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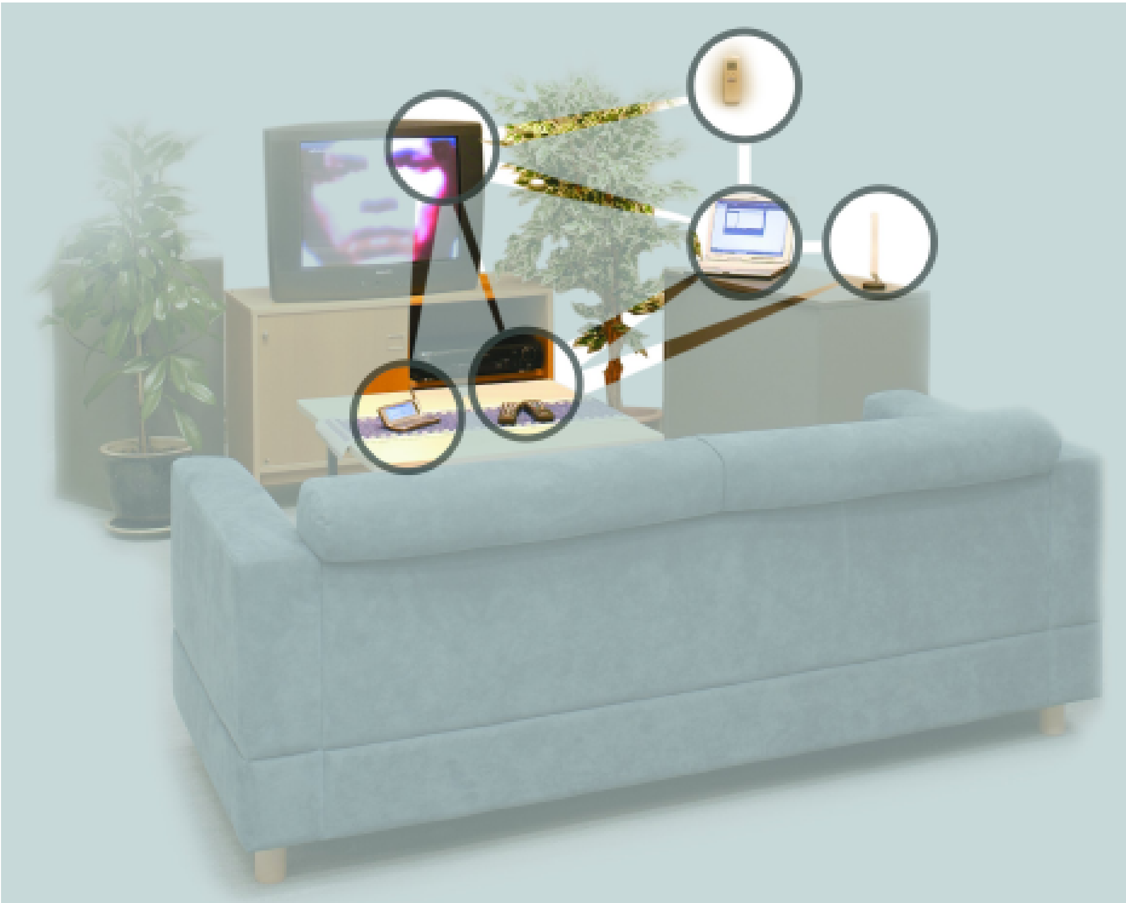

Heikki Ailisto, Aija Kotila & Esko Strömmer

Ubicom applications and technologies

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Abstract

The motivation for working up this report was to provide the parties involved or interested in Ubicom activities with information about opportunities and enablers in the area, and to contribute Tekes in defining research topics for the current and future research programs dealing with Ubicom. The main approach in the report is from the application system viewpoint. The main emphasis of the technical enablers is in short-range wireless communication technologies.

The report deals with the evolution and different approaches to the Ubicom concept around the world, possible application areas and scenarios with general requirements concerning them, key technical enablers with an estimation of their applicability and development during the next few years, aspects for the planning and evaluation of the business models of application systems, and recommendations for the future research activities and leading commercial applications.

The main suggestions of this report for the Ubicom research are: The research should be interdisciplanary, that is, it should combine human sciences, usability studies, business and economic research as well as legislation and ethical issues with the technology research, which is the basic enabler of the advancements in this area. Furthermore, both the application and the technology viewpoints must be combined. The core technology research should address short-range wireless communication, middleware, reasoning and smart algorithms, usability issues, as well as sensors and actuator technologies.

Preface

This report is based on the work that was possible thanks to the financial support of the National Technology Agency of Finland (Tekes) and VTT Electronics. The work has been done during autumn 2002 by surveying published material dealing with the subject, by interviewing experts at VTT Electronics and by interviewing experts from the following companies and research institutes: CCC Group, the Institute of Electronics at Tampere University of Technology, Metso Corporation, Nokia Research Center, Nokia Ventures Organization, Sonera Corporation, Suunto Corporation, and Vaisala Group. The work has also been contributed to by the management group of the ELMO research program of Tekes, the management group of the Interactive Intelligent Electronics research programme of VTT Electronics, and experts met in international conferences and company visits.

Oulu, December 2002

Esko Strömmer, Project Manager

Contents

1. UBICOM OVERVIEW

1.1 Ubicom vision

The term *ubiquitous computing* was first introduced by Mark Weiser in 1991 in the article *The Computer for the 21st Century* [Weiser 1991]. His main point was that the most profound technologies are those that disappear, giving as an example, *writing*, a technology which has for hundreds of years shaped our world, but is so commonplace that we do not even consider it as a technology. Weiser visioned a world in which humans and computers were seamlessly united.

During the last decade we have seen enormous advancement in the technologies that enable the ubiquitous computing vision: microelectronics, low power electronics, CMOS RF, memory, sensors, wireless and wired communications (both RF and optical), processor architectures, software technologies and communication systems such as mobile phones, Internet and WWW. At the same time, we have witnessed increasing research interest in the possible applications of ubiquitous (or pervasive) computing and its close successor, ambient intelligence. As a result of the technology evolution and research activities, the concept of ubiquitous computing has gained more versatile meaning, which is illustrated by some examples below.

Currently, two different approaches to ubiquitous computing can be distinguished, namely distributed and mobile terminal centered. Table 1 summarizes these views. The mobile terminal centered approach emphasizes communication technology even more than the distributed approach. In this connection we can talk about Ubicom^2 (ubiquitous computing & ubiquitous communication) or just Ubicom.

Table 1. Two visions and two approaches to Ubicom.

Distributed	**Mobile terminal centered**
Inexpensive, smart widgets everywhere	At the center is **"I"** who always carries a **mobile terminal**, phone or PDA
Embedded into appliances, things, even people?	Local & global connection
Research community	Mobile applications, community applications
Home appliance, A/V producers, home automation companies	Mobile phone business
Intelligent home, office	"Nordic"
"American, Central European"	

Figure 1 depicts the relationship between ubiquitous computing and *calm technology*. Calm technology is also a vision presented by Mark Weiser. Without going very deep into explaining the visions, we can briefly say that ubiquitous computing means that there will be more and more processors embedded in everyday objects around us. This evidently has some effect on the way we communicate with our surroundings and how the environment communicates with us. Calm Technology, on the other hand, is more concerned with the human side of communication. In Calm Technology the goal is to make human-computer or human-environment communication as calm as possible. By calm we mean that it requires minimum effort from the user, is unobtrusive and natural. Calm Technology is close to another commonly used concept, disappearing computer.

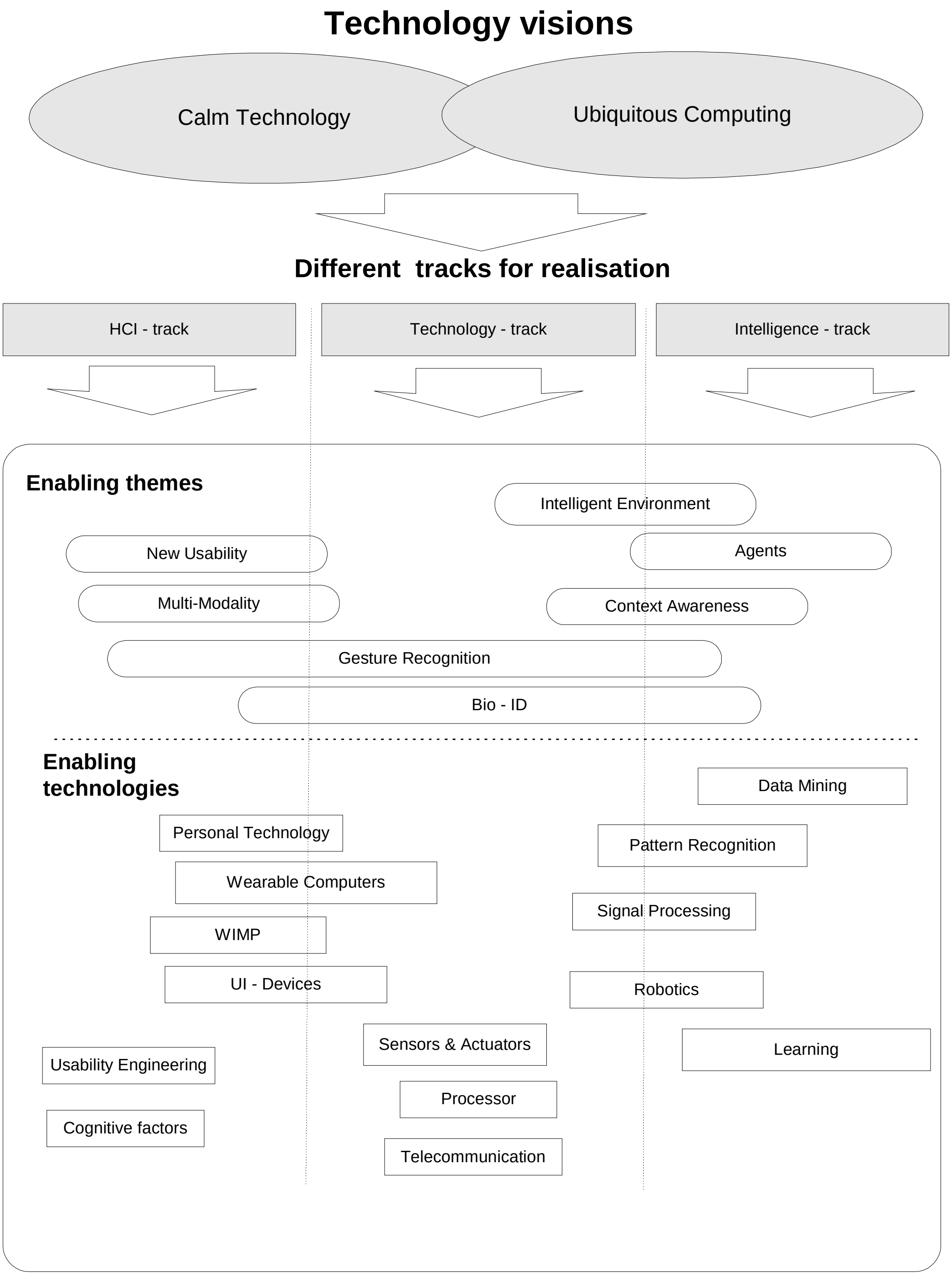

Figure 1. Calm Technology and ubiquitous computing (Esa Tuulari, VTT Electronics).

