ESPOO 2002

VTT RESEARCH NOTES 2146

Communications Technologies

The VTT Roadmaps

VTT TIEDOTTEITA – RESEARCH NOTES 2146

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ISBN 951–38–6050–7 (soft back ed.)
ISSN 1235–0605 (soft back ed.)

ISBN 951–38–6053–1 (URL: http://www.inf.vtt.fi/pdf/)
ISSN 1455–0865 (URL: http://www.inf.vtt.fi/pdf/)

JULKAISIJA – UTGIVARE – PUBLISHER

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Technical editing Maini Manninen

Yliopistopaino, Helsinki 2002

Sipilä, Markku (ed.). Communications Technologies. The VTT Roadmaps. Espoo 2002. VTT Tiedotteita – Research Notes 2146. 81 p.

Keywords telecommunications, information technology, networks, radio frequency, micromechanics, service architectures, smart human environments

Abstract

The view of VTT (Technical Research Centre of Finland) on the development of selected information and communication technologies is presented. The views are given as technology roadmaps in the areas of interoperability and mobility in future networks, micromechanical radio frequency systems, service architectures and smart human environments. The work is a part of a theme called Future Communications Technologies, one of VTT's strategic technology themes. The purpose of the work is to help the planners and players direct their activities towards better competitiveness in this rapidly developing field.

Preface

The work published here was made possible thanks to the financial resources allocated by the general management of VTT, represented by Prof. Jarl Forstén, the Deputy Director General. A group consisting of Research Director, Prof. Pekka Silvennoinen, Research Director, Prof. Jorma Lammasniemi and Research Manager, Prof. Pentti Vähä gave those who worked on the project guidance and encouragement. The thinking and writing was performed in four working groups, led by Prof. Pertti Raatikainen (Interoperability and Mobility in Future Networks), Prof. Markku Åberg (Micromechanical Radio Frequency Systems), Prof. Eila Niemelä (Service Architectures) and Senior Research Scientist Johan Plomp (Smart Human Environments). In addition to those named above, dozens of individuals at VTT Electronics, VTT Information Technology, VTT Industrial Systems and VTT Building and Transport, all experts in their fields, participated in the work. I wish to express my sincere thanks to all of them.

At Espoo, Finland, on 11th June, 2002

Markku Sipilä

Editor

Research Professor, Theme Leader

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Introduction

This publication gives the view of VTT (Technical Research Centre of Finland) on the development of selected information and communication technologies. The views are given as technology roadmaps in the following areas:

- Interoperability and Mobility in Future Networks
- Micromechanical Radio Frequency Systems
- Service Architectures
- Smart Human Environments

The work documented here is a part of a theme called Future Communications Technologies, one of VTT's strategic technology themes. The purpose of the roadmapping work is to help the planners and players direct their activities towards better competitiveness in this rapidly developing field by utilizing the best expertise of VTT.

1. Interoperability and Mobility in Future Networks

Pertti Raatikainen, Heikki Pentikäinen, Kimmo Ahola, Tapio Frantti, Arto Juhola, Aarne Mämmelä, Jaakko Lähteenmäki, Sami Pönkänen, Aki Rova & Timo Sukuvaara

Verkkojen yhteiskäyttö ja liikkuvuus

Tiivistelmä (Finnish Summary)

Tietoverkot ja niissä siirrettävät palvelut ovat käymässä läpi voimakasta muutosta. Palvelutarjonta monipuolistuu ja palvelujen käyttämä siirtokaista kasvaa. Samoin kasvaa myös palveluja käyttävien kuluttajien lukumäärä. Päätekijöinä tähän kehitykseen voidaan nähdä ensinnäkin tietoverkkojen käyttämien teknologioiden kehittyminen ja toisaalta yhteiskunnalliset tekijät. Elektronisten ja optisten komponenttien alati jatkuva kehitys on mahdollistanut entistä pienempien ja suorituskyvyltään tehokkaampien laitteiden ja siirtoväylien rakentamisen. Teollistuneissa maissa tapahtunut yhteiskunnallinen kehitys puolestaan korostaa tiedon määrää ja saatavuutta. Tulevaisuuden skenaarioissa tiedon on oltava saatavilla aina ja kaikkialla ja langattomuus on keino tämän toteutumiseksi.

Tietoverkkojen kehittäminen ja ennen kaikkea rakentaminen vaatii suuria investointeja, ja tämän vuoksi käytössä olevien verkkojen (erityisesti tilaajaverkon) ennustetaan säilyvän käytössä vielä pitkään. Koska uusien palveluiden ja laajemman siirtokaistan tarve pakottaa kehittämään uusia ja tehokkaampia verkkoratkaisuja, on nähtävissä että lähitulevaisuudessa verkkojen välinen yhteistoiminta tulee korostumaan. Koska erilaiset verkot perustuvat toisistaan poikkeaviin siirtokonsepteihin, yhteistoiminta ei aina ole ongelmatonta. Suurin haaste on piirikytkentäisten verkkojen joustava yhdistäminen pakettikytkentäisiin verkkoihin. Ongelmakohtia ovat mm. yhteyksien luontiin, ylläpitoon ja purkuun liittyvät kysymykset, siirtoväylien kapasiteetin jako ja varaaminen sekä verkkojen hallinta ja vikatilanteista toipuminen.

1.1 Introduction

In the forthcoming years, service supply that utilises the various kinds of communications networks is expected to diversify, whilst the advent of new high data rate applications will lead to increasing demand for bandwidth. The efforts aimed at achieving higher access rates are expected to allow new applications and services to evolve. Besides higher data rates, up-coming services require enhanced functionality of terminals and networks. Terminals should be capable of supporting, e.g., different addressing schemes and adopting different coding, compression and encryption algorithms. The network should, for example, be capable of converting between different channel allocation schemes and bit rates, harmonise connection control procedures and network management schemes, as well as offer seamless interworking between different networking technologies.

Optical transport is foreseen to meet the challenge of higher data rates in the backbone network, but technology breakthroughs to overcome the bandwidth limitation in the access network, both wire-line and wireless, are still awaited. A lot of investment is tied to the existing wire-line infrastructure and therefore the legacy networks are anticipated to survive for a lengthy period of transition. The conventional telephone, cable television and power distribution networks are largely penetrated and numerous transport concepts have been developed and demonstrated to utilise them in offering high data rate connections to end-users.

Wireless communications has shown its viability and enormous expectations have been placed on it. Available data rates are moderate compared to the wire-line networks, but freedom of movement is foreseen to compensate for the narrow band. However, a lot of research effort is going on and advanced band-saving techniques are constantly being developed as new frequency bands are introduced.

The reasons for the success of wireless mobile communications are manifold and are not just technological and economical ones. The availability of a wide range of information at all times and at any location is becoming more and more crucial in many areas of every day life. Therefore, supporting the mobility of users as well as terminals and services are foreseen as a key driving force in the development of the future networks. Since emerging networking concepts should exist side by side with the legacy networks, interworking between different networking concepts on various levels is another factor driving development.

In this part of the document, existing networking solution are surveyed and tomorrow’s networking needs are studied. A technology roadmap, reflecting the authors’ views of the various networking technologies, is included

1.2 Today’s networking

This chapter summarises networking and related technologies that are deployed in today’s communications networks. The presentation covers general networking technologies, transmission media, terminals and transport quality from services’ point of view. The emphasis is on techniques that are in operational use.

1.2.1 Networking technologies

Current networks operate either through wired or wireless connections to access points that are connected to a backbone network. Most of the research and development activities carried out so far have been motivated by the breakthrough of the Internet and the advent of the second generation (2G) cellular networks such as GSM and its packet switched enhancement General Packet Radio Service (GPRS). Ad hoc networking is a hot research topic, but so far there is only a large amount of different approaches. None has been standardised "officially" or even found better than others. The Mobile IP protocol is the only standardised approach in the field of user mobility with the Internet. Mobile IP provides virtual care of IP addresses thus enabling connections to networks where users are located at a given time. However, Mobile IP does not support actual mobility but instead location-independent connection to the network. At the moment, different kinds of physical networks cannot interoperate with each other even if interoperation between the same type of networks is possible (this is referred to as roaming).

1.2.2 Transmission media

Wire-line network

Wire-line networks are normally divided into backbone and access networks. Fibre optics is widely deployed in the backbone network and the theoretical transport capacity of the best quality fibres is almost unlimited. However, the technology used in implementing transmitters and receivers at both ends of an optical link set practical limits for the available bandwidth. The latest wavelength multiplexing techniques allow a capacity of a few terabits per second on a single fibre, but commercially available techniques limit capacity to a few hundred gigabits per second.

The access network, which connects end-users to the high capacity backbone, is the bottleneck from a service delivery point of view. The basic problem is that the old established twisted-pair links, the so-called last mile, cannot easily be replaced with high capacity fibre lines due to high installation costs. Therefore, a technology to exploit the existing copper-based infrastructure in high-capacity service delivery has been developed.

Bandwidth with the twisted-pair links has traditionally been limited to 3 kHz, which has been enough for voice communications. When the need for data communications arose, different modulation techniques were developed to increase bandwidth utilisation. Analogue modems, which are still widely used, operate up to 56 kilobits per second (kb/s). Digital transmission, along with sophisticated line-coding and modulation techniques, allows frequencies beyond the 3 kHz limit to be utilised and markedly higher data rates become available.

Different Digital Subscriber Loop (DSL) concepts have been developed and Integrated Services Digital Network (ISDN) was the first network concept that utilised them with subscriber lines. The frequency band extends beyond 100 kHz, but the link speed is still limited to 144 kb/s. The latest techniques exploit much broader bandwidth and allow the conventional analogue telephone service to exist side by side with digital services. Asymmetric Digital Subscriber Line (ADSL) has been the most tested one and many network operators are taking it to commercial use. In ADSL and systems alike, the transport capacity is allocated asymmetrically, implying that more capacity is offered for down-link than for up-link direction. ADSL's down-link capacity varies from a few hundred kb/s to 2 Mb/s and up-link capacity from 2 to 6 Mb/s. Transport distance depends on the quality of the installed copper wires and data rate offered; the higher the data rate, the shorter the distance. The highest 6 Mb/s rate can be carried less than a hundred metres.

The Community Area TeleVision (CATV) network has traditionally been a one-way communications medium and has been used to broadcast television programs to residential customers. The advent of cable modems has changed its role and it has become a two-way media. The physical customer access is based on coaxial cables and the available bandwidth is clearly broader than with the twisted-pair links. Most of the bandwidth is still used for broadcasting television programs, but some frequency bands have been standardised for data communications.

Cable modems share channel capacity asymmetrically like ADSL and, in present installations, down-link data rates vary from a few Mb/s to some tens of Mb/s and up-link rates from a few hundred kb/s to some Mb/s. Although cable modems offer substantially broader bandwidth, the average bit rate per user may remains quite small because this frequency band is normally shared between a large number of users.

Wireless network

Present wireless systems can roughly be divided into wireless local area network (WLAN), cellular mobile radio, broadcast and satellite system. WLAN systems normally use uncontrolled licence-free industrial, scientific and medical (ISM) frequency bands up to 2.4 GHz, with a maximum bit rate of about 10 Mb/s. Cellular mobile radio systems rely upon frequency reuse where users in geographically separated cells simultaneously use the same carrier frequency. The carrier frequencies presently in use with cellular mobile radio systems are 800–2000 MHz. The bit rates are increasing all the time from the present 10 kb/s up to about 100 kb/s. The received signal fades due to shadowing and multipath propagation, i.e., reflection and scattering from the ground, buildings, hills, etc.

Frequency reuse introduces co-channel and adjacent channel interference and various criteria are used to measure the spectral efficiency. Link spectral efficiency is the bit rate per unit bandwidth, measured in b/s/Hz. Area spectral efficiency is the sum of the maximum average bit rates per unit bandwidth per unit area for a specified bit error rate (BER), measured in b/s/Hz/m^2. Fading in general reduces the link and area spectral efficiencies.

There is a trade-off between the area and link spectral efficiencies. Quadri-phase shift keying (QPSK) is the optimum modulation method in fixed modulation systems, which are designed relative to the worst case interference/fading conditions.

Today's transmission media are mainly used for voice services. In present systems, the area spectral efficiency is the product of link spectral efficiency (measured in b/s/Hz), spatial efficiency (inverse of the area of reuse clusters, $1/m^2$) and trunking efficiency (channel utilisation, in percentage, %).

High link spectral efficiency can be achieved by using bandwidth-efficient modulation such as quadrature amplitude modulation (QAM). Link spectral efficiency is about 1–2 b/s/Hz in present binary or quadri-phase systems. High spatial efficiency can be achieved by (1) minimising the area per cell by using microcellular systems, and (2) minimising the co-channel reuse distance by i) minimising the threshold for the average carrier-to-interference ratio or by ii) controlling co-channel interference. In microcellular systems, the cell radius ranges from 100 m to 1000 m and in macrocellular systems from 1000 m to 30 km. The same frequency is normally reused in clusters of a few cells, i.e., the reuse distance is 7 or somewhat lower. High trunking efficiency can be achieved by using channel assignment schemes that maximise channel utilisation. There is usually a trade-off between trunking efficiency and quality of service (QoS). Grade of service for voice services include link quality, the probability of new call blocking, and the probability of forced termination. In data transmission systems, quality of service is measured by the bit rate (or throughput), delay, and BER performance.

Cellular systems with smaller cell sizes require faster and more reliable link quality evaluation and handoff algorithms. Mixed cell architectures (microcells overlaid with macrocells) are preferred for handling both low density fast-moving vehicular mobile stations (MSs) and high density low speed portable MSs. The threshold for the average carrier-to-interference ratio is minimised by using receiver techniques such as error control coding, antenna diversity, adaptive equalisation, etc. Co-channel interference is controlled by using cell sectoring, cell splitting, adaptive transmitter power control, discontinuous transmission, effective hand-off algorithms, macroscopic BS diversity, etc.

Channel assignment means allocating a channel upon a new call arrival or handoff attempt. The basic types of channel assignment algorithms include fixed, dynamic and flexible channel assignment. Distributed dynamic channel assignment outperform fixed channel assignment under conditions of light nonstationary traffic, but fixed channel assignment usually provides better performance under conditions of heavy traffic.

1.2.3 Terminals

Most of the wireless portable terminals are based on the second generation (2G) mobile phone systems infrastructure (e.g., GSM, PDC, cdmaOne, AMPS and D-AMPS). Terminals used with 2G systems are based on the circuit switched technology and offer mostly speech services and low bit rate data services. The 2G terminals include the functionality of mobile phones, personal digital assistance, combinations of these and communicators. The so-called 2.5G system (i.e., GSM EDGE, GSM GPRS) terminals already offer packet switched connections. The existing wireless terminals already include very promising elements, e.g., Java virtual machines (enabling wireless download of applications into the terminals), colour display, extended operating time and memory capacity and specialised operating systems, such as EPOC.

1.2.4 Services and transport quality

Voice and data calls that utilise the conventional circuit switched channels yet form the most important group of services offered to users over the various networks. Depending on the coding and compression methods, the required channel capacity varies from a few kilobits to 64 kb/s. This data rate is not enough for a number of new services, although the nominal required bit rate may not exceed the channel capacity. Multimedia services, for example, generate bursty data flows and to enable the smooth use of these services, substantially higher bit rates are temporarily required.

Transport concepts that are based on shared media and statistical multiplexing, e.g. Asynchronous Transfer Mode (ATM), Ethernet and GPRS, have been replacing conventional circuit switched user access. The real revolution in service delivery is related to the Internet Protocol (IP), which has gained popularity as the unifying network layer protocol. Basically, it offers the “best effort” service and conforms to the delivery of computer data. The transport of services that are sensitive to response time or delay is quite often confronted with a degraded service level. Nevertheless, special protocols have been developed to carry delay-sensitive real-time services reliably over the IP based networks, e.g., Voice over IP (VoIP). In spite of the new protocols, packet switched networks are not able to offer the same service level for real-time services as is available with the conventional circuit switched telecommunications networks.

Regardless of the physical media, an important measure of quality is the reliability of the transmission of carried bits. It is normally given as the ratio of bits (or packets) in error to successfully received bits (or packets). Computer data (e.g., used for network control) and real-time services (e.g., voice and video) normally form the two extreme ends of the error ratio requirements. Network control information requires very low error rate, normally better than 10^{-9}, whereas real-time voice communications can tolerate bit error rate as high as 10^{-3}.

From a networking point of view, resource allocation as well as connection set-up, maintenance and termination are questions that have been solved and standardised in the telecommunications networks. With the IP-based packet switched networks however, a lot of open questions still exist. Traffic engineering that is used for collecting all sorts of information from the network, e.g., for network management or customer billing purposes, is an area that needs harmonisation and further development. As the number of users and available services increase and as networks get more complicated, the question of service creation has gradually become a major issue.

1.3 Emerging and future networking

This chapter surveys anticipated future networking solutions and related technologies. The discussion involves general networking technologies, transmission media, terminals and transport quality from services' point of view.

1.3.1 Networking technologies

Active networking

Active networking (AN) is an emerging network concept that can be used for rapid evolution and deployment of network technologies. It is based on runtime environments that run on network devices (e.g., routers, servers or end-terminals) and active programs/applications, which can be inserted dynamically and run in those environments.

The key abilities of AN include the possibility to locate (new) services where, and only where, they best meet the requirements of services and economical network resource usage. Another important benefit is the possibility to introduce novel approaches to network control and management.

Ad hoc service placement

The AN technology promises to deliver an unforeseen range of services that make use of, and are dependent on, the ad hoc service placement capability. One such service is content distribution to multiple recipients (including functions not easily implemented with current Internet multicasting). Content distribution will be needed, for example, in push-type services, to enable them to become economical.

