easier could prove to be an essential

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[68] Hohensee, M.: Energische Sekretärin. In: Handelsblatt, 08.05.2002

[69] innovation-aktuell.de, 2001

[70] A short while ago, 30% growth for 2002 was estimated.

condition for the success of the introduction of ‘intelligent’ technologies to the workplace.

Support for mobile activities with a suitable mobile platform will convince users only if the ergonomic quality and the interfaces for the familiar data environment ensure that training in the new technology does not require any more time than it will subsequently help to save. In contrast to the private sphere, where working with complicated and delicate technology can apparently be an end in itself for some users, in the working environment there are operational pressures for time efficiency. The operational benefits of interactive office furniture are therefore much too uncertain to justify the high costs. In the foreseeable future, pens and notepads will be used more readily than interactive touch screens.

The breakthrough for corporate mobile computing, and therefore the future of PvC, is called into question by the inadequate data security of transmission networks. Intensive discussions are being held on security loopholes in W-LANs and solutions are being worked on. In this connection, virtual private networks could take on increasing importance. These are protected networks that can be realised on the basis of any unprotected network, such as the Internet. Transmission uses ‘tunnel technologies’, i.e. the actual data packages (from the virtual network) are built into the data packages from the transport network (the real network) in encrypted form and are unpacked and decrypted at the point of receipt.

A further restrictive factor could be the shortcomings of the technologies, which are often announced with great exaggeration. According to a recent study (Grass, 2002) by the Gartner Group, many recent developments do not meet the high expectations that were placed in them. There is perceptible disillusionment in particular in the fields of biometric authentication, speech recognition and Voice-over-IP (Internet telephone calls).

4.4 Health

4.4.1 Areas of use

In the health sector a range of ICTs are being used at present. Important areas are Internet consulting, reduction of health costs through ICT-aided preventive measures, and sport and wellness.

An increasing number of patients are finding out about illnesses using the Internet. In 2000, 84 million users obtained health information over the Internet. The predominant subjects are diets[71] and chronic illnesses. Many people search the Internet for a second opinion or for experts on their illness. This boom shows that ‘lay people’ take their health seriously and want to take responsibility for their own health. The quality of the decisions taken by lay people therefore depends on the quality of the available information.

Other areas where ICTs are used are in the field of medical technology, for example improved access to patient records as a result of digitally networked hospitals and doctors, image processing procedures, and special analysis software for diagnosis. Other areas of use are monitoring of patients’ bodily functions, assistance for those in need of special care, and implant technology (these aspects are discussed in greater detail in Chapter 6).

Another area is the training of medical personnel using simulation programs. Examples are practice operations on virtual patients[72] or simulations of the effects of drugs.[73] Simulation programs can also assist surgeons in planning operations. One example is the planning and virtual simulation of a brain operation first without the patient, on a screen using three-dimensional image data.[74]

Table 4-4 shows the developments that can be expected in the areas of patients, medical technology and communication. The transition to Pervasive Computing is fluid and characterised above all by increasing miniaturisation and wireless networking.

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71 Examples of virtual dietary advice: www.ediets.com, www.cyberdiet.com, www.dietsmart.com, sport and wellness such as virtual training advice at www.ryffel.ch, or illnesses, for example, at: www.medgate.ch, www.netdoktor.ch.

72 www.bbw.admin.ch/pressemitteilungen/2002-04-18/d/projekte/xitact-d.pdf

73 archiv.ub.uni-marburg.de/diss/z1999/0440/diss_77.html

74 www.uniklinik-freiburg.de/k/nch/aanc/de/pub/schwer.xml

Table 4-4: Developments towards Pervasive Computing in the health field

	Patients	**Medical technology**	**Communication**
vision for 2012	Treatment of damaged sensory organs or nerve tracts by implants	Augmented reality in surgery Remote diagnosis	–
ready for production by 2007	Navigation systems for partially sighted Home care (monitoring of vital functions) Assistance for those in need of special care Computer-controlled prostheses	Speech control in the operating theatre Microrobots in surgery Implant robots in dentistry	Digital hospitals Electronic patient records
currently on the market	Personal health monitoring Training programmes Simple electronic implants	Medical image processing Computer-aided diagnosis Minimally invasive operations	Multimedia Smart cards

4.4.2 Market trends

In addition to common ICTs, there is a wide range of *special applications* in medicine, which can generally be manufactured only in small runs. Very large production runs are made only where the patients themselves are the users (e.g. smart cards for insurance or frequently needed implants, such as pacemakers). The industry's development priorities are (Siemens Webzine, 2001):

- 'Digital hospitals' and 'electronic patient records': The aim is for all departments in hospitals to be linked together. This includes electronic patient records that can be accessed by authorised persons at any time. Expenditure and quality are to be optimised from diagnosis and treatment to aftercare, and costs are to be reduced.
- Imaging procedures: The procedures in development allow an even higher-resolution image of the inside of the body, can be linked together on the computer and improve the quality of simulations in preparation for subsequent operations.
- Computer-aided diagnosis: Databases and expert systems will be used to assist medical diagnosis.
- Augmented reality in surgery: 'Augmented Reality' allows real images to be augmented with additional information. For example, the surgeon can see a patient's brain tumour projected onto their head and visualise the movements of the treatment probe.
- Operation robots: Robots already assist in routine operations, such as hip operations and implantation of artificial knee joints. Benefits of this technology are pre-

operative planning using three-dimensional models and higher-precision implementation.

- Haptic output devices: An important field of research is dedicated to haptic output devices, which make the resistance of tissue and bones tangible for various cutting devices and arthroscopes.
- Health monitoring: In prevention, intensive care and rehabilitation, microelectronic systems for monitoring bodily functions have been used for some time. An innovation is automatic transmission of data to the hospital or the family doctor. In many cases, this allows health monitoring at home rather than inpatient treatment (see also Chapter 6.1).
- ICT-aided rehabilitation programmes: Special software for training and monitoring is being developed for rehabilitation.[75]
- Prosthetics: Computer-controlled prostheses for legs and feet are being developed, for example. The knee joint is controlled by a microprocessor. Walking pace is determined by a sensor system, processed microelectronically and converted into hydraulic movements during walking. Along similar lines, there are also attempts to control computers by brain patterns. Initial tests with paralysed patients have already been carried out.[76] Another example is the development of retina implants, which could help some blind people to see.[77]
- Pacemakers: In addition to heart pacemakers, which ensure that the heart functions properly, brain pacemakers are also being developed at present in various laboratories. These are electrodes that are implanted in the relevant region of the patient's brain and stimulated by a pacemaker. In the case of certain pacemakers, electrical impulses block over-active regions of the brain; in the case of others they stimulate under-active regions. In this way it has already been possible to help some Parkinson's patients, as well as patients with otherwise untreatable compulsive disorders and patients suffering from depression.[78]
- Implanted transponders: Microelectronic elements are being introduced into implants. Transponders are widely used in veterinary medicine and in dietary monitoring. One example is monitoring and, if necessary, tracing the origin of cattle. In salmon breeding transponders are used to verify the dressed weight.[79] Such implants could be used in future not only for animals, but also for humans. The benefits will include possibilities for the identification of persons at home and outside (body-integrated keys). Initial experiments are being conducted along these lines.[80]
- Nanorobotics: There are already 'micro-submarines', 4 mm in size and with a diameter of 0.65 mm. There is speculation that in future even smaller micro- or

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75 www.cc.ethz.ch/bulletin/

76 www.emory.edu/WHSC/HSNEWS/scico/brain.html

77 www.rwth-aachen.de/zentral/dez3_pm2002_pmretina.htm

78 www.hempelbs.de/article.php?sid=269; http://de.news.yahoo.com/020921/3/2yync.html

79 www.datamars.com/animal.htm

80 www.cnn.com/TECH/computing/9809/02/chippotent.html

nano-machines could be released into the bloodstream where they will perform therapeutic functions.[81]

Excursus: Applications where no treatment is needed

The same 'pervasive' technologies that release patients from serious suffering can be used in principle technically to extend the physical limitations of healthy people. This point should be examined in greater detail because it often forms part of technological visions and probably promises greater market potential for manufacturers than the treatment of relatively rare illnesses.

In particular there are visions of developing artificial sensory organs and of connecting microelectronic elements with the central nervous system. If progress continues to be made in linking up electronics and the brain, control of external devices by nerve impulses is conceivable. Initial efforts are already being made.[82] This makes direct access to technological information memory a possibility – 'external memory' for humans would be conceivable.

Such developments could ultimately mean that in many areas the artificial organs will be superior to the natural (biological) organs. It is conceivable that transplants will then no longer be carried out solely on medical grounds (after accidents, illness etc.), but because people wish to improve their capacities (and thus their lives) by means of artificial organs.

In neurosurgery, chips to expand memory and consciousness are considered to be possible in principle. If current trends continue, the breakthrough can achieved by 2029, claims computer scientist Ray Kurzweil in his book 'Homo s@piens'. The implants would then be so sophisticated that they would allow easy communication from humans to machines and vice versa. By directly linking up with the nerve system, microprocessors would then be able to play sounds, images, smells and feelings into the brain.

The possibilities of abuse and the ethical implications of such technologies cannot really be predicted, as is illustrated by the following example. A research group at New York State University implanted electrodes connected with a microprocessor into the brains of one in three rats. The researchers were able to direct the rats by remote control to places that they normally avoided (Clarke, 2001).

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81 www.heise.de/tp/deutsch/inhalt/lis/4319/1.html
www.heise.de/bin/tp/issue/dl-artikel.cgi?artikelnr=4319&rub ordner=inhalt&mode=html

82 www.emory.edu/WHSC/HSNEWS/scico/brain.html

4.4.3 Prospects

Medicine offers a range of potential uses for computer technologies. It can be assumed that the integration of computer technology will continue to make progress. This trend will be given impetus from several directions:

- Pervasive information and communication technology improves work processes and helps to raise quality; in particular, it is expected that costs will be reduced. It is hoped that as a result of electronic patient records unnecessary duplication and inappropriate treatments can be avoided.
- In industrialised states the proportion of elderly people in the population is growing. As a result, the overall needs for care are increasing. Pervasive information technology can assist with care for patients in their own homes, for example through automatic monitoring of bodily functions and transmission of information to the doctor, which may lead to a fall in costs.
- The trend is also being encouraged by the fact that aspects of body awareness, which is becoming increasingly important, precautionary medicine and care management are being assisted.

Lastly, it must be presumed that the health sector will be an area in which Pervasive Computing is widely used because all the possibilities for preserving and improving health meet with high acceptance in principle. The limits can be seen where fundamental ethical questions are concerned.

Pervasive Computing will also take on increasing importance with new leisure activity focusing on *wellness* and sport (*bodyshaping* but also extreme sports). The possibility cannot be ruled out that because of the ever-improving opportunities for following one’s own bodily functions online, the body will be used too ‘optimally’ (exhausted) and long-term damage will therefore occur. In addition, the improved treatment possibilities could lead to a greater willingness to take risks in sport. Both factors could have negative effects on health costs.

4.5 Wearables

Wearables are (electronic) devices that are worn on the body or are integrated into clothing. Such clothing is also called 'i-Wear' or 'intelligent clothing'. The range of functions covered by wearables includes recording and processing of body and environment data and communication via the Internet or local networks.

Figure 4-5 shows the most important milestones in the development of wearables in the 20th century. We regard wearables as a subsection of Pervasive Computing, since the essential characteristics of PvC are satisfied.

Hands-free interaction, multifunctionality and context sensitivity are the most important developmental objectives at present.[83]

The crucial difference from current ICTs is that with wearables it is possible to integrate closely processes and information from the real and the virtual world. Access to the virtual world becomes more natural because the means of access are worn on the body.

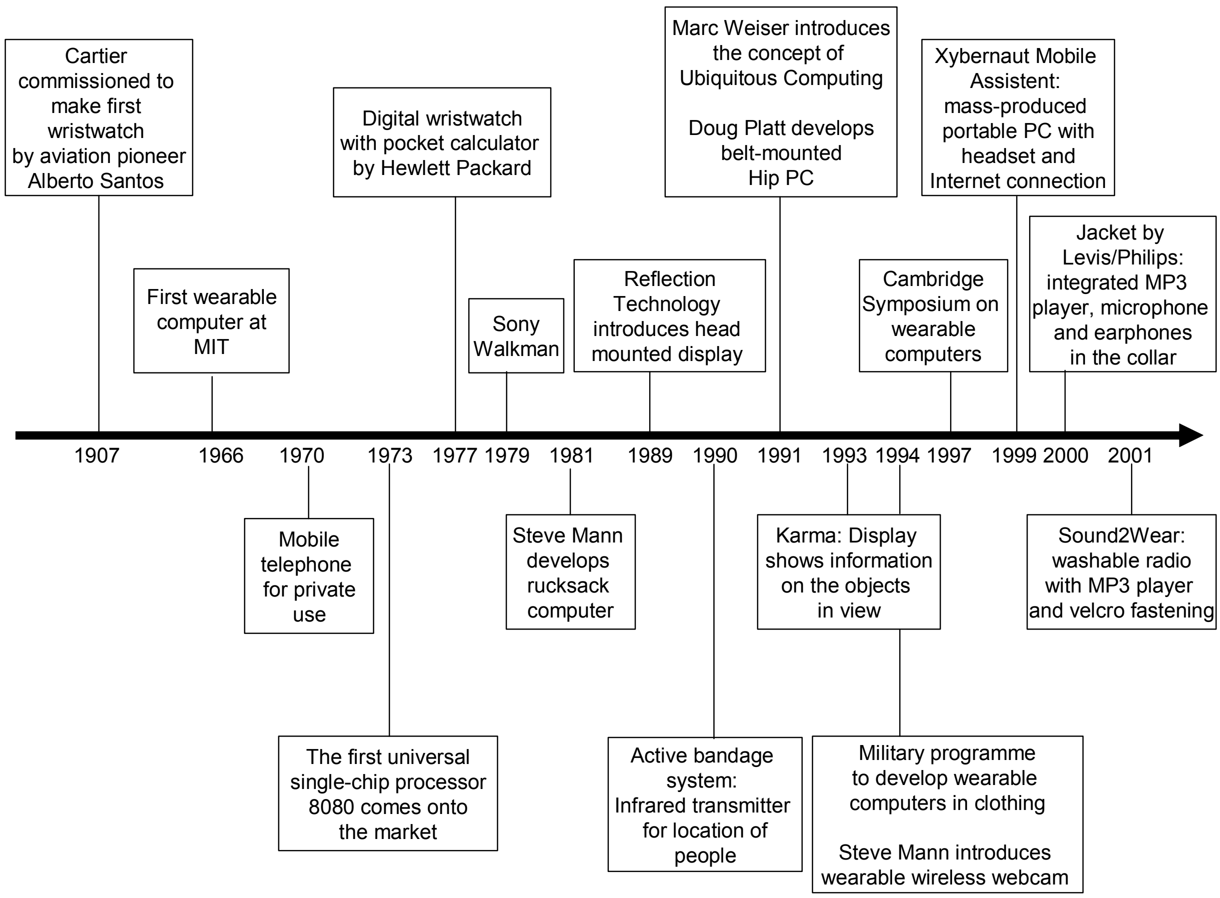

Figure 4-5: Milestones in the development of wearables in the 20th century

[83] cf. International Symposium Wearable Computer (2001)

Table 4-5: Developments in wearables in various areas of use

	Leisure	**Work**	**Control and adaptation**
vision for 2012	Personal Area Network: living behind a virtual shield	Data Glove: Processes controlled by hand in a simulated world or at a remote location	e-vision: glasses continually adjust viewing intensity and distance
ready for production by 2007	i-Wear: pocket inventory, alarm and context-sensitive music program Memory vest: integrated dictation machine	High-performance wearable PCs for professional applications, e.g. live reporting Cyber glasses: familiar working environment available in any location	Health monitoring: measurement, reading, monitoring for blood pressure, tanning etc. Location: monitoring of children and pets
currently on the market	Multifunctional wristwatch: e.g. with MP3 player Industrial clothing design: with MP3 player, mobile phone, earphones and microphone Memory glasses: glasses with camera, microphone and integrated display	Multifunctional wristwatch: e.g. organiser First wearable PCs: headset with microphone, voice recognition and integrated display Bluetooth headset for hip-mounted mobile phone	Multifunctional wristwatch: e.g. with data storage for access control Fitness: sports bra with pulse meter and display, electrical muscle stimulation with belt Navigation: speech-controlled navigation for visually impaired

4.5.1 Areas of use

Table 4-5 shows the developments in wearables that can be expected in the areas of leisure, work and control and adaptation. Of the variety of possible applications, wearables for controlling bodily functions and headsets for communication have comparatively high potential for realisation and diffusion.

To illustrate the possible uses, a description is given below of currently existing products and prototypes.

Existing products as illustrations

The Industrial Clothing Design (ICD) jackets made by Levi's and Philips have facilities for holding MP3 players and mobile phones. Earphones and a microphone are fastened to the collar. With a unit price equivalent to around € 1 200, the production run for this niche product is only 320. Further development towards context-sensitive i-Wear is currently being pushed by MIT, supported by the sponsors Adidas, Levi-Strauss Europe, Samsonite and Seiko Epson. The i-Wear is intended to recognise which items are being carried and possibly to remember the wearer e.g. from their key ring. An alarm function protects objects in the jacket against theft. By interpreting movement (jogging, strolling) and determining external interference factors, such as street noise, a music programme is automatically selected and the volume is regulated. The i-Wear is structured in three layers. The movement layer detects movement patterns by sensors, the sound layer provides the appropriate music by loudspeakers and the environment layer detects light conditions, temperature and sound. Communication is wireless and uses the Bluetooth standard.

Other approaches favour communication via textiles, into which polymer electronics and conductive fibres are woven.

IBM's 'wearable PC' weighs only 300 g. Hands-free work is possible thanks to a headset with integrated display, microphone and speech control.

The model from the Klaus Steilmann Institut and Sinn Leffers is a computer sewn into the clothing with 40 MB memory and a Pentium 3 processor, which weighs around 900 g. The product is designed for professional users like sports reporters for live reporting. The areas in which this can be used by industry are in the fields of internal communication, modern stock management, maintenance and repair. The systems technicians in factories or in aircraft construction can localise faults using systems plans shown in the head mounted display. The same information can be received and analysed simultaneously by all members of a team at different locations.

In 2001 and 2002 Ericsson and Motorola brought the first Bluetooth headsets for mobile phones onto the market. The mobile can for example be left on the user's hip. This is a first step towards a 'Personal Area Network'.

With the *sports bra* that measures the pulse, the use of wearables to monitor bodily functions has been extended from health to sport.

Devices for continual monitoring, of blood pressure for example, are becoming more and more convenient. In the not too distant future, in the light of growing health awareness and advances in technology and integration in clothing, more extensive wellness and health applications can be expected. For example, dedicated and multifunctional devices for measuring, displaying and monitoring pulse, blood pressure, tanning and perspiration are being developed.

The vision of the digital aura

The ultimate aim of these developments is the full networking of wearables with one another and with umbrella networks. Personal Area Networks (PANs) and Body Area Networks (BANs) network all local objects and have access to mobile radio communication networks or W-LANs, via which the Internet can then be accessed.

Users therefore carry around an informational and functional aura tailored to their interests, which at the same time connects them with the world. Their natural senses are expanded by the context sensitivity of wearables and by augmented reality. Whatever sensors find out about the user's body or the immediate environment can be merged directly into the user's visual field or indicated via the ear or the sense of touch. This also applies to additional information which is consulted and provided from remote sources, depending on the situation.

The following table brings together the technologies that can be integrated into a Personal Area Network and the areas in which they can be used.

Table 4-6: Personal Area Networks with interfaces (Source: mstnews - International Newsletter on Microsystems and MEMS, No. 2/02; authors' own classifications)

Area of use	**Technology**	**Examples of applications**
Leisure and entertainment	Mobile radio communication networks Bluetooth Transponders Input/output devices PC/PDA displays	Integrated mobile phone i-Wear layers Textile electronics Microphone/loudspeakers Headsets
Danger aversion and health monitoring	Transponders and GPS Sensors Actuators	Identification and location Pulse Emergency calls
Efficiency and safety aspects in work processes	Mobile radio communication networks Bluetooth Transponders Sensors Headsets	Integrated PDA Interface with office devices Access control Hazardous substance warning Virtual work environment

4.5.2 Market trends

The most important sales market for wearables from the point of view of manufacturers is the group of young, unconventional consumers. The devices should guarantee a maximum amount of flexibility, mobility, individuality and 'fun'. Uninterrupted accessibility, the possibility of data access on the move, retrieval and management of personal data, such as information on the environment or day-to-day events, are important criteria for use. Pockets and applications for small portable devices can possibly be seen as a 'gateway' to wearables with the cargo, utility, military and futuristic looks that are popular in the youth scene.

For this target group, satisfaction of the need to stand out through *visible* branded goods and technology is somewhat inconsistent with the idea of *invisible* or at least inconspicuous Pervasive Computing. It will be interesting to see how the suppliers resolve this inconsistency.

Target groups with quite different needs are people in need of special care and with great safety needs, single parents and working parents, and competitive fitness and extreme sports enthusiasts. Firstly, their own safety will be monitored (medical/attacks), and secondly, wearables, in conjunction with networks, can be used to monitor other people, e.g. children.

Senior citizens, single parents and singles are becoming increasingly significant in society. In this potential user group, the motivation for wearing wearables could come from the increased need for security and monitoring resulting from parallel activities. Since the fitness and wellness trend is continuing and also the population continues to age, there is great market potential in the monitoring and observation of bodily functions.

Because of improved information management, wearables in the working environment allow more efficient and – if user interfaces improve, which remains to be seen – more ergonomic work processes. *The crucial way in which they differ from current ICTs is that a close and productive linkage of processes and information from the real and the virtual world can be made.*

The integration of wearables puts the wearer in a position to have direct access to the data that are relevant to their work from any location. The flexibility, time saving and leap in knowledge that are created promise cost savings and could therefore represent a motor for the propagation of wearables as a work tool that is not to be underestimated. Bell Canada has carried out initial experiments with using wearables for telecommunications maintenance. According to that company, it will be possible to save one hour's working time per technician per day by using wearables.

Aside from clothing, jewellery is one possible way of having wearables on the body. Wearables in jewellery could be of interest above all to female users, since female clothing does not generally allow for many pockets, at least as fashion stands at present.

There is little information on the market trend for wearables. The Consumer Electronics Association in the United States puts the wearable computer market at US $ 25-50 million in 2000, and estimates that it will be as much as US $ 50 billion in 2005.[84] These astronomic growth rates that have been forecast appear to be very speculative.

The extent to which wearables become established depends on several factors. Important considerations are cost, comfort and safety. It is conceivable that in four to five years the costs of wearables will have fallen so far and the functionality of speech recognition systems and headsets will be so advanced that a high market penetration could be achieved (Shea, 2001). In call centres and other commercial environments headsets are already now part of everyday life, but these are isolated applications, that do not form part of the general vision for wearables or PvC.

According to a survey by the Klaus Steilmann Institut, 95% of men and 93% of women are interested in i-Wear.[85] In contrast, dealers give a surprisingly low estimation of the actual importance of wearables for the clothing industry. Only 6% of dealers believe that that there will be a market for wearables in the immediate future, although the estimate increases the further into the future we look. In a survey, 88% of dealers in the clothing industry agreed that functional fashion can be sold more easily and at higher prices, but only if the function can be explained to customers.[86]

[84] Consumer Electronics Association http://www.ce.org; as at: 3 June 2002

[85] Starlab and Klaus Steilmann Labors, 2001, unpublished

[86] Dealer survey for the textiles industry, in TextilWirtschaft-Zeitung 29.11.2001, No 48

4.5.3 Prospects

Figure 4-6 gives an impression of how manufacturers view the future of wearables (Siemens Forschung und Entwicklung 1997).

The market penetration of wearables will probably depend primarily on the following factors:

- health risks from non-ionising radiation (NIR)
- data protection
- further acceptance issues and technological deficits

NIR exposure

Wearables are particularly relevant in terms of radiation exposure firstly because they are worn *constantly* (and may be in constant operation) at least during the day and secondly because of the *proximity of the radiation sources to the body*. The combination of continuous operation and proximity to body tissue can result in high exposure even at low transmission powers (see also Annex 5).

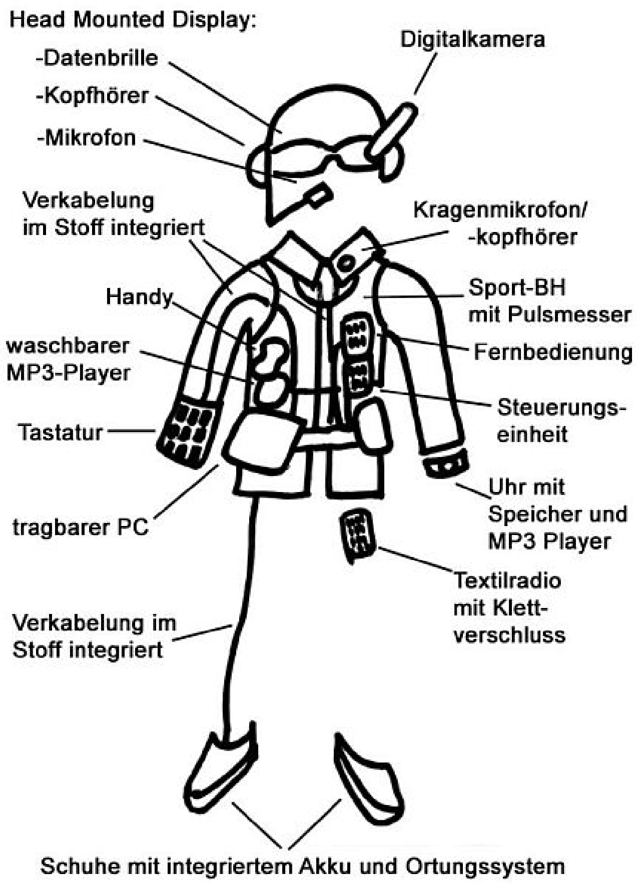

Figure 4-6: A vision for wearable computing.

Translator's note: For legend see p. 294 below

Data protection

The data flow produced by wearables could, even more than today, make their wearers into 'transparent customers' for commerce, 'transparent patients' for hospitals, or 'transparent citizens' for the police or other enforcement bodies. The reservations associated with this issue could act as a brake on developments.

Technical shortcomings and acceptance issues

Some manufacturers hope for a breakthrough in acceptance of wearables as a result of 'emotion awareness', a system that determines the emotional state of the user and reacts appropriately. However, such context-sensitive systems can be seen to be overbearing when they purport to know what is best for the user.[87]

In the monitoring of bodily functions, the assessment of what is 'healthy', 'normal' and 'right' is passed to technology. It is doubtful whether this will be accepted by many people.

Furthermore, there is no guarantee that users will be provided with correct information. Through familiarity, verification of the information received could be omitted with time.

With regard to i-Wear it is not yet clear what benefits it might have in comparison with conventional textiles with a *separate* PDA, for example.

There are unresolved technical problems with regard to power supply.[88] Furthermore, network protocols for ad-hoc networking of mobile devices are needed.[89]

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87 Even quite simple help systems for software (e.g. Microsoft Office) annoy users by feigning understanding without actually understanding.

88 Possible power supply systems are solar cells, minibatteries or charging devices integrated into clothing, which are charged by movement. Compaq has a patent on recharging of laptops through the keyboard. The use of body heat or methanol-based fuel cells are also possibilities.

89 One possible approach is JINI. In addition, there are other approaches in the field of inter-device communication. UPnP, HAVI and CORBA are possibilities, but they are not yet interoperable. Cross-manufacturer standards have not yet been developed. This prevents the systems in question from breaking through.

4.6 Digital information and home entertainment media

Books, newspapers, catalogues, music recordings and videos are now no longer linked to their traditional carrier media[90] (paper, video cassette, etc.) and are distributed in digital form, primarily over the Internet. Up to now the PC has been the predominant terminal for Internet access and therefore for the use of digital information and home entertainment products. However, there is little acceptance for PCs for this purpose. Specific terminals are therefore also being developed, e.g. e-books. Computer games and their consoles will not be examined further below.

4.6.1 Areas of use

Table 4-7 shows the expected developments in the areas of text and image, sound and video. As in other areas, the transition from traditional ways of using ICTs to Pervasive Computing is fluid. Crucial factors are the increase in portability and networking, which in this case allow mobile online access to information and home entertainment products.

For a few years now, there have been *electronic books,* or *e-books*. These are reading devices for digitalised book content. The first models include Nuovomedia's 'Rocket ebook', a book-sized device that can store 50 digital books. The successor model, the ebookMan, takes the form of a light PDA. Reading is one function among many, such as appointment management and listening to music. For this purpose, special e-book software is needed to read digital books. There are several data formats for these books. The most common are PDF (Adobe Acrobat Reader, Acrobat ebook Reader), the Rocket Edition for the 'Rocket ebook', and Microsoft-specific formats. There are also books in compiled form as executable files. With the 'NeoBook Professional' sound and video sequences can also be integrated.

In the newspaper and magazine sector, in addition to the traditional dissemination of information through printed media, there is the alternative of electronic publication on the Internet. Publishing houses for mass print media are making increasing use of this new medium. There are several thousand *electronic newspapers and magazines* worldwide, from small regional newspapers to international daily newspapers. In Switzerland 102 newspapers and 66 magazines are online. In most cases, however, complete daily editions are not offered, only selected articles. Examples of purely Internet-based newspapers are the American *Salon* and 'netzeitung.de', which has been published since 2000. Some national daily newspapers, e.g. *Financial Times Deutschland*, and magazines can be received by mobile devices, such as WAP mobiles, PDAs, smart phones or e-books.

[90] Media always form hierarchies, where the medium of the next level (or layer) down is described as the carrier medium for the medium being considered. For example, the possible carrier media for the medium of language are writing, sound etc., possible carrier media for writing are paper, digital data etc., possible carrier media for digital data are hard disk, diskette, CD-ROM etc.

Table 4-7: Developments towards Pervasive Computing in the use of media

	Text and image	**Sound**	**Video**
vision for 2012	E-paper replaces paper Digital kiosk for printing out individual articles	PAN[91] with speech input and output	Cyber glasses as headsets E-paper for video
ready for production by 2007	E-paper in mobile phones and handhelds Control of PDAs by speech input OLED mobile phone with shutter glasses	Digital radio PDA with speech control	Digital TV Mobile phone with digital video camera Projection displays Digital TV
currently on the market	Online newspaper e-book Mobile phone with camera function Webpad	E-book with music function MP3 downloads MP3 player	Digital video camera Webpad DVD player Video on demand

Mail order companies use *online catalogues* to present their products on the Internet as a new sales medium alongside the printed catalogue. The online catalogue offers the additional possibility of linking external additional information with product information and can be updated at any time. Up to now some mail order companies have offered only a selection of their product range over the Internet. The online catalogue is intended to be read on a PC as the terminal. Special WAP or UMTS applications are being developed. Online catalogues are used as *additional* marketing tools, whilst printed catalogues are still sent by post alongside them.

Music downloads are now widespread as a result of the MP3 data compression technique, but also as a result of the parallel development and propagation of suitable portable terminals (MP3 players) and software players for PCs. This has been aided by online music file sharing networks, the most famous of which is Napster. In 2001 more than 70 million people used the file sharing facility and more than 2.8 billion music files were shared in February 2001 alone. The music industry responded with actions brought for copyright infringement. Since then an effort has been made to develop a marketing model for the royalty-based distribution of audio products on the Internet. As well as Bertelsmann, other companies are also attempting to set up sales platforms, including ‘Musicnet’, ‘RealNetworks’ and ‘Pressplay’.

Unlike digital newspapers and audio products, the distribution of *digital video films* over the Internet is less established. ‘Video on demand’ has not become as popular as expected. Various US film studios are trying to secure a position on the Internet with film downloads. Cable and mobile network operators are buying video content and offering this on their websites to increase the attractiveness and cover the costs of their networks (Orwat, 2002). However, mobile radio communication is not suitable for the distribution of videos, a situation that could change with UMTS.

[91] Personal Area Network

4.6.2 Market trends

The *television and radio markets* are undergoing a profound change as a result of the digitalisation of production, storage and distribution technologies. First of all, digitalisation simply codifies the same content in another way. Through compression, however, it is possible to increase transmission capacities with the result that in future a hundred times the amount of programmes can be transmitted. At the same time, digitalisation offers the potential to develop television into an interactive, digital and multimedia platform. It will be able to offer not only traditional television services, but also a wide range of new content and services.

One characteristic of the market trend is the convergence of separate device functions. Mobile telephones are becoming more and more like PDAs, whilst PDAs will certainly soon be useable as telephones. Nokia's ‘Communicator 9110’ is one example. The device offers both conventional radio communication functions, WWW access and e-mail, as well as all the functions of a PDA. ‘Smart phones’ also use WAP technology to access the WWW. The Nokia ‘R380’ also has a wide range of applications: SMS, e-mail, address book, appointment book, dictation machine and note pad. A number of similar multifunctional devices will soon be on the market. Sony Ericsson offers a mobile phone that takes digital photographs. Vodafone sells combined telephone/photomodules and reports that there is great demand.

The market for electronic books is developing very slowly. At present between 10 000 and 50 000 reading devices are used worldwide. Thomson Multimedia announced in 2000 that it would soon be bringing several million e-book readers onto the market under the brand name RCA,[92] but these devices have not been able to establish themselves.

The development of better and lighter displays for reading text-intensive content will influence the market in digital information products significantly. It can be predicted that there will be a technological breakthrough in the development of a convenient electronic reproduction of printed media in the near future.

Manufacturers expect that OLED[93] screens will have a bright future, in particular for mobile applications. With lower energy consumption they offer higher brightness than backlit LCD monitors and considerably better contrast than non-backlit LCD monitors. Another advantage of OLED is the wide viewing angle of 170°. Initial estimates assume a potential market of $ 5 billion for OLED displays by 2005.[94]

‘Paper-like displays’, which offer comparable reading comfort to traditional newspapers, will be coming onto the market in the next few years. IBM and Rank Xerox have introduced first prototypes. The resolution is not yet sufficient to achieve adequate sharpness for high readability. In ten years electronic paper could become a serious rival to traditional paper.

Example: IBM’s Electronic Newspaper

The ‘Electronic Newspaper’ devised by IBM has some of the characteristics of a traditional newspaper. It can be folded and carried. The reader connects his newspaper

[92] c’t 23/2000, p. 78

[93] Organic Light Emitting Diodes

[94] Handelsblatt 27.02.2001

to the Internet, loads the content into the intermediate memory and can then read it on 16 double-side printed pages. The Electronic Newspaper will be given the 'feel of the old newspaper' and will have new functions. For example, articles can be immediately sent online or archived.

The Electronic Newspaper comprises 16 pages made by glass-fibre-reinforced paper, which was chosen because of its durability and flexibility. The pages are printed with 'electronic ink', which is currently being tested in the MIT Media Lab. This is a bistable compound whose molecules appear either white or black through electrical charge.

The format of the Electronic Newspaper is roughly A4. It can even be rolled or folded. Keys control the functions 'show new sections', 'cut article' and 'update edition' (Deider, 1999).

4.6.3 Prospects

Many earlier forecasts of possible sales of digital information products have proven to be excessively high. In general, it is currently assumed that there will be further growth, albeit slow.

Various positive and negative factors influence the future of ubiquitous provision of information products.

Positive factors are:

- a selective, personalised use of mass media is possible.
- UMTS will enable more convenient mobile access.
- terminals will continue to become more powerful and cheaper.

Negative factors are:

- the lack of a convincing range of products that make clear the benefits over conventional carrier media,
- the absence of practicable payment systems,
- the unwillingness of customers to pay for products offered online,
- poor ergonomics and poor compatibility of ICT products,
- excessively low operating periods of mobile terminals (a few hours) with current battery technology,
- non-secure data transmission,
- uncertainties over copyright,
- possible debt among young users.

The trend for technical developments in mobile terminals is comparatively easy to predict: higher resolution, lower weight with flatter construction, better reliability, higher speed, lower power consumption and wider viewing angle for displays.

It is unclear whether the expected market segmentation for terminals into at least three groups will stabilise, as Siemens presumes: [95]

- devices for voice communication, like current mobile phones
- devices for mobile office work
- devices concentrating on entertainment (games, videos)

It is also difficult to estimate acceptance of digital media products. Large numbers of customers are possible only if convincing content is offered. Conversely, if large customer numbers cannot be realised, suppliers may be prevented from investing in new products and services.

The current unwillingness of customers to pay is also seen as an obstacle to the implementation of new business models in the media sector (Oertel, 2001). Since, on the basis of its self-understanding from its first few years, the Internet has guaranteed free access to information, consumers regard its content as public property. It is therefore difficult to establish a willingness to pay for digital media services. Attempts to ask readers of digital newspapers to pay have failed, in the case of the New York Times for example. Subscription fees for online users were abolished again after a short time.

So far only special information services, for example for doctors, or commercially used products like the ‘Wall Street Journal’ or ‘The Economist’, have been able to generate profits with online subscriptions. These are taken out mainly by companies and are not paid for by private individuals in many cases. Advertising revenue is the main source of financing for Salon (140 000 readers[96]), the Wall Street Journal (150 000 readers[97]) and also the Financial Times Deutschland. It is to be suspected that the online services will also be cross-subsidised by revenue from printed media, at least in phases (Fichter, 2001).

We should not underestimate the importance of transparent customer payment procedures (microbilling), which are a precondition for the acceptability of business and cooperation models for operators. On the one hand, there are more accepted payment systems in radio telecommunications than the fixed-network-based Internet, whilst on the other, microbilling, the settlement of small payment sums, creates major difficulties and calls into question the efficiency of multimedia services in the media sector.

If it is possible to overcome the different obstacles, small portable devices for digital media should become part of everyday life within ten years. Experience shows that the new media will not replace the old media, however; it is more likely that the different media types will develop in parallel. The conventional media will continue to grow, although less so than digital media.

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[95] http//w4.siemens.de/FuI/en/archiv/pof/

[96] As at 1999, cf. Zerdick (1999, p. 171)

[97] ibid.

4.7 Smart labels and other automatic identification systems

The purpose of smart labels, like conventional labels, is to identify objects and to provide information about them. The automatic identification systems include four widely used techniques: bar codes, optical character recognition (OCR), smart cards and smart labels.

4.7.1 Areas of use

Smart labels have the highest affinity with the Pervasive Computing vision. Nevertheless, in order to clarify the areas in which automatic identification systems will be used, all four systems will be outlined. It is likely that all four systems will still be in use in 10 years' time.

The *barcode system* uses a bar code that is scanned by a laser beam.

Optical character recognition (OCR) is used in particular in conjunction with a special typeface, as on the bottom line of a cheque.

Smart cards (e.g. telephone cards) are read by a reader with galvanic contact surfaces for data and energy transfer. They contain a relatively powerful microchip.

Table 4-8: Advantages and disadvantages of different automatic identification systems

Bar codes	**Optical character recognition (OCR)**	**Smart cards (chip cards)**	**RFID transponders (smart labels)**
+ worldwide standards + many manufacturers + reliability + low costs	+ high information density + (additional) visual data acquisition	+ optional protection against unauthorised access	+ optional protection against unauthorised access + contactless reading and writing + range of metres + no susceptibility to soiling + bulk reading
- susceptibility to soiling - visual contact needed - not rewritable	- expensive readers - susceptibility to soiling - visual contact needed - not rewritable	- susceptibility to soiling and wear-and-tear	- cost disadvantages compared with bar codes - insufficient applications

Source: Bättig (2000), slightly modified

Table 4-9: Developments in automatic identification systems

	Bar codes	**Smart labels**	**Smart cards**
vision for 2012	Bar codes on nearly all everyday objects: packaging, crockery, clothing	Smart labels on nearly all everyday objects: packaging, crockery, clothing	A single personalised multifunction smart card with transponder
ready for production by 2007	Link with Internet services: bar code scanner with browser	'Product Identification Unit': with recycling information Production monitoring: tracking across process chains e.g. food Access control: local public transport	Extension to new areas of application: social and personal identity cards, driving licences Extension of functionality: biometric authentication, contactless readability, debiting
currently on the market	Price marking: in supermarkets Lending systems: book and video libraries Product logistics: in production processes and distribution	Lending systems: book and video libraries Product logistics: in production processes and distribution Access control: ski lifts, person and time recording	Personalised cards: money card, health insurance card, customer card, subscriptions Non-personal cards: telephone cards

Smart labels contain flexible, paper-thin RFID transponders (see Section 3.4) and can be read by a reading device without physical or visual contact. In active systems, power is supplied by a battery, whilst in passive systems electromagnetic fields charge an energy storage device. The range is typically 1 m (Bättig, 2000).

The four automatic identification systems have specific advantages and disadvantages (see Table 4-8).

Bar codes have been used for a long time to mark prices, in supermarkets and in product logistics for example. With two-dimensional bar codes, the information density compared with one-dimensional bar codes can be increased from around 15-50 characters to around 2 000 characters. In the United States bar code scanners with web browsers, which allow access to additional product information, are becoming increasingly widespread.

Smart labels have recently been competing with bar code systems. Object tracking, automatic sorting and lending systems are made much more efficient, i.e. with a higher degree of automation.

Baggage tracking is being used more and more in air transport. At check-in (e.g. at San Francisco International Airport), the item of baggage is given an exclusive 2.45 GHz transponder which is read by scanner arrays in the baggage logistics areas.

This is also possible for postal goods. The Italian postal service uses 13.56 MHz smart labels for automatic sorting; many items of post can be scanned at once.

In book and video libraries the books and videocassettes have smart labels that are rewritable at 13.56 MHz.

Transponder-based systems have also become established for access control and time recording. Contactless chip cards can cover such great distances with large coil surfaces that they are being used increasingly in ski lifts and in the identification of people in the workplace.

There will be applications of RFID in the near future in the production sphere. Rewritable transponders make it possible to monitor production at control points, to assure quality by writing to the transponder after each stage of production and to assist production and materials control.

The recycling of products such as vehicles, electronic devices and furniture could be encouraged though smart labels containing information on composition, services and guarantees and recycling recommendations.

The difference between bar codes and smart labels in terms of Pervasive Computing is shown by the following example: packaging with bar codes at supermarkets can generally be scanned at the cashier's desk or using a hand scanner. The 'intelligent refrigerator', however, can only use labels that can be read fully automatically, which is only the case with RFID labels.

It is no longer possible for the average European citizen to imagine life without smart cards. In addition to the most common applications, telephone and cash cards, the number of cards in a wallet often comes to a dozen. New functions such as biometric authentication of the user and contactless readability are expected to allow new applications such as driving licence smart cards. A personalised, multifunctional smart card with RFID transponders is technically feasible.[98]

4.7.2 Market trends

The propagation of identification systems based on RFID transponders (in particular smart labels) is contingent on further breakthroughs in cost reduction.

In the same way as bar codes, it can be predicted that RFID technology will first become established in the commercial sector. In many applications, such as post sorting and production logistics, the reasonable investment must be balanced against considerable efficiency improvements and therefore cost savings.

Public transport is seen to have great market potential. RFID transponders with a debiting function could save time for passengers and staff and make fare-dodging more difficult.

If it is possible to make further drastic reductions to the costs for smart labels (e.g. using polymer electronics, see Section 3.4), applications in inexpensive mass market products such as packaging that provides product-specific information and automatic billing in supermarkets could have great market potential.

Packaging with smart labels is a requirement for the 'intelligent refrigerator', which, for example, finds recipes on the Internet based on its contents or sends repeat orders.

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98 Smart Card – eine für alles, no author credited; Fraunhofer Magazin January 2002

Table 4-10 illustrates how the use of smart labels affects the general development of packaging and marketing:

Table 4-10: Increase in functionality of packaging (Source: Pfaff, 2002)

Product policy: packaging	**Objective**
Traditional marketing	- Design at the forefront
Marketing in e-business	- Design - Track and trace
Marketing in Ubiquitous Computing	- Track and trace - Content identification - Product characteristics - Expiry/use-by date - References - Technical documentation

By the end of 2000, around 10 million bar code scanners had been distributed free of charge in the United States, and this figure was said to be as high as 50 million in 2001. These 'CueCats' cost between US$ 5 and 10, which means that a total of at least US$ 500 000 was spent (Mattern, 2001). There are no figures for Europe or for Switzerland.

According to Frost & Sullivan, the global market for RFID systems (location and tracking) was around US$ 27 million in 2000 and is set to rise to around US$ 278 million by 2004. At present Europe has a market share of 28.1%.[99] According to a study by Venture Development Corporation, the worldwide market for RFID technologies yielded almost US$ 900 million in 2000, taking into consideration hardware and software, services in the field of goods management and tracking in logistics systems and security applications. RF ICs contributed US$ 76.3 million to the turnover. Total turnover is set up grow annually by 24% until 2005, whilst IC sales, with a 34% annual growth rate, will be disproportionate.

According to Frost & Sullivan, turnover for smart cards in Europe in 1999 was US$ 1.2 billion (almost 800 million smart cards), which corresponds to 60% of global turnover. Telephone cards alone account for 472 million. In 2006 around 2 billion smart cards sold in Europe are set to bring a turnover of US$ 4.1 billion.[100]

In 2000 the world market for short-range radio chips was US$ 1 340 million and in 2006 it is set to amount to US$ 4.8 billion. Bluetooth has seen the largest growth.[101]

4.7.3 Prospects

The diffusion of RFID transponders depends on the following factors:

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[99] Der globale Markt für RF-Lokalisierungs- und Verfolgungssysteme; available from: www.idlocis.de/infozine; 9 July 2002, as at: 15 December 2005

[100] Der europäische Markt für Smart Cards, no author credited; http://www.idlocis.de/infozine; 9 July 2002. This figure relates to Germany.

[101] Der globale Markt für Kurzstreckenfunk-Chips, no author credited; available from: http://www.idlocis.de/infozine; 9 July 2002, as at: 15 December 2002

- price trend for transponders
- compatibility of transponders and stability of ad hoc networks
- radiation risks
- security issues

If ‘intelligent’ labels are also to be used for low-value objects such as food packaging, prices have to fall from the current level of around € 0.2 - 1 to a few cents and below. This would not appear to be feasible using conventional silicon technology, but may be with polymer electronics (see Section 3.4).

At present, transponders are not yet very widespread. This is partly because of insufficiently integrated solutions and perhaps also because of inadequate information about the possibilities of RFID technology.

With the RFID standard, an important basis for wireless data exchange between chips was created in 1999. Further impetus for new applications can be expected from the sale of frequency windows for smart cards and new Java platforms. *SIMalliance* intends to devise open standards on the basis of which mass markets can be developed using new SIM-based applications and services. Aside from integration and interoperability with complementary technologies, continuous real-time information delivery is an important challenge for the development of potential mass-market commercial applications. The stability of ad hoc networks is encouraged by standardisation. In order to avoid data collisions where there are a large number of smart labels and smart cards in electromagnetic fields, anti-collision protocols are being developed (time division procedures and selection algorithms), allowing one contactless chip card from several to be selected and operated.

Radiation risks in connection with smart labels have not yet been highlighted. In the field of access control, there is possibly a need for geometric optimisation with respect to electromagnetic radiation: the more precisely a transponder is fixed, the smaller the radiated field can be.

There is a need for research on radiation exposure in a world of ubiquitous smart labels. This applies in particular where active labels with their own power supply are used.

In the case of smart cards with a monetary value, there are considerable risks of access by unauthorised persons to the transponder’s read and write functions.

On the road towards a multifunctional smart card, mini-displays and keyboards, thin-film batteries, integrated sensors and secure authentication systems have to be developed. Software solutions do not offer sufficient protection against hackers. Current fingerprint recognition systems for smart cards are still too expensive. The monitoring possibilities of smart labels are in some cases meeting with rejection from the general public.

Data protection issues could also act as an obstacle to propagation, since smart labels on packaging can not only reveal individual consumer habits in supermarkets, but could also lead to data protection problems in connection with waste. Mention can be made, for example, of the French town of Ribeauvillé in Alsace, where chip-based weighing of waste has already led to public protests, although this system is still accepted in Germany (Sattler, 2002).

4.8 Interim conclusion: The Pervasive Computing trend

The growth in wireless networked devices and objects in everyday life is obvious. Nearly all major ICT manufacturers are working on the Pervasive Computing vision and making it a development priority.[102] In some areas, such as the 'intelligent car', developments towards PvC are progressing rapidly. The car can therefore be seen as a 'test laboratory' for the potential and the limits of Pervasive Computing. In other areas, first potential applications are being tested. These include 'intelligent clothing' and the 'intelligent house'.

One indicator of the trend towards PvC is the propagation of mobile terminals like PDAs, handhelds and mobile phones. Another indicator is the number of devices with an Internet connection. Jupiter Communications puts the number of such devices in households worldwide at 769 000 in 1998 and 11.4 million in 2002.[103] IBM forecasts that in the next five to ten years there will be more than a thousand million people using more than a million million networked objects worldwide.

A propagation of Pervasive Computing that corresponds roughly to current mobile telephone use is to be expected in around ten years. This assessment is suggested by the following technological trends in particular:

- The most important technological driving force behind Pervasive Computing is the ongoing *miniaturisation* of microelectronic components. The trend towards improved performance of microprocessors and memory chips is undiminished at present (and is expected to continue until 2012).
- A crucial factor in equipping everyday objects (some of which have short lives) with computing power and context sensitivity is a *fall in the price* of electronic components. New impetus is expected inter alia from polymer electronics and OLED technology. From 2010 paper-like displays (e-paper etc.) could be so technologically sophisticated that they have the qualities of traditional newspapers.
- *Communication technology*, like developments in microprocessors and memory chips, must undergo a fall in price. According to 'Gilder's rule', the bandwidth, and therefore the performance, of communication networks triples every twelve months.
- *Context sensitivity* can be achieved using tiny GPS receivers and sensors. The development of appropriate sensors will be encouraged by advances in nanotechnology.

The assessment must be qualified, however, because it is difficult to estimate future developments in the following areas. In an extreme case, each individual area could be crucial for Pervasive Computing:

- New *energy supply systems* (body heat, mechanical energy, miniaturised fuel cells) must be made ready for production if a large number of wireless networked components is to be practicably operated.
- With respect to *human-machine interaction*, it is not yet clear whether the discussed alternatives to keyboards and mice (e.g. speech) will lead to user-friendly, ergonomic solutions.

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[102] For example: IBM, HP, Rank Xerox

[103] Cited in: http://www.wi-flensburg.de/wi/fendt/referate/pervasive/konzept.html

- *Marketability* is different in the various fields of application and ultimately depends on business models with acceptable pricing and attractive services that can be provided using that technology.
- The continuing penetration of everyday life could be limited by human capacity or willingness to process information. Even today *attention* is a scarce resource, which is fiercely fought for (e.g. by advertising).
- *Data protection* is called into question by PvC. In principle, the increasing networking and ubiquity widens the possibilities of collecting and evaluating data on the behaviour of users without their knowledge or consent.
- The *reliability and security* of complex, networked information systems is limited in principle, since each manufacturer will reject liability for damage that results from the use of such systems.
- With regard to *payment procedures* there is perceptible reticence among both suppliers and consumers. The settlement of small amounts ('micro-billing') is a challenge for providers. Online payment procedures are meeting with scepticism on the part of customers.
- The controversy surrounding *health risks from electromagnetic radiation* from mobile radio telecommunications could extend to Pervasive Computing in general. If the presumed risks are confirmed, this would slow down Pervasive Computing developments considerably.

For this reason, we are outlining three scenarios covering the range of possible developments.

4.9 Three scenarios for Pervasive Computing

Possible characteristics of the abovementioned trend over the next ten years are described here in the form of three scenarios, which differ primarily in the degree of penetration and networking achieved:

- Cautious scenario: obstacles predominate. There is an appreciable development towards PvC only where it can no longer be halted in practice or is not seriously affected by the obstacles.
- Intermediate scenario: the market develops in diverse ways. The trends that can be seen today continue without strong positive or negative influences.
- High-tech scenario: computing anywhere, anytime becomes a reality.

Cautious	**Intermediate**	**High-tech**
Obstacles predominate (e.g. data protection) High degree of penetration in few areas (e.g. cars) Lower degree of penetration in other areas of everyday life, such as wearables, smart homes Weak media convergence	Penetration of everyday life with 'smart' objects Wireless Local Area Networks (W-LANs) Smart homes slowly begin to be established Wide use of electronic labels (smart labels) Extensive media convergence	High degree of penetration in all areas of everyday life (e.g. wide use of wearables) Computer technology becomes ubiquitous and largely invisible Current visionary technologies become established Extensive replacement of print media by digital media

Degree of penetration and networking

Figure 4-7: Rough characterisation of the three scenarios

Scenario 1: Cautious scenario

In this scenario, the predominant influencing factors are obstacles. The technical conditions for access to information from any location are created. The market for content and services develops, but only slowly.

A decisive factor is the poor usability of technology: displays that are difficult to read, difficult management, long waiting times for data downloads and complicated security queries (possibility of forgetting the many passwords).

Security and data protection issues become hotter topics. The propagation of radio communication technologies intensifies the discussion on 'electrosmog' and slows development.

In view of these obstacles, the attempt to bring the Internet to everyday devices and objects and to develop home networks into a mass market is unsuccessful.

Many technological applications are not really accepted by users, since they do not really ease the workload, but, like ‘smart homes’, they tend to increase everyday coordination expenditure for a technology that will not function autonomously even in 2012.

A mass market for Pervasive Computing develops in only a few areas, e.g. in the motor vehicle sector.

Whilst the commercial sector, in keeping with the trend toward more flexible forms of work, specifically uses some of the opportunities offered by Pervasive Computing, the degree of penetration and networking in the everyday life of private individuals is low.

Main features of the cautious scenario

- The PC continues to be the most important terminal for Internet access until 2005. From 2005 there are more Internet access points using multifunctional mobile terminals.
- Mobile phones, PDAs and organisers mutate into multifunctional devices. In five years they can hardly be distinguished from one another in terms of functionality. Location and personalisation make possible new services.
- With frequently mobile employees, mobile computing (with PDAs and light notebooks) becomes popular. In the working environment, head-mounted displays and other wearables continue to be restricted to a few applications in specific professions (e.g. in the construction sector).
- Office work changes only slightly: slightly improved speech recognition systems and simple software agents come onto the market in 2005 and become widespread. ‘Intelligent’ interactive office equipment remains limited to management levels in high-tech firms.
- Apart from the mobile phone, standard equipment in homes includes a cordless telephone with a fixed network connection. However, the networking of home devices is still the exception. Nevertheless, refrigerators with a simple touch screen become popular. Their advantage is that they allow direct online orders from the kitchen.
- Of the numerous applications in cars, navigation systems and Internet connection become relatively quickly and widely accepted. In a few years nearly all medium and luxury class cars in Switzerland are equipped with navigation systems.
- Alongside the car, computer technology is used increasingly to develop more effective transport systems. Portable access and information systems are available for running intermodal services (e.g. mobility management).
- Body Area Networks and Wearable Computing are technically advanced, but remain restricted to small user groups. Individual devices such as ‘intelligent watches’, pulse meters, etc. are more widespread.
- In medicine, Pervasive Computing means among other things that medical practitioners in hospitals are networked. Computer-aided diagnoses are commonplace and computers are also used for operation planning and support. Electronic implants are reserved for special applications.

Scenario 2: Intermediate scenario

In this scenario we attempt to describe the most likely developments in Pervasive Computing on the basis of market assessments and expert opinions.

Mobile phones are regarded as heralds and indicators of the growth of mobile computer technology in many areas of everyday life. Market segmentation revolves around three groups of mobile terminals:

- devices that, like today's mobile phones, are used mainly for voice communication,
- devices that essentially assist with document handling, as part of the 'mobile office',
- devices that are used primarily for games and videos.

There are also multifunctional devices that can perform all these functions, but they do not have the same quality as dedicated devices.

Alongside the market penetration of *mobile terminals* there is also penetration from *smart objects*. These communicate, for example, with the Internet or with W-LANs and are intended to assist the everyday activities of the user.

Young adults in particular pioneer in adopting new technologies ('early adopters'). Multimedia becomes a part of their lifestyle, which runs smoothly into an 'always-on' communication culture.

In addition to the transport sector, where PvC makes significant advances, from safety applications to intermodal mobility services, business links, the working environment, media and medicine are particularly affected by radical changes.

Significant changes can also be expected as a result of the fall in the price of electronic labels (smart labels). The main areas in which these will be used initially are the automation of stock management and optimisation of value chains, which will mean considerable cost reductions.

Cashless supermarkets slowly become established. From around 2005, access control for public transport using RFID transponders replaces traditional ticket systems, book and video library lending is changed extensively to smart labels.

In sub-segments, transponders are also used for location of people (children, people in need of special care) and objects (e.g. locating bicycles following theft).

Main features of the intermediate scenario

- The computer in its present form loses its dominance. It is replaced by new types of mobile device and by stationary Internet connections in household devices.
- Alongside the convergence of different telecommunication, data processing and media technologies, the Internet continues to develop. Special gateways allow networking of household devices over the Internet.
- In the media sector, the volume of printed material continues to grow, but to a lesser extent than digital media. In each of the various areas (newspapers, magazines, books, catalogues, advertising flyers, etc.), a specific media mix develops, based on electronic and conventional sales channels. Digital TV becomes established as a result of quality advantages in connection with video applications (Video on Demand, video downloads).
- In motor vehicles, from around 2006 the virtual safety belt becomes standard equipment. The car can automatically adjust its speed to traffic conditions. Excessively short safety distances and danger situations in poor visibility are communicated to the driver by speech output. Wireless short-range radio communication replaces data cables (e.g. from wheel-mounted sensors).
- Location-based services are offered in all fields and at low cost. Using agent systems, which meet with great interest, various transport services, information and transport operators are linked in such a way that more efficient use of transport services is possible.
- From 2006 context-sensitive lighting and air conditioning technology is standard in new commercially used buildings. PCs, digital televisions, home technology and telephones are networked with LANs. Selected everyday objects have a chip and become ‘intelligent’, e.g. the digital ballpoint pen, which is also an input device.
- Speech dominates, despite certain shortcomings, from around 2012, replacing manual input devices. Interactive furniture becomes established in large businesses.
- The price of smart labels falls in a few years from the current level of 50 cents to a few cents. Consequently, they are of interest for mass market products, as well as for commercial logistics: packaging, recycling, perishable goods, blood stores which automatically trigger an alarm by radio if a temperature limit is reached.
- The mass marketability of ‘intelligent’ clothing remains small. Niche applications with clear added value for customers (for extreme sports enthusiasts, those requiring special care and certain work situations) contrast with mass market applications whose market remains fairly volatile, because it is dependent on fashion. Wearables are widely used in the health sector.

- Medical technology uses high-resolution imaging procedures and augmented reality. Patient data are archived in an electronic patient record and can be accessed at any time by authorised persons over a W-LAN or the Internet. Telemedicine supports home care. Virtual operations are carried out routinely in medical studies and also in practice in difficult, complex cases before the patient is operated on. Mobile microelectronic monitoring systems for bodily functions are standard. Electronic prostheses and brain pacemakers are used.

Scenario 3: High-tech scenario

In this scenario autonomous electronic systems penetrate all areas of life. Obstacles are almost entirely overcome. Computer technology becomes both ubiquitous and invisible.

The technologies currently being heralded in industry's development departments and research laboratories will become reality by 2012. 'Always-on', 'Anytime' and 'Anywhere Wireless' are the hallmarks of this trend. It stands not only for technical development, but for a new world of experience that is characterised by the extensive merging of real and virtual space.

A 'digital aura' surrounds and accompanies the user in everyday life. The computer is integrated into clothing as a wearable, a system individually tailored to the wearer.

Mobile professions are an initial target group here. They take on the pioneering role. From here the wider target groups are slowly developed.

Miniaturisation and the fall in prices for microelectronics are so far advanced that there is a chip in nearly all everyday objects, from chairs and packaging to salt cellars.

A server networks and organises all the 'intelligent' devices and objects in the home: heating, PCs, washing machine, clothing, coffee machine, coffee cups, etc.

This is made possible by radio telecommunication technologies such as Bluetooth, W-LAN and UMTS and/or new radio telecommunication technologies that are currently in development. The next mobile radio communication generation 4G will allow even higher transmission speeds.

Smart labels allow identification of nearly all products. These products also record their history in the smart label. This will revolutionise industry: *pay-per-use systems* will become possible and many products will no longer be purchased, but will be billed on the basis of leasing arrangements.

Smart labels enable a constant flow of information from raw material producers to traders to waste disposal companies. 'Intelligent' products provide manufacturers with important information on the state of their use.