Concepts often linked to ubiquitous computing are *context awareness* and *proactivity*. A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task [Dey]. Proactive systems try to deduce the user's intentions or needs, e.g. based on context information or *profiling* of the user.

In this study, the term Ubicom covers both the ubiquitous computing and the ubiquitous communication. The frame of Ubicom in this study is illustrated in Figure 2. From the technical point of view, the vision of Ubicom is that in a few next years the number of electrical devices around us will be much larger than currently. However, most of these devices will be physically very small, and the electronics embedded in the devices so that people don't even notice it. From the application point of view, the vision of Ubicom is that people (users) can access different kinds of services via local communication. The key point here is the local communication, which usually means wireless short-range communication links restricted around a single user, inside a room, inside a hall or inside a corresponding space out-of-doors. However, the local communication links can have wired or wireless extensions to larger networks such as the Internet. The scope of services is very versatile. Examples of services are access to some information that is stored in the same place where it is used (local information service) or somewhere in the Internet (global information service), control of some appliances, reading some sensor, defining the position of the user etc. The arrows illustrate that there will be no applications without suitable enabling technologies, and without suitable applications the enabling technologies are useless. Thus, technologies and applications cannot be developed independently of each other.

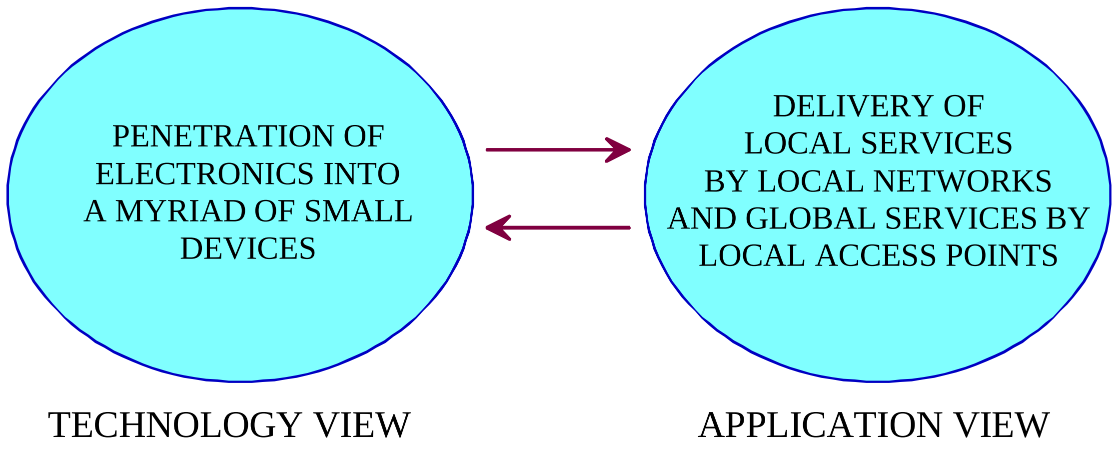

Figure 2. The frame of Ubicom in this study.

There are also many ongoing research programs with different approaches to Ubicom. Four currently ongoing significant research programs and their visions are briefly presented in the following chapters.

MIT Oxygen project

The MIT Oxygen project [MIT Oxygen] is best described by its motto "*Bringing abundant computation and communication, as pervasive and free as air, naturally into people's lives"*. The main challenges for the project are:

- Pervasive — it must be everywhere, with every portal reaching into the same information base
- Embedded — it must live in our world, sensing and affecting it
- Nomadic — it must allow users and computations to move around freely, according to their needs
- Adaptable — it must provide flexibility and spontaneity, in response to changes in user requirements and operating conditions
- Powerful, yet efficient — it must free itself from constraints imposed by bounded hardware resources, addressing instead system constraints imposed by user demands and available power or communication bandwidth
- Intentional — it must enable people to name services and software objects by intent, for example, "the nearest printer," as opposed to by address
- Eternal — it must never shut down or reboot; components may come and go in response to demand, errors, and upgrades, but Oxygen as a whole must be available all the time.

The Oxygen project is divided into four fields:

- Computational devices, called Enviro21s (E21s), embedded in our homes, offices, and cars sense and affect our immediate environment
- Handheld devices, called Handy21s (H21s), empower us to communicate and compute no matter where we are
- Dynamic, self-configuring networks (N21s) help our machines locate each other as well as the people, services and resources we want to reach
- Software that adapts to changes in the environment or in user requirements (O2S) help us do what we want when we want to do it

It is noteworthy that the H21s are anonymous devices that do not carry a large amount of permanent local state. Instead, they configure themselves through software to be used in a wide range of environments for a wide variety of purposes. For example, when a user picks up an anonymous H21, the H21 will customize itself to the user's preferred configuration. This is quite contradictory to the way people use handheld phones, PDAs and laptops today.

The resources of the Oxygen project include some 30 faculty members and students.

HP Cooltown

HP Cooltown [HP Cooltown] is a technology and business-oriented initiative for ubiquitous computing. It is described as "*A vision of mobility, connectivity, community, and transformation based on open standards and user needs*". Central to HP Lab's Cooltown is that in cooltown, every person, place, or thing can be connected to the web. As examples, web-connected wristwatches and cats (!) are given.

There are five underlying principles to the cooltown developers' community and the coolbase platform:

1. Rampant diversity of mobile and embedded information products, wireless and wired communication networks, and rich media content will be the norm, fueling an explosion of novel and sophisticated services.

2. The future network environment is the web. In contrast to tightly held proprietary platforms, the web is an open, extensible, heterogeneous, standards-based network infrastructure for delivery of services.

3. Everything has a web presence.

4. Bridging the physical and online worlds will bring the benefits of web services to the bricks-and-mortar world where people still live most of their lives.

5. Connected ecosystems of service providers will link together in creative and productive ways.

Project Aura, Carnegie Mellon University

The basic idea behind the Aura project [Project Aura] of Carnegie Mellon University is that the most precious resource in computing is no longer the processor, memory or network, but the human attention. The goal is stated as "*Aura's goal is to provide each* *user with an invisible halo of computing and information services that persists regardless of location. Meeting this goal will require effort at every level: from the hardware and network layers, through the operating system and middleware, to the user interface and applications.*"

Visions and development in Aura assumes that the tasks users want their computers do in future are not so different from what we have today: editing text, using spread sheets, preparing presentations, using CAD, emailing and communicating. What Aura will bring is a task-oriented approach instead of a program (Word, Excel...) oriented approach.

Disappearing Computer

The Disappearing Computer [Disappearing comp] is an EU-funded proactive initiative of the Future and Emerging Technologies activity of the Information Society Technologies (IST) research program. The mission of the initiative is to see how information technology can be diffused into everyday objects and settings, and to see how this can lead to new ways of supporting and enhancing people's lives that go above and beyond what is possible with the computer today. Specifically, the initiative focuses on three interlinked objectives:

- Create information artefacts based on new software and hardware architectures that are integrated into everyday objects
- Look at how collections of artifacts can act together, so as to produce new behaviour and new functionality
- Investigate the new approaches for designing for collections of artifacts in everyday settings, and how to ensure that people's experience in these new environments is coherent and engaging

The program was started in the beginning of 2001 and it involves 12 projects, two of them having Finnish members (University of Oulu in Atelier and VTT Electronics in Smart-Its).

1.2 Technical enablers

A summary of the main enabling technologies in the Ubicom application systems is shown in Figure 3.

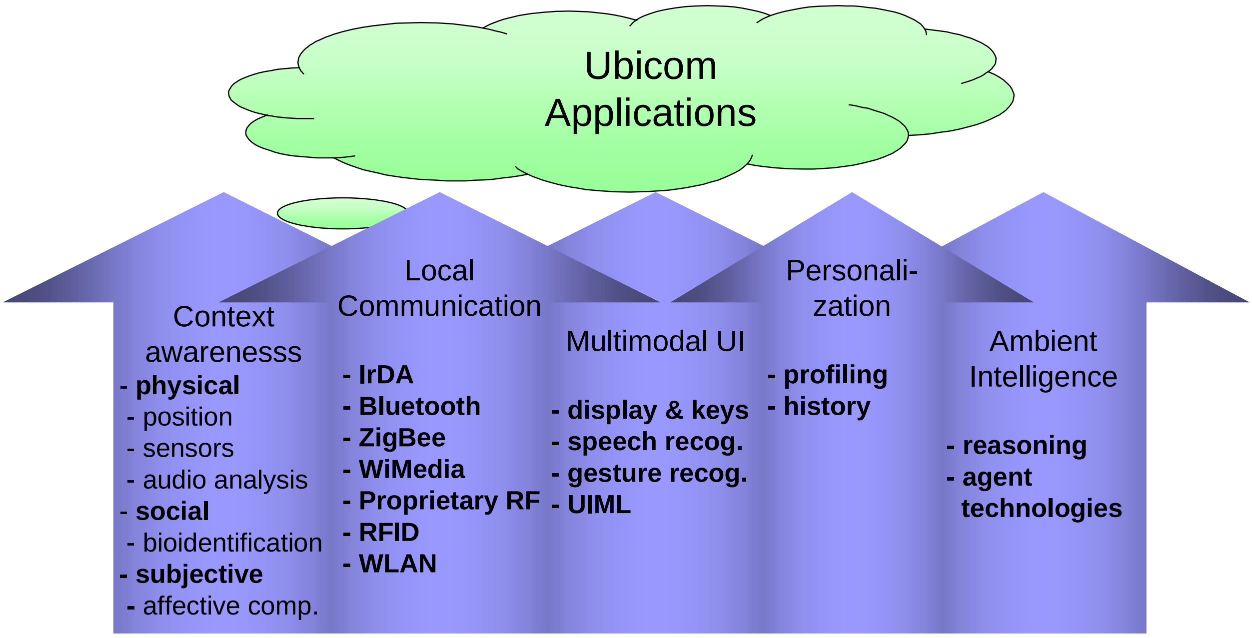

Figure 3. Main enabling technologies in Ubicom application systems.

VTT has made a roadmap towards the Smart Human Environment, which can be seen as a vision of a world with ubiquitous computing capabilities. This roadmap is summarized in Table 2.

Table 2. Smart Human Environment roadmap [VTT RN 2146].

	2002	2004	2006	Beyond
Ubiquitous computing	Embedded computing	Low-power ubi-communication embedded in devices	Ubi-environments, ubi overflow	Calm computing Ambient intelligence
Context awareness	Location-based services, sensor-based reactivity	Wearable embedded sensors, awareness of device context	Services using context-based information retrieval, environmental sensors	Awareness of social context
Positioning	GPS & GSM positioning- based services	Low-power RF-based indoor positioning (<2m), relative positioning (proximity)	Indoor cm-resolution positioning	Absolute integrated indoor/outdoor positioning
Personalization	Electronic identification, Web-services using customer profiles	Profile-driven services with learning features	Trusted biometric identification, Personalized context-driven services	Digital me
Multiple modalities	WAP and HTML adaptation, Voice control in consumer electronics	Pointing and voice combinations, versatile control	Spatial user interfaces, interactive soundscape, gesture recognition, natural interaction, multimodal adaptive UI	Electronic paper

1.3 Current Ubicom products

Although the term Ubicom is mainly used in the research world rather than as an attribute of commercial products, there are many commercial products in which ubiquitous communication and computing properties are embedded. In the following, a few examples are illustrated.