Another service is enhanced mobility support, an area in which VTT has already contributed. Quality of Service, routing and management, data transcoding to mobile terminals (including encrypted traffic) as well as automatic software updates are other interesting application areas.

Management and security

The AN technology promises to offer extremely light-weight and robust ways to manage networks. This includes ideas such as the “bacteriological” migration of service code (i.e., if an active service is found to be successful it may begin to spread into neighbouring nodes), different self-control features (tracking and filtering of malicious traffic) and enhancements to network security. Network security in a mobile environment is very difficult to provide with conventional means whereas active network solutions can be elegant ones.

An important aspect of security in active networks will be the authorisation of the active nodes, users or applications. Unless this is done in a closed network where all entities are known, we will need some sort of certification. Unfortunately, certificates can cause performance problems, which we need to minimise or solve. One possible area of research will be that of attribute certificates, which allow role-based, temporary and possibly anonymous authorisation. They can be used to increase the security and performance of the certification in an environment where the amount of signalling must be minimised.

Peer-to-peer networking

Peer-to-peer is a set of architectures and technologies that makes use of the huge amount of resources located on the edges of the Internet, inside users’ equipment. The peer-to-peer mode of operation differs strongly from the usual client-server model as all nodes are considered equal. A peer can operate in both client and server modes at the same time. These technologies enable internode communications and efficient sharing of storage and computing resources in a decentralised manner, regardless of the underlying network technology. Whereas mobile IP solves problems related to terminal mobility, the future peer-to-peer applications will support a variety of requirements related to user mobility.

Wireless ad hoc networks

Multihop and ad hoc networking are assumed to be promising technologies, especially in limited areas, despite their wasteful bandwidth usage. Each mobile host connecting to a network is also capable of acting as a wireless router to another host, as well as connecting to the network via other mobile hosts. As battery consumption is an essential issue, the primary objective of ad hoc route generation is power efficiency. This means not only a minimum overall consumption of power, but also fairness in power consumption between mobile hosts. Furthermore, the routing algorithm also knows when the battery of a particular host is about to run out and re-allocates the host's routing commitments to other hosts that have more power left. Future networks will also be fast enough to take into consideration the mobility requirements and control of mobility, respectively. Moreover, the future networks will not require a user to install every new piece of software, but the terminals/routers etc. will automatically update their protocols and applications as soon as new versions or applications become available.

With future wireless network, the amount of signalling will be minimised to only a fraction of today's signalling load. Another advance in bandwidth usage will be achieved thanks to an extremely dynamic resource allocation based on priority and fairness, e.g., a single user will be able to achieve multiple services at the same time with different quality of services. Connection control will no longer mean simply allocating resources, but also managing parallel co-existing different types networks in a power-efficient way. A more efficient use of resources will be indispensable due to the growing amount of data transmission and especially due to the explosively growing amount of streaming data, consisting mainly of real-time voice and video transmissions. Future networks will also support almost lossless handovers between protocols with different capacities (i.e., vertical handover).

Moreover, the personal area networks (PAN) is a promising technology for very short range communications. Examples of this technology are Bluetooth chips enabling the transfer of voice between headsets and terminal devices. Another promising application area is wearable computing, where the first commercial products have already been introduced.

Home networking

The concepts of ambient intelligence and advanced home networks have already been in existence for several decades, although they have not been able to produce any major breakthrough. The home networking and intelligent services at home have huge future market potential and are foreseen to create lucrative markets for manufacturers and service providers alike. Many relevant technologies have been available for a while, but more research, development and standardisation work in this area is required to enable a wide scale take-off to take place.

The intelligent home networks can easily extend the usability of home environments by empowering more convenient devices to home appliances, the "peripherals" of the future home. Intelligent networks are able to self-configure and detect changes in their environment (addition of new toaster, TV set or PDA, unplugging of a device, etc.). The computing is hidden in the appliances and takes place automatically, necessarily without any user interactions. The advanced home network infrastructure will enable the ambient intelligent and pervasive computing visions at home to become a reality.

The introduction of Ad hoc networking, IPv6 connectivity and distributed intelligence in residential networking, ease the installation and operation of home networks to a level of complete transparency for the user. With these technologies it also possible to solve important networking issues concerning QoS, security and privacy of communication and interoperability with the external communication world.

Wireless ad hoc networking will allow people at home to move, control, communicate and enjoy their entertainment system as well as control their home environment without noticing the underlying technologies or networks. Homes will be designed with the goal of supporting an efficient lifestyle while offering extreme comfort to all people. The fruits of communications and information technology within homes will significantly improve our quality of life by enabling a richer and more active residential existence, maintaining mental and physical health, guaranteeing safety at home and ensuring maximum privacy of family life.

Interoperability

Interoperability of networks can be divided into three levels: application, internet and data-link level. Currently, the Internet successfully hides away most data-link level details for packet traffic (i.e., WLAN, GSM, UMTS GPRS, LAN). At application level, there are adaptation functions and gateways between the Internet and non-Internet applications (e.g., Internet-phone vs. "normal" phone service). Here we consider the all-IP case and then cases where the networks in question are fundamentally different, such as voice-oriented networks and Internet. In these cases, a gateway containing network specific terminations for traffic and transport mode conversions are needed. Towards the Internet, an application entity will be presented and towards a non-Internet network (say, a phone network), a phone or a PBX could be emulated.

In order for application entities to interoperate over the Internet, they must be able to a) publish the network resources they offer, b) locate the network resources they need, c) exchange the messages needed to invoke the resources, d) make sense of the messages' application-specific content and e) react to this content in a proper way. In non-trivial cases, this means maintaining states and state information of the applications involved.

1.3.2 Transmission media

Wire-line network

With wire-line communications, the optical transport is anticipated to extend its legs closer and closer to end-users. Since the characteristics of optical transport clearly surpass those of electronic transport, going optics can be considered an obvious trend. As stated in the introduction, most of the investment in telecommunications networks is focused on the last mile, which, to a large extent, utilises the old established copper wires. Therefore, the replacement of copper lines with optical ones is a time consuming process and there is a clear demand for concepts transporting broadband signals over the electronic wire-line media.

Digital signal processing has proved to be the key factor in developing sophisticated transport concepts for the twisted-pair copper wires. The ADSL technology, introduced in chapter 1.2.2, can be seen as an interim phase because new and more effective methods are being developed. The next step is foreseen to be Very high data rate DSL (VDSL) that enables up to 56 Mb/s data rate but at the expense of transport distance. Such a high bit rate can be transported only tens of metres and lower VDSL rates to some hundreds of metres. However, these short link spans are considered feasible because optical links are expected to get nearer to the end-users, thus shortening the range of the twisted-pairs, especially in urban areas.

The CATV networks offer large frequency band, but due to the shared nature of this media the bit rate per user decreases as the number of users increase. More bandwidth can be gained for data communications when the digital delivery of television programs becomes more widespread. Another serious problem is related to the security of communication, because the tree-and-branch topology of the conventional CATV networks allows all users in the same network branch to monitor all traffic. Eavesdropping can be avoided by enhanced network topologies and by using advanced encryption and identification methods, but a lot of development work needs to be done to find secure solutions.

The use of power lines for data communications has been considered a realistic alternative because almost all residents, at least in industrialised countries, are connected to the power feeding networks. Power lines introduce a lot of disturbing noise and from a signal transmission point of view, the use of power lines for data communications is a demanding task. Another factor making power lines less attractive is that their topology is equal to that of a conventional CATV network, implying that the transport media is shared and the available capacity is divided among a group of users. The security of communications is also a problem and cannot be solved as easily as in CATV networks. So far, the systems under trial have demonstrated quite low bit rates going up to some hundred kb/s whilst transport distances have been limited to a couple of kilometres. Despite the great challenges, there seems to be an interest towards developing a technology for power line data communications.

Wireless network

Issues concerned with the management of radiowave propagation will continue to be important also in future wireless systems. Frequencies above 10 GHz are difficult to use with outdoor cellular mobile radio systems due to high attenuation and problems with mobility since the Doppler frequency may become several thousands of hertz and the channel is fading too rapidly. Thus in most future outdoor systems, the frequencies used should be less than about 10 GHz, but no decisions have been made yet. For WLAN systems, new allocated frequencies include 5.8 GHz and 17 GHz, and frequencies up to about 60–75 GHz have been planned for future civilian systems. Attenuation is high and normally radio waves do not propagate through walls. In addition, at high frequencies the Doppler frequency is several hundred hertz even at walking speeds.

When more advanced modulation methods are used, more accurate models for the physical channel and the analogue parts of the system are needed. The models are often nonlinear and the fading and noise are no more complex Gaussian. The most important propagation parameters are the attenuation and the scattering function, which defines the received signal power density as a function of delay and frequency shift. Attenuation will be a severe limitation due to tight link power budgets and high frequencies where propagation is significantly affected by nearby objects. Adapting certain parameters of the transmitted signal relative to the signal-to-noise ratio (SNR) leads to better link and area spectral efficiencies. In adaptive transmission systems, the optimal reuse distance is between one and four, depending on the interference configuration, but a feedback channel from the receiver to the transmitter is needed. The threshold for the average SNR will be minimised by improved error control coding such as turbo coding, and by cancellation or rejection of interference. Co-channel interference and capacity will be controlled by using smart antennas.

Various diversity methods will remain important, including space-time coding using Multiple Input Multiple Output (MIMO) techniques where several transmitter antennas are used in addition to several receiver antennas. Turbo codes are the best known channel codes. In multiple access systems, interference avoidance is a promising approach. On fast links, we often prefer multicarrier modulation or orthogonal frequency division multiplexing (OFDM) to reduce intersymbol interference. QAM will improve the link spectral efficiency, but may reduce the area spectral efficiency unless adaptive techniques are used. Although technology is maturing all the time, the complexity issue and the power consumption will be important problems.

Advanced transmission techniques, such as the MIMO and the Ultra Wide-Band (UWB) techniques using bandwidths of several gigahertz are highly dependent on the propagation channel characteristics. The usage of wideband code division multiple access (WCDMA) techniques will bring soft capacity to the network and decrease the need for conventional planning techniques, such as frequency planning. Instead, the WCDMA planning will be based on link and network simulation, which require both wide-band channel models and narrowband path loss models as input. Mobile phone location techniques are a new application area for propagation models. By taking advantage of the channel impulse response, improved location accuracy can be obtained. In addition to location-based services, the exact location of users can be used to enhance network planning, monitoring, handover algorithms and mobility management.

1.3.3 Terminals

In the near future, wireless portable terminals (e.g., mobile phones, personal digital assistants, personal communicators) have to support seamless interoperability between different underlying infrastructures. They have to support traditional circuit switched connections as well as multiple parallel packet switched connections that have different quality of service requirements. Moreover, the user interface of future terminals has to support context awareness, i.e., terminals have to be aware of the situation in which they are and the environment around of them as well as the "mood" of users. The future terminals will be more than personal assistants, which take care of many programmed tasks on behalf of users. Furthermore, the terminals will be capable of locating their geographical co-ordinates be it inside buildings or in the open in rural and urban areas. The future terminals will also be capable of downloading protocol and applications software via air-interface inconspicuously (e.g., software radios and active network terminals). They will also transmit real-time video and audio and act as a remote controller to electronic devices in the offices and homes. Moreover, they will be capable of locating themselves as well as other terminals in the neighbourhood both in indoor and outdoor environments.

The emerging 3G technology offers higher bit rate data services to users as well as multiple simultaneous connections for a single user at the same time. The terminals in the 3G networks have to support both GSM infrastructure and WCDMA-based 3G infrastructure. The first terminals with such capability will be on the market in Europe in the spring of 2002. It is worth mentioning that the extensively discussed video transmission has already been possible for a long time with the Japanese PHS system (1G system).

1.3.4 Services and transport quality

Multimedia services are expected to become the dominant type of service. Typical to these services is that they are composed of several components, e.g., voice, video, data and control. The different components usually confront the carrier network with dissimilar transport quality requirements. Voice and video are normally real-time components requiring low end-to-end delay and minimal delay variation, but can operate over links having low bit error or packet loss ratio. Computer data and especially service related control information often require very high error ratio, but can manage with long and varying end-to-end delays. When adding the different bandwidth requirements, there is a mixture of constraints that cannot easily be overcome.

One way to solve the quality problem would be to carry the different service components along special paths each designed to meet certain quality measures. This, however, leads to other equally difficult problems such as the synchronisation of the service components. When considering that the transport networks gradually turn into shared media packet switched networks, the synchronisation of the different service components becomes a problem in any case. In packet switched networks, the traffic tends to be bursty and, given that the bit rates of individual services increase the traffic, get more bursty. This causes an increase of delay variation and thus severe degradation of real-time service components. If the service components are directed along different paths, the synchronisation becomes an even worse problem.

Errors in transmission have normally been avoided by implementing line and error correction codes. Line coding is used to extract bit level timing whilst error correction codes are used to correct distorted bits and blocks of bits. As the bit rates increase and higher frequencies are introduced, more robust line codes and error correction schemes need to be developed both for wire-line and wireless transmission.

Summary of existing and emerging networking technologies

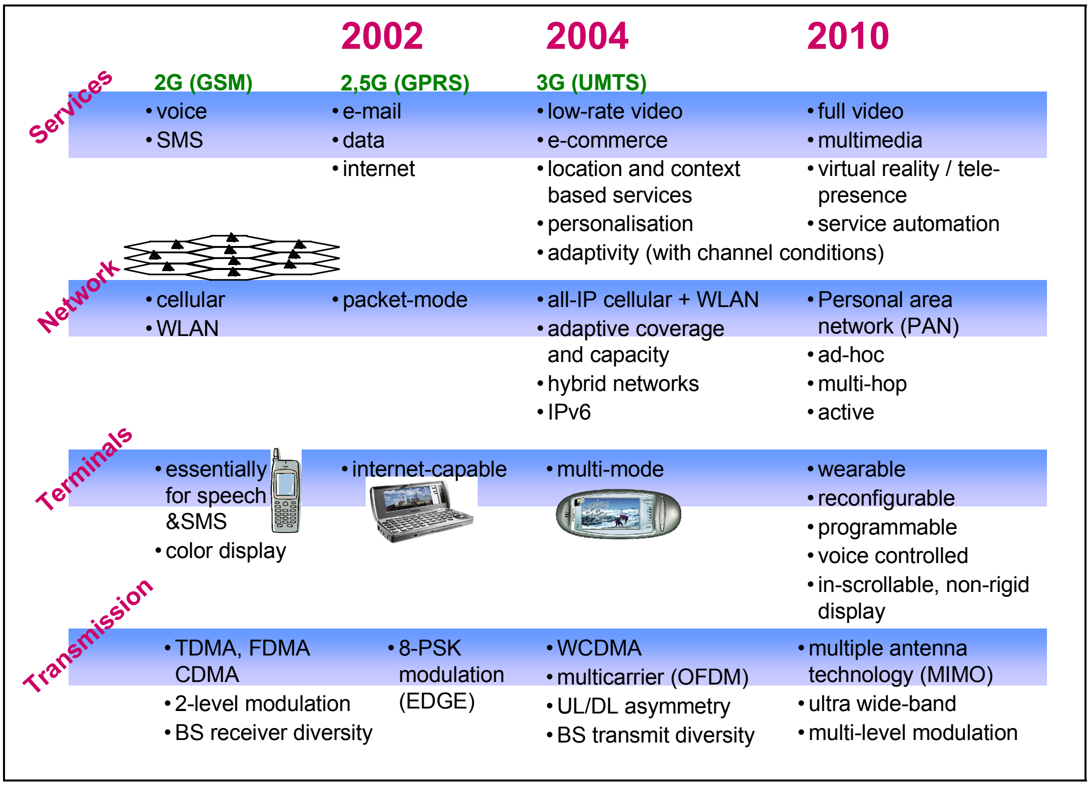

Figure 1.1. Wireless networking and related technologies.

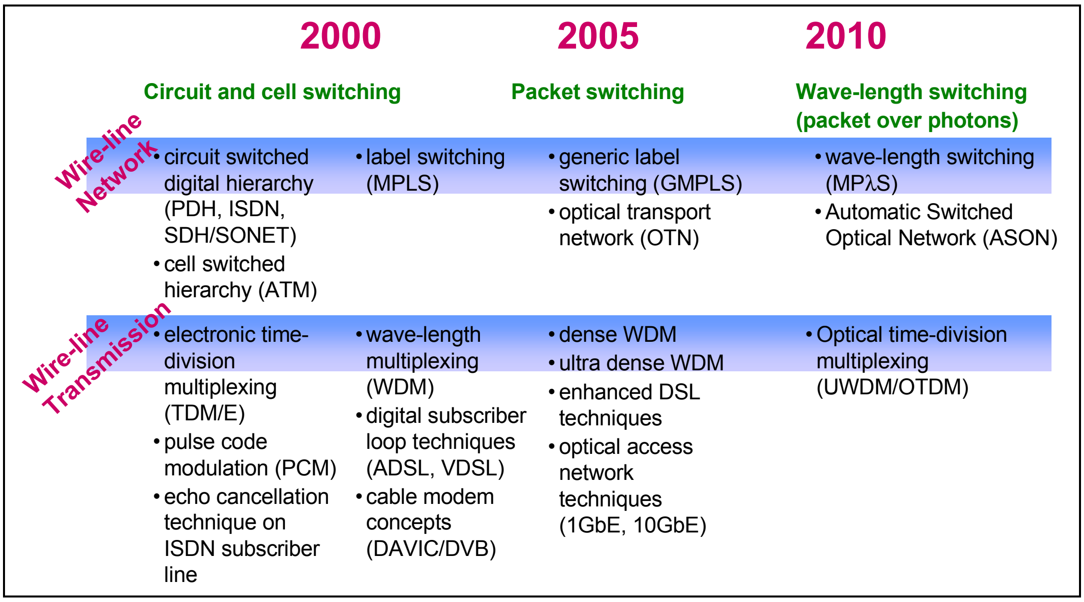

Figure 1.2. Wire-line networking technologies.