Insurers no longer have to fear that insured goods (e.g. works of art) might be lost. They can be identified and located at any time. In order to prevent child abduction, transponders are implanted under the skin of children.

Many applications are context-sensitive and adapt themselves to each user. 'Intelligent' agents help to process the variety of multimedia data in everyday life. Many services are automatically provided over networks to afford passive or active support for users. *The user is increasingly bypassed in decision-making.*

The process is accompanied by the disappearance of communication-free spaces. Being offline is the exception.

Main features of the high-tech scenario

- Mobile ICT devices no longer have much in common with current mobile phones. They consist of a display with glasses and can be controlled by speech. Other variants consist of a film using which information can be typed in or read. After use they are rolled up and put away in clothing. Microphones and earphones are integrated into clothing or jewellery.
- Each object on the market is equipped with a smart label for identification and location. Biometric authentication and automatic debiting systems revolutionise payment transactions with smart cards. Remote maintenance of larger household devices is common, and leasing becomes popular. Payment is for use only (pay-per-use).
- Production and marketing of information and home entertainment media are largely digital. Paper-like displays serve as all-purpose computers with the properties of paper. OLED cyber glasses with headsets are commonplace and offer video quality.
- Rather than transporting different portable devices, as has been the case until now, the user carries light, inter-networked individual components, which are distributed around the body and clothing.
- ‘Steer by wire’ and ‘brake by wire’ revolutionise vehicle control. Remote diagnosis and maintenance for cars are common. On-board monitors with digital television and Internet access become normal in the rear seats.
- Miniaturisation and the fall in prices for microelectronics are so far advanced that there is a chip in nearly all everyday objects, from chairs and packaging to salt cellars. A server networks and organises all ‘intelligent’ devices and objects in the home.
- Mobile, ICT-aided work becomes popular by 2004 in all areas where it is permitted in principle. In addition to PDAs and handhelds, head-mounted displays become more widespread, a little belatedly, to support virtual conferences between ‘mobile workers’.
- Offices become ‘intelligent’ and interact with their occupants via smart labels, speech and gesture. By 2008 all large companies have meeting rooms with fully networked interactive furniture.
- Electronic implants become routine in medicine for risk groups. Microchips under the skin store information. Microchips for paralysed people which bridge damaged parts of the nervous system and computer-controlled prostheses come onto the market. The first clinics use nanosurgery.

In the following chapters, the impacts of Pervasive Computing on health (Chapter 6) and the environment (Chapter 7) are discussed on the basis of these three scenarios. First of all there is a discussion of one fundamental impact of PvC, the increased efficiency of processes, with its side-effects (Chapter 5).

Unless otherwise stated, the considerations relate to the intermediate scenario. In these cases, the spectrum of the three scenarios is re-examined in the subsequent discussion on the uncertainty of the statements (Chapter 8).

5 Efficiency and rebound effects

Mathias Binswanger, Lorenz Hilty

A technology is not generally used as an end in itself, but for a specific purpose. The purpose may be

a) to make possible something new that has not been previously feasible, or

b) to perform a familiar process more efficiently.

This chapter deals with the efficiency-increasing impact of ICT – which will continue in the new form of Pervasive Computing (PvC) – and its consequences. The aim is to assess the 'rebound effects' that have been known for some time to result from efficiency increases. From an economic point of view, the existence of rebound effects is a fundamental aspect of the effects of technologies which influences other effects (e.g. on health, the environment or economic growth).

5.1 Information, communication and efficiency

Electronic information and communication technologies were completely separate systems until a quarter of a century ago. Computer technology was used for automatic data processing and communications engineering created telecommunication systems.

Historically, the *computer* has had much more to do with intention (b) than with (a). Computers have always been used to organise processes more efficiently, at first through automation of industrial production and then also in the services sector.[104]

Theoretically, a computer is able, like nothing else, to accelerate processes: It is designed to execute *algorithms*.[105] A computer is therefore used because it performs the same processes more quickly. Without computers it would 'merely' take longer – around a thousand million times longer as technology stands at present.

If we ask the same question of *telecommunication* technology, the answer is not much different. Historically, the important factor has also always been acceleration, even back in the pre-electronic age. An organised postal system was quicker than an individual messenger on horseback, the telegram was quicker than the letter, e-mail arrives quicker than a telegram. If, rather than sending a message to New Zealand by e-mail, it was to be delivered personally, this would 'merely' take longer – with current technology (Internet vs. aircraft) around a million times longer.

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[104] 'More efficiently' here means that the same result can be achieved in a shorter time. Efficiency can be generally defined as the ratio of the output of a process and the required input. For the time being, we will consider only time spent as an input and therefore time efficiency as a specific case of efficiency.

[105] 'Algorithm' is a fundamental term in information technology. The clearest (although not quite precise) definition comes from Donald E. Knuth: An algorithm is a precisely defined procedure that a person can in principle perform with pen and paper (e.g. written arithmetic or conversion of algebraic expressions). The exact definition refers to computability theory, which cannot be examined any further here.

The development of ICT has achieved this enormous acceleration in many small steps. Acceleration is certainly the most significant effect of ICT, the very heart of its potential for social change.

The merging of information and communication technologies, which became possible with the digitalisation of telecommunication, the imminent step to ubiquitous accessibility and the future dominance of *machine to machine* communication (see Section 3.7) in Pervasive Computing will continue this trend.

Current and future ICT therefore essentially accelerates processes that are generally familiar. We are stressing this so emphatically because ICT is often portrayed by the media as a field of *revolutionary innovations* (like genetic technology). In contrast, the most important effect of ICT is given less prominence: the gradual increase in time efficiency.[106]

Of course, the quantitative advances lead to qualitative leaps. For example, only through high processing and transmission speeds did it become possible to digitalise sound and video, which in turn made CD, DVD and GSM mobiles possible. The same arguments could be made in medicine with regard to the imaging procedures that have revolutionised diagnosis. Nevertheless, in this chapter we wish to focus on the purely quantitative acceleration effect, the underlying trend, because it is often neglected in favour of qualitative leaps.

5.2 Efficiency and productivity

Efficiency in the broadest sense is the ratio of the result (output) to the required resources (input). If the efficiency of a process is doubled, then twice as much output can be produced with the same input as before, *or* the same output with half the input. Efficiency simply indicates the ratio. Unlike effectiveness, efficiency is always a ratio.

Depending on the resources that are taken into consideration on the input side, various kinds of efficiency can be defined. If we consider only the resource ‘time spent’, as in the preceding section, we can talk about ‘time efficiency’. However, a distinction must be drawn between two cases: time as working time (measured in person hours, for example) or time as calendar time (interval on the absolute time axis).

For companies the second case is often more important than the first in the current competitive situation. This example should illustrate the distinction. Three teams in different continents work on a project. When one team ends its working day, it sends its interim results by Internet to the next team, which has just woken up. This ‘virtual shift operation’ does not save any working hours overall, but it does allow the project to be completed in a shorter time, i.e. at an earlier date in the calendar.

Other types of efficiency become apparent if, instead of time, the input of energy (energy efficiency) or materials input (materials efficiency) is considered. These types of efficiency are meant when ‘efficiency strategy’ or ‘efficiency revolution’ is mentioned in connection with sustainable development (Weizsäcker et al., 1995).

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[106] The interesting theory that for some time progress in the ICT sector has no longer contributed to efficiency progress (also known as the ‘IT Productivity Paradox’, Macdonald, 2002) will be ignored here because it probably relates to a temporary phenomenon.

The concepts of efficiency and productivity are not far removed from one another. If any given process is seen as *production* in the economic sense (which is always possible in principle), efficiency and productivity are the same. Productivity is defined as output per unit of factor of production. If we consider only one individual factor of production, e.g. work, then we talk about factor productivity, and in the case of the factor 'work' *work productivity*. Efficiency increases then become rationalisation.

Even though nature does not appear as a factor of production in the common production function, productivity can be defined with reference to the natural resources used, called *resource productivity* in environmental economics. A (radical) improvement in resource productivity is synonymous with *dematerialisation* (see Section 2.4 and Hilty/Ruddy 2002) and is also called 'rationalisation of the second type'. It is not people, but the overused natural resources that are to be made 'redundant' through this form of rationalisation.

5.3 Efficiency vs. sufficiency

Efficiency or productivity are ratios; they do not reveal anything about *absolute* quantities of inputs or outputs. An increase in productivity merely means that the *output/input* quotient (i.e. *output/working time* for work productivity or *output/'tonnes of nature'* for resource productivity)[107] becomes larger.

If, for example, a new microprocessor becomes smaller and faster, for each computing operation it needs less material (in manufacture) and less energy (in operation). Nevertheless, the electrical power that it consumes in operation is higher, because its output 'fizzles out' in the PC. Furthermore, because many users want to have these faster processors, their precursors are discarded earlier (obsolescence), which ultimately leads to more expenditure on materials in manufacture.

Higher efficiency is consequently not a sufficient precondition for saving resources. This statement applies irrespective of the resources in question (nature, time, income, etc.) If the aim is to save resources, a *quantitative restriction* is also needed on the input and output side. For example, an absolution restriction must be placed on CO_2 emissions if increasing energy efficiency is actually to lead to a fall in emissions.

In general terms, an efficiency strategy must always be accompanied by a sufficiency strategy; otherwise well-intended measures may have the reverse effect. This effect is known as the rebound effect.

5.4 The rebound effect

If, because of an increase in efficiency, the cost of the output is reduced and this results in growth in the volume of demand, this is called a rebound effect. A rebound effect > 0 means that the reduction in the input flow is smaller than is possible in principle, and there may in fact be no reduction at all, or even a rise. In the latter case, we talk about a rebound of greater than 100%.

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[107] This simplification would correspond roughly to the Wuppertal Institute's MIPS concept (Material Input Per Service Unit) (cf. Weizsächer et al., 1995).

Normally, the rebound effect is seen in connection with the *intention* or *expectation* of reducing the input. The fact that this is not fulfilled explains the term ‘rebound’. We will therefore examine this specific case (rebound effect in the narrow sense). In addition, for the sake of simplicity, we will explain the case of a rebound effect of at least 100%, where the reduction on the input side that is possible in principle is counterbalanced or outweighed.

Figure 5-1 shows the four cases that can occur as combinations of intention and result of an efficiency increase (with reference to *one* input factor).

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">expected effect of an increase in efficiency</td></tr>
<tr><td>reduce input</td><td>increase output</td></tr>
<tr><td rowspan="3">actual effect</td><td rowspan="2">input does not fall</td><td>rebound effect in the narrow sense</td><td>intended growth</td></tr>
<tr><td colspan="2">rebound effect in the broad sense</td></tr>
<tr><td>output does not rise</td><td>saving of input resource</td><td>(unintended) stagnation</td></tr>
</table>

Figure 5-1: The rebound effect as an effect of an increase in efficiency. For the sake of simplicity, a rebound effect R with $R \geq 100\%$ is assumed. In the case of $0 < R < 100\%$, the input does fall, but not to the extent expected.

- The *rebound effect in the narrow sense* occurs if an efficiency improvement is made with the intention of reducing the input and that effect does not then occur. Instead, the output grows.
- If the output does not grow despite an efficiency increase, this means that the saving efforts are successful (saving of input resources).
- If, on the other hand, an efficiency improvement is made with the intention of increasing the output and this is successful, this is intended growth.
- If, however, the output does not increase as expected despite an increase in efficiency, this is an unintended stagnation.

We will now consider this more specifically from the point of view of the three groups of actors in the economic system:

- private households
- enterprises
- the state

A *private household* may, depending on the case, be interested in both savings and growth. For example, a more economical car may be bought with the intention of saving energy and not of driving further than before. If, however, the intention is to be able to cover greater distances for the same petrol money, this is intended growth. The rebound effect occurs where the intention is to save energy, but then in reality – for example because of less pressure on a person's wallet or conscience – the car is driven more.

A *private enterprise* is generally interested in growth, with the result that rebound effects in the narrow sense occur only rarely. If, for example, a product is produced with only 80% of the material, the price falls and, as a result, twice the volume is produced and sold, the enterprise will not really see this as a rebound effect, even though it consumes more material in absolute terms.

The state, on the other hand, takes numerous measures with the intention of restricting (macroeconomic) inputs, for example energy consumption or CO_2 emissions.[108] Studies on the rebound effect are therefore particularly useful at macroeconomic level and were even developed in this field. For instance, it was established in the 1950s that despite the increasing energy efficiency of devices energy consumption in the national economy as a whole was not being reduced.

Rebound effects in relation to intended time savings

We will we now return to our conclusion from Section 5.1, that ICT essentially serves to improve the time efficiency of processes.

In order to be able to apply economic models of the rebound effect *in relation to time*, it is necessary to see the processes in question as *production processes*. Therefore, at first sight, private households now appear to be excluded from further reflections. However, it is they who are seen as the most important users of Pervasive Computing. The technology is designed for the end users.

Nevertheless, it is perfectly possible and – as we will explain – even natural to see a private household not only as a *place of consumption*, but also as a *place of production.* The household can be regarded as a 'small factory' in which the members produce 'commodities' for their own consumption, with the aid of technical goods. This approach will be introduced in the following two sections.

A basis is therefore established for assessing rebound effects from PvC in the private sphere, which is dealt with in particular in the sections on housing and transport.[109]

5.5 The notion of 'utility'

Consumers demand new products and services only where they expect an additional *utility* from them. Utility is essentially subjective. Works of art, fashion wear, pieces of music or holidays have a different utility for every individual. Absolutely no attempt will therefore be made to create an objective definition of utility.

108 Even an undesired material output (waste, emissions etc.) is an input in the economic sense; it is nature's waste disposal services that are used here as a factor of production.

109 The bulk of passenger transport is leisure transport.

The abovementioned cases are examples of *direct* utility, what is ‘actually’ trying to be achieved through consumption.

However, many products are not bought because of their direct utility, but because they have an *indirect* utility. This means that they help to produce goods with a direct utility, ‘commodities’. Household devices of all types typically have an indirect utility, as well as many services.

The car is a typical example. Its utility does not stem from ownership (ignoring utility as a status symbol), but from the production of the commodity ‘mobility’, which is made possible by the car. Mobility is the commodity which creates the direct utility for the household.

Economic theory generally does not talk about consumers as economic actors, but households; a household can consist of one or more people. Each household is attributed a utility function, from which demand for individual goods can be derived. This can be determined roughly from statistics on the actual buying behaviour or time allocation behaviour of households and then shows an ‘average household’ (which does not necessarily exist in reality).

If we wish to assess the effects of PvC on households, we must therefore first assess how PvC affects the production process in the private household. This will then also make it possible to assess rebound effects.

For this purpose we will use the concept of *household production function* developed by Gary Becker (1965), a brief introduction to which is given below.

5.6 The concept of household production function

The economist and Nobel Prize winner Gary Becker developed the concept of household production function in the course of his work on an economic theory of the family (Becker, 1965; Michael/Becker, 1973). The traditional economic theory of choice regards actors as passive consumers of goods and services. It is assumed that each actor endeavours to maximise the utility (U) from goods acquired directly from the market (X):

$$U = U (X_1, X_2, ..., X_n)$$

The only restriction on the acquisition of market goods is monetary income. It is therefore assumed that it is possible to provide a full explanation of consumer behaviour on the basis of the three factors *income*, *prices* and *preferences*.

However, the traditional theory has major weaknesses. In many empirical studies economists faced the problem that they had to explain consumer behaviour with variables such as age, family status, education, occupation etc., i.e. with the different preferences of different groups of people. Changes in preference over a period (e.g. the demand for heating oil is dependent on the time of year) or a life span were reasonably interpreted as intuitive, but difficult to integrate into the theory.

In order to rectify this situation, Becker introduces a ‘new’ kind of goods: commodities. They are the things that are actually valuable to people, such as health, recognition and peace of mind, although their utility is assessed differently in subjective terms. These goods cannot be purchased directly on a market, however, but must be 'produced' by the consumers themselves, the individual household taking on the role of a 'small factory'. Utility is thus a function of the commodities (Z)

$$U = U(Z_1, Z_2, ..., Z_m),$$

and only indirectly a function of the goods acquired on the market.

The commodities are 'produced' by households with the factors of production market goods (X), time (T) and human capital (H), where human capital reflects the *technical level of the production process*. The household production function for a commodity (Z_i) can then be formulated as:

$$Z_i = f_i(X_i, T_i, H_i)$$

The commodities (Z_i) do not have a market price, because they can be produced only for personal enjoyment and cannot therefore be purchased directly; instead, they have 'shadow prices' or 'opportunity costs'. They are contingent on the (individually different) costs of their production. The shadow price of an activity represents the income that *would* be received if gainful employment were pursued in that period (loss of income). It follows that for high-income earners the shadow prices of time-consuming activities are also high.

In the concept of household production function, particular importance is attached to time as a scarce resource. Consumers sell their time on the labour market and buy time in the form of services (e.g. restaurants, tax advisers, child care). If the opportunity costs for time are high, as is the case at present in industrialised countries, then time-saving innovations have a considerable potential utility for households. Becker mentioned the following example of time-saving innovations in 1965: the supermarket (time savings in shopping), the car (time savings in transport), the telephone (saves journeys).

As was explained in the introduction, the integration of *ICT* into private households can also be expected to increase time efficiency. *The common denominator of all ICT applications is their indirect utility in increasing time efficiency*.

5.7 Observations on the rebound effect

The rebound effect is created because people generally react to increases in efficiency with a change in consumer behaviour (see Binswanger, 2001; Energy Policy, 2000).

In quantitative terms, the rebound effect indicates how many per cent of the technically possible savings potential are lost because demand grows as a result of the increase in efficiency. A rebound effect of 50% therefore means that from a factor of 4 (which corresponds to a savings potential of 75%), a factor of 1.6 will result:

$$1 / ((1 - 0.75) + 0.75 \times 0.5) = 1.6$$

It is possible for the rebound effect to be more than 100%. This means that an increase in efficiency can even lead to a rise in time consumption. The rebound effect often means, particularly in the case of time-saving innovations, that more time is ultimately spent on a certain activity (Binswanger, 2001; Lindner, 1970).

A current example is the replacement of conventional letter correspondence by e-mail. E-mail is obviously a significantly more time-efficient method of communication, because there is no need to print out a sheet of paper, to copy attachments, to deal with the envelope etc. In addition, the address is generally already stored on the system. Nevertheless, everyday experience shows that we now spend more time on e-mails than we used to spend reading and writing letters, because there has been a sharp increase in the number of messages per unit of time.

This is, firstly, because of the temptation to keep up more contacts in the same amount of time spent and, secondly, because others have the same idea and expect their e-mails to be answered. Thirdly, calendar time is also a factor here: just the fact that it is possible to respond and receive a reply within minutes, whereas letters only arrive the following day, causes an acceleration and more correspondence per unit of time. These effects obviously add up to a rebound of more than 100%.

Let us take transport as a further example. Its development is characterised by the fact that carriers have become faster and faster over the last 200 years. A given distance can be covered in an ever shorter time. Time efficiency has therefore been significantly increased.

However, empirically this has not lead to any time savings, since each increase in efficiency has immediately been offset by more distant or more frequent journeys. The rebound effect here is roughly 100% and is also known as the 'constant travel time hypothesis'.

Throughout the world people travel for roughly 70 minutes per day, both in Tanzania and the United States (see Figure 5-2). The only thing that changes as a result of technical progress and the associated increases in efficiency is the distance covered, which is many times higher in the United States than in Tanzania. The rebound effect described here also leads to a constant increase in energy consumption for transport, since, because of faster means of transport, it is possible to travel more and more and farther and farther.

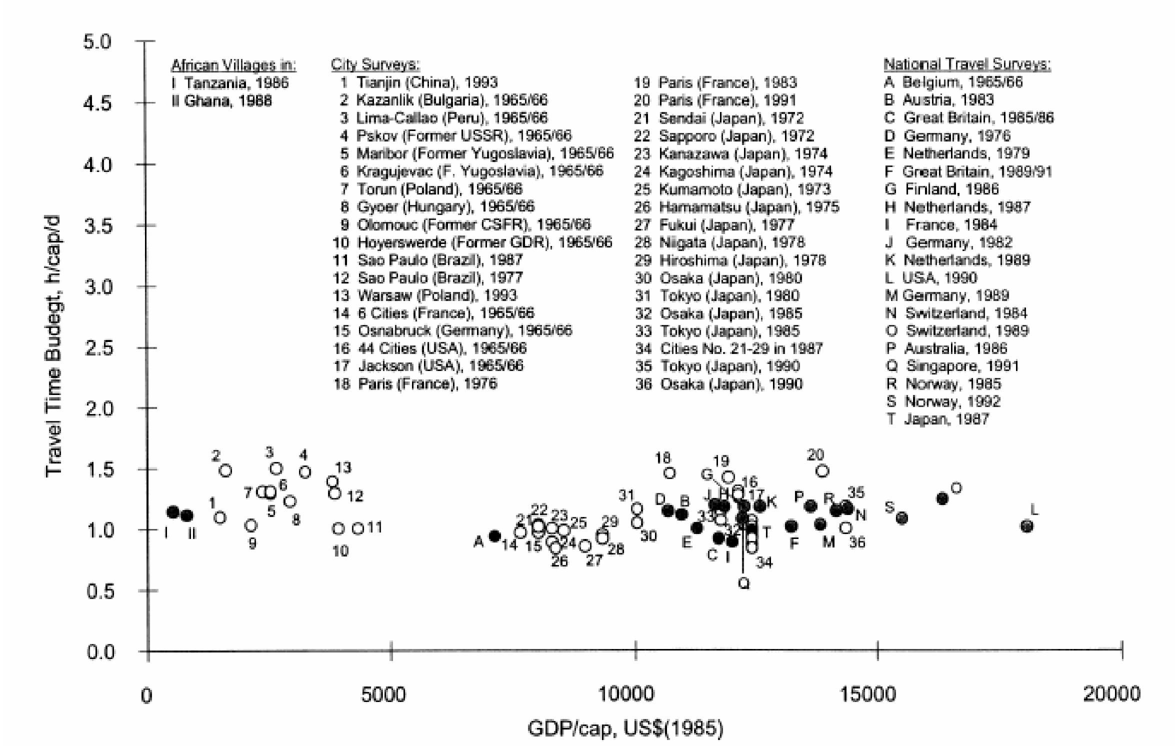

Figure 5-2: Empirical evidence of the 'constant travel time hypothesis'.

The figure shows the travel time budget of different cities and countries in relation to the gross domestic product per capita. It is clear that even where there are higher per-capita gross domestic products the travel time budget does not fall, despite the use of faster technology, but remains roughly the same.

5.8 Data on the economic behaviour of private households

We will discuss below some basic data on the economic behaviour of households. First of all, there are figures on the way households use their income and thus on the structure of household expenditure. Good statistics exist for this in Switzerland and the trend over time can also be traced.

Secondly, we will consider figures on households' time use. The data situation is rather unsatisfactory here and data collected systematically over a longer period exist only for the United Kingdom. Selective comparisons with other countries suggest, however, that these figures are representative of industrialised countries and that the same trends are apparent in those countries.

Both the data on the structure of household expenditure and the data on time use indirectly provide information on the utility of different items for households.

5.8.1 Consumer spending

Consumer spending accounted for 63% of household expenditure in Switzerland in 1998, whilst in 1990 it amounted to only 31%. The remaining 37% is *transfer expenditure* (tax, insurance). As is shown by Figure 5-3, there is an upward trend for the share of expenditure in *housing and energy* and in *entertainment, relaxation, culture and communication.*

In the case of *transport* it is necessary to take into account that whilst the share of overall expenditure for transport is falling, transport expenditure is rising in absolute terms. Furthermore, fuel prices and motor vehicle taxes have risen significantly less than household consumer spending.

If we consider the changes in household expenditure from a long-term perspective, the abovementioned trends can be seen even more clearly:

- The share of expenditure for foodstuffs and luxuries has fallen since 1920 from 40% to 8% and the share of expenditure for clothing and shoes has been reduced from 13% to 4%.
- At the same time, the shares for tourism, transport and leisure have risen from 6% to 20% and the share for transfer expenditure has increased from 3% to 37%.
- Housing expenditure has remained roughly constant, accounting for around 20% of the total expenditure of a household in 1920 and in 2000.

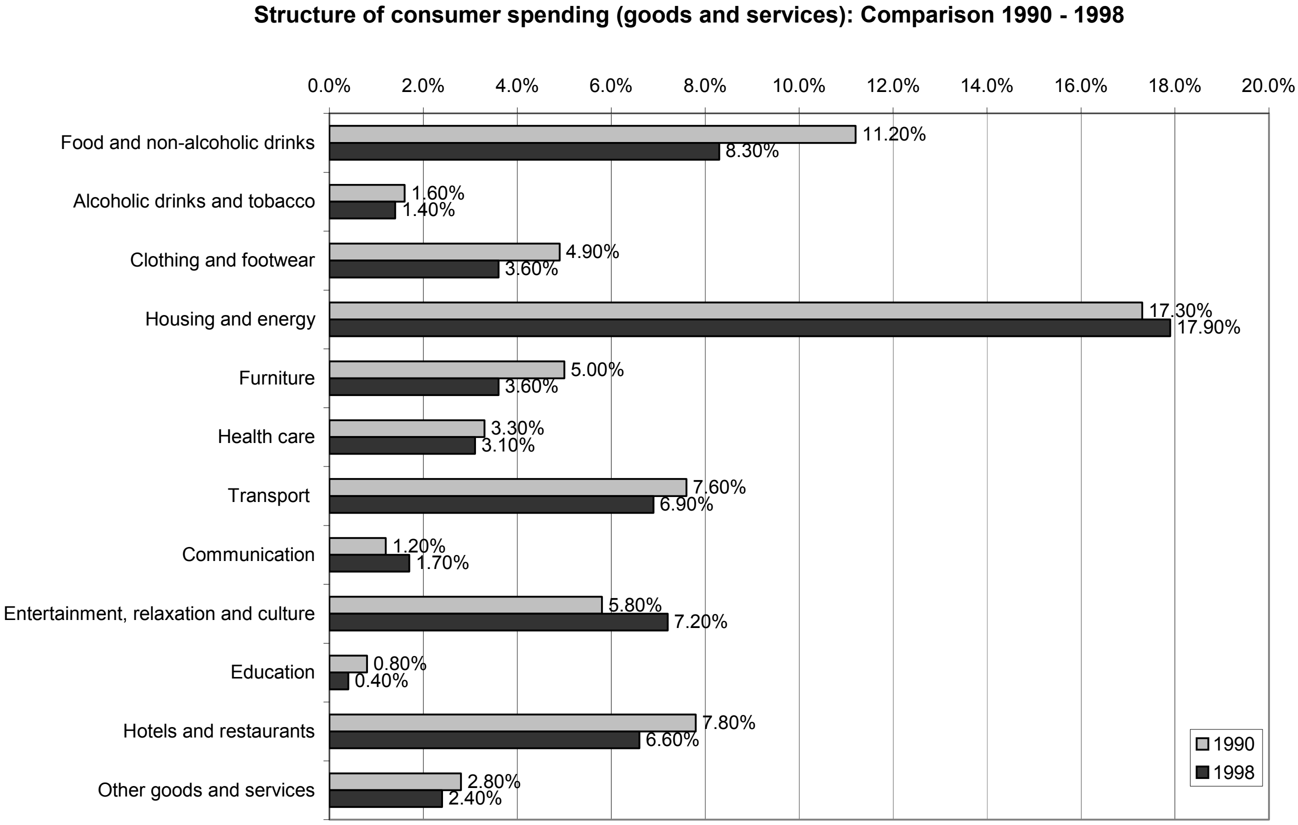

Figure 5-3: Structure of consumer spending in Switzerland (Source: Federal Statistical Office)

The housing and energy sector (excluding energy for transport) currently accounts for the largest share of consumer spending, with slightly under 18%. In addition, this proportion is slightly higher than in 1990, despite the already high level.

By and large, these trends indicate that households see a great utility in areas with rising expenditure and therefore move spending from other areas to these areas.

Where the level of expenditure is high, it is also worthwhile to use technologies that improve cost-efficiency.

It is interesting to compare the trend in the distribution of *income* and the trend for the distribution of *time*. This indicates possible needs for increases in efficiency (in particular through Pervasive Computing) and expected rebound effects.

5.8.2 Time budget studies

Table 5-1 shows the results of British time budget studies (Gershuny/Miles, 2001); the main trends can also be applied to other western industrialised states, such as Switzerland.

It can be seen that the time spent on paid work has fallen slightly since 1961.

Table 5-1: Household data for the United Kingdom (in minutes per day per person):

Activity	**1961**	**1975**	**1985**	**1995**
Paid work	296	271	250	246
Cooking	63	59	56	48
Cleaning, washing	55	47	44	47
Other housework	35	31	39	35
Child care	13	15	25	39
Shopping, regional travel	25	35	46	49
Total (work)	487	458	460	464
Eating out, cinema, pubs etc.	28	47	42	61
Social activities	35	42	35	40
Sport, walks	9	10	14	10
TV and radio	139	128	135	129
Other leisure at home	74	79	84	65
Total (specific leisure)	285	306	310	305
Eating at home	96	79	69	52
Sleeping, personal care etc.	572	597	601	619
Total (regeneration time)	668	676	670	671
Total	**1 440**	**1 440**	**1 440**	**1 440**

Source: BBC

Leisure activities *outside* the home are growing. We spend an increasing amount of time *eating out,* at *cinemas* and *pubs.* As a result, we eat less often at home. The proportion of time for *TV and radio* is remarkably constant. It can be assumed that this will remain constant at around two hours also in the future. Within housework there is a marked shift from *cooking* to *child care* and *shopping*.

The observed shifting trends indicate the areas in which a large, direct utility is seen. This appears to be the case for *going out*, *child care* and *shopping*. *Cooking,* on the other hand, seems to be increasingly ‘rationalised away’, which suggests that the indirect utility, the utility of the commodity ‘meals’ is the priority.

It can therefore be expected that, in the overall trend, private households will strive to use technical measures to reduce the time spent on housework, including cleaning, washing and in particular cooking, in order to have more time for going out, child care and shopping. This indicates where PvC will be used and attention must be paid to possible rebound effects.

The trend towards the outward orientation of leisure activities, which is shown by the general increase in *leisure transport*, confirms our assumption from Chapter 4 that PvC will become more established *in the car than in housing*. This is also suggested by the increasing proportion of time spent on shopping.

5.9 Assessment of rebound effects in the four fields of application

Against the background of these considerations, we will now examine the effects of PvC in the different fields of application introduced in Chapter 4 and attempt to offer a rough assessment of the expected rebound effect. Table 5-2 gives an overview of the results.

In addition to these results, we will also take rebound effects into consideration in laterm chapters, in particular in connection with effects on the environment (Chapter 7).

5.9.1 Housing

Observed trends

The housing sector accounts for a large, but only slowly growing share of household spending. Leisure activities, on which a sharply increasing share of income and time are spent, are more *outwardly oriented.* An increase in leisure time spent at home cannot therefore really be expected.

If there are convincing solutions for using PvC to make cleaning, washing and cooking more time-efficient, they will certainly be in demand, especially since the relevant investments are not likely to appear too high in relation to overall expenditure on housing and energy. The relevant technical products are purchased mainly because of their *indirect* utility; enthusiasm for technology, prestige or similar direct utilities are less important here than the efficient production of cleanliness, hygiene and meals.

Rebound effects

A rebound effect with respect to more efficient cleaning could be created by rising standards of cleanliness. This would mean, for example, that because washing with the ‘intelligent washing machine’ is more convenient, clothes will be changed more often. Cleaning and washing have continually benefited from more efficient technologies and this has also so far led to higher cleanliness requirements. On the other hand, this rebound effect does not appear to reach 100% because a slight decline in time expenditure has taken place (see Table 5-1).

With respect to cooking, a rebound effect appears to be somewhat implausible because we will not eat more because we can cook faster. In this case, the time saved by more efficient technology is actually available for other activities.

5.9.2 Transport

Observed trends

With the increase in leisure-time mobility, an efficient navigation system in the market in leisure products and services gives rise to a large indirect utility (logically and physically). *Location-based services*, whether in the ‘intelligent car’ or using wearables, for pedestrians, cyclists and passengers on public transport, will make a crucial contribution to a more purposeful and efficient use of leisure products and services.

We will no longer leaf through cinema guides, listings magazines, classified telephone directories or travel guides, but we will decide on destinations en route and be guided directly to them by electronic aids, which will deal with reservations, billing, background information, tips from previous visitors, contacts with like-minded people and many other possibilities.

Because it is increasingly possible to perform activities such as office work, meetings and information access at any location, many journeys that are necessary for work purposes will no longer be needed. However, the existing trend shows a corresponding growth in distances and also in leisure transport, with the result that the time spent on transport remains constant by and large. Along with mobility potentials, the corresponding expectations and requirements also increase, in both professional and private sphere.

Rebound effects

In the case of information and communication that is highly efficient and optimised to the local context, a rebound effect results from the possible information overload, behind which lie interests that are difficult to assess. The higher time efficiency as a result of more focused information for beneficiaries will be counterbalanced or outweighed by a growth in the volume of information and more time spent assessing this information (with respect to credibility, concealed motives etc.). Initial signs can already be seen in the WWW and e-mail correspondence.

In extreme cases, navigation systems could be ‘corrupted’ by directing users to sales outlets that pay for the service. Users will accept this overbearing nature provided there still is a certain balance with the utility or such systems are significantly cheaper than neutral ones.

The time budget for transport activities, which has been roughly constant thus far, will not really be reduced by the greater opportunity to perform activities anywhere. On the contrary, there could even be an additional incentive to be on the move more often because the benefits of certain locations will lose importance.

5.9.3 Work

Observed trends

ICT has always been used primarily to increase productivity. Only a small proportion of the advances in productivity in the last decade have been translated into a reduction in working hours. However, there is a trend towards more flexible working time models.

In the workplace, a distinction should be drawn between the perspectives of employers and employees. By using efficiency-increasing technology, employers normally intend to produce more output from the same input of employee working time. The employees’ intentions may coincide, e.g. on grounds of intrinsic motivation or because their success is rewarded by the company or on the labour market.

Rebound effects

However, it is also possible that the employee is hoping for an easier workload as a result of efficiency improvements. Part-time work and less stress could be expectations associated with PvC. In this case, a rebound effect is very plausible provided the technology achieves a high degree of diffusion. Through competition among PvC users, output requirements will increase accordingly, with the result that there is no overall easing of the workload.

One example from previous developments of ICT applications in the working environment should make this clear. With the facilities offered by PCs and projectors, presentations can be prepared much more efficiently than previously, when, for example, overhead acetates were written by hand. In principle, there is great potential to reduce workload here. With the technical facilities, however, there has been a marked increase over several stages in standards for the visual quality of presentations: from text to multimedia, from black and white to colour, from still images to animation. The result is that time spent preparing a professional presentation is many times higher than before. The same applies to the appearance of publications, teaching materials, offers, websites, etc.

The advances in efficiency from ICT for visual design tasks are just one example of a rebound effect in the work environment that appears to higher than 100%.

5.9.4 Health

Observed trends

If medical diagnosis and treatment become more efficient, this has positive effects on the health service and its patients. Costs can be reduced or stabilised and a quicker diagnosis can offer benefits in terms of treatment. (The health benefits of PvC that cannot be attributed directly to time efficiency are dealt with elsewhere in this study; see Sections 4.4 and 6.1).

Rebound effects

A distinction must be drawn between the perspectives of medical personnel and patients. For personnel in doctor’s practices and hospitals, the statements made under Work apply. For patients, the higher efficiency of the treatment system (e.g. telemedicine applications) may lower the threshold for consultations. This results in some additional expenditure for minor consultations, which can be seen as a rebound effect. However, there are, on the other hand, the benefits of early diagnosis and treatment.

A generally more efficient health system can give patients a stronger impression of technical feasibility, which may increase willingness to take risks.

5.10 Conclusion: Rebound effects in the fields of transport and work

In summary, it must be stated that the increases in efficiency as a result of Pervasive Computing in the fields of transport and work in particular will probably not ease the workload. It can even be expected that mobility and performance requirements will be raised to a greater extent, with the result that the expected easing of workload will be outweighed.

Table 5-2: Rough assessment of the rebound effects of PvC in the fields of application

Field of applic-ation	**Effect**	**Estimated qualitative rebound effect**	**Estimated quantitative rebound effect**	**Reason**
Housing	Simplification of housework: cleaning/washing	Time spent on cleaning and washing is not reduced as expected	20 to 60%	As before, higher standards of cleanliness will partially counterbalance advances in efficiency
	Simplification of housework: cooking	Small	< 10%	More efficient cooking does not lead to additional consumption or higher quality standards
Transport	Efficiency through location and context-dependent information on leisure services and products	Utility of information is partially diminished by the difficulties in evaluating it	10 to >100%	Experiences with WWW search engines transferred to geographical searches
	Efficiency through the possibility of performing activities anywhere and better transport control	Time spent on transport is not reduced or increases because mobility requirements and needs increase	>= 100%	Constant travel time hypothesis, not yet refuted, and previous experiences with ICT and transport
Work	Higher productivity in the workplace	Working hours and workload are not reduced because of rising requirements	>= 100%	Competition in companies, between companies and on the labour market
Health	More efficient diagnosis and treatment	Threshold for medical consultations lower, higher willingness to take risks	10 to 50%	Efficiency increases above all for medical personnel (see Section 4.3.3), mixed picture for rebound effect on the patient side

6 Effects on health

Felix Würtenberger, Andreas Köhler, Arie Bruinink, Jürg Fröhlich

This chapter describes the effects of Pervasive Computing (PvC) on physical health.[110] The opportunities resulting from the use of PvC in health care (Section 6.1) contrast with the risks of direct contact with electronic components (Section 6.2) and risks from non-ionising radiation (NIR).[111] Because there has been controversy surrounding the health risks of NIR and because additional NIR sources can be expected through the realisation of the PvC vision, we will give this subject particularly in-depth treatment:

- Section 6.3 introduces the relevant basic physical principles.
- Section 6.4 offers an overview of the discussion on biological effects.
- Section 6.5 describes the most important influencing factors and frameworks for future developments in radiation exposure.
- In *Annex 5* to this study, the radiation exposure expected as a result of Pervasive Computing is assessed.

Section 6.6 summarises the key conclusions from this chapter.

Readers who are short of time are referred to Section 8.3, which summarises the key conclusions drawn from all the parts of this study relating to health.

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110 Adopting a broader understanding of health, would also include psychosocial aspects, but that is not the aim of this chapter. However, there is a discussion of health-related influencing factors and social aspects in Chapter 8.

111 Non-ionising radiation (NIR) covers all forms of electromagnetic radiation whose intensity is not high enough to have an ionising effect. In the case of *ionising* radiation, molecules are altered and a harmful effect on biological organisms is undeniable.

6.1 Opportunities of Pervasive Computing for health

For the health service and social welfare, PvC offers a wide range of possible applications that can help to improve the success of treatment and quality of life for patients.

6.1.1 Health monitoring and preventive diagnostics

Through 'Personal Health Monitoring' it is possible to measure health-related physical parameters on a continual basis, without cables restricting patients' freedom of movement. Data can be recorded and transmitted directly to the hospital. It is therefore possible to monitor important parameters thoroughly, not just for a short period during a doctor's visit or a stay in hospital.[112]

Monitoring is particularly beneficial for high-risk patients and for chronic illnesses, because the database for diagnosis is improved and the doctor can be automatically notified if the patient's state of health deteriorates acutely. For patients, this cuts out some trips to the doctors, long waiting times and some in-patient diagnosis.

Experience with technologies already available is positive:

- 'Continuous monitoring is already being tested in practice for type 1 diabetics. The scientific evaluation of the project shows that trained diabetes patients have significantly fewer hospital visits in the subsequent period.' (Gerlof, 2001).
- Continuous analysis of respiratory murmurs helps asthmatics to recognise imminent asthma attacks as early as possible and thus to reduce the risk of emergencies (Mediendienst Forschung, 2002).
- For people with a high risk of heart attack, miniature sensors that can be worn on the body continuously monitor the ECG. Data are transferred to a PDA,[113] which displays the figures. The system includes an alarm function, which also automatically notifies the emergency services using a mobile phone in the event of an emergency (Hey, 2002).

The PvC trend will help to continue to develop approaches of this kind and enable broad, low-cost use.

Large overall potential for cost reductions is seen in Personal Health Monitoring, because there will be a marked reduction in in-patient visits or care in nursing homes (Grote, 2001b).

6.1.2 Usefulness for emergency services

For emergency doctors, a WAP-based[114] medical information service (MedicWAP) already allows mobile access to pharmacopoeias, tables for emergency care of children, toxin telephone numbers and special information such as medicine dosages that are

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[112] One example is the diagnostic ring being developed by Mitsubishi (www.mitsubishi.co.jp/ En/index_top.html).

[113] Personal Digital Assistant, a wearable minicomputer.

[114] Wireless Application Protocol. Protocol for (limited) access to the WWW by mobile telephone.

dependent on age or body weight. It is also possible to search for hospitals, doctor's practices and chemists by means of WAP mobile and to organise hospital admission at the scene of the accident.

However, WAP is not an ideal basis for user interfaces that have to meet the high requirements of an emergency service. Significant improvements in response time would be necessary at least. It can be expected that these problems will be overcome with new forms of interaction and higher data transmission rates in Pervasive Computing.

Pen PCs, which could record medical findings during use and send this treatment-relevant data to the hospital by radio, are suited to use in emergency doctors' cars. On the basis of the transmitted data, preparations can be made for effective further care in the accident and emergency department before the ambulance has even arrived.

The limitations of current WAP use (low bandwidth) will no longer apply with radio telecommunications standards that will be available in the future (e.g. GPRS), with the result that, in emergencies, emergency doctors can consult the entire spectrum of medical information available on the Internet and in databases by mobile telephone. In addition, high-resolution images can be transmitted, which is an additional benefit for initial emergency medical assistance. High-resolution image data assist with correct diagnosis. Even during transportation the emergency doctor can make contact from the ambulance with specialists by videoconference and, with their assistance, initiate time-critical treatment measures.

In cases where no medically trained personnel are on the scene, mobile medical technology and videoconferences with specialists can increase the chances of saving patients. An existing example is the automatic external defibrillator (AED), which can be kept in aircraft and public buildings. With this technological and expert support, it would be possible even for non-experts to carry out a life-saving defibrillation in the shortest possible time.

6.1.3 Medical robots in surgery

In combination with high-resolution imaging procedures (e.g. PET scans), medical robots allow micro-invasive operations with an accuracy of a few hundredths of a millimetre. Since the incisions are very small and organs can be manipulated very precisely, the rehabilitation phase is shortened. In neurosurgery in particular, micro-invasive medical robots allow patient treatments that were previously impossible, or possible only at high risk (Redmann, 2001). The further development of these robots will benefit from the general trend towards PvC (Spektrum der Wissenschaft, 2001).

6.1.4 Intensive care and rehabilitation

For patients in intensive care, wireless data transmission may in future obviate the need for most cable connections for medical apparatus. As a result, patients are given greater freedom of movement, which makes personal body care and hygiene easier and reduces the risk of decubitus.

During aftercare, hospital stays are shortened by up to several weeks, since health data will no longer be monitored during in-patient treatment (see also Section 6.1.1), but by sensors or mobile webcams, for example. Patients can stay in their own homes and have an improved quality of life and a lower risk of infection from hospitals. However, a precondition for mobile telemedical applications is a higher degree of coverage by radio telecommunications technology. Those using this technology are at risk if they unknowingly go where there is no coverage.

With current technology, the MOBTEL project (Mobile Technology in Telemedicine) has been developed at the University of Leipzig for patients with disorders of the memory or executive functions. It is based on a handheld computer that is connected by a radio telecommunications network with a distributed care system. Patients are therefore under the remote care of a specialist or family members and can at the same time lead an autonomous life. This solution allows better medical care for patients and improves quality of life.

ICT support is also a possibility in general social services. The decentralised use of computers can improve the provision of information to care personnel and allow skilled treatment. One example is an ‘intelligent manual’ that has mobile access to a central information system (Weiler, 1998).

In general social services ICT support could lead to an improvement in quality of care, increased skills for care staff and a cost saving from more efficient operations.

Offset against these advantages are the risks that patients might suffer from a loss of human contact. Instead of holistic care and observation, the individual could be reduced to the few aspects shown by the data. In addition, excessively high trust in technology on the part of personnel may mean that in dangerous situations a doctor is called too late.

6.2 Health risks from direct contact with electronic components

According to the Pervasive Computing vision, microelectronic components are in some cases to be worn directly against the skin (bracelet, ring, glasses, clothing) or implanted in the body. In the case of implantation in particular, the question arises as to possible risks caused by material incompatibility. With the implantation of endogenic materials, there is a possibility that the body will react to that as *foreign matter.*

Such a reaction may be caused firstly by substances that are released from the surface of the implant under the influence of the biological environment – which is aggressive for many materials. Secondly, the surface structure and the atomic/molecular composition of the implant surfaces determine the functionality and behaviour of cells that come into contact with the implant. These effects are based on protein adsorption and denaturing on the implant surface. Mechanical stress of the tissue in the immediate environment also influences acceptance of the implant. Another effect on the biological environment can occur where active implants emit radiation or consume energy. All these factors may mean that cells die in the immediate environment of the implant, the functionality of the cells is altered, cell composition shifts in the wrong direction, and an inflammatory or allergic reaction is caused.

The abovementioned problems may in principle occur in the case of all implants. However, specific issues relating to PvC are

- the expected increase in the use of implants (the threshold for the use of active implants will probably fall),
- the possibility that new materials will be used, and in particular,
- the fact that PvC implants emit non-ionising radiation in the immediate vicinity of tissue in order to transmit data to installations outside the body (see also Sections 6.3, 6.4 and the Annex 5).

Acute effects of individual factors can be determined by constantly improved, standardised examinations (see OECD and ISO guidelines). These tests can avert the risks of these effects with a relatively high probability.

In the case of *long-term effects* this becomes more difficult. In some cases, negative effects can be recorded in 24-month-long animal studies, as described in OECD Test Guideline No 452 (Chronic Toxicity Studies), for example. However, the significance of this test is limited by the very large differences between animals and humans with respect to elimination and detoxification/bioactivation.[115] In addition, the occurrence of multi-factor, synergy effects cannot be ruled out with the existing tests, and probably even in future.

One method that is used increasingly is the application of insulating layers (e.g. a-C:H; Meng, 2001) or coatings made of biologically compatible material (e.g. glass) in order to shield potentially difficult – e.g. nickeliferous – materials from biological systems. In addition, new materials are constantly being developed, which are selected and optimised with respect to their biocompatible and functional properties.

In the case of active implants, account should be taken, in accordance with the precautionary principle, of the limits of current knowledge on communication between cells: cells communicate

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[115] It should be noted that differences can be seen even within the human population.

- in the case of direct contact, by means of cell-bound molecules, forces, electrical signals
- without direct contact, by means of emission of soluble substances and possibly also by means of photons (BION, 2000; Popp, 1999).

This means that electrically or optically active implants may possibly disrupt cell-cell interaction and therefore have a negative long-term effect on the functionality of the biological environment.

6.3 Effects of electromagnetic fields: basic principles

There has been debate on possible effects of electromagnetic fields on human health for years. It has been a controversial subject of discussion not only in public (‘electrosmog’), but also in scientific circles. The risk of harmful effects below the thermal threshold must be described at present as *largely unclarified*. Since the *number of EMF sources* will increase greatly with Pervasive Computing (see also the scenarios in Section 4.9), an in-depth examination of this aspect in the light of the precautionary principle is needed. This section introduces the necessary basic principles.

6.3.1 Basic physical principles

Static fields

Stationary electrical charges produce a static (invariable over time) *electrical field*. For example, a negatively charged metal sphere is surrounded by a spherical-symmetrical electrical field which attracts positively charged objects and repels negatively charged objects. The strength of an electrical field at a certain point, i.e. its dynamic effect on a charged object at this point, is described by its *electrical field strength E*. *E* is a directional parameter, i.e. a vector. Such a field strength vector is best illustrated by an arrow whose length indicates the field strength and whose direction indicates the direction in which the field affects charged particles.

Magnetic fields are produced by electrical charges in motion. In an electromagnet, the field-producing charges move in the current-carrying coil, whilst in a permanent magnet (e.g. a compass needle) the field is produced by microscopic currents in the atoms in the magnet. A permanent magnet or a coil with a constant current produces a static magnetic field. In the same way as an electrical field, a *magnetic field strength B* is defined; this is also a directional, i.e. vectoral parameter.

Dynamic fields and radiation

The static fields described above are caused by stationary charges or constant charge currents. If, on the other hand, a charged particle is accelerated, it constantly produces different field states, i.e. it is surrounded by a dynamic (variable) field. In dynamic fields, the electrical and magnetic field can no longer be considered separately; they are coupled, i.e. they influence one another. Dynamic fields can also ‘separate’ from their source (the charges that produce them) and propagate autonomously through space. In this case we talk about an electromagnetic wave or *electromagnetic radiation*.

One example of the production of electromagnetic radiation is the Hertz dipole: in an electrical conductor the charge oscillates around and emits electromagnetic waves. The Hertz dipole antenna is at the same time a simple model of an *antenna* and will therefore be examined in greater detail below.

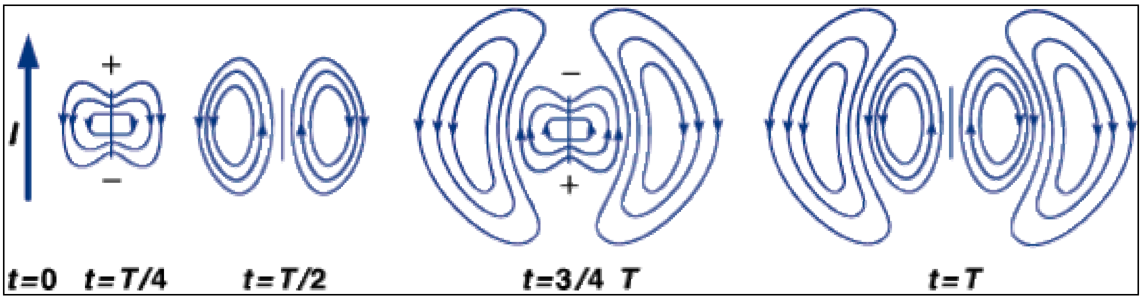

Figure 6-1: Field of a dipole antenna. The separation of the field from the source can be clearly seen (Source: http://geochron.geologie.univie.ac.at/physics/daten/kap_14/node90.htm)

Since the charges in the stub antenna oscillate back and forth, its two ends change their polarity sign with each oscillation. With each of these changes of sign, the fields produced separate from the antenna and propagate into space at the speed of light (Figure 6-1). In an electromagnetic wave of this type, the vectors of the electrical and magnetic field strength E and B oscillate permanently around the null position. The two field vectors are perpendicular to one another and also perpendicular to the direction of the wave propagation.

A few important physical parameters

The *frequency* of the charge oscillation in the antenna also determines the frequency of the electromagnetic wave produced. The frequency of the wave indicates how often the E vector (or the B vector) oscillates back and forth at a point of the wave. Frequencies are given in Hertz (Hz), 'oscillations per second'.

The *wavelength* of a wave reflects the physical distance between two adjacent wave peaks.

There is a simple connection between frequency and wavelength. The product of the two parameters is constant and equal to the speed of light in a vacuum (300 000 km/s). The smaller the wavelength, the higher the frequency.

The *amplitude* of an electromagnetic wave indicates its maximum (electrical or magnetic) field strength during one oscillation.

An electromagnetic wave transports energy. A measure of the *intensity* of an electromagnetic wave is the 'flux density'. It indicates the amount of energy transported per unit of time and area and is expressed in watts per square metre. One W/m^2 means that an energy of one joule per second flows through an area of one square metre. In the case of a wave in the far-field region, the flux density is equal to the product of the electrical and magnetic field strengths and is therefore directly linked to the amplitude of the wave.

The electromagnetic spectrum and high-frequency radiation

Since the characteristics of an electromagnetic wave are determined by its frequency, the different types of radiation (radio waves, visible light, X rays, etc.) are normally brought together, according to frequency, in an electromagnetic spectrum. Figure 6-2 shows such a spectrum, emphasising the frequencies that are relevant to this study.

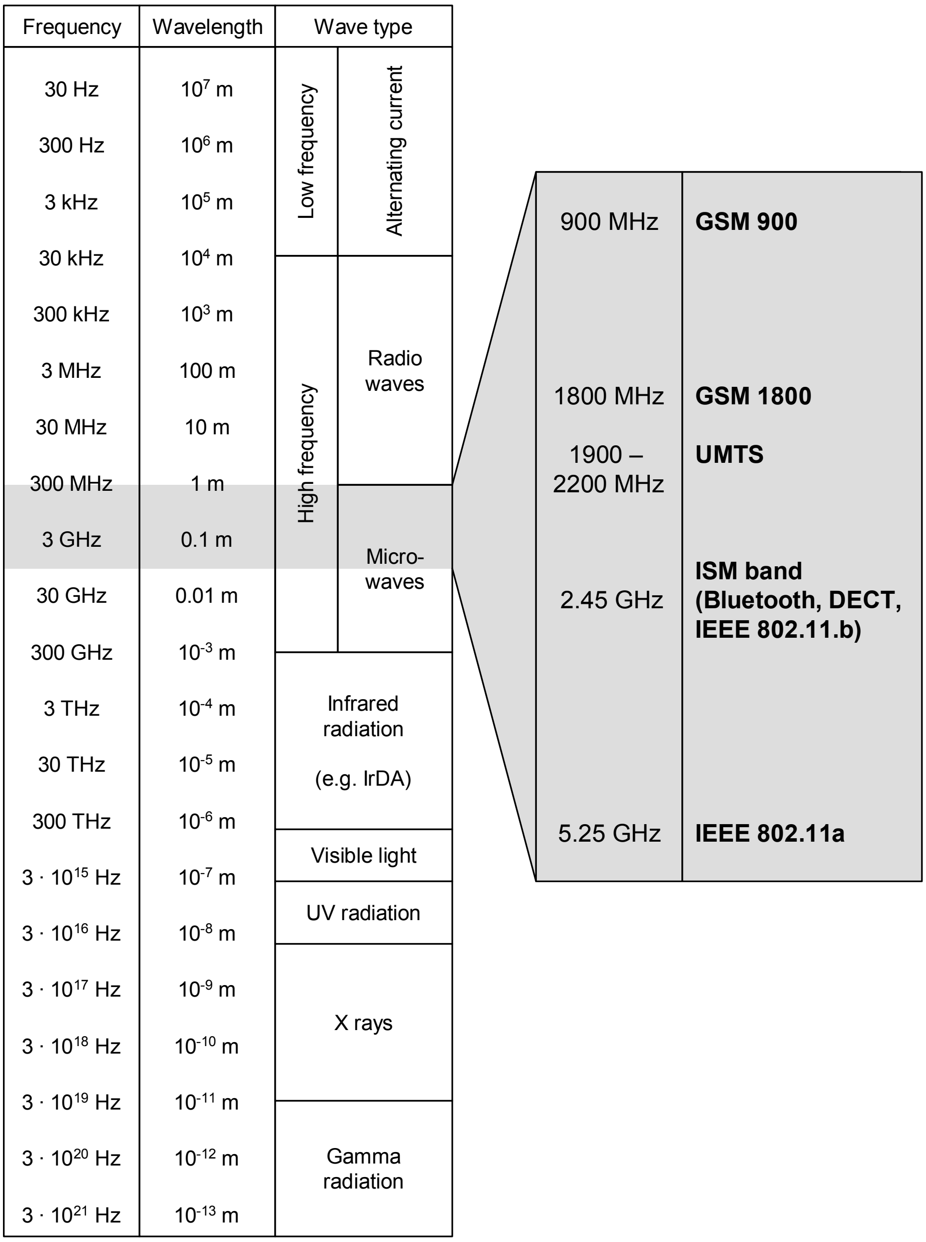

Figure 6-2: Electromagnetic spectrum. The areas of particular relevance to this study are shaded in grey (Source: IZT)

Modulated waves

In order to use an electromagnetic wave as a data carrier, it is 'modulated'. In the modulation, the carrier wave is superimposed on a signal which modifies its amplitude (or another wave parameter) (Figure 6-3).

The modulation of electromagnetic radiation is important in this connection, since any modulation of the carrier wave automatically adds field components of other frequencies (according to the Fourier analysis).

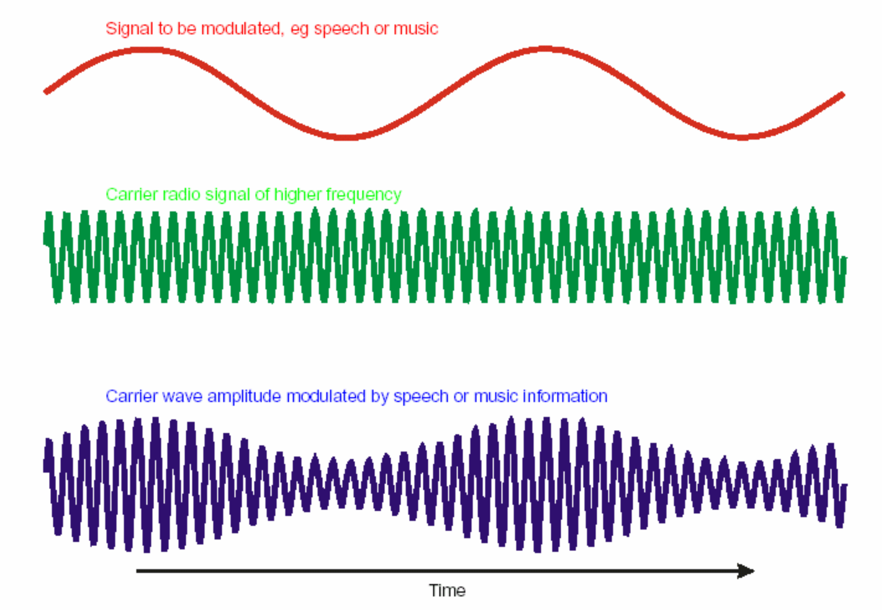

Figure 6-3: Amplitude modulation for an analog signal. At the top is the signal, below that the unmodulated carrier wave, and at the bottom the resulting modulated wave (Source: Stewart Report)

A special case of modulated waves is pulse modulation. It is required for many radio standards in connection with the 'channel access mode'.[116] For example, in GSM mobile radio communication networks the TDMA mode is used. The base station and the mobile radio communication device exchange data packets on a certain carrier frequency; several calls can be transmitted on one carrier frequency. Data is divided by 'time division', by allocating time slots which are periodically repeated. The individual mobile phone receives a new data packet exactly every 4.615 ms. This results in a pulse frequency of 1 / 4.615 ms = 217 Hz.

6.3.2 Radiation exposure from an individual source

Naive assessment

In order to assess radiation exposure stemming from a source, it must be determined how the intensity (flux density) is propagated in space. It is particularly easy to calculate the flux density around an emission source for the following idealised case:

- *Isotropic source:* there is equal irradiation in all spatial directions and the resulting field distribution is spherical-symmetrical.
- *Source in an empty space:* no obstacles (furniture, walls, floor) interfere with wave propagation.

[116] See, for example, Schiller, 2000.

- *Consideration of the far field:* Only the field distribution far (more than one wavelength) from the source is taken into consideration.

In this case, the flux density S at distance r with a transmission power P is:

$$S = \frac{P}{4 \cdot \pi \cdot r^2} \quad [\mathrm{W/m^2}]$$

It quickly becomes apparent, however, that this naive approximation is too rough to assess radiation levels in interiors. The reasons are explained briefly below.

Influence of antenna characteristics

Antennas are not isotropic (i.e. spherical-symmetrical) emission sources, as can be seen from Figure 6-1. In reality, they radiate with different intensities in different directions and can therefore produce considerably higher energy flux densities in individual directions than would be expected under the above formula. This phenomenon is described by the 'antenna gain', i.e. the degree of deviation from isotropic radiation.

Near-field effects

The above formula applies only to the *far field* of a radiation source, i.e. the area that is considerably more than one wavelength from the source. At short range, the relationships are much more complicated. The *near field* is heavily dependent on the geometry of the source. The magnetic and electrical field are no longer closely connected and, in particular, are no longer in phase. The near field is therefore also much more difficult to measure than the far field, where knowing the strength of a field (E or B) is enough to calculate the intensity. It is often not possible to obtain a reliable measurement in the near field. A rough representation of energy flows in the near field is shown in Figure 6-4. It is known that far from the source all energy flows outwards, whilst at short range the bulk of the energy flows back and forth parallel to the antenna. These energy flows can be just as effective (i.e. they can be absorbed) in bodies as flux densities in the far field.