An example of applied Ubicom is Sonera wGATE, which is a wireless data service based on 11 Mbit/s wireless LAN technology (IEEE802.11b). The service enables fast wireless Internet access through WLAN access points, so called "wireless hot spots". Several wGATE access points have already been installed in public areas such as airports. The implementation is based on Nokia's WLAN technology. To enable the network access, the user has to install a WLAN module with a GSM SIM card in his or her laptop PC. The user can buy the WLAN module or rent it from the host of the premises. The billing of the user is based on the existing GSM billing system, which also handles the billing between teleoperators. Existing GSM roaming practices and elements can also be applied. [Sonera wGATE], [Nokia wGATE].

Another example of applied Ubicom is Digidim light control systems of Helvar. Digidim is based on the DALI communication standard. DALI is a dedicated communication standard for lighting systems that the European lighting device manufacturers have established. The product family incorporates ballasts, dimmers, an adjustable low-voltage VDC converter, a multisensor module (lighting level, presence sensor, IR remote control receiver), and a LON gateway. DALI communication is based on twisted pairs. No wireless communication except IR-based remote control has yet been applied. [Helvar]

Another example of applied Ubicom is the Butterfly environmental control system of Pikosystems in Tampere, Finland. Butterfly is aimed at helping handicapped or disabled persons in their daily life at private homes or sheltered homes. Examples of supported actions are power switching of appliances, setting various alarms, and activating communication devices for social intercourse with other people. The center of the system is a remote controller device that can be attached e.g. on a wheelchair and that communicates with the appliances by wireless IR. The user interface of the remote controller can be configured considering the individual needs of the user (graphic display, speech output, ability switches). [Pikosystems]

There are some typical characteristics in the above-mentioned and other current commercial Ubicom application systems:

- There are no open wireless interfaces. This especially concerns the Digidim and Butterfly systems. The wGATE system is based on widely used WLAN technology and communication modules from a single manufacturer.

- There are not many parties involved. Thus, the business model is rather simple and similar to that of the more traditional and non-electrical products. This especially concerns the Digidim and Butterfly systems. The business model of the wGATE system is more complicated, but it is based on the existing business model of the GSM system.

- The products are designated for existing applications, replacing older conventional products without any electronics. Electronics and wireless communication has penetrated into the existing products for adding their value. The added value can be e.g. easier use, higher performance, and new functions such as remote control and diagnostics capability through the existing network infrastructure.

2. APPLICATIONS AND SERVICES

2.1 Potential application areas

There are several ways to categorize potential Ubicom applications. The first categorizaton is based on environment or place of usage and it is presented in Table 3.

Table 3. Categorization by operational environment.

Environment / place	Motivation	Cost sensitivity	Compatibilty / standardization	Ease of use / training
Work places – industry	Efficiency and savings	Relative to added value, may tolerate high cost	Dedicated, proprietary	Training possible, use must be efficient
Work places – offices	Efficiency	Relative to added value, moderate cost	De facto standards	Some training possible, use must be efficient
Homes, - private homes, - shelterted homes for elderly and disabled people	Quality of living, ease	Sensitive to cost, price as a part of other appliances, audio-video or home automation	De facto standards	No training, use must be invisble in some cases
Places people visit - shopping centers - public buildings - leisure centers	Improved service, savings in work costs	Relative to added value, usually moderate cost	Proprietary or user's own terminal	No training, use must be very easy or invisible
Cars	New features, automation	Included in price, moderate cost	Proprietary	No training, use must be invisible
Special – military – medical	Performance	High cost acceptable if value in performance	Proprietary	Training possible, use must be efficient

The second way of categorizing the Ubicom applications is by function. A rough categorization can be made like in Table 4, where for each function the existing or traditional "non-ubi" realization, the possible ubiquitous realization and the added value of the ubiquitous realization are listed. It can be stated that a ubiquitous realization already exists in many functions, as is the case with ubiquitous broadcast radio (Walkman) and ubiquitous telephoning. However, it should be noted that here ubiquitous only means “present everywhere”, and these realizations are not completely within the frame defined in Figure 2, since local communication is not applied.

Table 4. Categorization by functions.

Functional category	**Traditional counterpart**	**Possible or existing ubiquitous realization**	**Added value of the ubiquitous realization**
Information and entertainment delivery	TV Radio Web	Mobile video delivery Sony Walkman Mobile Internet	Information and entertainment available everywhere and all the time
Communication	Phone	Mobile phone	Reachability everywhere and all the time
Services	Face-to-face (personal) Call center Internet browser-based	Digital assistant (e.g. shopping) Speech recognition Machine reasoning	Cost savings in wages and wait time
Automation (industrial)	Centralized system Control room	Distributed "technician & terminal"	Robustness On the spot access
Automation (home, car)	Electro-mechanical solutions	Embedded sensors, control & computers	Savings (fuel, water, ...) Comfort (air conditioning, ...)

2.2 Application examples (scenarios)

Three Ubicom application scenarios are presented here as examples. These are:

- Local info delivery systems in public buildings
- Distributed health care support system
- Shopping centre

2.2.1 Public buildings and spaces

Many *public buildings and spaces* could benefit from local digital information delivery systems. Examples of such public buildings and spaces include:

- Large office buildings, where public could be directed to right officer or service
- Museums, where information on suggested tours or descriptions of individual art pieces can be given

- Airports, where travellers could get information about flights, gates, restaurants and shops and local communication could provide mobile access to web services

- Educational institutions, where students could get information about lectures etc.

Local information delivery systems in public buildings require local database and wireless network infrastructure, and mobile terminals, preferably with context awareness, i.e. awareness of location and the user.

2.2.2 Distributed health care support systems

Distributed health care support systems may be of crucial importance in the ageing industrial societies by improving the quality of life of the elderly and saving costs by prolonging the time they can live at their homes instead of in institutions and hospitals. These systems might include:

- Personal and infra-based measurement and monitoring sensors (e.g. heart rate, blood pressure, sugar level, movement, activity and location)

- Easy-to-use communication devices for contacting next of kin, friends, home-care personnel or medical professionals (e.g. wrist phones, easy to use visual communication methods and Internet access)

- Solutions for medical specialists for monitoring and helping their customers remotely

Development of automatic reasoning methods may facilitate machine intelligence capable of decision making in crisis situations, e.g. to call para-medics based on measured biosignals. It can be stated that distributed health care systems require the development of wireless sensors, smart signal processing methods, human-technology interaction methods, machine reasoning and, of course, local wireless communication methods. Using local wireless communication does not exclude the need to use wireless and wireline global communication networks.

2.2.3 The ubiquitous shopping centre

The ubiquitous shopping centre would be equipped with various digital services, for example with:

- Location-specific info systems to guide and to advertise

- Intelligent (RFID-based) tags conveying product id, product data (this may also be fetched from intranet based on product code) and the history and condition of that specific product

- Various means of electronic payment

Technical enablers needed include context aware and personalizable terminals, local wireless ad hoc network, inexpensive product tags with the possibility to access product data directly or through small and inexpensive sensors for monitoring the condition of the product (e.g. freshness of food), extensive and easily accessible databases, and intelligent methods for personalizing advertisements, special offers and other information directed at each consumer specifically. The emerging e-wallet/e-payment technologies will also be central to ubiquitous shopping centres and virtual (net-based) shopping.

3. ENABLING TECHNOLOGIES

3.1 General trends of ubiquitous electronics

The great expectations placed on Ubicom are based on the long-term trends of electronics known as Moore's law. Moore's law states that the packaging density of electronics doubles every 18 months. It can also be stated that the size of an electronic device with certain capabilities, such as number of MIPS or memory capacity, is halved every 18 months. This also implies that the price (or to be exact, manufacturing cost) of this device decreases 50% every 18 months. Moore's law has defied many pessimistic forecasts for more than a decade and there are no grounds to predict this to change. In certain cases, such as mass memory (hard disk), the capacity and price development has been even faster than predicted by Moore.

Besides the development predicted by Moore in integrated electronics, new technology trends, such as Micro Electro Mechanical Structures (MEMS) and Opto Electro Mechanical Structures (OEMS) and their combination MOEMS are paving the way for new Ubicom applications by providing technology to tiny and low-cost sensing and communication devices [PRESTO]. For example, pressure and force sensors widely usable in Ubicom applications can be manufactured on silicon together with their interface electronics. Compact RF components can also be manufactured with this technology. The typical advantages of the MEMS in sensor and RF component implementations compared to more traditional technologies are mechanical robustness, long-term stability, small size, small power consumption, and better integrability with other electronics.

An interesting research topic in low-cost electonics manufacturing is *printable electronics*. The idea is to use methods developed for printing (cheap, fast, high volume) in low-end electronics manufacturing. This "from roll-to-roll" manufacturing of electronics is being also studied with simple devices such as passive low-end RF-tags in Finland [PRINTO].

Still more ambitious and thus longer-term research activities include nanotechnology (a final attempt at artificial molecyles) and bioelectronics combining biological systems, such as biosensors – and finally humans – with electonic computing. The most futuristic researchers predict that *biocomputing* will replace digital computers in the foreseeable future.

All these technological trends, the future of which is clear in cases such as Moore's law, and more uncertain in cases such as nanotechnology and biocomputing, could have an influence on the proliferation of Ubicom application systems during the years to come.

3.2 Ubicom application systems

3.2.1 System architecture

A key element in Ubicom application systems is networking devices by wireless *local networks*, which here means networks that are restricted to operate inside a room, inside a hall or inside a corresponding space out-of-doors. A generic Ubicom network architecture is presented in Figure 4. The main parts of the architecture illustration are the *portable user devices* that are moving with humans, and the *local infrastructure* that consist of fitted items in some environment. Items moving separately from humans (e.g. in logistics applications) can also be considered as a part of the local infrastructure.

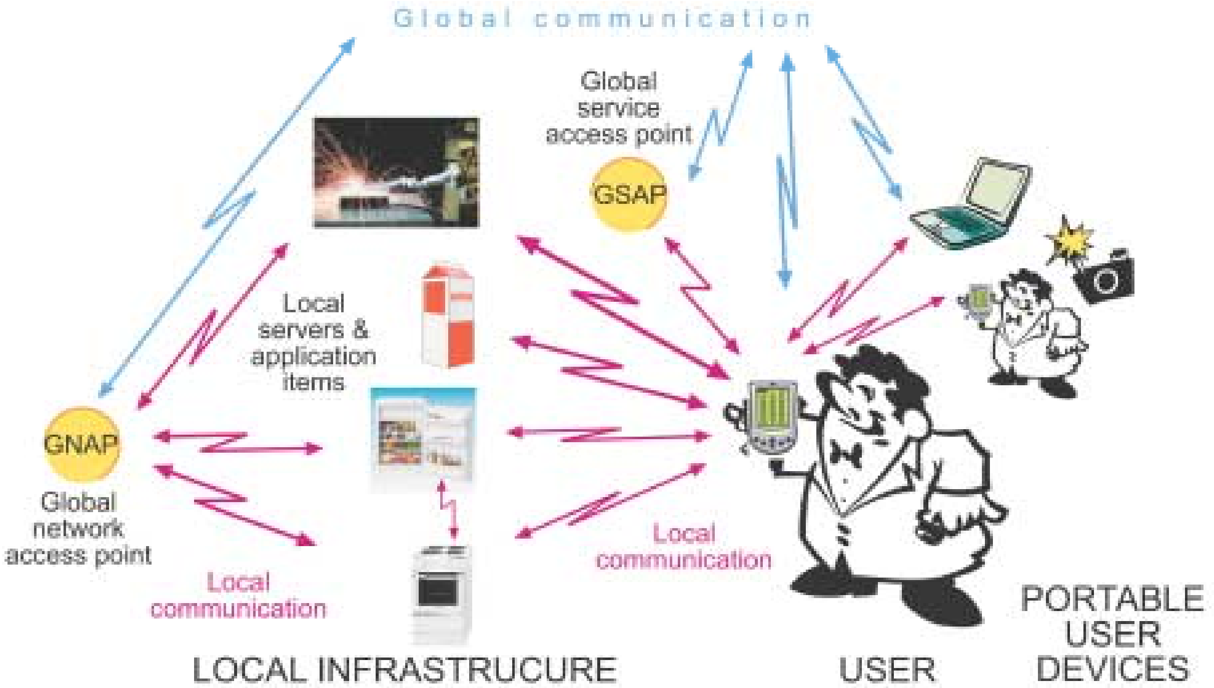

Figure 4. A generic Ubicom network architecture.