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2. Micromechanical Radio Frequency Systems

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Mikromekaaniset radiotaajuusjärjestelmät

Tiivistelmä (Finnish Summary)

Prosessiteknologian kehitys on tehnyt mahdolliseksi valmistaa elektronisten komponenttien lisäksi mekaanisia komponentteja mikroelektroniikan kokoluokassa. Näitä komponentteja tai niistä koottuja piirejä ja järjestelmiä kutsutaan siten nimityksellä "mikromekaniikka" tai "mikroelektromekaaniset järjestelmät" (MEMS). Tämä kehitys on tehnyt mahdolliseksi tehdä komponentteja siten että

- niillä on uusia toimintoja
- niillä on mahdollista saavuttaa ennen mahdottomia suoritusarvoja
- niitä voi integroida yhteen elektroniikan kanssa
- niitä voi valmistaa paljon hyvin alhaisella yksikköhinnalla.

Tästä kehityksestä on syntynyt myös ajatus käyttää mikromekaanisia komponentteja suurtaajuisissa, esimerkiksi radiolähettimiä ja/tai -vastaanottimia sisältävissä järjestelmissä.

Lähettäjän ja vastaanottajan välistä informaatiovuota voidaan tarkastella kolmessa moodissa riippuen lähettäjän ja vastanottajan tyypistä. Vuo voi olla:

- eri ihmisten välillä
- ihmisten ja tavaroiden tai tavaroiden ja ihmisten välillä
- eri tavaroiden välillä.

Ensimmäinen näistä on jo vakiintunutta – esimerkiksi matkapuhelimet. Sen tekniset ja suorituskykyvaatimukset ovat liian suuria MEMS-radioille, ainakin nyt ja lähitulevaisuudessa. Vain joissain erityistapauksissa korvaavia MEMS-komponentteja voidaan ajatella elektronisten sijalla. Kaksi muuta mainittua moodia ovat sen sijaan vähemmän vaativia: pienempi lähetysteho, lyhyempi kantamavaatimus ja alhaisempi siirtonopeus. Ne ovat myös vasta kehittymässä. Siksi MEMS-radioiden kehitys alussa tulee kohdistumaan halpoihin tavaranhallinta- ja kontrollisovelluksiin.

Uuden teknologian ensimmäisessä vaiheessa sitä käytetään *korvaavasti*, MEMS-komponenttien tapauksessa pyritään järjestelmän jotkin elektroniset komponentit korvaamaan vähintään saman suorituskyvyn omaavilla mekaanisilla vastineilla, itse järjestelmän pysyessä muuttumattomana. Tämä on MEMS-teknologian nykyvaihe. Toisessa vaiheessa pyritään järjestelmät suunnittelemaan alusta alkaen uuden teknologian lähtökohdista. Arkkitehtuurit optimoidaan – tässä tapauksessa – mikromekaniikalle sopiviksi ja jako toiminnallisiin lohkoihin tapahtuu MEMS-teknologian eikä vain pelkän elektroniikan toiminnasta lähtien. Mikroelektromekaniikka tulee siirtymään tähän vaiheeseen lähivuosina, jolloin tulemme näkemään aivan uusia teknologian toimintaperiaatteita ja sovelluksia.

2.1 Introduction

The development of process technology has made it possible to also manufacture mechanical devices in addition to electronic ones with the size of microelectronic components, i.e. in the order of micrometers. Thus the name "micromechanics" or "microelectromechanical systems" (MEMS). This development has made it possible to make mechanical components

- With new functions
- For parameter ranges hitherto impossible
- Integrable with micro electronic circuits
- Mass produced with a very low price per device.

This development has generated the idea of using micromechanical devices in high frequency systems, for instance in radio type transmitting and/or receiving systems. Much effort has already been spent on implementing micromechanical devices into radio systems.

When a new technology emerges in an existing system field, the first phase is to make *replacements*. In this case, this means making mechanical devices that imitate some micro electronic device or block in an existing system architecture. One tries to make the replacement device superior in some parameter, to justify the replacement, and at the same time keep the other parameters within the existing system specifications. This often leads to considerable difficulties and bad compromises, because the existing system requirements are optimised to the characteristics of existing electronic devices.

Therefore one must proceed to a second phase: *total design from the start point of micro mechanics*. This means the choice or development of system architectures optimised to the characteristics of mechanical devices as well as new system partitioning between electrical and mechanical blocks. Also, the mechanical devices must be designed for these architectures and not as performance parameter look-alikes for electronic blocks. This may require totally new thinking about what is for instance a mixer or an oscillator, or perhaps instead the creation of the new concept of "mixcillator".

The main thread of this survey is to provide a roadmap for developing radio systems from the conditions of micro mechanics: to study and develop system architectures, to develop mechanical devices, to develop design methods and tools and tailor and apply processing technologies from this starting point.

2.2 Development scenarios

Markets and applications

There are three modes of information flow within the frame of possible senders/receivers; flow between:

- human - human
- human - goods/goods - human
- goods - goods

The first one of these is already well established – e.g. mobile radios, and its technical and performance requirements are too high for MEMS radios, at least for the first versions. Only in special cases can some MEMS replacements such as switches be used. On the other hand, the other modes are often less demanding, with low transmission power, short range and low bit rate. Also, these are still in an emerging phase. Therefore the development of a MEMS radio should be focused at the beginning on low cost logistic and control applications.

There are several applications where short-range communication is needed. In the following, we give some examples and discuss the properties of the radio system that is necessary for successful operation.

In electric power plants voltage, current and power can be detected by using a low power microchip radio (MCR). Keeping the required power of the radio low enough, it can be energised from the electric field. Mostly, a distance of between 10 to 30 m is sufficient.

The gas station consists of several tanks spread around the field. The fuel level has to be measured at least twice a day. It is done manually thus far. If each tank could consist of a transmitter that is able to communicate with a base station on the gas station, the fuel consumption of different tanks could be monitored continuously. This would help to optimise the distribution system. It would also be very useful if the fuel tank could inform the delivery vehicle of its content to avoid mixing different fuels together. In such a case, the delivery vehicle should also consist of a receiver.

In industry, motors, valves etc. have to be monitored regularly to ensure their uninterrupted operation. They are usually lacking communication networks, so each time an inspector has to set an instrument close to the shaft and monitors vibration, acoustic emission etc. From the data, he/she can deduce the condition of the machine. With a cheap transmitter able to communicate up to 100 m, a continuous monitoring of industrial machines could be possible. Since industrial machines such as valves and motors are powered, the power consumption of the transmitter is not very critical. In addition to motors, the condition of the vehicles could be monitored via a wireless network.

A cheap radio would also be very useful in households to control TV sets, radios, lights, etc or to monitor outside temperature or the temperature of the oven. There are plenty of applications in households where a short range radio with low power consumption would be very useful.

With regards to the application, the most important features are: low power consumption so that a single battery can be used for several years. The radio should be set to stand-by mode by a base station to decrease the battery lifetime. In many applications it is not necessary that the uplink and the downlink be symmetrical. When reading the data from the sensor, a sufficiently high baud rate is needed (100 kbist/s) but when the base station commands the sensor to start sensing information, a low baud rate is sufficient (maybe 1 kbits/s). This means that the radio could be made so that it receives information slowly but it is able to send information to the base station fast.

When using bulk acoustic mode, a very stable and accurate reference oscillator can be constructed. In addition, using flexural modes tuneable oscillators to be used as local oscillators can be made. Not only oscillators, but also filters, mixer and parametric amplifiers can be constructed by using microelecromechanical components. Usually, frequency is limited to below 100 MHz. In addition, high bias voltage, as high as 100 V, is needed when using MEMS.

2.3 Preconditions

Technologies: Micro mechanics

There are three major technological alternatives to realise the mechanical building blocks of the micro system: bulk micro machining, surface micro machining, and SOI micro machining. *Bulk micro machining* is the most traditional choice where silicon is used throughout the overall wafer thickness. It provides high quality devices with essentially defect-free single-crystalline silicon as the structural material. *Surface micro machining*, on the other hand, makes use of deposited thin films with either amorphous or polycrystalline structure. They are not quite as perfect structural materials as a single crystal but are still often capable of providing adequate lifetime and stability. The materials choices are numerous in surface micro mechanics. *SOI micro machining* is a synergetic combination of the two aforementioned, with a single crystalline structure layer of limited thickness, typically 10–20 µm.

The micro system developed in this context must contain different parts. It requires a power source for operation, antennas to transmit and receive signals as well as signal processing functions. It would be a major advantage if all or most of those could be fabricated using a single technology. It appears that SOI has the biggest potential to fulfil the various functions needed, including the possible integrated electronic circuits. Even though it may prove too demanding to integrate the complete micro system monolithically in the time scale of this project, SOI is given preference due to its flexibility. Other options are still adopted whenever necessary.

Technologies: Integrated circuits

The integrated circuit technology has for a long time followed a steady path of constantly shrinking device geometry and increasing chip size. This development has been driven by the increased performance that the smaller devices make possible and the increased functionality those larger chips provide. Together, these performance and functionality improvements have resulted in a history of new technology generations emerging every two or three years, which is commonly referred to as "Moore's Law" [1].

It is estimated that line widths that are now around 0.1 µm will shrink to 0.02 µm by 2020. After this, basic physical laws start to prevent any further reductions in transistor size. Even before this, processing cost explosion may slow the progress down. A state-of-the art fab (0.8 µm–0.13 µm) costs about 2 billion euros in 2001 and it also follows some kind of "Moore's Law", constantly doubling over a few years. Because of rising fab costs, the trend is now to form manufacturing clusters instead of a single comprehensive manufacturing line. Companies specialise in certain process steps that they sell as services to other companies in the manufacturing net [2]. Also, fabless foundries, i.e. companies that do all the processing by subcontracting, are becoming more and more common.

Micro mechanics is thought to be an alternative to high performance and/or low cost with less demanding line widths and simple processes and structures for complex functions. Of course, there cannot be a micromechanical circuit in a strict sense. Electro-mechanical and opposite conversion has to be carried out at some stage, and this leads to the most crucial point of micro systems: mechanics and electronics co-integration.

However, in MEMS technology we are dealing with other aspects than shrinking the device and therefore the pace of progress will be set slower than the Moore's Law expects. Similar development like in dynamic range of A/D converters is expected.

Co-integration

A further issue is the combination of electronic circuits and micromechanical devices. They can be combined either at package level or at chip level. At package level there are several chips, one or more with electrical devices or circuits and one or more with micromechanical devices. These are connected together with interconnects, and either on a separate substrate or using one chip as the substrate for the other. The interconnects are done either by conventional wire bonding or by flip-chip bonding. In the latter, joints are made with small (30–100 µm) metal balls and the chips are mounted on the substrate (or other chip) component side down.

Other package issues are dealt with in the packaging chapter below.

Th ultimate goal is to integrate electronics and micro mechanics in one chip, to make a system-on-chip (SoC). Up to now, efforts to combine on-chip micro mechanics and electronics have not been very successful because of severe compromises that have been necessary for process reasons, either on the mechanics side or on the electronics side. A lot of process development is going on however, and the future trend clearly is to develop joint processes that are free of compromises.

Radio architectures and antennas

The true potential of the MEMS technology is not yet clear. Nevertheless, it is obvious that it may not cause its most important impact at the component level but at the systems level, by offering alternative transceiver architectures that emphasise selectivity over complexity so as to substantially reduce power consumption and enhance performance. In the modern transceivers, higher levels of transistor integration and alternative architectures are used to reduce the need for the off-chip, high-Q filters and resonators, with obvious size advantages [3]. However, transistor integration may cause some disadvantages such as increasing the power consumption or reducing the device performance due to e.g. active filter semiconductor non-linearity.

The most obvious way to use MEMS technology is to apply it to the RF circuit architectures by substituting the conventional devices with micromechanical ones, i.e. imitating the operation of a microelectronic device/block by a micromechanical equivalent. This will probably lead to a good performance in terms of certain parameters. However, it may be relatively difficult to achieve an acceptable performance in terms of many other parameters, at least in the beginning whilst the technology is still being developed. Some examples of conventional RF devices that may be realised with the help of micromechanical technology are antennas (above about 10 GHz), antenna switches for diversity operation, phase shifters in smart arrays, antenna duplexers and transmit/receive switches, high-Q filters, adjustable matching circuits (micromechanical impedance tuners) and resonators for voltage controlled oscillators.

Micromechanical technology may also be applied to such RF circuit architectures that are not revolutionary but that have been difficult, expensive or unpractical to realise with other means. An example of such a development is a parallel receiver, where a multi-standard capable software defined radio is implemented by adding a switch-coupled parallel filter bank before the front-end low-noise amplifier (LNA) to select the active frequency band [4]. Another example is a massive parallel-switched array of very narrow-band tiny micromechanical filters deposited between the antenna and front-end amplifier of a receiver, which function as tuneable channel selection filters. With such arrays, very resilient frequency-hopping spread spectrum transceivers can be envisioned [5]. A multi-slot antenna with micro machined switches for reconfigurable resonances has been introduced by the University of Michigan [6]. A reconfigurable antenna has also been made through moving micro machined antenna elements by micro actuators to steer the radiation pattern at 17.5 GHz [7].

It is also probable that MEMS technology will offer good opportunities to develop novel RF circuit architectures. Such a paradigm shift emerges only under certain conditions. Basically, when a new kind of technology with new kinds of characteristics becomes available, it is possible to see really original developments. Utilising high frequency micromechanical technology, new functional architectures for amplification, mixing and digital signal processing are being developed. Already a micromechanical mixer-filter for RF signals from 40 to 200 MHz, based on the non-linearity of the voltage-to-force capacitive input transducer, has been introduced [8].

Technologies: Packaging

Packaging issues are very important and challenging for the applicability of high frequency micro systems. In many cases, packaging is the crucial barrier to realising commercial products. The successful packaging of micro electromechanical systems (MEMS) can seldom exploit the traditional IC packaging practices due to the special packaging requirements of these components. Although the MEMS components are mainly based on silicon processes, they usually differ very much from ordinary ICs with respect to packaging and interconnection. They are usually very sensitive to mechanical or thermo-mechanical stresses and very often there are restrictions or special demands for the materials in connection with the component. At very high frequencies, there are also restrictions for the electrical characteristics of the materials and for the types of interconnections to allow the proper operation of the system. One big challenge is related to the cost of packaging. In order to find real applications aimed at everyday life, the packaging costs must not overcome the other cost factors of the technology. The actual packaging concept and the size of the construction depend on the selection of the components needed for the system. If the system includes several components, the most promising packaging concept is the so-called SOP (system on package) concept which utilises modern high density circuit boards together with small size active components i.e. bare dies or CSP components.

Allowable frequency bands

Table 2.1 [9] gives the frequency bands and power levels allocated for short-range radio devices (SRD), mainly in Europe but also in America. No license is needed if the device operates within the given bands and power. Further global harmonisation of the regulations of SRD communication is needed. For example, the widespread acceptance of RFID (radio frequency identification) systems is hampered by the lack of harmonised regulations.

With the VHF (30–300 MHz) and UHF (300–3 000 MHz) bands there is only one band that is accepted worldwide, i.e. the 2.45 GHz ISM (Industrial Scientific Medical) band. In this band, however, the allocated radiated power is only 0.5 W in Europe whilst in the US a power of 4 W is allowed. A 0.5 W power limit is too low for many applications. The 2.45 GHz ISM band will be crowded in the future: Bluetooth, WLANs, RFIDs, and other SRD systems are operated in this band. At frequencies below 1 GHz there are no common frequency bands. In Europe, the most used band will be 869 MHz, whereas in the US the corresponding band is around 915 MHz. Again a much higher power is allowed in the US (4 W vs. 0.5 W). Because the frequencies above 900 MHz are reserved for GSM in Europe, a discussion focused on allocating band of 865–868 MHz with a power of 2 W to SRD is going on.

Table 2.1. Frequency bands power levels allocated for SRD in Europe. Some American bands are also given.

FREQUENCY BAND	POWER, LIMITATIONS, REGION
125 kHz	Inductively coupled RF tags
1.95, 3.25, and 8.2 MHz	Inductively coupled theft tags, worldwide
13.56 MHz	Inductively coupled RFID tags, worldwide
27 MHz and 40 MHz	0.1 W ERP, Europe
138 MHz	0.05 W ERP, Duty cycle < 1%, Europe
402–405 MHz	Medical implants, 25 µW ERP
433.05–434.79 MHz	25 mW ERP, Duty cycle < 10%, Europe
468.200 MHz	0.5 W ERP, Europe
869.40–869.65 MHz	0.5 W ERP, Duty cycle < 10%, Europe
902–928 MHz	4 W EIRP, America
2 400–2483.5 MHz	ISM band, 0.5 W EIRP Europe, 4W America, Bluetooth
5 725–5 875 MHz	25 mW EIRP
24.00–24.25 GHz	0.1 W EIRP (Police radars)
61.00–61.50 GHz	0.1 W EIRP
122–123 GHz	0.1 W EIRP
244–246 GHz	0.1 W EIRP

EIRP = Equivalent Isotropic Radiated Power
ERP = Equivalent Radiated Power

Juridical and ethical constraints

With the advent of wireless technology applications, massive amounts of RF-micro modules will be produced for people's everyday environment (homes, offices, airports, factories, hospitals etc.). This process will lead to the emergence of many kinds of unforeseen circumstances that should be investigated thoroughly beforehand. One of the most harmful sequel for a private individual (or a company) may be the potential to control and spy on one's activities through radio waves. It is also of utmost importance to study the health risks of the radio frequency power to which the population may be exposed when large amounts of low-power transmitters are operating in the vicinity. Another problem, related to standardisation, may be the cumulative radio frequency disturbances rising from these devices to other devices or systems. Of lesser degree is the question as to whether an individual should allow his/her property to be used by other individuals, which will happen when signals hop from an RF-micro module to another one in an ad hoc network, using the capacity of one's terminal and decreasing the potential of one's battery.