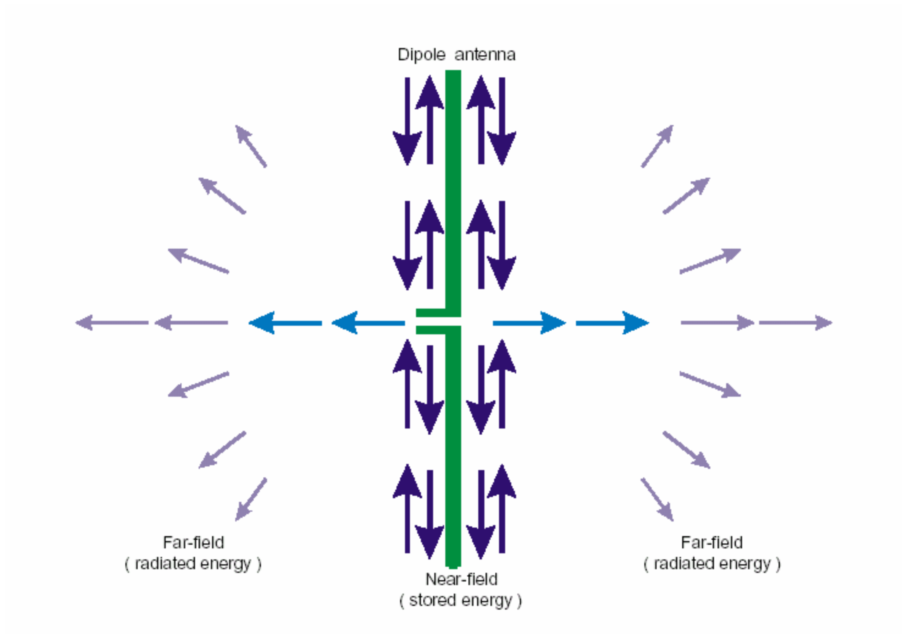

Figure 6-4: Near and far field of a dipolar antenna. The main directions of the electromagnetic energy flow are shown (Source: Stewart Report)

However, the near field cannot be completely ignored by this study, as is shown by the following. Most communication technologies (GSM, UMTS, Bluetooth, IEEE 802.11, DECT etc.) use frequencies in the single-digit GHz range. This corresponds to wavelengths of centimetres. In many cases – in particular in the case of components worn on the body or implants – the human body will therefore be in the near field of the radiation source.

Influence of room geometry and interior reflections

In a realistic situation, around an emission source there are always various objects such as walls or furniture that reflect or absorb the radiation or simply let it pass without interference. These effects are heavily dependent on materials and frequencies. For example, window glass is transparent to visible light, but not to UV radiation (which is why the sun does not have any tanning effect through windows).

Reflection effects in metallic interiors in particular (e.g. cars or railway carriages) could lead to a clear increase in radiation exposure compared with a radiator in an empty room. However, a recent study from Japan (Hondou, 2002) which concludes that there is a marked rise in exposure in metallic interiors was received with great scepticism in specialist circles. For example, scientists at ETH Zurich stress that, contrary to the statements made by Hondou, the direct fields of a source on the body are themselves considerably higher in a means of transport with metallic external walls than the reflected fields (cf. Kramer et al., 2002).

6.3.3 Simultaneous radiation exposure from several sources

If radiation from several sources is superimposed, it might be assumed that the amplitudes have to be added together, which would lead to a quadratic rise in the flux density with the sum of the amplitudes. However, this not the case in the *far field*, where only the flux densities S_i are added:

$$S_{tot} = \sum_i S_i = \frac{1}{4 \cdot \pi} \sum_i \frac{P_i}{r_i^2} \quad [\mathrm{W/m^2}]$$

The amplitudes are not added together because the signals from different sources generally have different frequencies or at least differently fluctuating phases.

In the *near field* there is a local addition of flux density and in this case the formula in 6.3.2 can no longer be used.

If different sources transmit on different frequency bands, further consideration must be given to the different biological effect of the frequency ranges.

6.3.4 Interaction with matter and biological systems

Interaction with free charge carriers and electrical dipoles

Electromagnetic fields exert forces on charged particles. Freely moving charge carriers are accelerated in fields and electrical (or magnetic) dipoles are aligned according to the field direction. In biological tissue there are a large number of charge carriers (in particular ions) and dipoles (for example the water molecule). In fields they perform movements which are cushioned by the surrounding tissue fluid. Like any friction, this cushioning produces heat. In this interaction of electromagnetic radiation and matter, the field energy is therefore converted into heat energy (dissipation). The energy of electromagnetic waves can only be absorbed in energy quanta, in amounts of the size $E = h \cdot \nu$, where ν is the frequency of the wave and h is Planck's constant.

Thermal effects

As has been explained above, biological tissue is heated up under the influence of electromagnetic radiation. This local temperature increase grows with the radiation intensity and, under certain circumstances, can damage the affected tissue or the whole organism.

Athermal effects

Athermal effects are any effects that cannot be explained by thermal effects. They cover a large number of different effects. In various areas there are indications of the existence of athermal effects. It has not really been clarified what the connections are between the effects. There are various attempts to provide an explanation, but these are very controversial (see also Section 6.4.2).

The effect of modulated waves

Different studies indicate that certain biological effects occur only with modulated or pulse-modulated waves, but not with unmodulated waves of the same carrier frequency. This is seen as an indication of the existence of athermal effects, since a modulation influence cannot be explained by the thermal effect mechanism. Evidence along these lines has recently been given, for example, in a study by the Institute of Pharmacology and Toxicology at the University of Zurich (Huber et al., 2000).

Absorption mechanisms and measured variables

Electromagnetic fields penetrate an organism, where some of their energy is absorbed by the tissue. This process cannot be measured directly and can be described only approximately because of the heterogeneous external and internal structure of the affected tissue.

The specific absorption rate (SAR) indicates how much energy the body absorbs by time and body mass and is measured in watts per kilogram. It is regarded as the biologically relevant quantity that indicates the exposure of the organism (or of a body part). However, the SAR notion is clearly based on thermal effects and it doubtful whether it also correctly describes the degree of exposure in the case of possible athermal effects. Nevertheless, the specific absorption rate is the normal way of measuring the immission of high-frequency electromagnetic fields.

Depending on whether absorption is considered only for a spatially limited region of the body or is averaged across the whole body, a distinction is drawn between whole-body SAR and local SAR.

The absorption rate is heavily dependent on frequency, which is connected with resonance effects in and on the human body.[117] A distinction is drawn between the following frequency ranges:[118]

- *Sub-resonance range:* The wavelength is greater than the expanse of the body. In the case of humans, the sub-resonance range extends below around 30 MHz. In this range, the whole-body SAR increases with the frequency roughly quadratically.
- *Resonance range:* The absorbing body is about half as large as the wavelength. In the case of humans, the absorbing body can be the whole body, body parts or organs. This range lies between 20 and 400 MHz. The whole-body SAR is highest in this frequency range.
- *Hot spot range:* Focusing effects can result in local increases in SAR here. In the case of humans, hot spots occur between 400 MHz and 3 GHz. This range is particularly relevant for Pervasive Computing technologies.
- *Surface absorption range:* Above 3 GHz (as with infrared or light) absorption on the surface of the affected body dominates. This range includes some recent radio communication standards, such as the 5 GHz variant of the IEEE 802.11 Standards.

Because of measurement difficulties, efforts are being made to infer the SAR from the field strengths or flux densities outside the body, which are more easily measurable.

[117] As a rule, a body in a radiation field behaves resonantly if its expanse is precisely equivalent to half a wavelength.

[118] cf. BUWAL(1990), p. 8 f.

However, these quantities do not reveal anything a priori about the proportion of incoming energy that is actually absorbed in the body. In certain situations, however, a maximum assessment is possible; statements can be made such as ‘If the flux density of a value does not exceed X W/m^2, the SAR is below Y W/kg.’

A distinction must be made here between far-field and near-field exposure.

The field of a far-field source (for example from a remote base station) can be described well by freely propagating wave fronts. As a result of reflection on house walls or other surfaces, interference patterns and standing waves occur. In the far field flux density is well defined and allows inferences to be made regarding the maximum SAR in the body.

In the near field (for example where a device is used directly on the body), things are much more complicated. Numerical simulations (Kuster/ Balzano, 1992) show that the specific absorption rate for the near-field effect essentially correlates with the magnetic field strength and therefore depends on the antenna current and not on the power consumed by the antenna. Many experiments are being carried out on replicas of individual body parts (‘phantoms’) in order to determine the effect of near-field exposure.

6.4 Health risks from high-frequency radiation

6.4.1 The state of the discussion and current data

The 'electrosmog' controversy

There has been debate on the harmful effects of 'electrosmog' on human health for years. The fear that electromagnetic fields radiated by power lines or transmitters have a negative effect on human health and well-being is currently directed at mobile radio communication networks. As regards the development of UMTS networks, fears have been fuelled of growing radiation exposure in everyday life.

Whilst opponents of mobile radio communications regard the health risks (in particular an increased risk of cancer) as proven and warn against the unforeseeable long-term consequences of an increasing daily radiation dose, the other side considers the radiation level from current technologies to be harmless and believes that this assessment is confirmed by numerous scientific studies. At present there is barely a social discussion on the effects of a technology where disagreement over the scientific findings is as great as in the debate on mobile communication.

There are different assessments of the health risks not only between different interest groups in society, but also among scientists. An initiative by the German company T-Mobile, which obtained a report on the possible health risks of mobile radio radiation, is informative in this regard. The four experts came to surprisingly different conclusions on the basis of the same publicly available primary literature. The reason is that the scientific findings have to be evaluated and that there is no consensus at present on the assessment criteria to be applied. An attempt at a moderated, scientific dialogue on risks between the four experts was not able to bring a consensus any closer either (Wiedemann et al., 2003).

There is a much wider gap in the assessments with regard to athermal effects than for thermal effects.

Thermal effects

There is broad consensus on the existence of thermal effects. They have been thoroughly researched and form the scientific basis for most limit values. Proven negative health effects of a strong radiation-induced tissue heating have also meant that the radiated power of mobiles is much lower at present than it was a few years ago. Groups in industry (but also many neutral scientists) therefore take the view that health effects from thermal effects related to modern mobile radio communication technologies can definitely be ruled out. The other side contends that the absence of evidence of health effects should not be misinterpreted as evidence of absence.

Athermal effects

In the case of *athermal effects* the discussion is far more polemical. This is mainly because for this group of effects the scientific findings are extremely inconsistent and controversial. Many studies which demonstrate the effects of electromagnetic radiation with regard to non-thermal intensities stand in contrast to at least as many which do not confirm any such connection. The sceptics therefore accuse the studies with positive findings of being unscientific or at least claim that the experiments' results cannot be reproduced. The opposing side, for their part, explain that the results cannot be reproduced because of a possible non-linearity of athermal effects. According to this theory, the experiments' results are extremely sensitive to the tiniest variations in experimental conditions. This non-linearity also accounts for the explosive nature of possible athermal effects. If there is no linear connection between intensity and effect or if effects occur in narrow frequency windows, which vary from individual to individual, the danger cannot easily be dealt with by using stricter limits or low-radiation technologies.

In general, it can be said that many of the studies that have been conducted have used exposure systems that were unsatisfactorily characterised both experimentally and numerically and therefore do not allow any clear conclusions to be drawn from the results. Current studies include replications of such studies and should clarify outstanding questions through careful characterisation.

Despite the limitations of current knowledge on athermal effects, attention is also paid to provisional information in this study, which relates expressly to the application of the precautionary principle to future technologies. Experience shows that it takes years, if not decades, before possible health risks from new technologies can be firmly proven or ruled out according to scientific standards. As part of a prospective analysis of opportunities and risks it is therefore necessary to rely on provisional evidence.

Current data

There are thousands of scientific studies on the effect of electromagnetic fields on organisms, and some experts say there are around 20 000 publications. Although only some of this extensive literature deals with high-frequency radiation in the low GHz range, which is the focus of the present study, it should nevertheless be clear that a critical approach to and evaluation of all relevant studies is not really possible.

On the other hand, there are already sound reviews that examine and evaluate the available scientific data and literature and infer from it statements about possible health risks. There are also comprehensive opinions by national and international radiation protection institutions on the scientific discussion on health risks from EMFs. In addition to selected primary studies, the present study used relevant reviews and opinions from key institutions. In addition, it also reproduces the evaluation by the German Ecolog Institut (Neitzke et al., 2000; Depner et al., 2001), which conducted a scientific assessment of the risk potential of mobile radio communication radiation specifically from the perspective of precaution.

In Section 6.4.2 below, there is a systematic explanation of the biological effects that are the subject of the scientific discussion. The relevant assessment of the following five expert reviews and reports are added:

- Report by the Institute for Social and Preventive Medicine at the University of Basel on behalf of the Federal Agency for the Environment, Forests and Landscape (BUWAL) (Röösli/Rapp, 2003).

  In spring 2003, the Federal Agency for the Environment, Forests and Landscape published a compilation and evaluation of recent scientific human studies which had examined the influences of high-frequency radiation on human health and well-being. On a sophisticated scale the evidence for the existence of a biological effect and its importance for health were assessed and the threshold was indicated above which it was observed. With regard to evidence, the effects examined are classified in five groups:

- 'certain'
- 'probable'
- 'possible'
- 'improbable'
- 'not measurable'

As far as relevance to health is concerned, a distinction is drawn between three groups:

- 'serious health effects',
- 'restriction of well-being'
- 'not measurable'

• European Commission SCTEE

In October 2001, the Scientific Committee for Toxicity, Ecotoxicity and the Environment in the Directorate-General 'Health and Consumer Protection' produced an opinion on possible effects on human health of high-frequency fields.

• German Radiation Protection Commission (SSK)

In 2001, the German Radiation Protection Commission adopted a recommendation entitled 'limit values and precautionary measures to protect the population from electromagnetic fields'. It discusses the biological effects of lower-frequency and high-frequency fields and the question of whether existing limits are adequate.

• Report by the Ecolog Institut on behalf of the German company T-Mobile (Neitzke et al., 2000; Depner et al., 2001).

In 2000 the Ecolog Institut in Hanover produced an 'Assessment of current scientific knowledge from the perspective of precautionary health protection' on behalf of the German company T-Mobile, relating to mobile radio communications and health (Neitzke et al., 2000). This study was one of four opinions that T-Mobile had obtained from four different experts. The four assessments and the resulting recommendations were highly divergent, which prompted the contacting body to organise a moderated, scientific dialogue on risks (Depner et al., 2001). In this structured scientific discussion, it was not really possible to move towards a consensus. The assessment by the Ecolog Institut is included here because it is the only one that expressly focuses on precaution. Of the four reports, it is the one that claims the greatest risk potential. It therefore represents a minority of critical scientists who are warning against the unforeseeable consequences of mobile radio communication radiation. The Ecolog Institut has produced a summary based on the detailed report and subsequently classified the biological effects under examination into five groups (Wiedemann et al., 2003). These are, in order of evidence becoming weaker:

- 'proof'
- 'consistent evidence'

  - ‘strong evidence’
  - ‘evidence’
  - ‘weak evidence’
- Stewart Report

  In 1999, the British National Radiological Protection Board (NRPB) appointed an interdisciplinary ‘Independent Expert Group on Mobile Phones (IEGMP)’, chaired by Professor Sir William Stewart. The result of their work was the Stewart Report published in 2000, which provides a very detailed examination of the different health risks from mobile radio communication radiation based on a number of studies.

In addition to the expert reviews and reports mentioned, a selection of recent results is discussed in the Annex 5.

6.4.2 Effects on the human organism

An overview is given below of biological effects of high-frequency radiation, including an evaluation of those effects by the most important reviews and expert commissions. In many cases, there is no opinion from one or more of these sources. The reason for this is that the quoted sources vary in their level of detail or use different systematic approaches.

Interaction with cells and sub-cellular structures

Molecules and membranes

Ionisation of atoms and molecules by high-frequency fields can be ruled out on physical grounds. The quantum energies in the frequency range relevant for Pervasive Computing (~ 0.5 - 10 GHz) lie in the one to two-digit μeV range and are therefore around 100 000 times smaller than the energy (a few eV) that are needed to ionise atoms or to destroy DNA molecules. Consequently, we can also talk about non-ionising radiation. Direct damage to DNA (with the accompanying carcinogenic effect) can therefore definitely be ruled out.

A further exclusion criterion for biological effects can be seen in thermal noise. The radiation-induced kinetic energies can generally have a biological effect only if they lie above the thermal noise. At typical tissue temperatures, this threshold lies at around 26 meV. Effects from agitated ions, for example, can be ruled out. However, this statement must be qualified by the fact that these considerations apply only to systems that are in thermal balance, a requirement not met by living organisms. Influences on situations of imbalance, such as biochemical reactions, cannot be ruled out on the basis of this argument. Different non-linear mechanisms that could be responsible for effects below the abovementioned threshold (e.g. resonance effects, coherent excitation of macro-molecules) are therefore also being postulated.

Assessment by important reviews and expert commissions	
SSK (D) 2001	Physical hypotheses such as cooperative effects, non-linear interactions in thermodynamic processes at low exposure intensities or resonance phenomena have not been confirmed thus far. Further investigations on the effect on membranes are needed under controlled conditions.
Stewart Report (GB) 2000	There is little evidence of resonance effects, but further research is needed. On the other hand, there are indications of the influence of cell membranes and ion flow through membranes. However, health repercussions are uncertain. In addition, there is not yet any independent confirmation of the effects.

At cellular level, there are further discussions on changes in cell membranes. For example, studies on artificial membranes show that electromagnetic fields (at 900 MHz) can cause a current flow through membranes. These findings have not yet been confirmed for living cells.

Calcium

Calcium ions play a key role for neurons and other cells. They are particularly crucial in passing on information in the form of action potentials.

An influence by high-frequency EMFs on calcium ion transport through membranes of nerve cells and other cells was demonstrated in the 1980s. More recent studies (using other frequencies) have not yet been able to establish such a connection.

Assessment by important reviews and expert commissions	
SCTEE (EU)	Evidence from studies on calcium flow through neuron membranes inconsistent and not convincing.
SSK (D) 2001	Older significant results have not been either confirmed or refuted by modern analysis techniques.
Ecolog Institut (D) 2001	The findings on a modified calcium homeostasis for non-thermal intensities of high-frequency radiation are considered to be 'consistent evidence'.
Stewart Report (GB) 2000	The evidence of an increased calcium flow from brain tissue for non-thermal values must be taken seriously despite contradictory findings. The correlation with the modulation frequency is interesting, but difficult to interpret. A risk to health cannot readily be concluded. As a precautionary measure, however, 16 Hz should be avoided as a modulation frequency for future technological developments.

Nervous system and brain

Electroencephalogram (EEG)

Using electroencephalograms, possible direct influences by electromagnetic fields on brain activity can be examined. A distinction must be drawn between the spontaneous EEG (brain activity with eyes closed and without external stimuli) and the evoked EEG (brain activity with visual, acoustic or other stimuli).

There are a number of studies on this subject, some of which indicate a connection between radiation exposure and EEG. However, it must be stressed that an EEG change caused by exposure does not necessarily mean any health impairment.

Assessment by important reviews and expert commissions	
BUWAL (CH) 2003	It is considered 'probable' that exposure to mobile telephones changes brain patterns. Most consistently, an amplitude increase in the alpha band for the brain patterns was observed. The health relevance is unclear.
SCTEE (EU) 2001	Evidence not reproducible.
SSK (D) 2001	Results contradictory in some cases, but to be assessed as evidence of changes in neurophysiological processes caused by exposure.
Ecolog Institut (D) 2001	The existing results should be assessed as 'consistent evidence' of influences of high-frequency electromagnetic fields on the central nervous system.
Stewart Report (GB) 2000	The studies provide evidence of non-thermal effects of high-frequency fields on brain activity.

Sleep

Both laboratory experiments and cross-sectional studies of the population have been carried out to establish whether high-frequency fields can lead to sleep disturbances. The studies establish a correlation between EMF exposure and sleep disturbances.

Assessment by important reviews and expert commissions	
BUWAL (CH) 2003	There are individual findings relating to sleep disturbances in the vicinity of radio transmitters. A detrimental effect on sleep quality is classified as 'possible'. This constitutes an impairment of well-being.
SSK (D) 2001	Studies have significant deficiencies in some regards and should at best be seen as unconfirmed evidence.

In the last few years, however, there has been a marked improvement in the data available on the influence on sleep and it must now be assumed that the sleep EEG changes after exposure. The health relevance of the observed effects remains unclear, however (for details see Annex 5).

Cognitive functions

Using behavioural experiments, it can be examined whether electromagnetic fields have an influence on cognitive performance, i.e. active intellectual information processing. In particular, various studies have used attention tests to measure reaction time under the influence of mobile radio communication radiation. In several instances a reduction in reaction time was observed, which could be attributed to localised heating and thus improved blood flow to the relevant areas of the brain.

Many tests have also been carried out on learning and memory behaviour, mainly on animals.

Assessment by important reviews and expert commissions	
BUWAL (CH) 2003	It is considered 'probable' that exposure to a mobile telephone tends to shorten reaction times. The health relevance is unclear.
SSK (D) 2001	Studies do not provide a uniform picture, but can be seen as first indications of a connection
Ecolog Institut (D) 2001	The available results from experiments with animals and humans relating to influences on cognitive functions and behaviour must be seen as 'consistent evidence'.
Stewart Report (GB) 2000	There is no consistent experimental evidence of modified learning or memory behaviour in animals in the intensity range of mobile radio communication. Nevertheless, further research is advisable, in particular on changes in the learning and memory behaviour of humans.

Blood-brain barrier

Among other things, the blood-brain barrier regulates the absorption of different substances into the brain. Heating of the brain can impair this function. The energy that would be needed for such heating is not transmitted by radiation from mobile telephones. However, various studies examine whether the pulsed high-frequency EMF of mobile radio communication can *nevertheless* influence the integrity of the blood-brain barrier. The most recent studies on this subject report an increase in the permeability of the blood-brain barrier and resulting damage to neurons by substances that cannot enter the brain under normal conditions (Salford et al., 2003).

Assessment by important reviews and expert commissions	
SCTEE (EU) 2001	Evidence of effects for non-thermal values inconsistent and not convincing.
SSK (D) 2001	The existing results are not consistent and can at best be recognised as evidence.
Ecolog Institut (D) 2001	An increase in the permeability of the blood-brain barrier for foreign substances under the influence of high-frequency fields was established in several experiments. The findings were regarded as 'strong evidence'.
Stewart Report (GB) 2000	The existing studies are inconsistent. More recent, impeccably conducted studies were not able to establish any effects.

Cancer risk

As has already been explained, high-frequency EMFs have quantum energies that are too low to cause strand breaks in DNA and do not therefore have any mutagenic potential. They can at most influence cancer promotion or progression processes.

ODC

Several studies on cell cultures have shown that the activity of the cancer-related enzyme ornithine decarboxylase (ODC) cannot be increased by modulated fields in the high-frequency range.

Assessment by important reviews and expert commissions	
Ecolog Institut (D) 2001	According to some experiments, ODC activity can be increased in ways other than through known chemical tumour promoters. It has been shown that this effect can also be caused by high-frequency fields with lower-frequency amplitude modulation. The results are regarded as 'evidence'.
Stewart Report (GB) 2000	Pulsed high-frequency mobile radiation possibly also causes a slight increase in ODC concentration and activity at non-thermal intensities. A tumour-promoting effect is very unlikely, however, as are synergistic effects with other environmental factors.

Gene expression

Another connection between high-frequency EMFs and cancer that has been discussed can be found in gene expression, the activation of individual genes and their conversion into proteins. For example, stress phenomena in the cell may cause the activation of certain genes. Changes in gene expression may disrupt cell differentiation and cell growth or result in cell death.

The hypothesis that high-frequency EMF could influence gene expression has been investigated in numerous studies both in vitro and in vivo.

Assessment by important reviews and expert commissions	
Ecolog Institut (D) 2001	The findings on the effects of high-frequency radiation on gene expression, gene transcription and gene translation are regarded as 'consistent evidence' of an effect.
Stewart Report (GB) 2000	Although there is little to suggest at present that mobile radio communication radiation leads to a stress reaction in mammalian cells, the findings regarding nematodes give evidence of a connection in principle between non-thermal EMF exposure and gene expression.

DNA individual strand breaks

Using the 'Comet Assay method', one study (Lai and Singh, 1995) investigated DNA individual strand breaks in the brain cells of rats after EMF exposure. However, subsequent experiments could not reproduce the results.

Assessment by important reviews and expert commissions	
Ecolog Institut (D) 2001	In investigations of cell cultures, changes in genotype such as individual and double strand breaks and damage to chromosomes were established. The existing studies are regarded in general as ‘consistent evidence’ of changes in genotype under the effect of high-frequency electromagnetic fields below the thresholds for macrothermal effects.
Stewart Report (GB) 2000	This subject merits further research efforts, although numerous in vivo and in vitro studies do not confirm earlier positive findings on DNA breaks in the case of mice.

Melatonin

The hormone melatonin is ascribed a protective function with regard to cancer, since it scavenges free radicals that could otherwise lead to cell death. For some time, there has been discussion of the effects of lower-frequency fields on melatonin balance. Some studies also exist on the effect of higher-frequency fields.

Assessment by important reviews and expert commissions	
BUWAL (CH) 2003	The scientific bases are not adequate for assessing any influence on melatonin or other hormones. If an influence did exist, its health relevance would be unclear.
SCTEE (EU) 2001	Melatonin hypothesis not yet confirmed. Relevance for long-term effects appears to be negligible.
SSK (D) 2001	Current research does not support melatonin hypothesis.
Ecolog Institut (D) 2001	Results from the animal test are regarded as ‘evidence’, those from studies on humans as ‘weak evidence’.
Stewart Report (GB) 2000	Current research does not support melatonin hypothesis. Even if a change in melatonin balance were proven for animals, it would be doubtful whether this could be applied to humans because the relevant glands are further from the body surface and on account of other differences.

Genotoxicity

Various studies examine whether high-frequency EMFs have a genotoxic effect, i.e. whether they can lead to DNA damage and mutations. In addition to mutation rate, indicators of such damage to the genotype include ‘indirect indicators’, such as

- Chromosome aberrations: Chromosome deformations often occur in the event of DNA damage or abnormal interactions between DNA and proteins and often correlate to cancer or miscarriages.
- Micronucleus formation: The occurrence of cells with unusually small cell nuclei is also regarded as evidence of damaged DNA.
- Sister chromatid exchange (SCE): Genotoxic substances often lead to an exchange of DNA between two chromosomes.

Each of these indicators has been examined in connection with EMF exposure in a number of studies. Whilst most investigations of chromosome aberrations and SCE produced negative results, several studies gave indications of an EMF-induced increase in micronucleus formation. The health effects of these findings are disputed, however.

Assessment by important reviews and expert commissions	
BUWAL (CH) 2003	The few investigations on humans do not allow a statement to be made on whether high-frequency radiation can have genotoxic effects. If such effects were to exist, they would have to be classified as serious health effects.
SCTEE (EU) 2001	Despite minor inconsistencies in the literature, it can be stated that in vivo and in vitro experiments on induction of micronuclei, chromosome aberrations and SCE could not prove any effective connection.
SSK (D) 2001	Different studies have not provided any clear evidence that high-frequency fields below the limit value can have a genotoxic effect.
Ecolog Institut (D) 2001	In investigations of cell cultures, changes in genotype, like individual and double strand breaks and damage to chromosomes, were established. The existing studies are regarded in general as 'consistent evidence' of changes in genotype under the effect of high-frequency electromagnetic fields below the thresholds for macrothermal effects.
Stewart Report (GB) 2000	The numerous investigations could not provide any clear evidence of the genotoxicity of high-frequency radiation for non-thermal exposure. The most consistent evidence comes from the observation of micronucleus formation. Health risks are uncertain, however.

Spontaneous and initiated tumour formation

Numerous scientific studies exist on tumour formation and tumour promotion in animals. The results do not allow any clear conclusions to be drawn.

There is also discussion whether high-frequency EMFs can synergistically intensify the effect of genotoxic substances. In addition, overheating can increase the carcinogenicity of substances.

Assessment by important reviews and expert commissions	
SCTEE (EU) 2001	Synergistic effects between EMFs and physical or chemical carcinogenic influences have not yet been adequately investigated, but represent an interesting hypothesis.
SSK (D) 2001	Further studies on tumour development should be carried out.
Ecolog Institut (D) 2001	Animal experiments offer ‘evidence’ of an increased risk of cancer in general and lymphoma and ‘weak evidence’ with regard to brain tumours, breast cancer, skin cancer and other forms of cancer.
Stewart Report (GB) 2000	A tumour-initiating effect of high-frequency fields in the non-thermal range is improbable. Evidence of synergistic effects could be explained by thermal effects. Nevertheless, further research is needed here.

Epidemiological studies

There are a certain number of epidemiological studies that investigate a statistical connection between exposure from high-frequency fields and certain illnesses, in particular tumour formation.

Assessment by important reviews and expert commissions	
BUWAL (CH) 2003	There are a few studies that observed higher leukaemia and/or lymphoma rates than expected in the vicinity of television or radio (RF) transmitters. However, the study results are not consistent and many studies have methodological deficiencies. An increase in the risks of the abovementioned forms of cancer are therefore regarded only as ‘possible’, not as ‘probable’. An increased risk of a brain tumour connected with the use of mobile telephones also appears to be ‘possible’. It is not possible to make any statement on breast cancer, eye tumours and testicular tumours. An increased risk of types of tumour other than those mentioned is regarded as improbable.
SCTEE (EU) 2001	In general the epidemiological results for RF do not suggest any long-term increase in the incidence of cancer and do not therefore give any grounds to reduce existing exposure limits. Nevertheless, a few restrictions of the existing studies indicate the need for further epidemiological monitoring: i. the relatively short period of observation compared with the possible latency period of long-term effects; ii. the use of proxies (i.e. distance to the presumed sources, extent of use of mobile telephones etc.) in assessing the exposure of individuals, which could be unreliable and artificially reduce the estimated risk, and iii. low statistical stringency of analyses, which suggests insufficient association.
SSK (D) 2001	Studies do not give any evidence that mobile telephone use increases the risk of brain tumours. There are fundamental problems with exposure assessments in the studies and observation periods are much too short.
Ecolog Institut (D) 2001	‘Evidence’ includes the findings from humans on cancer in general, leukaemia, brain tumours and testicular cancer, whilst ‘weak evidence’ includes findings on lymphoma, breast cancer, eye cancer, skin cancer and other forms of cancer.
Stewart Report (GB) 2000	The overall results of epidemiological studies (both regarding the use of mobile phones and regarding occupation-specific exposure) suggest that high-frequency radiation increases the risk of cancer. However, it should be stressed that the periods under review and the scope of existing studies are not sufficient definitively to rule out a significant risk of cancer.

Effects on the eye

The temperature balance in the eye, in contrast to the brain, is assisted only slightly by blood flow. Therefore, the eye is discussed as an organ potentially at risk from EMFs.

In the numerous studies that have been performed on laboratory animals, some cataracts were detected after exposure to very high frequencies. However, it is unclear whether this is a thermal effect.

Assessment by important reviews and expert commissions	
SCTEE (EU) 2001	The experimental schemes of the existing studies are difficult to reproduce and the results are disputed. Therefore, the relevance of current findings – apart from thermal effects – is very low.
Stewart Report (GB) 2000	Although the intensities of the pulsed fields used were well above the absorption rates that can be induced in the eye by mobile radiation, the existing studies do give cause for concern about possible damage to the eye from pulsed fields with high power peaks.

Reproduction and development

Effects of EMF exposure on reproduction and development in animals that have been discussed range from the number of offspring to neurophysiological changes and deformities among offspring.

Assessment by important reviews and expert commissions	
BUWAL (CH) 2003	By and large, it cannot be assessed on the basis of the existing studies whether the risk of miscarriage is increased by exposure to high-frequency radiation. In addition, the only study on sperm quality is not very meaningful.
SSK (D) 2001	Studies are highly deficient and cannot be regarded as evidence.
Ecolog Institut (D) 2001	The findings on infertility and teratogenicity from human epidemiological studies and animal experiments are classified as 'evidence' or 'weak evidence'.
Stewart Report (GB) 2000	The evidence of a danger to the foetus or male fertility in the case of mobile radio intensities is not convincing. The results of the study by Magras and Xenos (1997) regarding effects on female fertility are also doubtful. However, further research should be conducted here.

Blood and immune system

There are various studies on the influence of high-frequency EMFs on the blood-forming system of rats. The results are highly divergent; whilst some arrive at a negative result (no connection), others report a reduction of monocytes. Investigations using mice prove that high-frequency EMFs have an influence on the immune system (increased macrophagy).

Assessment by important reviews and expert commissions	
BUWAL (CH) 2003	The few in vivo studies that currently exist on influences on the human immune system are not comprehensive enough to be able to assess whether such an effect exists. If an influence did exist, its health relevance would be unclear.
SCTEE (EU) 2001	Effects on the immune system for thermal values of a temporary nature. Lasting effects of weak RF exposure on blood-forming and circulating blood cells or on immune reactions are not known.
SSK (D) 2001	Evidence of effects on the immune systems of mice at very high frequencies (8.5 – 18 GHz). Applicability to humans not yet clear.
Stewart Report (GB) 2000	Results on supposed effects on the blood-forming system are not consistent. The same applies to effects on the immune system, at least in the case of non-thermal exposure.

Cardiovascular system

Various potential effects of high-frequency electromagnetic fields on the heart and circulation have been investigated. These include, as well as a direct influence on blood vessels, indirect effects caused by damage to the brain stem or the hormonal balance.

Assessment by important reviews and expert commissions	
BUWAL (CH) 2003	In general it cannot be assessed on the basis of existing studies whether the cardiovascular system is affected by exposure below the ICNIRP limits. One study indicates that high field strengths have an effect on the autonomous nervous system and, as a result, parameters of the cardiovascular system change. These changes were not classified as pathological. The health relevance of influences on the cardiovascular system cannot generally be classified. In view of the fact that cardiovascular diseases are among the most common diseases and causes of death in industrialised countries, changes are potentially very serious. Even a small increase in risk would mean a large number of cases. Individually, however, small changes in cardiovascular parameters (e.g. pulse rate) do not necessarily constitute a health risk.
SCTEE (EU) 2001	With the exception of one study (to be confirmed elsewhere), which indicates a change in blood pressure as a result of mobile phone exposure close to the head, the available results do not contain any consistent evidence of the effects of mobile telephones on the heart and circulation.
Ecolog Institut (D) 2001	Findings on the influence on the cardiovascular system are classified as ‘weak evidence’.
Stewart Report (GB) 2000	Animal experiments give no reason to presume that EMFs at mobile radio communication intensities influence the cardiovascular system. Observed effects for high intensities appear to be attributable to body heating.

Electrosensitivity

The term ‘electrosensitivity’ covers a number of neurovegetative symptoms about which a very small percentage of the population complain in connection with EMF exposure. These include sleep disturbances, tension, headaches, tiredness, anxiety and dizziness. According to various sources, it must be assumed that the proportion of the population affected is well under 10%.

Assessment by important reviews and expert commissions	
BUWAL (CH) 2003	It has been shown on several occasions that non-specific symptoms increase with frequent use of mobile telephones. These symptoms include headaches, pain sensations, discomfort, tiredness, dizziness and burning of the skin. The existence of these symptoms is assessed as 'probable'. It cannot be assessed on the basis of the existing studies whether and to what extent influences other than radiation have contributed to these findings. It could be possible that mobile telephone calls are often found to be stressful as a result of poor connection quality or that mobile telephone users perceive non-specific symptoms (in particular headaches) after using their telephone differently from people who do not use mobile telephones. However, the symptoms are stress-related and frequent mobile use is merely an indicator of a person's increased stress level. There are also plausible individual findings on electromagnetic hypersensitivity to high-frequency radiation and on sleep disturbances in the vicinity of transmitters. The existence of symptoms under these exposure conditions is regarded as 'possible'. All the abovementioned symptoms constitute a restriction on well-being.
SCTEE (EU) 2001	Reports on the phenomenon are unclear with regard to exposure conditions and frequency of occurrence. It is therefore difficult to assess at present whether these are genuine radiation effects.
Stewart Report (GB) 2000	An effective link between high-frequency radiation and the occurrence of the abovementioned complaints is not proven. However, further research is advisable.

Summary assessment of the effects discussed

In the light of the wide range of biological effects that have been discussed, a provisional assessment is given below of the health risks.

Effects on cells and sub-cellular structures

It has not been possible to prove any of the proposed effect mechanisms for athermal effects thus far. Evidence of an increased calcium flow from brain tissue in the case of non-thermal values is assessed in very different ways, but should be taken seriously. However, a health risk cannot be automatically inferred even if the findings are confirmed.

Nervous system and brain

There is serious evidence of an influence on neuronal excitability, the neurotransmitter function and various behaviour patterns at intensities that can cause a marked heating of tissue (~ 1°C). The available evidence that even weak exposure in the electroencephalogram can have a demonstrable effect on neurophysiological processes is increasingly being corroborated. It has not been clarified whether this could produce health risks.

Risk of cancer

Current scientific data on an increased risk of cancer from high-frequency radiation at athermal intensities is inconsistent and suggests that an increased risk of cancer is possible. The uncertainty relates primarily to synergitic effects. Epidemiological studies cover time periods that are too short to be able to rule out a risk of cancer with certainty. Considerable research must still be carried out.

In particular, it probably would not have been possible at all to prove possible tumour risks in connection with the use of mobile telephones in view of the considerable latency period. At international level, a major epidemiological study (the 'Interphone Study') is being conducted under the auspices of the World Health Organisation and investigates the effects of longer periods of use of mobile telephones on the risk of brain tumours. Results can be expected in 2004/2005 at the earliest.

Effects on the eye

At intensities used in mobile radio communication, damage to the eye is unlikely, according to current research. However, it can be definitively ruled out that pulsed fields with high power peaks might lead to critical exposure for the eyes in individual cases.

Reproduction and development

The studies that suggest negative influences of high-frequency fields on fertility or on pre-natal development are not convincing in general, but stress the need for further research in this field.

Blood and immune system

Lasting damage to the blood-forming or immune system with non-thermal exposure has not been proven thus far. Evidence of such effects at very high frequencies (> 8 GHz) should be further investigated.

Cardiovascular system

The current state of research does not allow any definite conclusions to be drawn regarding impairment of the cardiovascular system below thermal intensities.

Electrosensitivity

An effective connection between high-frequency radiation and the occurrence of symptoms linked with electrosensitivity has not been proven. However, further research is advisable.

6.5 Factors determining radiation exposure from Pervasive Computing

For wireless networking of a large number of mobile components, radiation sources with various technical characteristics and applications will be used as a result of Pervasive Computing (PvC).

The differences in exposure intensities and the lower-frequency components in the amplitude modulation for the various technologies are dealt with in Annex 5. There is discussion of the exposure scenarios for the different mobile radio communication systems, Wireless Local Area Networks (WLAN), Body Area Networks (BAN), Ultra Wide Band (UWB), Bluetooth as well as passive and active RF implants.

The expected additional radiation exposure from PvC is by and large dependent on various influence quantities, including non-technical ones, which together indicate the basic *scope* for PvC with regard to NIR. Table 6-1 shows the most important quantities and their determinants.

Table 6-1: Factors determining radiation exposure and their determinants

Factors	**Determinants**
Number of radiation sources	Degree of penetration
Radiated power	Radio distances Radio communication standards Hardware and software used Transmission rates Network infrastructure (ad hoc vs. cellular)
Frequency characteristics (carrier frequency, modulation frequency, standby signals)	Radio communication standards Always-on applications and standby modes
Radiation pattern over time	Always-on applications and standby modes User behaviour
Distance of body from radiation source	Applications (wearables, terminals etc.) Network infrastructure (ad hoc vs. cellular) User behaviour

The most important factors and prospective technological trends are described below.

6.5.1 Number of radiation sources, degree of penetration

With ICTs' continuing penetration into everyday life, there will almost inevitably be an increase in electromagnetic radiation sources. Two trends that will play a central role in PvC as driving forces here:

- Growing importance of mobile Internet access

- Wireless local networking of (predominantly mobile) devices and 'intelligent' objects

However, quite different scenarios are conceivable for the speed and characteristics of this propagation. In Chapter 4 three scenarios ('cautious', 'intermediate', 'high-tech') were explored whose different degrees of penetration were also reflected in moderate to very strong growth in the number of radiation sources in everyday life. For example, in the high-tech scenario 10-100 times more radiation sources would be expected, though in some cases these are weaker. However, an increase in radiation exposure cannot be inferred directly from the number of sources since circumstances are more complex (see also Annex 5).

6.5.2 Radiated power from sources

Various trends in radiated power can be observed:

- Falling power requirements on account of shorter radio links
- Rising power requirements on account of rising transmission rates
- Falling power requirements on account of technological developments

Shorter radio distances

There is a roughly squared correlation between transmission power and range, i.e. if the required range is halved, one quarter of the transmission power is sufficient. Since the radio distances are much smaller in the case of most Pervasive Computing technologies than with traditional mobile radio technologies, the devices can manage with less power. Whilst GSM terminals have to cover radio distances of more than 30 kilometres in many regions, these distances are generally only a few metres in the case of Bluetooth applications. Consequently, the maximum radiated power of most Bluetooth devices is smaller by several orders of magnitude than that of mobile telephones. The necessary transmission power is also reduced in the transition from GSM to UMTS, since UMTS networks have smaller radio cells.

Rising transmission rates

The trend towards increasingly high transmission rates calls for a rising power requirement, since there is a correlation between signal strength and bit error rate and, ultimately, the transmissible data rate. This could partially compensate for the reduction in radiated power.

Technological possibilities for the further reduction of transmission power

Many devices and embedded technologies that are discussed in connection with Pervasive Computing have a considerably lower radiated power, even at the current state of technology, than conventional mobile telephones. Furthermore, there is technological potential for the further reduction of the radiation level at a constant range and transmission rate. However, certain economic limits are placed on the utilisation of this potential, since the relevant technologies are associated with higher prices. On the other hand, experience shows that scale effects quickly take place specifically for innovative electronic components. The utilisation of this technological potential could also depend considerably on non-technological factors, such as further developments in the electrosmog debate. A brief description is given below of some important trends:

Software:

- *Optimisation of signal processing algorithms:* Incoming signals are evaluated and processed by receivers using complex algorithms. These algorithms can be optimised in order to extract the same information even from weaker signals.
- *Reduction of control data portion:* Individual protocol layers can be modified in such a way that the control data portion (the data overhead) is reduced in relation to the payload data portion. This reduces the volume of data to be transmitted and therefore the required transmission power.
- *Demand-driven power control:* Modern mobiles already have a power control system, which adjusts the radiated power to the lowest possible level according the transmission situation (distance from base station, reception quality etc.). The Bluetooth standard also requires 'intelligent' control of this kind in the 100 mW version. On the other hand, devices that are designed for Pico Bluetooth transmit constantly at 1 mW. There would, for example, be further potential for an adaptation along these lines here.

Hardware:

- *Development of low-noise amplifiers:* The sensitivity of receivers is limited (inter alia) by the noise produced in the amplifier. With the development of low-noise amplifiers (LNA), this problem should be minimised.
- *MIMO systems (Multiple Input Multiple Output):* By using antenna fields for both transmitters and receivers, the data transmission rate can be clearly increased or the same data transmission rate can be achieved with reduced transmission power.
- *Radiation pattern of antennas:* Within certain limits the radiation pattern of antennas (for example for mobile phones) can be modified so that more power is emitted away from the body than towards the body (see the study by Haider, Garn, Neubauer, Schmid). This is also of technical interest, since energy for information transmission that is absorbed in the body is lost.

6.5.3 Local versus global networks

In addition to local networking, mobile access to umbrella networks and services (Internet, mobile telephony etc.) is becoming more important. With regard to radiation exposure of users, a crucial factor is whether the 'last radio mile' to the mobile terminal is covered by a local network (for example a W-LAN) or by the radio interface of a mobile radio network (GSM and in future UMTS). In the former case, it is necessary to cover only a short distance to the local access point (generally less than 100 metres). From there, connection to the Internet or other networks is mainly by cable. On the other hand, in the case of direct access to a mobile radio network the distance to the nearest base station (in the order of a few kilometres) must be covered by radio. Accordingly, the required transmission powers are theoretically much lower where local networks are used.

However, a comparison between the maximum transmission power of a UMTS device and that of a IEEE 802.11 device shows that local networks do not necessarily operate with lower radiation than mobile radio communication networks. For a definitive comparison between the two standards, consideration would have to be given to average transmission power rather than maximum transmission power. No solid data is available on this subject, however.

Nevertheless, it is true that the potential for reducing transmission power is much higher in local networks than in mobile radio communication. For radiation exposure, the role played by local networks in the future and what radio standards they use could therefore be crucial. It would be conceivable for radio coverage to be available in a highly networked world in many locations and through different networks and for mobile terminals to log onto the network that offers transmission at the lowest power. Access to speech and data services would use mobile radio communication only when no local networks are available. This would admittedly require terminals that support unlimited 'roaming' between networks.

6.5.4 Ad hoc networks

In local networking in particular, ad hoc architectures will gain increasing importance, since they have a number of benefits, in relation to network stability and redundancy, for example. It therefore seems reasonable to ask whether ad hoc networks are preferable to cellular networks, as far as NIR exposure of users is concerned. No systematic studies exist on this subject. In an initial approach to the problem, a distinction must be drawn between two effects:

- Because there are no base stations in ad hoc networks, these (often very strong) sources of radiation do not occur.
- On the other hand, the switching and transmission function of the base stations and the higher (mainly cable-based) network levels must be fully assumed by the terminals. This means that they deal with a considerably higher data traffic in ad hoc networks than in conventional, cellular networks. For example, a mobile telephone on a DIRC network transmits not only when its user is having a conversation or exchanging data, but also when their device is required to forward another call.

The disappearance of base stations in ad hoc networks is therefore 'bought' by higher transmission activity for terminals. It is not possible to offer a general assessment here. However, it is clear that existing hopes that ad hoc networks could clearly reduce NIR exposure from mobile communications must be treated with scepticism.

6.5.5 Distance of radiation sources from the body

Many of the technologies discussed in connection with Pervasive Computing are located directly on the body or in its immediate vicinity, with the result that a large proportion of the radiated power is absorbed into the body. As a result, even a relatively low amount of radiated power can lead to comparatively high local tissue exposure. This problem is familiar from mobile telephones, but takes on a new dimension in the light of the Pervasive Computing trend. For example, wearables that are equipped with Bluetooth technology are an NIR source directly on the skin.

In the case of local networks, it can be presumed that radiation in a room of distributed terminals is negligible compared with devices in direct proximity to the body. This follows directly from the roughly quadratic drop in intensity around the devices, but applies only where the number of sources at a distance from the body does not outweigh the drop in radiation due to the distance.

The situation regarding base stations and access points is more difficult. However, the maximum radiation intensity of a base station at average distances (one metre or more) is generally considerably lower than that of terminals.[119] However, it should be noted that the base stations in many communication networks constantly emit a standby signal. This permanent low-level exposure of users could ultimately be more relevant to health than short phases of high exposure (see Section 6.5.7).

6.5.6 Carrier frequencies used

Compared with conventional mobile radio frequencies (~ 1 – 2 GHz), more recent short-range standards operate in higher frequency bands (Bluetooth at 2.5 GHz, IEEE 802.11 up to 5.3 GHz). It must therefore be clarified whether (frequency-)specific risks can be inferred from current knowledge about the health risks of high-frequency radiation. In this connection, particular regard should be had to the lower penetration depth of higher-frequency radiation (‘area of surface absorption’, see Section 6.3.4).

6.5.7 Pulse modulation and lower-frequency radiation components

Since evidence[120] is increasing that lower-frequency portions of high-frequency radiation are of particular relevance for biological effects, attention should be paid to this specific point against the background of Pervasive Computing.

In this connection, particular mention should be made of the pulse modulation and the standby signals of many wireless technologies. Pulsed radiation occurs in certain channel access modes (see Section 6.3.1). It is already used in the current GSM mobile radio communication standard and is not a specific feature of Pervasive Computing technologies. Typical pulse frequencies are in the order of 100 Hz (TDD mode for UMTS) to 1600 Hz (Bluetooth).

Significantly lower frequencies occur typically in the form of standby signals in many wireless technologies. In this connection, mention should be made of ‘always-on’ applications, where the devices are permanently in an active or standby mode and transmit permanent signals at low frequencies (a few hertz). Here the Pervasive Computing trend, with its ‘anywhere, anytime’ ideal, has a reinforcing effect.

6.5.8 Comparison of future vs. current exposure situation

The present discussion on possible health effects of mobile communication concentrates on three types of sources of high-frequency fields (Joss, 2002):

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119 See, for example, the Opinion of the nova-Institute for Ecology and Innovation (nova-Institut 2001)

120 See, for example, Huber et al. (2000).

- 'Mobile' type sources: these are terminals that are a small distance from the user or are worn directly on the body. They could be, for example, a mobile telephone, a PDA with a W-LAN card or a Bluetooth headset.
- 'Transmitter mast' type sources: this type includes base stations for mobile radio communication networks. They have a high average transmission power, but also a high average distance from users and non-users.
- 'Local base station' type sources: these are base stations for local networks, such as the fixed station for a cordless telephone system (DECT etc.) or the access point for a W-LAN.

The main characteristics of these types are shown in Figure 6-5.

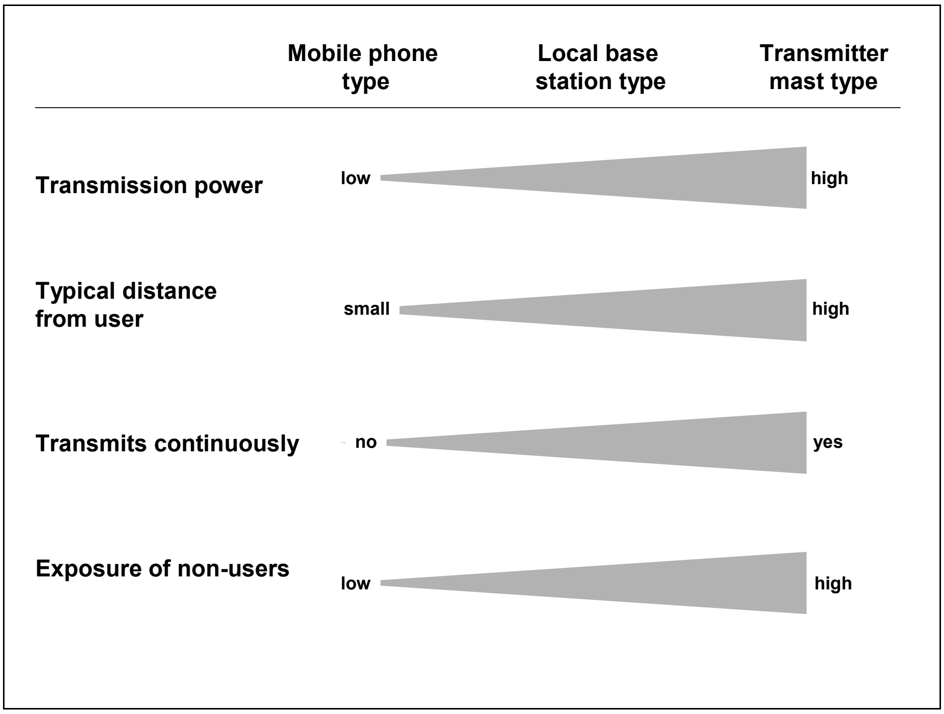
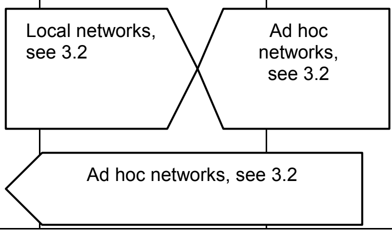


Figure 6-5: Typology of sources of high-frequency fields (Source: IZT)

This typology of sources appears appropriate for organising and assessing the new exposure situation created by Pervasive Computing. All types will continue to play a role in Pervasive Computing. In addition, there is a new type of radiation source, which has played virtually no role so far: 'intelligent objects' that form a wireless network. These smart objects communicate autonomously and are not necessarily located in the vicinity of the human body. Table 6-2 offers an overview.

Table 6-2: Effects of Pervasive Computing according to type of source

	'Mobile' type	**'Transmitter mast' type**	**'Local base station' type**	**'Intelligent object' type**
Today's devices	Mobile telephones, notebooks with W-LAN cards, DECT cordless telephones	Base stations for mobile radio communication networks	DECT base stations, access points for W-LAN networks	-
Expected **growth effects** from Pervasive Computing	**Strong** Strong growth, since all mobile terminals are covered (smart phones, wearables etc.)	**Moderate** Growth through increasing importance of mobile Internet access. Partial substitution by W-LANs (see below).	**Strong** Growth through increasing importance of W-LANs. Partial substitution by ad hoc networks (see below).	**Strong** Strong growth as a result of trend towards 'smart objects' and 'ambient intelligence'
Possible **substitution effects** from Pervasive Computing				

Source: IZT

As the table shows, as part of Pervasive Computing it will be primarily 'mobile type', 'smart object type' and 'local base station type' sources that will experience strong growth. The main driving forces are the local wireless communication trends in both ad hoc and cellular networks and the penetration of ICT into everyday objects. However, the problem of transmitter masts could worsen, since, with the growing importance of mobile Internet access, there will be a marked increase in data traffic in mobile radio communication networks. This growth will be covered only partly by W-LANs.

6.6 Conclusions

6.6.1 Conclusions on the opportunities and risks of Pervasive Computing in the health service

Pervasive Computing offers great opportunities for monitoring high-risk patients and chronically ill people, for preventive diagnostics, accident rescue, surgery, intensive care and rehabilitation. The advantages primarily benefit the patient, who can expect a quicker and better diagnosis and treatment and greater freedom of movement as a result of PvC.

For the health service in general there are potential cost reductions. However, a possible rebound effect must be taken into consideration because the technical progress here – as in all areas of life – creates incentives for wide use of the new possibilities, with the result that the cost benefits of the originally qualitative advances are counterbalanced by quantitative growth.

There is a risk in trust in technology, in so far as this replaces social contact and the holistic perception of patients in practice, because technical deficiencies and the inherently limited perspective can always have undesired consequences.

A specific risk area is active implants, which will be used much more frequently in the future under the Pervasive Computing vision. The following conclusions can be drawn for the future:

- The guidelines and toxicity tests for implants should be further improved and made more rigorous. It is good that knowledge about the materials used and cell-material reactions is constantly growing. In addition, more suitable materials are being developed. The risk of a wrong assessment of the toxic potential of the materials used will decrease.
- The long-term influence on humans from the use of *active* elements has not yet been determined and there are not yet any sufficiently validated models. Negative effects from active implants are therefore relatively difficult to assess at the present time. Systematic studies are necessary in which conceivable effects are clarified. Valid models are also needed. In the use of active implants, the advantages should continue to be weighed very critically against the possible disadvantages.

6.6.2 Conclusions on the health effects of electromagnetic fields

Whether and to what extent Pervasive Computing technologies will lead to a substantial increase in radiation exposure in everyday life depends on various influencing factors and developments, which were explained in Chapter 4. Conclusions are drawn from those considerations below.

Growing number of radiation sources in everyday life

At the same time as the increasing penetration of everyday life by ICT, there will be a marked increase in the number of radiation sources in everyday life. The individual scenarios (‘cautious’, ‘intermediate’, ‘high-tech’) differ greatly in this respect. In the high-tech scenario, the number of radiation sources is expected to increase tenfold or even a hundredfold.

Falling radiated power from individual sources

Since most technologies that are being discussed in connection with Pervasive Computing are designed for short-range networking, they generally have a much lower radiated power output than conventional mobile technologies. A further reduction in the radiation levels of all wireless technologies would be technically possible even today, but it is not marketable at present because of high prices. In the medium term, however, clear improvements can be expected. Diffusion could also depend significantly on non-technological factors such as further developments in the electrosmog debate.

This trend towards ever lower transmission powers must be weighed against the trend towards ever higher transmission rates, which mean a growing power requirement for devices. This could counterbalance the reduction in radiated power only partially, however.

Different network infrastructures

In network infrastructures for networking of devices and access to umbrella networks, two developments can be observed:

- Growing importance of local networks (W-LANs) for mobile Internet access
- Transition from cellular networks (with base stations) to ad hoc networks between terminals.

Linked to both trends is the hope that the same transmission rate can be achieved with less radiation exposure for users. It is not possible to make any general statement because total radiation is highly dependent on the radio standards and use patterns actually employed. There is some potential to reduce radiation, however, in particular for local network access (as opposed to access via GSM or UMTS).

Distance of radiation sources from the body

Many of the technologies discussed in connection with Pervasive Computing are used directly on the body or in its immediate vicinity, with the result that a large proportion of the radiated power is absorbed into the body. In effect this partially counterbalances the reduced radiated power output. In local networks, the critical sources from the point of view of health are emission sources located close to the body (because of radiation intensity) and continuously transmitting base stations (because of the permanent low-frequency whole-body exposure). On the other hand, devices not located on the body and ‘intelligent objects’ are of secondary importance.

Growing relevance of low-frequency components

Serious indications have attributed a particular biological importance to low frequencies; in view of them, special attention should be given to pulsed radiation and always-on applications. Pervasive Computing, with its trend towards unlimited availability of communication in time and space, reinforces the problem of a permanent background of lower-frequency standby radiation.

Overall trend in radiation exposure

The tendencies towards a significant increase in radiation exposure from Pervasive Computing must be weighed against many developments that point in the direction of a strict limitation of the radiation levels of the relevant technologies.

It is difficult to give an overall assessment of the situation. The question of the range of possible developments is particularly interesting, with regard to both the speed of diffusion of technologies and the technological development potential. It is therefore perfectly possible that full utilisation of the development possibilities for low-radiation technologies and development of network infrastructures proves to be ultimately more crucial for future exposure levels than the actual degree to which radiation sources penetrate everyday life, as expressed in each of the three scenarios ('cautious', 'intermediate', 'high-tech').

7 Effects on the environment

Lorenz Erdmann, Andreas Köhler

A distinction is commonly (see, for example EITO, 2002; Fichter, 2001; Türk et al., 2002), drawn between three types of effects of ICT on the environment:

- Primary effects: hardware causes environmental impacts during its *life cycle* from production, distribution and use to waste disposal (also known as 'direct effects').
- Secondary effects: the use of ICT has consequences for *other processes* (e.g. transport), whose effects on the environment are modified positively or negatively ('indirect effects').
- Tertiary effects: behaviour and structures are adapted to the conditions modified by ICT (changes in consumption patterns, new forms of work organisation, economic structural change, also known as 'indirect effects' or 'knock-on effects').

The rebound effect (cf. Chapter 5) comes under tertiary effects.

The primary environmental effects of ICT have been the subject of scientific studies for several years (Behrendt, 1998). We will use these conclusions and apply them to the Pervasive Computing (PvC) scenarios, where possible (Section 7.1).

The secondary effects of ICT have been dealt with only selectively thus far. This produces a diverse picture of positive, neutral and negative environmental effects. Empirical findings exist only selectively on tertiary effects too, for example on rebound effects in the transport sector. Because, on closer examination, it is difficult to draw a distinction between secondary and tertiary effects, we will examine them together and organise them according to areas of ICT application (Section 7.2).

7.1 Primary effects

The primary environmental effects of processes, products and services are generally assessed with the Life Cycle Assessment (LCA) methodology. An LCA is divided into the following parts: *goal definition and system limits, inventory analysis, impact assessment* and *evaluation.*

However, an LCA for Pervasive Computing (PvC) is not possible for the following reasons:

- The *cross-section technology ICT* and hence too its future manifestation PvC cover a wide and dynamic spectrum of technologies and applications, so that a narrow system definition, as would be required for an LCA, is not possible.
- An inventory analysis of *microchip production*, with more than 400 process steps, different vertical ranges of manufacture, and changing suppliers from all over the world, is not practicable and can be carried out only at great expense and for very precisely defined current products.
- Experience with LCAs relating to ICT products shows that the uncertainties of *user behaviour*[121] in the consumption phase often outweigh errors stemming from the imprecise representation of manufacturing processes. Consequently, only very simplified LCAs are carried out as a rule in the electronics sector (cf. Stutz, 2000; ZVEI, 2000).