The local infrastructure incorporates:

- *Local application items* that provide some services to the user or to other application items

- *Local servers* that provide local communication capability for the local application items with user terminals, with other local application items, and with application items or user terminals in the global network through a *global network access point*

- A *global service access point* (hot spot), with which the user can access services in the global network by the local communication technology, which is usually faster and cheaper than using the global wireless communication technology (e.g. GPRS, UMTS) in his or her terminal

An application item is considered here as an entity (a physical device or a piece of information) that provides some *services* to users or other application items. Examples of application items are sensors, actuators, appliances, information delivery tags, positioning tags, etc.

Local networks can be connected to *global networks* that are topographically larger networks and usually connected to or a part of the global Internet. This enables interaction between local application items and *global application items*, as well as the delivery of Internet-based services by local Ubicom networks. Global extensions of the local networks can be based on wireless communication technologies such as GPRS and UMTS, or wireline communication technologies such as Ethernet and ADSL.

Three types of local servers are illustrated in Figure 4: stand-alone servers without direct communication capability with the global network, servers with communication capability with the global network, and servers that also have communication capability with each other, which is useful in M2M (machine to machine) systems and other application systems where the users have no role in the local communication. In this kind of system, industry automation systems as a typical example, the user actions are often carried out via the global network. The need for the global network is also obvious in maintenance and diagnosis of large local infrastructures with numerous servers and application items. Case examples are information delivery systems of big supermarkets, where the maintenance of the application system e.g. by a portable terminal would be troublesome.

3.2.2 General technical requirements

There are some general requirements concerning the technologies used in the local infrastructure, especially the local wireless communication technologies:

- *Low cost.* This means that the local infrastructure usually has to rely on PAN (Personal Area Network) or other technologies cheaper than WLAN (Wireless Local Area Network) technologies. This also means that all functionality inherent to WLAN technologies is not possible.

- *Small physical size.* This helps to make the fixed devices more invisible and portable devices smaller and lighter. This also helps the integration with the existing systems and devices.

- *Easy integration of the communication components to the application items.* Even if there will be various types of Ubicom application systems, the number of communication component types should be minimized for enabling their mass production. Thus, open, flexible and standardized application interfaces for the communication components are required. If some configuration of the application interface is needed, it should be able to be done by a PC or by some other commonly used tool.

- *Easy installation and maintenance.* Low cost communication components are worthless if professional people are needed for the installation or maintenance of the devices. Mass volume application systems are possible only by launching everyman's networking technologies. In practice this means self-configurability of the network, and plug-and-play type installation of the devices. Wireless communication facilitates portability or easy installation of the fixed devices. However, these advantages are obtained only if a mains-independent power supply such as a small battery or a solar cell can be used. Especially in the case of fixed intallations that typically are more difficult to recharge than portable devices, this calls for average power consumption far below one milliwatt. Typically the limited power supply also restricts the peak power consumption of the devices. In addition, communication technologies that require an individual radio licence are not possible, which calls for operation by unlicenced radio bands, also called ISM bands (Industrial Scientific Medical), or infrared technologies.

- *Ease of use of the portable devices.* From the communication point of view this means open and standardized wireless interfaces, interoperability of devices from independent vendors without any manual configuration of the terminal, and adaptivity of the terminal to the operational environment. The portable user terminals should preferably be multimode terminals that support several access technologies so that the same device can be used for both local and global communication. The user terminals should be context-aware, which brings with it adaptation to the user's personal habits and the operational environment. The application items should be able to adapt automatically to the user terminals, e.g. on their screen and memory size and processing capability. Above all, the portable devices should be cheap, light and easy to handle. The user interface should be simple and easy to use.

- *Tolerance of the coexistence of various networks.* Several types of wireless networks may exist at the same premises or geographical area. All of these networks should be able to coexist without severe interference behaviour in the radio domain. The possible wireless networks include cellular mobile radio networks (GSM/GPRS, UMTS) for global communication, WLAN network for local and global communication, and Bluetooth or some other short-range network for local communication. The problem arises especially between WLAN and WPAN networks since they both use the same unlicenced ISM frequency band. Some mechanisms have been developed to allow coexistence in the same frequency band. Frequency multiplexing, time division multiplexing and spatial diversity are some known access methods. Bluetooth and IEEE802.11b WLAN (Wi-Fi) use different access methods, namely frequency hopping spread spectrum (FHSS) and direct-sequence spread spectrum (DSSS) techniques respectively. In any case, the performance of Bluetooth and Wi-Fi networks suffer from the existence of each other. The standardization body of WPAN is developing coexistence mechanisms to tackle the problem [IEEE802.15 TG2].

- *Interworking with global networks.* Local networks are not always stand-alone systems but are connected to larger networks such as an industry automation network in a factory or the GPRS network, and thus also to the global Internet. The local network has to be able to seamlessly interwork with the global network during operations such as the maintenance of the local infrastructure via a global network access point, downloading data or software to the user terminal via a global service access point, and communication between application items far from each other via their global network access points. From the interworking point of view, protocols generally used in global networks such as TCP/IP, http and ftp should be preferred in local networks, even though they can increase the cost and power consumption of the local infrastructure.

- *Communications security.* If the local communication is based on standardized WPAN communication, a security thread arises when an unauthorized person with the same type of device enters the range of communication. The security of the local network can be also violated via the connection to the global network. In many application systems, special actions such as data encryption and user authentication have to be taken to prevent unauthorized persons from accessing the local application items. On the network level, security can be ensured by using IPSec protocol. The new Internet Protocol version IPv6 has IPSec included as a mandatory protocol. However, the use of security functions can increase the power consumption dramatically, which can be a problem for the local infrastructure.

- *Scalability of the performance parameters (bit rate, communication range, communication latencies) with respect to each other and to cost parameters (price, power consumption, physical size).* Different Ubicom application systems require different communication technologies. The flexibility in trading off between the performance parameters and cost parameters means more general purpose communication components, which leads to higher production volumes and lower prices. Scaling the performance and cost parameters of the communication components can be carried out during their manufacturing, installation or use.

- *Support for positioning of the users and the application items.* Positioning can be used as a means to support context-aware services. Outdoor positiong can be based on GPS technology. Indoor positioning methods are being researched and developed, but commercial technologies are not widely available yet.

3.3 Short-range wireless communication

In the following chapters, short-range wireless communication technologies are contemplated by dividing them into the following categories:

- Wireless local area networks (WLANs)

- Wireless personal area networks (WPANs): Bluetooth, high data rate WPANs, low power WPANs, proprietary WPANs

- Body area networks (BANs)

- RFID-technology

- Infrared-based communication technologies

3.3.1 WLANs

Wireless local area networks (WLAN) have originally been developed for wireless extensions of fixed local area networks such as Ethernet. Later, WLANs have also been used in other applications such as local wireless access to Internet (wireless hot spots) and even in wireless communication of automation systems.

WLAN standardization activities are carried out by the IEEE 802.11 and ETSI-BRAN standard groups. Commercially the most important standard is currently 802.11b, which specifies a communication technology based on 2.4 GHz unlicenced RF-band and DSSS (direct-sequence spread spectrum) modulation, with the maximum bit rate being 11 Mbit/s on the physical level. The newer 802.11a standard-based devices operate with 5 GHz unlicenced RF-band and OFDM (orthogonal frequency division multiplexing) modulation and offer a maximum bit rate 54 Mbit/s. The Wi-Fi alliance is a nonprofit international association formed in 1999 to certify the interoperability of wireless Local Area Network products based on the IEEE 802.11 specification. Currently the Wi-Fi alliance has 200 member companies from around the world. [IEEE802.11], [WiFi]

Even though there are some commercial products that are based on WLAN and that can be considered Ubicom application systems (see also chapter 1.3), WLAN technologies are generally too costly for real mass product application systems consistent with the Ubicom vision presented in Chapter 1.

3.3.2 Bluetooth

Bluetooth is a technology for small-form-factor, low-cost wireless radio communications between computers, personal digital assistants, cellular phones and other portable devices, and for their connectivity to Internet. Bluetooth technology is promoted by the Bluetooth Special Interest Group (SIG), which was formed at the beginning of 1998 by Ericsson, Nokia, IBM, Toshiba and Intel. Version 1.0 of the specification was published in July 1999 by Bluetooth SIG. The current specification version is v1.1. Together with Bluetooth SIG, the IEEE802.15 task group 1 (TG1) has established the Bluetooth standard IEEE Std 802.15.1™-2002, which was approved by the IEEE Standards Association (IEEE-SA) on April 2002. The standard is adapted from portions of the Bluetooth PHY and MAC level specifications. [Bluetooth], [IEEE802.15 TG1]

To promote the interoperability of devices from separate vendors, Bluetooth SIG maintains a product certification process in Bluetooth Qualification Reference Document (PRD), and a qualified product list (QPL), which currently includes about

800 qualified Bluetooth products. Bluetooth SIG has also defined a series of profiles representing common usage models. The profiles specify which protocol elements are mandatory in certain applications. Thus, simple devices such as a headset or a mouse can be implemented with a reduced protocol stack for minimizing the memory capacity and processing power. [Bluetooth]

The frequency band of Bluetooth is the unlicenced 2.45 GHz RF band. The modulation method is binary Gaussian-shaped frequency shift keying (FSK), which allows demodulation via a low-cost limiting FM discriminator. The nominal transmit power is 0 dBm, which provides a typical operating range of 10 meters. However, the specification allows transmit powers up to 20 dBm, if a closed loop received signal strength indication (RSSI) based power control is applied. [Haartsen 2000]

The multiple access scheme is based on frequency-hopping code-division multiple access (FH-CDMA). A set of 79 hop carriers has been defined with a 1 MHz spacing and with a nominal hop dwell time of 625 μs. Full-duplex communication is achieved by applying time-division duplexing (TDD). Both synchronous (SCO) and asynchronous (ACL) links have been defined, supporting the transmission of both voice and bursty data respectively. The maximum user data rate that can be obtained over the asynchronous link in point-to-point communication is 723.2 kbit/s, also allowing a return link of 57.6 kbit/s. The synchronous link supports full-duplex communication with a user data rate of 64 kbit/s in both directions. Synchronous and asynchronous links can be mixed so that both voice and data can be transmitted simultaneusly in the same piconet. A Bluetooth piconet consists of one master and up to seven slaves. The piconet connection is established by the master, which also defines the hopping sequence and its phase in which the slaves synchronize themselves during the connection establishment procedure. Several operating modes have been defined for enabling the management of the current consumption. [Haartsen 2000]