Environmental concerns also present a number of technology issues for RF-micro modules. The major challenges are to minimise the environmental impact of products at the end of their life and enhance their disposal or reusability. Significant attention needs to be devoted to eliminating the identified hazardous materials throughout the electronics infrastructure by identifying, developing and qualifying alternatives [10].

2.4 International development and measures

General roadmap

"Would you tell me please, which way I ought to go from here," asked Alice.
"That depends a good deal on where you want to get to," said the Cheshire Cat.
"I don't much care where -" said Alice.
"Then it doesn't matter which way you go," said the Cat.
" -so long as I get somewhere," Alice added as an explanation.
"Oh, you're sure to do that," said the Cat, "if you only walk long enough."

Roadmap generation on integrated circuits technology is quite a straightforward task. For the last thirty years, the industry has followed a statistical regression curve called "Moore's Law", which is a result of individual small process development steps all targeted at the same goal: the shrinking of line width. The driving force on the applications' side has also been the same all this time: memories and processors.

On the other hand, micro mechanics is a technology still in an emerging phase. There is no such paradigmatic parameter in micro mechanics similar to line width in IC-technology. There are several possible process technologies and there are several fields of applications, of which many are still surveying possibilities, with no established concepts or products. Therefore the situation is like that of Alice in Wonderland: no clear idea of where to go and which road to take. Therefore very few, if any at all, general roadmaps are being published for micro mechanics.

Within the EU project NEXUS (Network of Excellence in Multifunctional Microsystems), one project has carried out surveys on the possibilities and development of micro mechanics. Within the US benchmarking mission, 19 industrial companies, 3 universities, 4 research institutions and representatives of SEMI, DARPA, NFS and NIST were interviewed. The conclusions regarding Microsystems Technology (MST) were [11]:

- MST is an application-specific technology, in contrast to IC technology. Different technological approaches are being successfully employed. Discussion on standards is too early. There is little resemblance between IC technology and

MST. MST/MEMS will not affect innovation to the same extent and the same pace as microelectronics; the replacement of devices by new generations will be slower.

- The main business is conducted using bulk micromachining; however, some organisations with a background in IC technology are trying to use surface micromachining for high volume low cost products.
- Hybrid approaches are normally seen as the best solution; the monolithic approach is an exception.
- A fab-less factory is an exception: it is believed that the development and manufacture must be in one hand.
- Co-operation between universities and the industry is essentially restricted to the feasibility level, and usually stops when it comes to development. There is a complete absence of confidence in designs coming from universities.
- The technology drivers in the beginning were ink jet print heads; later on, it was automotive technology and there is now a shift towards biotechnology and towards biomedical applications.

As can be seen, there is nothing on SOI micro mechanics and nothing on RF MEMS.

There is a NEXUS MEMS roadmap under construction: see The NEXUS Microsystems Roadmap – Intermediate Report (January 2000) [11]. It is application-oriented, telecommunications as one application field. However, the intermediate report had detailed results and roadmap figures only in the Automotive application field. There was also in [11] a mention about a roadmap being under preparation at SEMI, but at the time of writing, this it is not yet available from SEMI.

The NEXUS MST Market Analysis 2002, Executive Summary [11] has some market forecasts. Figure 2.1 displays the predicted growth of the whole market. Inkjet print-heads, read/write heads for hard disk drives, cardiac pacemakers, hearing aids, test strips for in vitro diagnostics, pressure sensors and accelerometers form the products with the largest market share. In Figure 2.1 these are labelled as "MST Products".

In addition, the study [11] predicted that over the years 2000 to 2005, a number of new products would emerge. Although there was no reliable information for such products until 1998, the study predicts their introduction on the market within the next 5 years; typical examples include micromachined flat panel displays, the optical mouse, components for optical telecommunications, RF-MEMS, implantable drug delivery systems, and bio-chips and fingerprint sensors. These are labelled as "Emerging MST Products" in Figure 2.1.

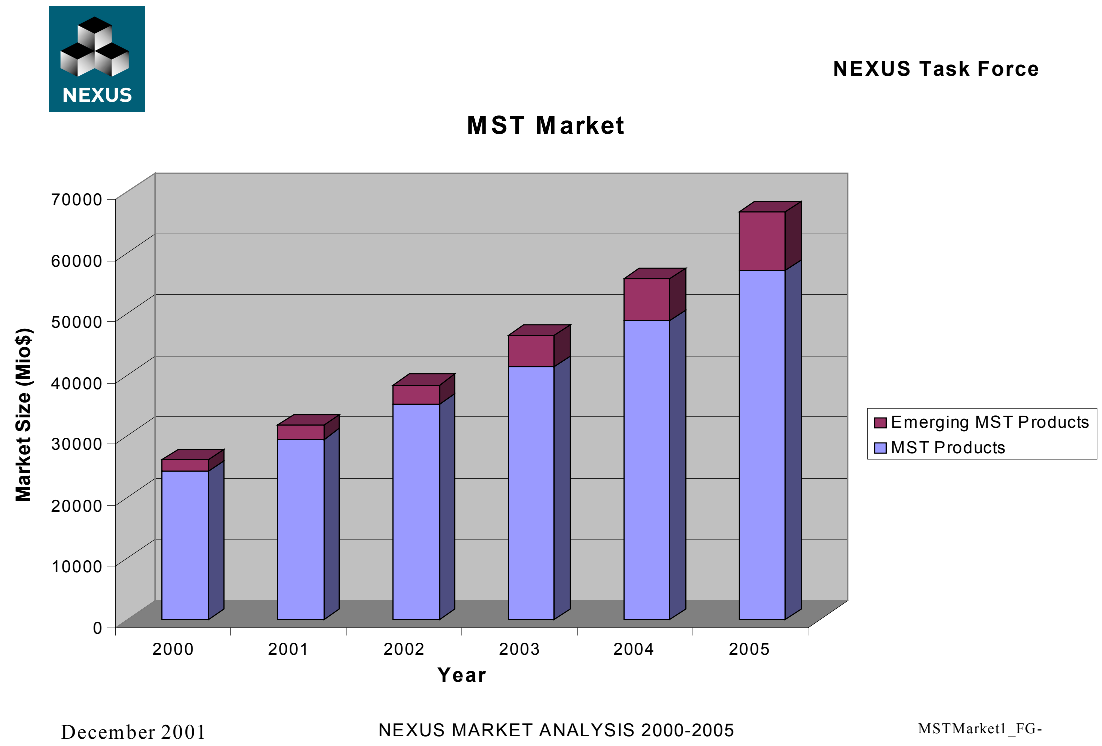

Figure 2.1. A market roadmap for Micro System Technology (MST) products.

The predicted markets for different application fields for the years 2000 and 2005 are shown in Figure 2.2 [11]. One can see that telecommunications applications are still in an emerging phase in 2005, with roughly a US$2 billion market compared to a peripherals market of about US$40 billion.

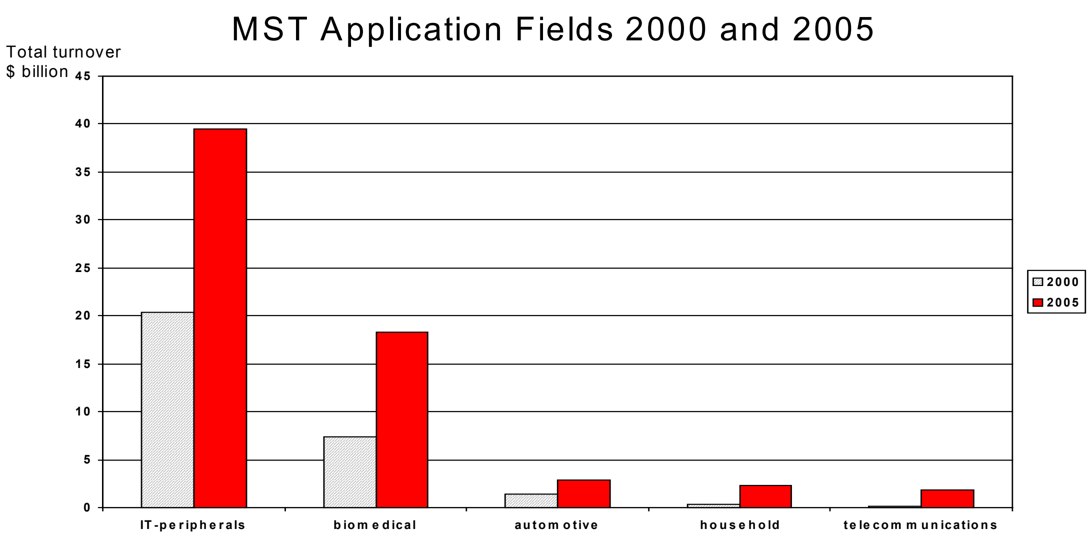

Figure 2.2. Micro System Technology (MST) markets for different application fields.

Short range radio development scenarios

Of the commercial concept available today, Bluetooth is a competitor to the development proposed in this paper. The Bluetooth transceiver is a standard for short-range wireless communication. Bluetooth systems are, however, not well suited for the applications targeted here. Bluetooth radios cost more that 10 euros and consume more than 100 mW. The PicoRadio being developed by Berkeley University is the closest match to our development. It is expected to be ready for commercialisation in a few years.

PicoRadio

For supporting ultralow-power wireless networking, Berkeley University has initiated the PicoRadio project [11]. It is mainly targeted at the sensor market. The technologies developed include multi-hop networks and media-access layers that support low, variable-rate data transmission and low energy-consumption. Other issues involve the choice of the platforms and chip architectures that enable the implementation of new algorithms. The PicoRadio concept includes low cost (< 50 cents) transceivers for ubiquitous wireless data acquisition that minimizes power dissipation. Specifically, the project is striving to

- minimize energy (<5nJ/(correct) bit) for energy-limited source
- minimize power (<100μW) for power-limited source
- enable energy scavenging

The PicoRadio uses the following strategies:

- self-configuring networks
- fluid trade-off between communication and computation
- Integrated SOC approach, aggressive low-energy
- architectures and circuits

By the end of 2002, the PicoRadio project will develop a single chip for ultra-low power PicoNode, as well as custom low power application, protocol, network, and physical layers implemented on flexible low-power computation fabrics.

2.5 Milestones

The development towards microelectromechanical radio proceeds on three fields of activity that gradually merge together to construct a true system on chip (SoC) – or on a couple of chips – a MEMS radio.

The fields of activity are:

- Design
- Hardware Design
- System

Design

At the moment, there are as yet no established or "standard" MEMS design systems, especially not for RF MEMS. With design, new models for micromechanical structures are needed, especially for RF simulations. The development of models goes together with the development of structures. In addition to proper models, a reliable design needs an efficient and easy way to extract the model parameters and their deviation range for a particular design or process.

The design tools should be suitable for a fluent electronics-mechanics co-design, also in the RF regime. Some tool development is also needed. A new methodology for optimised co-design must be developed. All these developments will form, when they are ready, an efficient design system for RF MEMS radio. This will take at least one year to reach a practical level.

Hardware Design

Effective RF MEMS structures need both process and device structure development. Also, at least some capability of monolithic electronics and mechanics integration would be feasible. Otherwise interconnection problems would kill the ideas – especially the simple and low cost ideas – both technically and economically. At the moment there are no good processes for monolithic integration. Much work is going on in this field around the world but the results are still awaited.

Many of the proposed new devices or structures are still at the level of theoretical ideas. Much experimental work is needed before usable components are at hand. Process and device development is slow, and it will take two to three years before the new ideas are realised at a usable level practically. Because of this slow progress, the model and design development must be done together with the device development, even at the risk of some extra work because of non-stabilised device design.

System

The new architectures need much analysis and refinement before they are at the stage of realisation. A totally new thinking must be developed because of the micro mechanics starting point and reference frame. System, applications and device development must be in constant mutual interaction to see what is needed and what is possible.

The packaging of the MEMS radio needs development both at hardware and at system level. There are several, partially contradictory, requirements for the packaging of the radio: good RF characteristics, small size, possible vacuum for the mechanics and low price. The packaging solutions must be designed together and in interaction with the system development.

Putting all together

The goal of the development is a real system on chip: SoC – or "SofC" system on a few chips – with different technologies and physical paradigms combined together on a single integrated system.

The described development scenario is presented in a roadmap form in Figure 2.3.

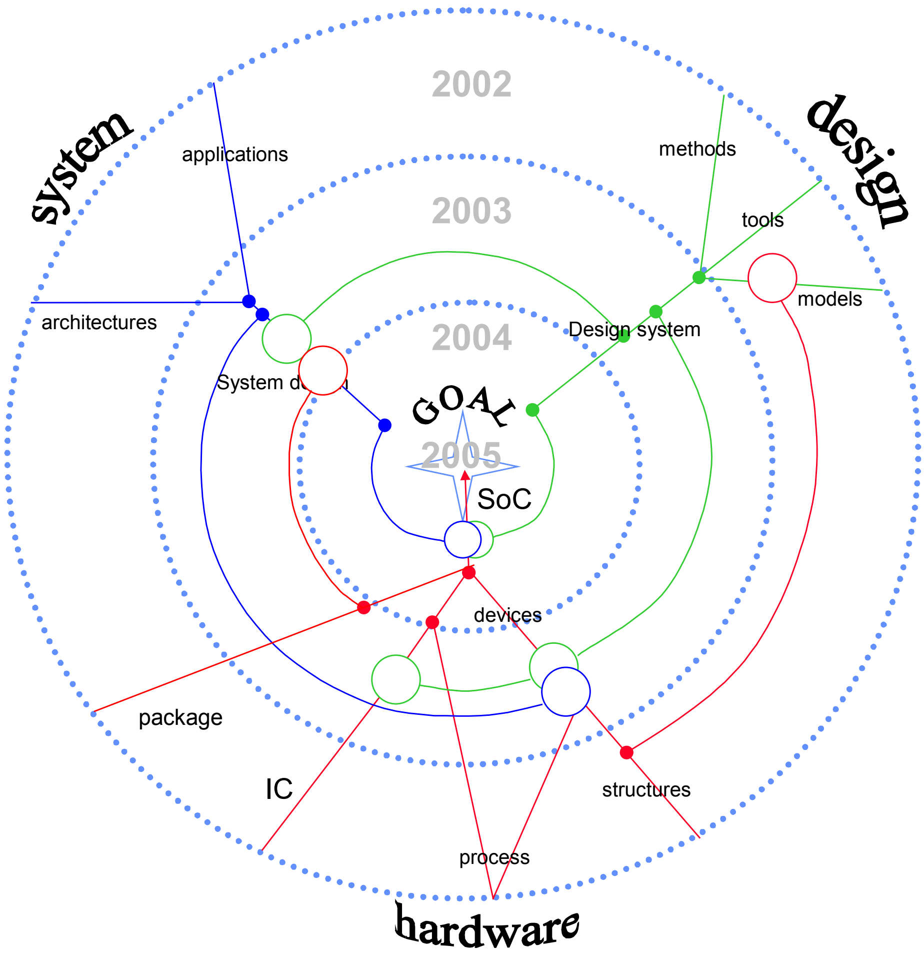

Figure 2.3. A technology development roadmap for a monolithically integrated MEMS system.

2.6 Summary

We have presented a development scenario for a MEMS radio. The idea is to generate a radio design from the starting point of micro mechanics, using its possibilities in an optimum way and not only making replacements for existing electrical devices or blocks. The first field of application is seen to be within short range wireless logistics and instrumentation communication.

It is seen that a lot of development and even basic innovations must be done in all fields of development: in design tools and methods, in device structures and processing, in system architecture, design and packaging.

If the goal is reached, it will pave the way to a new area of industrial applications and mass production.

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3. Service Architectures

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Palveluarkkitehtuurit

Tiivistelmä (Finnish summary)

Palvelulla tarkoitetaan yksittäisen laitteen tai järjestelmän kykyä vastata toisen laitteen tai järjestelmän vaatimukseen/pyyntöön siten, että vastauksesta on hyötyä sitä pyytäneelle. Palveluarkkitehtuuri on niiden käsitteiden, periaatteiden, mallien, ohjelmistojen ja ohjeiden joukko, jotka mahdollistavat palveluiden toteutuksen ja hallinnan. Tulevaisuuden tiedonsiirtoteknologiat -teemassa keskitytään verkkopalveluihin, eli verkon tiedotiedonsiirtokykyjen kehittämiseen siten, että heterogeeniset päätelaitteet ja järjestelmät saavat tarvitsemansa tiedonsiirtopalvelut. Sovelluskohteita ovat niin liikkuvan käyttäjän sovellukset ja kotiverkot kuin liikkuvien koneiden ja joustavan tuotannon ohjaussovelluksetkin.