The primary environmental effects of PvC cannot therefore be shown for practical and methodological reasons. With very simplified assessments, however, hot spots of environmental impact can be identified.

The basis for our assessment is existing ecobalances on individual ICT products and applications. In individual cases, we will discuss the extent to which the results can be applied to PvC.

The investigation focuses on the expected environmental effects of PvC in Switzerland and the development potential in accordance with the precautionary principle.

Figure 7-1 shows the basic scheme for the analysis of the primary environmental effects of PvC. They result from the production, distribution, use and disposal of the required hardware. The hardware includes:

- all microelectronic components,
- other components of devices (displays, cables, plugs and cases, etc.) and batteries,
- infrastructure (all additional components needed to operate wired and wireless networks, including special systems for power supply and cooling)

[121] e.g. how long devices are used in what state of operation, whether plug-in power supplies are disconnected when the device is not in use, etc. These are aspects of user behaviour that influence the ecological life cycle balance of an ICT product. The relevant factors are the influence of user behaviour on technology and environmental pollution. This should not be confused with the influence of technology on the user behaviour, which can lead to secondary and tertiary environmental effects.

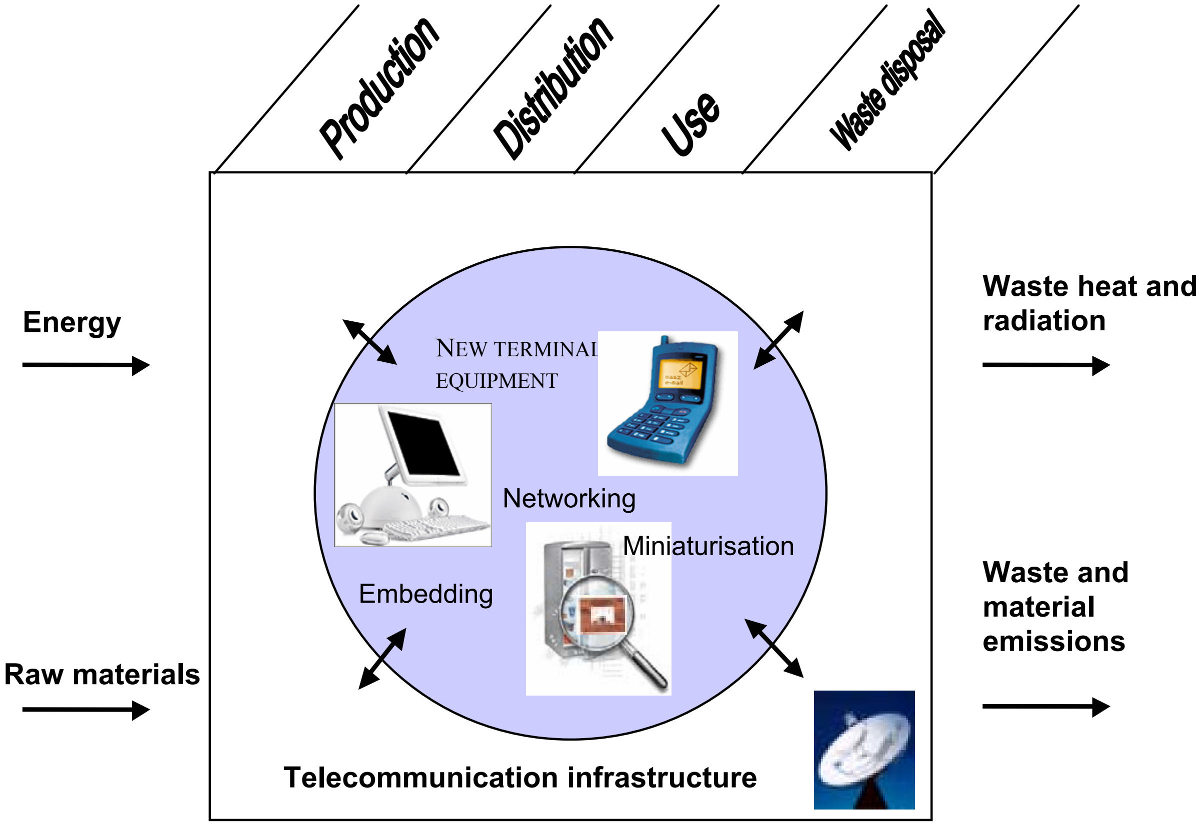


Figure 7-1: Scheme for analysis of the primary environmental effects of Pervasive Computing

The Pervasive Computing vision means, first of all, the propagation of ICT use, with the result that a general increase in the number of ICT components produced, used and disposed of can be expected. This must be weighed against further miniaturisation, which could in principle help to reduce specific environmental impacts, i.e. impact per unit of output. In addition, the increasing portability of components will give incentives to minimise energy consumption. For reasons that are still to be explained in detail, however, we act on the assumption that, all things considered, there will be an absolute increase in known primary environmental effects of ICT.

This means that the input of energy and raw materials in the system shown in Figure 7-1 will increase, which entails a corresponding increase on the output side (waste heat, radiation, waste, and material emissions).

Waste heat is relevant only in cases where it requires active dissipation and cooling. This contributes to the energy requirement and is therefore dealt with under energy consumption.

The emission of electromagnetic radiation is discussed in this study mainly from the point of view of human health (see Chapter 6), whilst effects on the living environment (plants and animals) are less significant and are not therefore examined.

The production of ICT components and devices, and the necessary extraction of raw materials, takes place only to a very small extent in Switzerland. Since this study focuses on the possibilities for action in Switzerland, we will therefore concentrate on the use and disposal phase.

Experience shows that distribution plays a secondary role in the life cycle of ICT products, as far as environmental impacts from production and use is concerned (cf. Behrendt, 1998). Distribution-related environmental impacts from PvC, like impacts from manufacture and use, could increase, but it must be presumed that there will be no fundamental shift in these relationships.

Below we identify the *hot spots* for primary environmental effects resulting from PvC in three stages:

1. Initial screening of selected fields of application (see Chapter 4) with regard to material requirements, waste, pollutants, and energy requirements.
2. Assessment of consequences of miniaturisation based on previous experience of miniaturisation trends in the ICT sector.
3. Closer analysis of the consequences of PvC for waste disposal and energy requirements through in-depth analyses and example-based model calculations.

The quantitative assessments in the following sections are based on the assumptions made in the three scenarios defined in Chapter 4. With respect to the diffusion of Pervasive Computing, additional assumptions for the three scenarios are made, as shown in Section 7.1.7.

7.1.1 Screening of the primary environmental effects of Pervasive Computing

The key question for Switzerland is the new responsibilities for waste and energy policy. Waste-policy issues are raised as a result of the changes in the volume and composition of old electric and electronic devices, old cars and residential waste (packaging, domestic waste) stemming from increasing ICT embedding. Qualitatively, the integration of microelectronics and displays in previously non-electrical objects such as furniture and clothing must be stressed. With respect to labelling, an annual output of thousands of millions of smart labels can be expected if they become established in the foodstuffs sector.

Energy-policy issues are raised in the light of the additional power consumption resulting from home networking and more intensive use of devices.

Table 7-1 sets out the hot spots for primary environmental effects that are expected in individual fields of application. In this context hot spots mean those fields where there is high damage potential and which therefore merit special attention from the point of view of the precautionary principle.

Table 7-1: Screening of the primary environmental effects of Pervasive Computing; expected hot spots are highlighted in grey.

Field of application (see Chapter 4)	**Material requirements, waste and pollutants**	**Energy requirements**
Housing	increasing embedding of microelectronics in electrical equipment in the home, waste disposal problems manageable	growing power requirements as a result of increasing (in particular wireless) networking in the home with infrastructure largely in continuous operation, after propagation only minor development possibilities
Transport	integration of microelectronics and displays in the shredder light fraction for car recycling, essentially resolvable problem	additional power requirement in cars is negligible compared with drive energy and power requirement for heating and air conditioning systems
Work	increasing ICT-related material flows stemming from wide use of ICT in completely new areas, e.g. embedding in office furniture	because of ubiquity of wireless networked components, growing requirements for availability of infrastructure; consequently, permanent operation and measures for uninterrupted power supply
Medicine	low relevance compared with health effects	low relevance compared with health effects
Wearables	waste disposal problems resulting from microelectronics and batteries in textiles, jewellery, microdevices, etc.	low relevance compared with power requirement for fixed infrastructure (dealt with under housing and work)
Media	growing mass flows stemming from wide use of ICT in completely new areas, e.g. electronic books and newspapers, at most partially counterbalanced by decline in paper consumption	because of ubiquity of wireless networked components, growing requirements for availability of infrastructure; consequently, permanent operation and measures for uninterrupted power supply
Smart labels	integration of microelectronics and displays in all waste fractions; existing waste disposal systems called into question by toxic contents	increasing energy consumption by readers, if they become widespread and are used in continuous operation; relevance compared with other PvC infrastructures quite low

We will take a closer look at these hot spots in the following sections. However, before that, there follows an excursus on the consequences of miniaturisation for the primary environmental effects.

7.1.2 Excursus: Does miniaturisation of ICT relieve the pressure on the environment?

The manufacture of a 32 MB memory chip requires around 1.6 kg of petroleum, 72 g of chemicals and 32 kg of water. In addition, 41 MJ of energy per chip is needed. By way of comparison, throughout its entire life cycle, the chip typically consumes 15 MJ of energy (Williams et al, 2002).

With the rising data transmission capacity of networks, the network infrastructure, including its auxiliary systems (e.g. waste heat cooling), takes on growing importance for the environmental relevance of ICT. In order to guarantee the demands for availability and comfort for a number of possible applications, most devices have considerable storage and computing capacities, which are required at most for short periods in normal operations. Since these untapped capacity reserves repay their cost of manufacture only very poorly, ideas for their better utilisation contribute to the protection of resources.

In principle, it could be expected that the miniaturisation of ICT – the same performance can be achieved with less and less space, material and energy requirements – will lead to a reduction in ICT-caused primary environmental impact. 'Moore's law' (see Chapter 3.1) leads almost to a dematerialisation of integrated circuits, a doubling of efficiency with regard to space, material, energy and, through the increase in switching speed, also time, every 1-2 years. Even though the trend does not progress at the same speed for all the abovementioned resources and other components (such as transmitters, receivers and batteries) do not keep pace, this is a drastic growth in efficiency, which could hardly be envisaged in other areas.

Miniaturisation in microelectronics is pushed forward above all by the reduction in size of IC structure (Moore's Law) and IC cases, components and structures in PCB construction. It allows the size of electronic products to be reduced, which creates the conditions for powerful mobile devices and for the integration of microelectronics in other devices and objects.

In some areas, however, dimensions have been fixed and miniaturisation does not therefore lead to an absolute reduction in size, but to the integration of further functions, e.g. televisions. In the case of some products, miniaturisation leads partly to a reduction in the size of the product and partly to an increase in functionality, as in the case of notebooks or mobile telephones.

On the whole, previous experience shows that the mass and energy flows caused by ICT production, use and disposal are not generally reduced despite miniaturisation. At the end of the cycle, with regard to electronic waste, there is even a rapid rise at present in industrialised countries.

There therefore appears to be a *rebound effect of miniaturisation.* The reduction in ICT-dependent mass and energy flows expected as a result of miniaturisation are not occurring.

There are several reasons why this expectation is not being fulfilled or is being fulfilled only in sub-areas:

- Environment impacts from production do not fall in proportion with the dimensions of products.

- For new, 'dematerialised' products new areas of application are being developed in order to achieve higher production runs; otherwise the high fixed production costs are not amortised. The Pervasive Computing vision can by and large be seen from this perspective.
- As can be seen from twenty years of PC development, efficiency increases lead to higher performance requirements, with the result that the resource input per PC is not reduced, but the performance output increases. This is a typical rebound effect in the sense introduced above (Chapter 5).

These statements can be illustrated by the change in technology from CRT to LCD displays, the trend in the weight of mobile telephones and a model calculation for the 'e-grains' vision. Below are the conclusion on this excursus.

Development in the mass flows of mobile telephones

Figure 7-2 shows the material mass bought with *mobile telephones* in Switzerland, based on official telecommunication statistics supplied by BAKOM and the weight trend[122] of a common mobile telephone brand.

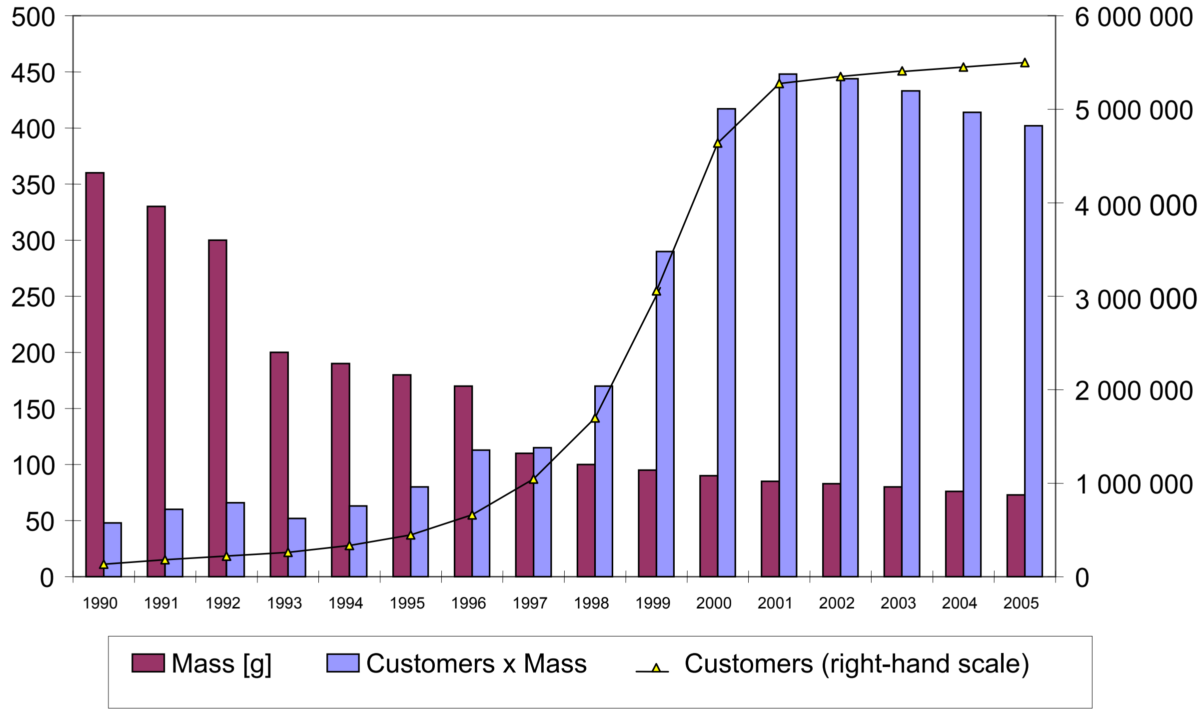


Figure 7-2: Trend in mobile telephones purchased in Switzerland by number of customers and physical mass. Source: customers: BAKOM (2001a), mobile telephone weight up to 1999: Federico (2001), mobile telephone weight from 2000 and customers from 2002: own estimates

A clear rebound effect could be seen for mobile telephones in Switzerland between 1994 and 2000. Whilst the average unit weight fell by a factor of around 2, the total

[122] We talk – rather imprecisely from the point of view of physics – sometimes of mass and sometimes of weight. A consistent use of the term 'mass' could lead to misunderstandings because of ambiguities (e.g. 'mass trend').

mass of all devices sold increased by a factor of more than 5 because of the major market growth. In view of saturating markets and falling miniaturisation potential, no great change can be expected in the near future, i.e. the total mass flow will stabilise at a very high level (400 – 500 t/a). It should be noted that this level is many times higher than even before the mid-1990s, when mobile telephones were larger and heavier.

However, the high-level stabilisation applies only for the limited outlook of mobile telephony. As soon as new mobile radio communication terminals come onto the market as a result of Pervasive Computing, there will be an additional mass flow. If, however, the boundaries between the different ICT technologies that are common today disappear and devices with new bundles of functions come onto the market developments become difficult to predict.

Developments in the mass flow of computer monitors

A saturation of the market in *desktop monitors* can be observed in Switzerland. However, LCD displays are increasingly replacing the old CRT monitors. Laptops and notebooks are equipped with LCD displays. The proportion of LCD flat-screen monitors in relation to the total number of desktop monitors sold in Switzerland in 1999 was just under 21%, but as much as 49% in 2001 (Suter, 2001). The effects of the change in technology from CRT to LCD on the quantities of monitor glass to be disposed of in Switzerland have been assessed in the following scenario:

Scenario for the assessment of the mass flow of computer monitors in Switzerland

- In a 15” LCD desktop monitor weighing 6 kg, there are around 850 g of LCD panel;[123] in a 13.3” laptop weighing 3 kg, this figure is estimated at 500 g. A 15” CRT desktop monitor weighs around 10 kg, with a glass content of around 56% (Eenhorn , 2000).
- The laptop market will grow by 30 000 units p.a. up to 2012, and the desktop monitor market by 10 000 units p.a.
- The share of LCD flat-screen monitors on the whole desktop market will rise from the current level of just under 50% in 2001 to around 90% in 2012.

[123] Viewable area like a 17’’ CRT monitor (Socolof 2001).

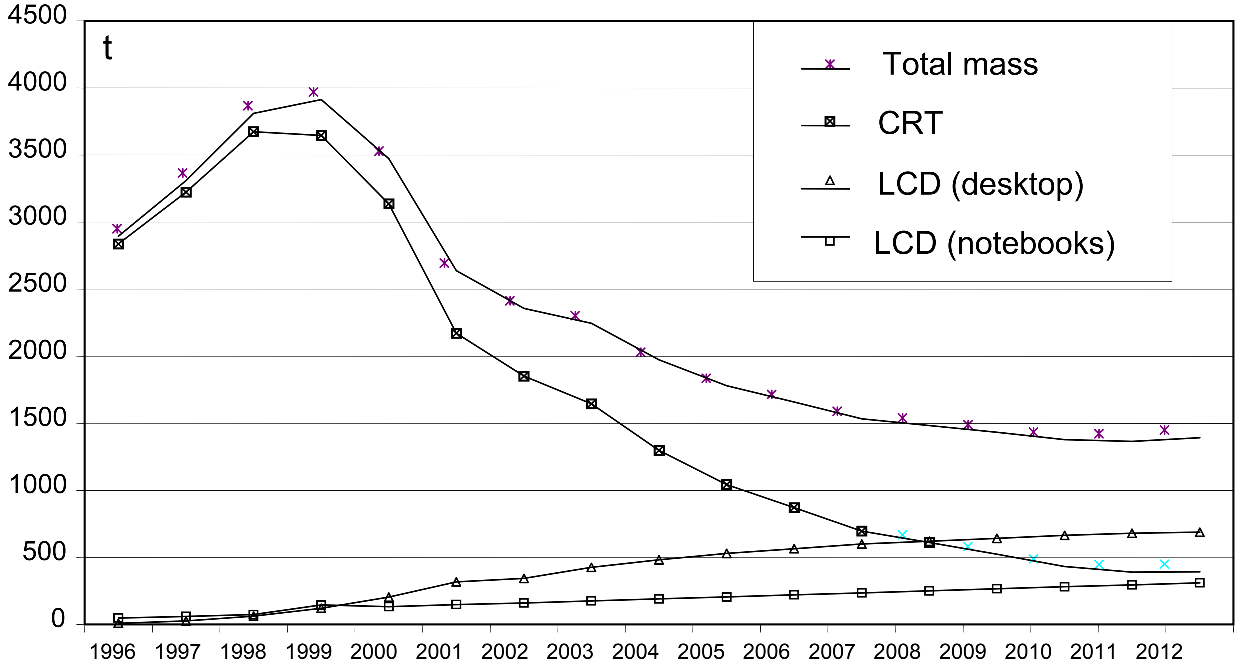


Figure 7-3: Trend in the mass flow of computer monitors purchased in Switzerland (Source: own calculations based on Weiss (2002) and Socolof et al. (2002)).

As Figure 7-3 shows, despite the assumed high growth rate for LCD desktop monitors, the mass of picture tube glass for CRT monitors will be greater than the mass of LCD monitors for some time yet. Given an operating life of 3-5 years for laptops and desktop monitors, a notable return flow of LCD monitors in the order of 1000 t/a can be expected around 2010.

The benefits of LCD over CRT monitors in terms of power consumption and waste are so marked that no rebound effect is to be expected (Behrendt, 2002). This means that in the case of monitors the efficiency increase in terms of mass and energy will probably not mean that demand for monitors rises so sharply that the environmental relief is counterbalanced. This is due, on the one hand, to the price ratio between LCD and CRT monitors and, on the other, to the fact that the market for computer monitors is already quite saturated, with the result that only a substitution takes place.

This consideration applies only to the limited perspective that underlies this example. It is well known that the manufacturers of LCD displays very quickly move into other markets, e.g. mini-displays in navigation devices, PDAs, home appliances etc, which in turn creates growth there.

The next step forward should be similar. If OLED displays become available for large screen diagonals, further efficiency increases will be possible, even in relation to LCD displays. The high fixed costs for capital-intensive production are forcing manufacturers to produce high outputs. New markets are then developed again, which increases the total quantities sold.

A scenario for the e-grains vision

According to a very ambitious vision, e-grains are to be used as 'intelligent wall paint' (see Section 3.1). In the following thought experiment, we want to show what the material consequences of this vision would be if it is taken literally.

e-grains scenario: a thought experiment

- Hypothetical assumptions relating to Switzerland: 140 000 e-grains per room (4m * 4m * 2.5m with 25 e-grains per 100 cm^2), room's storage capacity: 18 Gbit, maximum transmission power: 140 W; maximum power consumption: 2 800 W, weight of the 'computer': 10.5 kg, 15 million rooms in Switzerland (with 7.5 million inhabitants and an average of 2 rooms per person)
- For the barrier layer in e-grains there is currently no better alternative than nickel.
- This means that there is an e-grain mass of 146 000 t with a nickel content of 5 500 t. By way of comparison: Around 110 000 t of electronic waste are created in Switzerland each year.

The arithmetical example illustrates that miniaturisation does not necessarily lead to economies on materials when there is a high increase in volume. Furthermore, e-grains as 'paint' could lead to considerable building rubble pollution. Nickel, as an allergen and carcinogenic substance, would presumably lead to a significant increase in human exposure as a result of this dissipative use.

This example can also be used to illustrate global aspects. Global nickel production in 2000 was around 1.2 million tonnes (US Department of the Interior, 2000). If e-grains became standard in the developed regions of the world (North America, European Union, Japan), there would be an additional demand for nickel of well over 500 000 tonnes.

The supply of exotic raw materials could be a limiting factor for PvC, as has already been shown by the example of tantalum in 1999-2001. Only two companies extract tantulum from the mineral coltan in the Democratic Republic of Congo and Australia. This scarcity appreciably slowed the growth of the ICT industry, e.g. in the mobile telephone and games console segments (Horvath 2002).

Overview and conclusion: rebound effects resulting from miniaturisation

Aside from our example-based assessments, there are further opinions on rebound effects resulting from the miniaturisation of ICT in the specialist literature. Table 7-2 gives an overview.

It is apparent that, viewing individual product groups in isolation, miniaturisation and system integration can in some cases lead to material or energy savings. Advances in miniaturisation and the output volumes of intermediate and end products are subject to a complex network of effects, and for that reason it is only meaningful to indicate rebound effects for a certain period and for a certain geographical area. As can be seen from the example of the LCD display, a product-specific, absolute material saving for desktop monitors can be counterbalanced by other applications. The example of the e-grains vision shows that even extreme miniaturisation and system integration do not necessarily lead to a reduction in primary environmental effects.

Table 7-2: Primary environmental effects resulting from miniaturisation and system integration

	Effects in question	**Trend resulting from miniaturisation**	**Time and place**	**Source**
Integrated Circuits (ICs)	Environmental impacts from production	↗ upward	unvarying	Nissen (2001)
IC Packaging	Toxicity, energy requirement for materials production	↗ upward	1997-2002, global	Nissen (2001)
Components/ modules	Toxicity, energy requirement for materials production	specific impact is reduced [124]	no information	Stutz et al. (2000); Nissen (2001)
Computer monitors	Mass flow from monitors with CRT glass as a specific problem	↗ upward	1996-1999, CH	own calculation
		↘ downward	2000-2012, CH	
Mobile telephones	Mass flow from mobile telephones	↗ upward	1994-2000, CH	own calculation
		↘ downward	2001-2005, CH	
e-grain vision	Mass flow from electronics with nickel as a specific problem	↗ upward	> 2012, CH	own calculation based on Reichl (2001)

7.1.3 Disposal of ICT waste

Pervasive Computing will lead to a worsening of existing ICT waste problems in two respects:

- Increasing ICT waste streams: PCs, mobile telephones, PDAs etc.
- More PCBs and displays from electrical and electronic devices and motor vehicles

In addition, PvC also affects other waste streams:

[124] Falling specific environmental pollution of the modules under examination, no absolute figures for quantities available.

- Previously electronics-free waste streams become riddled with ICT.
- The addition of ICT to recycling processes may cause quality problems.

In order to minimise resource use and waste, there are three product-related main strategies: ecodesign, ecological utilisation concepts, and recycling. These strategies must be reinterpreted for PvC. Developing the three scenarios, the opportunities and limits of these three strategies are examined below.

Worsening of existing ICT waste problems

Because of the *increase in the number of ICT devices* being produced and the reduction in their service life, growing ICT waste streams have to be expected. Based on the considerations in Section 7.1.2 above, we are disregarding the counteracting effect of a weight reduction per device resulting from continuing miniaturisation. Previous experience has shown that, as part of a general trend, this effect is counterbalanced, either by increased functionality or by development of additional areas of use (which we will not take into consideration in the rather conservative estimates below).

In the cautious scenario, the growth in the number of devices is 10%, in the intermediate scenario 50% and in the high-tech scenario 100% over the whole ten-year period. In assessing the waste streams, the life cycle is also varied in the scenarios for the individual product groups.

Table 7-3: Waste streams resulting from growing numbers of ICT devices (selected products)
Source: numbers for 1999: Brunner et al. (2001); weight: Behrendt et al. (1998) and own estimates; life cycle: own estimates

	Number 1999/2001 [units]	**Weight [kg/unit]**	**Service life [a]**	**Waste stream [t/a]**		
				cautious	**inter-mediate**	**high-tech**
PCs (fixed)	3 850 000	11.60	3 / 2.5 / 2	14 887	19 650	33 495
Notebooks	850 000	3.00	3 / 2 / 1.5	850	1403	2550
Mains adapters/receivers	2 713 300	0.14	5 / 3 / 2	76	139	285
mCRT/LCD displays	3 850 000	6.40	5 / 4 / 3	4928	6776	12 320
Printers	2 925 800	7.00	5 / 4 / 3	4096	5632	10 240
Faxes, scanners, multi-function devices	285 000	7.00	5 / 4 / 3	399	549	998
Copiers	220 930	72.00	7 / 5 / 3	2272	3500	7953
Mobile telephones	2 900 000	0.80	3 / 2 / 1	773	1276	3480
Cordless phones	632 900	0.35	5 / 2 / 1	44	122	332
Handhelds, PDAs	500 000	0.40	3 / 2 / 1.5	67	110	200
Total	**19 153 240**			**28 392**	**39 157**	**71 853**

The reduction in service life clearly exaggerates the differences in the waste streams between the scenarios, which highlights the importance of service life. Often the first utilisation phase is followed by a second or third (in children's rooms etc.), which delays disposal.

The life cycle of ICT products has been reduced so far mainly because software (e.g. MS Windows; MS Office) is making increasing, often incomprehensively high demands on the hardware, which requires the replacement of hardware, and new storage media (e.g. CDs instead of floppy disks, DVD instead of VHS) require new hardware components. Given the drop in the price of new equipment, which is more powerful, many customers prefer to get new hardware rather than upgrading old hardware. The trend towards low-cost electronics has already led to low-grade electronics and disposable products in some product groups (cameras, mobiles). PvC will continue to reinforce this trend.

There is potential to reduce the number of devices by standardising interfaces (e.g. battery chargers) and offering support for several radio communication standards in one terminal (e.g. UMTS, Bluetooth, W-LAN). There could possibly also be savings in terms of new equipment as a result of multifunctionality, e.g. when a mobile phone can also be used as a PDA, door opener and TV remote control. However, a crucial factor is whether the products to be replaced are actually *not produced*. Due to the combination of actors, this is doubtful because not one systems supplier, but several competing suppliers will bring optimised individual solutions onto the market. This could lead to a large number of specialised individual devices (including wearables).

Through *sharing*, the number of devices in operation can be reduced or – as in the case of the decentralised voice mail service – 'virtualised'. The capacity of the computers installed around the world has been used only to a small extent. In initial projects such as prime number research, 130 000 users have voluntarily made available their idle computing capacity (Jain/Wullert, 2002).

The *embedding of ICT products in electrical devices and vehicles* leads to a change in their waste disposal characteristics. Displays are becoming part of cars in the upper and middle class in the form of navigation devices and screens for passengers. The same applies to controls for domestic appliances such as washing machines, refrigerators and coffee machines. The assumptions for the degrees of diffusion in the individual scenarios can be seen in Section 7.1.7.

Table 7-4: Waste streams resulting from increasing embedding of ICTs in vehicles and household devices.

	Number	**Displays [t/a]**			**PCBs [t/a]**		
	Units	cautious	realistic	high-tech	cautious	realistic	high-tech
Motor vehicles							
Cars	3 629 713	14	54	142	166	197	302
Buses	41 342	0	1	3	1	1	2
HGVs	285 246	1	1	1	8	9	14
Household devices							
Refrigerators/ freezers	4 880 000	2	24	44	98	117	146
Cookers/ovens, microwaves	3 120 000	2	16	28	62	75	94
Dishwashers	1 210 000	1	6	11	24	29	36
Washing machines	1 370 000	1	7	12	27	33	41
Tumble driers	720 000	0	4	6	14	17	22
Total		21	113	247	400	478	657

Assumptions about the integration of displays in motor vehicles and large household devices

- In a navigation device there is a 100 g display, and the same weight is also assumed for displays in large household devices. Screens for passengers in cars are estimated at 250g/screen. In buses there will be two large screens each with a 750 g display.
- In a typical motor vehicle there will be around 500 g of PCBs and in large household devices this figure will be 200 g.
- The useful life of cars is estimated at 12 years, that of buses and HGVs at 20 years, and that of household devices at 10 years.

On the basis of the intermediate and high-tech scenario, the volume of LCD/OLED to be disposed of will increase by 100-250 t/a as a result of screens in motor vehicles and the integration of displays in large household devices. Even taking other devices into consideration, in view of the forecast LCD volume from computers (around 1 000 t/a), a fairly moderate intensification of waste disposal problems can be expected. Large household devices and motor vehicles are generally shredded and the LDC or OLED panels will go in the shredder light fraction. Given the large quantities of plastic, glass and rubber in cars, these displays should not lead to appreciable additional volumes. In qualitative terms, the backlighting system for LCDs, which contains mercury, is relevant. However, efforts are being made to reduce the mercury content and to identify the components for dismantlement (Behrendt et al., 2002).

Of the two million tonnes or so of electronic waste that were produced in Germany in 1998, 150 000 tonnes were PCBs. Converting this to the volume of EE waste in Switzerland (110 000 t), the share accounted for by PCBs is around 8 000 t. According to the scenarios, the volume of PCBs from large household devices and motor vehicles in Switzerland will be around 400-700 t/a – corresponding to around 0.5% of electronic waste. It is expensive to disassemble PCBs. Boards can contain up to 400 different materials. The reusable materials and pollutants are closely packed and mixed, which makes recycling of the materials more difficult.

It is clear from the analysis of volume flows that the biggest tasks for waste disposal are determined by the increased volume of ICT products and their useful life. The embedding of information technology components in long-lasting products like large household devices and motor vehicles will cause significant worsening of the existing problems only if it is accompanied by a marked reduction in useful life. The small absolute volumes in Switzerland call for efficient logistics for separate collection. Either collection and recycling schemes for a number of devices in Switzerland should be consolidated or Switzerland should consider participating in a European collection and recycling association.

Effects on residential waste streams

The composition of residential waste will change as a result of PvC. This applies both to residual waste (rubbish bags) and to separate collections (packaging, textiles, bulky waste).

Electronics in the rubbish bag

At present, small electrical and electronic devices weighing less than 100 g – roughly the weight of a mobile phone – may be put in a *rubbish bag*, but larger electrical and electronic devices are collected separately. In 2001, around 88% of residential waste in Switzerland was taken to waste incineration plants, while the remaining 12% went to dumps. A further extension of incineration capacities can be expected. The integration of information technology into everyday objects as part of PvC will lead to a greater volume of ICT components in residual waste. In qualitative terms, the following effects can be expected:

- The backlighting of LCD displays will possibly cause an increase in mercury emissions from incineration plants, since it is not sufficiently suppressed.
- The use of halogenated flame retardants in connection with increased copper discharges (catalytic effect) and chlorinated substances may lead to increased PCDD and PCDF formation, which would possibly necessitate a more expensive flue gas cleaning system.
- There will be more heavy metals such as copper, nickel and zinc in the clinker, as well as glass from LCDs and silicate PCB material. The net effect on composition of the clinker, which is generally dumped, and exhaust behaviour cannot be assessed.

The comparatively low additive material flows from the integration of ICTs as part of PvC do not suggest that waste incineration will have to perform any new tasks. Irrespective of the waste and toxicity tasks, which will probably be manageable, an increasing amount of copper and other high-grade metals in the residual waste means a loss of raw materials that must be repeatedly balanced by new materials.

Electronics in the separate collection of textiles

The embedding of ICT in everyday objects may have important effects on *separate collections*.

- Through the introduction of ICT in packaging recycling (bottle glass, paper/cardboard/compound, plastic, e.g. PET, aluminium and tinplate), conflicts with quality standards for materials recycling are possible. (This aspect will be dealt with in the following section on the subject of smart labels).
- The embedding of electronic components in other objects may impose restrictions on re-use. We will assess below, using the example of i-Wear, what new challenges are faced by waste policy.

Around 18 kg of textiles per inhabitant are sold in Switzerland each year, of which around 10 kg per inhabitant is accounted for by clothing. Each year 32 000 t of textiles (4.4 kg/person) are given to recycled clothing collections and 7 kg/person are disposed of with residual waste (BUWAL, 2002). The gap amounting to an estimated 6-7 kg/person could be attributable primarily to the accumulation of clothes in wardrobes and the long useful life of some textiles such as curtains and carpets.

What are the consequences for these waste streams if customers adopt i-Wear in the future? At present a three-layer concept is being developed for i-Wear. A movement layer captures movement patterns using sensors, a sound layer supplies information and music through loudspeakers and an environment layer records light conditions, temperature and noise. Information transmission is via Bluetooth, but research is also being done on electronic textiles into which polymer electronics and conductive fibres are woven. Possible power supply systems are batteries, solar cells/fuel cells and body heat/kinetic energy. If we assume that a typical i-Wear customer purchases a jacket weighing two kilograms every two years, the useful life of the power supply unit is also two years. With a population of 7.3 million Swiss people, this produces the volume flows shown in Table 7-5 for the three scenarios:

Table 7-5: Specification of the scenarios for i-Wear

	cautious	**intermediate**	**high-tech**
Level of diffusion	1%	20%	80%
Waste (i-Wear)	73 t 0.01 kg/inhabitant per year	1 500 t 0.21 kg/inhabitant per year	6 000 t 0.82 kg/inhabitant per year
Waste (energy supply)	36 500 batteries	730 000 batteries (max. 25 t), photovoltaics, fuel cells	3 million batteries (max. 100 t), photovoltaics, fuel cells, body energy converters

The 10 g of i-Wear waste per inhabitant per year in the cautious scenario are of no consequence when compared with the 4.4 kg that go to recycled clothing collections and the 7 kg that are disposed of together with the residual waste. In the intermediate and high-tech scenario, however, the scale is relevant. Special features of the disposal of i-Wear are the high-tech-oriented user group, the presumably low useful life, and the pollutants in the microelectronics.

If the reason why the i-Wear stops being used is that the electronics break down or newer, more powerful i-Wear is to be purchased, it must be asked, as far as recycled clothing collection is concerned, whether the i-Wear can actually be re-used. Old clothing is sold predominantly in second-hand shops, distributed to the needy or exported to developing countries. It is extremely doubtful whether i-Wear that is no longer used will be accepted by the customers or recipients, since older customers are less open to modern technology and younger customers would prefer to buy a high-tech product new, in keeping with their lifestyle. Reconditioning to restore functionality seems fairly implausible for these reasons and separating the 'intelligent' components from the other textiles is very expensive and could ruin the clothing in most cases. Exportation to developing countries will – aside from other obstacles such as acceptance issues – merely move the waste disposal problems elsewhere.

The introduction of i-Wear into residual waste is an additional source of pollutants in incineration plants and at dumps. In accordance with the precautionary principle, it may be necessary to work towards ensuring that electronic components (e.g. batteries and loudspeakers) are separated from i-Wear and that, in the case of compounds, materials with a very small share of toxic sustances, e.g. polytronics, are used. In terms of waste policy, the question arises whether i-Wear is an electronic product or can continue to be disposed of together with the residual waste. By way of comparison, at present electronic waste in Switzerland amounts to around 110 000 t, corresponding to 15 kg/inhabitant per year. i-Wear would make a significant contribution to the growth of electronic waste streams, though less so in the intermediate scenario, with 0.21 kg/inhabitant per year, than in the high-tech scenario, with 0.82 kg/inhabitant per year.

If it is not possible to convert the power supply for wearables to solar cells/fuel cells or body heat/kinetic energy, a growth in old battery streams can be expected. In the intermediate scenario, there will be an additional volume of up to 730 000 batteries per year, whilst in the high-tech scenario it would be almost 3 million in the worst case. If, as has been the case with mobile phone chargers, standardisation is not possible, worsening waste problems are expected to be caused by charging devices. Aside from the effects on battery recycling capacities, particular attention is drawn to the need to develop regenerative or body-based energy supply systems for reasons of waste policy.

At present in Switzerland, at 2332 t, around 67% of the weight associated with battery sales is collected separately and sent for recycling. In the case of Germany, the total volume of device batteries amounts to one thousand million per year, with a weight of around 30 000 t (Umweltbundesamt, 2001), which corresponds to an average unit weight of 30 g. If similar ratios are taken to exist in Switzerland, it will be necessary, as a result of i-Wear, to dispose of an additional volume of batteries amounting to just under 25 t in the intermediate scenario and amounting to slightly less than 100 t in the high-tech scenario. In comparison with the total battery volume, these are not major substance flows, but, combined with the increasing propagation of portable terminals, they will noticeably contribute to the growth in the volume of batteries to be disposed of (see Table 7-5).

The example of i-Wear makes clear that embedding ICTs in objects that were not formerly electrically operated may lead to a change in waste streams. The waste volumes are not dramatic in the case of i-Wear, but if we consider the whole product group of wearables and other product groups such as ‘intelligent furniture’, digital ballpoint pens and electronic paper, together they may lead to significant qualitative changes in the residential waste industry.

If the innovation dynamism of ICTs is also transferred to long-lasting goods such as office furniture, even ‘intelligent office furniture’ would be incinerated, and it would be necessary to look at the removal and recycling of electronics.

On the whole, it must be examined which waste streams should be treated separately and, if necessary, logistics and separation capacities will have to be adapted and consolidated.

Smart labels in other cycles of reusable materials

If smart labels are applied to products, this may have different effects on the further sections of the life cycle, depending on the product and the technology used.

Smart labels (RFID transponders) are generally based on flexible substrate materials like polyimide or polyester. The antennas are made of copper or aluminium. The standard PCB material FR4 is used mainly for the housed components. The substrate is so thin that FR4 can be applied as a flexible material with a copper antenna or conductive thick film paste.

Commercially available chips are based mainly on silicon technology. However, progress has been made in polymer electronics, where the electronics could be printed directly onto packaging like ink. At present, it is still unclear whether smart labels based on polymer electronics can be realised without copper cladding. The electrical contact in chips is made mainly by nickel bumps, whilst bonding technologies (Ni/Au) are used predominantly for flexible, low-cost chips. The smart labels produced by Gemplus (used for retail, transport/logistics, libraries, parcel services and aircraft baggage) have dimensions of around 50 by 50 mm and weigh around 0.1 g/unit. A smart label for laundry weighs around 0.5 g (GEMPLUS, 2002). Limits are placed on miniaturisation by the required transmission powers of antennas.

Table 7-6 gives an overview of the scenarios for smart labels.

Table 7-6: Assumptions about smart labels in the scenarios

	cautious	**intermediate**	**high-tech**
Logistics and transport	Production and distribution Recording of time and persons	Payments on public transport Book and video libraries Location of people and objects (small areas)	Localisation of people and objects by the use of active transponders (wide areas)
Packaging	Level of diffusion 1%	Level of diffusion 20%	Level of diffusion 100%
Household	Organisation of audio media (~ 200 items/household)	Media and laundry items (~ 1000 items/household)	all objects (tens of thousands of items/ household)

For many areas in which smart labels can be used (e.g. production and distribution, book and video libraries), no meaningful estimates of numbers of units can be made. Since there is no general data on the number of objects in Switzerland, the following figures are merely intended to illustrate that there are several thousand million objects for which smart labels might be used:

- Each year, the Swiss postal service handles almost 5 billion postal items and each year supplies around 500 million stamps (Die Schweizerische Post, 2002).
- According to the Swiss Association for Public Transport (2002) more than 1.65 billion people used public transport in Switzerland in 2001 (Verband öffentlicher Verkehr, 2001).
- In the intermediate scenario, the number of smart labels on media (CDs, MP3, DVD, video, books) and laundry items amounts to around 1 000 units/person, with around 200 units per year ceasing to be used. For the entire population of Switzerland, waste for smart labels is then around 1.1 billion units per annum.
- In 2001, 320 265 t of bottle glass were consumed in Switzerland and 293 700 t of bottle glass were collected (BUWAL, 2002b). Assuming a weight of 200 g per glass or bottle, the number of units sold is then 1.6 billion and the number collected is 1.46 billion.
- There is a total volume of around 300 million aluminium drinks cans, tubes and pet food bowls in circulation. The ratios of return are 93%, 30% and 65% (BUWAL, 2002a).
- Of 756 million PET bottles, 622 million were returned (2000) (BUWAL, 2002e).
- In 2001, 17 200 t of tinplate were consumed for cans and 12 000 t were collected. With the typical weight of a tin can of 55 g, the number of units is 312 million and 218 million (BUWAL, 2002d).

This rudimentary assessment gives around 10 billion units. Taking into account a weight of 0.1 g/unit for smart labels, this corresponds to a mass of 1 000 t in the high-tech scenario. However, smart labels can also be used for a number of objects on a larger scale (including paper packaging, industry, etc.). This would mean an annual mass of 100 t in the cautious scenario, 2 000 t in the intermediate scenario and 10 000 t in the high-tech scenario. The large difference in these figures indicates the need for monitoring that also incorporates qualitative aspects.

Using the example of food packaging, possible tasks that must be performed by waste policy are identified below.

Example: Smart labels for food packaging

The frequently cited vision of the 'intelligent refrigerator' requires data exchange between the refrigerator and food packaging. Supplementary product information, for which there is no space on conventional paper labels, can also be transmitted. In addition, smart labels on food packaging allow fully automatic payment transactions to be made in supermarkets (the cashless supermarket).

Food packaging has a short useful life and in some cases is not disposed of with domestic rubbish, but is collected separately and recycled. As far its materials are concerned, a distinction is drawn between the following fractions: bottle glass, paper/cardboard/composite, plastics (e.g. PET), aluminium and tinplate. If most food packaging is to be equipped with a smart label, the main question raised concerns the acceptability of the materials for recycling and the dissipation of pollutants. The answer to this question differs depending on the smart label technology used and the product labelled.

There is still little awareness of these potential problems. The Fraunhofer Institute for Reliability and Microintegration (IZM) has conducted initial assessments for industrial partners on the effects of the introduction of smart labels into recycling cycles. The results are not available to the public, however.[125] The assessments made below should be seen as initial indications of a possible need for research and action, even though there is no valid basis for assessment.

- Glass recycling:
  In 2001, 320 265 t of bottle glass were consumed in Switzerland and 293 700 t of bottle glass were collected, 34% of which was used for the domestic production of new glass containers. The remaining waste glass, amounting to 191 000 t, was either exported, used in the production of building materials or ground and used as a sand and gravel substitute in the building industry. Existing paper labels do not have to be removed before this melting procedure, because they burn up completely at 1 500°C.
- The permitted pollution value for waste glass in Germany is 25 g/t for ceramics, stoneware and porcelain and 5 g/t for nonferrous metals. With a smart label weighing 0.1 g on 200 g of bottle glass, the proportion by weight is 500 g/t. If – as in the high-tech scenario – all bottle glass is fitted with smart labels, breaches of such quality standards cannot be ruled out and even in the intermediate scenario the proportion by weight amounts to around 100g/t. As far as processing is concerned, it would have to be guaranteed that the smart labels are removed. If chips and substrates consist of organic materials, they should be incinerated without difficulty, but there is a risk of copper entering the glass.
- Paper recycling:
  No meaningful assessments can be made about the volume of paper and cardboard packaging because of the large number of different uses and sizes of paper and

[125] Oral communication by Mr Middendorf (Fraunhofer Institute IZM) on 25 October 2002

cardboard. Sorting provides quality assurance before the used paper is delivered to producers. When the used paper and cardboard are sorted, non-paper elements and unwanted paper and cardboard are separated. Other foreign materials are divided in the pulper and separated off. The introduction of copper into paper recycling through paper clips and staples is a well-known problem. No additional problems with regard to copper are to be expected from the use of smart labels. The silicon or polymer substrate can also be separated off in the pulper, with the result that the labelling of paper and cardboard with smart labels in small volumes is not expected to raise any new problems.

- Tinplate recycling:
  According to the Informations-Zentrum Weißblech e.V. (Tinplate Information Centre), no recycling problems occur as a result of coatings, compounds and residual adherents, e.g. the remains of labels, if the steel works' quality standards for scrap metal are met.[126] This is partly because the recycling process takes place at temperatures of around 1 600 ºC, at which coatings are completely incinerated. If smart labels were polymer-based, they would largely be incinerated, but a considerable amount of the silicon substrate is expected to enter into the slag. On the other hand, the addition of copper to the steel recycling process is more of a problem. The accumulation of copper in steel as a result of recycling of old products is not a feature peculiar to PvC, however. In view of the much higher recycling volume and the addition of copper to shredder scrap, it must be presumed that little will change regarding this situation.

- Aluminium recycling:
  The separation of foreign materials in aluminium recycling is done by magnetic separators, eddy current procedures or swim-sink processes. Coatings are removed either by separate processes or during the smelting process. Common paper labels are incinerated in the smelting process. Cu proportions in the scrap are particularly critical for aluminium recycling, but Fe, Pb, Sn and Zn may not exceed a maximum level of 1% either. For the recycling of alloy groups, the different proportions of silicon are the crucial factor. The proportion of silicon in wrought materials is between 0.001% and 0.7%. If silicon-based smart labels are used, breaches of quality standards are possible. Aluminium packaging weighing 50 g with a smart label of 0.1 g has a content of foreign materials of around 0.2%. The copper portion may also contribute to a long-term accumulation in the aluminium cycle, but should not in itself cause problems in the near future.

- Plastics recycling:
  Thermoplastics like PET packaging are melted in a temperature range of 150-300°C in recycling. Foreign materials are strained off. In the case of polymer-based smart labels, material incompatibilities could occur, whilst for the silicon substrate straining off can be expected to be successful. The smelting of solder alloy could cause problems if, for example, the lead enters the plastic and possibly exceeds the maximum quantities for metal (including under the EU directive on packaging).

The example of smart labels on food packaging highlights the complexity of the material effects of smart labels in different recycling cycles. Depending on the materials contained in the smart labels and the cycle, a slightly different assessment of material compatibility has to be made. The ubiquitous use of smart labels could cause problems

[126] At least 93% tinplate packaging; other Fe proportions suitable for the same recycling are counted towards the 93% quota, up to 5% (Informations-Zentrum Weißblech e.V., 2002)

because additions to waste streams are almost irreversible as a result of high entropy. In the light of the accumulation of copper in steel recycling, the scrap metal specifications have been tightened, which has in some cases led to expensive pre-separation of cupriferous elements. Given the low, finely distributed volumes of smart labels, separation into individual procedures is considerably more difficult.

Conclusion on the disposal of ICT waste

At present, too little consideration is being given to the possible effects of Pervasive Computing on the waste industry. The effects can be divided into volume problems and collection and recycling problems.

The volume problems result from the general growth in the number of computers, rising sales figures for mobile telephones, PDAs and other small devices, the integration of ICTs into many everyday objects and the shortening useful life of individual product groups.

As a result of the penetration of potentially all objects with highly miniaturised electronic components, the collection of products is made more difficult with PvC. The separation of miniaturised electronics will come up against economic and environmental limitations in many cases, which will inevitably lead to discharge into other waste streams and material cycles. Miniaturisation means a low content of reusable materials, with the result that recycling is not really worthwhile, and high diversity of materials and the melting of electronic components make recycling at a higher value-added stage even more difficult.

However, since the PvC vision has not yet been realised, there is extensive development potential which should be utilised proactively by taking into account environmental effects in the design phase, by taking measures to extend useful life and by adapting recycling systems.

7.1.4 Power requirements for terminals and 'intelligent objects'

In view of the expected large number of terminals and 'intelligent objects' in the PvC vision, the question of power supply arises. A distinction may be drawn between the following categories:

- Devices that do not operate or consume energy very differently from current digital terminals (PCs, PDAs, mobile telephones, etc.).
- Stationary devices that are used at a fixed location and so turned into terminals as a result of increasing networking ('intelligent household devices'), which has consequences for energy consumption (standby losses).
- Wearables and portables that are smaller, lighter and more numerous than current portables and therefore require new power supply systems.
- Components with very low energy requirements that can be operated with passive supply units, as are currently prevalent with smart labels.

Components in *means of transport* are a special case. Their energy requirements do not really raise any problems, because compared with the drive energy and other power consumers (heating, cooling) they are of no real significance and the components can generally be connected by cables.[127]

A further special case is formed by *implants*. They are powered in some cases passively by body energy, or – in the case of higher energy requirements – by special batteries. Implants are of no consequence as far as their energy requirements are concerned either.

The two special cases will not be taken into consideration below.

Power requirements of current digital terminals

In operating and standby modes, the computing and memory units of digital terminals must be supplied with energy. The waste heat that is created can be carried off either passively through design measures or actively by ventilation fans that also require power. Important factors influencing power requirements also include factory-installed power management systems and utilisation patterns in practice.

The terminals for Internet access that can be obtained on the market at present include:

- PCs in combination with modems or network cards
- Portables: mobile telephones and handhelds
- Embedding of ICT: digital television, household devices and means of transport

In the case of desktop PCs with a CRT monitor, it is generally the monitor that consumes the most power. More energy-efficient LCD displays and the use of energy-saving modes, on the one hand, and rising power consumption by main and graphics processors, on the other, have shifted the emphasis. An Intel 80486 processor has a power consumption of 3 W, whilst a current Pentium 4 processor consumes around 65 Watts (Türk et al., 2002).

[127] However, the requirements of an uninterrupted supply are more difficult to meet here than in the case of stationary equipment, with the result that operational security and availability may be greater problems than energy consumption.

A 19” IBM G96 CRT monitor consumes 110 W (11 W idle), whilst an equivalent 17’’ IBM T750 LCD monitor consumes only 45 W in operation (3 W idle).

Significant losses of current occur if chargers for mobile telephones or PDAs are left connected to the socket. A mobile telephone consumes around 6 kJ/day in battery operation and 110 kJ/day if the charger is switched on (Jain/Wullert, 2002). The amount consumed can be reduced by appropriate battery and plug-in power pack design.

Little attention has been paid in the public discussion to the high energy requirement for the cooling of ICTs. First, the devices consume power to carry off heat and, secondly, in the case of larger devices the heat created must be further carried off in air-conditioned rooms. Industry is working on systems for its devices that reduce forced cooling (e.g. by fresh air) or can be set up where existing cooling effects can be used (e.g. appropriate floors, air currents).

There are great potential savings in the choice of data transmission system for ICT devices. For example, a Bluetooth-enabled terminal consumes much less power than a device with equivalent functions that supports the W-LAN standard. An environmental LCA-based comparison between the components of a USB system and those of a Bluetooth system reached almost identical conclusions with respect to CO_2, NO_x, SO_x and methane emissions (Andersson et al., 2000).

The trend towards hybrid network structures suggests that the devices will support several standards and operate depending on the situation in W-LANs and Bluetooth networks. These complex environmental effects can be influenced by government action only with difficultly, given the high level of innovatory dynamism and competition.

The way in which the Internet is used depends greatly on Internet access and pricing. If the customer takes the option of a flat-rate broadband connection, there are no incentives for energy-aware Internet use. There is a great temptation to leave the associated terminals constantly switched on in order to be permanently online.

Broadband connections include all connection technologies that have a higher data transmission rate than a telephone modem or ISDN connection. They are constantly on standby without the need explicitly to create a connection to the Internet. The main fixed-network broadband transmission technologies are ADSL and CATV, while Powerline (data transmission over power cables) is still a niche market and will probably remain so, since this technology is not really competitive against W-LAN and Bluetooth.[128] Broadband connections over glass fibres and leased lines are aimed at business customers.

In the wireless sector, UMTS will offer a comprehensive broadband infrastructure, whilst broadband islands can be built with W-LANs.

The number of ADSL connections in Switzerland has risen from 5 000 (2000), through 80 000 (end of 2001) to 95 000 (May 2002). In the case of CATV Internet customers, there has been growth from 38 000 (2000), through 100 000 (end of 2001) to 155 000 (May 2002). According to a BAKOM study, broadband services will become established as a result of market forces and there is no need for government action (BAKOM 2002).

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[128] Contrary to a widely held view, Powerline – and not only radio communication technologies – raises the question of undesired radiation, since the unshielded power cables radiate high-frequency signals.

All in all, in the light of more powerful terminals, more intensive use and permanent standby operation, growth in power consumption by laptops, PCs, mobile telephones and handhelds can be expected. Since these devices are not produced in Switzerland, the potential for policy action lies predominantly in the diffusion of energy-efficient terminals and in influencing user behaviour.

Standby losses from household devices

Because of the large number of 'intelligent household devices', significant additional consumption can be expected as a result of standby losses. At present, one Internet interface in a household device consumes around 3 W, but using 'switch mode' technology power consumptions of 1 W could be possible.

If, for example, the cooker, refrigerator, freezer, dishwasher, washing machine, tumble drier, extractor hood, microwave, lighting and circulating pump are connected to the Internet, under current conditions there will be an additional constant power consumption of 30 W.

Whilst most new electrical and electronic devices have a lower power consumption than the average existing devices, the current trend is for devices to be increasingly in standby mode (always-on, anytime) and for a growing number of devices (e.g. with a rising number of households and a higher level of equipment).

The contribution of computerisation to energy efficiency cannot be determined. On the one hand, it allows the energy required by the washing process to be optimised, for example, whilst on the other it may give rise to additional power consumption through connection to the Internet. It is therefore not possible to make a general statement about all groups of devices.

In most classes of devices there are wide ranges in terms of no-load losses, but when purchases are made other priorities, such as price, functionality and design, take precedence. It has proved to be difficult to influence user behaviour with regard to electrical and electronic devices, and for that reason (semi-)automatic technical solutions are preferable.

There will continue to be considerable energy saving potential (e.g. with plug-in power supply units), but the energy efficiency issue can be seen less as a task for innovation, than as a task for diffusion (Brunner, 2001).

In general, it is to be feared that, all things considered, standby problems will be worsened as a result of PvC.

The special case of digital television

It can be expected that the *introduction of digital television* will lead to a marked increase in standby losses in the home. In the United States, the following standby outputs of various components were ascertained:

Table 7-7: Standby outputs of selected components in the home
Source: (Meier, 1999) cited in Aebischer/Huser (2000)

Components	Standby range [W]	Standby average [W]
Security systems	4-22	14
Digital modem	10-14	12
TV receiver (analog)	2-18	10.5
TV receiver (digital)	19-24	23
Satellite receiver	10-19	13
Cordless telephone	1-5	2.5

In a study by the Wuppertal Institute, the range of power consumption for digital television platforms is given as 40 W (business as usual) and 9 W (optimisation) (Langrock et al., 2001). The savings potential can be developed in particular by more intelligent power management in the standby and 'off' modes (0-1 W). However, this requires coordinated joint action by industry and politics in Europe and throughout the world.

Power supply for wearables and portables

Reichl (2000) states that around 50% of all electronic devices are battery-operated. However, the exponential advances in performance in the last few decades stand in contrast to a merely linear increase in the power density of conventional batteries.

Research should develop autonomous energy supply systems for portables and wearables that guarantee both high computing power when needed and low overall energy consumption. Development objectives for the battery industry include an increase in power density by a factor of 3-5 and the reduction of self-discharge. With chip-controlled 'intelligent batteries', battery life can be extended and the remaining capacity can be determined more precisely.

Great progress has been made with lithium-polymer batteries in particular. In addition to their high energy density, their flexibility also makes possible thin-film batteries for smart labels and smart cards. The potential for battery-operated smart cards is estimated by manufacturers at 10-20% of all chip cards; in 2000, this figure was 3.8 billion worldwide (Reichl, 2000). These flexible batteries could also be integrated into watches and belts.

Since conventional batteries have inherent limitations, research is also being conducted into alternative energy supply systems: solar cells, fuel cells, body energy. Whether photovoltaics and body energy are adequate energy sources depends largely on the reduction of energy consumption for wearables and portables. It is expected that in a few years mobile telephones will be able to cover their energy requirements with solar cells (Reichl, 2000).

There is also potential to reduce energy requirements for wearables and portables in systems architecture and in the formulation of algorithms for protocols (e.g. for data indexing or wireless data transmission).[129]

[129] Through half duplex multiparty calls power consumption for a telephone call can be halved.

Reliable fuel cells could also cover high energy requirements, but this would remove a considerable incentive to reduce energy consumption. There is a need for research into flexibility and increased capacity.

For wearables specifically, energy could also be provided by the human body, in particular kinetic energy from the legs, and body heat. With a view to using energy from walking, work is being done on piezo films, and thermo generators for small temperature differences are being developed. However, the breakthrough in technically and economically realisable variants is still to be made, aside from niche examples such as remote control for locking motor vehicles (Timmers et al., 2000).

Major environmental relief potential could be realised if it becomes possible to reduce power consumption of future wearables and portables to such an extent that power can be supplied by heat or kinetic energy from the body or by light. However, even then they will in many cases still require rechargeable batteries as back-up power supplies.

The use of rechargeable batteries made from more environmentally-friendly materials will therefore be a central environmental aspect of PvC.

The Fraunhofer Institute for Reliability and Microintegration (IZM) has assessed various battery systems for wearables and portables on the basis of the toxic potential indicator (TPI) for their materials (FHG-IZM, 2000). Of the primary (non-rechargeable) batteries, the lithium batteries (Li-MnO_2) came out worse than conventional zinc-carbon, alkali-manganese or zinc-air batteries, in particular because of their nickel content. Among the secondary (rechargeable) batteries, Li-MnO_2 batteries have clear benefits in terms of the TPI in comparison with nickel-cadmium or nickel-hydrogen batteries. In the long term, polymer-electrolyte-membrane-based fuel cells could be an alternative to existing battery systems.

7.1.5 Rising power requirements from networking

The 'Always-on – Anywhere & Anytime' paradigm implies that, in the light of the growing number of 'intelligent' devices and products and the propagation of hybrid network structures (UMTS, W-LAN, Bluetooth etc.), we must expect rising power consumption in all operating states.

Figure 7-4 shows the annual power consumption for ICT devices in Switzerland in 2000. The office and communications device sector contributes a total of 1 840 GWh (3.59%) to total electricity consumption in Switzerland. Of the electricity consumption for all EE devices – 51 213 GWh (equivalent to 54.42%) – this is 6.6%.

Which of these devices are now to be attributed to networking is partly a question of definition. Depending on its use, a PC can be regarded as an Internet terminal or purely a writing device. However, the situation is clear with regard to consumption by computer networks/servers, which is as high as consumption by stationary PCs. Consumption by networks and servers is affected by PvC to the extent that the data throughput will increase considerably. It must therefore be presumed that network infrastructure and the provision of content by servers will be the main part in PvC energy requirements.

In order to examine energy requirements more closely, we will use a study on networking of private households by Aebischer und Huser (2000) and apply the findings to our scenarios.