Bluetooth Special Interest Group (SIG) is preparing a new version 2.0, which is expected to support gross rates of 4, 8 and 12 Mbps and operate at the same 10 m distance. Bluetooth 2.0 will offer new communication modes by using a non-hopping narrow-band channel and distributed media-access control protocols. It will also have faster response times and built-in quality-of-service, and offer broadcast/multicast support. Bluetooth 2.0 is designed to alleviate the problems of the present Bluetooth's master/slave-based Piconet, which drops the Piconet when a master leaves. Bluetooth 2.0 dispenses with masters and makes any device on a Piconet a supervisor, so devices on the Piconet can continue to communicate. Bluetooth 2.0 is expected to be released in 2004. Bluetooth SIG is also working on a medium rate Bluetooth version 1.2, offering communication rates of 2 to 3 Mbps. [Yoshida 2002a]

3.3.3 High data rate WPANs

High-speed Ubicom applications such as wireless multimedia delivery and digital imaging require higher and more guaranteed data rates than Bluetooth can offer. On the other hand, WLAN technologies are too costly for many commercial Ubicom application systems. To fill this gap, IEEE802.15 task group 3 (TG3) has worked since 2000 with the aim of established PHY and MAC level standard for high-rate (20 Mbit/s or greater) wireless personal area networks. Besides the high data rate, the target of the IEEE802.15 TG3 is a low-power and low-cost technology addressing the needs of portable consumer devices. A draft version of the standard has been completed and submitted to the standard working group for ballots and final resolution. The final standard is expected to be available for ratification by the IEEE in the middle of 2003. [IEEE802.15 TG3], [WiMedia]

To support the work of IEEE802.15 TG3 and promote commercial application systems based on the standard, the WiMedia alliance has been launched in September 2002. The WiMedia alliance is a non-profit open industry association formed to promote personal area range wireless connectivity and interoperability among multimedia devices in a networked environment. The promoter members of the WiMedia alliance are the following application, system and technology producers: Appairent Technologies, Eastman Kodak Company, Hewlett-Packard Company, Motorola, Philips, Samsung, Sharp, STMicroelectronics, Time Domain Corporation and XtremeSpectrum. In addition to these, there are some contributor members. WiMedia alliance forecasts the first products to be commercially available by the end of 2003. [WiMedia]

The current IEEE802.15.3 standard version supports communication on the same unlicenced frequency band as the Bluetooth (2.4 GHz) with five selectable data rates 11, 22, 33, 44 and 55 Mbit/s. The transmit power is approximately 8 dBm, and the communication range 5 - 55 m. The modulation formats are BPSK, QPSK and QAM. Power management, security, coexistence with Bluetooth and WLAN, and Quality of Service (QoS) capabilities have been incorporated to support high-quality multimedia transport, portable devices and ad hoc networking. The products will be more expensive than Bluetooth products but less expensive than WLAN products. Concerning power consumption, the IEEE802.15.3 based products will be between the Bluetooth and WLAN products. [Gandolfo 2002], [WiMedia]

Recently, a new IEEE802.15 SG3a study group has been launched. The aim of this study group is to provide a higher speed enhancement to the IEEE802.15.3 standard, capable of reaching speeds as high as 480 Mbit/s. The future standard may adopt a new radio technology called UWB (ultra wideband). UWB is a technology based on the transmission of very short radio impulses, which spreads the spectrum of the RF signal and thus lowers its spectral density to a level that enables coexistence with other radio devices. The first commercial products based on UWB have already been launched. General benefits of the UWB compared to more conventional radio technologies are better robustness to the multipath propagation, lower total transmission power, position location capability, and flexibility in trading-off between the data rate and the distance. General disadvantages are the need for large-bandwith antennas and a precise clock in the implementations, strict governmental application specific restrictions, and coexistence problems with GPS systems. [Hillson 2002], [WiMedia], [Yoshida 2002b]

3.3.4 Low power WPANs

With many small devices such as simple sensors and actuators, continuous communication with high data rate is not usually necessary. Occasional wireless communication through interconnections with the maximum data rate of a few, a few tens or a few hundreds of kilobits per second, and the maximum communication range of a few tens of meters, can facilitate the portability or installation of this kind of devices. Compared to maximizing the data rate, it is usually more important to minimize costs, physical size and power consumption. Many applications belong to the cost critical consumer market. In many places, the electronics should be non-visible. Power supply through the mains, or recharging or replacing the batteries weekly or even monthly is impossible. Instead, the power supply has to be based on energy scavenging [Rabaey 2000] or a small battery lasting several months or years. This often calls for average power consumption far below one milliwatt per device.

Since the year 2000, IEEE802.15 task group 4 (TG4) has worked to standardize a physical and a MAC-layer applicable in very low-power wireless application systems, which should be able to operate at least several months on a battery without replacement [IEEE802.15 TG4]. In parallel with IEEE802.15 TG4, the ZigBee alliance has been founded, now incorporating about twenty industrial companies and aimed at establishing open industry specifications for unlicensed, untethered peripheral, control and entertainment devices requiring the lowest cost and lowest power consumption communications between compliant devices anywhere in and around the home. The target for the power consumption is 0.5 to 2 year's operation with two AA-size batteries. According to the alliance, the first commercial products will appear on the market in 2003. [ZigBee]

As an alternative to ZigBee, Nokia has proposed a Bluetooth evolution to IEEE802.15 TG4. Nokia's proposal takes Bluetooth as the basis but suggests relaxation of some parameters such as data rate, transmitted power, receiver sensitivity and frequency hopping to enable very low-power implementation. One of the main ideas of the proposal is to use standard Bluetooth RF parts as far as possible, which would enable better integrability to the mobile phone environment. [IEEE802.15 TG4b], [Honkanen 2002]

There are also some ongoing or finished research projects concerning the subject, e.g. the following:

- Picoradio project at Berkeley Wireless Research Center [PicoRadio]

- PEN at AT&T Laboratories [Jones 2000]

- Smart Dust at the University of California (UCLA) [Kahn 1999]

- SoapBox at VTT Electronics, Finland [VTT SoapBox]

The Picoradio research project at the University of California (UCLA) Berkeley Wireless Research Center aims at the development of a radio-based ultra low-power system, in which piconodes communicate with each other. The final target is a piconode, implemented by one chip with a maximum power consumption of 100 μW. PEN (The Prototype Embedded Network) is a finished research project of AT&T Laboratories, in which a low-power communication module was developed for networking small appliances. The target of the project was also to minimize the physical size and price. The Smart Dust research project at the Department of Electrical Engineering and Computer Sciences, University of California, Berkeley, aims at constructing a network of nodes of a few cubic millimeters. The nodes should incorporate communication, computing and power supply. The communication is based on optical links. The small size of the nodes calls for power consumption to be minimized down to a few microwatts. SoapBox, developed by VTT Electronics, Oulu, Finland, is a configurable platform offering the ultra low-power implementation of wirelessly interconnected low data rate devices. Potential applications of SoapBox include wireless sensors and actuators, location-based information tags, wireless user interfaces, enhancing the user interfaces by gesture recognition and context awareness, and wireless applications in industrial, office and home environments. VTT Electronics also has research activities aimed at ultra-low power implementation of devices with infrared communication capability.

3.3.5 Proprietary WPANs

Since generic WPAN technologies such as Bluetooth may lack some properties important for some specific applications, some companies have developed their own non-standard WPAN technologies. These are usually based on commercial RF circuits or modules [Hänninen 2002] and some controller handling the modulation/demodulation and protocol operations. Typical applications are alarm systems, in which single messages are sent infrequently. Usually the communication circuits and protocols are not very generic and designed to aim only at the specific target application system.

Many of the proprietary WPAN technologies are targeted for devices with very restricted power supply, which makes the use of standardized technologies such as Bluetooth or WLAN impossible. An example of a low-power, short-range communication module is i-Bean, which has been developed by Millennial Net Inc. in Massachusetts, USA. The target applications are wireless devices with very low-power consumption. According to the manufacturer, the power consumption depends on the communication duty cycle, the maximum current consumption being about 1 mA from a 3-volt battery [Millennial Net].

Some microcontroller vendors such as Atmel and Microchip, as well as some RF IC vendors such as Chipcon, have foreseen the expanding need for tiny low-power devices with short-range communication by launching ICs with a small microcontroller and RF circuits integrated in the same chip [Atmel], [Microchip], [Chipcon].

The basic advantage of the proprietary WPANs compared to the standardized WPANs is the possibility to optimize the most critical cost or performance parameters from the point of view of the application systems they are used in. Typical disadvantages are a lack of open communication interfaces and mass production potentiality.

3.3.6 Body area networks (BANs)

Body area networks (BANs) are considered here as communication networks operating in the immediate vicinity of the user body so that the maximum communication range is about two meters. Body area networks can have longer-range extensions based e.g. on some WPAN technology. Examples of communication scenarios are interconnecting portable devices carried by individual persons (IntraBAN), communication between the portable devices of people close to each other (InterBAN), and communication between portable devices and the access points of larger networks (Network access). Examples of application areas are wearable computing, which means electronics that is adapted to the users natural operations in different situations and is thus easier to use and more ergonomic, and smart clothing, which means embedding electronics together with sensors and actuators into clothing.

Several physical layer technologies have been proposed for BAN implementations, including near-field links such as those based on magnetic or capacitive coupling, far-field (RF) links, infrared links, wired links such as integrated wires into garments or conducting fabrics, and heterogenous links consisting of several different types of technologies. [TUT Smart clothing], [Van Dam 2002], [Zimmerman 1996].

Different propagation properties bring along some advantages to near-field links compared to far-field links in very short-range communication: an RF transmitter propagates energy with a signal strength that decreases with distance squared, whereas the signal strength of a near-field transmitter decreases with distance cubed. This makes the near-field link less susceptible to eavesdropping and to disturbances from adjacent links. Another point is that, compared to an RF link, a near field link can operate at baseband frequency or at lower carrier frequency , which makes the implementation cheaper and less power consuming. Examples of commercial devices applying near-field magnetic coupling are the heart rate monitors of Polar Electro. An example of a commercial component for BAN implementations based on near-field magnetic coupling is the Aura LibertyLink transceiver IC of Aura Communications Inc. According to the manufacturer, the transceiver can provide a full-duplex wireless link with a data rate of 64 kbits/s and a communication range of 1.25 m [Aura].

3.3.7 RFID-technologies

RFID (Radio Frequency Identification) is a technology for implementing very low-power and low-cost modules called RFID transponders, which can communicate with a module called an RFID interrogator or reader. The communication range varies from below 1 cm (close-coupled transponders) up to several meters or even more (long-range transponders). The communication typically operates on some unlicenced RF-band. Examples of RF-bands used are 125 kHz, 13.56 MHz, 869/915 MHz (Europe / USA & Australia) and 2,45 GHz. The transponder can be passive or active. A passive transponder does not have any internal or external power supply, but draws its energy from the electrical or magnetic field of the interrogator during the data transfer operation. An active transponder has a separate power supply that is typically a small battery integrated in the transponder module. [Finkenzeller 1999]

Compared to WPAN technologies, RFID technologies offer lower price and lower power consumption, even the possibility to operate without a separate power supply, which is possible by sacrificing the longer communication range of WPANs. Depending on the required communication range, the size of the antenna in the transponder can be a problem, especially with the passive RFID technology.