Heterogeeninen solmu (käyttäjä, kone, laite tai agentti) käyttää sovelluksellaan tiedonsiirtoverkon palveluja, jotka on rakennettu palveluarkkitehtuurin mukaisesti. Palveluarkkitehtuuri on siis sovelluksen ja verkon välissä oleva ohjelmisto, middleware, joka on riippumaton käyttöjärjestelmästä ja piilottaa hajautuksen sovellukselta. Välitason ohjelmisto hyödyntää tunnettuja ohjelmistokehitysmenetelmiä, komponenttimalleja, suunnittelumalleja ja hajautusarkkitehtuureja.

Tiedonsiirtopalveluissa Internet ja matkapuhelimen toiminta eri tukiasema-alueilla on nykypäivää. Suurin osa sovelluksista on rakennettu asiakas-palvelin tai julkaisija-tilaaja-mallin mukaan. Mikäli halutaan tarjota palveluita dynaamiselle ja heterogeeniselle järjestelmä- ja laitejoukolle, monimutkainen järjestelmä hajautetaan parviälyä (swarm intelligence) ja moniagenttiarkkitehtuureja hyödyntäen, jolloin tiedonsiirto tapahtuu vertaisverkossa (peer-to-peer).

3.1 Introduction

The general future architecture of a mobile telecommunication system can be represented for example as shown in Figure 3.1. The architecture is based on the widely accepted assumption and consensus that the wireless and mobile access systems will converge with Internet systems. This trend is shown, for example, from the initial commercial versions of 3G that will soon arrive on the market and converge the cellular wireless mobile world and Internet to form a mobile Internet. There is also quite a clear consensus in the service architecture/service infrastructure working group of WWRF (Wireless World Research Forum) about all-over-IP services, appliances and applications.

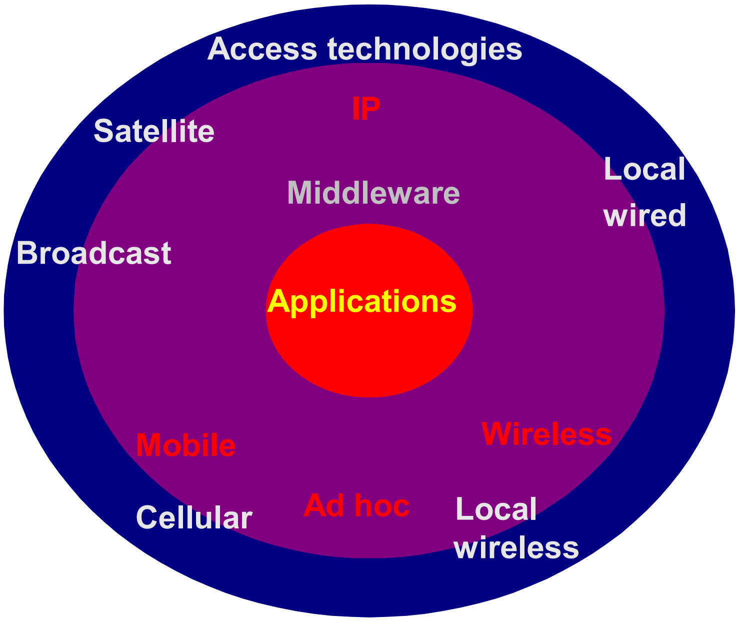

Figure 3.1. General architecture of mobile Internet systems.

The *service architecture* refers here mostly to the architecture of applications and middleware, although it has been seen that the IP and *access technologies set requirements and challenges for the service* architectures. Mobile Internet applications are executed with *middleware*, the software that

- locates between applications and network layers,
- is independent from operating system(s), and
- hides distribution from applications.

Internet protocols (IP) form the IP networks, which today are based on IPv4 and tomorrow most likely on IPv6. Internet protocols are executed on top of wired and wireless access technologies such as, for example, 3GPP accesses, wireless local area networks (WLAN) and Bluetooth. Thus, the *service architectures* include both the aspects of mobile system architecture (mobile computing) and the aspects of service software architecture (software engineering). A service is the capability of an entity (the server) to perform, upon request of another entity (the client), an act that can be perceived and exploited by the client. Service architecture is a set of concepts and principles for the specification, design, implementation and management of software services.

In the near future, software business will change too. Software products and services can be classified in four categories: infrastructure software services, business applications, information delivery services and others. The first category is the largest one, representing more than half of the market. In the next few years, the maturing of software solutions is going to extend the global software market. With global software market, generic infrastructure and middleware services will be the hot topic, as well as software solutions for application integration and information delivery software for communication and collaboration. Quality of services becomes a vital factor for software purchasing decisions, ASP (Application Service Provider) is becoming a core area of business for integrators and open source movement will continue in platforms.

Pervasive computing and rental (ASP) software-based services will constitute major shifts within the next five years. Pervasive computing provides any information service or application to any device over any network in an integrated and personalised way. Application services are a collection of co-operating services that deliver personalised functionality to support the user's activities. These services are executed in distributed devices and machines that are connected wirelessly and recomposed dynamically. Heterogeneity of devices, access technologies and services requires adaptive solutions and user-driven management of heterogeneity in an easy way. Therefore, pervasive computing needs a new service architecture that also supports service engineering, i.e. service creation, control and execution of local and remote services that can be personalised according to the needs of the end-users.

Chapter 3 presents VTT's future activities in the research area of service architectures. The roadmap of the service architectures research presented here is based on the related enabling technologies, standardisation and international research activities as well as the research challenges identified during the survey of the state-of-the-art service architectures and future challenges of mobile Internet systems services.

3.2 Future research activities

Future research activities in the area of service architectures are based on the vision of Cyber Space (Figure 3.2). In Cyber Space a human, any type of machine, agent or service is able to communicate in a unified way, share any type of information in a meaningful form, co-operate anywhere in real-time by using available tele-communication services. The aim of Cyber Space is to provide the relevant service in the right form anywhere and at any time the service is needed by humans, machines or agents. Therefore, the objective of the *Service Architecture Framework* is to support users subscribe to, and pay for, an open set of services. As a framework, the Service Architecture Framework provides a skeleton for co-operating services with an integrated set of components that can be reused and customised.

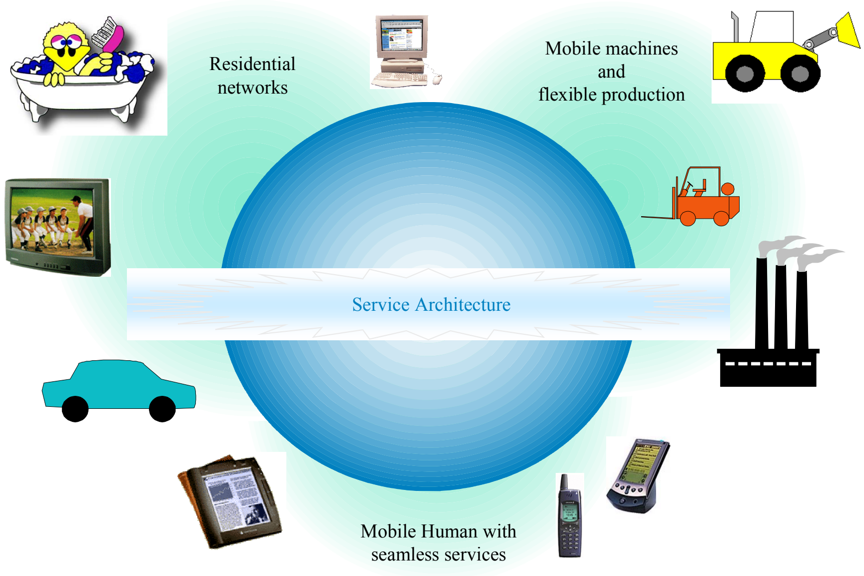

Figure 3.2. Vision of future seamless services. Heterogeneous networks provide (communication) services for heterogeneous mobile nodes, which are either human, machines, devices or agents.

3.3 State of the art

In this section, we describe the state-of-the art, i.e. enabling technologies, standardisation and ongoing research activities related to service architectures (Figure 3.3).

Enabling technologies

Enabling technologies of heterogeneous networks that constitute the basis of service architectures are classified in four categories: generic software technologies, application level technologies, service level technologies and infrastructure level technologies. Generic software technologies concerning software engineering methods, architectural styles and patterns as well as component models and appropriate languages are used at the application level as well as at service and infrastructure level.

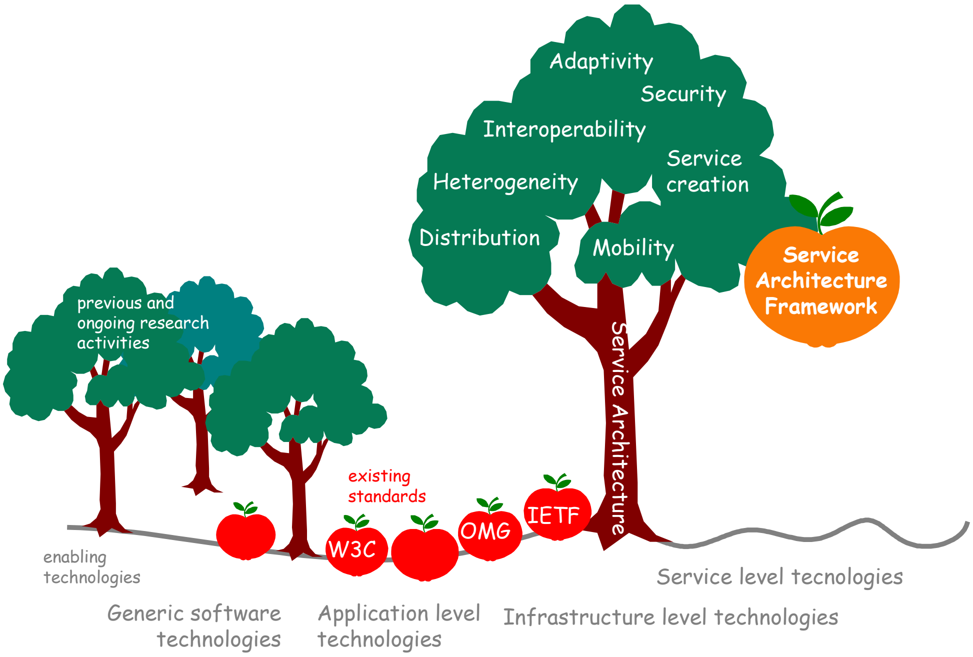

Figure 3.3. State-of-the art and future challenges of service architectures.

Generic software technologies

- Object-oriented engineering methods (e.g. UML (Unified Modeling Language))
- programming and interface languages (e.g. Java, C++, IDL (Interface Definition Language), XML (EXtendable Markup Language))
- component models (e.g. COM+ (Component Object Model), EJB (Enterprise Java Beans))
- architectural styles and patterns (e.g. the implicit invocation and object-oriented styles, an observer pattern)
- architectural viewpoints (e.g. structural, behavioural, deployment and development viewpoints)

Application level technologies

- web technologies (HTML, XHTML, WML, XML)

Service level technologies (middleware)

- service communication interfaces (OSGi, HAVi)
- service architecture APIs (VHE OSA, Parlay, JAIN, Jini)
- security technologies (SSL, PKI)
- session technologies (SIP, TINA)

- distribution architectures (ODP (Open Distributed Processing), CORBA (Common Object Request Broker Architecture))
- distribution technologies (e.g. RPC (Remote Procedure Call), RMI (Remote Method Invocation), MOM (Message-Oriented-Middleware))

Infrastructure level technologies

- mobility technologies and protocols (MIP, IPv6, Fireware)
- wireless networks (WLAN, Bluetooth, HomeRF/SWAP)
- cellular networks (2G, GPRS/EDGE, 3G, 4G)
- ad hoc networks (Bluetooth, Manet)
- wired networks (Powerline, cable, xDSL, IP over Fibre)

Standardisation activities

Several standardisation forums are active in the topics related to the Service Architecture Framework. However, there are other related standardisation groups not included the following list, which gives only an overview of current activities:

- OMG (Object Management Group): OMG's aim is to set vendor-neutral software standards and enable distributed enterprise interoperability. The most important topics related to the Service Architecture Framework are UML (Unified Modelling Language), MOF (Meta Object Facilities), XMI (Meta Data Interchange) and the telecommunications domain task force.
- IEEE AWG (Architecture Working Group): Initial standardisation has been started by Recommended Practice for Architectural Description of Software-Intensive Systems.
- FIPA (The Foundation for Intelligent Physical Agents): The mission of the Architecture Technical Committee is to construct abstract architectural specifications that provide a framework which includes services necessary to support the end-to-end interoperability of agents.
- ETSI (European Telecommunications Standards Institute)
- ITU (International Telecommunication Unit) [12]: Open Distributed Processing – Basic reference model, protocol support for computational interactions
- IETF (Internet Engineering Task Force) [14]: IPv6, IMPP, SIP
- 3GPP: VHE/OSA

- Parlay (Parlay Group) and JAIN APIs (Sun) for the development of telecom products and services
- OSGi [13], the Open Services Gateway initiative for delivering services between the external Internet and local devices

- W3C [15]: The World Wide Web Consortium develops interoperable technologies to boost the Web as a forum for information, commerce, communication, and collective understanding.

Software architecture is an abstract and overall design description of a system integrating different issues that are separate but have a contrary influence on each other. Component-based software architecture is a structure of the system including software components, the externally visible properties of those components and relationships between them. Stakeholders, i.e. people and organisations that are interested in the development of systems, have different needs that they wish the system to provide. Therefore, the software architecture seeks to achieve a balance between understandability, functionality and economy and provides the basis for independence and co-operation of software components. A layered architecture style follows a traditional bottom-up software architecture that decomposes software hierarchically. A new service architecture style may be based on a set of architectural styles that use asynchronous message-oriented communication instead of synchronous procedure calls.

Contrary to software architecture, a system architecture is an architecture that consists of a set of platform decisions, a set of component frameworks, and interoperation design for these component frameworks. From the viewpoint of software architecture, adaptability is a quality attribute of the service architecture and is the most important quality of middleware services in future networked systems. Therefore, the development of adaptive agent-based services of middleware needs a set of predefined viewpoints of software architecture and its own architectural style and patterns.

The OMG Telecom Task Force currently focuses on six main topics: network management, open service marketplace, mobility services in CORBA, Generic services, CORBA core extensions and UML for telecom. In the near future, it may also concentrate on security for telecom and CORBA/Java inter-working.

The Internet world is based on the assumption that network is not intelligent, but the intelligence is in the hosts located at the edges of the network. Today, the network centric mobile telecom world and host centric internet world are converging. IETF is making new versions of Internet protocol (IPv6 and its evolution) to support hand-overs required by the mobile world so that the internet protocol can be applied to mobiles. Also IETF is including support for ad hoc networking into the IP protocol. In addition, IETF is developing multimedia protocols to better support multimedia applications. IETF/IMPP defines protocols and data formats for an internet-scale end-user presence awareness, notification and instant messaging system.

Ongoing 3G/IETF standardisation focuses on converging the Internet, wireless and cellular systems to form a working mobile internet. We will see in the near future (0 to 3 years) how the already existing initial 3G mobile Internet standards and the forthcoming implementations work in practice. The same is also true for the residential automation environments based on the existing internet and available wired/wireless access technologies. While discussing the goals for research (3 to 10 years) the focus shall be on the systems beyond 3G.

Research activities and future research items

Finnish research programmes

In Finland, the National Technology Agency, Tekes, together with a number of companies, has launched several research programmes around future telecommunication technologies:

- User-Oriented Information Technology USIX 1999-2002. USIX is a multi-discipline technology programme set up to increase Finnish know-how in the development of products, applications, services and contents based on information and communications technologies.
- Networks of the future, NETS 2001-2005. NETS will support and maintain the leading position of Finnish development in the areas of wireless systems and broadband packet switched networks. The program will also speed up the exploitation of new networks by funding the associated development of service and application concepts.
- Intelligent Automation Systems, 2001-2004, concentrates on the new technological challenges and software development in automation.
- Miniaturisation of electronics, ELMO, 2002-2006. ELMO focuses on hardware-related software solutions, ubiquitous computing and generic middleware services.

European research programmes

The Fifth Framework Programme of the European Commission has both thematic and horizontal programmes for research and technological development. Service architectures are covered in the Information Society Technologies (IST) programme. IST has a vision of an ambient intelligence landscape where computers, interfaces and networks are integrated into the everyday environment and provide a multitude of services through easy and natural interactions. Prioritised research topics of new IST projects include

- developing and validating open architectures and tools to allow for the provision of a variety of networked services, paying special attention to service management and the development of middleware,
- novel architectures for interoperability, scalability, multilinguality, dependability, and user-centred design principle, and
- extending residential appliances to better support their interoperability, and the access to and from the global Internet.

IST will be important also in the Sixth Framework Programme 2002–2006 of the European Commission. According to the proposals, the most relevant research topics for service architectures will be:

- New software technologies for service creation and control environments, which underline scalability, reliability and self-adaptation. These technologies will address new strategies, algorithms, tools, and middleware for systematic and accurate design, prototyping, control and management of complex distributed systems.
- Mobile and wireless systems and networks beyond 3G, where software technologies and architectures ensure co-operation and seamless inter-working at service and control planes of multiple wireless technologies over a common IP (Internet Protocol) platform.
- Electronic and mobile commerce targeted at interoperable services across heterogeneous networks. This will include anytime-anywhere trading, collaboration, workflow, and electronic services covering the whole value creation cycle of extended products and services.
- Research on security technologies for trust and confidence.

Information Technology for European Advancement (ITEA) has a futuristic vision for software-intensive systems that include groups of products and components controlled by, and interacting with, the world through software. The development of intermediation services and infrastructures for home environments and mobile use are also the objectives of ITEA.