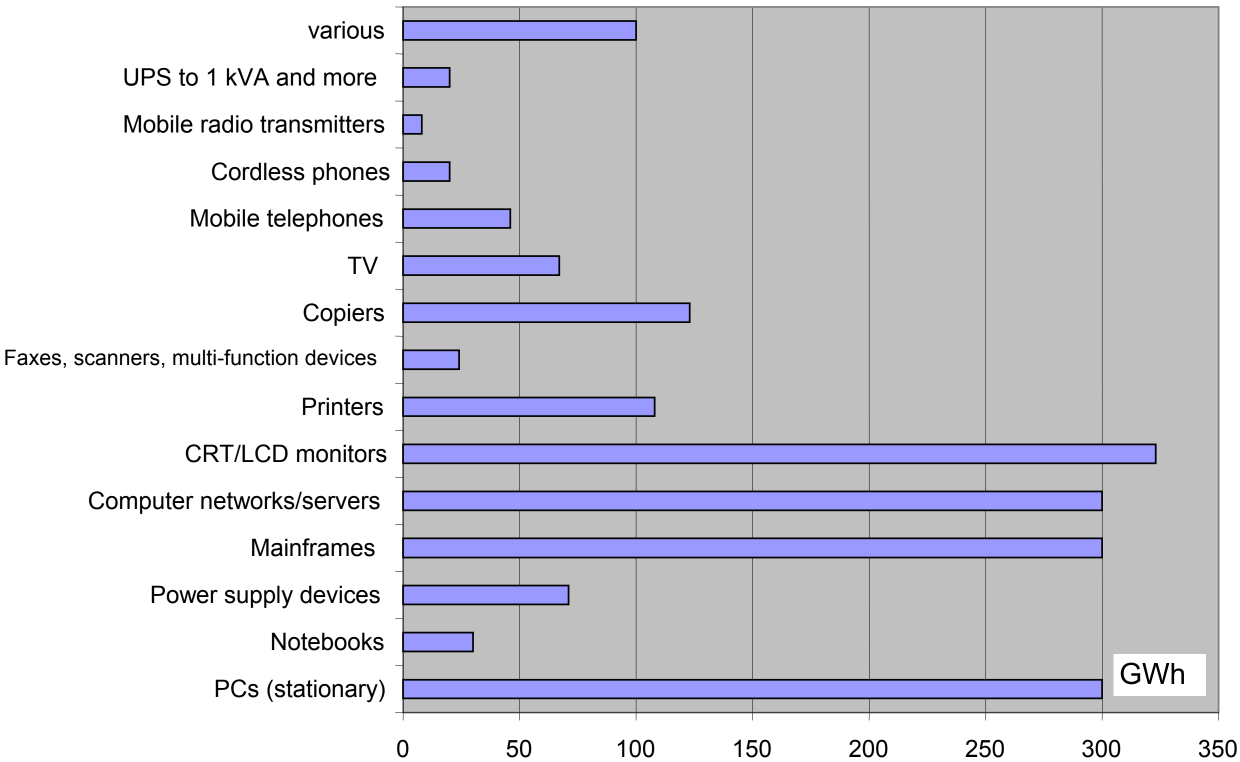

Figure 7-4: Annual power consumption by ICT devices in Switzerland for 2000. Source: Brunner et al. (2001)

Networking in private households

The effects of home networking on power consumption in Switzerland were examined in a study on behalf of the Federal Office of Energy (Aebischer/Huser, 2000).

According to the authors, networking will be the biggest growth factor for power consumption in the household sector in industrialised countries. Three variants of home networking were examined (see Table 7-8).

In the case of networking with the EIB, light control makes the biggest contribution to standby power output at 20-30 W. Multimedia data cannot be transferred using the EIB, but requires an Ethernet, coaxial cable or wireless communication link. If an Ethernet architecture is chosen, an additional 4 W standby power demand can be expected for each connected device. There are also large differences between individual variants if cabling is chosen. For example, a comparison of coaxial and twisted pair cabling with LAN cabling revealed that twisted pair cable produced 55 times less environmental impact (Brandström, 2000).

In two scenarios, the *range of possible developments* in additional power consumption up to 2020 was outlined, with the vision of a fully networked home as the maximum variant and a minimum variant. The simulation was calculated separately for the areas of multimedia, large household devices and light control. The use of additional devices and increased utilisation of devices and systems were taken into consideration. It was assumed that the reduction in power demand will be counterbalanced by growth in services.

The following were not taken into consideration by Aebischer and Huser: networking of small household devices, security and other additional home technology, networking by Powerline and radio communication, additional power consumption from the use of mobile terminals. However, because some of these will be important in the specific case of PvC, the study by Aebischer und Huser (2000) can be seen as a *cautious estimate* with regard to PvC.

Table 7-8: Standby power resulting from home networking (Source: Aebischer/Huser, 2000)

Variant	**Main feature**	**Standby power**
New detached family house with EIB	latest ICT, two floors and 6 rooms, EIB for home technology, Ethernet for data transmission, coaxial cable for video signal transmission, telephone and satellite receiver	**20 W for EIB** (building technology) **55 W for multimedia** (Ethernet: 42 W, television signal distribution 13 W)
Ethernet in older house	Renovation of an old farmhouse, twisted pair cat. 5 cabling, Internet in 9 rooms with 15 connection points	**75 W for multimedia** (PC 30 W, hub 23 W, ISDN NT 1 W, ISDN Gigaset 3 W, 3 network connection cards 6 W, 3 webcams 6 W, 3 decentralised control devices 6 W)
Model household with EIB	14 rooms, house and household devices fully networked by EIB	**30 W for EIB** (building technology (light, shutters, security))

Table 7-9: Additional power consumption per networked household and year as a result of networking
Source: Aebischer/Huser (2000)

	Power consumption per household (2000)	**Power consumption per household (2012)**	**Power consumption per household (2020)**
Multimedia[130]	323-727 kWh	605-1127 kWh	811-1393 kWh
Large household devices[131]	489-708 kWh	564-783 kWh	615-834 kWh
Light control[132]	57-328 kWh	57-328 kWh	57-328 kWh
Total (average)[133]	926 kWh	1680 kWh	2175 kWh

The average[134] power consumption for home networking for 2000, at almost 1 000 kWh, is between 20 and 25% of current consumption. By 2020 this figure will more than double.

There was then an assessment of the effects on power consumption in Switzerland, broken down into single and multiple family dwellings, and by diffusion rate, saturation level and diffusion time. Accordingly, in 2020 all households in single and two-family dwellings will have full multimedia networks, whereas in the case of large household devices a saturation level of 100% (single family dwelling) and 80% (multiple family dwelling) will not be achieved until 2040 because of the longer useful life. For light control a much lower saturation is assumed (Aebischer/Huser, 2000). According to this model calculation, in 2020 consumption is set to have increased by 5 000 GWh/a – more than 30% above current power consumption (around 15 000 GWh). The average annual growth rate is 1.3%, whilst the share of power consumption accounted for by the standby and 'off' modes is around one quarter.

Application of the findings by Aebischer/Huser to the three Pervasive Computing scenarios

Since the level of diffusion for the upper variant (fully networked house) has had a linear increase from 0% to 100%, additional power consumption for the three PvC scenarios for 2012 can be roughly assessed if it is assumed that the crucial factor for the overall result is not temporal dynamics, but induction effects (new devices, changes in user behaviour). By transforming the time perspective into the diffusion level, it is possible to calculate additional power consumptions in the cautious, realistic and high-tech scenarios. In the cautious scenario (diffusion level for single and multiple family dwellings around 10%), additional power consumption is around 250 GWh/a and in the intermediate scenario (diffusion level for single and multiple family dwellings around 30%) approximately 1 000 GWh/a. If the smart home becomes popular in accordance

130 The ranges follow from various assumptions regarding additional equipment, standby, off and operating powers, and utilisation time.

131 The ranges stem primarily from the powerful broadband gateway variant.

132 The ranges are based on equipment in the rooms and standby power.

133 Certain components are shared by the three applications, so total consumption is less than the sum of the individual consumption figures.

134 Non-networked households were not counted.

with the high-tech scenario (diffusion level for single family dwellings 90%, multiple family dwellings 70%), by 2012 an increase of up to 3 000 GWh/a in power consumption by Swiss private households is to be expected.

Development potential

The most important technical measures to reduce power consumption are (Aebischer/Huser, 2000):

- minimisation of the use of power supply units by central electricity supply using the communication bus (EIB, USB)
- use of separate and adapted power supply units for additional communication components in large household devices and home entertainment electronics
- use of high-frequency plug-in power supplies with high efficiency and low standby losses (below 0.25 W)

The effects on energy consumption outside the home (secondary effects) were also assessed for the example of e-commerce and teleworking. However, the expected savings were below the maximum additional power consumption in households by at least one order of magnitude.

Conclusion

Local home networking, as is required for Pervasive Computing, may lead to additional consumption of electrical energy in Switzerland in the order of 1 000 GWh/a (intermediate scenario).

An important influencing factor is whether PvC components are constantly online or whether they are active only for a limited time according to certain utilisation requirements. Whilst there is an incentive towards maximum energy efficiency in the case of mobile components and alternative power supply systems may become established, in the case of fixed infrastructure and networked household devices there is a risk that inefficient energy utilisation systems will continue to be propagated.

7.1.6 The backbone in Pervasive Computing

Local PvC networks are integrated into Swiss, European and worldwide information and communication networks. It can be expected that the Internet will emerge as a leading medium and new devices will be designed to support the Internet standard. As far as the primary environmental effects of PvC are concerned, the more intensive use of the Internet backbone and the development of new mobile radio communication networks and Internet infrastructures are of particular interest.

It can therefore be presumed that development potential in accordance with the precautionary principle will be seen above all in Internet and mobile radio communication infrastructures. In principle, digital radio (DAB) and television (DVB-T) could also play a role in PvC. However, the existing infrastructure can continue to be used with comparatively low additional material expenditure.

According to BAKOM (2003b), DVB-T affords the possibility not only of better reception quality and comfort, but also of new services, such as additional, detailed programme information or interactive services, games, etc. The content range for DAB digital radio, in addition to audio, also includes programme-related data (e.g. visible programme sections in text form), non-programme-related data services (e.g. traffic control systems, electronic newspapers, tourist information and weather reports) and interaction. DAB is indeed not suitable for backward channel operation (BAKOM, 2003c), but using other telecommunication networks (fixed telephone network, GSM and UMTS networks, CATV, etc.), interactivity can easily be created if receivers are properly equipped.

In the United States, Japan and increasingly also in Germany, there have been intensive and fierce discussions about the proportion of national power consumption represented by the Internet and other communication networks. A relevant amount of consumption can be apportioned to desktop PCs and their monitors and the operation of fixed and mobile radio communication networks. Call centres and 'Internet hotels' are also significant energy consumers, if account is taken of energy consumption by air conditioning systems.

- According to a study by Arthur D. Little, power consumption by all commercial office and telecommunication equipment in the United States will rise from just under 3% of power consumption in 2001 to no more than 4% by 2010. If 'green' practices become popular, a 2% reduction by 2010 is even possible (Little, 2001).
- For Germany, the estimates and forecasts range from just under 1% of total power consumption to around 6% in 2010. If savings potential is mobilised, however, this figure could be reduced to 1-3% (Langrock et al., 2001).

There is no variation in backbone-related environmental impact in the scenarios in view of the insufficient database. Even without being able to have recourse to valid data, the backbone in PvC offers a few starting points for minimising primary environmental effects.

Expansion and more intensive use of Internet infrastructure

More intensive use of Internet-ready terminals as part of PvC means that we can expect increased data throughput over the Internet backbone. Whilst there is overcapacity with regard to global glass-fibre cables, Switzerland's ambitious plans for the information society will require the further expansion of infrastructure installations in Switzerland. In order to supply the Internet-ready terminals mentioned in the previous chapter, the following infrastructure installations are needed (cf. Türk et al., 2002):

- *Servers:* WWW, file transfer, mail and other servers can be implemented either as individual devices or as partitions on larger computers. In order to operate server farms, it is necessary to have expensive air conditioning installations and systems and uninterrupted power supply (e.g. back-up batteries).
- *Switching devices:* Clients and servers are connected to one another by routers, gateways, repeaters and switches. Since the switching devices are located at nodal points on the global Internet, there are obviously fewer of them than servers and terminals.
- *Data transmission:* Data is transmitted by cable or by radio communication between distribution centres (hubs). Because of their high transmission rates compared with copper cables, glass-fibre cables are predominant over longer distances. Sizeable volumes of data can also be transmitted by directional radio or satellite.

Servers and switching devices are often housed in ‘telehouses’ or ‘colocation centres’. The high power requirement has led to the development of new power station capacities (cf. Amsterdam, Frankfurt). On the other hand, existing connection and power station capacities can also be better used through regional economic policy. According to the ‘Bring the Fiber to the Power’ principle, in some instances the new economy becomes established where the old economy has retreated (Knolmayer/Scheidegger, 2001). There is great savings potential in energy consumption by telehouses in the field of cooling technology and in the choice of location (minimisation of transmission losses and choice of locations in cooler regions).

Large volumes of material are linked to the Internet infrastructure. With regard to transmission satellites, issues of space rubbish (collisions, plutonium power) are priorities. Alongside GPS, a further positioning system is to be developed in the form of Galileo. The thirty satellites are to be fully in operation by 2008 (Roth, 2002).

In the last century, the material content of toll cables fell by a factor of 10 each decade. Glass-fibre cables require a lower volume of material and have much higher transmission rates. In the case of switching systems, the size is set to be reduced by a factor of 4, whilst maintaining the same functionality, as a result of nanotechnology and micro-electromechanical systems (GeSI, 2002).

Setting-up of new mobile radio communication networks

The number of mobile phone users in Switzerland increased almost exponentially from 1998 to 2000. Since then saturation has been observed. Alongside the GSM and GRPS standards, 3rd generation mobile radio communication networks are currently being set up. This temporary coexistence is reflected, for example, in the shared use of base stations.

However, mobile terminals can in some cases also be used in ad hoc networks. A growing number of new mobile phones also support the Bluetooth, W-LAN and USB standards. The use of these free frequency bands is partly competing with the services offered by mobile communication suppliers, which use the hierarchical network structure of UTMS networks.

The setting-up of UMTS networks gives rise to considerable material flows in the form of base stations and antennae. Initial LCA-like assessments are being conducted in current research projects, but valid results are still to be delivered (Malmodin et al., 2002; Frischknecht, 2000).

The material intensity of the GSM mobile network infrastructure in Italy is 133.85 kg/user, whilst the ecological rucksack of a T28 Ericsson mobile telephone is 75.5 kg (Federico, 2001).

The energy requirement for 1st generation mobile radio communication was 90 parts the operation of infrastructure and 10 parts the operation of terminals (Schaefer/Weber, 2000).

The power consumption of Deutsche Telekom alone, at 2.4 TWh, accounts for around 0.5% of national power consumption. The company has, among other things, introduced energy-saving objectives as cost headings in its ‘Management Score Card’. Because of the reduced transmission power, UMTS base stations have a 35% lower power requirement than existing GSM base stations, but the setting-up of an expanded infrastructure and the rising data transmission volumes resulting from PvC mean that the net effect is unclear.

One of the key strategies for environmental relief through PvC is ecodesign. Since the UMTS networks are still being set up, there is potential here – even without detailed LCA data – for the application of the precautionary principle.

The ‘Global e-Sustainability Initiative’, set up in June 2001, brings together representatives from the fields of telecommunications infrastructure (including Cable & Wireless), telecommunication terminals (including Ericsson) and telecommunications services (including Deutsche Telekom), as well as two supporting organisations, the United Nations Environmental Programme (UNEP) and the International Telecommunication Union (ITU). According to its constitution, the central objectives include the gradual adoption of a corporate social responsibility agenda, starting from environmental issues, and improvements in environmental management and development, as well as sharing of best practices.

The urgent tasks referred to in the work programme are extending coverage (within businesses, participation of other large businesses in the industry, developing countries), linking up with existing regional work and forming a ‘Working Group on IT and the Environment’. At the World Summit for Sustainable Development in Johannesburg in 2002, a report was presented in which the industry’s contribution to the implementation of Agenda 21 was outlined (GeSI, 2002).

As part of the Federal German Government’s ‘Sustainability in Information and Communication Technology’ project, a roadmap for *3rd generation mobile radio communications* was drawn up; it attempted to exploit the key scope for development in the form of objectives and measures for system technology and terminals. On the basis of analyses of the current situation, trends and normative scenarios, the scope for development was identified.

This project involves T-Mobile, Siemens AG, Alcatel SEL AG, Lucent Technologies, Motorola and Nokia, the Deutsche Umwelthilfe NGO and the Fraunhofer Institute for Reliability and Microintegration (Griese et al., 2002).

The development objectives shown in Figure 7-5 are underpinned by measures. These include measures for requirement-based cooling (including increasing the threshold temperature to 27°C, temperature regulation optimised to reliability requirements, new systems for carrying off heat) and requirement-based operation of base stations (including requirement-based shutdown to reduce standby losses, online energy management, staff training) and promise potential energy savings in Germany amounting to 400 GWh per year, which have been identified inter alia by benchmarking:

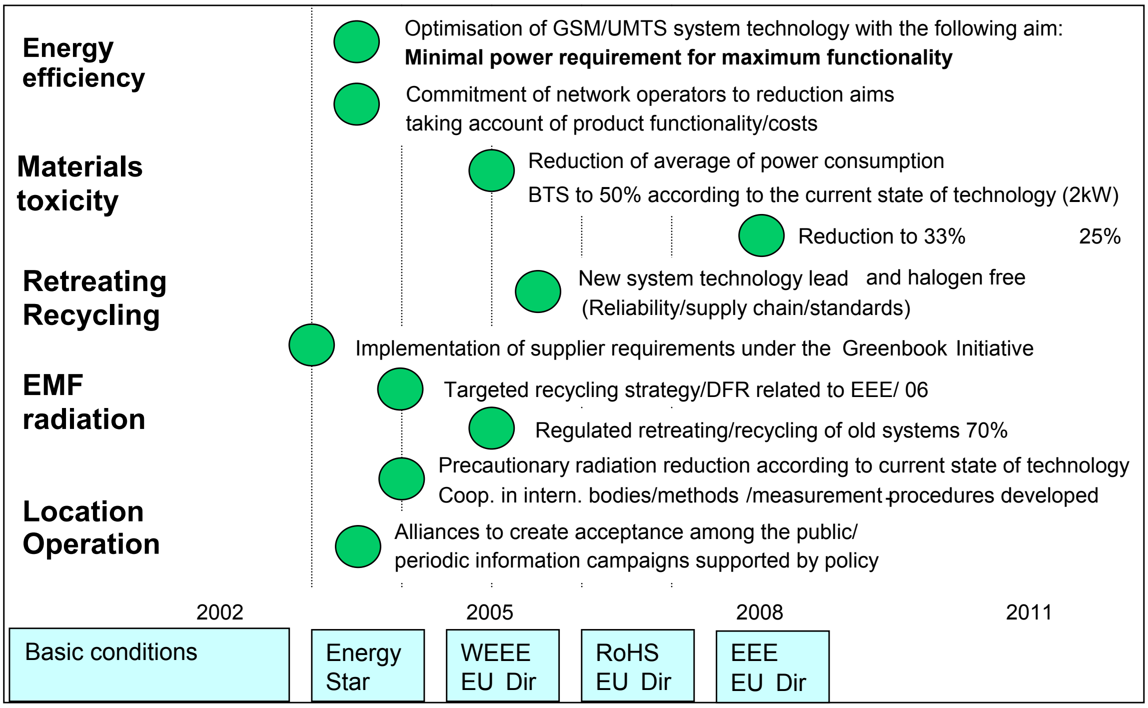

Figure 7-5: Development objectives for UMTS system technology according to the Roadmap for sustainable information and communication technology. Source: Griese et al. (2002)

7.1.7 Conclusions

The devices and infrastructures required for PvC give rise to consumption of raw materials and energy, waste and pollutant emissions during their life cycle. The PvC vision marks a trend which leads to high dissipation. Compared with current information and communication technology, which is based on smaller numbers of larger devices, the finer distribution of electronics could lead to the spread of known negative environmental effects caused by hardware (waste and power consumption), although the primary environmental effects expected up to 2012 cannot be assessed with any great certainty.

Worsening of waste problems

PvC will lead to a wide distribution of a growing number of miniaturised ICT components. It cannot be expected that further miniaturisation will lead to absolute material savings at a macro level (rebound effects).

Separate recovery of individual components such as chips, batteries, etc. for recycling would entail enormous logistical and technical expenditure and therefore also considerable energy expenditure. Low volume and weight, embedding in other objects and ubiquitous use may mean that they are lost.

Miniaturisation of end products and microelectronics reduces the content of reusable materials and may make separation of electronics more difficult. As part of larger mass streams, no high-grade recycling is possible, only downcycling. It is therefore also possible that problems with pollutants and foreign materials in other material cycles will worsen.

As regards labelling, thousands of millions of dissipative smart labels can be expected. Incompatibilities between microelectronics and packaging recycling, for example, could have noticeable effects on future waste streams.

As a result of the penetration of ICT components into everyday objects and the trend towards low-cost electronics, a reduction in useful life, even as far as disposable products, is to be expected.

Growing power requirements as a result of networking

Based on cautious assumptions, local home networking, as is required for Pervasive Computing, may lead to additional annual consumption of electrical energy in Switzerland in the order of 1 000 GWh. This corresponds to 1.2% of current power consumption in Switzerland. If, like Cremer et al. (2003), we assume that roughly half of power consumption by ICT is in homes, that the remainder can be attributed to offices and infrastructure and that there will be a similar trend for these three sectors, there is an estimated additional consumption of 2 000 GWh/a.

This estimate is trebled if we use our high-tech scenario. In this case, an additional 6 000 GWh/a (or around 7% of current power consumption in Switzerland) would be consumed for networking.

Even through there are great uncertainties over these estimates, it can be stated that there is at least a risk of a significant increase in power requirements as a result of ubiquitous networking. In this case, the precautionary principle suggests that early measures should be taken to minimise that risk. The measures include reduction of these primary effects by incentives to use energy-efficient technologies, e.g. to reduce standby and 'off' losses to the minimum level that is technically necessary.

In order to draw conclusions in terms of the need for energy policy action, however, consideration must be given to the secondary and tertiary effects discussed in Section 7.2 below. If, for example, heat energy can be saved by home networking (secondary effect), the additional power consumption may pay off in energy terms. If this means in turn that heat in the home is treated more thoughtlessly (tertiary effect), the net effect may ultimately be negative.

The complex dynamics of effects in all three stages cannot really be controlled in any detail by policy measures. They will probably lead to a reduction in energy consumption if medium and long-term incentives to use energy rationally are created by the basic conditions. There will be further growth in consumption if there are no such incentives.

An important influencing factor is whether PvC components are constantly online or whether they are active only for a limited time according to certain utilisation requirements. Whilst there is an incentive towards maximum energy efficiency in the case of mobile components and alternative power supply systems may become established, in the case of fixed infrastructure and networked household devices there is a risk that inefficient energy utilisation systems will continue to be propagated. Particular mention should be made of digital television.

It cannot be foreseen that the power consumption of units and networks will be optimised solely by market forces and it is unrealistic to think that user behaviour will be geared to energy-saving without active assistance.

The growing data traffic in local PvC networks also calls for corresponding capacities in larger-scale networks. On the one hand, further expansion and utilisation of the Internet can be expected in Switzerland whilst, on the other, new mobile radio communication infrastructures will be set up. In general, it must therefore be presumed that PvC will also contribute to a growing power consumption by large-scale infrastructure.

Uncertainty over the trend in primary environmental effects

The primary environmental effects of a developing technology are difficult to quantify, so the range of possible developments is formulated in three scenarios (see Table 7-10).

In the cautious scenario, only a moderate worsening of existing problems with energy, waste and pollutants can be expected. In the intermediate scenario, PvC applications become widely established in individual areas. However, as a result, nascent waste and energy-policy tasks are identified and dealt with appropriately in accordance with the precautionary principle. In the high-tech scenario PvC penetrates all areas of life. Power consumption and treatment problems for individual waste streams increase dramatically because components are so finely distributed.

Table 7-10: Trends in primary environmental effects in the three scenarios

	cautious scenario	**intermediate scenario**	**high-tech scenario**
ICT waste	moderate rise	marked rise	dramatic rise
Effects on waste disposal processes	further worsening of problems with pollutants and recycling	high recycling rates at high value-added stage in sub-segments	change in waste streams through addition of ICT components
Useful life	further reduction	stabilisation through better upgradability	rapid fall as a result of disposable electronics trend
Power consumption	efficiency gains counterbalance the need for digitalisation and networking	efficiency gains limit the increase in digitalisation and networking	increase in the number of units and 'always-on' practices outweigh efficiency gains
Power supply for wearables and portables	more efficient batteries	mix of batteries, photovoltaics and fuel cells	additional use of body energy

The range of developments in the scenarios highlights scope for development and a need for policy action, where the developments are contrary to environment policy objectives.

Switzerland's *energy policy objectives* are laid down by the federal constitution, the Law on energy and CO_2, and obligations under the international climate convention, and are being implemented in particular under the 'Energy and Switzerland' programme. The consumption of fossil energy sources and CO_2 discharges are each to be reduced by 10% from 2000 levels by 2010. Power consumption may grow by at most 5% over the same period (Bundesamt für Energie, 2002).

In accordance with Switzerland's *principles for waste policy,* waste is to 'cause as little environmental impact as possible in accordance with precautionary principle [...]' (BUWAL, 2002). Objectives include maintaining the high level of separate collections and recycling. Measures include the avoidance of waste through long-lasting goods, the reduction of pollutants in goods and the reduction of the volume of residual waste to be dealt with through recycling.

In view of these uncertainties, *monitoring* is an important strategy for narrowing down the need for action in energy and waste policy.

Monitoring

Power consumption and the volume and composition of waste streams are to a large extent dependent on the technological paths taken and their diffusion. The e-grains vision highlights the need for 'technology monitoring' and systems for the earliest possible removal of pollutants.

As a result of PvC the volume and quality of individual waste steams will change. Monitoring is a prerequisite for proactive, appropriate reactions to waste policy tasks, e.g. identification of material flows for which separate microelectronics collection makes economic and environmental sense.

Power consumption in PvC has thus far been assessed only on the basis of examples – e.g. for home networking – with the aid of scenarios. There have not yet been any empirical studies or systematic monitoring as an 'early warning system' that covers technical developments and user behaviour.

Waste policy tasks

As part of integrated product policy, and having regard to LCAs und LCC,[135] ecodesign is a key strategy for minimising the primary environmental effects of PvC. Product liability over the whole life cycle, including recycling and recycling-oriented design, as defined in the draft EU WEEE and EEE directives, could prove a significant impetus over the next few years, which will also affect Switzerland. In the design phase for PvC objects, this means in particular developing mass-flow microelectronics that do not disrupt other recycling cycles, or creating the conditions for easy separation of electronics, as well as developing regenerative energy supply systems.

The volume of waste produced by PvC can be reduced by working to extend the utilisation phase. For example, using open software standards, new applications can be downloaded in order to extend both functionality and useful life. Appropriate interfaces should be envisaged for PDAs and wearables. Modular hardware structure and 'innovative packaging' systems may also help to extend useful life.

[135] Life cycle costing

The computerisation of previously purely mechanical objects, such as furniture and clothing, requires adjustments to be made in recycling. Integration with residual waste appears to be manageable in terms of pollutants, but important resources are lost. In future, greater attention will have to paid, in terms of an intended closed-loop economy, to the recycling of individual electronic modules and components, since, because of their complex composition, recovery of all reusable materials is virtually ruled out. Requirements for recycling at high value-added stages include product information that goes beyond one life cycle, appropriate dismantling and test procedures, and markets for used microelectronics. Furthermore, this raises the question of extending collection (e.g. co-collection of small devices as common dustbin rubbish) and recycling capacities (e.g. proactive LCD recycling). The battery types used and the operation of regular waste disposal for batteries (including worn-out rechargeable batteries) are of central importance for the environmental performance of PvC.

The initial estimates of the effects of including smart labels in packaging recycling highlight the need for monitoring of smart label technology. If incompatibilities are identified – presumably in bottle glass and aluminium recycling, in particular – a systematic assessment will have to be conducted of the environmental impacts of smart labels and their application. Possible reaction models include ecodesign (e.g. removal of pollutants), adaptation of treatment and recycling processes to the modified characteristics of smart-label-equipped packaging (e.g. readjustment of crushing apparatus on account of different hardness values) and revision of acceptance criteria for used packaging (e.g. maximum copper content requirements).

Energy policy tasks

In general, it would appear to be difficult to influence the whole heterogeneous range of PvC devices through energy policy and therefore it seems pragmatic to concentrate on a few hot spots.

In accordance with the precautionary principle, there is scope above all for diffusing energy-efficient devices, influencing user behaviour and utilising energy-saving potential in *setting up new infrastructures.* Since only a small portion of PvC objects will be produced in Switzerland, it is possible to influence construction only indirectly.

Up to now, there has been only little awareness, both among customers and among network providers, of the energy-saving potential from using energy-efficient ICT devices and cabling solutions. It is also worth considering appropriate information and education initiatives in order to raise awareness of energy-saving user behaviour. There is considerable technical potential for reducing standby losses, and information could be widely disseminated through labelling systems such as energy efficiency classes, information campaigns and public procurement.

The infrastructure for the PvC backbone (Internet including servers, mobile radio communication networks) contributes increasingly to environmental consumption. There has been little discussion up to now on influencing energy requirements for air conditioning through choice of appropriate locations for larger computer centres (e.g. telecentres, server farms). In setting up new infrastructures like UMTS, there is also considerable potential for environmental relief in terms of requirement-based cooling and operation of base stations.

7.1.8 Annex to primary effects

In addition to the main features of the scenarios in Chapter 4, the following assumptions on the trends in waste and energy-related parameters concerning the diffusion of Pervasive Computing in Switzerland have formed the basis for the assessment of primary environmental effects in Sections 7.1.1-7.1.7.

Percentages with a plus or minus sign indicate changes in the period 2002-2012, whilst percentages without a plus or minus sign show the degree of diffusion in 2012. For example, in the high-tech scenario it is assumed that in 2012 around 90% of all large household devices will be equipped with a display.

Table 7-11: Specification of the scenarios from Chapter 4 with regard to the most important parameters for Pervasive Computing waste and energy requirements.

	cautious scenario	**intermediate scenario**	**high-tech scenario**
Waste			
Growth in the number of ICT devices	+ 10%	+ 50%	+ 100%
Integration of displays in large household devices	5%	50%	90%
Growth in the number of chips per motor vehicle	+ 10%	+ 30%	+ 100%
Navigation devices	40%	80%	95%
Screen for passengers in cars	1%	20%	75%
Embedding of ICTs in products that were previously not electrically operated (e.g. i-Wear): Food packaging with smart labels	1% 1%	20% 20%	80% 100%
Energy			
Smart home	2%	10%	80%
Wearables and portables	predominantly battery operated	predominantly photovoltaics or fuel cells, since batteries are no longer practicable	new energy supply systems such as body energy (temperature gradients, movement) become established

7.2 Secondary and tertiary effects

The use of ICT gives rise to a number of indirect environmental effects (secondary and tertiary effects, as explained in the introduction to Chapter 7), which, unlike primary effects, can also be positive, i.e. they may contribute to environmental relief. In this section, previous experiences with indirect environmental effects of ICT will be summarised and the changes that can be expected with regard to each effect as a result of Pervasive Computing (PvC) will be discussed.

A general expectation linked to the use of ICT is that this technology will contribute to a *dematerialisation* of processes, i.e. to a far-reaching improvement of resource productivity. This is in turn a necessary condition for sustainable development, as we have explained in Section 2.4.

An important aspect of dematerialisation is the replacement of material goods by services. However, it should be noted that services are not immune from environmental effects either (cf. Köhler, 2001).

The environmental relief expected to result from dematerialisation is counteracted by rebound effects (see Chapter 5), which must be taken into consideration as tertiary effects in each individual case.

7.2.1 Dematerialisation potential and rebound effects in the transport sector

Environmental relevance

Transport processes are among the most ecologically relevant economic processes. Both goods and passenger transport cause environmental impact through:

- energy consumption (fuel, electricity)
- emissions (greenhouse gases, atmospheric pollutants, noise)
- land use (transport land, parking spaces, airports, etc.)
- resource consumption for infrastructure construction and maintenance.

In particular, there is a continued increase in climatically relevant CO_2 emissions from road transport. At 15.6 million tonnes per year, transport causes around 34% of total anthropogenic CO_2 emissions in Switzerland (BUWAL, 2002).

The different means of transport have different efficiencies in relation to these environmental effects (transport output per unit of environmental impact). It should be stated that nearly all transport systems where ICT can be used display a marked upward trend. The highest growth rates can be seen in air transport and road haulage. Air and road transport cause the largest proportions of emissions.

Current and future ICTs influence the transport sector in the following way:

- Substitution: possible substitution of transport processes by telecommunication
- Induction: incentives for additional transport processes because it is possible to coordinate activities over larger distances
- Efficiency: optimisation through route planning and better utilisation of vehicle and infrastructure capacity

- Modal split: influence on the choice of means of transport through the availability of transport-related information

Previous experiences with indirect environmental effects of ICT in the transport sector

The section below shows, on the basis of case studies, what influence existing ICT use has on transport systems and what environmental effects are the result. The integrated use of information and communication technologies in the transport sector is known as transport telematics.

Effects of ICT on passenger transport

Advances in telecommunication have long been seen as an opportunity to substitute journeys. At the same time, however, telecommunication also gives rise to additional transport. In this area of tension, two questions are relevant:

1. How do the environmental effects of telecommunication relate quantitatively to those of passenger transport, i.e. what is the dematerialisation potential of substitution?
2. To what extent will substitution effects be counterbalanced by induction effects?

These questions will be examined below using the example of virtual conferences (e.g. videoconferences). Videoconferencing is an audio-visual form of cooperation between groups at different locations to replace or supplement business trips (Rangosch, 2000).

The dematerialisation potential was determined in an LCA study, using the 15th International Environmental Informatics Symposium, which took place in Zurich in 2001 with 500 participants, as an example. A comparison was made between the environmental effects of preparing and running the conference and the environmental effects of a hypothetical virtual alternative (Hischier/Hilty, 2002).

The results show that the total environmental impact from this international conference was 4 650 EIP.[136] The largest environmental impact factor by far, with 4 207 EIP, was the flights by the conference participants, even though only 35% travelled by air. In comparison, the environmental impact from printed conference materials, including a two-volume book (on account of the consumption of paper and cardboard) is of minor importance, with a total of 172 EIP for the whole run.

A conference that was held completely virtually using current ICT would cause an environmental impact of only 10 EIP. Account was taken of energy consumption for the Internet, terminals, etc. Since this completely dematerialised scenario is of little practical relevance, a scenario with three virtually linked conference locations (Zurich/Dallas/Tokyo) was also studied. In this case there would still be an ecological benefit of roughly 50% compared with a central conference location, because of the flights saved. In this case too, the physical journeys of conference participants still caused the highest environmental impact.

However, according to Rangosch, the main area in which videoconferences are used is intra-company communication, in particular for regular meetings, where the subject of

[136] Eco-indicator points. The eco-indicator 99 method is used for the aggregation of different environmental effects in a single scale of assessment with the unit EIP.

the contact does not require a physical presence. This is often the case where personal communication between the interlocutors is of only secondary importance, for example in work meetings, issuing of job orders, discussion and reporting. Videoconferences are not used by the businesses surveyed primarily to replace personal contacts, but to complement them. Videoconferencing cannot replace initial contacts with customers and other business partners. In such cases, personal contact is regarded as essential in order to establish a basis of trust between the people involved (Rangosch, 2000).

Against the background of intensified international competition, it is vital for businesses that are active in this environment to speed up their coordination and decision-making processes. The benefits of ICT are therefore seen primarily as the time benefit in relation to physical business trips.

In earlier studies, the substitution potential for business trips was put at 40% of meeting occurrences. A survey of Swiss businesses conducted by Rangosch revealed a range of estimates from respondents from few to 25% of business trips.

However, the businesses surveyed by Rangosch indicated that the total volume of business trips had *not been reduced* since the introduction of videoconferencing. The cause was said to be a general increase in the number of business relationships, which were only made possible in part by the possibilities offered by modern telecommunication. It is pointed out that the frequency of communication made possible by videoconferencing encourages an absolute increase in the number of business relationships. In addition, it is made easier for individual actors to increase the simultaneous number of business relationships of this kind. As a rule, therefore, this is also linked with an increase in the amount of physical travelling, because personal contacts with business partners are still seen as essential. The dematerialisation potential of videoconferencing often therefore lies in business trips which would not even materialise without the use of modern ICT (Rangosch, 1997).

Such rebound effects can be expected in particular where the need arises for personal meetings with virtual acquaintances. Studies on the use of existing ICT show that Internet chats in leisure time tend to give rise to physical mobility. It is mainly chat partners in close geographical proximity (up to 20 km) who tend to arrange personal meetings, whilst around half of chat users at some time cover distances of more than 500 km for personal meetings with Internet acquaintances. More than three quarters of these virtual contacts lead to repeated personal meetings and consequently entail repeated travelling for the those involved (Zoche, Kimpeler et al., 2002).

Effects of ICT on goods transport and transport logistics

The effects of new communication media on goods transport were examined in the Swiss National Research Programme 41. According to the results, transport telematics offer a high optimisation and substitution potential in the haulage industry. Nevertheless, induction effects generally predominate.

Up to now, however, computer-aided transport telematics have been employed rather hesitantly in businesses. It is notable that the previously common CB radio linking drivers and dispatchers will be almost completely replaced by the mobile telephone within a few years. The reasons given by the businesses interviewed for this technological substitution are greater flexibility and lower costs (Rangosch, 2000).

As part of the ‘Comprehensive Information Technology Solution for the Transport Industry’ project, a software system was developed to allow dynamic route planning in the haulage industry (Rogger et al., 2001; Hartmann et al., 2003). The system is supported by on-board computers, GPS and smart phones. The aim is to optimise HGV journeys by haulage companies not only in advance, but also for vehicles that are already on the move, where orders are received at short notice or in the event of disruptions.

The optimisation potential for this system was assessed with respect to costs and the environment by simulation experiments. The effects are optimisation of routing for HGVs and better utilisation of the load capacity of the vehicle fleet. As a result, higher efficiency can be expected from road haulage, which also produces benefits for the environment as a result of falling mileage per tonne of freight.

The simulation results forecast a possible route optimisation through the use of transport telematics. However, the authors also point to the existence of a probable rebound effect: higher competitiveness of road haulage compared with rail transport, as a result of greater flexibility. Consequently, there may be a further shift in goods transport from rail to road.

Results from Mühlethaler (2002, p. 70) point in a similar direction: ‘It is likely that the capacity reserve obtained will sooner or later be exhausted as a result of the higher demand,’ because efficiency increases lead to a fall in transport costs.

Expected changes resulting from Pervasive Computing

Passenger transport

In passenger transport, the focus of the developmental dynamism of PvC is currently the car. As shown in Section 4.2, the car offers a platform, which is already well equipped with basic technologies, for a wide range of new components that can be classified as PvC.

The car is therefore pioneering new PvC technologies and this will be rewarded, at least potentially, by a broad customer base. Consequently, the car will become more attractive. This could influence the modal split in the direction of motorised private transport.

In extreme cases, there is a risk, above all in the field of work, that there will be no alternative to the car for certain occupational groups. This may even affect occupational groups that currently manage without a car of their own or use exclusively public transport.

Possibilities of countering this trend are offered by PvC-assisted transport telematics. Wearable computers offer individual mobility logistics (Personal Travel Assistant) with the mobile accessibility of transport information (timetables, etc.). The user can request individual logistical support for their mobility requirements at any time on an ad hoc basis. Since the need for forward planning is de facto one of the competitive disadvantages of public transport in relation to the car, individual logistical support of this kind would make bus and rail transport more attractive.

In order to make public transport more attractive to a wide group of customers, it could, like the ‘intelligent car’ (see Section 4.2.1), be fitted with the network infrastructure required for PvC, e.g. W-LAN. Unlike in private cars, the journey time on a train can be used productively for work. This is an important competitive advantage of trains over cars from the user’s point of view, which could become more significant in future.

In the long term, wearable computers could become competition for the ‘intelligent car’. With continuing miniaturisation of PvC hardware and the possibility of ubiquitous network access, the benefit of the car as a carrier platform is no longer relevant in the long term. If a fully equipped personal communication system could be miniaturised to such an extent that it could be worn comfortably on the body, the link to the car would become obsolete and even a nuisance. There are potential developments here above all in minimising energy consumption for electronics and in reducing the size of the power supply by using low-temperature fuel cells.

With low-cost multimedia user interfaces that can be used anywhere, PvC could in principle play a bigger part than existing ICT in the substitution of passenger transport by telecommunication. Using multimedia mobile telephones, virtual meetings could become a form of communication for large sections of the population. In particular, occupational groups with a high logistical work content would benefit from this technology. However, the same rebound effects that have already counterbalanced previous ICT substitution potentials in passenger transport can also be expected here.

It is conceivable that mobile videoconferencing via mobile phones will become part of a new lifestyle and, as a result, a mass market similar to SMS. Mobile participation in multimedia chat rooms could become a new form of communication. Depending on the characteristics, as with previous forms of mobile telecommunication, a mass application may be developed. On the mass market, the costs of mobile videoconferencing would fall sharply and attract potential users until there were signs of addiction, as can already be observed at present in the case of Internet chat rooms or SMS (Hahn et al., 2000).

Goods transport

By using PvC in goods transport, there are possibilities for optimisation for both road transport and rail transport. As with previous experiences with the use of ICT in the transport sector, the new functionalities of PvC can help to make better use of transport capacity and to optimise transport routes. However, the optimisation potential will be developed above all in the HGV haulage sector, since flexible changes in operational processes are possible here at any time. Unlike HGVs, the essential drawback regarding flexibility of rail transport will remain even if PvC is used, unless fundamental innovations in the entire rail transport system are introduced at the same time. The future European Train Control System offers initial signs of being such a system. However, because a large amount of money and time are needed to convert the rail system, HGVs can be expected to enjoy a growing competitive advantage over rail as far as goods transport is concerned.

As a general point, it should be stated that the additional optimisation potential resulting from PvC use cannot bring an appreciable improvement as regards the environmental impact caused by goods transport at the macro level as long as key basic conditions (low energy prices and environmental costs that can be externalised) remain unchanged.

7.2.2 Dematerialisation potential of digital media

Environmental relevance

In the case of conventional media (print media), environmental impacts occur primarily through manufacture and transport. Electronic media may have ecological advantages over printed media in certain cases.

Previous experiences with indirect environmental effects of electronic media

Print media vs. electronic media

A study has been conducted on the environmental effects of typical applications of electronic media compared with print media in an EMPA example-based LCA study (Reichart/Hischier, 2001).

The following cases were used as the basis for comparison:

- search for a telephone number
- reception of a typical news item

According to the study, electronic media are ecologically more beneficial than print media only under certain circumstances:

- in the case of selective, targeted use, but not in the case of non-specific entertainment use,
- where digitally transmitted information is not printed out on paper,
- where electricity with a high share of renewable energy sources is used to operate the electronic infrastructure (Swiss electricity mix).

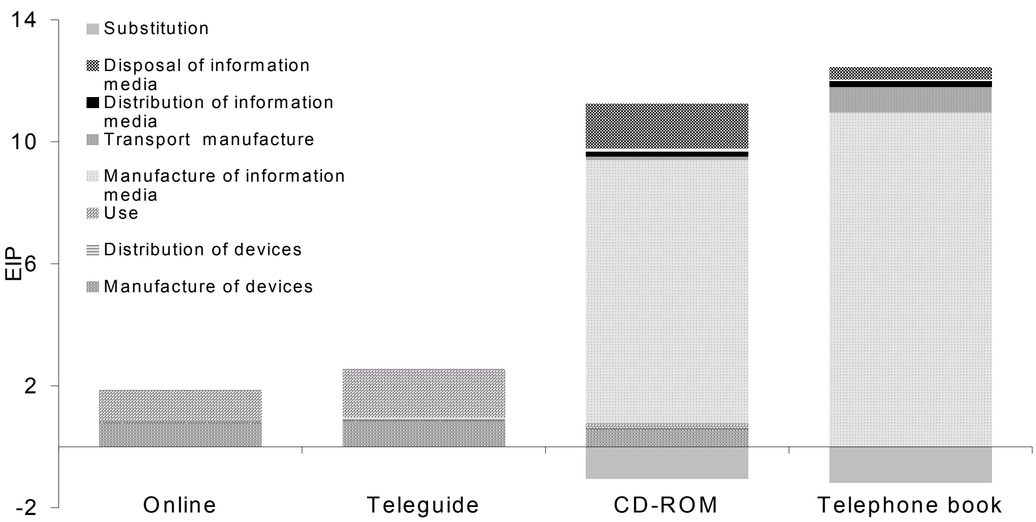

Figure 7-6: Comparison of the environmental impact in various preliminary stages of a telephone number search expressed in environmental impact points (EIP). The parts of the bar in the negative area are credits for paper recycling for the CD-ROM manual or the telephone book. Source: Reichart, Hischier (2001).

Figure 7-6 shows that an online search on the Internet and queries via Teleguide (a device installed in telephone boxes) are more favourable on average than the telephone book, even if it is purchased only in the CD-ROM version. However, in the case of the CD-ROM, the bulk can be attributed to the cardboard packaging and the manual that comes with it.

Because PCs and infrastructure are also used for purposes other than online searches, only a small proportion of the total life-cycle impact caused by the telephone number search was attributed, on the basis of the proportion of time taken by this activity against the total useful life. As soon as the PC is switched on for longer than necessary, the impact increases both on account of the attributed proportion and through additional power consumption.

With very frequent searches for telephone numbers, the benefit of electronic media is reduced. Even after eight searches per week, electronic and print media are more or less equal in terms of their aggregated environmental impact.

A similar picture can be seen in news consumption: electronic media are ecologically advantageous only if they are used for selective news reception. Reading an online newspaper is ecologically more advantageous than buying a daily newspaper up to a period of 20 minutes, whilst in the case of television news this value is around an hour. In the event of prolonged use, print media are ecologically more advantageous.

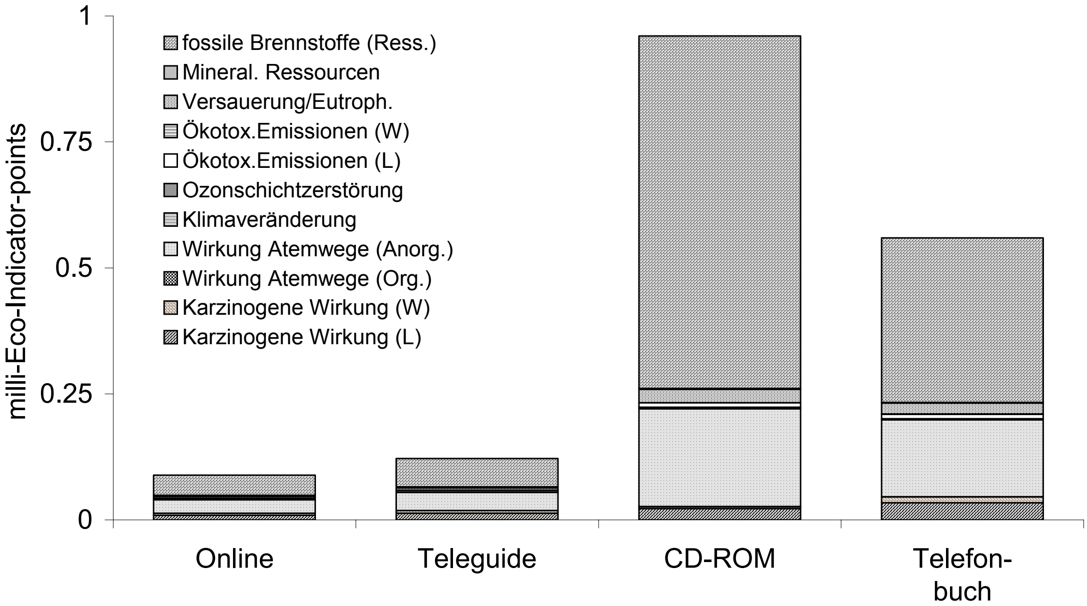

Figure 7-7: Environmental impact of a telephone number search expressed in milli-eco-indicator points. This aggregation method shows the categories of environmental effects and weights them differently than the environmental impact point method used in Figure 7-6. Source for figure: Reichart, Hischier (2001)

Translator's note: For legend see p. 295 below.

Dematerialisation potentials for electronic media therefore occur only where they are used selectively for short periods and the information is not printed out. On the other hand, prolonged use for entertainment or a constant stream of information is ecologically less favourable, since in this case the environmental impact from power consumption in online mode dominates.

An LCA comparison of print and online newspapers by Plätzer (1998) highlights the high dependence of the identified environmental impact on the selected system boundaries and functional units (here: reading a reference article). The (primary) energy consumption that is crucial from the point of view of environmental impact is given for a printed newspaper made from secondary fibre pulp as 14.7 kJ, and for reading the online article as 141 kJ.

Furthermore, there is a clear ‘rematerialisation effect’ from printing out online content on a laser printer: compared with the online article, the environmental impact increases as a result of a print-out on paper by 76% to 257 kJ. The main effect of this additional environmental impact consists in the energy consumption (201 kJ) from the manufacture of printer paper. In the assessment of effects in relation to the online newspaper, Plätzer found clear additional environmental impacts from the emission of atmospheric pollutants during energy generation, whilst the printed newspaper comes out worse with regard to emissions into water. The environmental aspect ‘waste for disposal’ mirrors the electronic waste disposal problems, with around five times higher waste volumes in the case of the online article (Plätzer, 1998).

Digital photography

Cost reductions in the field of digital photography are prompting an increasing number of consumers to buy a digital camera. The first generations of mobile phones are now already equipped with an integrated digital camera. According to the IDC, around 12.4 billion digital photographs were taken worldwide in 2001. A study on behalf of printer manufacturer Lexmark concludes that, despite the growing number of photographs, fewer pictures are being developed on paper. Only one quarter of digital pictures taken are printed out (Lexmark, 2002).

In the light of past experiences with user behaviour in relation to online media, it can be expected that rebound effects will lead to an increase in the consumption of paper and photographic chemicals or printer ink. Estimates for 2005 assume growth of around 30 billion digital photographs per year. The photographic industry is responding to the drop in demand at present with a range of low-cost offers that are intended to encourage customers to print out their digital photographs. For example, with ‘Print-Foto.com’, Lexmark has created a Europe-wide platform for promoting digital photography with, of course, many incentives to print out pictures.

Expected changes resulting from Pervasive Computing

As a result of PvC, the trends for the existing new media are continued: consumption of information and entertainment increasingly uses digital transmission systems, which can now be accessed increasingly from any location (mobile systems).

Energy consumption

It can be expected that the characteristics of the environmental effects of PvC-based electronic media will not differ markedly from those of current online media, since the process of providing online content will not change dramatically. New elements in this process are broader-band data transmission links, data storage/provision mechanisms (decentralisation through distributed computing) and, of course, the mobile terminal for the online customer.

Mobile media consumption produces a marked growth in data volumes on servers and transmission channels, in particular if more multimedia content is downloaded from the Internet in the future. The transmission capacity of the networks will continue to grow with increasing bandwidth and better compression techniques, but experience shows that each capacity increase will very quickly be exhausted. Electronic media with data-intensive content will make an important contribution to the rapid expansion of electronic infrastructure (Internet/mobile radio communications).

Impact on transport

The media consumption practices that have changed as a result of PvC may influence individual mobility. Wearable computers and other portable PvC components (Webpads, e-paper) will allow consumption of news and entertainment media at any location. Current Internet users spend an average of up to 17 hours per week on the Internet (Hahn et al., 2000) and consequently stay at one location during this time. Compared with other leisure activities, stationary online media consumption is relatively environmentally friendly.

If media services also become mobile as a result of PvC, the user will no longer be tied to the location of the Internet connection while he is online. This means that at least part of one's weekly online time will be used for mobile peripheral activities, e.g. journeys in the 'intelligent car' (see Section 4.2). Thus, the time available for electronic media consumption will also increase, which will result in rising volumes of data being demanded and transmitted.

7.2.3 Thermal protection for buildings

Environmental relevance

Thermal protection for buildings is one of the most important fields of action for the protection of energy resources. Around 39% of energy consumption in Switzerland is the result of the operation of buildings (heating and cooling) (BFS, 2002).

In Switzerland the 'Minergie' standard is established as a label for energy-efficient construction (Minergie, 2002). The most attention in the present Minergie concept for thermal protection is given to equipping buildings with passive thermal protection technology (thermal insulation of the building exterior), heat storage and energy-efficient heating systems.

Nevertheless, the use of electronic mechanisms such as active measurement, control and regulation systems forms a useful complement to passive thermal protection. In particular, Minergie buildings are actively ventilated using electronic control units. Demand-driven temperature and ventilation control allows heat energy to be saved.

Previous experiences with measurement, control and regulation systems in thermal protection

In the field of building technology, a wide range of energy-saving systems have been developed and are now available in the form of sophisticated products. In addition to passive building insulation, there are already active systems that respond where the demand exists and thus reduce heat energy consumption. One such system is the single room regulation system; through networking of microprocessor-controlled automation units, it allows demand-driven control of heat consumption and reduces losses. Integrated building technology is based on extensive networking of different components. Remote control of heating systems by telephone has been a reality for some time; in the last few years there has also been the added option of remote control over the Internet. The integration of heating control into digital data networks allows additional functions, such as heat demand planning based on up-to-date weather forecasts and the user profiles of the inhabitants. Despite technical feasibility, these additional functions have not yet become established on the market.

A more promising development appears to be the integration of systems for producing regenerative energy, e.g. solar power systems or heat pumps, into the heating system. These energy sources require demand-driven control and regulation, in particular where they are used together with conventional heating systems. Currently, measurement, control and regulation systems of this kind are normally constructed with programmable electronic control units, which have recently also been fitted with interfaces for network integration. Using these technologies, the use of regenerative sources of heat energy is supported and therefore becomes more attractive. Modern building control systems have their own sensors to record current values such as temperature, solar radiation and wind strength inside and outside. In combination with actuators for the control of ventilation systems or shutters on the outside of the building, a building control computer can determine the optimal point of operation for the air conditioning system. There has not been any systematic research thus far into the energy efficiency of these measures.

Expected changes resulting from Pervasive Computing

Whilst at present these functions are mostly implemented as isolated solutions, in future electronic building technology will be networked (see Section 4.1) and will also be connected with umbrella networks. With PvC, further low-cost components (sensors, actuators) can be integrated into building technology to assist and expand the functions of the single room regulation system. In the intermediate 'smart home' technological scenario, extensive networking of all household devices and building technology is expected in the next generations of new residential buildings, and this scenario can also be applied to other categories of building. A building equipped in such a way will have an automated energy management system that determines the optimal energy operating mode depending on the energy programme selected. With this technology, buildings can be managed in an energy-efficient manner:

- Adjustment of energy consumption for the building's air conditioning system to the current requirements
- Avoidance of heat losses as a result of manual operating errors or negligence, e.g. specialists can adjust the heating optimally over the Internet.

Naturally, PvC cannot be used to replace tried-and-tested thermal protection mechanisms, but merely to complement them.

However, it is also necessary to take a critical look at the abovementioned variant of energy-saving building equipment using 'smart' technologies. Energy-efficient construction is possible and economically attractive even today without using 'smart' building technology. The passive house standard, which is stricter than the Minergie standard and bears the label 'Minergie-P' in Switzerland (Minergie, 2002), dispenses entirely with conventional heating systems. The concept is based on regenerative heat sources (e.g. solar collectors) and optimal structural thermal protection. The basic premise of this approach is 'simple and economical', and expensive measurement, control and regulation technology that is prone to faults is largely avoided. Instead, this approach is founded on the intelligent use of the self-regulating properties of the building material (thermoactive building subsystems (tabs)) and on properly thought-out building planning. The aim of a '2000 watt society' laid down in the Swiss Sustainability Strategy (Bundesrat, 2002) is satisfied by this technology, since passive thermal protection, unlike electronic control elements, does not require any electrical power supply, calls for little maintenance and is long-lasting. In addition, the passive house standard eliminates an important NIR source: wireless data transmission by ‘smart’ measurement, control and regulation elements (Koschenz, 2002).

One disadvantage of the passive house standard is that it is difficult to implement in old buildings and in rented accommodation. PvC-assisted measurement, control and regulation systems could reasonably be used here, since they can be retrofitted relatively easily and require comparatively minor structural modifications. Thermal protection measures can therefore be implemented in a shorter time and at lower cost than the installation of passive thermal protection systems, which generally necessitate the complete renovation of old building fabric.

Quantitative estimates on the savings effects that can be achieved through automated heating control in a networked house lie between 15% and 35%. It is therefore quite possible to achieve a net effect in terms of an energy saving, even if that saving is no longer quite so pronounced when the primary energy for power generation is taken into consideration (Cremer et al., 2003).

7.2.4 ‘Virtual wear-and-tear’: shortened life as a result of embedded ICT

Environmental relevance

The useful life of material goods is an important parameter for consumption of materials and energy. If the useful life is halved, twice the amount of resources is used for production and there is twice as much expenditure for disposal. The useful life can be shorter than the technical service life.

In the ICT sector, experience shows that devices are taken out of service and replaced by new ones when they have completed only 10-50% of their technical service life. For example, a PC may be functional, from a technical point of view, for around 20 years, but used for only 2-5 years. The same applies to home entertainment electronics.

Technical innovations are a driving force for this rapid change. Products become unusable long before the end of their technical service life mainly as a result of changes in the technical environment which lead to compatibility problems.

There is a risk that this trend will now extend to objects in which ICT components are embedded. For example, a networked refrigerator might be replaced because the old model cannot handle a new network protocol. For this conceivable effect we have introduced the term ‘virtual wear-and-tear’.

Previous experiences with the useful life of ICTs

A typical – though not specific – feature of ICT is the high technology-driven innovatory dynamism. This produces rapid developments in each high-end sector. Microelectronics continues to develop according to ‘Moore’s Law’, postulated in 1965 (Moore, 1965), according to which the packing density of transistors over the area of a chip roughly doubles every 18 months. In conjunction with higher clock frequencies and higher data transmission rates in telecommunication, this leads to exponential growth in the performance of ICTs.

This high innovatory dynamism leads to a rapid depreciation in the value of devices and software. This would be the case even if the technical wear-and-tear was almost zero (in the case of non-use). With periodic upgrading and retrofitting measures, the performance gap for individual components can be reduced, but not completely eliminated.

The depreciation has the following causes:

- Relative performance losses: with constant performance, the gap with the increasing performance of the environment grows. For example, the computing speed of a PC system with a Pentium 1 processor is no longer adequate for displaying animated websites.
- Increasing incompatibility with the environment, because with new software versions, which utilise higher hardware performance, new data formats are often also introduced. For example, swapping text formats in different versions of a word processing program (e.g. Word for Windows) is not possible or entails additional expenditure.
- Relative obsolescence of data media. For example, data which is only ten years old and stored on 5¼" diskettes can no longer be read, because the relevant drive types are no longer supported. The same problem will soon affect 3½" diskettes and, in the not too distant future, even CD-ROMs.
- In the 'lifestyle' products market segment in particular, fashion trends determine the subjective assessment of products. An example is the subjective obsolescence of mobile phones because of rapidly changing design features.

Expected changes resulting from Pervasive Computing

A feature of PvC is the embedding of ICT components in other objects, making them 'smart' or 'intelligent'.

In the case of objects with a relatively long useful life, such as furniture or household devices, the abovementioned innovatory dynamism of ICT could mean that these also suffer from premature depreciation if the ICT components are not replaceable or not worth replacing.

The environmental effects of such a trend are difficult to quantify at present, but the potential damage is very high, since the useful life of material goods is a central parameter for mass and energy flows in the economic system. If the useful life is shortened, more natural resources will be consumed in the same time, and more waste and emissions will be produced.

However, a reverse effect comes into play if more recent products are more favourable than their predecessors in terms of environmental effects during the utilisation phase. For example, because of better control and regulation, a new washing machine may be more efficient in energy and water consumption than an old one, so that replacement after a certain time is ecologically worthwhile. At present it also makes ecological sense to replace intensively used CRT monitors with LCD monitors, because they reduce power consumption (Behrendt et al., 2002).