RFID appeared first in tracking and access applications during the 1980s to replace barcode labels, particularly in manufacturing and other hostile environments for printed barcodes. During the years, RFID has established itself in a wide range of applications, e.g. livestock identification and automated vehicle identification. Standardization activities are carried out by ISO and IEC. [AIM]

Currently, there are several manufacturers providing RFID ICs, modules and systems based on them. Examples of IC-vendors involved are Atmel, Microchip, Philips and Texas Instruments. The global market for RFID systems was nearly 900 million USD in 2000, with the transponder ICs covering about 76 million USD of the total market. The annual growth of the market is estimated to be 24 % during the next five years.[Grebs 2001]

Originally the RFID transponders were aimed at the electrical labelling of physical objects. In these kinds of application systems, the main parts of the transponder are an antenna and a semiconductor chip that incorporates communication circuits and a small read only memory block. Currently, more versatile IC chips are also available, incorporating e.g. a microprocessor with programming capability and some external interface for memory extension or for connecting the transponder to some electrical application item, thus enabling the implementation of more versatile application systems.

Most of the current commercial RFID products are based on near-field magnetic coupling. Longer operating distances call for the use of higher radio frequencies with backscattering. One project dealing with this is Palomar in the EU IST program. Members of the project consortiom are Idesco Oy, VTT and Atmel (France and Germany). The aim of the project is to develop a passive long-distance RFID technology operating on ultra-high frequency (UHF) bands. A prototype transponder operating on the 868 MHz band (allowed in most countries in Europe) exists. It achieves a 4 m operating distance with 0,5 W RF power from the interrogator. Other bands under consideration are 915 MHz (USA and Australia) and 2,45 GHz (golbal). [Annala 2001]

3.3.8 Infrared-based communication technologies

Infrared communication is commonly used in devices with local communication capability such as remote controllers, mobile phones and other portable devices. From the technical point of view, infrared offers the following generic advantages and disadvantages compared to RF in close range (a few meters maximum) communication:

- The spatial resolution inherent to the infrared technology is an advantage e.g. in limiting the disturbances from the adjacent cells. When a user wants to communicate with some visible application item in the local infrastructure by a hand-held terminal, spatial resolution of the infrared beam enables him or her to select the target application item easily by pointing the terminal towards the application item. A drawback of spatial resolution is the line-of-sight (LOS) requirement between the communicating devices that is often mandatory and difficult to fulfil. Other disadvantages are sensitivity to contamination in unclean or moist environments, and sensitivity to weather conditions.

- High-frequency electronics, precise frequency sources (e.g. chrystals, ceramic resonators, SAW-resonators) and antennas can be avoided, which facilitates better optimization of power consumption, size and costs. However, some optical components such as infrared LEDs and optomechanics can increase the costs and size.

- Because the signal bands are not limited by regulations, more versatile modulation schemes are available. On the other hand, there are eye-safety requirements to which infrared devices have to conform.

The most prominent standard organization for infrared-based communication technologies is the Infrared Data Association, which maintains IrDA standards. The Infrared Data Association was founded in 1993 for promoting interoperable, low cost infrared data interconnection standards that support a walk-up, point-to-point user model. The Infrared Data Association has defined two sets of standards, IrDA Data and IrDA Control. IrDA Data is recommended for high-speed short-range, line-of-sight, point-to-point cordless data transfer. IrDA Data supports data transmission up to 16 Mbit/s with a minimum communication range up to at least 1 m (typically 2 m can be reached). IrDA Control allows cordless peripherals such as keyboards, mice, game pads, joysticks and pointing devices to interact with many types of intelligent host devices such as PC's, home appliances, game machines and set top boxes. IrDA Control supports data transmission at 75 kbit/s with a minimum communication range of 5 m. Components for both IrDA Data and IrDA Control are available from numerous manufacturers listed by the Infrared Data Association. [IrDA]

3.4 Ad hoc networking

Ad hoc networking is an emerging new technology that can be used to build communication islands in geographically limited areas. A mobile ad hoc network can be formed by a group of wireless hosts with no pre-existing infrastructure required. There are two types of ad hoc networks, singlehop and multihop. In singlehop ad hoc networks there is a direct transmission link between the transmitting and the receiving mobile host. In multihop ad hoc networks each mobile host is capable of acting as a wireless router or a bridge between the transmitting host and the receiving mobile host. If the nodes of an ad hoc network can also establish a connection to the core network through an access point, the concept is called a hybrid network. An example of a hybrid network is shown in Figure 5.

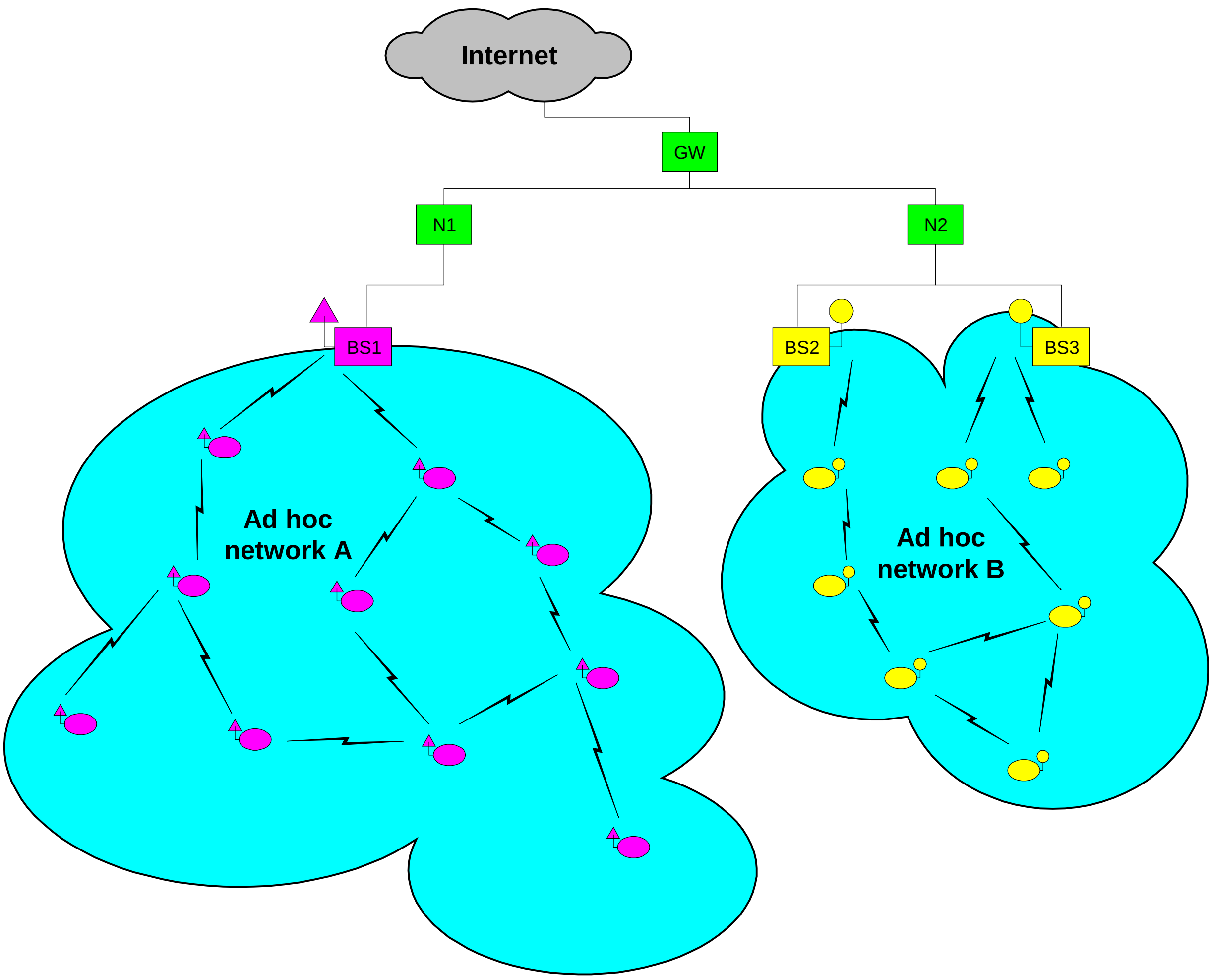

Figure 5. Example of a hybrid network consisting of two multihop ad hoc network islands.

Since the nodes in a multihop ad hoc network may move often, it is necessary to use an efficient routing protocol. The routing protocols of ad hoc networks are divided into two categories: table-driven or proactive, and source-initiated or reactive. In the recent research activities the focus has been on reactive ad hoc routing protocols such as Ad Hoc On-Demand Distance Vector (AODV) and Dynamic Source Routing (DSR), which establish routes on a demand basis. Routing has many optimization goals, e.g.

throughput, power consumption, and connectivity. Since terminals have limited battery resources, the power-aware methods in routing are also becoming more and more important. This means not only minimizing overall power consumption, but also fairness in power consumption between every mobile host. The standization activities of ad hoc routing protocols are carried out in IETF's mobile ad hoc networking (MANET) working group [Perkins 2001], [Royer 1999], [Toh 2001], [Manet].

Ad hoc networks can be used in personal area networking (PAN), home area networking, military environments and search-and-rescue operations. The research and implementation of ad hoc networking has been mainly based around the IEEE 802.11b and Bluetooth standards. For many years the U.S. DARPA has been sponsoring the research of ad hoc networking for military purposes.

3.5 Network interoperability

The term interoperability means the ability of systems to provide services to and accept services from other systems, and to use the services so exchanged to enable them to operate effectively together. It also means the capability to provide useful and cost effective interchange of data among different signal formats, transmission media, applications and performance levels. By interoperability, we also mean that the devices from the different vendors based on the same communication standard can operate together [ANSI].

In our vision, local networks are not always stand-alone networks but they have to be able to communicate with other networks as well. At least the connection to the Internet core network has to be established to enable effective application software and data loading.

Interoperability of the different networks can be divided into three levels: application, Internet and datalink level. In most cases, the Internet layer hides away most of the data-link level details for packet traffic. Third generation (3G) wireless infrastructures have already adopted Internet Protocol (IP) as the core network protocol in their subsystems. Bluetooth was also designed to be able to work together with networks using IP-based TCP, UDP and WAP. The Logical Link Control and Adaptation protocol (L2CAP) forms an interface between data transport protocols and the Bluetooth protocol [Haartsen 2000].

The next version of the Internet Protocol (IP), IPv6, extends the functionality of the current IPv4, mainly considering expanded addressing capabilities, header format simplication, improved support for extensions and options, and an elaborated interface for quality of service (QoS) provisioning. The IPv6 address is composed of 128 bits. This implies that even the smallest devices in the world could have their own IPv6 addresses. Thus, each device in the local infrastructure could be individually addressed [Huitema 1998].

An example of actions taken for interoperability between devices from independent vendors is the Wi-Fi alliance, which was founded in 1999 to certify the interoperability of WLAN products based on the IEEE802.11b and 802.11a standards. The Wi-Fi certificate guarantees that WLAN products can interoperate with other Wi-Fi certified WLAN products from other vendors. Currently the alliance has 193 member companies and 509 products have received Wi-Fi certificates. Wi-Fi certified products include access points, gateways, PC, PCI and PCMCIA cards, USB devices, wireless print servers and other application specific devices. [WiFi]

3.6 User interfaces

The paradigms related to the user interfaces (UIs) and Ubicom can be divided into the following types:

- Natural and disappearing UIs
- UIs relying on displays and input devices in the local infrastructure
- UIs using mobile personal devices.

It can be stated that the two first paradigms are linked with the *distributed ubicomputing* model of Table 1 and the third one with the *mobile terminal centered* model. These paradigms are not clearly distinctive and, for example, natural UIs may be used together with mobile personal devices.