Other directions on pervasive computing and service architectures

DARPA (Defence Advanced Research Projects Agency) is the central research and development organisation for the Department of Defence (DoD) of the United States.

DARPA aims at wireless ubiquitous computing and has launched several research projects with the following topics:

- The concept of an invisible "personal information aura" that spans wearable, handheld, desktop and infrastructure computers.
- An information utility that is able to operate on a planetary scale.
- A system that is as available as air, and as such pervasive, embedded, nomadic and eternal.
- Self-organising and highly reliable information systems that will allow users to focus on the task at hand while the great majority of the computing and communication tasks fade into the background.
- Next generation systems software for pervasive computing environments with high quality, performance, availability, maintainability and survivability.

Wireless Village Initiative, established in April 2001, intends to define and promote a set of universal specifications for mobile instant messaging and presence services (IMPS). Wireless Village focuses on establishing architecture, protocol and test specifications for IMPS. These specifications are targeted to play a significant role in the development of 3G applications.

VTT's research activities on service architectures

VTT has investigated service architectures in several international ACTS, IST, Eureka and Eurescom projects.

- The DOLMEN (ACTS/EU) project developed, validated and promoted a service architecture for open provision of communication services over both fixed and mobile, heterogeneous and multi-provider telecommunication networks.
- ABS (ACTS/EU) focused on the design, specification, implementation and validation of an open broker architecture to permit the efficient provision of online information services, in the context of electronic commerce.
- The Eurescom Services Platform project P715 provided perspective on how middleware technologies based on TINA concepts can be exploited to provide value-added services on top of bit transport and basic services to the customer.
- MONTAGE (ACTS/EU) applied software agent technology to service provision in an environment that involved mobile users and multiple competing and co-operating service retailers.

VTT's ongoing research activities on services architectures, software engineering and residential and industrial production environments are as follows:

Service architectures

- The PLA programme, funded by VTT [21], focuses on quality-driven architectural design and analysis methods and new architectural styles and patterns for intelligent agent-based services.
- The MOOSE project (ITEA/Eureka) will aim at developing design and analysis methods for middleware services and hardware-related software.
- The VESPER (IST/EU) project defines, demonstrates, and validates a service architecture for the provision of a Virtual Home Environment across a multi-provider, heterogeneous network and system infrastructure.

Service engineering

- The WISE (IST/EU) project focuses on the development of service architecture, agent-based services and service management. Strong attention is paid to heterogeneity and adaptability of networked services.
- P925 (EURESCOM) focuses on the "Internet Middleware" in order to provide operators with additional capabilities for selecting and integrating third party commercial software components and services to offer customised interactive multimedia service bundles to Internet/intranet users.
- P920 (EURESCOM), UMTS Network Aspects, aims to investigate in detail the current mechanisms and protocols that are used to provide service support in the mobile environment, and investigate whether the next generation IP suite will provide secure service provisioning and interworking across heterogeneous access networks.

Residential environments

- The VHE project (ITEA/Eureka) is focusing on residential services in wired and wireless networks, the service architecture and the development of services for the OSGi environment.
- Future Home is a research project to study wireless network architecture solutions for home networks. The key technologies of the project are WLAN, Bluetooth and IPv6.
- Current research activities in the Future Home project include the definition of the requirements and architecture for a wireless, IPv6-based residential network that

supports secure stream and control traffic between home appliances and also external Internet nodes.

Industrial production environments

- VTT has integrated the real time control of physical devices such as an AGV (Autonomous Guided Vehicle) or a robot into extranet applications, where a remote user can monitor or control devices at the a task level in a graphical user interface on his/her common browser.
- Co-operation of heterogeneous devices has already been studied in the international Holonic Manufacturing Systems (HMS) consortium, where our case was a surface treatment cell with one hydraulic robot and another simulated one.
- Co-operation of several AGVs on a factory floor has been developed with agent technologies and simulated by QUEST tools (Mascada/EU).

3.4 Road map of service architectures

This section lists the research challenges that must be tackled and solved in order to gain comprehensive open service architecture for pervasive computing (Figure 3.4).

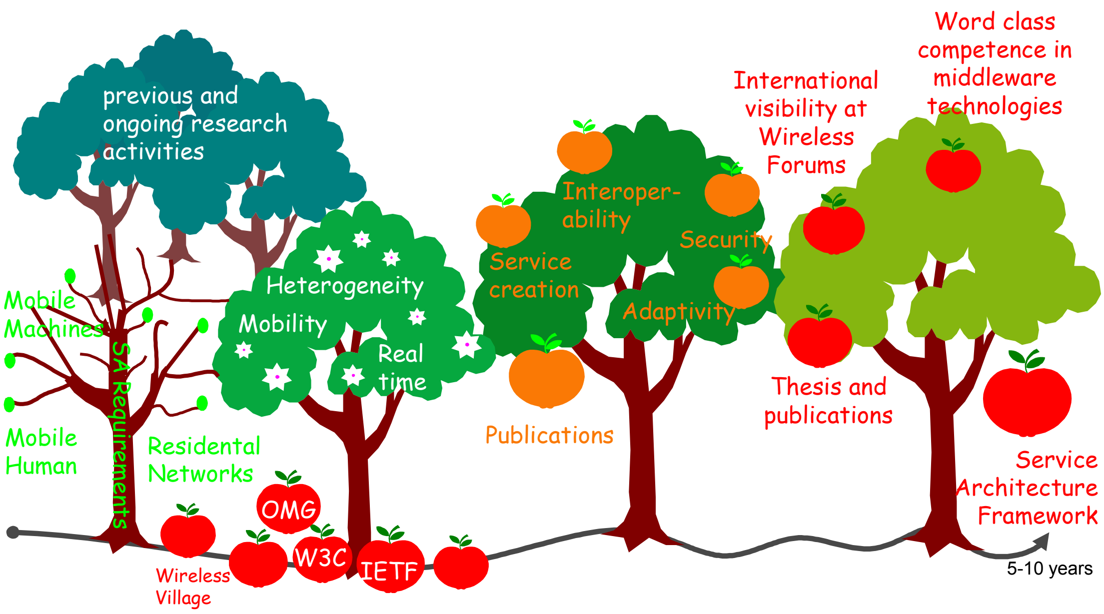

Figure 3.4. Road map of the Service Architecture Framework.

Business models

The currently applied telecom and Internet service architectures are not sufficient for ubiquitous computing. For example, as network operators do not provide all services, new business roles emerge to develop and provide services. Open stable interfaces are needed between these roles.

Heterogeneity

Service architecture must take into account different kinds of heterogeneity. Services will be accessed through many different kinds of networks with widely varying transport capacity, quality, and usage costs (i.e. wireless and wired networks). Terminal equipment will have different screen resolutions, input methods, memory and processing capacities, as well as levels of mobility. Services may have different requirements for bandwidth, real-time capabilities as well as input and output methods. Furthermore, services can be free or chargeable, and they can be used anonymously or only after authentication.

The main flow of telecommunication business currently focuses on applications and services allocated to mobile humans with any terminal equipment (e.g. handheld, PDA). A human user needs a user interface, either graphical of textual with or without buttons. Sometimes the user of communication services is an autonomous machine, which does not care whether it has any user interface.

Mobility

Terminal mobility, user mobility, and service mobility must be supported in such a way that users can move from one place or terminal to another and still get a personalised service.

Security

Security mechanisms should support authentication, authorisation, confidentiality, reliable transactions, and privacy of communication, end systems and user’s location, as well as protect against denial of service. Heterogeneity and mobility create new security threats.

Interoperability of services

On the one hand, some service interfaces must be statically defined so that software components can use other components and various standards can interoperate to support, for example, service discovery and management. On the other hand, dynamic downloading of user interfaces and software must be supported so that new services can be introduced flexibly.

Adaptive and dynamic services

Services must adapt to different kinds of terminals and networks, as well as handle dynamically emerging and evolving users' preferences. User profiles may describe personal service sets, interests, technical awareness and cost sensitivity. In the future, networks can also be structured in an ad hoc manner. These dynamically changing networks can also be mobile.

Service management

Service management allows service operators to monitor and configure services. Several interoperable layers may be needed to gain control from end-user services to network elements. Access to a subset of management operations may be granted to customers.

Service engineering

With a quickly growing number of services, fast service creation gets increasingly important. Software engineering methods should be competitive. Tools, platforms and component libraries must be written specifically for service engineering and deployment.

Business and social factors

All the listed challenges must be solved before the open service architecture is complete. We believe this would be possible within a reasonable time if technical problems were the only stumbling block. However, there are also business factors and even political issues that make things more complicated. The contradicting benefits of different parties will create more heterogeneity and slow down standardisation processes, but they will also encourage innovative enterprises.

3.5 Conclusion

Service architectures shall stay invisible while providing network services for various nodes. End users can obtain the sophisticated service architecture only through better, mobile, adaptive and real-time data (or knowledge) transfer. The deployment of service architectures will exploit new generations of network technologies and middleware including SW tools, distribution architectures, design patterns, component models etc. Currently, the Internet world provides mostly client-server applications. We believe the share of publish-subscribe and peer-to-peer applications will increase dramatically. The distribution of computation power will exploit multi-agent technologies and the QoS (Quality of Service) requirements will employ swarm intelligence methods. Adapting swarm intelligence and peer-to-peer architectures will produce the goal: seamless hard real-time network services for mobile users (human, device, machine or agent) in heterogeneous network environment. (Fig. 3.5.)

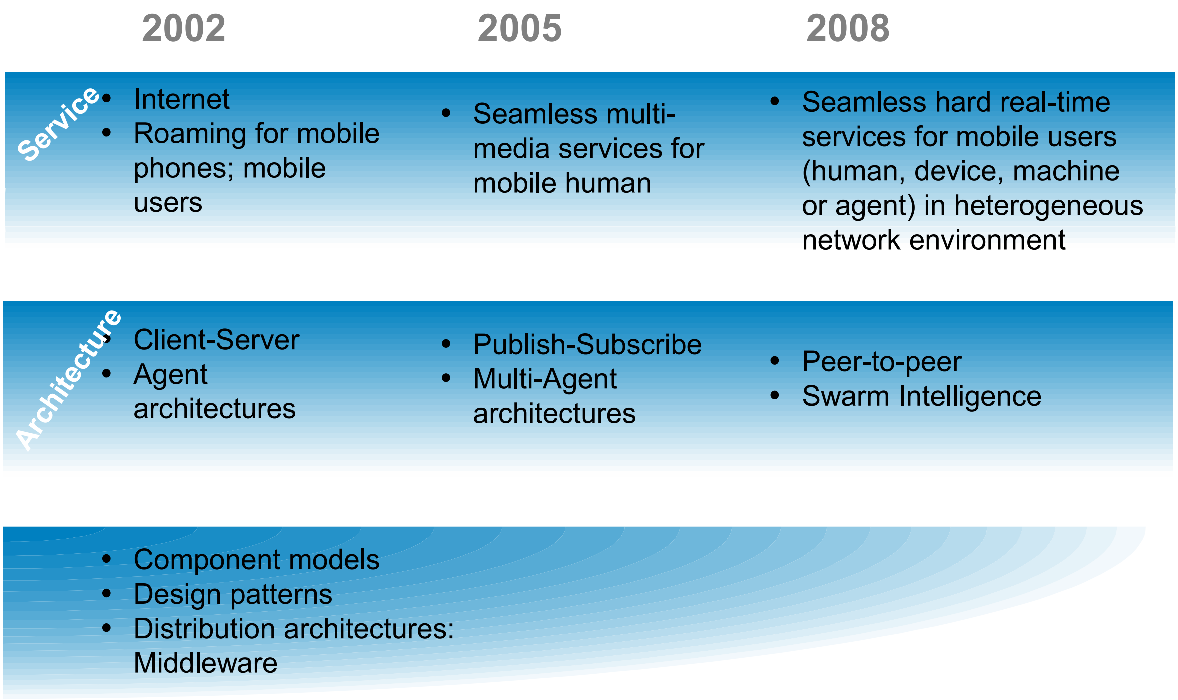

Figure 3.5. Roadmap of the network services.

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4. Smart Human Environments

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Älykkäät ympäristöt

Tiivistelmä (Finnish summary)

Älykkäät ympäristöt tulevat muuttamaan erittäin voimakkaasti ihmisten tapaa olla vuorovaikutuksessa muiden ihmisten ja teknisen ympäristönsä kanssa. Ihmiset kommunikoivat informaatioteknisen ympäristönsä kanssa *luonnollisesti* käyttäen erilaisia laitteita ja modaliteetteja. Ympäristö on tietoinen käyttäjänsä kontekstista, toisin sanoen ymmärtää käyttäjän toimintatilanteen, sosiaalisen tilanteen ja hahmottaa fyysisen ympäristön tilan. Ympäristö kykenee auttamaan käyttäjää älykkäästi tämän toimissa. Ympäristön apuna tässä tehtävässä ovat käyttäjän toiminnalliset profiilit samoin kuin “talonpoikaisjärki”. Ympäristö toimii ennakoivasti suorittaakseen tehtäviä ja tarjotakseen käyttäjälle mukautettuja henkilökohtaisia informaatiopalveluja. Kaikesta tästä huolimatta muutokset tulevat olemaan hienovaraisia, tiedon käsittely on sulautettu jokapäiväisiin esineisiin ja toiminnat tapahtuvat käyttäjää häiritsemättä.

Tässä luvussa käsitellään teknologioita, jotka osaltaan mahdollistavat älykkäiden ympäristöjen vision toteutumisen. Luvussa tunnistetaan neljä erillistä tutkimusaihetta: Ambient Intelligence (ympäristön äly), Smart Interaction (älykäs vuorovaikutus), Smart Communication (älykäs tiedonsiirto) ja Smart Information Management (älykäs informaation hallinta). Näiden tutkimusteemojen tulosten yhdisteleminen tulee olemaan ensiarvoisen tärkeää ympäristön tietoisuuden, informaatiosisällön ja vuorovaikutus-tapojen toteuttamisessa.

Tässä luvussa selvitetään edellä esitettyjen tutkimusalueiden nykyinen tilanne ja pyritään arvioimaan näiden alueiden tulevaisuuden kehittymistä tiekartan (roadmap) muodossa.

4.1 Introduction

Our daily life is gradually being pervaded by the technological advances of the information age. Soon, the strand of these high-tech products will be so interwoven with the fabric of our daily business that the patterns would be lost without it. Their presence will be taken for granted, their services matter-of-course. Still, the changes to our physical environment may be rather subtle, hiding the additional functionality in commonplace objects.

This *Smart Human Environment* will completely change the way we interact with our environment and with each other. People will communicate with their technological environment *naturally*, using a variety of *modalities* and devices. The environment will be *aware* and will understand the user's social, physical and situational *context*. The environment will be able to *smartly* assist the user in his tasks, based on this context awareness and knowledge of the user's behavioural profile as well as common sense knowledge. It will exhibit *pro-active* behaviour for recurring tasks and provide *personalised* information services.

While reviewing the technologies enabling the smart human environment vision, four main fields of research were distinguished within the IT research: *Ambient Intelligence*, *Smart Interaction, Smart Communication* and *Smart Information Management*. The combination of the results of the research in these fields is vital to realise the awareness, informative content and interaction that are sought for a smart environment. This report surveys the state of the art in these fields and attempts to estimate their future achievements in a roadmap.

The next chapter will define the terminology specific to the research in these fields. Chapter 4.3 will provide a few scenarios illustrating the functionality of a smart human environment. Chapter 4.4 elaborates the technologies and chapter 4.5 dwells briefly on the socio-economic effects of this technological advancement. The roadmap presenting the major developments of the enabling technologies in the coming years is presented in chapter 4.6.

4.2 Terminology

As a concept, Smart Human Environment may be considered to cover many other terms that are frequently used and closely interrelated, but approach the concept from slightly different viewpoints. In this section we try to describe these terms and their interrelationships.

Ubiquitous Computing (UbiComp) has roots in many aspects of computing. In its current form, Mark Weiser first articulated the term during the 1980's at the Computer Science Lab at Xerox PARC. Weiser describes UbiComp to be roughly the opposite of virtual reality. Where virtual reality puts people inside a computer-generated world, UbiComp forces the computer to live out here in the world with people. UbiComp can be described as invisible (*invisible computer*); its highest ideal is to make a computer so embedded, so fitting, so natural, that we use it without even thinking about it. It doesn't live on a personal device of any sort, but is in the woodwork everywhere.

Ambient Intelligence. Emile Aarts, head of New Media Systems & Applications at Philips Research, describes ambient intelligence as the integration of technology into our environment, so that people can freely and interactively utilize it. In concrete terms, ambient intelligence is provided by a large number of small, intelligent devices that are 'in-built' into our surroundings. These devices have three important characteristics: they can be personalized, they are adaptive and they are anticipatory. The important point about interaction with distributed, hidden virtual devices is that it must happen in a natural way by using gesture, smell, body language, touch and speech. As Aarts puts it, "In an ambient intelligence system, you won't need a mouse. You will be the pointing device of the future!"

SmartHome can be said to be an application of UbiComp. The home of the near future will contain intelligent objects, which can learn to behave in ways that fit our lives – that get to know our home environment, our relationships and the rituals of our everyday activities. The overall goal is to create a home environment that is cosy, functional, safe and necessary. Smart home systems will have the capacity for a total control of the home, understand speech and even understand gestures.

HomeNetworking refers to future smart homes, and its slogan is "everything is connected to everything, and everything can be controlled remotely". The home network is usually envisioned to be connected to the internet via a gateway. Both wireless and wired technologies, the latter including powerline solutions, are covered by this term.