However, it is difficult to imagine how PvC can ultimately have a net positive effect here. This follows simply from the fact that many objects that previously managed without any energy supply will have to be permanently connected to the mains or regularly charged as a result of PvC.

The actual virtual wear-and-tear occurs when the relative performance of the embedded chips is no longer consistent with the general state of technology or if new protocols and data formats are established, with the result that the ‘intelligent object’ becomes a foreign matter in the network.

Measures to prevent virtual wear-and-tear should be directed primarily at standardisation, so that a maximum degree of compatibility between different manufacturers’ applications and between different generations of devices can be achieved.

This should also be taken into account in terms of engineering design, for example by offering the possibility of upgrading or replacing ‘smart’ components. On the consumer side, measures could be taken to promote longer useful lives, e.g. through communication measures to counter the preconception that each innovation cycle brings an actual improvement of utility.

8 Summary of the opportunities and risks of Pervasive Computing

Lorenz Hilty, Andreas Köhler, Claudia Som

This chapter summarises the most significant opportunities and risks of Pervasive Computing (PvC) and characterises the risks in qualitative terms.

PvC permits a broad range of applications. Consequently, the possible effects of the introduction of PvC are varied and not entirely amenable to description. Therefore, to highlight some of these effects as social opportunities or risks, as we do below, requires an assessment in two respects:

- an assessment of relevance: why is this particular effect selected and discussed as an opportunity or risk, whilst other conceivable effects are not examined in detail?
- a division by utility or harm: by which criterion is an effect classified as potentially useful (and thus as an opportunity) or as potentially harmful (and thus as a risk)?

Only after taking these two steps, whose criteria we will set out in Sections 8.1 and 8.2, is it is possible to describe the opportunities and risks (8.3-8.6) and to make the actual risk assessment. As a quantitative risk assessment does not appear appropriate on account of various uncertainties, we will restrict ourselves to a qualitative characterisation of the risks involved (8.7). This will form the basis for the recommendations set out in Chapter 9.

In this chapter we will consider only the effects of PvC which have social significance, that is to say which have significance beyond the relationship between the manufacturer and consumer of a PvC product[137]. In particular, the *subjective utility* that the purchaser of a PvC product takes into consideration when he freely opts to make a purchase will not be dealt with here as an opportunity. Therefore, the fact that it is possible to listen to music through a shirt collar does not constitute an opportunity for the purpose of the following considerations. Similarly, any *subjective harm* which may have to be endured (e.g. having to remove one's shirt during a security check at the airport) is not regarded as a risk. Such effects are regulated by a functioning market.

Here we concentrate on effects which the market does not 'see'. This may be because the effects are *unfamiliar* or *generally unknown* to the purchaser or because they *occur insidiously* or affect *third parties* (external effects). This is true, for example, as regards unexpected health effects or environmental pollution which can affect uninvolved bystanders and subsequent generations. The development of costs in the health system is also an aspect of social significance.

[137] Both here and elsewhere, reference to 'PvC products' can also include PvC services.

8.1 Relevance criteria

The selection of the opportunities and risks discussed below is based on the following relevance criteria, which must be satisfied simultaneously:

- The effect is relevant in the view of the experts questioned[138].
- The effect is specific to PvC, that is to say it is not to be expected in the case of other current technologies, or not to the same extent.
- The effect falls within one of the two areas examined as part of this project (health and the environment).

We have not interpreted these criteria very strictly in order to reduce the risk of prematurely eliminating potentially important aspects.

During the expert workshops great interest was shown in effects which lay outside the subject areas of

- health and
- the environment

in the narrow sense. In particular, great relevance was attached to social risks and to a certain extent also to economic risks. Consequently, we will add two sections dealing with

- social and
- economic effects.

However, these sections (8.5 and 8.6) are less firmly embedded in the considerations set out in the preceding chapters than those concerning the two core subjects since they are not covered by the initial focus of this study. They will form a basis for further studies focused more on social and economic aspects.

8.2 Dividing the effects into opportunities and risks

In Section 2.6 we introduced a normative framework which provides guidance for identifying opportunities and risks. For example, it is relatively clear from the objective relating to sustainability that the effect 'Less material consumption by ICT' is to be classified as an opportunity, and 'Greater material consumption by ICT' as a risk.

It is more difficult to predict the direction that development will actually take than it is to assess such effects. Many features or trends of ICT are *ambivalent* in terms of their effects (see Kündig, 2002). For example, further miniaturisation results in greater material conservation where the number of manufactured components grows more slowly than specific material use. However, where it grows more rapidly - as is indicated by some of the factors cited in Section 7.1.2 - it results in an increase in material flows (and thus also in the consumption of resources). In this case the uncertainty as to the assessment of such a risk (or opportunity) is due not to a lack of knowledge (as it is in relation to the effects of NIR), but to the unpredictability of social

[138] Two workshops were held to question experts (see 1.2). The assessments of the members of the project monitoring group were also taken into account.

processes (acceptance, user behaviour) or the fact that future development is still uncertain in objective terms.

We refer to effects of this kind as 'Janus-faced risks'.[139] Irrespective of the assumed scenario (Section 4.9) and other prevailing circumstances, the initial indications they provide can be positive or negative. They are particularly interesting from a precautionary aspect because there is great potential for influencing developments in this respect.

Excursus: The notion of uncertain risk

Conventionally, a risk is characterised by the mathematical product of probability and extent of harm. Therefore, a risk is possible or potential harm. Although the occurrence of harm is unpredictable *in a specific case*, certainty can exist as to a general causal link, for example as to the link between smoking and lung cancer.

However, where a link between a given cause and a (presumed) effect is unclear per se and possibly can be established only after a long period, an entirely different situation exists. In such cases - to which the precautionary principle relates, see Section 2.1 - we speak of an *uncertain risk.*[140]

There are *various kinds of uncertainty* which may be responsible for the fact that a risk is regarded as unknown. In the cases which we examine in this study the distinction between the following two kinds of uncertainty is relevant:

1. Uncertainty on account of incomplete knowledge of an existing situation (insufficient level of knowledge).
2. Uncertainty about a situation that does *not yet* exist (uncertainty regarding a development).

An example of the first case is the uncertainty as to whether non-ionising radiation (NIR) can cause damage to health below the thermal threshold level. The situation exists per se but the level of knowledge is still insufficient.

The second case occurs in particular in connection with social developments. They include the abovementioned 'Janus-faced risks', that is to say those cases in which the nature of the spread and application of the technology is decisive in terms of its effect and therefore it is impossible to say with certainty whether the opportunities or risks will predominate. Somewhat definite statements can be made only as regards potential developments in either direction.

[139] It is equally legitimate to speak of 'Janus-faced opportunities'.

[140] Strictly speaking, it is only a possible risk, that is to say 'possible possible harm'. However, since it is doubtful whether, in logical terms, the 'possibility of a possibility' differs from a straightforward possibility, we avoid the expression 'possible risk' or 'potential risk' and speak of unknown risk.

8.3 Health

The following sections will deal with two kinds of effect of PvC on health:

1. direct effects (Section 8.3.1)
2. effects on health-related contributing factors (Section 8.3.2)

The topic of non-ionising radiation (NIR) is a special case in that it is dealt with in both sections. Two questions relating to NIR must be examined.

1. What effect does a particular NIR exposure have on health?
2. What effect does the development towards Pervasive Computing have on NIR exposure?

Irrespective of the answer to the first question, NIR exposure is one of the health-related contributing facts that must be considered here. Even assuming that NIR could be ruled out as a cause of damage to health, subjectively perceived harm or pollution by NIR exposure would be relevant.[141] In more detailed terms, the causal links are as shown in illustration 8-1.

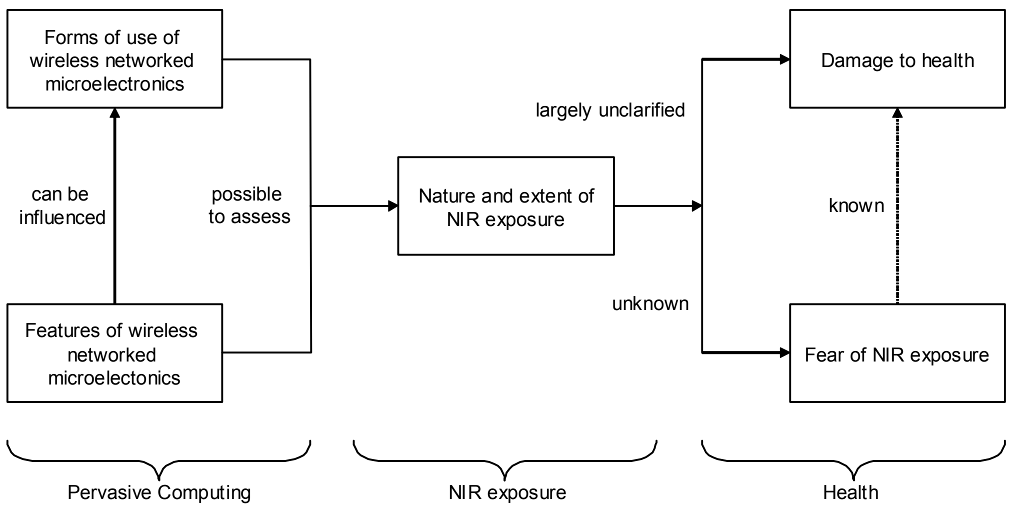

Illustration 8-1: Causal links between PvC, NIR exposure and health with a rough characterisation of the uncertainty involved.

8.3.1 Effects on health

Table 8-1 summarises the opportunities and risks of PvC in relation to human health which are clear as a consequence from Chapter 6 and Annex 5 to this study.

Where both an opportunity and a risk are indicated in a row, the effect concerned belongs to the class of 'Janus-faced risks' introduced above. Depending on the further course of development, one and the same cause can have a positive or negative effect on the aspect under consideration.

[141] 'The fear of a subjectively perceived threat can cause objectively measurable symptoms, e.g. disturbed sleep and the associated health consequences.' (Gutscher, 2002).

The column headed 'Level of knowledge' indicates whether a risk is now regarded as known or how great the degree of uncertainty is. Since, for our purposes, the level of knowledge is of interest only with regard to risks, we provide no indication with regard to opportunities.

Each row of the table will be explained in detail below.

Table 8-1: Effects of PvC on health

No	Field of application	Cause	Opportunity	Risk	Level of knowledge
G-1	all	NIR exposure through PvC	–	damage to health by NIR	largely unknown
G-2	all	physical contact with PvC components	–	allergies and chronic poisoning	partially unknown
G-3	health	monitoring state of health through PvC	greater safety and quality of life for the chronically ill	–	–
G-4	health	monitoring state of health though PvC	swifter and better informed assistance in emergencies	–	–
G-5	health	PvC-aided operating techniques	greater treatment success in surgery	-	-
G-6	health	use of active implants	improved possibilities for therapy	unexpected side effects of active implants	side effects partially unknown

G-1. Damage to health by NIR

Non-ionising radiation (NIR) encompasses all forms of (electro-magnetic) radiation whose intensity is not high enough to cause ionisation.[142] This includes in particular radio waves that are used for radio, television, mobile telephony and wireless data transfer.

The accepted measurement for the NIR exposure of body tissue is the specific absorption rate (SAR value) which is expressed in watts per kilogram of tissue (W/kg). It is not disputed that where exposure is correspondingly high damage to health is caused by *thermal effects*:

- In the event of a value of 100 W/kg or more, tissue damage definitely occurs.
- Limits for thermal effects are applied with a safety factor of 50 and therefore stand at 2 W/kg.

The present debate on the health risks posed by NIR relate to the possibility of *athermal effects*. These are effects that are not due to the warming of tissue and therefore can occur at lower levels of exposure.

The distance between the source of radiation and the body has a considerable influence on the level of exposure. Consequently, present levels of exposure through base stations (fixed transmitter units) are much lower than through the use of terminals which are held close to the head. Carrying a NIR source *directly on the skin* results in considerably higher levels of exposure because then up to 50% of the radiation penetrates into the body, and where a transmitter is *implanted* the figure is 100%.

Most investigations into athermal effects have been motivated by the spread of mobile telephony and apply only to head exposure and the radiation properties of mobile telephones of the now common second generation (2G), that is to say GSM mobile phones. As long as there are no causal explanations for the biological effects that have been found, no statement can be made as to the general nature of empirical results. In particular, they would not automatically apply to the mobile technology of the third generation (3G), that is to say UMTS, or to PvC (see also Annex 5).

From previous studies, in particular the most recent investigations by the group under P. Achermann at the Institute for Pharmacology and Toxicology at the University of Zurich, it is known (see also Section 6.4 and Annexn 5) that

- there are athermal biological effects from NIR, in particular on brain activity (EEG) during sleep;
- these effects depend on the modulation of the signal, that is to say they do not occur in the case of an unmodulated carrier signal.

What is unknown, however, is

- the causal mechanism underlying the proven biological effects;
- whether these effects result in damage to health;
- whether there are serious long-term effects of NIR exposure.

There are indications that there are effects on the activity of the enzyme ornithine decarboxylase (ODC), on the distribution of the hormone melatonin in laboratory animals, on calcium ion transport through the membranes of nerves and other cells, on

[142] If ionisation were caused, molecules would be altered.

cognitive functions (reduced reaction times), on the blood-brain barrier, on gene expression in mammalian cells and also adverse effects on the blood-forming or immune system. Disturbed sleep and electrosensitivity can also be regarded as a further indication of biological effects.

The psychosomatic effects of NIR exposure must also be taken into account in addition to the biological effects. Individuals with a predisposition to somatisation can develop genuine symptoms when they believe their health is suffering and it is presumed that this also occurs as a group phenomenon (‘mass sociogenic illness’, MSI). It is also known that the feeling that NIR is harming health is reduced in individuals with a predisposition to somatisation where they compare the risk under discussion with other risk scenarios (so-called ‘contrast effects’, Frick et al., 2002).

However, it is not known whether the electrosensitivity observed is due to biological mechanisms.

G-2. Allergies and chronic poisoning

As the number of microelectronic components used close to the skin grows, skin contact with the surfaces of these products (polymers containing additives), the inhalation of abraded or evaporated material and the risk of unintentional swallowing (in particular in the case of e-grains measuring less than a cubic millimetre) increases accordingly. As the variety of materials used grows, the risk of allergic reactions (as has been demonstrated by the example of nickel in the past, for example) or chronic poisoning can rise. On account of the similarity between microelectronics and nanotechnology, materials with new surface features and nanoparticles will also constitute possible sources of risk in the future.

The level of risk depends on the range of materials used, the nature of the components’ covering and design measures to prevent abrasion or evaporation.

G-3. Greater safety and quality of life for the chronically ill

In the case of chronic illnesses the monitoring of physiological parameters (e.g. heart rate, blood pressure and blood sugar) can lead to an increase in safety. Both long-distance monitoring (telemetry) and a local evaluation of the data measured for the wearers themselves are possible. See also the risks referred to under ‘Psychological side effects of high-tech medicine’ (Section 8.3.2).

G-4. Swifter and better informed assistance in emergencies

The response to a medical emergency can be speeded up and improved by the monitoring of an individual’s state of health, the automatic sending of an emergency call, swifter location of the casualty by the emergency services and the automated provision of information (e.g. of an electronic medical file). The chances of survival and recovery of the individual concerned are thereby increased.

G-5. Greater treatment success in surgery

The use of micro and nano robots and sensors in surgery offers great opportunities for minimally invasive operating techniques and will benefit from the trend towards PvC.

Augmented reality can also improve the precision of interventions and the availability of information during operations.

G-6. Improved possibilities for therapy / unexpected side effects of active implants

Active implants, that is to say microelectronic components inserted into the body, offer great therapeutic opportunities, e.g. as components of computerised prostheses, as brain pacemakers, or as artificial sensory organs (sensory prostheses). If active implants were used without systematically clearing up possible side effects, the risks could predominate. The possible side effects are:

- reactions to substances which become detached from the implant surface under the influence of the biological surroundings;
- effects on the functionality and behaviour of cells which come into contact with the implant as a result of protein absorption and denaturation on the implant surface;
- mechanical stress on the tissue in the area immediately adjacent;
- disruption of cell-to-cell interaction as a result of electrical or optical activity;
- irradiation of electromagnetic fields by implants which can result in high local levels of NIR exposure.

These risks can be influenced by the tests carried out, by the covering of implants and by further research into the as yet unknown effects.

Where active implants communicate without wires, it should be noted that even where transmitting power is very low - in comparison with mobile communications - local exposure levels of the order of 100 W/kg could arise in the surrounding tissue. This is due to the very close proximity to the tissue and the small dimensions of the implants (see Annex 5).

8.3.2 Effects on health-related contributing factors

In addition to the possible *direct* effects of PvC on health, there are also *indirect* effects, that is to say effects on health-relevant contributing factors such as, for example, stress or physical mobility. Table 8-2 shows the corresponding opportunities and risks. These indirect effects are just as relevant (see Section 8.1) as the direct effects.

Here the uncertainty in the risk assessment lies less in the field of scientific knowledge and more in the difficulty in forecasting society's response to the technical possibilities, particularly since that response can in fact be influenced.

Therefore, the *influence of the three scenarios* rather than the level of knowledge is indicated in the fourth column. The three scenarios were introduced in Chapter 4 to demonstrate possible courses of development for PvC.

Table 8-2: Effects of PvC on health-related contributing factors

No	Field of application	Cause	Opportunity	Risk	Influence of scenarios
E-1	all	ICT environment altered by PvC	NIR exposure decreases	NIR exposure increases	decrease only in intermediate scenario on additional assumptions
E-2	all	new forms of human-machine interaction	less stress as a result of ergonomics[143]	greater stress as a result of poorer ergonomics	opportunity always exists, necessary in high-tech scenario
E-3	all	dependence on a growing number of networked PvC components	–	stress as a result of subjectively unpredictable behaviour of the technology	risk increases with degree of penetration and networking
E-4	all	larger number of objects which interact with humans	–	stress as a result of overstimulation and distraction of attention	high in intermediate scenario, unclear in high-tech scenario
E-5	health, work	ICT is carried on the body	greater physical freedom of movement	–	increases with degree of penetration and networking
E-6	health	monitoring of physiological parameters by PvC	healthier lifestyle	e-doping	opportunity and risk exist in intermediate and high-tech scenario
E-7	health	greater use of technology for diagnosis, treatment and care	greater autonomy for patients	psychological side effects of ‘high-tech medicine’	risk predominates in high-tech scenario
E-8	health	altered cost structure in the health system as a result of PvC	contribution to cost stabilisation in the health system	wave of cost increases in the health system	opportunity and risk low in cautious scenario
E-9	transport	systems to aid drivers of vehicles	enhanced transport safety	increased risk of accidents	risk high in high-tech scenario

[143] Ergonomics, in the sense in which it is used here, seeks to adapt working conditions to people to an optimal degree in terms of the interaction between people and machines. The criterion ‘ergonomic’ is therefore more comprehensive and extensive than ‘usable’ or ‘user friendly’, ‘reliable’, etc. See also the entry on Ergonomics in the glossary.

E-1. NIR exposure decreases / NIR exposure increases

Pervasive computing can lead either to a decrease or an increase in average everyday NIR exposure in comparison with the present. A decrease is possible if the following conditions are satisfied:

- Wireless local networks (W-LANs) become established; *and*
- Mobile access is also gained to other networks indirectly via W-LANs, wherever this is possible, that is to say that access to mobile wireless networks (GSM or, in future, UMTS) remains limited to situations in which no W-LAN is available; and the use of networked wireless terminals close to the body does not increase significantly.

Future mobile terminals would have to be able to access all networks, such as the Internet and the fixed telephone network *via* a W-LAN, where there is a W-LAN base station within a 100 m radius, and would attain a high level of coverage. Only in exceptional cases, that is to say outside W-LAN coverage in conurbations, would access to mobile wireless networks be necessary.

Under these conditions exposure would decrease because mobile wireless networks would be accessed less frequently. On account of the larger distance to the base station (several kilometres) this requires a transmission power in the terminal 10 to 20 times greater than that required when accessing a W-LAN.

Where even one of the three conditions is not satisfied, an increase in NIR exposure must be anticipated. This is true in particular where wireless terminals are used directly on the body (and thus closer than a mobile phone aerial). Local exposure may be many times higher on account of the greater proximity to the body (see also Annex 5).

E-2. Less stress as a result of better ergonomics / greater stress as a result of poorer ergonomics

New forms of human-machine interaction are necessary if keyboard, mouse and monitor are not to put a brake on implementation of small mobile ICT applications (e.g. input through speech, gestures, mimicry, direction of vision, new kinds of keyboards, data gloves or simply by the use of common objects; output through retina displays, etc.). However, optimal adaptation of a technology to humans does not occur automatically and perhaps poses the greatest challenge to developers.

There is an opportunity for PvC to adapt to humans more effectively than current ICT, such as notebooks and mobile telephones, for example. However, previous experience shows that human willingness to adapt to ICT is so great that people will even accept poor solutions with great stress potential. For example, even now there are ICT products which do not satisfy the 'plug and play' criterion, that is to say do not function after having been plugged in and switched on, but are still bought. In many cases they even have a larger market share than competing products which satisfy this criterion to a greater degree.

From the present perspective it is therefore difficult to predict whether PvC will bring about a higher level of adaptation of technology to people or whether, conversely, the pressure on people to adapt to (possibly poor) technology will increase.

E-3. Stress as a result of subjectively unpredictable behaviour of technology

On account of the complexity of programmed systems, the user is often unable to rely on them behaving as they should.[144]

This is true in particular where several systems are networked, as is the norm at present. This gives rise to distributed systems whose behaviour is particularly difficult to predict. The possibilities of formal verification, which would ensure that unwanted system states could not occur, are also limited in this case.

As the dependence on such systems increases, the potential harm which could result from a misjudgement of their behaviour also rises. Where more is at stake than the results of few hours' work (as at present in the case of normal PC use) the stress on users will also increase accordingly.

E-4. Stress as a result of overstimulation and distraction of attention

Nowadays many people feel disturbed by the ringing of mobile telephones or having to listen to other people's conversations. Therefore, the use of mobile phones is not permitted or is unwelcome in certain areas (theatres, quiet compartments in trains and restaurants).

Despite the intended inconspicuousness or even invisibility of PvC components, they have to attract the user's attention in many cases. The signals by which this will be done, and the extent to which the disturbance of third parties can be avoided, is a question of how the human-machine interaction is organised and remains unanswered.

There is a risk of a general increase in disturbances and interruptions (in relation to conversations, concentrated work, relaxation, etc.) as a result of the technology-related distraction of attention which can lead to increased stress.

E-5. Greater physical freedom of movement

The possibilities for using ICT from any location, which should come to fruition in line with the vision of PvC, offer opportunities for increased freedom of movement. The reasons for being 'tied' to a desk, a sick bed or other places become increasingly inapplicable. Sporting activities can be combined more easily with other activities, such as media consumption.

This can result in greater physical exercise and have a positive effect on health both in terms of rehabilitation and as a general contribution to a healthier lifestyle.

E-6. Healthier lifestyle / e-doping

The monitoring of physiological parameters by PvC can provide health-conscious individuals or those in rehabilitation with useful information which even permits a

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[144] Although a digital computer is a deterministic machine, that is to say its behaviour is objectively predictable, the behaviour of a computer system can - even where the hardware is functioning quite correctly - reach a stage, on account of the complexity of the software, at which a person (and even the developer themselves) is no longer able to build up a proper mental model of the system. The behaviour of the system *subjectively* appears to be unpredictable even though it is determined entirely by the initial state and the input data. The transparency of software or even the formal verifiability thereof is regarded as a rare exception in information technology.

systematic optimisation of their lifestyles. Food, sport and relaxation are, as it were, optimised in a closed loop.

However, an aid to preventing excessive stress can also be used to push the limits of possible stress or even to take a calculated risk and exceed them. Consequently, it cannot be ruled out that PvC forms of 'e-doping' will arise.

E-7. Greater autonomy for patients / psychological side effects of 'high-tech medicine'

PvC can reduce patients' dependence on support and nursing staff, shorten hospital stays and improve patients' level of information. All this creates an opportunity for providing patients with greater autonomy during the course of their treatment.

As a rule, greater use of technology also means a reduction in staff. A further step towards 'high-tech medicine' could cause psychological side effects, such as the feeling of being watched or exposed or a fear of technical failure. This is to be anticipated in particular where monitoring is carried out involuntarily or only partially voluntarily, e.g. under pressure from health insurance providers.

E-8. Contribution to cost stabilisation in the health system / wave of cost increases in the health system

The effects of rationalisation, early identification of illness and other effects of PvC in the health system could have the effect of bringing down costs. At the same, new, possibly cost-intensive therapies (e.g. in the field of active implants) arise which could lead to a new wave of cost increases where they involve frequent indications.

E-9. Enhanced transport safety / increased risk of accidents

In transport, additional monitoring, guidance and control systems could improve safety for vehicles and drivers.

If the technical complexity of the systems used and their 'autonomy' is not strictly limited, the risks could predominate. These risks lie, on the one hand, in the realm of technical failure (software error with serious consequences) and, on the other (where the systems function correctly), in the driver's increased willingness to take risks on account of the feeling of safety that is created.[145]

In addition, systems which divert the driver's attention from the road give rise to high levels of risk.

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[145] There was a similar experience with anti-lock braking systems (ABS) (Schibalski 2002)

8.4 The environment

On the basis of the environmental effects described in Chapter 7, the most important opportunities and risks of PvC in respect of the environment are as set out in Table 8-3.

Table 8-3: Effects of PvC on the environment

No	Field of application	Cause	Opportunity	Risk	Influence of scenarios
U-1	all	PvC as dominant form of application of ICT	lower ICT-related material consumption	higher ICT-related material consumption	depends on prevailing circumstances
U-2	all	PvC as dominant form of application of ICT	lower ICT-related energy consumption	higher ICT-related energy consumption	depends on prevailing circumstances
U-3	all	disposal of small electronic components	-	disposal problems caused by electronics	increases with degree of penetration
U-4	all	measurement, guidance and control become simple and cheap	processes that are more material and energy-efficient	-	depends on prevailing circumstances
U-5	all	support for organisation of services	trend towards buying services rather than material goods	-	significant extent in intermediate and high-tech scenario
U-6	all	large number of embedded systems	-	goods have shorter lifespans on account of ‘virtual obsolescence’	risk in intermediate and high-tech scenario established
U-7	housing	smart homes	lower energy consumption in the home	higher energy consumption in the home	opportunity and risk in high-tech scenario
U-8	work, media	increasing ability to conduct activities from any location	decrease in motorised transport	increase in motorised transport	depends on prevailing circumstances
U-9	transport	increasing use of ICT whilst on the move	competitive advantage of public transport compared with private transport	competitive disadvantage of public transport compared with private transport	opportunity and risk in all scenarios

U-1. Lower ICT-related material consumption / higher ICT-related material consumption

Specific material consumption in the ICT sector will fall as a result of further miniaturisation of microelectronics. PvC as a form of ICT application requires, of necessity, the use of very small and light components. In the cautious scenario, this could bring about an absolute fall in material consumption in the ICT sector. However, this effect is diminished by the fact that material consumption in the manufacture of an ICT product does not decrease in proportion to the mass of the product. For example, at present between 500 - 1500 kg of material are used to manufacture a desktop PC with a 17" CRT monitor (altogether 23 kg), but 435 kg are used to manufacture a 4 kg laptop (Wuppertal-Institut, 2002).

In the intermediate, and in particular in the high-tech scenario, the fall in specific material consumption will, in all likelihood, be compensated for, or overcompensated for, since the number of manufactured components will increase sharply. This is indicated by the following factors:

- The vision of PvC assumes a large number of components that are used in parallel (estimate: 1000/person).
- As a result of the anticipated reduction in the price of the components, their useful life will be reduced further in comparison with a present-day notebook or mobile telephone (trend towards disposable products).

Therefore, there is a risk of an increasing raw material requirement in the ICT sector.

U-2. Lower ICT-related energy consumption / higher ICT-related energy consumption

A distinction must be drawn between energy consumption for manufacture and for use. Previous experience shows that energy consumption in relation to ICT is higher at the use stage than at the manufacturing stage, when fixed equipment in constant use is taken into consideration (in particular servers). In the case of equipment which is in operation only during direct use, and in particular in the case of mobile equipment, energy consumption in the use stage is lower than in the manufacturing stage.

As regards cumulative energy use in production (grey energy), the same comments generally apply as those concerning material consumption (see above).

As regards energy requirement in the use stage, there is a major opportunity for savings in the case of *mobile terminals*

- because the required mobility of the product provides incentives for greater energy efficiency, as has already been observed in the case of notebooks;
- because the anticipated large number of very small components makes it necessary to fit solar cells or other sources of energy independent of the grid and recharging via parts of the grid or changing batteries is no longer practicable.

However, the risk of a net increase in consumption can predominate if there are no incentives to design the requisite *fixed infrastructure* (servers, base stations, routers, gateways, repeaters, switches, etc.) in such a way as to save energy and *auxiliary equipment* such as UPS[146] and air conditioning exist (see Section 7.1 and Türk et al., 2002).

[146] Uninterruptible power supply

U-3. Disposal problems caused by electronics

Instead of a small number of large electronic components it will become necessary to dispose of a larger number of very small products, some of which are embedded in other products and in most cases contain rechargeable batteries (which are required even for power supplies via solar cells).

There is therefore a risk of uncontrolled disposal of hazardous materials through domestic waste because the system for taking back electronic products; e.g. established in Switzerland by the Regulation on the return, taking back and disposal of electric and electronic equipment (VREG) and SWICO[147], may no longer be practicable for a growing proportion of the mass flow. This also results from an information problem: it becomes increasingly difficult for consumers to distinguish between electronic and non-electronic products.

Influencing factors are: the trend away from the use of NiCd batteries[148], the prohibition of lead solder in the EU, the properties of future lead-free solders and the further development and future role of polymer electronics.

U-4. Processes that are more material and energy-efficient

Many processes in production, consumption and disposal can be optimised through improved monitoring, guidance and control. The aim of optimisation can be to reduce material or energy consumption. In much the same way as the local control of heating by means of thermostatic valves became established, in future everyday processes requiring a more complex processing of information could also be optimised. This can also include charges in proportion to the quantities used, which thus far have been calculated on a flat-rate basis ('micro-billing'). Such individual cost incentives can easily give rise to changes in behaviour in favour of conserving resources (Diekmann, 1994).

PvC offers an opportunity for lowering the threshold for the use of such systems and reducing amortisation periods.

U-5. Trend towards buying services rather than material goods

The replacement of material goods by services is an important component in strategies to dematerialise economic processes, as discussed in the context of sustainability. Although material goods (capital goods, consumer goods, etc.) are required to supply services, the provider of a *service* has an economic interest in the efficient use of these products, that is to say in full utilisation of capacity, long lifespan, ease of repair, and a high degree of effectiveness. By contrast, the provider of *material goods* is not interested in the long lifespan or efficient operation of their products. For their part, the purchaser has only limited possibilities for improving capacity utilisation, e.g. by lending goods.

PvC could greatly boost this trend because

- the sale of services can be more effectively organised and billed as a result (e.g. pay-per-use leasing, see also Bohn et al., 2002)

[147] Swiss Trade Association for Information, Communication and Organisation Technology

[148] As regards NiCd batteries, the Regulation on materials (StoV 1986) provides for a compulsory deposit.

- the use of ICT hardware, programs and data can itself assume the character of a service. This would make it possible to make fuller use of the hardware capacity and could be implemented if the anticipated level of networking were attained.

This opportunity depends on the areas in which service models gain sufficient acceptance (importance of ownership of material goods to personal image).

U-6. Goods have shorter lifespans on account of 'virtual obsolescence'

The useful life of material goods is an essential parameter for material and energy consumption. Halving the useful life means doubling the resources required for manufacture and doubling the disposal required. The period of use can be shorter than the technical lifespan.

Experience in the ICT field shows that equipment is taken out of service and replaced when it has completed only between 10% and 50% of its technical lifespan. For example, although a PC can, in technical terms, function for around 20 years, it is used for only 2-5 years. The same applies to entertainment electronics.

Technical innovations drive this rapid change. Mainly on account of changes in the technical environment leading to compatibility problems, products become unusable well before the end of their technical life.

There is a risk that this development will now spread to objects in which ICT components are embedded. For example, a networked refrigerator could be replaced because the old model is unable to master a new network protocol. We have introduced the term 'virtual obsolescence' to describe this possible effect. In view of the large number of embedded systems to be expected in line with this PvC vision, this would be a setback to efforts to achieve sustainability.

A special case is the introduction of PvC itself, which will initially lead to a devaluation of conventional non-'intelligent' and non-networked objects.

U-7. Lower energy consumption in the home / higher energy consumption in the home

In principle the vision of a 'smart home' offers the opportunity of optimal control and regulation of the household processes that are most relevant in terms of energy (heating, ventilation, hot water, possible solar energy use, heat pumps, etc.). Unnecessary losses could be prevented more effectively than at present.

However, as long as there are no huge incentives to use energy sparingly, there is a risk that energy consumption will increase as a result of the increased operation of base stations (W-LAN), of servers (continuous operation) and of electronics with standby consumption.

U-8. Decrease in motorised transport / increase in motorised transport

PvC provides favourable conditions for substituting physical presence by virtual presence. There is an opportunity for team cooperation from any location to become a natural part of work culture if the ergonomic weaknesses of the current groupware approaches are overcome[149]. This could save numerous journeys to the workplace,

[149] Groupware or CSCW (computer-supported cooperative work) systems are used to support group working.

business meetings, training locations, etc. In this regard, it is not assumed that physical presence will be completely replaced, but that it will be reduced to occasions which actually require such presence (initial contact, confidential contacts, conclusion of deals).

This contrasts with the risk of a rebound effect[150] with the additional problem that the ability to conduct activities from any location can create an incentive for greater mobility, in particularly by engagement in activities and relations at locations far apart from one another.

U-9. Competitive advantage of public transport compared with private transport / competitive disadvantage of public transport compared with private transport

We assume that public transport causes less environmental pollution per passenger kilometre than private transport, in particular on account of its greater space and energy efficiency.

There is an opportunity for passengers on public transport to have even greater scope to use their ‘travel time’ more productively through PvC than they do with current ICT in the form of notebooks and mobile telephones. Consequently, the use of public transport becomes more attractive whilst in private transport the drivers at least cannot and may not take advantage of this development because their attention is occupied. Furthermore, the public transport services on offer can be made more transparent through PvC (e.g. by mobile access to travel information with context-sensitive route planning).

On the other hand, it is precisely the car that, in accordance with manufacturers’ plans, is being converted into a multimedia communications centre. In the main the passengers benefit from this development, but the aim is also to assist the driver (navigation). Therefore, there is a risk that public transport will be ‘unhitched’ from this development in spite of its essentially better starting position. It must also reconcile the opposing needs of the various groups of customers (e.g. the train as a mobile office / the train as an electronics-free zone / the train as a children’s paradise / etc.).

The risk is affected by how far public transport succeeds in developing a forward-looking plan for the use of time by its passengers under PvC conditions.

[150] Time saved would be spent on other journeys, as the overall trend has been thus far (see also Chapter 5).

8.5 Social aspects

Social effects of PvC are, in the broadest sense, also relevant to health and are therefore dealt with extensively. However, we would point out that the statements made in this part of the study display greater uncertainty than the comments on health effects in the narrower sense and on environmental effects.

Table 8-4: Social effects of PvC

No	Field of application	Cause	Opportunity	Risk	Influence of scenarios
S-1	all	penetration of everyday life by ICT	removal of the digital divide	restriction of consumers' freedom of choice	opportunity predominates in cautious scenario
S-2	all	ubiquitous access to information	efficient access to information and knowledge	economy of attention	risk predominates in high-tech scenario
S-3	all	ubiquitous access to information	formation of virtual communities	loss of social contact	unclear, as it depends on other factors
S-4	all	monitoring and identification by ICT	enhanced protection against criminal acts	data privacy is undermined	opportunity can predominate in cautious scenario
S-5	all	ubiquity, embedding, networking of ICT	-	new forms of computer crime	increases with degree of penetration and networking
S-6	all	extension of unmasterable complexity	-	polluter-pays principle reaches its limits	increases with degree of penetration and networking
S-7	housing, work	increasing ability to conduct activities from any location	better compatibility of work and family life	-	increases with degree of penetration and networking

S-1. Removal of the digital divide / restriction of consumers' freedom of choice

The division of society into those who use ICT and those who cannot or do not want to use ICT is termed the 'digital divide' in society.[151] In that regard, access to the Internet is now the central criterion.

[151] We are referring to the digital divide within the Swiss population and not to the 'global digital divide' between the global North and South.

On account of the abovementioned opportunities provided by new forms of human-machine interaction (see E-2) it is possible that the threshold for the use of ICT will fall considerably. For example, the use of a keyboard will be necessary in fewer and fewer cases. It will also be easier to develop applications that will make it possible or easier for disabled and ill people to gain access.

At the same time there is a risk that consumers' freedom of choice will be restricted for the following reasons:

- people who refuse using ICT, in particular for certain limited purposes (e.g. banking), could be disadvantaged by a change to the supply structure and thus actually forced to use ICT.
- ICT is based decisively on technical standards and this is true in particular where the level of networking is high. As long as proprietary de facto standards continue to play an essential role, there is a possibility that competition will disappear.

In the first case the consumer is no longer free to choose *what* they do or don't use ICT for. At the point where conventional services go from being the rule to being the exception, they are subject to high charges and/or the supply diminishes (e.g. closure of libraries, banks and post offices) or disappears altogether. In the second case the consumer no longer has the choice of *which* ICT products or ICT services they use because the ICT market tends to adopt a 'winner-takes-all' structure. This is the case at present with software but it could spread to hardware on account of the close link between hardware and software in PvC, that is to say the providers will attempt to sell software licences in a 'bundle' with hardware products.

S-2. Efficient access to information and knowledge / economy of attention

Access to information and knowledge will function even more efficiently as a result of PvC. Points of access are available everywhere and at any time (ubiquity) but nevertheless relevant to the surroundings (context sensitivity). For example, someone standing in front of a tourist attraction automatically receives historical information, opening hours or messages left by other tourists. More efficient access to information offers an opportunity for self-guided learning without the pressure to perform from an educational establishment.

The user is inundated by the range of information to an even greater extent than on the Internet.[152] Since human ability to take in information is limited, the user is caught in the so-called 'information paradox'. In order to decide whether he wishes to consider a piece of information, and to assess the reliability of the sender, he must first consider that information.

Consequently, conscious attention becomes a scarce resource. People may not be able to afford to 'pay' attention but will instead divide it up sparingly into different 'worlds'. Physical surroundings still appear to a be special case, as it were a 'Channel 1' of an immense range on offer. Advertising will fight harder and harder for the scarce attention resources and therefore it will become increasingly closely connected with the information on offer. The final preserves of non-commercialised attention will be occupied.

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[152] 'Trying to learn from the Internet is somewhat like trying to get a drink of water from a gushing fire hydrant.' (source unknown)

S-3. Formation of virtual communities / loss of social contact

Virtual communities are groups of people with common interests who, in spite of great geographical distance, are able to interact and articulate themselves as a community. To date the Internet has established an enormous number of such communities, e.g. to exchange information on rare diseases, for political and ethnic minorities, or people with unusual hobbies. Virtual space makes it possible to form communities which could not exist in actual space on account of their insufficient 'density'. PvC could promote this trend because access thresholds will be lower than in the case of Internet access via a PC.

If there is an extreme switch to the virtual world, there is a risk that direct social contact will be lost. The attempt to replace love of one's neighbour by 'love of distant strangers' is already occupying psychotherapists. The ability to access the virtual world any time and anywhere will presumably strengthen the addictive tendencies that are already being observed in connection with the Internet (cf. Schauer, 2002).

S-4. Enhanced protection against criminal acts / data privacy is undermined

There is an opportunity for protecting buildings and facilities more effectively from unauthorised access by means of thorough and inexpensive surveillance and new possibilities for personal identification. The protection of objects from theft is made considerably easier by means of 'smart labels' and other identification systems. The monitoring of individuals' data traffic (e.g. their Internet use) can form an integral part of the fight against crime in the same way as tapping telephone conversations.

The same technology can be used to invade privacy and record sounds and images without the knowledge of those concerned, to document their whereabouts, to monitor their data traffic and to store and pass on the information thus acquired. Under the Swiss Federal Law on data protection (DSG), such actions constitute invasions of personal privacy which are permitted only in certain exceptional cases. Everyone has a right to information, that is to say they can demand from the holder of a data collection information on whether and what data on them is being processed.

There is a risk that, as a result of PvC, the establishment of data collections containing personal data will go from being an exception to being the rule. Exercising the right to information thus becomes almost unfeasible because individuals would have to make requests to an enormous number of potential holders of data collections, from every provider of network services, via the neighbours in a block of flats sharing the same W-LAN, to a stranger who might have taken a picture with their mobile phone in a fitness centre.

Since the right to information is no longer practical in this context, PvC means, at least in the high-tech scenario, accepting a considerable loss of privacy.

> ‘Because the systems that we use are becoming more and more complex, the user is increasingly forced to trust them blindly in order to be able to use them efficiently.’
>
> Klaus Brunnstein, IFIP President (Brunnstein, 2002).

S-5. New forms of computer crime

In the same way as the Internet has produced new forms of crime, PvC will also open up new possibilities for criminal abuse as a result of the even more sophisticated networking, embedding and ubiquity of ICT. In that respect it should be borne in mind that embedded systems not only process information but can also guide physical processes. Whereas the virtual world of the Internet is in contact with the real world only indirectly via the user’s head, the virtual world of PvC has a direct line to reality. This is clear from the example of implants or ‘drive by wire’. Physical processes are also guided via ICT in the case of the ‘smart home’.

Consequently, there is a risk that the guidance of the processes will be manipulated with criminal intent. This can occur by:

- reprogramming components
- directly affecting components by radio waves
- creating effects via networks
  - by unauthorised access (network hacking)
  - by overloading networks
  - by introducing computer viruses
  - by disrupting radio links and cable connections.

The question whether or not absolute security is possible *in principle* is not decisive in this regard. Instead, in the ICT field there is a general trade-off between security and usability. The safer a system, the less efficiently it can be used (see also the insert above). Since both a high degree of networking and progress in the usability of systems is expected from PvC, it is difficult to imagine how data and network safety can be maintained at an acceptable level.

S-6. Polluter-pays principle reaches its limits

Software licensing agreements normally contain a comprehensive clause on exception from liability (a disclaimer). Software manufacturers are aware that they cannot guarantee that their programs are correct.

This is due to the fundamental problem that information systems can easily take on a complexity which is not easily understood by the developers and cannot be mastered by formal means (see also paragraph E-3 in Section 8.3.2).

The extent of unmastered technical complexity will increase as a result of PvC. This is indicated by the following factors:

- the behaviour of distributed systems - which is what PvC is - is particularly difficult to describe and verify formally;
- as a result of the mobility of networked components, distributed systems whose properties are predictable to only a limited degree are being formed continuously;
- new software concepts are coming into use, such as so-called ‘agents’ which carry out operations independently - on behalf of their user (e.g. bidding at auction).

The problem of a potential loss of responsibility, because decisions are increasingly based on ICT, has been known for some time as the ‘problem of incontinence’ (Mitcham, 1986).

In the event of harm it will probably be very difficult to establish a cause in the legal sense on account of the complexity of the systems concerned. The behaviour of a system is determined by the combination of a large number of software products, hardware products, user interactions, network protocols, etc. In view of the complexity which man has created but not mastered, the polluter-pays principle reaches its limits.

In the light of the actual damage that software errors can create, it is astounding that software cannot, from a legal viewpoint, be clearly described as a product within the meaning of the Swiss Law on product liability. Software is not regarded as an object because it is not ‘corporal’ (Kull, 2002, p. 6).

S-7. Better compatibility of work and family life

By making it possible to engaging in an increasingly large number of activities from any location, greater opportunities open up for people of both sexes to combine work and family life, in particular in terms of childcare.

This development could contribute towards progress on equal rights for men and women in our society.

8.6 The Swiss economy

In order to set out the most significant opportunities and risks of ICT in relation to the Swiss economy, we will use an ICT layer model as a diagram (see illustration 8-2).[153] Each layer requires and uses the underlying layer. The consumer is interested in the content and services. They motivate the consumer to build up the relevant infrastructure in their own home and to acquire mobile terminals and 'intelligent objects'.

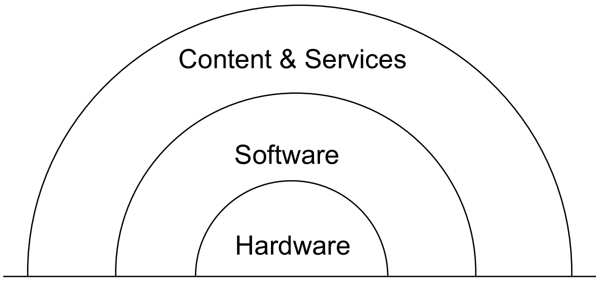

Illustration 8-2: Simplified ICT layer model.

Reliance on foreign countries for hardware and software

The vast majority of the hardware for PvC is imported. In that respect opportunities exist only for the retail trade, which will benefit from the wave of mobile electronic components and the infrastructure which can be installed by customers themselves, and for electrical installation businesses, which will install the remaining part of the infrastructures.

On the software level too foreign manufacturers will probably dominate and therefore it would be unrealistic to regard PvC as an opportunity for the Swiss software industry. The reliance on foreign licensers will increase and constitutes a risk in that the economy and society as a whole is becoming increasingly reliant on the availability of such systems.

Opportunities in relation to the supply of content and services

By contrast, major opportunities could open up on a third level in relation to the supply of content and services. On the basis of the experience of supplies on the Internet, it can be assumed that there is *a large demand for local and regional content and services*. This means that average ICT users have a pronounced preference for being supported in their actual, local surroundings. Consequently, the relevant supplies must be produced locally.

This applies all the more as a consequence of the *context sensitivity* of PvC applications, which make it possible, inter alia, to offer users contents and *services relevant to their precise location and other situation parameters* and, naturally, in their native language. Weather reports, timetables, delivery services, event information and tourist information - to name but a few examples - can be localised and personalised to a great degree. In this context a countertrend arises to globalisation through the Internet. Although PvC

[153] The subdivision in accordance with the so-called 'onion layer model' of information technology, or even in accordance with the OSI reference model, is more differentiated. For our purposes this rough division is sufficient.

will also facilitate access to global cyberspace, local contents and services will dominate. If the rebound effects described in Chapter 5 can be successfully prevented and the relevant business models are not discredited by violations of data privacy and disreputable providers - and companies should, in their own interest, take measures to ensure that they do not - a market with great growth potential will open up in this regard. It offers opportunities for many sectors, from small businesses which will benefit from greater local transparency in respect of supply, to publishing houses that will develop entirely new forms of information products.

Experience of dealing with multilingualism and cultural differences within a small area is a particular feature of Switzerland. Therein lies potential for the development of local contents and services for PvC and the relevant know-how could possibly be exported.[154]

More in-depth consideration of the opportunities and risks of PvC in respect of the Swiss (or any other national) economy would require a study focused on that theme.

[154] Even now there is a great demand in the applied software sector for know-how relating to adaptation to national and regional contexts.

8.7 Qualitative characterisation of the risks

Uncertain risks cannot be assessed in quantitative terms. Even though in some cases it is possible to make a rough estimate of the scale of the harm, the probability of it occurring cannot be determined. This is true of both the kinds of uncertainty which we referred to in Section 8.2.

Therefore, we can characterise the risks only in qualitative terms. Various criteria for doing so are put forward in risk research. By analogy with Müller-Herold (2002), a selection of such criteria is described as a 'filter'. The aim of a filter is to identify those risks which have higher priority than others in terms of precautionary measures and to gain indications of the type of measures appropriate to the relevant risk.

In defining a filter we initially proceed from the criteria which are frequently referred to in academic writings. Renn, Klinke and Kastenholz (2001) have suggested the following criteria:

- uncertainty: level of knowledge about the risk;
- ubiquity: geographical range of potential harm;
- persistence: duration of potential harm;
- reversibility: the possibility of restoring the situation which existed before the harm occurred;
- the delay effect: the period of time between the original event and the actual consequences;
- mobilisation potential: the encroachment on individual, social or cultural interests or values.

We have combined another list of criteria, which is orientated more towards risk perception and acceptance, from several sources (see Brown, 1999; Mehl, 2001; Wiedemann/Brüggmann, 2001):

- voluntariness: a risk which is entered into voluntarily is more acceptable than an involuntary risk;
- controllability: if a risk appears to be controllable, it is more likely to be accepted;
- trust: if the causer of the risk or the regulatory authority is trusted, the risk is more likely to be accepted;
- fairness: if the utility and possible harm are distributed unequally, the risk is less reasonable;
- disaster potential: for example, a plane crash is perceived as more serious than the same number of deaths on the roads over longer periods.

A filter must also be defined in context. For example, the filter (with the criteria of ubiquity, bio-accumulation and persistence) defined by Müller-Herold for chemicals in the environment would not be suitable for our purposes. Nor is a 'maximal filter' including all conceivable criteria sensible since many criteria are not selective in a given context and are therefore unsuitable for prioritising risks. Furthermore, a filter should be clearly and simply defined so that the conclusions are open to discussion.

The following criteria have proved to be selective in characterising the risks referred to in Sections 8.3-8.5:

- *socio-economic irreversibility:* is restoration of the original situation virtually impossible for economic or legal reasons? (see also Section 2.2 explaining this criterion)
- *delay effect:* is there a major delay between the time at which the cause arises and the time at which the harm occurs? [155]
- *conflict potential* with the two sub-criteria
  - voluntariness: is the risk taken voluntarily?
  - fairness: are the utility and possible harm distributed equally?[156]
- *burden on future generations:* does the situation that has arisen diminish the opportunities of future generations or satisfy their needs?

We have introduced this last criterion as a variant on the persistence criterion in order to establish a clear connection with the principle of sustainability.

The criteria are worded partially in positive terms and partially in negative terms for linguistic reasons alone.

Before we apply this filter, let us summarise some of the original 24 risks[157] which are similar on account of the nature of the harm:

- the two risks relating to NIR exposure: E-1 (NIR exposure) and G-1 (damage to health by NIR),[158]
- all the risks relating to stress: E-2 (poor ergonomics), E-3 (unpredictable behaviour), E-4 (overstimulation),
- all the risks relating to the life of materials (from the extraction of raw materials to disposal): U-1 (material consumption), U-3 (disposal problems), U-6 (virtual obsolescence),
- the two risks relating directly to energy consumption: U-2 (energy consumption of ICT in general), U-7 (energy consumption of ICT infrastructure in the home).

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[155] A delay - in relation to the speed at which the cause spreads - is disadvantageous because then countermeasures in connection with the protection principle (hazard control) take effect too late. Delay effect is therefore a central criterion in relation to the precautionary principle .

[156] This can relate both to local distribution and global - North-South - distribution.

[157] The 'pure' opportunities are not dealt with further here. The economic risks are not examined further as this does not fall within the study's terms of reference.

[158] Therefore, the increase in exposure is no longer considered separately but as a link in the chain leading to possible damage to health.

8.7.1 Application of the risk filter

The application of the filter to the now 18 risks shows that 11 of them clearly satisfy at least two of the criteria (see Table 8-5). We consider that these risks take priority over the others.[159]

Table 8-5: 11 unknown high-priority risks of Pervasive Computing. A dash ('-') means that the criterion is not satisfied or is only satisfied to a very small extent.

No	Risk	Socio-econ. irrevers-ibility	Delay effect	Conflict potential		Burden on future generations
				involun-tariness	unfairness	
G-1 E-1	damage to health by NIR	high	high in part [160]	high in part	high in part	—
E-2 E-3 E-4	stress by technology	high	—	high	high	—
E-8	wave of cost increases in the health service	high	medium	medium	—	—
U-1 U-3 U-6	material consumption and disposal problems	high	—	—	high in part	high in part
U-2 U-7	ICT-related energy consumption	high	—	—	high in part	medium
U-8	increase in energy-intensive mobility	very high	medium	—	high in part	high
U-9	competitive disadvantage of public transport compared with private transport	very high	medium	—	—	medium
S-1	restriction of consumer's freedom of choice	high	medium	high	—	—
S-4	data privacy is undermined	high	medium	high	high	—
S-5	new forms of computer crime	high	medium	high	high	—
S-6	polluter-pays principle reaches its limits	high	medium	high	high	medium

[159] However, it should not therefore be concluded that no precautionary measures should or could be taken to minimise the other risks.

[160] Low in relation to psychosomatic effects and electrosensitivity.

We will first discuss the picture which emerges from viewing the individual criteria, then summarise in *clusters* the risks which display a similar profile in accordance with these criteria. That will further reduce the complexity involved.

Socio-economic irreversibility

All the risks listed in Table 8-5 satisfy this criterion because the spread of the technology gives rise to a risk that cannot in fact be reversed.

As regards the possible *indirect* effects on the development of traffic, it is also true that this too is difficult to reverse.

Delay effect

A major delay between cause and effect as regards the possible long-term damage by NIR (G-1) and indirect effects on traffic (period of 5-20 years) is established.

In the other cases (medium delay) the possible effects will probably be visible 2-5 years after the market breakthrough of the technology.

An exception is the possible stress which would become evident in the short term on account of its immediacy.

Conflict potential

In the case of this criterion a very mixed picture emerges and will therefore be discussed in greater depth in relation to the individual risk clusters.

Burden on future generations

Although all the risks were classified as socio-economically irreversible, they could fade in the course of further historical development.

However, this does not apply to states which are persistent from a scientific point of view such as the scarcity of resources, loss of bio-diversity, and destabilisation of the climate. Therefore, the risks connected directly or indirectly with environmental pollution are classified as a burden on future generations.

The problem of the polluter-pays principle is classified as a social risk with possible consequences also for later generations.

8.7.2 Clustering of the priority risks

The risk clusters are described below. A cluster can also consist of a single risk alone. The cluster headings can also be read as the shortest possible summary of the conclusions of this chapter. We would also point out that some of these risks are also contrasted with the opportunities that were referred to extensively in Sections 8.3-8.5. However, the considerations set out here are intended to lead to precautionary measures (see Chapter 9) and are therefore limited to the risk aspect.

Cluster 1 (G-1, E-1):
Non-ionising radiation - an unknown risk with continuing high conflict potential

The possibility that exposure to non-ionising radiation even below the threshold for thermal effects could pose a danger to health hangs like a sword of Damocles over the development of mobile telecommunications. Although the greatest levels of exposure are accepted voluntarily (use of mobile phones), the much lower involuntary levels of exposure give rise to conflict.

Pervasive computing will probably exacerbate this problem because it relies heavily on wireless networking. In this regard too the use of sources of radiation close to the body, which is generally voluntary, will cause the greatest levels of exposure. However, the background exposure to NIR - to which non-users are also exposed - could increase as a result of PvC. The number of bodies which operate wireless networks, and are therefore regarded as causers of emissions, will rise sharply with the anticipated spread of W-LANs. In spite of the very low transmission powers in comparison with mobile telephony there is a risk of increasing conflict.

Cluster 2 (E-2, E-3, E-4, S-4, S-5):
Stress, spying and high-tech crime could threaten quality of life

The ubiquity of a technology which

- is unusual or difficult to use,
- is perceived subjectively as unpredictable,
- leads to frequent disruption to concentration,
- reduces privacy and gives rise to an uncontrollable stream of data, and
- is not protected against criminal abuse,

can adversely affect quality of life. The decisive factor here is whether or not the abovementioned risks are entered into voluntarily, and that means:

- whether there is compulsion or pressure to use PvC (voluntariness)
- the extent to which harm to non-users can be avoided (fairness).

Consequently, this risk cluster has a high conflict potential which could lead to serious social tensions, in particular in conjunction with the conflict potential of cluster 1.

Cluster 3 (S-1, E-8):
Consumers and patients bear the costs of a somewhat involuntary development

Even if no one is coerced into using PvC, the general development may result in a burden on non-users via the price mechanism. In specific terms that means that

- conventional services for a remnant minority of ‘technology abstainers’ will be offered at higher prices or not at all
- possible increasing costs in the health system will be borne by the contributors to health insurance funds.

Cluster 4 (U-1, U-2, U-3, U-6, U-7, U-8, U-9):
Possible impediments to environmental sustainability

Microelectronics require a broad range of very rare raw materials, and the mining of some of these materials causes huge environmental damage. By the time they can be used as materials in the manufacturing process, they already have considerable amounts of 'grey energy' on their environmental account. If the well-ordered disposal of electronics is impeded as a result of the miniaturisation and embedding of PvC components, these valuable materials will be lost. However, a reduction in absolute quantities used is not to be expected because miniaturisation will probably be compensated or overcompensated by the expansion of production runs. The distribution of pollutants in the environment could also become an additional problem if disposal is not carried out appropriately.

The energy consumption by the operating infrastructures for PvC could take on significant dimensions. The installations to operate the network and provide the contents will be necessary in large numbers and be permanently switched on. The installations necessary for homes alone could, in the next ten years, lead to additional annual household electricity consumption of 1%-3% of current electricity consumption in Switzerland if no countermeasures are taken. This figure is twice as high when office applications and infrastructure are included. The upper limit of this estimate (+6%) is reached only if a very high degree of PvC penetration is assumed (high-tech scenario). However, in accordance with the precautionary principle the risk of a development which is so unfavourable in terms of energy policy must be minimised.

The effects of PvC on transport may, instead of substituting journeys and flights by telecommunications, actually bring about the opposite, namely an increase in traffic, because the ability to conduct an increasing number of activities from any location will create incentives for greater mobility. It will become increasingly possible to engage in relationships and activities at locations far apart from one another, which will make at least occasional journeys necessary or appealing. The predominance of this induction effect over the substitution effect appears to be likely on the basis of previous developments.

The aggressive actions of car manufacturers in relation to PvC could become a competitive disadvantage for the providers of public transport and in environmental terms could have an unfavourable effect on the modal split.

There is therefore a risk that PvC will increase raw materials and energy consumption (including fossil fuels) and the distribution of pollutants as a result of direct and indirect effects and thus place a burden on future generations.

Risks will arise also for the present generation on account of the unequal global distribution of opportunities as a result of technology, on the one hand, and the resulting environmental pollution (caused in particular by resource depletion and production), on the other. The areas concerned lie mainly in the less developed countries with poor environmental and social standards. In the medium term this could give rise to international conflicts.

Cluster 5 (S-6):
Possible collapse of the polluter-pays principle in the face of technical complexity

There is a risk that implementation of the polluter-pays principle will collapse in the face of the difficulty of identifying the cause and causer of the harm triggered by networked information systems. The harm could relate not only to intangible assets (data) but also to tangible assets or health.

The emergence of *unmastered technical complexity* is a long-standing problem in information technology. The penetration of everyday life with systems whose behaviour is dependent on complex hardware and software in a distributed system makes it quite difficult to identify the cause and causer where harm occurs. This situation could be further exacerbated by PvC because there will be a very great incentive to use software designs with programs acting on behalf of their users (software agents). The incentive arises from the fact that the flood of possibilities, in conjunction with the social pressure also to use them, is pushing the boundaries of human processing capacity.[161]

This is due to the basic problem that, unlike people, machines are not capable of making commitment but are increasingly perceived in daily life as objects that act. A promise made by a machine - e.g. to carry out a particular function - is in principle worthless as it cannot feel obligation and cannot be held responsible. The inability of machines to make commitment in principle excludes them from social interaction.

Consequently, there is a danger of a ‘dissipation of responsibility’. In the same way as a de facto irreversible state occurs in the environmental field as a result of the fine distribution (dissipation) of materials, because they can no longer be ‘gathered up’, in the social field a fine distribution of cause and responsibility as a result of the multilayered or networked nature of digital ICT can arise which can no longer be controlled by legal means. An associated problem in that regard is the total reliance of the courts on independent experts who are not available to the necessary extent.

PvC could result in a growing proportion of everyday life actually being withdrawn from the scope of the polluter-pays principle. If there is great reliance on this technology, this problem could also be a burden on future generations.

[161] The flood of e-mail today and the control systems which automatically filter and reply to e-mails are just the beginning of what will probably be a far-reaching development.

9 Recommendations for precautionary measures

Lorenz Hilty, Andreas Köhler, Claudia Som

The following recommendations are based on the precautionary principle. They are not delivered on the assumption that failure to take a measure would result in an acute danger. Rather, the measures are intended to minimise risks *before* they become acute dangers. In the view of the project team, they can assist Switzerland's medium and long-term development towards a *sustainable information society*.