Natural and disappearing UIs rely on using natural ways of communicating with the environment, specifically on using touching, pointing, voice commands and gestures for interaction. In this paradigm the aim is also to minimize interaction in the spirit of *calm technology*. A lot of current academic and industrial research is devoted to this paradigm. In particular, advances have been made in voice command and speech recognition. In controlled conditions and environments, limited vocabulary speech input achieves over 95% correctness. Even the semi-free vocabulary speech recognition is viable in some applications, e.g. telephone-based services. Gaze controlled applications have made some advances in certain military applications, such as helicopter piloting. Gesture-based UIs have been demonstrated in research institutions (e.g. VTT

Electronics Soapbox, which can be used to guide slide show presentation or a maze game), in gaming applications and in wearable computing applications.

A major American and Japanese trend in research activities has been to use existing resources such as office PCs, digi-TV, info kiosks and wall displays for user interfaces. Here the idea is that people do not carry any display or input capable device with them, but instead they seize nearby resources for temporary use.

Using the UI capabilities of a mobile personal device in Ubicom application systems can be seen as a natural part of the mobile terminal-centered Ubicom model. In this paradigm, the mobile personal device is not only used for communication and other "long-range" mobile services, but also for local - or ubi - services. For example, the device can be used as a universal remote controller for home appliances or as an interface towards a vending machine. Some kind of mechanism for getting in contact and eventually getting hold of the resource to be controlled (washing machine, TV...) is needed. This can be done, e.g. by choosing the URL of the resource, but a more natural way would be to use proximity or active pointing for this purpose.

The UI capabilities of mobile devices have been very limited, partly due to their specific use (cf. mobile phones), but the development is rapid. Table 5 summarizes the capabilities of current mobile devices and makes a prognosis for their development.

Table 5. UI capabilities of mobile devices.

Device type	**UI capabilities**	**Trends**
Mobile phone	Small text & graphical display Numerical keys Vibration, sound, melodies Spoken command recognition	Color display, video display, larger display Camera/video input Proximity, noise level sensing
Communicator /mobile phone	Medium-resolution colour display QWERTY keyboard Loudspeaker Microphone	Camera Voice recognition?
Personal Digital Assistant (PDA)	Moderate size color display Pen & touch screen, hand writing Beeps, recorded voice output	QWERTY option Camera Voice recognition?
Laptop	High-resolution color display QWERTY keyboard Loudspeaker Microphone	More of the same Voice recognition?

3.7 System software

Two characteristic features of the Ubicom application systems are the integration of computing into physical objects and spaces, and spontaneous interoperation [Kindberg 2002]. These features set the Ubicom system software - or *middleware* - requirements, which are in some respects very different from those for typical desktop computing [Kindberg 2002]. The system software for Ubicom environments must deliver functionality in our everyday world. It must be able to operate with limited resources and with failure-prone hardware. Varying physical conditions and the inherent mobility of Ubicom devices sets extra constraints to the system software.

Major challenges facing the Ubicom system software are [Kindberg 2002]:

- *Discovery*. How does a device find other devices and services in the Ubicom environment?

- *Adaptation*. When being near other heterogeneous devices, how can a Ubicom device display, manipulate data or UIs of these other devices?

- *Integration*. How does the device's software connect with the physical environment (e.g. sensing)?

- *Programming framework.* How do we write a "Hello world" program for a Ubicom device? Are the issues addressed on the application, middleware, OS, or language level?

- *Robustness*. How are the device and user shielded in, e.g. out of network situations?

- *Security*. What is the device allowed to do? How are authentication and privacy handled?

Yau and colleagues [Yau 2002] view Ubicom from the middleware perspective. Their analysis is very similar to Kindberg's: A ubiquitous computing environment exhibits two characteristics: context sensitivity and ad hoc communicatons. Context sensitivity and ad hoc communication cuts across system and application layers. A middleware-oriented approach can effectively address such issues by providing development and runtime support and by forming a balance between awareness and transparency to the application software [Bernstein 1996].

A middleware solution called Reconfigurable Context Sensitive Middleware developed specifically for pervasive computing environments is suggested by Yau et al. [Yau 2002]. Other initiatives include CORBA, COM, TAO and ACE ORB.

3.8 Current research activities in Tekes projects

Because of the comprehensiveness of the Ubicom concept, many of the current ongoing research programs of Tekes include areas dealing with Ubicom enabling technologies. Most of them belong to the information and communications technology program cluster. Examples of ongoing research programs are [Tekes]:

- ELMO: Miniaturizing electronics (2002 - 2005)
- NETS: Networks of the future (2001 - 2005)
- PRESTO: Future Products - Added Value with Microtechnologies (1999-2002)
- USIX: User-oriented information technology (1999 - 2002)

The development trends envisaged in the ELMO program description are miniaturizing, integration and cost-efficiency, which are also key design drives of Ubicom application systems. The areas of emphasis in the NETS program are architectures and implementation technologies of future wireless systems and networks, technologies of broadband packet switched networks, and new service concepts and applications utilizing the networks, all of which are essential in Ubicom application systems. PRESTO is a more manufacturing-oriented program and concentrates on MEMS technologies and the realization of miniature components and products. The USIX program is aimed at developing user-friendly information technology, the need for which is obvious in future Ubicom application systems. If people have to use hundreds of devices in daily life, the use of the devices should be as intuitive as possible without reading any manuals or operating instructions.

In addition to these technology-oriented programs, most of the other programs provide opportunities to apply Ubicom technologies in environments the programs are devoted to.

4. BUSINESS MODELS

The purpose of this chapter is to present some aspects that can help in the planning and evaluation of business models for Ubicom technologies and application systems.

4.1 Companies and their roles

There are many possible roles for companies in the Ubicom business. All of them are not relevant in every case. This can be because they are not at all needed, or some participants have more than one role. This is considered more in chapter 4.3. It should also be noted that there are cases in which some participants are individual people instead of companies.

- *Application system hosts* are owners of individual application system installations and are thus responsible for acquiring and maintaining them. For instance, in the ubiquitous shopping centre application scenario described in chapter 2.2.3, the application system host is the owner of the shopping centre.

- The role of the *application system users* is to use services produced by the application system installations. In the ubiquitous shopping centre application scenario, the main application system users are the customers in the shopping centre. In the case of industry or home automation systems, the main users are typically application system hosts at the same time.

- *Application system producers* provide other participants with complete systems consisting of a set of devices communicating with each other. Systems can be destined for some specific application such as controlling an industrial manufacturing process, or systems can be more general purpose and configurable application platforms, which can be used in different specific applications more flexibly.

- *Device producers* provide other participants with devices such as mobile terminals, other portable user devices, and appliances in the local infrastructure.

- *Component and module producers* provide other participants involved (mainly system and device producers) with building blocks that can be hardware or intellectual property (IPR), such as software modules or design data.

- *Network operators* provide other participants with global communication services, which enable the portable user devices and the application items in the local infrastructure to communicate with remote users and application items.

- *Content providers* provide other participants with contents (information, entertainment etc.) dedicated to some application system or even for some individual application system installation. In many cases, the content producer is the same as the application system producer, and the separation of these two participants is somehow obscure. However, there are applications in which these roles can be separated more clearly. An example of this is the ubiquitous shopping centre scenario described in chapter 2.2.3. In this scenario, some company (an application system producer in this context) can provide the shopping centre with the intelligent tags and user terminals, while the host of the premises or the producers of the commodities for sale can be content producers that produce the information delivered by the tags.

4.2 Potential added value of Ubicom

The basic issue in the Ubicom business is the added value gained by the application systems or used technologies, which each participant has to consider before making investments in a new application system product, in a new application system installation, or in the development of a new technology. However, it should be noted that the added value envisaged by some participant depends on the role of the participant. Application system hosts have usually to consider the added value gained by the application system users. Meanwhile, the added value for application system producers can be cost savings or better quality of current products in comparsion with using current implementation technologies, or totally new products, all of which can improve the market position of the participant involved. Examples of the envisaged added value from different viewpoints are:

- From the viewpoint of an application system user: some positive experience (e.g. private persons in the case of home automation or in the case of public information delivery systems)

- From the viewpoint of an application system host being a user at the same time: cost savings in the production line (e.g. industrial companies in the case of industry automation)

- From the viewpoint of an application system host not being a user: cost savings in the delivery of services (e.g. health care authorities in the case of distributed health care support systems)

- From the viewpoint of an application system producer: better quality of the existing products or totally new products

In the next chapters, the viewpoint of the business models is that of the application system host, which is the participant that is responsible for individual application system installations and thus plays a key role in the Ubicom business. In this context, the viewpoint of the application system host is reasonable, because the application system hosts are customers of other participants, so the other participants also have to understand the business of the applicaton system hosts. As mentioned before, the business models from the viewpoint of the other participants can be different.

4.3 Design aspects of business models

A generic business model from the viewpoint of the application system host is illustrated in Figure 6. In many cases, a participant can have more than one role, which makes the business model simpler. Examples of these kinds of application systems are local Internet access hot spots, in which the network operator is the application system host. Other examples are industry automation, home automation or personal electronics systems, in which the application system host is the same as the user. In many cases, not all participants are involved, which usually makes the business model simpler. Examples of these kinds of application systems are those without global extensions, in which the network operator is not involved.

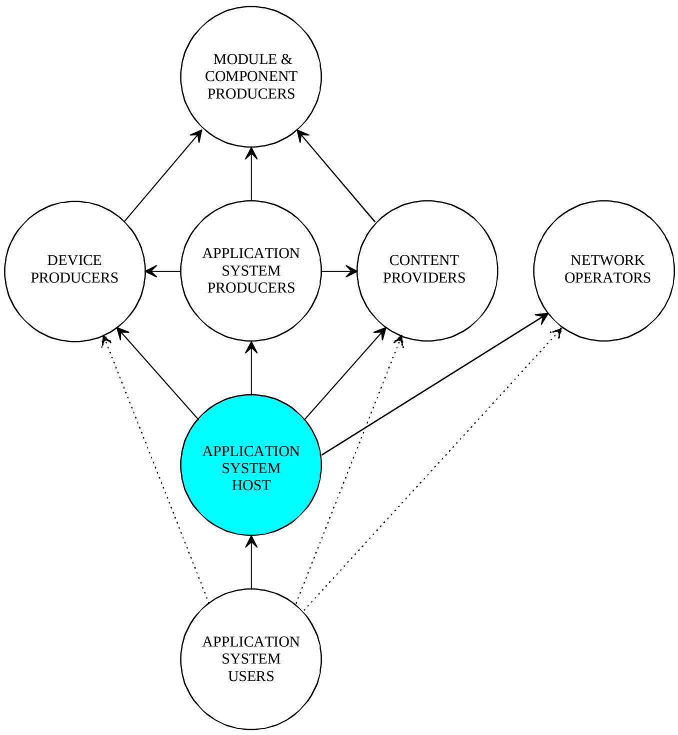

Figure 6. A generic business model from the viewpoint of the application system host
- Continuous arrows: typical flow of money
- Broken arrows: possible flow of money

Before making any investment in a new application system installation, the application system host has to consider the following questions:

- Which or who will be the application system users and what is the added value the users gain?

- Does the application system host have to be able to charge the users? If yes, how (e.g. per month / per service)?

- What are the expenses of the application system host?

- Can the application system host reduce its expenses by directly saddling the application system users with some costs charged by other participants?

- Can the application system host cover all of its expenses?

The expenses of the application system host can come from:

- Payments to the application system producer and to device producers for the system components and support service

- Payments to the content providers for their services

- Payments to the network operators for their services

- Possible payments to the other technology providers

Usually the application system user is the participant that gains the primary added value from the application system installation and is thus liable for paying for the produced services. However, there are many cases in which this is not needed and the business model is thus simpler. Typical examples are industry automation and home automation cases, in which the application system user is the same as the application system host. Other examples are cases in which the application system host is a governmental office or a public utility association that can cover the expenses in some other way.