Home automation is a home environment in which all systems within the home, offering comfort, security, entertainment and communication to its residents, are well developed and thus can learn from changes in the living situation and react accordingly. Home automation systems offer more comfort to the household. They mainly act in the background and they process the daily repeated routines without bothering the residents.

Pervasive computing can help us manage information quickly, efficiently, and effortlessly. It aims to enable people accomplish an increasing number of personal and professional transactions using a new class of intelligent and portable devices. UbiComp can be seen as the ancestor of pervasive computing, in as much as pervasive computing aims to help manage and control information.

4.3 Scenarios

One does not need to spend a long session on the Internet in order to find a huge amount of scenarios related to the smart human environments vision. The analysis of these scenarios produces roughly six categories divided according to the nature of the actions and the amount of intelligence (smartness) required by the system: 1) Control, 2) Communications, 3) Information request, 4) Notification, 5) Information logging, and 6) Automation.

Control over devices in the scenarios will be more flexible, free and at the same time intuitive in the future than it is today. Control actions are user initiated, which means that nothing happens if the user does not make the first move. There are basically two kinds of controls: remote and local. In the remote control case, the user gives a command by some mobile device, usually a PDA or mobile phone. Local control is done by using an interaction technology that may be embedded in the environment

> *Susan has been working late. She sits by her desk and decides to leave little by little. She takes her mobile phone and sends a "Sauna on" message. When she arrives home in 2 hours time, the sauna will already be warm and she won't have to wait. Earlier, during her lunch hour, she sent a message to her video recorder, because she wants to watch "The Survivors". As she leaves the building, she identifies herself to the gate control by holding her ID card in front of the wall panel in order to access the parking place without triggering the alarm. Approaching her car, Susan clicks a button on her car key and the doors open. When Susan arrives home, she shows her key card to the front door. The door reads the key card and configures lighting and heating according to Susan's preferences.*

In the second type of scenarios, **communication** between people is emphasised. Communication will be more natural than it is nowadays. The procedure might start and finish more intuitively. Naturalness arises when communication starts imperceptibly. The communication process starts smoothly when the companion appears to other people without radically disturbing what they are doing. There isn't any particular telephone machine or sound but just for instance a quiet beep or a companion's picture somewhere. The ways to communicate refer for example to mobile phone usage, PDA usage, e-mail, visual phone etc. Communication can take place between two people or between groups of people.

> *Mother and father are having breakfast. The small mobile screen on the kitchen table begins to beep. Daughter Susan is trying to make video-contact. Mother touches the mobile screen and says "Hi dear" to Susan. The small camera on top*

of the screen records mother’s picture for Susan. Father is leaving the house and on his way out, he says: "Contact me when Peter arrives". In the afternoon, Peter arrives home and his PDA automatically sends a message to his father's PDA who now sends a message to Peter that says "Could you please pick up your grandmother from the doctor’s. She isn’t feeling very well. Thanks".

In the evening, when everyone has come home, the family decides to play some game to cheer up grandmother. Mother, father, Peter and grandmother sit down around the game board. Susan participates remotely. The game board is activated and 'Yazz' for five is ready, so the game can start.

The third kind of scenario is **information request**. The user-device-communication is interactive. The user starts the interaction by giving a command to the system and the system again gives an answer to user. The command can be given intuitively with a simple gesture that activates a device, or specifically by giving an order in some way (clicking a button, touching a screen, speech etc).

Peter is planning a weekend at his summer cottage. If the weather is nice and the water is warm, he'll go there with few of his friends. He takes his PDA and sends a message to his summer cottage asking for the weather and water temperature. He receives the answer "Sunny, no clouds, air temperature 27 degrees and water temperature 18 degrees". Peter decides to organize his planned cottage weekend and asks the local fishery association if it is worth trying to catch fish over the weekend. He receives a message saying that fishermen's luck recently has been better than ever before. The football World Cup finals is on. Peter takes his personal digital assistant (PDA) and orders to watch the game from the television Company. The TV-company now sends the television broadcast to Peter's PDA and charges him automatically. Peter can watch the whole game live while fishing and besides this, he receives further information about the game along with the program.

In the **notification** type of scenarios, the device or the environment gives the user some information, alarm or reminder of something in the form of information pushes. The environment has the initiative, i.e. it decides whether a condition requiring alarm or notification is fulfilled.

Paula and Susan are having a girls’ evening. Paula has been very ill during last week and she’s on a course of antibiotics. As she searches for a some good restaurant nearby with her PDA, the device starts to beep and the current time is blinking on the screen with the message "it is time to take your pill". At the same time, Susan receives a message on her mobile phone that her children have not come home yet. She phones her son Mike who says that he’s just on his way *home. Paula orders a taxi with her PDA and receives a message saying that the nearest taxi will be there in 5 minutes.*

The fifth kind of scenario type could be called "**information logging**". In these scenarios, different kind of devices collect data and store it in order to give the user and other devices information when needed. The best known of these applications are health monitoring devices, which collect data about the users' condition and monitor his/her health. Another example might be a digital diary. Typically these applications are combined with others such as notification type of services.

Susan is trying to loose weight in order to fit into these fabulous trousers she bought last month. After getting up in the morning, she struggles towards the bathroom and steps onto the scales. But then the alarm clock rings and she rushes to turn it off. Her PDA is on the bedside table, displaying the measurement results and a curve that shows that indeed, she has lost some weight this month. As she walks towards the kitchen, the coffee machine is already on and today's newspaper has been loaded to her portable screen at the table. While reading, Susan receives a notification that her old mother has got out of bed and that her condition is quite normal.

In the most intelligent and demanding case, two or more devices are communicating, often without user involvement. These scenarios could be described as automation.

Paula returns home after a watching a movie and having dinner with Susan. At the front door, she is recognized by an intelligent surveillance camera. The door alarm is switched off, and the door unlocks and opens. When she enters the hall, the house map indicates that her husband Mike is playing tennis, and that their daughter Rose is upstairs in her room. The remote children surveillance service is notified that Paula is home, and subsequently the online connection is switched off. She then goes to check the washing machine; in the afternoon she received an alarm indicating that the machine had broken down but she didn't need to worry: immediately after the leak was detected, the water tap was automatically turned off to avoid further damage. Downstairs, she smiles, relieved: everything is OK and the repairman the system had suggested, and whom she had approved, has already fixed the washing machine.

In these scenarios, the devices should be seen as a much larger concept than simply a single device. All devices together construct an environment where technical details are mostly invisible to the user, and the user only sees those features that are meaningful and necessary in view of his current action – top of the iceberg. Intuitive interaction is performed through presence, gesture, voice, touch or smell or concretely by clicking a button or touching a screen.

4.4 Enabling technologies

This chapter contains a survey of the key technologies relevant for the realisation of the smart human environments vision. Each technology is briefly described, an overview of the state of the art is given and the direction of the research sketched. The scope of this document does not permit a very detailed description.

The technologies are divided into six categories: ambient intelligence, smart interaction, usability, information management, smart communication and ubiquitous systems. The first three will be addressed in detail, whilst the last three are rendered outside the scope of this overview and will only be introduced briefly.

4.4.1 Ambient intelligence

Ambient intelligence is perhaps best described by means of its three most important enabling technologies: ubiquitous computing, ubiquitous communication and intelligent user friendly interfaces.

Ubiquitous computing refers to concepts such as disappearing computer, 'when they are everywhere', and pervasive computing means the integration of computing power (microprocessors) into anything, including not only traditional computers, personal digital assistants, printers, etc., but also everyday objects such as white goods, toys, house, furniture or even paint ('smart dust'). Ubiquitous communication, in turn, means enabling the communication anytime, anywhere of anything with anything else. It refers not only to people but also to artefacts such as those listed above as having some computing power. Central technologies in ubiquitous communication are ad-hoc networking and wireless communication technologies. The intelligent user-friendly interfaces enable natural interaction and control of the environment by the human 'users', or inhabitants of the ambient environment. The interfaces support natural communication (speech, gestures), take into account user preferences, personality and usage context, and enable multisensory interaction. An *AmI infrastructure* hence *provides a seamless environment of computing, advanced networking and specific interfaces*. The infrastructure is aware of its users and usage context (context awareness), and is capable of responding to user needs intelligently, or remain unobtrusive, even invisible, when it cannot. *The AmI is the intelligence of this infrastructure embedded within the actual applications*. These applications integrate the required enabling technologies to perform certain advanced functions, which may be either pre-programmed or learned by the experience gathered by the system during its existence.

4.4.1.1 Ubiquitous computing

The trends in computer miniaturisation, power consumption and wireless communications seem to rapidly converge to the vision of omnipresent, but mostly hidden, computing power, cooperating to provide services. People have grown accustomed to using mobile devices daily, being observed by sensors embedded in the environment and living surrounded by a variety of appliances with growing intelligence. It only seems to be a small step to enter a home where not only your television, but the complete environment responds to your commands or even your mere presence.

Naturally there are still a number of obstacles blocking the realisation of the vision. Firstly, a proper and *standardised way* needs to be found to get the ubiquitous computational components to *communicate* with each other. This requires advances on all layers of the protocols; the *physical layer* including short-range wireless communication and e.g. powerline solutions. The protocols need to support *ad-hoc communication*; managing elements appearing and disappearing from the environment without user intervention. Proper *middleware solutions* hiding the complex and diverse implementations of the underlying communication layers from the applications and providing sufficient security.

Secondly, still *smaller and less power consuming processors* are needed to achieve truly unnoticeably embedded solutions. Creative solutions such as the use of parasitic power may be the key to overcome the bother of frequent battery replacements.

Thirdly, a wealth of *new sensing methods* is needed to achieve more perceptible and aware services. Both *sensor technology* as well as *algorithms* to analyse the sensor data and interpret it into context information are needed.

Writing applications in this kind of environment may require a different approach as that used for simple computer-based applications until now. The applications need to function in an embedded environment and will inherently interact with other applications in this environment, using their services or supplying services to them. *Software methodologies* from *agent systems*, *modularised software systems*, *embedded software* and *distributed solutions* may be used as a basis, but new *software architectures* may arise.

4.4.1.2 Context awareness

Making applications aware of context, be it their own context or that of their user, is expected to make a great difference for the naturalness of the interaction between the application and the user. By making the application aware of the situation of the user and his intentions, a great amount of irrelevant information can simply be ignored and the user can be provided with a selection of to-the-point and useful options.

Many simple context exploiting applications exist today, such as tourist guides and fieldwork assistants. Although most of them are based simply on location and time, some studies report recognising more complex contexts such as the user activity and state of the environment. Machine learning and data mining methods among other artificial intelligence (AI) methods are often utilised to learn or discover patterns from data acquired by sensors e.g. embedded into a mobile device.

The ultimate context-aware device will be able to serve us like an intelligent butler. This, however, will require breakthroughs in areas such as *knowledge representation and reasoning*, common sense reasoning, *machine learning* and *data mining*, *pattern recognition* and *small size low power electronics*. A probable course of wide deployment of context-awareness technology is a gradual increase in the consciousness of machines of their surroundings and of people that are using them. An increasing number of items will be augmented with hardware and sensors, eventually enabling a greater control over our physical reality. Advances in the areas of AI will contribute by harnessing the power of the information flood. Completion of major efforts such as the Semantic Web and CYC will revolutionise the possibilities of computing and will be a major milestone on our way to the new era of intelligent machines.

4.4.1.3 Positioning

Outdoor positioning systems may be divided in two main streams: satellite-based and mobile network systems. Satellite-based systems provide much better accuracy than the latter, but have a much higher unit cost for the consumer. The problem of positioning can be divided in two questions: *Where are you?* and *Where am I ?*.

The answer to the first question is easier because only the location of the terminal is needed. For example, in case of an emergency, rescue organisations use your location coordinates with map software in order to see where you are. The localised terminal can be an ordinary mobile phone. Some operator-based service applications also use this technique.

The second question is more difficult. Location coordinates are more or less useless without a map. Therefore the terminal needs more advanced features: a good display, mass storage capacity or/and a decent network connection. Guidance needs continuous and accurate tracking, which sets more requirements to the system.

Indoor positioning is a challenging task. Unlike satellite systems, where GPS is the de-facto standard, there is no such standardised method developed for indoor use. There are many commercial systems available, but each one of them has unique characteristics depending on the application.

There are several possibilities to set up a general indoor positioning system: GPS-type triangulation systems, active or passive beacons, sensor-based methods or a combination of the aforementioned methods. The applied positioning method should be easy to integrate with positioning systems (and terminals) used in outdoor environments.

4.4.1.4 Environment perception and modelling

Environment perception means collecting information from the environment. The sensing technology is quite straightforward and no breakthroughs are to be expected in the near future. Understanding the information is a much more complex question and is highly related to context awareness. The most used environment perception technologies are vision and range finders.

Typical range finders are laser scanners, microwave radars, ultrasonic sensors and infrared sensors. Ultrasonic measurement is applicable to distances up to 10 m and low speeds, whilst microwave radar can measure distances greater than 100 m. There are three basically different approaches to measuring range: *time of flight* (TOF), *phase-shift measurement* (or *phase-detectio*n) and frequency-modulated (FM) radar. The first is based on measuring the travelling time of a reflected pulse of emitted energy, while the latter two measure the phase-shift of the reflected pulse.

Camera technology is rapidly developing and new CMOS technology has considerably brought down prices. The continuous increase of computing power facilitates image processing and more operations can be done in real-time. It is a more difficult task to make sense of the measurement data. After basic signal processing for noise reduction etc., features are extracted from the image that serve as input to pattern recognition algorithms. The recognised patterns are then matched to models of the world. Matched objects allow the assessment of assumptions on the state of the outside world and a construction of a model of the environment. This in turn can be used as input to a decision-making process, which reacts to changes in the outside world.

Modelling the environment is important for positioning and navigation purposes, but also for more general context awareness and the realisation of augmented reality applications. The manual construction of such environmental models is tedious and often not desirable, although e.g. in factory environments such models may be readily available and the required accuracy does not leave another choice. Constructing an environmental model automatically by means of sensors is still at an experimental stage. Perception techniques as mentioned above are still not readily available off-the-shelf and their performance is generally poor. For augmented reality purposes, some experiments have been conducted by enhancing the environment with tags that can be easily located by vision techniques and used as anchors for virtual information overlaid on the real-world picture.

4.4.1.5 Personalisation

Tailor-made software is a luxury that few can afford. Products are made for great numbers of customers and their features are balanced to satisfy most. The personal touch that human services usually provided is missing, even though in some other respects the service may have been improved. Personalisation is a key factor in improving customer satisfaction for computer-based services.

By personalisation we mean the ability of a service (in a broad sense) to be altered to better suit the wishes of its user. The changes may affect e.g. the means of interaction, the look-and-feel, the content, or the selection of services. The way personalisation is achieved differs between the application areas and the following levels of automation can be discerned:

Manual personalisation – tools are provided to the user to adjust the services to fit the user's preferences. An example can be found in Yahoo, where the user can customize the information and its layout shown on the My Yahoo page. This kind of personalisation derives from macro-building techniques for facilitating often-repeated tasks.

Profile-directed personalisation – a user is either categorized into a group with an associated profile, or (s)he interactively defines a profile. This profile is then used to filter or structure information to meet the user's interests. The profile definition phase is still manual, but the application requires decisions based on the rules in the profile.

Learning personalisation – the system observes the user and is able to learn from his/her and other behaviour. The knowledge obtained from these observations is then used to support the user in his/her tasks.

The last of these is clearly the most demanding approach, but since the area of application for personalisation is very wide, there are challenges at each level.

4.4.2 Smart interaction

Interaction with a supportive and pleasant technological environment should be *natural*. Naturalness is achieved by mimicking human-human interaction, by taking the user and his context into account (personalisation and context awareness) and by adding active support for perceived user activities (pro-activeness). The environment will be perceived as smart, when it understands our intentions even when they are only partly expressed using a variety of modalities.

Compared to traditional interaction, natural interfaces call for methods to establish the user's identity, the use of new interaction techniques (multimodality, including e.g. gestures and speech), context awareness, personalisation and adaptation. Naturalness also means that we do not want to be bothered by the interfacing technology. It should be unobtrusively embedded in our environment, appliances and even in our clothing.

4.4.2.1 Adaptive UI

The term *user interface* indicates that its objective is to mediate between a user and the non-specified object of use, but generally assumed to be a (computerised) device (cf. MMI – Man-Machine Interface and HCI – Human Computer Interaction). It provides the channels (modes) through which a human being can interact with electronically realized services. The time when this could be identified with one particular paradigm for interaction (WIMP) is over, and a great variety of interface paradigms using different modalities is available. Additionally, the device(s) comprising the actual user interface are not necessarily those providing the used service functionality; interface and functionality are separated, allowing so-called multi-tiered UI solutions.

A user interface can be called adaptive when it is able to change its interaction based on an external factor. These factors can be found from the parties involved in the interaction and include:

The user – the UI may adapt itself to user preferences (profiles, style, etc), user skills and abilities (beginner/advanced, disabilities, …), user context (location, occupation, environment, …).

The service – since UI's have usually been service specific, this kind of adaptation has not before been an issue. The advance of UI description techniques and embedded content objects may change this and a variety of UI's may be used to access one service.

The devices used to interact – different modes of interaction are used by different devices (visual, aural, tactile, etc) and device features differ (display size, keyboard size, speech recognition features, etc.).

The interaction feature to be affected may be:

The mode of interaction, i.e. which output and input channel to use and how to combine them, including also interaction (dialog) models (mode adaptation).

The amount and format of information to be presented, e.g. filtering of relevant information, changing the "look and feel" of an interface, selecting a suitable graphical representation for a graph, … (content adaptation).