The recommendations are divided into subsections according to groups of actors (policy, research, education, business). Within the subsections, the recommendations are organised roughly according to priorities. Specifically, fundamental measures which have very wide effects, as a 'coarse control', are mentioned at the beginning of each subsection and specific measures that have effects only in limited areas are mentioned at the end.

The risk clusters from Section 8.7.2 and the individual risks from Sections 8.3 to 8.5 that are connected with the measure are shown in round brackets with their code numbers in the form 'G-1', 'E-1', etc. This is intended to make it easier for the reader to refer to the description of the risks to which the measures relate. In addition, each recommendation is introduced by a brief description of the problem, so that the context is comprehensible even without reference to the preceding chapters.

9.1 Policy

9.1.1 Coordination of the Federal Council's 'Information Society' and 'Sustainable Development 2002' strategies

In 1998 the Federal Council adopted its 'Strategy for an Information Society in Switzerland'. The Information Society Coordination Group, an interdepartmental body headed by the Federal Office of Communications, was given responsibility for implementing this strategy. The strategy is gaining political importance in connection with the first UN World Summit on the Information Society (WSIS), which takes place in 2003/2005 in Geneva and Tunis.

In addition, with the 'Sustainable Development Strategy 2002', the Federal Council defined the framework conditions for its sustainable development policy for the next few years, in particular with a view to the UN World Summit on Sustainable Development in Johannesburg in 2002. This strategy is also of major national and international importance.

The documents relating to the two strategies do not make reference to one another. There are common denominators in principle in the themes of human rights, social acceptability of technology, use of ICTs in education and information platforms for monitoring sustainability.

As the present study shows in general, however, there are much further-reaching links between the two central ideas of ‘information society’ and ‘sustainable development’. These include, on the one hand, the opportunity to create *necessary conditions* for sustainability in the transition from an industrialised society to an information society. On the other, there is a risk that the information society will develop ecological and social ancillary effects that undermine the successful achievements of sustainability policy.

We therefore recommend that the Federal Council initiate a process to examine the consistency of the two strategies, to identify synergies and to coordinate the further development and implementation of the two strategies.

This measure relates to Risk Cluster 5 and, in the broader sense, all the risks discussed in the study.

9.1.2 Tax system

In the ICT sector in particular, it is now necessary to produce a steering effect towards rational energy use and careful management of raw materials by adapting the fiscal framework conditions. The technical potential is available and will not be fully utilised without incentives for resource savings or CO_2 reductions, as can be clearly seen from previous experiences in the ICT sector.

Fiscal steering effects could be crucial in order to

- set the course for energy efficiency in the network infrastructure for PvC that will be installed over the next ten years;
- develop the major, as yet unrealised substitution potential of ICT (replacement of material and energy-intensive processes by information processing and telecommunication);
- avoid the threatening induction potential and rebound effects of ICT (avoidance of accelerated consumption of materials and energy that can be caused by ICT).

We therefore recommend that the Federal Council and the Parliament implement the Sustainable Development 2002 Strategy consistently and continue to pursue fiscal incentives as instruments of energy and climate policy.

(Cluster 4: U-2, U-7, U-8)

9.1.3 Liability rules

The penetration of everyday life with wireless networked microelectronic components means that an increasing number of processes run automatically or semi-automatically. Because of the wide range of possibilities offered by these technologies, users have a growing responsibility for their effects on the environment, health and other protected assets. If damage occurs, however, it is very difficult to determine the cause. Because in complex systems there is no simple causal chain from the cause of damage to the damage, it cannot be clearly determined who should be regarded as the perpetrator. From device manufacturers, component manufacturers and state and semi-state standardisation bodies to the operator of the base network and, lastly, the user, many actors are possible perpetrators.

A particular problem with PvC is the fact that hardware-software systems are embedded in other products (e.g. refrigerator, clothing) and are networked to distributed systems (e.g. smart homes).

In the areas of transport, housing and medicine, it is clear that major damage can occur if the technology does not behave as expected, for which there may be various causes. One important cause, to which the legislator has paid too little attention thus far, is software error or deficient software quality, in particular in connection with networks. We therefore recommend that the liability rules for software are subject to a thorough review.

An important subsidiary aspect of the liability problem with regard to software is that the legal status of software under the Law on product liability seems to be unclear at present. From a technical perspective, moreover, it is difficult to understand why the law draws a distinction between hardware, software and software built into hardware. Since the boundary between hardware and software is movable in principle,[162] it seems necessary to treat these three cases identically as far as liability law is concerned.

The status of software under the existing liability rules (product liability/law of obligations) must be clarified and it must be examined whether the liability of software manufacturers should be more firmly enshrined by law. Furthermore, the need for and possible consequences of a special causal liability (strict liability) for hardware-software systems that are operated in networks should be examined.

(Cluster 5: S-6; also G-6).

9.1.4 Protection of personal data

As part of the revision of the Federal Law on data protection, the legislator should review whether that law is suitable given the future ubiquity and networking of information and communication technologies:

- There will be a marked increase in the number of data collections that can be utilised for personal data. Because of networking, automatism and complex causation structures in distributed systems, it could become virtually impossible to ascertain who is the owner of a data collection under the Federal Law on data protection.
- Because of the desired context sensitivity of PvC, service providers automatically obtain data concerning the place of residence of customers (movement profile) and their transactions. The principle under Article 1(3) of the Federal Law on data protection ('Personal data may be processed only for the purpose that was indicated when it was obtained') could lead to frequent definition problems regarding the respective purpose.

[162] Functions that are performed by a software product can also be built into hardware. Conversely, the function range of hardware can be reduced to a few elementary operations, as a result of which more functions have to be implemented in software. In practical terms, it makes no difference, aside from efficiency issues, whether a function is implemented in software or hardware.

An adjustment could aim to extend the notification and cooperation requirements that relate to data collections to the operation of installations whose technical nature is such that they are capable of compiling data collections *autonomously* under the Federal Law on data protection.

We also recommend a declaration requirement for hardware and software products that can *pass on* data from the environment in which they are used *without the express consent of the user* (e.g. over networks to the manufacturer or third parties).

(Cluster 2: S-4, S-5)

9.1.5 e-Government

The trend towards e-Government is not intended to mean that citizens can avail themselves of fundamental rights and the public service only by electronic means. The state must also remain capable of action if security problems in the ICT infrastructure occur.

According to the Swiss Federal e-Government Strategy of 13 February 2002, in future voters will be able to vote, elect and sign initiatives or referenda electronically (e-voting). The electronic counter (*guichet virtuel*) allows direct access to the state authorities at all levels. As well as providing information for citizens, dealings with the authorities are also to be carried out electronically.

The aim laid down in an earlier version of the e-Government Strategy that conventional communication channels should be preserved is underlined by this recommendation for two reasons:

- *Optionality* in the use of electronic products or services should be maintained. No one should be placed at a disadvantage because they cannot or do not wish to use the electronic channels, e.g. because they do not believe that data protection is guaranteed.
- The *security* of electronic communication channels is limited. Therefore, in the event of security problems, for example in cases of criminal manipulation, all participants must be able to return to conventional communication channels.

(Cluster 3: S-1; Cluster 2: S-4, S-5)

9.1.6 Public procurement and Integrated Product Policy

In the Sustainable Development 2002 Strategy, the Federal Council mentions the introduction of an Integrated Product Policy (IPP) as an implementing measure. The aim of the IPP is to 'shift demand in the public and private sectors to products that meet high economic, ecological and social standards' (Bundesrat, 2002, p. 17). All policy areas relevant for the IPP are to be incorporated. The state can be active here on several levels (federation, cantons, municipalities).

In the procurement of ICT products (both material goods and services), regard should be had for energy efficiency, useful life, waste disposal characteristics and ergonomics. In the Pervasive Computing age, it will be a major challenge to develop a long-term procurement policy despite short innovation cycles.

The focus should not be the characteristics of the individual hardware product, but the systems to which the components procured are connected. The life cycle of the *overall system* should be assessed on the basis of ecological, social and economic criteria. For this purpose, we recommend that a check list be drawn up and that purchasing staff be given appropriate training. Responsible institutions at federal level could be the RUMBA[163] programme and the Federal Government's Procurement Commission.

It is important to pay attention to indirect effects of the procured products in this context, as well as the direct effects. In the environment sector, these are the 'secondary' and 'tertiary' effects (cf. Chapter 7). An evaluation of indirect environmental effects is recommended for larger investments and for public services.

In economic terms, regard must be had above all to the increasing dependence on foreign manufacturers and licensers. Public procurement policy, with its sizeable volumes of demand, should not encourage the market dominance of individual, mainly foreign suppliers. Otherwise, in the long term, the 'electronic nerve system' of the state will be at the mercy of the success of individual lines of technology, proprietary standards and pricing policy of a few dominant suppliers.

These risks can be minimised by giving preference to open, product-independent standards, because only these allow fair competition in the ICT sector in the long term, and the use of open source software.

(Cluster 2: E-2, E-3; Cluster 3: S-1; Cluster 4: U-1, U-2, U-3, U-6)

9.1.7 Electronic direct advertising

For the revised version of the Law on telecommunication, a provision is being discussed that could allow advertising SMS messages to be sent only to people who have given express consent or with whom the sender already has a business relationship.

We suggest that this proposal be implemented, but without giving special treatment to the SMS medium. An SMS-specific provision would not be future-proof because of media convergence and technical development. Rather, the sending of advertising by electronic means to *personal addresses* in general should be linked to this condition. This would also include faxes, e-mail accounts and future 'smart' objects and terminals, such as the 'intelligent refrigerator' or the 'Personal Travel Assistant'. Electronic direct advertising could become a problem specifically as a result of Pervasive Computing and the even better accessibility of recipients.

The special treatment of electronic media compared with conventional media (post) is justified by the fact that only electronic media allow distribution to a large number of addresses with almost constant expenditure (i.e. independent of the number of recipients). In the long term this may lead to all electronic communication channels becoming jammed with direct advertising.

However, countermeasures under national law are effective only to a limited extent because they do not really have implications for e-mail and other media with *non*-distance-related costs – i.e. for all Internet services – since the sender can operate from abroad. It would therefore make sense for the provision to be limited to communication

[163] Ressourcen- und Umwelt-Management in der Bundesverwaltung (Resource and Environmental Management in the Federal Administration) .

services with *distance-related* costs and, additionally, providers of *gateways* between the Internet and such services should be required to take reasonable measures to ensure that no mass direct advertising is forwarded.

(Cluster 2: E-4; also S-2)

9.1.8 Energy labels for ICT

The 'energy label', which is already in use for conventional household devices and lamps under the Regulation on energy, should also be introduced for ICT devices that are operated on the mains supply (plug-in and permanently installed devices). The Federal Office of Energy should develop a variant of the label for this purpose and initiate an appropriate process at EU level.

The focus for this measure is the expected *continuous operation*[164] of a large number of devices per household or workplace, which may also lead to relevant energy consumption in the case of small or medium-sized power requirements. Continuous operation can be expected for all devices forming part of the network infrastructure (such as modems, hubs, gateways, base stations, etc.) and for all servers. Once the investments have been made, it will no longer be possible to rectify an unnecessarily high power consumption for many years.

For mobile ICT devices that are charged by a power supply unit, a special label for power supply units is possible.

(Cluster 4, risks U-2, U-7)

9.1.9 Declaration requirement for technical data on NIR sources

The manufacturers and importers of NIR-emitting electronic products should be required to disclose to the user the following technical data on NIR sources (e.g. in the instructions for use):

- what transmission powers occur in what operating states,
- for sources that are intended to be used close to the body, the relevant SAR value for each of these transmission power figures,
- for sources that are intended for stationary use (e.g. base stations), the transmission power and power consumption for each operating state.

Other studies on NIR risks make similar proposals for measures (cf. Wiedemann, 2001).

In addition, it should be examined whether a warning on the packaging for NIR sources that are intended to be worn directly on the body would be reasonable. This is because NIR exposure is highly dependent on distance.

(Cluster 1, risk E-1)

[164] 'Continuous operation' means an uninterrupted power requirement, irrespective of the operating state. Standby periods or 'off' periods with a consumption of > 0 watt are therefore included.

9.2 Research

9.2.1 Ongoing participatory technology assessment (TA)

An ongoing technology assessment (TA) for future ICTs and their applications appears to be urgently needed on account of the far-reaching effects of future pervasive ICT. A participatory TA, which includes all social groups in the discussion at an early stage, can help to minimise risks as an 'early warning system'.

TA-Swiss has for years held 'PubliFora'.[165] Around 30 members of the public discuss controversial fields of technology and applications with experts and draft a report containing recommendations for action for politics, science and industry. Difficult social policy subjects can be identified at an early stage and policy decisions can be helped to set up safety nets for developing and using technology. Lay people and experts can exchange information and experiences; a wide-ranging public discussion is stimulated.

On the way to the information society, Pervasive Computing and related visions for ICT use will repeatedly raise questions that call for a broad public discourse and that can be dealt with in PubliFora.

(Measure concerns all risks)

9.2.2 Round table

The 'round table' principle is for a research project or field to be monitored by a representative group of members of the public. Needs, hopes and fears will be expressed and incorporated into the formulation and implementation of the research projects. The Science et Cité foundation, together with the Swiss Federal Institute for Environmental Science and Technology, has held a round table of this kind as a Swiss pilot project.[166]

Holding 'round tables' at public research institutes (institutes of higher education) and possibly also at private research laboratories, such as the IBM laboratory at Rüschlikon, could help to involve society more in the far-reaching developments in the ICT sector. A round table on Pervasive Computing or related subjects could help to steer developments in a desirable direction from the point of view of social policy and to identify potential conflicts as early as possible.

(Cluster 1: E-1; Cluster 2: E-2, E-4; Cluster 3: E-8)

9.2.3 Assistance guidelines for ICT research

State assistance for new technologies should in future be linked more closely to an assessment of technological consequences. On the basis of the far-reaching social effects of information and communications technologies (ICT) and their high developmental dynamism, there is a clear deficit in this area. Research and development

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[165] www.ta-swiss.ch; www.publiforum.ch

[166] www.science-et-cite.ch/projekte/tableronde/de.asp; www.eawag.ch/rundertisch

financed from taxes must highlight future opportunities and possible risks to society and introduce them into the discourse.

In the case of larger research projects in the ICT sector, a technology assessment (TA) should therefore accompany the project and be conducted on the applicant's own responsibility. In addition, some of the assistance funding in a field of technology should be used for *cross*-project TA studies for the early detection of risks.

State research assistance institutions like the Swiss National Science Foundation (SNF) and the Commission for Technology and Innovation (KTI) are urged to review their assistance guidelines in this regard. Universities, technical colleges and other research establishments are also advised to take similar action when awarding *internal* research funding.

(Measure concerns all risks)

9.2.4 National research programme

The proven, though still unclarified biological effects of NIR in the case of exposure below the thermal effect threshold and the lack of knowledge about health effects suggest that further research is urgently needed. The Pervasive Computing vision cannot be put into practice without ubiquitous NIR sources in continuous operation.

Switzerland should conduct this research in a national programme – integrated into international cooperation projects – in order to ensure a high level of credibility and neutrality in the studies.

The proposal from the Federal Agency for the Environment, Forests and Landscape (BUWAL) to the Federal Office for Education and Science on a new National Research Programme (NRP) on 'Non-ionising radiation, the environment and health' should therefore be supported.

(Cluster 1: G-1, E-1)

9.3 Education

9.3.1 General higher secondary schools

A self-aware, critical and responsible approach to ICT is the best protection against the social risks of the information society. The social risks of ICT in particular will increase as a result of PvC.

In terms of general education, this means that the priorities should not be the pointless learning of skills for dealing with ICT, but the acquisition of meaningful knowledge and a critical basic attitude.

In the same way as the principle that 'not everything that you read in the newspapers is true' has long been part of general education, in the ICT age awareness should generally be raised of the following subjects:

- Possibilities and limits of the manipulability of digital content

- The problem of assessing the authenticity and credibility of the originator of a piece of information
- Limits of the reliability of hardware-software systems, e.g. using the history of well-known computer errors
- Risks arising from the possibilities of criminal misuse of ICT
- Effects of ICT on society, e.g. using historical developments since the invention of the computer
- Competition and market concentrations in the hardware, software and content markets
- The difference between humans and machines, possibilities and limits of 'Artificial Intelligence'
- Data privacy, information rights, security measures (cryptography)
- If NIR is a relevant subject, basic physical principles of NIR, current knowledge about effects, importance of transmission powers and SAR values.

This content should, where possible, be integrated in stages into *existing subjects*.[167] The focus should be on longer-term principles, and shorter-lived phenomena[168] should be included only where they provide a clear example of a general principle.

This measure requires several individual measures, including the incorporation of these subjects into revised curricula and the further training of teaching staff.

(Cluster 2: E-2, E-3, E-4; S-4; Cluster 3: S-1; Cluster 5: S-6; also S-3, S-4, S-5).

9.3.2 Colleges and Universities

Institutes of higher education should ensure that courses in ICT-relevant subjects integrate the following content:

- ICT and society: effects of ICT on society
- Knowledge from technology assessment (TA) or from 'impact and design research', which came into being in the field of computing
- Promotion of awareness of development potential for health and the environment in the development phase of new technologies

The integrated treatment of these aspects in technical teaching units would be welcomed. However, special teaching activities are also appropriate, like the ones that have been offered for many years at the Information Technology and Electrical Engineering Department and the Computing Department at the Swiss Federal Institute of Technology Zurich.

The Zurich University of Applied Sciences Winterthur (ZHW) has set up a 'Competence Centre for Safety and Risk Prevention' (KSR).[169]

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[167] e.g.language, history, economics, physics, biology, philosophy.

[168] Such as current hardware and software products

[169] 'The aim of the Competence Centre is to promote technologies, both in innovation processes (e.g. R&D projects) and in the economic environment (production, services), that are innovative, high-quality and socially/ethically

In other European countries, social aspects are naturally integrated into computing studies in many places, in particular in the north (northern Germany and Scandinavia).

(Cluster 2: E-2, E-3, S-4; Cluster 5: S-6)

9.3.3 Energy efficiency of ICT as a training subject

Planning decisions and the resulting investments in equipment and installations often have effects on energy requirements that can be rectified subsequently only within narrow limits. However, there are often no experts to provide competent advice to future users for such decisions.

The infrastructure built up for Pervasive Computing (e.g. wireless networks, servers) offers great development scope in energy terms. At present there is still a possibility of rational energy use for this infrastructure. Therefore, the appropriate knowledge and awareness should be developed among those occupational groups that have a tangible influence (architects, electricians, etc.) as soon as possible. Important subjects would be energy consumption by devices in continuous operation, standby losses and losses where equipment appears to be switched off, optimisation potential for domestic installations and secondary energy requirements for professional installations, e.g. for cooling and uninterrupted power supply (UPS). In principle, the focus should be not on individual components but on systems.

The occupational groups in question include architects, building technicians and electricians, but also sales staff for electronic products in the retail trade. This measure supplements and supports Measure 9.1.8 (energy labels). Aebischer und Huser (2000) reach similar conclusions in their study on networking in the home.

Institutions that offer initial and further vocational training (vocational colleges, industry federations and professional associations[170]) are urged to integrate the relevant expertise into their vocational teaching curricula, in particular in higher specialist training.

In coordination with the Federal Office for Education (BfA), the educational objectives and examination regulations at vocational colleges and for higher specialist examinations (Degree with Federal Specialist Certificate and Federal Diploma) should be expanded to include the aspect of energy efficiency.

In addition, a relevant selection of vocational further training measures should be created for those employed in SMEs (e.g. in the electrical engineering sector) and procurement managers (buyers) in businesses and public institutions. The initiative for this could come from economic assistance from the cantons or chambers of industry and commerce. Cooperation with industry federations, such as the association of Swiss Electrical Installation Firms (VSEI), could ensure that the further training developed is as practical as possible.

(Cluster 4: U-2, U-7)

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responsible. On the basis of this practical orientation, teaching modules will be developed and implemented in both initial and further training.'

[170] e.g. the Federation for the Swiss Mechanical, Electrical and Engineering Industries (SWISSMEM); Swiss Association of Engineers and Architects (SIA)

9.4 Recommendations to private and public enterprises

9.4.1 Global e-Sustainability Initiative (GeSI)

The Global e-Sustainability Initiative (GeSI) has the objective of improving the global environmental situation, encouraging the development of sustainable technologies in the communications industry and minimising waste. By becoming a member of GeSI, companies commit themselves to promoting the principles of sustainable development and to putting them into corporate practice, in particular through:

- Participation in international activities of the ICT industry relating to the drawing up of agreements (e.g. standards for recycling-friendly design and energy efficiency in products, non-use of certain pollutants)
- Cooperation with partners in science and industry in order to minimise NIR exposure from products and services in accordance with the current state of science and technology (voluntary minimisation requirement)
- Requirement for suppliers to observe GeSI principles, in particular environmental management and development of energy-saving devices
- Transparent corporate policy and partnership-based communication with consumers and other interested groups.

By joining GeSI, Swiss enterprises in the information technology and telecommunication industry (e.g. Swisscom) could reinforce their efforts towards a sustainable corporate policy and coordinate with international activities.

(Cluster 1: G-1, E-1; Cluster 4: U-1, U-2, U-3, U-7)

9.4.2 Public transport

The trend towards Pervasive Computing appears superficially to strengthen private transport, although there is at least as much utility potential in public transport.

Rail and bus transport providers should therefore develop a joint long-term strategy for the use of ICT by the enterprises themselves and, above all, by their customers. If PvC becomes established, the following questions will be particularly relevant:

- How can PvC be used for even better transparency of services and products? (Example: online route planning, which, as well as timetable information, also takes into account information about delays and other real-time variations and which can be used by customers via mobile devices, e.g. through ‘Personal Travel Assistants’)
- What conditions must be created so that passengers can use their time on the transport optimally (time on trains, in buses, waiting time, etc.) and how can the varying needs of different customer groups best be reconciled?
- How can the transport enterprises itself use PvC for the efficient organisation of its passenger and goods transport operations?

(Cluster 4: U-9)

9.4.3 Telecommunication providers

The providers of current communication services – and future PvC services – are urged to organise voluntary self-regulation to ensure that minimum ethical standards for the content of services are met. In this way, the providers could also counteract statutory measures that generally make them liable for content.[171]

A model, though with a very limited sphere of operation, is the Association for Voluntary Self-Regulation of Value-Added Telephone Services in Germany. The aim of this association is to counter abuse of 0190 numbers in Germany by awarding labels to reputable suppliers.[172]

The members agree to adhere to a code of conduct for value-added telephone services. The following areas are covered:

- Respect for the legitimate interests of users and the general public
- Rejection of any form of censorship
- Guidelines against racial discrimination and glorification of violence
- Exclusion of children and young people from use of dangerous services
- Publication of name and address of content providers
- Statement on charging information
- Principles for advertising
- Supplier identification in advertising
- Guidelines for the operation of chat and dating services

This code of conduct could serve as a model in wider market segments for future information and communication services.

(Cluster 2: E-4, S-5, Cluster 5: S-6, also S-2)

9.5 Recommendations addressed to several actors

9.5.1 Waste incineration plants

Waste incineration plants and their operators are recommended to adjust their monitoring to a possible increase in the volume of small electronic components in domestic rubbish.

If it transpires that the proportion of electronics in domestic rubbish becomes a problem for waste incineration plants, they should consult with the Swiss Association for the Information, Communication and Organisation Technology Industries (SWICO) about possible voluntary measures (e.g. extending the scope of the SWICO recycling

[171] The measures proposed by this study explicitly do not include an extensive liability for suppliers of communication services for content that they carry.

[172] It was founded in response to the abuse of value-added telephone services for disreputable services that had discredited this business model.

guarantee) at an early stage, in order to separate the fractions of the domestic rubbish streams that have the largest volumes of electronics content and to feed them into the recycling system for electrical and electronic devices. If this proves to be necessary, the waste incineration plants should propose a modification of the definition of electronic devices in the Regulation on the return, taking back and disposal of electrical and electronic devices and/or the Regulation on dealings with waste.

(Cluster 4: U-3)

9.5.2 Ombudsman's Office for NIR

An independent Ombudsman's Office should be set up to deal with NIR emissions, their minimisation and their effects, its mandate to extend to *all types of NIR sources*. This is particularly appropriate in the light of the expected propagation of W-LANs (including in schools). The Ombudsman's Office could disseminate practical information on low-emission implementation of wireless networks and communicate any fears or observations that are expressed to scientists and policy-makers.

This measure might possibly be implemented by extending the mandate of the 'Ombudsman's Office for Mobile Communication and the Environment', which currently has responsibility solely for mobile radio base stations. If, however, its independence is called into question by members of the public, it must be considered how an office that is perceived as independent could be set up.

(Cluster 1: G-1, E-1)

9.5.3 Areas with limited electronics use

The operation of mobile electronics can be limited at locations where there is a need for protection from annoyances caused by the presence of electronic devices or from non-ionising radiation (NIR). This measure will prevent conflicts that may arise over noise annoyances, NIR and the need for protection of privacy. The last reason could become increasingly important in the next few years.

Such locations can be public establishments like hospitals, nursery schools, cultural establishments or sports centres. Operators of these establishments may enforce their house rules to get users to deactivate these devices or to limit use.

In future, with miniaturisation, it could be more difficult to enforce such bans. Nevertheless, stressing undesirability may help to create a culture of mutual consideration with regard to 'pervasive' use of electronics.

(Cluster 1: E-1; Cluster 2: E-4, S-4)

Annex 1: List of abbreviations and glossary

3D
Three-dimensional

ABS
Anti-lock braking system. Brake technology for motor vehicles.

Ad hoc network
Data network without a fixed structure formed by mobile units over wireless connections.

ADSL
Asymmetric Digital Subscriber Line. Transmission method that allows digital data to be received at up to 8 Mbit/s over a conventional two-core copper telephone line.

Agent
See Section 3.5

All-in-one utility device
Device that performs several functions in one device that were previously performed by different devices, e.g. e-mail, telephone calls, photography, address management.

Athermal effect
(Biological) effect of electromagnetic radiation which is not based on tissue warming, because the radiation is too weak.

Augmented reality
Application of ICT where the user is provided with additional information on the object being examined according to the situation. Example: a surgeon can almost look inside a patient during an operation through a virtual window (realised in the form of a semi-transparent screen). Integrated ultrasound imaging continuously updates the required data during the operation.

Avatar
A visually simulated person represented on the screen.

Backbone
Central, usually large-scale, high-speed part of a telecommunication network.

BAKOM
Federal Office of Communication

BAN
1. Body Area Network. Network for data transmission between electronic components worn on the body.
2. Basel Action Network. Non-governmental organisation that works to enforce the Basel Convention, in particular to combat the export of electronic waste to developing and threshold countries.

Base station
Base station or ‘GSM base transceiver station’ (BTS) means any radio communication systems (using the GSM standard), antennas and other equipment that are installed at a certain fixed location and supply one or more radio cells (BAKOM). Irrespective of the GSM standard, all fixed transmitter and receiver systems that communicate wirelessly with terminals can be described as base stations.

Bluetooth
Radio communication standard in the ultra-high frequency range, by means of which mobile devices can connect with one another wirelessly. Unlike infrared interfaces, no visual contact is needed.

BUWAL
Federal Agency for the Environment, Forests and Landscape

CAD
Computer-Aided Design

Carcinogenic
Cancer-causing

CATV
Community Antenna Television – bi-directional high-speed networks for cable television based on glass-fibre and coaxial cable.

CD
Compact Disc. Digital storage medium that was originally developed as a medium for digital audio data and as such replaced analogue records.

CDMA
The Code Division Multiple Access procedure allows a transmission channel (on a certain frequency) to be used by several users. Available frequency resources can thus be used and shared more effectively. Principle: the transmitted data packages are identified by a code for each recipient.

CD-ROM
Compact Disc that is used as a universal data medium (not specifically for audio).

CFC
Chlorofluorocarbons. Group of substances that cause a risk to the ozone layer.

Chat room
Virtual room in which several Internet users can communicate with one another by typing in sentences which appear simultaneously on other users' screens.

CO_2
Carbon dioxide

CPU
Central Processing Unit, which executes programs.

CRT
Cathode Ray Tube. The traditional display technology for televisions and computers.

Cryptography
Data encryption

Cyber glasses
Glasses with integrated displays, making possible a three-dimensional representation of virtual worlds.

DECT
Digital European Cordless Telecommunication. European standard for cordless telephones, mainly in the 1.88 - 1.9 GHz frequency band.

Desktop (computer)
A computer that is small enough to be operated on a desk.

Distributed system
A distributed (data processing) system consists of several autonomous processor/storage systems which cooperate by message exchange.

DNA
Deoxyribonucleic acid. Carrier of genetic information in the cell nucleus.

Download
Transfer of data from a remote data source over a network (generally the Internet) to the computer of the user who has initiated the process.

Drive-by-wire
Driving without any mechanical connection between the driver of a motor vehicle and the gears, brakes etc., i.e. the vehicle responds to the driver's actions via electronic control.

DSL
Digital Subscriber Line (see ADSL)

DVB
Digital Video Broadcasting

DVB-T
Mobile television

DVD
Digital Video Disk. Digital storage medium

ECG
Electrocardiogram. Record of the electrical activity of the heart.

EDGE
Enhanced Data Rates for GSM Evolution. A standard that the International Telecommunications Union (ITU) has ratified as an official mobile radio communications standard. EDGE uses modulation procedures that are similar to the UMTS standard, but uses conventional GSM frequencies.

EEG
Electroencephalogram. Record of the electrical activity of the brain.

EE devices
Electrical and electronic devices

e-Government
Umbrella term for the digitalised performance of government functions.

e-grain
Miniaturised 'electronic grains' which can form networks.

EIB
European Installation Bus

EMF
Electromagnetic field

e-paper
Rewritable paper-like display

Ergonomics
Here: software ergonomics (synonym: cognitive ergonomics). The aim of software ergonomics is to adapt working conditions in human-computer interaction to the sensomotor and cognitive capabilities and processes of the user. In this field, studies are being carried out on human work and cognitive capabilities, on the effects of user interfaces on people and on the effect of features of the user interface of the usability of systems.

FDMA
Frequency Division Multiple Access. A transmission channel can be divided efficiently among several users. A frequency range is divided into several sub-bands, which are allocated to different users. Similar techniques are CDMA and TDMA .

Flat rate
Here specifically a tariff for telecommunication services that is independent of connection time and transmitted data volume.

Fuel cell
Catalytic combustion module for power generation.

Fuzzy Logic
Logic that allows any finely-graded truth values between ‘true’ and ‘false’ to be represented.

GHz
Gigahertz. Unit of measurement for frequency. 1 GHz means one thousand million cycles per second.

GPRS
General Packet Radio Service: allows data transmission rates of up to 115.2 kbit/s per user.

GPS
Global Positioning System. System originally developed for the US Army, with which it is possible to determine precisely the own location to within a few metres anywhere in the world.

Grid computing
Shared processing of large-scale computing tasks by several computers that are combined to form a network.

GSM
Global System for Mobile Communications: Digital cellular radio communication technology operated in the 900 MHz frequency range. Second generation cellular phone network (G2).

Handheld (computer)
Computer that is small enough to be held in the hand during use.

Head-mounted display
Visual output device worn on the head, mainly in the form of glasses (see Cyber glasses)

Headset
Device worn on the head for information and/or communication e.g. combination of earphones and integrated microphone for hands-free telephone use.

HGV
Heavy goods vehicle

HSCSD
High Speed Circuit Switched Data

HTML
Hypertext Markup Language. Language to describe hypertext, which is used on the WWW.

Human-computer interface
see User interface

Human-machine interaction
The process whereby human actions influence (control) a machine and vice versa.

Hypertext
Text that at any point can contain references to other text, which can automatically be followed (‘links’). A hypertext, unlike a traditional text, does not have a linear structure, but a network structure.

IC
Integrated Circuit

ICD
Industrial Clothing Design

ICNIRP
International Commission on Non-Ionising Radiation Protection. An organisation under private international law dealing with non-ionising radiation protection.

ICT
Information and communication technology. Umbrella term for all (electronic) technologies and devices used to process, store or transmit (digital) data. Examples: PCs, mobile telephones, organisers, car navigation systems.

Induction effect (of ICT)
The indirect effect of using ICT products to stimulate demand for other products. For example, using printers stimulates demand for paper, because paper can be written on more quickly than using typewriters. See also: Substitution effect.

Infrared
Spectral range of light, invisible to the human eye, that can be used to transmit signals.

‘Intelligent clothing’
Clothing into which ICT components are integrated.

Internet
Worldwide network for the transfer of data based on the TCP/IP standard. E-mail and the World Wide Web (WWW) use the Internet. Because it is a universal infrastructure, the question of which services can be performed using the Internet in future is open.

Internet POP
Point of Presence: A point at which users can connect with the Internet backbone.

IrDA standard
Standard of the Infrared Data Association. It allows data to be transferred between devices by infrared.

ISDN
Integrated Services Digital Network

ISO
International Organisation for Standardisation

ISOS
Internet Scale Operating Systems

IT
Information technology. ‘IT’ is now generally used as a synonym for ‘ICT’.

i-Wear
see ‘intelligent clothing’

Java
Programming language that is specially suited to Internet applications.

JINI
Java Intelligent Network Infrastructure. Allows data and executable programs to be dynamically assigned to any network node and executed there. JINI provides a service that activates a device and makes it useable, provided it is connected to the network.

‘Killer application’
An application that helps the system platform on which it operates to break through onto the market.

LAN
Local Area Network. A locally limited network for data transmission, mostly linked to the Internet

Laptop (computer)
A computer that is small enough to be operated on the lap.

LCA
Life Cycle Assessment; assessment of environmental effects and/or costs ‘from cradle to grave’

LCD
Liquid Crystal Display. Flat alternative to the CRT monitor.

LED
Light Emitting Diode

Media convergence
The convergence of previously distinct transmission methods for services, information and forms of presentation on shared terminals.

meV
Milli-electron volts

MHz
Megahertz. Unit of measurement for frequency. 1 MHz means one million cycles per second.

Microbilling
Billing of very small payment amounts.

Modal split
Division of transport among different modes of transport.

MP3
Data compression technique; used in particular for digital transfer and storage of music.

Nanotechnology
Technology that makes the characteristics of tiny material structures in the nanometre range useable.

NIR
Non-ionising radiation

Notebook (computer)
A computer that is small enough to be carried like a notebook.

NOx
Nitrogen oxides

NRP
National Research Programme

OCR
Optical Character Recognition. Area of information technology that deals with the automatic recognition of characters written on paper.

OECD
Organisation for Economic Cooperation and Development.

OLED
Organic light-emitting diode

OMG
Object Management Group

Open source
The source code is the text in which a computer program was originally written. It can be understood by properly trained readers. ‘Open source’ products are based on a ‘General Public License’ (GPL). The GPL means that anyone may view and modify the source code of the program in question; however, it is not permitted to sell the program without authorisation or to make it ‘closed source’. The main advantage of ‘open source’ software, aside from the lower costs, is now the higher degree of maturity of the software.

Organiser (Digital organiser)
Mobile device for managing addresses and appointments. Input is generally by a stylus.

OSGi Gateway
Open Services Gateway Initiative. Forum for the development of open specifications for the provision of services over WANs to LANs and devices.

Palmtop (computer)
Computer that is small enough to be operated in the palm.

PAN
Personal Area Network

Pay-per-use
Use-dependent payment

PC
Personal computer

PCB
1) Polychlorinated biphenyls

2) Printed circuit board

PCDD and PCDF
Polychlorinated dibenzodioxins and dibenzofurans

PDA
Personal Digital Assistant. Pocket computers or handhelds. Their functions increasingly include, aside from an electronic diary, communication and multimedia.

Peer-to-peer network
Computer network without central access control, in which all computers have equal privileges. A direct data link always exists between users without the need for a network server.

Pen PC
PC in ballpoint pen form.

Plug and Play
An ergonomic criterion for devices which requires that they are able to function after being connected and switched on without the need for further action on the part of the user.

Polymers
Large molecules composed of a large number of individual molecules.

Portables
Portable ICT devices

Powerline technology
Data transmission over powerlines.

PP
Precautionary principle

PSU
Places of sensitive use (term used in the Swiss NIR regulation). The following are regarded as places of sensitive use: a. rooms in buildings where people regularly stay for lengthy periods; b. public or private children's playgrounds as defined in regional planning law; c. areas of undeveloped land on which uses defined in letters a and b are permitted.

PTA
Personal Travel Assistant

PvC
Pervasive Computing

PVC
Polyvinyl chloride

Radiation exposure
Impact of radiation on the body.

RAM
Random Access Memory; a computer's working memory.

Rebound effect
also: boomerang effect. Increase in output rather than a planned reduction of input through efficiency increases (see Section 5.3)

Resource efficiency

Ratio between the output of a process and the necessary input of natural resources (raw materials and energy).

Retina display
Output device that uses a deflected laser beam to project directly onto the retina of the human eye.

RFID
Radio Frequency Identification

SAR
Specific absorption rate. Shown in watts per kilogram of tissue mass. The SAR value indicates how much energy is absorbed by a body. In general, a limit of 0.08 Watts per kilogram averaged across the whole body applies; in parts of the body up to 2 W/kg averaged over 10 grams is permitted; this value applies to mobiles.

SCTEE
European Commission's Scientific Committee for Toxicity, Ecotoxicity and the Environment in the Directorate-General 'Health and Consumer Protection'.

Set-top box
Device for analogue televisions for receiving digital TV signals and subsequent analogue conversion.

Shutter glasses
Glasses to display high-resolution, three-dimensional images.

SIM
Subscriber Identification Module

Smart label
Electronic label which can be read without contact.

Smart card
Microchip-equipped card that stores alterable data.

Smart phone
Combination of Personal Digital Assistant (PDA) and mobile telephone.

SME
Small or medium-sized enterprise

SMS
Short Message System: system for the transmission of short text messages (up to 160 characters) on mobile telephones on GSM networks.

SO_2
Sulphur dioxide

SRR
Short Range Radar

SSK
German Radiation Protection Commission

Standby
An operating mode of electronic devices.

Substitution effect (of ICTs)
: The indirect effect of using ICT products to reduce demand for other products, e.g. the propagation of e-mail reduces demand for the carriage of conventional letters. See also: Induction effect.

SUV segment
: Sports Utility Vehicle segment.

TA
: Technology assessment

TDD
: Time Division Duplex

TDMA
: With Time Division Multiple Access, GSM radio channels are used more efficiently. ‘Time slots’ are used, in the order of microseconds. In the case of GSM, one radio channel can be occupied by up to eight users; each terminal transmits for a period of around 577 microseconds and then maintains radio silence in order to allow the other terminals to operate on that frequency.

Teraflop
: One million million arithmetic operations per second; unit of measurement for computer system performance

Thermal effect
: Electromagnetic fields can be converted into heat. An effect caused by the heat is called a thermal effect of the exposure to the field.

Touch screen
: Touch-sensitive screen, used, for example, in organisers for input or function control by stylus.

Transponder
: Contraction of the words transmitter and responder; wireless communication, monitoring or control unit that captures input signals and automatically responds.

UMTS
: Universal Mobile Telecommunications System: European variant of the 3G third generation mobile radio communication system (IMT2000). Together with a telephone service, UTMS allows multimedia services (data, image, sound) to be provided with transmission rates of 144 kbps (vehicles), 384 kbps (pedestrians) and 2 Mbps (buildings).

USB
: Universal Serial Bus. Interface for input and output devices.

User interface
: The part of a computer system’s hardware and software that allows interaction between the user and the system.

UV
: Ultraviolet. Short-wave, invisible light.

Videoconferencing
: Telecommunication technology with image and sound transmission, allowing several physically remote participants to take part in a virtual meeting.

Video on demand
: Provision of video films on demand, using special devices (decoders) and conventional electronic transmission methods.

Virtual
: Opposite of ‘real’. The characteristic of having only some of the features of a corresponding real phenomenon. As a mirror shows a virtual situation (unlike the real situation it is not possible, for example, to go inside), a virtual presence has only some of the features of a real presence, a virtual team has only some of the features of a real team, etc.

Virtual reality
: A deliberately paradoxical concept (see ‘Virtual’), which expresses the vision of using digital means to create virtual situations where there is no longer a relevant distinction from real situations.

Voice-over-IP
: Telephone calls over the Internet.

W/m^2
: Watts per square metre. Unit of measurement for the intensity of electromagnetic radiation (flux density).

WAP
: Wireless Application Protocol. Protocol for (limited) access to the WWW by mobile telephone.

Wearables
: Digital devices worn on the body.

Web browser
: A program that allows access to the World Wide Web (WWW). Well-known browsers are ‘Netscape Navigator’ and ‘Microsoft Internet Explorer’.

W-LAN
: Wireless Local Area Network.

WWW
: World Wide Web. An Internet-based network of multimedia hypertext documents, provided on servers. Called the ‘Internet’ by an increasing number of people (see also ‘Internet’).

Annex 2: Legend to the Figures

Figure 3-1

y axis reads:

Satellites
Underwater cables
Pan-European optical fibre network
DAB and DVB
GSM, GPRS, UMTS
Outdoor W-LANs (< 1 – 20 km)
UMTS cell (< 8 km)
Outdoor DECT (< 300 m)
Cabling in buildings and indoor W-LANs
Bluetooth (1 – 100 m)
Indoor DECT (1 – 50 m)
Conductive textiles (approx. 1.5 m)
RFID (approx. 1 m)

x axis label:

'The last mile' (TV, Powerline, radio, telephone)

Reichweite = Range

Figure 4-2

Left-hand column:

External
Service Provider
Content Provider
Service Platform of Deutsche Telekom AG
Police
Fire fighting service
Security

Next column:

Satellite
Radio
Copper
Gateway
Coax
Optical fibre

Right-hand side, reading across left to right, top row first:

Internal

Household devices
PCs
AV devices
Telephone

Heating control
Bathroom/drainage

Operations centre
Power consumption meters
Thermostat

Light
Power sockets
Hot water/heating
Security

Figure 4-3

Digitales Autoradio = Digital car radio
Mobiltelefon, Pager = Mobile telephone, pager
Lesegerät = Reader
Computer-Platform = Computer platform
Sprachverarbeitung = Speech processing
Navigationen = Navigation

Otherwise all the text is in English already.

Figure 4-6

Left-hand side:

Head mounted display:
Data glasses
Earphones
Microphone
Cabling integrated within fabric
Mobile phone
Washable MP3 player
Keyboard
Portable PC
Cabling integrated within fabric

Right-hand side:

Digital camera
Microphone/earphones within collar
Sports bra with pulse meter
Remote control
Control unit
Watch with memory and MP3 player
Textile radio with velcro fastening

Bottom of diagram:

Shoes with integrated battery and positioning system

Figure 7-7

y axis:

milli-ecoindicator points

x axis:

Online
Teleguide
CD-ROM
Telephone book

Labels
Fossil fuels (resources)
Mineral resources
Acidification/eutrophication
Ecotox. emissions (into water)
Ecotox. emissions (into air)
Destruction of the ozone layer
Climate change
Effect on respiratory passages (inorg.)
Effect on respiratory passages (org.)
Carcinogenic effect (via water)
Carcinogenic effect (via air)

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Annex 4: Detailed table of contents

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Annex 5

Expected Exposure from Pervasive Computing

Jürg Fröhlich and Niels Kuster

Zurich, April 2003

Statements or results from this report may only be cited in publications other than the report to the funding bodies after written approval from Prof. Dr. N. Kuster.

Executive Summary

Safety Limits

Most countries have already implemented regulations which require that consumer devices transmitting RF must comply with the corresponding safety guidelines for EM exposures (e.g., EU, US, Japan, China, Korea, Canada, Australia). These guidelines are currently being harmonized and are widely considered to reliably protect the general population against thermal effects. The standardization commissions had considered the data regarding non-thermal effects to be insufficient to serve as a basis for safety guidelines. However, the results of recent studies seem to confirm the hypothesis of athermal effects, which appear to be amplitude-modulation dependent. Nothing is known about the physical-biological interaction mechanism; little is known about the required field strengths or about the most effective modulation schemes. The huge parameter space and the relatively weak diverse biological response make a systematic approach methodologically difficult, time consuming and requiring more resources than currently available. The current understanding is that these effects are not dependent on the carrier frequency. Due to the relatively large uncertainty, some governments (e.g, Switzerland, Italy, etc.) have issued precautionary limits in order to address possible adverse athermal health effects. It is also important to note that all guidelines address external exposures, i.e., the data is predominately based on far-field exposures, such that the special exposure characteristics of implants are not covered.

In conclusion, compliance with current safety guidelines is a necessity to avoid health hazards as a result of thermal effects but does not protect against possible hazards from athermal effects. It is also questionable whether the current standards are suitable to evaluate wireless implants.

Strengths of RF Exposures

The strength of the exposure is approximately proportional to the RF magnetic field generated at the skin of the user and to the frequency [32]. In other words, the higher the frequency, the larger the current density on the source, and the closer this source is to the skin, the larger the resulting exposure. It is important to note that reactive RF field components couple to the body as efficiently as radiating components. It is obvious that exposures from base stations are considerably lower than from transceivers operating in, on or in the vicinity of the body. For thermal considerations, only the averaged power is of significance. However, peak power might be of relevance for athermal effects.

Time-Averaged Exposure Strengths

Although 2G and 3G mobile communication devices will continue to be the devices with the highest maximum time-averaged output power, BAN and other pervasive computing applications will result in similar exposure levels due to their closer proximity and smaller size. Communications with implants and in-body communications belong to a different category of devices. This category will result in locally very high exposure levels, even when the spatial peak SAR values are relatively small. Highly local exposures are currently not scientifically addressed and need further attention.

Peak Exposure Strengths

For pulsed systems (e.g., TDMA) peak power can be considerably higher than the time-averaged values, whereas for CDMA and FDMA systems the maximum exposure is similar to the maximum time-averaged exposure levels.

In general, pervasive computing applications will result in significant spatial peak time-averaged exposure levels in various relevant tissues (0.01 - 2 W/kg) which are orders of magnitude above those induced by traditional broadcast systems and exposure from base stations. The exposure levels are close to the safety limits recommended by the guidelines. For systems utilizing in-body communications or implants, local tissue exposures can well exceed 100 W/kg. Special attention must be placed on the induced peak exposure levels when discussing potential athermal effects.

Power Spectrum of Amplitude Modulation

The power spectrum of amplitude modulation is given by system relevant parameters (e.g., frame structures) as well as by the response of the system to environmental parameters (e.g., power control). For instance, the frame structure of GSM causes $8\,Hz$, $217\,Hz$ and $1.73\,kHz$ components plus the corresponding harmonics in the non-DTX mode. In the DTX mode, an additional $2\,Hz$ component is generated by the implementation of the comfort noise. GPRS increases the signal complexity. These system relevant parameters are superposed by the power control functions due to changes of the environment or due to handovers. On the other hand, WCDMA requires fast power control, which results in incoherent modulations within a wide ELF spectrum, and only the switching frequency is coherent (e.g., $1.5\,kHz$ for the FDD mode or $100/750\,Hz$ in the TDD mode). In general, the resulting power spectrum of amplitude modulation is strongly dependent on the implementation.

In conclusion, pervasive computing applications will result in exposures with significant ELF components from the amplitude modulation spectrum. The spectrum will depend on the technology utilized as well as on the implementation. Little to no data are currently available to assess the potential health hazards, and none of the currently conducted studies will be able to provide a sufficient scientific basis.

Exposed Tissues

The predominantly exposed tissues during the last two decades have been the head tissues and in particular the ear, brain and salivary glands. Pervasive computing will result in significant exposure of other relevant tissues, organs and glands. Current data do not enable any ranking of tissue sensitivity.

In conclusion, little is known about high-level local tissue exposure other than for head tissues. The currently collected epidemiological data will not enable any risk assessment other than for head exposures. More relevant knowledge can be expected from the currently conducted high-exposure whole-body animal studies performed within the European 5th Framework.

ELF Exposures

ELF exposures are generated by the power supply circuitry and are most dominant for high power pulsed systems like TDMA. However, exposures are not considerably different from exposures from other devices or household appliances.

In conclusion, stronger local exposures from ELF can occur through body-mounted

high power pulsed systems. Other systems do not result in exposures significantly different than those from other household appliances.

Expected Scientific Outcome from Current Research

A significant and coordinated research effort was launched in Europe in the year 2000. Several countries have also begun their own national programs (e.g., France, UK, Italy, Finland, Germany, etc.). In addition, further projects are being supported by industry. The majority of these projects investigate biological endpoints under GSM exposures. Little is being done to address future exposure conditions from, e.g., UMTS, etc. Research in the US has basically come to a halt, except for the recent initiative of NIEHS to conduct a large-scale NTP study with free-running animals and of CTIA/FDA to conduct a new epidemiological study and some small-sized *in vivo* and *in vitro* studies. Only the outcome of the relatively large Japanese program will enable some conclusions to be drawn beyond GSM.

In conclusion, in 2006 a considerable database regarding GSM exposure will be available, as well as the results of replication studies. The analysis will show which issues can definitely be answered and which will require additional efforts. However, it is obvious that the currently conducted research will not provide the required data for the risk analysis of 3G and pervasive computing applications.

Knowledge Gap

- procedures for assessing the exposure of body-mounted applications other than mobile phones operated next to the ear
- procedures for determining ELF exposures
- safety guidelines for highly local exposures as occurring from implants and skin-mounted devices
- a complimentary research program for risk assessments of 3G exposures
- systematic evaluation of the biological response caused by exposure from more general amplitude modulation schemes covering the possible range of pervasive computing technologies

Risk Assessment

Pervasive computing will result in a significant increase of EM exposure. The exposure caused by body-mounted devices or devices operated in the closest vicinity of the body will be in a range similar to exposure from 2G devices and will be orders of magnitude higher than exposures from traditional broadcast services or base stations. The ELF components of the amplitude modulation spectrum will also significantly differ from 2G or other sources. Neither the current scientific database nor the research currently being conducted worldwide will provide a sufficient basis to conduct a reliable risk assessment.

In conclusion, a considerable research effort is still needed before a thorough scientifically based risk assessment of pervasive computing can be conducted. Although the cumulated data do not support the hypothesis of a high individual risk, a thorough analysis is justified in view of the enormous population penetration.

Contents

1 Background

The Center for Technology Assessment *TA-SWISS* at the Swiss Science and Technology Council issued a project entitled "The Principle of Precaution in an Information Society: Pervasive Computing and its Effects on Health and on the Environment". The objective of this study is to present possible scenarios for the evolution of the new information and communication technologies, with a special focus on pervasive computing. The study shall then go on to assess the risks and benefits which future developments will pose in terms of health and the environment, debating this issue in light of the principle of precaution. Based on the result, the authors of the study shall recommend measures which should be taken in order to cope with the possible risks of pervasive computing.

The background and the motivation of this study is described as follows:

> *"Information and communication technologies are constantly opening up new horizons, holding forth fascinating applications for the future. Current research endeavors are aimed at putting men and machines comprehensively and continuously on line, a situation often described as pervasive - or ubiquitous - computing. However, the undeniable benefits of these new technological developments (optimization of the communication processes) and their economic potential run the risk of being offset by unwanted side effects. The total networking of man and machine threatens in particular to injure the health of the individual (owing primarily to an intensified exposure to electromagnetic fields), and perhaps also to imperil sustainable development (notably as a function of an increase in energy consumption and the production of wastes). Without calling into question their potential, it is nonetheless essential to submit these new information and communication technologies to some deep reflection based on the guiding principle of precaution."*

In addition to this study *TA-SWISS* issued a mandate to the *Foundation for Research on Information Technologies in Society (IT'IS)* on the following issues:

- Review and completion of the work package on possible impacts on health
- Report on future exposure scenarios and their possible impacts on health as well as the identification of knowledge gaps

1.1 Analysis of the Current Situation

The relevance of topics concerning health effects from new information technologies can be seen primarily through the heavily emotional protests against the determination of new base station antenna locations for GSM networks. The planned UMTS technology will require a large number of new antenna locations. The research conducted on biological responses after pulsed RF exposures has produced conflicting results. Conclusions range from the need to greatly reduce safety limits as a precautionary principle to the request for further research.

The discussion of information technologies and their effects leads in divergent directions. Information technologies are technology-driven systems that have impacts on and are also impacted by politics and the media, as well as public opinion. Politicians are promising globalization realized by innovations without any adverse effects. The producers and distributors of these technologies see themselves pressured and restrained through public resistance and therefore wish to retain certain regulations. The essential basis of the conflict is twofold: the number of mobile phone users is steadily increasing, while at the same time it is becoming increasingly difficult to expand the required network. The involuntary (proximity to base station) versus voluntary (handset) exposures result in the pronounced risk perception.

By the end of this decade it is expected that we will all have high-bandwidth, reliable wireless communication. Personal computers will be invisible because they will be so tiny. Because of their small size they could be placed in eyeglasses or in any piece of clothing. Current visions point to one large communications infrastructure for which it does not matter whether a bit is voice or video or data. Information shall be available everywhere and anytime. In whichever direction the development of new information technologies will go, the population will be *"immersed in a sea of low-level, pulsed microwave signals"* [20].

The determination of appropriate precautionary measures requires the creation of the most reliable basis possible for the development of a widely acceptable overview of the problem. Politicians and industry alike remain in high profile positions. The EU and mobile industry as well as several national programs in Europe are currently funding several extensive research programs addressing the questions of GSM exposure. The coming together of political interests for public safety from potential risks on one side and the promotion of new technologies on the other, as well as the incorporation of the economic interests of industry, urgently require a serious clarification of the facts.

The results of these currently funded long-term studies will be evaluated together with the previously published data in the year 2006 by WHO. As explained below, it cannot be expected that sufficient data will be available by then to complete the evaluation for exposures other than from GSM systems. Consequently, politics and economics will remain confronted with the current controversial situation and will have to decide on what basis "prevention" and "sustainability" shall be determined.

1.2 Problem Statement

'Pervasive computing' will generate new exposure situations for biological organisms as well as additional sources for electromagnetic compatibility problems between electronic devices. In addition it will have a large social impact and will generate new aspects for the sustainable development of technology.

In order to assess the exposure situation in the future, the development of information technologies in upcoming years has to be estimated. Another key figure is the expected penetration of society with these new technologies. The specific aspects of the technology used determine the quality of the exposure to electromagnetic waves. Based on the research conducted for risk assessment of current mobile communication devices, the scientific gaps of future technologies have to be identified.

Scenarios about future information processing devices include small, highly integrated and computationally efficient 'stand-alone' devices communicating with each other. The mass production of one-way devices, e.g., for medical applications, is also a consequence, as well as the increased need for powerful micro-sized energy sources. Current developments in the area of material science can give an insight on the sustainable development capabilities of the materials intended for use in manufacturing these new kinds of devices.

2 Objectives

The objective of this report is to provide an estimation of the future exposure of the public generated by current and future communication technologies with special emphasis on the exposure generated by technologies used within pervasive computing. This includes communication devices as well as the necessary infrastructure, e.g., wireless networks and backbone technology, such as the power supply. The assessment of future exposure is carried out in the following steps:

- Review of current safety guidelines and their physical and biological basis including discussions of their limitations based on some of the latest research results
- Description of current and new technologies with respect to their electromagnetic characteristics
- Discussion of expected exposures from pervasive computing in terms of exposed tissues, induced RF field strengths, amplitude modulation and ELF fields
- Identification of scientific gaps
- Preliminary exposure assessment of pervasive computing

3 Risk Assessment

Different paradigms exist for risk assessment and risk management. They are discussed, e.g., in [38]. In the following we will use the paradigm according to Covello and Merkhofer [16]. Risk is defined as a characteristic of a situation or an action wherein two or more outcomes are possible, the particular outcome that will occur is unknown, and at least one of the possibilities is undesirable. Their model incorporates risk assessment as well as risk management. Risk assessment is defined as a systematic process for describing and quantifying the risk associated with hazardous substances, processes, actions and events. Risk management is defined as identifying, selecting and implementing appropriate actions to control the risk. In Figure 1 the different aspects of the risk paradigm used are shown. Hazard identification is a separate process that is necessarily conducted prior to risk assessment.

3.1 Risk

Based on the definition of [16], exposure to the fields emitted by mobile communications equipment is a risk. Obviously, the undesirable outcome is an adverse health effect caused by the electromagnetic fields. The substantial literature on thermal effects and the numerous but controversial literature on non-thermal effects demonstrates that several outcomes are possible and that there is considerable uncertainty on the outcome that will occur.

3.2 Hazard Identification

For hazard identification we can refer to [38]. There the current status of hazard identification for exposure to EMF is described as follows:

> *"For a discussion on hazard identification, it is useful to distinguish between thermal and non-thermal effects of electromagnetic fields. According to [36], thermal effects are effects caused by a change in temperature or from heat added to the system. Non-thermal effects occur at exposure levels which neither challenge thermoregulation nor produce any significant change in organism temperature.*

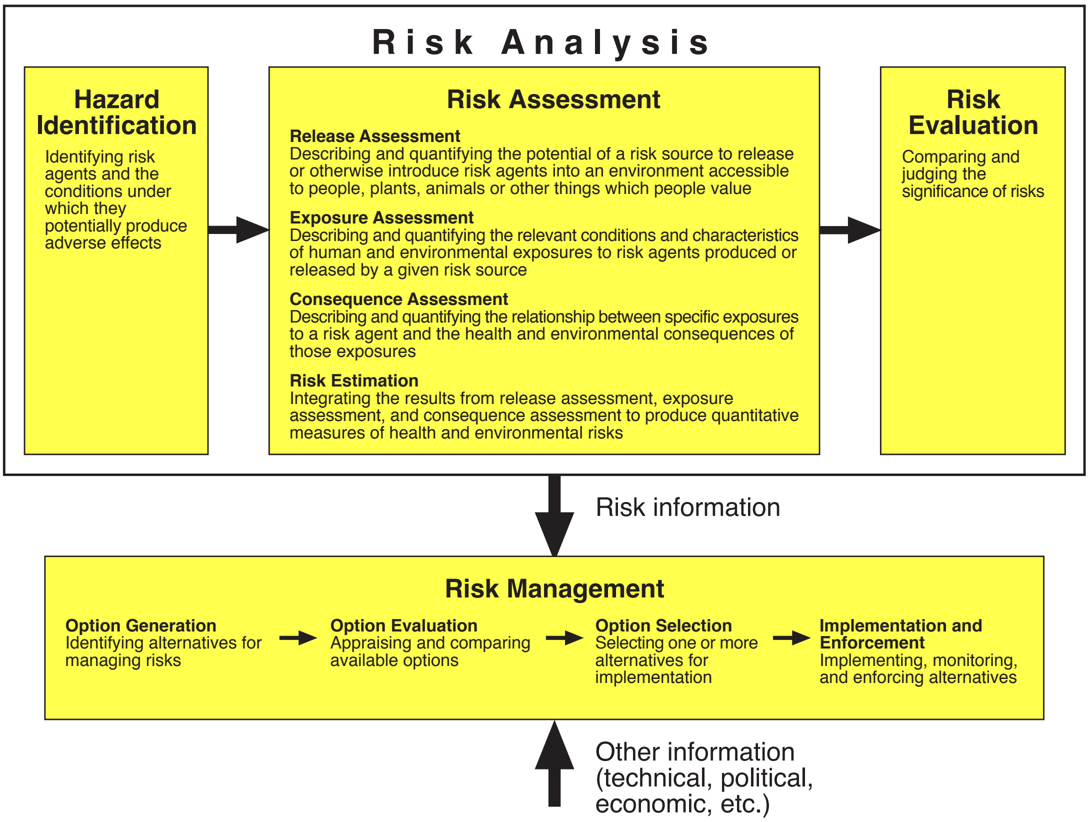

Figure 1: Risk paradigm according to Covello and Merkhofer [16]

> *"The studies discussed in [25] clearly show that excessive absorption of electromagnetic energy in the mobile communications frequency range can lead to hazards caused by thermal effects. Other identified hazards are indirect health effects caused by interference problems of mobile phones with technical systems (e.g., pace makers [30]). With respect to non-thermal health effects the ongoing studies are still mainly dedicated to hazard identification."*

3.3 Release Assessment

While the release assessment is a critical point during the risk analysis of classical risk agents released unwillingly or accidentally, the electromagnetic fields of mobile communication devices are released intentionally. The power level of such devices is usually dynamically adapted according to the quality of the uplink. Parameters such as the pulse shape, repetition rate, frequency of power regulation, data modulation, additional data transfer between base station and mobile communication device, etc., impose additional frequencies beside the carrier frequency. The result is a complexly modulated signal with many ELF components in the amplitude modulation spectrum. One major part of release assessment is the analysis of the power levels as well as of these frequency components for the technologies used for pervasive computing.