The application system host can try to reduce its expenses by directly saddling the application system users with some costs charged by other participants. For instance, the services can be delivered to mobile phones or other user terminals owned by the users instead of to terminals owned by the host. This reduces both the host's investments in the application system and payments to the network operator if needed.

5. RECOMMENDATIONS FOR ACTIONS

5.1 General recommendations

Until now, the commercial breakthrough of Ubicom is yet to be seen. This is due to various reasons, including:

- Technical complexity and fragility of proposed Ubicom application systems with ad hoc communication, interoperability of devices from several vendors, sensoring and reasoning

- Too high costs of components, installation and management

- Ethical or other psycho-social obstacles that relate to the properties or alleged properties of Ubicom application systems, such as threats to personal privacy

- Purely "proof of concept" or the non-interesting nature of the first attempted Ubicom application systems (PDA-based museum guides, smart coffee cups), i.e. the application systems had no commercial potential or paying-customer-interest

- Too complicated or non-healthy business chains, e.g. the party making the investment is not the one getting the added value

This situation has postponed the advent of Ubicom application systems. Yet, the Ubicom business may be among the fastest growing ones in the ICT field during next decade. For the Finnish economy, it is important to find and analyze potential business opportunities in order to be in a good position to benefit from the growth of this sector.

Towards this aim, work with *Pioneering Applications* that have a simple business model and rely on existing technologies should be identified and implemented. One way of categorizing different business models is given in Table 6. The simplest case is the one called "department case". Since it is limited in scope and aim and it is executed within one organization, it is the easiest to accomplish. Experience of these applications may then lead to success in "company cases" and later in more widespread commercial applications, "customer cases". The viewpoint here is that of an application system host as defined in chapter 4.

Table 6. Business model categories.

Department case	**Company case**	**Customer case**
Clear and defined purpose Inside a department The decision maker, the payer and the benificiary is the same party	Aim is to improve a process in general Inside a company or an organization The decision maker, the payer and the benificiary is the same party	Large volume "Your everyday life" applications Many parties needed Breakthrough requires cooperation and customer acceptance The decision maker, the payer and the user/beneficiary are different parties

It should be noted that the decision maker and the user are closest (perhaps the same persons) in the "department case" but are much further away from each other in the customer case. This also implies that the decsion maker's knowledge of user needs is clearer in the "department case" and more vague in the customer case.

Concurrently with the first pioneering applications, significant R&D effort should be put into the key technologies that are discussed in detail in section 5.2. Figure 7 depicts this approach.

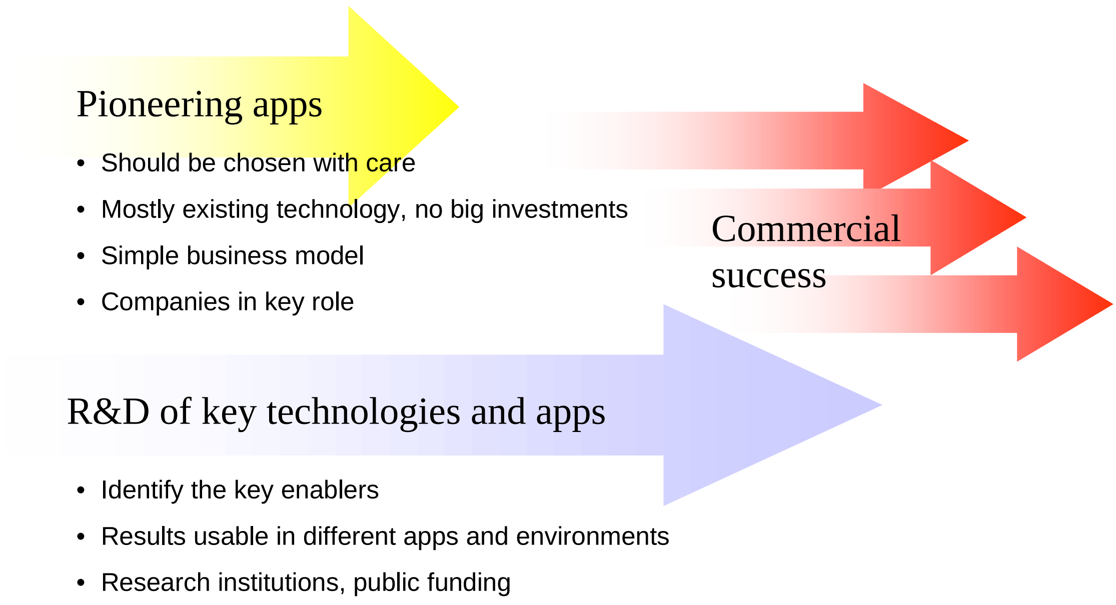

Figure 7. A possible approach to Ubicom R&D in Finland.

5.2 Recommendations for research activities

To break down the obstacles to the commercial breakthrough of Ubicom listed in the previous chapters, interdisciplinary research activities should be promoted. Human sciences, usability studies, business and economic research as well as legislation and ethical issues should be combined with the technology research forming the basic enabler of the Ubicom application systems. The approach in the research activities should be from both the technology and the application viewpoint, preferably including both of these viewpoints in the same projects. Moreover, the project participants should incorporate several roles described in chapter 4.1.

From the technology viewpoint, the research activities should produce and evaluate e.g. new enabling technologies, knowledge for applying existing technologies, and technology roadmaps. From the application viewpoint, the research should produce and evaluate e.g. application scenarios, usability knowledge and business models. The gap between the research and development activities may be narrowed in research projects by investigating technological synergies between different application scenarios. Based on this, technology platforms targeted for several different application systems can be defined and developed, facilitating the implementation of several application system products. The gap between the research and development activities can also be narrowed by implementing application demonstrators that can be used for verifying the suitability of the selected technologies and for user studies.

The research on enabling technologies is typically long-term research, and thus the topics should be selected carefully. The commercial benefits of research on enabling technologies can be in component manufacturing or the IPR business. However, it should also be remembered that participation in the enabling technology research can help in forecasting the general technology trends and thus also in making the right technology selections for product applications. As mentioned above, research on enabling technologies should be closely connected to the applications. Some important enabling technologies and thus relevant research topics from the technology viewpoint are:

- Technologies for short-range wireless communication, especially the following sub-topics:
  - energy-efficiency
  - cost-efficiency
  - ad hoc communication between terminals and inside distributed sensor systems
  - coexistence of different wireless technologies
  - novel air interfaces, e.g. UWB

- Ubicom middleware:
  - service discovery
  - QoS management

- content adaption
- network adaption
- ad hoc service management
- instant messaging, peer to peer communication

- Reasoning methods, smart algorithms:
  - context awareness
  - pattern recognition
  - personalization, profiling
  - case based reasoning, fuzzy methods, etc.

- Usability research:
  - adaptive UIs
  - UI technologies
  - design for all
  - context sensitive UIs, especially location sensitivity
  - multimodality (e.g. gesture and speech)

- Sensor and actuator technologies for smart application items, especially the following sub-topics:
  - parasitic energy sources
  - software technologies for management of large sensor networks
  - MEMS-technologies

From the user viewpoint, two opposite usage paradigmas can be recognized. These are illustrated in Table 7 and can be called the disappearing computer approach and the mobile user terminal centered approach. In commercial Ubicom application systems, the applied user paradigma can include elements from both of the extreme examples in Table 7.

Table 7. Two extreme examples of the usage paradigmas for Ubicom application systems.

	Disappearing computing approach	**Mobile user terminal centered approach**
Underlying philosophy	Devices do not disturb people, because they are unobtrusive.	People want to control and interact conciously with the environment, retrieve information and use their mobile terminal as a tool to do this.
Key components and systems	Smart items, i.e. sensors, actuators and their networks	Smart mobile terminals, communicating items
Strengths	Ambient Intelligence without users' effort Reduced staff costs in professional applications	Users' ability to actively control and monitor the environment, interact with the environment, and retrieve information from the environment
Critical research issues derived from the underlying philosophy	Smart embedded sensors Smart embedded actuators Reasoning, intelligence Short-range wireless communication: technologies enabling an especially low price, small size and very low power consumption	User interfaces of mobile terminals (the use should be as intuitive as possible) Short-range wireless communication: technologies enabling an especially low price, small size and very low power consumption

The mobile terminal centered approach can be divided into sub-classes according to the terminal, which may be a PDA-like device, customized (application specific) device or a mobile phone. Because of the strong mobile phone industry in Finland, it is reasonable to consider the last sub-class in closer detail.

Arguments for the mobile phone centered approach could be the following:

- The Ubicom business could take advantage of the strong mobile phone industry in Finland, also providing smaller companies with business opportunities in the same way the PC has provided small software companies with business opportunities since the 80's.

- Mobile phones possess wide penetration and people are accustomed to using them.

- Mobile phones are developing towards open application platforms.

- The mobile phone centric approach could facilitate the development of a uniform user interface culture, which is necessary if people are to use hundreds of devices in daily life, and thus the use of the devices should be as intuitive as possible without reading any manuals or operating instructions.

Special challenges and potential risks in the mobile phone centric approach are:

- In the research activities supported by the public sector, the interests of both the mobile phone industry and other companies in the Ubicom business should be united.

- The current user interfaces of the mobile phones are too limited for many Ubicom application systems.

- The lifespan of individual mobile phone types is typically short, whereas the lifespan of the devices in the infrastructure is typically long. Thus, special attention must be paid to the question of how to guarantee interoperability between these devices in the long run.

In the disappearing computing approach, the following application areas can be named: industrial automation, public and commercial buildings (e.g. shopping centres), home automation, which can be divided into home appliance systems, home audio-visual systems and home utilities (electricity, heating, ventilation, water, draining). Industrial automation is a well-established field that can still benefit from Ubicom, and the experience of which the other Ubicom applications can also learn from. From the

Finnish viewpoint, the home audio-visual system industry is not very strong, so the business background is weaker than in the other sub-classes mentioned and also weaker than in the mobile terminal centric approach in general.

Pure cases of either the disappearing computing approach or the mobile terminal centric approach will probably not be seen as such, but different combinations of the two will prevail. It should be noted that from the technology research viewpoint, many goals are common to both approaches. However, from the application point of view, there are differences between these approaches to be taken into consideration when choosing research topics.

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Abstract

The motivation for working up this report was to provide the parties involved or interested in Ubicom activities with information about opportunities and enablers in the area, and to contribute Tekes in defining research topics for the current and future research programs dealing with Ubicom. The main approach in the report is from the application system viewpoint. The main emphasis of the technical enablers is in short-range wireless communication technologies.

The report deals with the evolution and different approaches to the Ubicom concept around the world, possible application areas and scenarios with general requirements concerning them, key technical enablers with an estimation of their applicability and development during the next few years, aspects for the planning and evaluation of the business models of application systems, and recommendations for the future research activities and leading commercial applications.

The main suggestions of this report for the Ubicom research are: The research should be interdisciplanary, that is, it should combine human sciences, usability studies, business and economic research as well as legislation and ethical issues with the technology research, which is the basic enabler of the advancements in this area. Furthermore, both the application and the technology viewpoints must be combined. The core technology research should address short-range wireless communication, middleware, reasoning and smart algorithms, usability issues, as well as sensors and actuator technologies.

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ubiquitous computing, ubiquitous communication, pervasive computing, short-range wireless communications, smart human environment

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