Context awareness and personalisation can also be seen as adaptation techniques, responding to user context and user preferences.

4.4.2.2 Multimodal interaction

Using many senses and modes of communication is an essential part of the natural behaviour of human beings. Humans have good abilities to receive and process information from many sources simultaneously. Multimodal interfaces use many modalities at the same time, so they take advantage of the human interaction and perception abilities. Multimodal interaction can, and often does, involve more natural modes of communication than the ones provided by traditional desktop systems. It is about handling a combination of natural inputs to produce output. Multimodality allows a transition from traditional windows-icons-pointers-menus interfaces to more natural ones.

In task-oriented applications, for example personal navigation, communication or office automation, the purpose of multimodal interaction is to enhance the efficiency and the expressive power of the interface. There is also another field of applications in which multimodality has another purpose: in entertainment or virtual reality applications. For example, new modalities can enhance the sense of presence and thus create more interesting experiences.

The requirements for effective systems using multimodal interaction are an understanding of 1) the intended modalities and the information they convey, 2) how to combine the modalities so that they complement each other, and 3) an architecture that can handle time-critical and interdependent inputs and cope with errors in recognising them (Oviatt, 1999).

4.4.2.3 Wearable technology

At the moment, the field of "wearables" is expanding. So far, they can be viewed from at least two different perspectives: wearable computing and smart clothing.

In the research and development of *wearable computing,* the main goal is to develop a computer that can be worn: the development process starts from the computer. This point of view is justified by usage and applications where the user cannot sit down to use his computer. An example of these applications is the work done by machinery assembly and repair personnel. (See e.g. Massachusetts Institute of Technology, 2000 and Orang-Otang Computers, 2000)

Concurrently in the research and development of *smart clothing* the development process starts from designing clothing for specific situations. They stress that the wearable system must offer functionality in a natural and unobtrusive manner, allowing the user to dedicate all of his or her attention to the task at hand with no distraction caused by the system itself (Carnegie Mellon University, 1999). Smart clothing should have the look of ordinary clothing, the feel and draping of ordinary clothing, an extremely simple or preferably no user interface at all (except dressing up) and no user operating. Context-aware garments function automatically according to the current conditions and situations (Malmivaara, 2001). Stuart F. Elton (2001) also defines smart clothing as self-operating. He stresses that in order for clothing to be smart, it must adapt to the surrounding environment automatically. (Elton, 2001)

4.4.2.4 User identification

User identification in smart environment can be done by traditional means, such as user ID and password, or it can be done by electronic identification (i.e. by electronic tags) or biometrics. Biometrics (bioidentification) means identifying individuals by their physical (e.g. fingerprints, iris) or behavioural characteristics (e.g. signature, speech, gait).

Automatic bioidentification is advancing rapidly. Several techniques exist for this: fingerprints, iris pattern, retinal scan, hand geometry, hand vein, ear, face, face thermograms, odor and DNA. Behavioural techniques include voice print, signature, gait (walk) and keystrokes. By far the most mature method is fingerprinting, followed by iris scanning. For both these methods, commercial products exist and fingerprints-based systems are finding market acceptance due to their reliability. Fingerprinting systems are reaching low cost applications (between €10 and €100), while Iris-based methods are more expensive. Commercial vendors include Veridicom Inc, Infineon, Thomson CSF (Atmel), ST Microelectonics, Identicator Technology (all fingerprints) and IrisScan.

Leading researchers and groups include Anil K. Jain at Michigan State University, Ruud Bolle at IBM's Thomas Watson Research Center, L. O'Gorman (now at Veridicom) and J. Daugman at Cambridge University (iris methods). Face recognition is being studied by a number of research teams and commercial applications are expected.

4.4.3 Usability issues

The research on human-computer interaction has, until very recently, focused mainly on single persons interacting with a single computer and a well-defined task (Hollan et al. 2000). Smart human environments provide many ways to make people's daily life easier, but at the same time this kind of technology includes many new usability challenges.

In smart human environments, the user is not alone but several people may interact with the same environment at the same time. How then can the user be in control of an environment that reacts not only to the user's own commands but also to the commands of other people who may or may not be present in the environment? In addition, the environment may act automatically, without user intervention.

The targets of the interaction are not always visible to the user. How then can the user get feedback on what in going on? How does the user know the objects and commands available? How can the user get an overview of the whole situation when there are e.g., hundreds of devices at home? How can the user access the same services and information everywhere, with different devices?

Personalisation and adaptation to the context improve the usability of many systems. However, defining personalisation can be a major challenge to the user and may even be an obstacle for utilising the system. Personalisation should be an optional feature, the user must be able to use the system as such to begin with. Context adaptation may confuse the user if she/he does not understand what the adaptation is based on and why unpredictable actions happen.

An important usability challenge for context-awareness is that the context may be continuously changing. The implication of this for the design of the user interface is significant since it raises the problem of integrating changes in such a way that the user remains in control. For instance, if the display is updated as the user moves, the information that the user is currently reading could be accidentally overwritten. (Davies et al. 1998).

4.4.4 Smart information management

Smart information management is an important enabling technology for smart human environments. Ubiquitous computing and context awareness produce massive amounts of information to be stored, managed and interpreted, while on the other hand requiring ubiquitous access and reliable high-level interpretation of this information. Smart information management includes technologies from database management to data mining and interpretation methods, all of which are under intensive research and may be expected to progress significantly in the coming years. However, a detailed treatment of this topic is beyond the scope of this report.

4.4.5 Smart communication

Smart communication is a collection of enabling communication technologies for smart human environments. Communication and co-operation between devices should be possible in wired and wireless environments and ad-hoc joining communication networks should be supported. Usage of global heterogeneous networks also requires standardised middleware and distribution systems. Smart communication enables global access to everything and everywhere, making security in communication a mandatory requirement. These topics are described in more detail in the service architecture subtheme.

4.4.6 Ubiquitous system evolution

In the future, SHE (Smart Human Environment) technology will provide us with smart service systems that are aware of the context and circumstances where the user is acting. The SHE system adapts its services automatically according to the user by benefiting available background services. Ubiquitous computing, environmental perception and modeling in addition to personalisation are other properties usually tied with such products. A SHE product may be a stand-alone device or system, but more often it is represented by distributed intelligence emerging as ad-hoc networks and communication capability.

A typical environment for the user is a building or a home. In the future even more so than now, they will contain a number of technical systems and infrastructure assisting the user in daily living, control, maintenance, entertainment and security. These background services are based on dedicated technical equipment, home and building automation, communication systems, gateways to the Internet etc. This technical infrastructure, "firmware", forms a platform and background services for smart human environments.

Integrating SHE technology with available infrastructure will raise several research and development challenges, such as the overall control and management of the environment, interoperability, interfacing, task sharing, functional safety, diagnostics etc. Integration starts from functions, defining the tasks and interactive operations of each user, device and participating system, and leading to a comprehensive system model. Similar integration and a systematic approach will be needed in other common environments such as office/business, leisure, industrial, public spaces, health care and schools.

4.5 Socio-political factors

Until recently, debates regarding new information technologies, their adaptations and implications have been dominated by the so-called *technological determinism*. Technology has been seen as governed by an “inner logic”: if the consequences of certain technologies are socially or ethically problematic they should be resolved through new technological innovations.

Matters of responsibility for new technologies and products are particularly difficult because the ethical debates and legislation tend to lag behind. The so-called “ethics gap” occurs when new computing technologies emerge and neither the designers nor the market are ethically prepared. It is vital to incorporate ethical audit as an essential part of the whole design project. (Sotamaa et al. 2001)

Key ethical issues related to smart human environments include:

privacy	Who owns and who can use the information that is collected about the behaviour of the user
responsibility	Who is responsible if the environment gives misleading information or takes wrong actions
helplessness	Do people lose previous skills when technology does more and more things for them
equality	Can all people benefit from the technology or does it increase the social gaps between people? Disabled and elderly people may benefit from the technology the most. Can they afford the technology and have their abilities and needs been taken into account in the design?

As a national technical research institute, VTT should be aware of current legislation related to the issues mentioned above. VTT should also actively participate and raise discussions about ethical issues related to new technologies within society.

4.5.1 Business and industrial models

The development of smart human environment creates great opportunities for completely new businesses. The ‘development of new, beneficial and competitively priced connectivity-based services to consumers and the availability of low-cost standard based home networking' (Gatespace 2001) and enabling technology will be the main driving forces for these businesses. The rapidly changing technology and growing markets will also change the business logic and value-chain of the players in the field, and lead to new players stepping in.

The main players in the field are *consumers, device and product manufacturers, service providers, network/infrastructure operators* and *service system providers*. In the mass market, the customer will need reasonably priced, easy-to-use, interesting, and useful zero-admin services and products. The term *mass-customisation* will emerge. The main obstacle towards smart human environment-based commercially successful services may be expected to be the frustration arising from the unpredictability of the technology (where it works, where not, when it works, when not, compatibility problems, etc.), the importance of which becomes essential as the added-value of the services goes from the packaging of the needed services in a seamless fashion, to a package where value is more than the sum of its components. Hence, the chicken-egg problem of the smart human environments will be that there is no demand (and payers) for the infrastructure without advanced services, which do not develop without the necessary infrastructure and the pioneering users. A solution to this problem requires strategic partnership and mid to long-term investments from the other players in the field.

Due to the rapid technological developments and the emerging need for a short technology generation lifetime, the business may be expected to be based on leasing and franchising models. As the value of the technology is based on the integrated and packaged services provided, the value-chains will be very complex and the retain logic will need to be carefully considered. This also calls for strategic partnerships between the different players – and also cross-disciplinary and cross-sector capabilities in the application development and provision.

Identification and (de facto) standardisation of the necessary interfaces is a prerequisite for smart human environment visions to become a reality, as they require seamless interoperability of an almost countless number of devices and services. As business models have a significant effect on the evolution of the 'winning' technology, it is essential that the VTT units involved are aware of these emerging models. A natural role for VTT would be to actively participate and follow up the different key standardisation initiatives in the field.

4.6 Roadmap

When reviewing the state of the art of the enabling technologies for smart human environments, some educated guesses can be made as to how this field of research will evolve. In order to create this roadmap, the enabling technologies were first divided into five categories: Ubiquitous computing, context awareness, positioning, personalisation and multiple modalities. Then a team of experts were asked to provide some examples of applications likely to be available in 2002, 2004, 2006 and beyond. Figure 4.1 contains the result of this research.

	2002	2004	2006	Beyond
Ubiquitous computing	•Embedded computing	•Low-power ubi-communication embedded in devices	•Ubi-environ-ments, 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
Personalisation	•Electronic identification, Web-services using customer profiles	•Profile-driven services with learning features	•Trusted biometric identification, Personalised context-driven services	Digital me
Multiple modatities	*WAP and HTML adaptation, Voice control in consumer electronics*	•Pointing and voice combinations, versatile control	•Spatial user inter-faces, interactive soundscape, ges-ture recognition, natural interaction, multimodal adaptive UI	Electronic paper

Figure 4.1. The technology roadmap of smart human environments.

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Published by

Vuorimiehentie 5, P.O.Box 2000, FIN–02044 VTT, Finland
Phone internat. +358 9 4561
Fax +358 9 456 4374

Series title, number and report code of publication

VTT Research Notes 2146
VTT–TIED–2146

Author(s)
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Title

Communications Technologies
The VTT Roadmaps

Abstract

The view of VTT (Technical Research Centre of Finland) on the development of selected information and communication technologies is presented. The views are given as technology roadmaps in the areas of interoperability and mobility in future networks, micromechanical radio frequency systems, service architectures and smart human environments. The work is a part of a theme called Future Communications Technologies, one of VTT's strategic technology themes. The purpose of the work is to help the planners and players direct their activities towards better competitiveness in this rapidly developing field.

Keywords
telecommunications, information technology, networks, radio frequency, micromechanics, service architectures, smart human environments

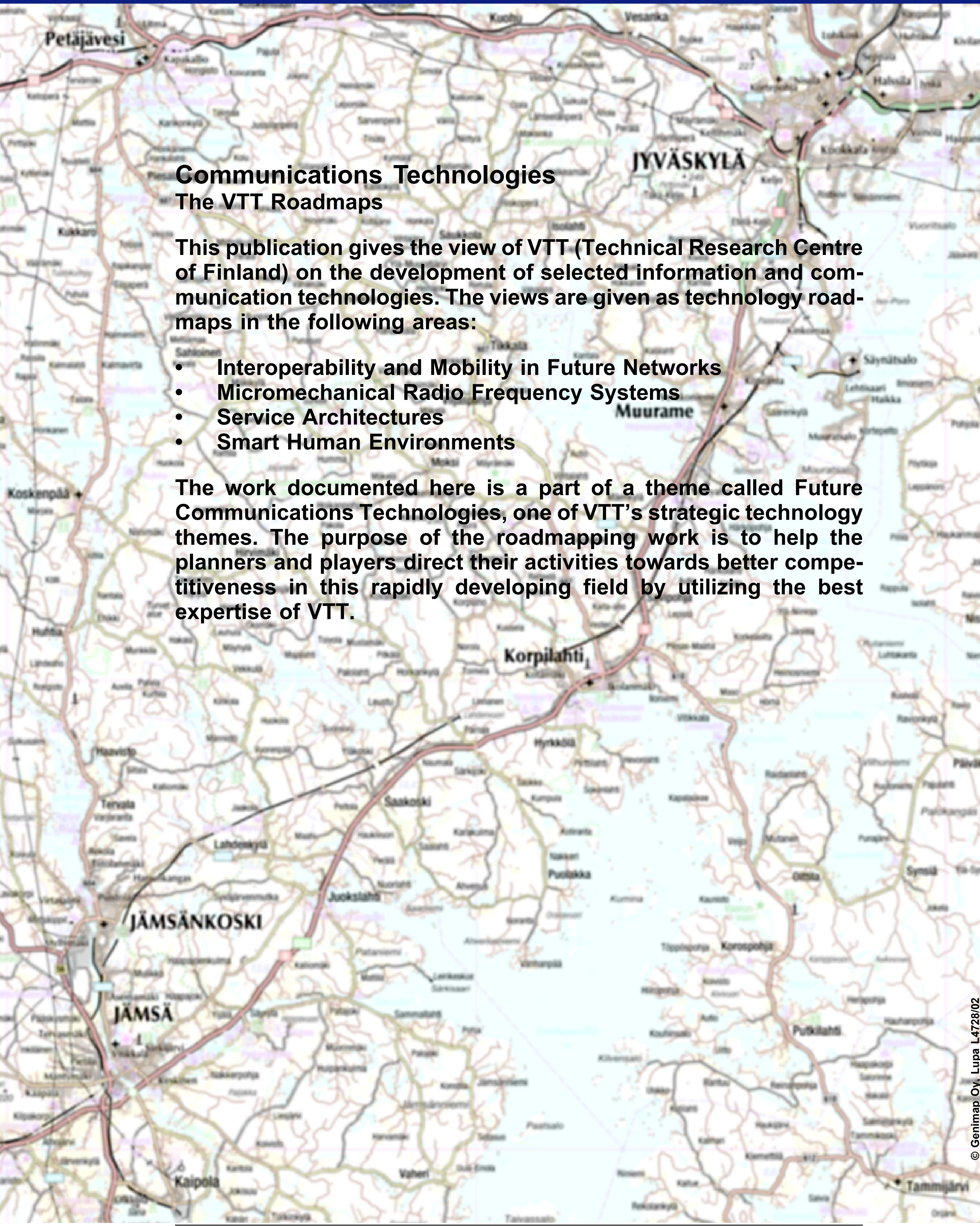
Activity unit
VTT Information Technology, Otakaari 7 B, P.O.Box 1202, FIN–02044 VTT, Finland

ISBN	Project number
951–38–6050–7 (soft back ed.) 951–38–6053–1 (URL: http://www.inf.vtt.fi/pdf/)	T2SU00060

Date	Language	Pages	Price
June 2002	English, Finnish abstr.	81 p.	B

Name of project	Commissioned by
	VTT

Series title and ISSN	Sold by
VTT Tiedotteita – Research Notes 1235–0605 (soft back edition) 1455–0865 (URL: http://www.inf.vtt.fi/pdf/)	VTT Information Service P.O.Box 2000, FIN–02044 VTT, Finland Phone internat. +358 9 456 4404 Fax +358 9 456 4374



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The VTT Roadmaps

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- **Interoperability and Mobility in Future Networks**
- **Micromechanical Radio Frequency Systems**
- **Service Architectures**
- **Smart Human Environments**

The work documented here is a part of a theme called Future Communications Technologies, one of VTT's strategic technology themes. The purpose of the roadmapping work is to help the planners and players direct their activities towards better competitiveness in this rapidly developing field by utilizing the best expertise of VTT.

VTT RESEARCH NOTES 2146 Communications Technologies. The VTT Roadmaps

Tätä julkaisua myy
VTT TIETOPALVELU
PL 2000
02044 VTT
Puh. (09) 456 4404
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Denna publikation säljs av
VTT INFORMATIONSTJÄNST
PB 2000
02044 VTT
Tel. (09) 456 4404
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This publication is available from
VTT INFORMATION SERVICE
P.O.Box 2000
FIN–02044 VTT, Finland
Phone internat. + 358 9 456 4404
Fax + 358 9 456 4374

ISBN 951–38–6050–7 (soft back ed.)
ISSN 1235–0605 (soft back ed.)
ISBN 951–38–6053–1 (URL: http://www.inf.vtt.fi/pdf/)
ISSN 1455–0865 (URL: http://www.inf.vtt.fi/pdf/)