3.4 Exposure Assessment

Determination of the SAR distribution caused by exposure to electromagnetic fields emitted by mobile communication devices has proven to be rather difficult. Only the combination of the most advanced experimental and numerical methods allows a reliable assessment of the actual level of exposure in the body of a user. A detailed review on this matter with respect to mobile phones is given in [13]. The exposure of a mobile communication device user to electromagnetic fields emitted by his/her device depends on a large number of parameters which are difficult to control. Major external parameters influencing the exposure are the type of the device and position of the device with respect to the user. The absorption inside the user is determined by the distribution and the electric parameters of the tissues. The exposure assessment must allow the determination of the field distribution inside the body of a user for a given external situation (type, operating modus and position of device), including the expected variation between different individuals and a sound estimation of the uncertainty of the assessment. This has already been assessed for the case of mobile phones in [31][37]. For pervasive computing the types of devices will be even more diverse than for the case of mobile phones. Another important difference is the location of the devices, which is no longer restricted to the head. In this context other tissues and organs are affected.

3.5 Consequence Assessment

Epidemiology is a powerful method with the primary objective of establishing a statistically significant association between adverse human health effects and exposure to risk agents. However, not many studies of direct relevance to MTE users have been completed [25]. Many experiments on possible adverse health effects of EMF are performed with animals or *in vitro* systems. Careful design, construction, dosimetry and operation of the exposure setups are indispensable prerequisites for scientifically sound experiments. All technical and biological requirements must be listed carefully, and close cooperation between engineering and biological groups should be established. A full characterization of the applied electromagnetic fields is necessary to allow the extrapolation from *in vivo* and *in vitro* experiments to humans. Most studies with chemicals use high doses during *in vivo* experiments to assess possible effects and use extrapolation models to extrapolate to the usually much lower doses to which humans are exposed. This possibility is largely barred to researchers in the area of possible health effects from low level RF electromagnetic fields, since high doses will result in thermal effects. Careful assessment of the thermal properties of an exposure setup and the expected temperature increase during the exposure is very essential in experiments on the possible health effects of RF electromagnetic fields.

3.6 Risk Estimation

Integrating the knowledge collected during the preceding steps of risk assessment leads to risk estimation. With respect to thermal effects the risk estimation of ICNIRP for time-varying electric, magnetic and electromagnetic fields up to 300 GHz led to the conclusion that whole body averaged SAR values of 4 W/kg and local values of 100 W/kg is the threshold for adverse health effects [25]. However, most of these data are based on experiments with animals. Therefore, the extrapolation to humans requires a factor sufficiently large to exclude the possibility of thermal effects in humans using mobile communication devices. ICNIRP proposes a factor of 10 for occupationally exposed people and a factor of 50 for the general public. The exposure assessment gives detailed information on the SAR expected in the body of the users of mobile communication devices and shows that SAR levels of 2 W/kg (averaged over 10 g of tissues) can be reached, e.g., during mobile phone use. With respect to non-thermal effects the database was judged by ICNIRP to be insufficient to give a quantitative risk estimation [25].

3.7 Risk Evaluation

Well established studies on thermal effects show that no thermal effect is expected in humans if the local absorption is less than 2 W/kg and if the whole body averaged absorption is less than 0.08 W/kg. Knowledge about the range of absorption shows that a local absorption rate of more than 2 W/kg is possible with mobile phones of the GSM standard [31]. A violation of the exposure limit for the whole body averaged SAR is possible within a short distance from a base station antenna. Therefore, the risk cannot be judged as a priori insignificant and risk management is necessary. This is also true with respect to electromagnetic compatibility, since many technical systems have proven to be sensitive to interference problems. The risk evaluation of non-thermal effects is very controversial. ICNIRP came to the conclusion that "overall, the literature on athermal effects of AM electromagnetic fields is so complex, the validity of the reported effects so poorly established, and the relevance of the effects to human health is so uncertain, that it is still impossible to use this body of information as a basis for setting limits on human exposure to these fields" [25]. For comparing and judging the significance of the risk, it is important to note that the impact on public health and economy could be enormous even with a small adverse health effect, due to the large and fast growing number of users.

3.8 Risk Management

Based on the recommendations of ICNIRP, most European countries have adopted or will adopt the basic limit of 2 W/kg averaged over a tissue mass of 10 g and a time of 6 min [2]. In the USA a slightly different exposure limit of 1.6 W/kg averaged over a tissue mass of 1 g and a time of 30 min was defined [1]. However, it is difficult to verify whether a certain device is in compliance with the basic limits set by the regulatory agencies. Therefore, standardized procedures must be defined to guarantee reliable and reproducible compliance testing [31].

Specific restrictions on the use of mobile phones have been implemented to reduce the risk of malfunction of sensitive technical devices due to interference problems (e.g., on board airplanes and in hospitals). Since the effects of low level exposure is controversial, risk management should also rely on the principle of prudent avoidance. A reduction of the ICNIRP limits for local exposure may not be justified on the basis of current knowledge. However, according to prudent avoidance, it may be recommended that the publication of the results from compliance tests become mandatory. Concerned consumers would then have the possibility to choose a device which causes low absorption in the body of the user. With respect to pervasive computing a large list of new requirements will add to the existing methods for compliance testing. New measurement protocols have to be established allowing a general characterization of various devices over an extended range of frequencies. New measurement tools are also necessary in order to reliably assess the quantities of interest.

4 Safety Standards

Several regulatory bodies worldwide have issued safety recommendations or requirements regarding the maximum permissible electromagnetic exposure from handheld mobile communications equipment (MTE), e.g., [1], [2]. A short review of the background and the current safety limits is given in the following subsection.

4.1 Definition of Limits

In 1982 the American National Standards Institute (ANSI) became the first organization to introduce the *Dosimetric Concept* for protection from *non-ionizing radiation* (NIR). This represented a marked improvement, since all previous standards, e.g., the ANSI standard of 1974, were based strictly upon exposure quantities, such as power densities and field strengths. This new approach was subsequently adopted by most national and international standards commissions, e.g., DIN/VDE (1984), NCRP (1986), NRPB (1986), IRPA (1988), TTC/MPT (1990), CENELEC (1995). In 1992 ANSI/IEEE [9] revised the standard, and ICNIRP, formerly IRPA, issued new guidelines [27]. These two standards are currently the dominant guidelines. For example, the EU has adopted the ICNIRP guidelines in favor of the ENV50166-2 of CENELEC [2].

The dosimetric concept was initially developed and successfully applied for ionizing radiation. The ionizing standard is based on an established correlation between the dose and the biological effects, whereby 'dose' is defined as the energy absorbed per unit mass. Derived values, such as the incident radiation in terms of radiometric quantities, and the definition of dosimetric terms, such as whole body and organ dose, population dose, and relative biological effectiveness, were also defined.

In Table I examples for limits in terms of whole body average SAR and spatial peak SAR are given. In addition ICNIRP defined derived limits in terms of field strength and power densities for occupational and public exposure. These limits are given in tables II and III. The reference levels or derived levels for the electric and magnetic field strengths as well as for the power density are defined for the incident field at the location of the body but without the presence of the human body. If they are satisfied, the basic restrictions given in Table I for the ICNIRP guidelines are met as well.

In the near field it is not sufficient for only one of these field measures to be satisfied. At least the reference levels of electric and magnetic field strengths must be met. Although the reference levels are normally exceeded in the closest vicinity of MTE, the basic restrictions are not necessarily exceeded.

	ANSI/IEEE C95.1-1992	ICNIRP
Group 1:	controlled env.	workers
whole-body av. SAR	0.4 W/kg	0.4 W/kg
spatial peak SAR	8 W/kg	10 W/kg
averaging time	6 min.	6 min.
averaging mass	1 g	10 g
shape of volume	cube	cube
Group 2:	uncontrolled env.	general public
whole-body av. SAR	0.08 W/kg	0.08 W/kg
spatial peak SAR	1.6 W/kg	2 W/kg
averaging time	30 min.	6 min.
averaging mass	1 g	10 g
shape of volume	cube	cube

Table I: Examples of SAR limits proposed in the USA [9] and by ICNIRP [2] for the frequency range of mobile communications (40 MHz - 6 GHz)

Frequency range	RMS - value of electric field strength (V/m)	RMS - value of magnetic field strength (A/m)	Mean power density (W/m^2)
up to $1Hz$	-	$1.63 \cdot 10^5$	-
$1 - 8Hz$	$20'000$	$1.63 \cdot 10^5/f^2$	-
$8 - 25Hz$	$20'000$	$2 \cdot 10^4/f$	-
$0.025 - 0.82kHz$	$500/f$	$20/f$	-
$0.82 - 65kHz$	610	24.4	-
$0.065 - 1MHz$	610	$1.6/f$	-
$1 - 10MHz$	$610/f$	$1.6/f$	-
$10 - 400MHz$	61	0.16	10
$400 - 2000MHz$	$3 \cdot f^{0.5}$	$0.008 \cdot f^{0.5}$	$f/40$
$2 - 300GHz$	137	0.36	50

Table II: Occupational exposure: Derived reference levels for field strength and power density for continuous exposure (f in MHz)

4.2 Basis of Safety Standard

The scientific rationale of these guidelines is based on reviews of reported biological effects resulting from exposure to static and extremely-low-frequency (ELF) electric and magnetic fields.

To protect the public from extensive exposure to electromagnetic fields, the maximum tolerable exposure is limited. As mentioned before, until 1982 the limits were simply defined by exposure quantities such as frequency, power densities and field strengths. In 1982 the American National Standards Institute (ANSI) introduced a dosimetric approach for non-ionizing radiation referring to the same concept as for ionizing radiation protection [10]. The dose is defined as the energy absorbed per unit mass. As is the case for ionizing radiation, a direct correlation between dose and biological damage is assumed. In the frequency range of mobile communications biological damage is predominantly correlated with the temperature increase in tissue due to absorption of the incident electromagnetic energy. Biological tissue contains primarily water (70 - 75%). The penetration depth of the absorbed energy in the mobile communications frequencies ranges from 20 mm to 40 mm. Since human temperature sensors are adjusted to infrared detection they are located in the outer skin layers. Therefore, the body is not “equipped” to react adequately to energy deposition in the frequency range of mobile communications.

A difficulty which arises for the definition of an absorption limit is the fact that the dose and passive heat dissipation not only determine the actual temperature increase in tissue but also the active thermo-regulative mechanism of the human body [12], [43]. This highly complex mechanism enables dissipation of whole body temperature increases, and to a much larger extent, local temperature increases. Nevertheless, this mechanism is highly dependent on various factors such as age, health, and which organs are affected. To take these effects also into account the dose concept was extended by defining the absorbed power per unit mass (W/kg) as the critical quantity for safety considerations rather than the absorbed energy per unit mass (J/kg). The *rate* of the absorbed energy is called Specific Absorption Rate (SAR) and defines the incremental electromagnetic power (dP) absorbed by an incremental mass (dm) within a volume element (dV) with the specific mass density (ρ).

Frequency (MHz)	RMS - value of electric field strength (V/m)	RMS - value of magnetic field strength (A/m)	Mean power density (W/m^2)
up to $1Hz$	-	$3.2 \cdot 10^4$	-
$1 - 8Hz$	$10'000$	$3.2 \cdot 10^4/f^2$	-
$8 - 25Hz$	$10'000$	$4 \cdot 10^3/f$	-
$0.025 - 0.8kHz$	$250/f$	$4/f$	-
$0.8 - 3kHz$	$250/f$	5	-
$3 - 150kHz$	87	5	-
$0.15 - 1MHz$	87	$0.73/f$	-
$1 - 10MHz$	$87/f$	$0.73/f$	-
$10 - 400MHz$	28	0.073	2
$400 - 2000MHz$	$1.375 \cdot f^{0.5}$	$0.0037 \cdot f^{0.5}$	$f/200$
$2 - 300GHz$	61	0.16	10

Table III: General public. Derived reference levels for field strength and power density for continuous exposure (f in MHz)

$$SAR = \frac{dP}{dm} = \frac{dP}{\rho dV} \quad (1)$$

The absorption rate can be determined by either assessing the electric field (RMS value of the Hermitian magnitude) in tissue or the temperature increase in tissue (dT/dt).

$$SAR = c\frac{dT}{dt} = \frac{\sigma}{\rho}|E|^2 \quad (2)$$

Where c is the thermal constant of the tissue, ρ the mass density and σ the conductivity of the specific tissue. The SAR must be averaged over a certain time period to maintain a relation between absorbed power and the temperature increase in tissue (see Table I).

A correlation between (hazardous) biological effects and the rate of absorbed electromagnetic power was mainly based on exposure situations which lead to whole body temperature increases in animal experiments [28]. This was set as the basis for the maximum tolerable SAR.

Although local temperature increases are seen as less critical, this had to be limited as well, since near-field exposure can lead to strong local temperature increases before the whole-body averaged SAR limit is violated. For local exposure, a minimum averaging tissue mass had to be determined that would reflect the non-hazardous nature of strong superficial heating of the skin. Various averaging volumes were chosen (see Table I, and ref. [9], [14], [41]). The choice of these masses and selecting the cube to describe these masses lacks physical and biological backing and has been subject to ongoing discussions. The cube was selected simply because of the shortcomings of earlier experimental and numerical methods. The fact that a variety of tissues of different specific weights can exist within the averaging volume complicates the evaluation. Better approaches are currently being discussed in the standards organizations.

The assessment of the induced SAR is a difficult task and requires extensive experimental and numerical resources. Furthermore, it also requires modeling of the human body. Therefore, exposure limits were derived which allowed assessment of the absorption rate by solely determining exposure quantities such as incident field strengths. These exposure quantities would be easy to measure using known methods [26].

However, the induced SAR in the human body depends on a variety of complex parameters such as the frequency, field polarization and properties of the exposed biological body. A direct relationship between the exposure and the dose, i.e., the SAR, is difficult to determine, also with regard to the fact that the presence of the body alters the field distribution and that in near-field situations the body directly interacts with the source itself. Exposure limits must therefore include all exposure conditions approximating the worst possible situation. The current derived current exposure limits for the electric and magnetic fields are based on this approach. Maximum absorption occurs in a human being standing upright under plane wave exposure with an incident E-field polarization parallel to the body axis [15]. Under most other exposure situations smaller induced SAR values are found and the derived exposure limits would overestimate the actual absorption. This is especially true when the body or parts of the body are in very close proximity to a radiating source, such as a low power handheld mobile telephone. Although the exposure limits would be exceeded, the actual induced SAR would only be a fraction of the SAR limits.

4.3 Basis of Safety Guidelines

In the evaluation of safety guidelines, the entire body of literature is considered. In order to provide a scientifically sound rationale, the criteria for selecting the relevant literature is strict: the experiments must be reported in the reviewed literature and must be judged to be sufficiently replicated by the commission, i.e., scientifically established. The result is that only discernible effects serve as bases which can be explained as thermal effects. However, several health agencies have pointed out that there is ground for the hypothesis of athermal effects. Some of the latest results add to this body of literature and also illustrate the difficulties of establishing low-level effects.

4.3.1 In vitro: Effects of RF on gene expression

Recent results obtained within the REFLEX project of the 5^{th} Framework Program of the European Union showed interaction between RF signals and the stress pathway. The group of D. Leszczynski at the Radiobiology Laboratory of STUK in Helsinki has examined whether non-thermal exposures of cultures of the human endothelial cell line EA.hy926 to $900 MHz$ GSM mobile phone microwave radiation could activate stress response [33]. Results obtained demonstrate that 1-hour non-thermal exposure of EA.hy926 cells changes the phosphorylation status of numerous, yet largely unidentified, proteins. One of the affected proteins was identified as heat shock protein-27 (hsp27). Mobile phone exposure caused a transient increase in phosphorylation of hsp27, an effect which was prevented by SB203580, a specific inhibitor of p38 mitogen-activated protein kinase (p38MAPK). Also, mobile phone exposure caused transient changes in the protein expression levels of hsp27 and p38MAPK. All these changes were non-thermal effects because, as determined using temperature probes, irradiation did not alter the temperature of cell cultures, which remained at $37 \pm 0.3°C$ throughout the irradiation period. Changes in the overall pattern of protein phosphorylation suggest that mobile phone radiation activates a variety of cellular signal transduction pathways, among them the hsp27/p38MAPK stress response pathway. Based on the known functions of hsp27, they put forward the hypothesis that mobile phone radiation-induced activation of hsp27 may (i) facilitate the development of brain cancer by inhibiting the cytochrome c/caspase-3 apoptotic pathway and (ii) cause an increase in blood-brain barrier permeability through stabilization of endothelial cell stress fibers. They postulate that these events, when occurring repeatedly over a long period of time, might become a health hazard because of the possible accumulation of brain tissue damage. Furthermore, their hypothesis suggests that other brain damaging factors may co-participate in mobile phone radiation-induced effects.

4.3.2 Human studies: Effects of RF on sleep and cognition

In several experiments carried out at the Institute of Pharmacology and Toxicology of the University of Zurich within the group of P. Achermann, it has been shown that the modulation of a GSM signal affects the sleep EEG [22], [23], [24], [21]. In two studies they demonstrated that radio-frequency electromagnetic fields (RF EMF) similar to those emitted by digital radiotelephone handsets affect the brain physiology of healthy young subjects exposed to RF EMF ($900MHz$; spatial peak specific absorption rate (SAR) $1\,W/kg$) either during sleep or during the waking period preceding sleep. In the first experiment (Expt 1), subjects were exposed intermittently during an $8-h$ nighttime sleep episode and in the second experiment (Expt 2) unilaterally for $30\,min$ prior to a $3-h$ daytime sleep episode. An extended analysis of the two studies as well as the detailed dosimetry of the brain areas including the assessment of the exposure variability and uncertainties was carried out. The latter enabled a more in depth analysis and discussion of the findings. Compared to the control condition with sham exposure, spectral power of the non-rapid eye movement sleep electroencephalogram (EEG) was initially increased in the $9-14\,Hz$ range in both experiments. No topographical differences with respect to the effect of RF EMF exposure were observed in the two experiments. Even unilateral exposure during waking induced a similar effect in both hemispheres. Exposure during sleep reduced waking after sleep onset and affected heart rate variability. Exposure prior to sleep reduced heart rate during waking and stage 1. The lack of asymmetries in the effects on sleep EEG independent of bi- or unilateral exposure of the cortex may indicate involvement of subcortical bilateral projections to the cortex in the generation of brain function changes, especially as the exposure of the thalamus was similar in both experiments (approx. $0.1\,W/kg$). The second experiment was carried out using CW signals as well as a modulated GSM signal [21]. Using a CW signal did not show the effects which occurred by using a modulated GSM signal. This indicates that the effect is purely related to the modulation of the GSM signal and not to the carrier.

Another study carried out by N. Edelstyn et al., of the University of Keele, UK, showed effects of RF signals on the performance of different tasks which tapped capacity and processing speed within the attentional system [17]. Thirty-eight healthy volunteers were randomly assigned to either an experimental group which was exposed to a connected mobile phone or a control group in which the mobile phone was switched off. Subjects remained blind to mobile phone status throughout duration of the study. The experimental group was exposed to an electromagnetic field emitted by a $900MHz$ mobile phone for $30\,min$. Cognitive performance was assessed at three points (prior to mobile phone exposure, at 15 and $30\,min$ post-exposure) using six cognitive neuropsychological tests (digit span and spatial span forwards and backwards, serial subtraction and verbal fluency). Significant differences between the two groups were evident after $5\,min$ on two tests of attentional capacity (digit span forwards and spatial span backwards) and one of processing speed (serial subtraction). In all three instances, performance was facilitated following mobile phone exposure. No deficits were evident.

4.3.3 In vivo: Effects of ELF magnetic fields on DBMA induced rats

The following example illustrates the experimental difficulty of determining and replicating low-level biological effects.

Rat mammary carcinomas represent a standard laboratory animal model in the study of human breast cancer. In line with the possible relationship between electric power and breast cancer risk as well as the underlying *"melatonin hypothesis"*, it was shown in [39] that 50 Hz magnetic fields (MFs) at μT-flux densities enhance mammary gland tumor development and growth in the 7,12-dimethylbenz[a]anthracene (DMBA) model of breast cancer in female Sprague-Dawley (SD) rats. However, in contrast to this data, in a similar study conducted by Battelle in the United States, no evidence for a cocarcinogenic or tumor-promoting effect of MF exposure was found in the DMBA model in SD rats [11], [7]. The investigators from the two studies recently discussed differences between their studies that might explain the apparent discrepancies between the results of MF exposure [8]. The probably most important difference was the use of different substrains of Sprague Dawley (SD) rats; the U.S. rats were much more susceptible to DMBA but possibly less sensitive to MF than the European rats used in the study in Hannover [39]. It has been previously demonstrated that there are inherent differences between substrains of SD outbred rats obtained in the U.S. and Europe in regard to their mammary neoplasic response to DMBA, as well as their response to radiation [42].

The recent results of a study further addressing this issue was reported. In this study two different SD substrains were obtained from Charles River. One (SD1) was the substrain used in the previous MF/DMBA studies in Hannover, the other (SD2) had never been used by this laboratory and was considered by the breeder to be genetically different from the SD1 substrain. Preliminary experiments indicated that SD2 rats are insensitive to the cell proliferation-enhancing effect of MF exposure recently reported by the same lab for the mammary gland of SD1 rats, which is a likely explanation for the cocarcinogenic or tumor-promoting activity of MF exposure in SD1 rats. In the present study, two experiments were performed. In the first experiment, the two substrains (20 rats per substrain) were compared in their carcinogenic response to DMBA. DMBA (5 mg) was administered by gavage at weekly intervals up to a total of 4 applications per rat. Rats were about 50-54 d of age at onset of the experiment. Rats were palpated once weekly to assess the development of mammary tumors. After 18 weeks, all of the rats were killed for necropsy. In the second experiment, the effect of MF exposure on breast cancer development and growth was compared in the two substrains. Per substrain, two groups of 45 rats received DMBA at the dosing protocol described above and were either MF exposed or sham exposed for 18 weeks. Palpation of mammary tumors and necropsy for histological verification of grossly recorded tumors was done as in the first experiment.

In the first experiment, SD2 rats showed a significantly higher tumor incidence in the DMBA model than SD1 rats, substantiating the genetic difference between these substrains. In the second experiment, MF exposure significantly increased mammary tumor development and growth in SD1 but not SD2 rats.

The difference in the mammary neoplastic response of the SD1 and SD2 substrains to DMBA substantiates previous studies that SD substrains may markedly differ in their sensitivity to this carcinogen [42]. Furthermore, as previously reported for ionizing radiation [42], the present data demonstrate that SD substrains may differ in their response to MF exposure. SD2 rats resemble the SD substrain used in the Battelle studies in that these rats exhibit a high susceptibility to DMBA but not to MF, whereas the reverse is true for the MF-sensitive SD1 substrain. These substrains can thus serve to evaluate which genetic factors underlie enhanced sensitivity to cocarcinogenic or tumor promoting effects of MF exposure [18], [19].

Based on these results, further experiments will attempt to reveal the factors relevant for the observed effects and to identify the mechanism. In any case the question of whether ELF MF promote tumor growth remains open and must be further clarified.

4.4 Limitations of Safety Guidelines

The standardization commissions only considered the data regarding thermal effects as sufficient and those of non-thermal effects to be insufficient to serve as a basis for safety guidelines. However, the results of recent studies seem to confirm the hypothesis of athermal effects, which appear to be amplitude-modulation dependent. Nothing is known about the physical-biological interaction mechanism; little is known about the required field strengths or about the most effective modulation schemes. The huge parameter space and the relatively weak diverse biological response make a systematic approach difficult and time consuming. The current understanding is that these effects are not dependent on the carrier frequency. Due to the relatively large uncertainty, some governments (e.g, Switzerland, Italy, etc.) have issued precautionary limits in order to address possible adverse athermal health effects. It is also important to note that all guidelines address external exposures, i.e., the data is predominately based on far-field exposures, such that the special exposure characteristics of implants are not covered.

Hence, compliance testing with current safety guidelines is a necessity to avoid health hazards as a result of thermal effects but does not protect against possible hazards from athermal effects. It is also questionable whether the current standards are suitable to evaluate wireless implants.

5 Technologies

The principle aim of mobile communication is the possibility to receive and transmit data from anywhere to everywhere. In order to achieve this, the most complete coverage possible has to be achieved. The first generation cellular systems were based on analog technologies, e.g., the advanced mobile phone standard (AMPS) in the US, NMT 450/900 in parts of Europe and other similar systems.

In North America, the wireless industry began to explore converting the existing analog network to digital as a means of improving capacity back in the late 1980s. In 1989, the Cellular Telecommunications Industry Association (CTIA) chose TDMA over Motorola's frequency division multiple access (FDMA) (today known as narrowband analog mobile-phone service [NAMPS]) narrowband standard as the technology of choice for existing 800 MHz cellular markets and for emerging $1.9 - GHz$ markets. With the growing technology competition applied by Qualcomm in favor of code division multiple access (CDMA) and the realities of the European global system for mobile communications (GSM) standard, the CTIA decided to let carriers make their own technology selection.

In Europe, the standardization process has been more aggressive and successful. GSM has converted from a European system to a worldwide cellular system. Most of these 2G systems are based on TDMA (GSM, the Japanese Digital Cellular (JDC), and North American Digital Cellular (NADC)), except for some narrowband CDMA. However, 3G will be exclusively based on WCDMA.

All devices used for pervasive computing are based on similar technologies with respect to the exposure assessment. Every device which will enter the market will be tested with respect to the valid safety guidelines. This also applies for environmental exposure where safety guidelines exist for maximal field values at any location assessed by a defined measurement protocol. For new technologies additional measurement protocols are necessary in order to adequately assess the imposed fields at any location.

In the following different technologies will be discussed with respect to their emitted power and modulation characteristics. This includes technologies for mobile communications as well as technologies for wireless local area networks (WLAN), body area networks and implants. The amount of data available varies among the different technologies. Some are still in the standard setting phase and no final data is available.

5.1 Mobile Communications

The technical characteristics of the two major (competing) systems today that split the RF, TDMA and WCDMA, are described. 2G GSM services, based on TDMA, have evolved via HSCSD and GRPS to provide higher data rate packet services. The use of advanced coding and modulation schemes allows the delivery of 2.5G services within a GSM network. UMTS, based on WCDMA, was developed from the start for 3G services. Aspects relevant for exposure assessment for these two systems were previously discussed in [6] and [35]. In the following the main aspects are reviewed and the background for the relevant measures for exposure assessment, such as power classes and the main modulation components, are identified.

5.1.1 TDMA

Time division multiple access (TDMA) allows eight users to share one physical radio channel by dividing the channel into eight time-slots. The handset transmission in the TDMA system (GSM) occurs in bursts of power of a duration of $0.577\,ms$ and $4.6\,ms$ between the bursts. This is a strict periodicity, which is perceived as a basic frequency of $217\,Hz$ and multiples thereof. The bursts also mean that the peak power is much higher than the average power. The peak powers are varied by the system such that the transmitter only emits what is necessary for a given connection. The dynamic range is $28\,dB$, whereby the maximum peak is $2\,W$. The power classes for GSM900 and GSM1800, both based on TDMA, are given in Table IV.

Power class	*Nominal maximal output power (dBm) GSM900*	*Nominal maximal output power (dBm) GSM1800*	*Tolerance normal / extreme (dB)*
1	-	30	±2 / ± 2.5
2	39	24	±2 / ± 2.5
3	37	21	±2 / ± 2.5
4	33	-	±2 / ± 2.5
5	29	-	±2 / ± 2.5

Table IV: User equipment power classes for GSM900 and GSM1800

The most common RF power classes for handheld GSM devices are class 4, the $2\,W$ output power class for GSM900, and class 1, the $1\,W$ output power class for GSM1800.

Timing of the power: The handset receives a signal from the base stations (down link) and transmits a signal to the base stations (up link) at different instances in time. The frequencies for transmitting and receiving are given in table V. Each time slot is $0.577\,ms$ long and repeated every eighth time slot for a full-rate GSM device giving a periodic signal with a period of $4.615\,ms$, called a frame in GSM terminology, corresponding to a RF burst repetition rate of $217\,Hz$. The time slot results in a $1.73\,kHz$ component in the power spectrum. One multiframe consists of 26 frames and lasts for $120\,ms$. For the first 25 frames in a multiframe the device transmits power, but in frame number 26 in all multiframes the device is inactive. Thus the mobile communication device emits power in one eighth of the time, sending an amplitude-modulated burst signal. This signal also includes simulated speech using pseudo-random binary sequences with a length of $23\,bits$. Multiframes (MF = 26 frames) and intermediate multiframes

(IMF = 104 frames, duration: 480 ms) are implemented. This leads to an enhanced spectrum including 8 Hz and 2 Hz components.

Frequency band	*Mode*	*Frequency range*
GSM900	up link	880-915MHz
GSM900	down link	925-960MHz
GSM1800	up link	1710-1785MHz
GSM1800	down link	1805-1880MHz

Table V: Frequency bands for GSM Networks

If the connection quality allows a reduction of the emitted power by both, base station and mobile, it can be reduced by the control of the base station. The Power Control (PWC) technique enables the reduction of the power emitted by handsets in order to reduce problems due to interference and to save battery power. It does this by reducing output power in steps of 2 dB. The number of PWC levels depends on the network. The maximum average power for the highest power control level is therefore 240 mW for GSM900 and 120 mW for GSM1800.

Frequency band	*Max. peak power (W)*	*Max. avg. power (W) (W)*	*ELF components (Hz)*
GSM900	2	1/4	2, 8, 217, 1.73k
GSM1800	1	1/8	2, 8, 217, 1.73k

Table VI: Frequency bands for time division multiple access (TDMA) and their associated maximum power levels and low frequency components

ELF magnetic fields: Considering ELF, the essential component in the handheld device is the battery. Today typical handhelds use battery packages with a voltage of 4.8 V; however, trends are towards lower voltages, e.g., 2.7 or 3.6 V. For a handheld with a 4.8 V battery supply in a burst nature TDMA, the current drawn from the battery will also be of a burst nature and quite large. For example, a typical 2 W peak power GSM phone with an efficiency of 45% will draw a burst current in the order of 1 A.

In table VI the characteristics of the currently used systems in Europe are listed with respect to their maximum emitted power and the low frequency components involved.

Different advanced coding and modulation schemes exist which allow the delivery of 2.5G services in a GSM network. They are discussed in the following section with respect to their impact on the power delivery of the handset. All of them use the same principle: use of an enhanced coding scheme in a GSM time slot and assignment of more than one time slot to the same user in order to increase the amount of transmitted data.

High Speed Circuit Switched Data (HSCSD): High Speed Circuit Switched Data (HSCSD) is an enhanced high-speed variation of the 43.2 $kbps$ or higher over the existing GSM radio infrastructure. This is achieved using an improved coding algorithm to allow up to 14.4 $kbps$ in a single GSM time slot compared with the usual 9.6 $kbps$ as well as with the allocation of multiple time slots per channel in the up link and down link. In this case the maximum average power is increased by a factor corresponding to the number of assigned time slots.

General Packet Radio Services (GPRS): General Packet Radio Service (GPRS) is a packet switched radio access technique based on the GSM radio interface. GPRS takes into account the bursty nature of data traffic and effectively optimizes spectrum use by dynamically sharing time slots between different users. As a result, multiple users can make data and voice calls using the same time slots. GPRS supports direct end-to-end IP connectivity using transparent and standard data protocols such as TCP/IP and X.25. Bandwidth is effectively supplied to the MS on demand. Data rates up to 171.2 $kbps$ can be supported in theory; however, a more realistic practical maximum rate may be 40.2 $kbps$. Unlike GSM, CS links which are charged by air-time GPRS connections are "always-on" and are charged by the amount of data transferred across the link. GPRS co-exists with standard GSM in the same network. To achieve higher data rates on flexible packet transfer over the existing GSM air interface, two changes are made at higher layers in the network: A number of different levels of error coding are employed to allow up to 21.4 $kbps$ of data to be transmitter over a single time-slot under favorable propagation conditions. Up to eight time slots can be used per user to achieve the theoretical maximum rate of $8 \cdot 21.4 = 171.2\,kbps$. In this case the maximum average power is increased by a factor corresponding to the number of assigned time slots.

Enhanced Data Rates for GSM Evolution (EDGE): Enhanced Data Rates for GSM Evolution (EDGE) is an extension of the GSM air interface to allow higher data rates by using new coding and modulation schemes. It can be used with both circuit switched and packet switched data services: 1. Enhanced Circuit Switched Data (ECSD): Circuit switched data at rates of up to 48 $kbps$ with a single TS or 384 $kbps$ using eight TS; 2. Enhanced General Packet Radio Service (EGPRS): Packet switched data at a rate of 59.2 $kbps$ with a single TS or 473 $kbps$ with eight TS. In this case the maximum average power is increased by a factor corresponding to the number of assigned time slots.

In conclusion the average emitted power from the handset for these advanced coding and modulation schemes is increased from 0.24 up to 2 W.

Base Stations: The power classes for GSM base stations are given in table VII. The output power can be reduced from its maximum level in at least six steps, of nominally 2 dB with an accuracy of $\pm 1\,dB$, to allow fine adjustment of the coverage by the network operator. As an option, the base station can also use downlink power control with 15 steps of power control levels with a step size of 2 dB $\pm 1.5\,dB$. The tolerance for the given power classes is divided into $\pm 2\,dB$ under normal conditions and $\pm 2.5\,dB$ under extreme conditions. The emitted power from a base station therefore varies depending on the cell type, the antenna type and the environment. Compliance is required according to the NIS guidelines for the maximum allowed level of the electric field released by BUWAL in 2001 [3].

Application Range: The TDMA system is designed for use in a range of environments and situations, from hand portable use in a downtown office to a mobile user traveling at high speed on the freeway. The system also supports a variety of services for the end user, such as voice, data, fax, short message services, and broadcast messages. TDMA offers a flexible air interface, providing high performance with respect to capacity and coverage, and unlimited support of mobility and capability to handle different types of user needs. All current systems based on GSM use the TDMA technology.

5.1.2 WCDMA

Wideband Code-Division Multiple-Access (WCDMA) is one of the main technologies for the implementation of third-generation (3G) cellular systems. It is based on radio access techniques proposed by the ETSI Alpha group, and the specifications were finalized in 1999 (http://www.etsi.org/). CDMA is a spread-spectrum technology that allows multiple users to share the same frequency

Power class	*GSM900 Nominal maximum output power (dBm)*	*GSM1800 Nominal maximum output power (dBm)*
Macro cell base stations		
1	55 - (<58)	43 - (<45)
2	52 - (<55)	40 - (<43)
3	49 - (<52)	37 - (<40)
4	46 - (<49)	34 - (<37)
5	43 - (<46)	
6	40 - (<43)	
7	37 - (<40)	
8	34 - (<37)	
Micro cell base stations		
M1	(>19) - 24	(>27) - 32
M2	(>14) - 19	(>22) - 27
M3	(>9) - 14	(>17) - 22
Pico cell base stations		
P1	(>13) - 20	(>16) - 23

Table VII: Power classes for GSM900 and GSM1800 base stations

channel. CDMA codes every digital packet it sends with a unique key. This implies that all phones are sending all the time at a quickly changing power level. A CDMA receiver responds only to that key and can pick out and demodulate the associated signal. In WCDMA interface different users can simultaneously transmit at different data rates and data rates can even vary in time. Two different modes will be used, frequency division duplex (FDD) and time division duplex (TDD), and they have different power vs. time characteristics. The frequencies allocated to WCDMA are shown in table XII.

Mode	*Frequency range*
FDD up link	1920-1980MHz
FDD down link	2110-2170MHz
TDD	1900-1920MHz and 2010-2025MHz

Table VIII: Frequency bands for WCDMA Networks (FDD and TDD modes)

Handsets, FDD mode: The $60\,MHz$ uplink band is divided in $5\,MHz$ bands, where the power is in principle on all the time.

Timing of the power: The handset power is controlled by the base station in a closed loop power control, ensuring that the received power is at the correct and constant level. The steps of the power control are $1, 2, 3\,dB$, and the frequency is $1500\,Hz$. Since this faster power control tends to compensate for the channel variations due to movement, the actual power variations depend on the velocity of the user and the environment. In general there will be a $1500\,Hz$ component in the spectrum of the power variations, and a wider continuous spectrum at lower frequencies. The various power classes for user equipment for FDD are shown in table IX.

Modulation: The basic chip rate is $3.84\,Mbps$, which is then modulated with various spreading codes. The modulation is QPSK, which is notably different from the constant envelope signals

Power class	*Nominal maximal output power*	*Tolerance*
1	33 dBm, 2 W	+1 / -3 dB
2	27 dBm, 0.5 W	+1 / -3 dB
3	24 dBm, 0.25 W	+1 / -3 dB
4	21 dBm, 0.125 W	± 2 dB

Table IX: User equipment power classes for FDD

used in GSM. The TDMA bursting is avoided, but there is an envelope periodic modulation at the chip rate. There are repetitious, coherent phenomena in the FDD mode, namely the $100\,Hz$ pilot tone, the $1500\,Hz$ power-control rate, and the $3.84\,MHz$ chip rate due to the non-constant envelope. We must then expect to see these three frequencies in the frequency spectrum of the power.

Handsets, TDD mode: The basic parameters, such as chip rate, channel spacing, frame length and modulation, are similar to FDD. The main difference is that the same frequencies are used for up and down links, thus necessitating a time separation between the two transmissions. The 15 slots per frame may be divided very asymmetrically to allow for higher data rate in one direction than the other, typically high downlink rates for downloading large files. The frame length is $10\,ms$, such that one slot is $0.666\,ms$. The power will be bursty with transmission on only a certain fraction of time, depending on the asymmetry. The basic repetition rate corresponding to the $217\,Hz$ of GSM is $100\,Hz$, but the spectrum will be more complicated, since multiple, not necessarily contiguous timeslots may be applied. The average power levels will decrease depending on the number of active time slots for transmission. It will vary from $-0.6\,dB$ (13 out of 15 time slots in uplink) to $-12\,dB$ (single uplink time slot) relative to the peak power. The various classes are shown in table X, including the output power for single slot transmission.

Power class	*Nominal maximal output power (dBm)*	*Single slot transmission (dBm)*	*Tolerance (dB)*
1	30	18	+1 / -3
2	24	12	+1 / -3
3	21	9	± 2
4	10	-2	± 4

Table X: User equipment power classes for TDD

Base stations, FDD mode: The downlink case for transmission is complicated by the unknown traffic distribution, and also by the possible co-siting by several operators. Furthermore, a user may be exposed to several base stations at the same time. The power level at the base-station transmitters is expected to be limited to $43\,dBm, 20\,W$ per carrier. There may likely be one to two carriers per operator, and perhaps several operators at one site. A target power level of $10-15\,W$ is typical for full traffic, and this includes a constant control (pilot) channel of 10%, i.e., $1\,W$. The power control to the individual user is similar to that above for the handsets, with a frequency of $1500\,Hz$. The total power to many simultaneous users will be slowly varying, due to the varying traffic.

It is well known that in most practical situations, the incident power density from a base

Signal property	*Frequency*
Carrier	e.g. 2 GHz
Spreading modulation	3.84 MHz
Power Control (FDD mode)	1.5 kHz
Power Control (TDD mode)	750 Hz
TDD (TDD mode)	100 Hz
DTX	variable

Table XI: Signal properties for UMTS

station transmitter is much less than the limits set by the guidelines. Nevertheless, it is the cause of much discussion, and it is prudent to quantify the response, even if it is weak. Since the exposure will be largest at close range, the line-of-sight condition may be used. Using a base station transmitter power of $20\,W$, a $17\,dB$ antenna gain, and a power density of $10\,W/m^2$, a safety distance of $3\,m$ is obtained using far-field formulas (which tend to overestimate at such close distances). Such a high antenna gain would correspond to a high antenna mast or the top of a building, where it is unlikely that the public would be close to the direct line of sight. Assuming the existence of two such transmitters at the same site increases the distance to $4\,m$.

For micro- and pico-cell situations, it is necessary to consider the actual power levels and to estimate the proximity of users. Power control is also present in the downlink; thus, the $1500\,Hz$ (FDD) stepping frequency is present, as is the $3.84\,MHz$ chip rate.

Base stations, TDD mode: Power levels may be like FDD in principle for macro cells ($20\,W$), but it is likely that TDD will be applied more in pico cells with $0.25\,W$ output power. The TDD power bursting is similar to that of handsets with highly asymmetrical service from the download of files. This means that the average power will be close to the nominal output power. Power control in the downlink will have variable rates from 100 to approximately $750\,Hz$.

Mode	*Max. power (W)*	*ELF components (Hz)*
TDD	2	100, 1500, $3.84 \cdot 10^6$
FDD	2	1500, $3.84 \cdot 10^6$

Table XII: Frequency bands for Wide Band Code Division Multiple Access (WCDMA) and their associated maximal power levels and low frequency components

ELF magnetic fields: For CDMA devices current to the power amplifier will be drawn proportional to the inverse of the random propagation loss. This will result in a significant ELF magnetic field, however without any periodicity.

Application Range: The WCDMA system is designed for use in a range of environments and situations, from handheld portable use in a downtown office to a mobile user traveling at high speed on the freeway. The system supports all 2G services and in addition new broadband services such as multimedia message service, etc. It should be noted that all high speed, broadband services are limited with respect to the velocity of the user. Reliable high speed, wideband transmission will only be possible in stationary situations.

In conclusion WCDMA will introduce a variety of new low frequency components to the spectrum of transmitted electromagnetic power. Even if the power emitted from a single device is expected to be lower than those of TDMA, the number of cells and therefore the number of base stations will increase.

5.2 WLAN

A Wireless Local Area Network (WLAN) is a flexible data communications system which provides short to medium range network connectivity to a range of devices including both mobile and fixed computers, typically implemented as either an extension to, or as an alternative for, a conventional wired LAN. WLANs typically operate in one of two modes. One is the so called "Ad-Hoc Mode" where two terminals establish a peer-to-peer connection with no assistance from other infrastructure. The second is the "Infrastructure Mode" whereby an Access-Point (AP) is used to connect many terminals into a LAN, which may be an extension of a wired LAN. Infrastructure based WLANs can range in complexity and size from a single AP in an office to deployments with many overlapping cells to give blanket coverage over an entire site. This is similar to a small-scale cellular radio system using an "always-on" packet switching interface with the access points acting as base stations. A number of WLAN systems have been standardized or are in the process of standardization by various organizations.

Air Interface: The main characteristics of the air interface are summarized in table XIII. Additional modifications and enhancements are currently being developed for IEEE802.11.

Frequency Bands: Currently, the available and planned WLAN systems operate in the ISM bands at $2.4\,GHz$ and $5.2\,GHz$. The different frequency ranges are given in table XIII.

Power Classes: The power classes for the various WLAN systems are also given in table XIII.

Property	*IEEE 802.11*	*IEEE 802.11a*	*IEEE 802.11b*	*IEEE 802.11g*	*HiperLAN Type 1*	*HiperLAN Type 2*
Frequency Bands (GHz)	2.4-2.4835	5.15-5.35, 5.47-5.725	2.4-2.4835	2.4-2.4835	5.15-5.35	5.15-5.35, 5.47-5.725
Max. transmit power EIRP (dBm)	20	16, 23, 29 with 6dBi	20	20	10,20,30	23, 30

Table XIII: Frequency bands and maximum transmit power for Wireless LAN described in different standards (EIRP: Equivalent Isotropically Radiated Power)

WLAN transmitters operate at a power of $0.035\,W$ $(35\,mW)$ in the $2.4\,GHz$ band, depending on the specific product in use and the local regulations. The IEEE 802.11b standard includes 11-13 possible frequencies. Mostly spread spectrum technology is used. Therefore only 3 frequencies can be used at the same time. However, this also implies that several access points can be simultaneously active. The carrier frequencies for LAN's are rather unexplored frequencies, from a dosimetric and biological viewpoint. WLAN includes the DECT, IEEE 802.11 standards, Hiperlan/1 and Hiperlan/2, Bluetooth, HomeRF. The frequency ranges for these standards are given in table XIII.

5.3 BAN

A Body Area Network consist of one or more Body Sensor Units (BSU's) and a central base station, the so-called Body Central Unit (BCU). The BCU is worn on the body and communicates in one direction with the Body Sensor Units or wearable devices, in addition to communicating with a fixed base station, a so-called Network Access Unit (NAU). This NAU provides access to a larger network such as a Local Area Network or something similar. The communication between the BCU and the NAU can be based on either mobile communication standards such as DECT, Bluetooth, WLAN or UMTS. The communication between the Body Area Network components is expected to be based on the Bluetooth technology.

5.4 Ultra Wide Band (UWB)

Ultra wide band is a future concept for wireless communications that is being developed now but is still far from completion. The most modern standards of data transmission are narrow band standards: all work within a quite narrow frequency band allowing for only small deviations from the base (or carrier) frequency. Within this narrow band the transmitter emits a considerable amount of energy necessary for the following reliable reception within the designed range of distance ($100\,m$ for the 802.11b). The range is strictly defined by regulatory bodies and requires licensing. Data are encoded and transferred using the method of frequency modulation (control of deviation from the base frequency) within the described channel.

In contrast a UWB transmitter emits short pulses of a special form which distributes all the energy of the pulse within the given, quite wide, spectral range (approximately from $3\,GHz$ to $10\,GHz$). Data, in their turn, are encoded with polarity and mutual positions of pulses. With much total power delivered into the air and, therefore, a long distance of the reliable reception, the UWB signal does not exceed an extremely low value (much lower than that of the narrow band signals) in each given spectrum point (i.e., in each definite licensed frequency band). As a result, according to the respective FCC regulation, such a signal becomes allowable although it also takes spectral parts used for other purposes. So, the majority of the energy of the UWB signal falls into the frequency range from 3.1 to $10.6\,GHz$, and the energy spectral density does not exceed the limit determined by the Part 15 of the FCC Regulations ($-41\,dBm/MHz$). Below $3.1\,GHz$ the signal almost disappears; its level is lower than $-60\,dBm$. The more ideal the form of a pulse formed with the transmitter, the less the energy leaves the main range. This mode of operation allows the transmission of hundreds of $Mbit$.

The wide band characteristics will be of importance with respect to low level, pulsed signals that are discussed regarding possible athermal effects. There the peak power as well as the modulation is assumed to be of great importance.

5.5 Bluetooth

Bluetooth is a wireless system for the transmission of voice and data. It provides an alternative to the wires and infrared connections previously used. The data rate can be from $57kbit/s$ up to $721\,kbit/s$, and the working range is $10\,m$ in radius at a power of $1\,mW$ or $100\,m$ at a power of $100\,mW$. Bluetooth can support a network with up to eight participants. These short-range wireless links can be used for setting up a distributed Personal Area Network (PAN) of devices using Bluetooth to access a terminal which interfaces to the rest of the world by a LAN, WLAN or 2.5G/3G mobile communications link. This allows the main radio terminal to be placed in virtually any location on the body thus creating many possible exposure scenarios.

Bluetooth is of special interest, since it can be expected that it will be embedded in most digital devices of the future, from mobile phones to cameras, printers, household devices, and so on. There is a general trend towards low exposure from the individual device, but at the same time towards an increase in the number of devices. Another trend is towards an "always on" mode of all communication devices.

Air Interface: An FHSS transceiver is used to combat interference and fading. The modulation uses Gaussian Frequency Shift Keying (GFSK) with a transmitted symbol rate of $1\,Ms/s$. A slotted channel is applied with a nominal slot length of $625\,\mu s$. For full duplex transmission, a time division duplex (TDD) scheme is used. The channel spacing is $1\,MHz$.

Frequency Bands: Radio frequency operation is in the unlicensed industrial, scientific and medical (ISM) band at 2.4 to 2.48 GHz, using a spread spectrum, frequency hopping, full-duplex signal at up to 1600 $hops/sec$. The signal hops among 79 frequencies at 1 MHz intervals to give a high degree of interference immunity.

Power Classes: RF output is specified as 0 dBm (1 mW) in the 10 m-range version and -30 to $+20$ dBm (100 mW) in the longer range version. The equipment is classified into three power classes, 1 to 3, as defined in table XIV. Power control is required for Class 1 equipment. The power control is used for limiting the transmitted power over 0 dBm. Power control capability under 0 dBm is optional and could be used for optimizing the power consumption and overall interference level.

Power class	*Maximum output power (dBm)*	*Minimum output power (dBm)*
1	20	0
2	4	-6
3	0	N/A

Table XIV: Bluetooth power classes

5.6 Implants

With respect to implants, two main principles of operation can be distinguished. The first principle includes implants based on inductive coupling that can be used for “tagging-like” applications. In the second application range, implants only radiating messages to the outside world are considered. The frequency range of operation will usually be in the low frequency range, where the path-loss will be low due to the dielectric properties of the tissue.

Inductive Coupled Implants: These devices work, depending on the implementation, in the frequency range between a few kHz up to 50 MHz. For inductive coupling the main power is used for energizing the implant, whereas for the communication only very low power is needed. The total power is in the range of 100 mW. Regulations exist for the maximum power density allowed in order to avoid hazards. In the ANSI/IEEE C95.1 standard the maximum power density is limited to 10 mW/cm^2.

There are examples of successfully applied implants such as “cochlear implants” or “brain implants”. In the case of a cochlear implant the device operates using an external exciter that is held directly above the implant module by magnetic location of an RF coil energized at 2.5 MHz to power the implant and to transfer signals to it. An external microphone and sound analyzer provides the necessary acoustic reception, amplification and spectral analysis necessary to drive the implant.

Implants Sending RF: These devices work in the same frequency range as those mentioned above. The main difference is that the power used for operation is alternatively supplied. One typical application is a device monitoring a physiological parameter from time to time and sending a warning signal or a short pulse sequence to a receiver placed outside the body or to a band-aid with an integrated receiver/transmitter which activates further processes.

One rather unusual method of power supply was developed in connection with brain implants for severely disabled people. Using these brain implants, these people were able to control the cursor on a computer screen just by thinking about moving parts of their body. Each implant consists of a hollow glass cone of about the size of a ball-point pen tip. The cones are laced with neurotrophic chemicals extracted from the patient's own knees which encourage nerve growth. Over several months, the implant becomes naturally 'wired' into the patient's brain as neurones grow into the cones and attach themselves to the electrodes mounted inside. When the person thinks of an action which would normally occur through the nervous system, it is transmitted from the electrode to the computer. An FM transmitter under the scalp transmits the signal without wires, and power induction means no batteries are needed. The signal is transmitted out, processed and then fed back to the patient, so that he/she can hear the activity, and also see the cursor move (biofeedback).

These examples show possible developments in this field. The relevant parameters are the method used for power supply, the depth of the device in the body (subcutaneous or deeper), the type of antenna and the power needed for communication. Depending on the application, either a continuous signal acts on a device for energizing and sending data to it, or the device collects data at given time intervals and sends a short signal to the outside world if a certain level is over- or under-run.

6 Exposure Scenarios of Pervasive Computing

The increasing number of users and the limited spectrum available forces the deployment of smaller and smaller cell sizes, which means proximity to many base stations as well. The overall illumination of the general public will not grow proportionally, since the output power will tend to decrease [5]. The 2G digital systems are dominated globally by GSM, a TDMA system with a characteristic bursty nature of its power. This has given rise to some fears in the bioelectromagnetics community about possible low-frequency effects, since the burst frequency is $217\,Hz$. For many years to come, millions of people will continue to use basic GSM. Further studies for providing the rationale for selecting the functions and parameters for simulating the environmental EMF exposures which occur during usage of a GSM handset show a wide range of occurring low frequency components [34]. The data is based on recordings along routes in Paris and its vicinity of the power control level for different situations [44]. The simulations include statistics about handover, environment events, target level change, power ramp, DTX and nonDTX. Extrapolation of these findings to new technologies for wireless communication and broadcasting imply an increase of power in the low-frequency components with several distinct spectral peaks within everyday exposure. Recent studies have confirmed the hypotheses about modulation related effects [21].

For exposure from UE the key issues in the transition from 2G to 2.5G and 3G are:

1. Different frequencies and power levels from the mobile transmitter
2. The new services that will be delivered over 2.5G/3G will lead to different types of devices with new form factors and usage
3. The Man-Machine Interface will become divorced from the radio transmitter using a PAN for communication; the main communication device can then potentially be placed at many different places on the body

Addressing the frequencies of operation and power levels is fairly straightforward, though if multiple radio systems can be used simultaneously, these will need to be accounted for in the exposure assessment. For example, the core communications device may contain both a GSM or UMTS together with a Bluetooth transceiver, both of which could be operating at full power during a two way video call which is being made from an external device via the Bluetooth link. The new device formats are important, since they determine the location and type of antenna system on the device. This could include the use of diversity/smart antenna systems on larger devices and will certainly mean the use of wideband/multi-band or multiple antenna systems to support different radio communication services. The services will also dictate the way in which the devices will be used, in particular the relative location of the device(s) on the body. For example, a videophone will need to be held in front of the face, assuming the screen and camera are integrated into the device. This will limit the exposure of the body. The separation of the main communications system from the MMI is perhaps the most significant change, though this has already happened in 2G to some extent due to the increased use of Hands Free Kits (HFK) in general (i.e., non-vehicle) use. The main transmitter could then be located anywhere within a few meters of the body; voice control or other peripheral may be used, and it is not necessary to use controls on the main handset to use a service. The exact location of the major source of RF exposure from the terminal is then much more difficult to specify but could reasonably be one of the following:

1. Trouser/skirt pocket
2. Pocket of a jacket, shirt, blouse or other garment
3. Carried in the hand
4. Attached to a belt around the waist
5. Held/laid in lap or on a leg when seated
6. On a table top away from the body

This means that many other parts of the body could be in close proximity to the handset antenna and therefore exposed to RF radiation. For the case of a wired HFK the cable may also need to be considered as part of the antenna system when assessing exposure. Increasingly, the HFK is likely to become a wireless peripheral using a short-range radio link such as Bluetooth to communicate with the handset (such devices are already available for 2.5G mobile phones). The implications are the same as for the wired HFK. The main transmitter is now elsewhere on (or off) the body, though now there are two additional transmitters involved in the scenario, one on the headset and one on the main terminal, albeit at lower power levels. Similar considerations apply to the use of other peripheral devices in a PAN. The higher data rates achievable with third generation terminals will increase the use of wireless data modems. These modems, or data terminals, are likely to be used with laptop and palmtop computers and other multimedia devices and could either be integrated into the computer or connected externally. This allows the possibility of the data terminal antenna to be close to many different parts of the body during transmission. While the exposure levels of members of the public from base station radiation is typically much lower than that from handheld terminals, some consideration needs to be given to the likely exposure scenarios from the increased use of smaller cells. Note that the base stations used for micro- and pico-cells will have much lower power than those used for macro-cells. However, they are likely to be mounted in more accessible locations, for example lampposts / building walls, and may employ new technologies such as smart antennas.

6.1 Implants

For the case of sources located in the body, no guidelines or standard has yet been defined. For inductive coupling safety standards with respect to power density exist. The main exposure will arise from the loop antenna located near to or on the skin. This will cause significant absorption. If the source is located in the body there will be local heating. This case has to be assessed scientifically in order to deliver reliable estimates on the absorption behavior of such devices.

6.2 On-Body Transmitters or Close Near-Field Exposures

The exposure corresponding to sources located near to and on the body has to be assessed for every single case separately. There is no general way of quantifying the exposure arising from near- or on-body devices. In [32] the energy absorption mechanism by biological bodies in the near field of dipole antennas above $300\,MHz$ is systematically assessed. An approximation formula is derived showing that the spatial peak SAR (the amount of absorbed power averaged over a given mass of tissue) is quadratically proportional to the antenna current and the distance between the feedpoint of the antenna and the biological body. This has been rigorously assessed numerically and by measurements. The results are generalized for any antenna and for any shape of the biological body. What is shown is also the necessary accuracy of both the numerical and measurement method in order to be able to deliver reliable results on near-field effects. Depending on the design of the device, in addition to the direct coupling from the antenna current there is also the possibility of coupling from surface currents caused by mismatched impedances. Therefore standardized procedures for assessing the absorption in biological bodies caused by wireless devices have been elaborated or are currently being elaborated [4]. In these standards the measurement problems associated with radio frequency hazard assessment is treated in more detail. In general it has to be pointed out that reactive RF field components couple to the body as efficiently as radiating components.

6.3 Intermediate Near-Field

If the body is in the intermediate near-field of a transmitter, larger regions of the body are irradiated. The main components coupling to the body are the radiating ones resulting in a more far-field like behavior and therefore in generally lower absorption.

6.4 Far-Field

The far-field region corresponds to the region of the field of an antenna where the angular field distribution is essentially independent of the distance from the antenna. In this region, the field has a predominantly plane-wave character, i.e., locally uniform distribution of electric field strength and magnetic field strength in planes transverse to the direction of propagation. In this case the safety limits are defined over the field strength occurring around objects. However, there is not necessarily a direct dependence between the absorbed power by a biological body and its surrounding field strength. Dependence also exists on the polarization and the specific exposure situation. Therefore, public exposure is normally described by a limiting field strength for which a certain level of absorption is not exceeded for all possible cases [25].

6.5 Exposures from Reradiating Structures

Reradiating structures can result in strongly enhanced incident field components, e.g., in the vicinity of metallic structures or standing wave patterns in closed rooms. However, it can be shown that these strong incident fields do not translate into high induced fields or SAR levels, e.g., [40], [29], and therefore pose no additional health risk. On the other hand, active transmitters might be rather sensitive to scattered fields and might require additional considerations.

7 Scientific Gaps for Risk Assessments

Based on the previously outlined aspects of technologies and exposure scenarios, the following scientific gaps for a full risk assessment for pervasive computing can be identified:

- procedures for assessing the exposure of body-mounted applications other than mobile phones operated next to the ear
- procedures for determining ELF exposures
- safety guidelines for highly local exposures as occurring from implants and skin-mounted devices
- a complimentary research program for risk assessments of 3G exposures
- systematic evaluation of the biological response caused by exposure from more general amplitude modulation schemes covering the possible range of pervasive computing technologies

It has to be pointed out that at the current time only a preliminary assessment of future exposure with respect to possible health impacts can be given. Therefore it is obvious that a considerable research effort is still needed before a thorough scientifically-based risk assessment of pervasive computing can be conducted.

8 Conclusions

An overview of the current safety standards as well as of their limitations has been provided. Compliance with current safety guidelines is necessary to protect the general population from adverse thermal effects. Current safety guidelines do not include the possible athermal effects occurring at low doses of absorbed energy. Examples of current research demonstrate the difficulties of conducting a complete health risk assessment, which includes the possible athermal effects. Another unresolved issue is possible long-term effects, which has not yet been intensively investigated. It is also questionable whether the current standards are suitable to evaluate wireless implants.

The technology used for future developments within the field of pervasive computing has been discussed with respect to power and modulation characteristics. Differences between current technologies and future technologies have been identified. In general, pervasive computing applications will result in significant spatial peak time-averaged exposure levels in various relevant tissues ($0.01 - 2\,W/kg$) which are orders of magnitude above those induced by traditional broadcast systems and exposure from base stations. The exposure levels are close to the safety limits recommended by the guidelines. For systems utilizing in-body communications or implants, local tissue exposures can well exceed $100\,W/kg$. Special attention must be placed on the induced peak exposure levels when discussing potential athermal effects.

Pervasive computing applications will also result in exposures with significant ELF components from the amplitude modulation spectrum. The spectrum will depend on the technology utilized as well as on the implementation. Little to no data are currently available to assess the potential health hazards, and none of the currently conducted studies will be able to provide a sufficient scientific basis.

With respect to future exposure scenarios one major change can be seen in the variance of the exposed tissue types. Little is known about high-level local tissue exposure other than for head tissues. The currently collected epidemiological data will not enable any risk assessment other than for head exposures. More relevant knowledge can be expected from the currently conducted high-exposure whole-body animal studies performed within the European 5th Framework.

With respect to ELF it can be stated that stronger local exposures from ELF can occur through body-mounted high power pulsed systems. Other systems do not result in exposures significantly different than those from other household appliances.

Current research activities will result in 2006 in a considerable database regarding GSM exposure, as well as the results of replication studies. The analysis will show which issues can definitely be answered and which will require additional efforts. However, it is obvious that the currently conducted research will not provide the required data for the risk analysis of 3G and pervasive computing applications.

The identified knowledge gaps show the need for a considerable research effort before a thorough scientifically based risk assessment of pervasive computing can be conducted. Although the cumulated data do not support the hypothesis of a high individual risk, a thorough analysis is justified in view of the enormous population penetration.

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