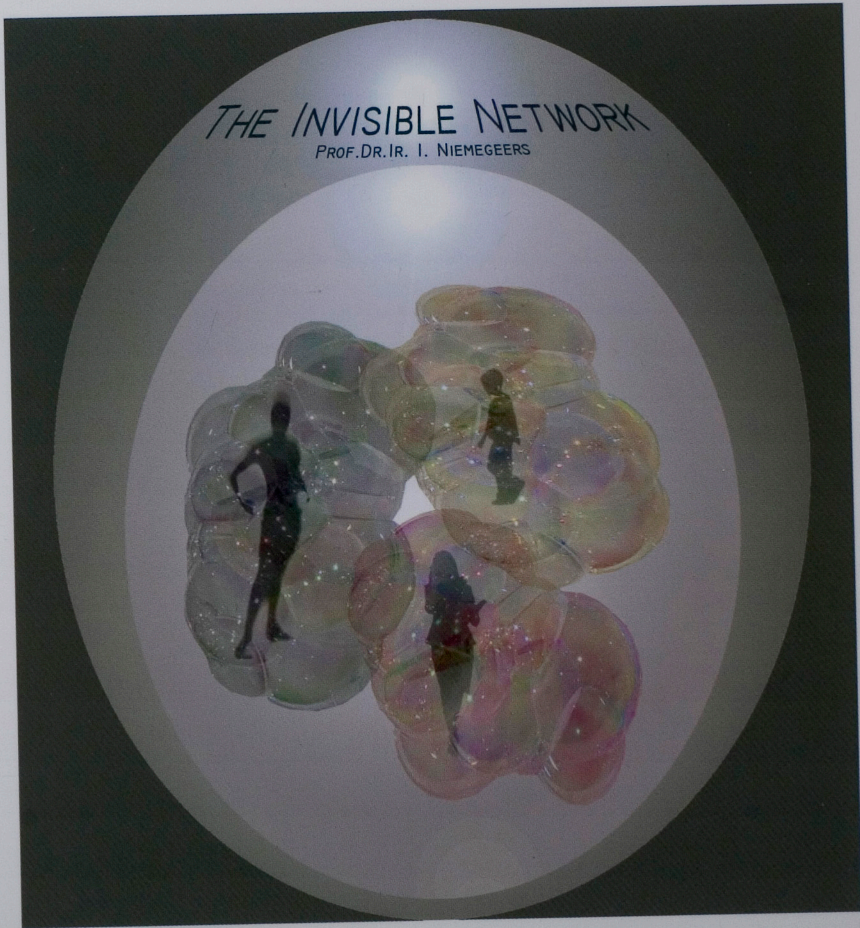

Inaugural speech

October 28, 2005

TU Delft
Faculty of Electrical Engineering, Mathematics and Computer Science
Delft University of Technology

The Invisible Network

inaugural speech

held on 28 October 2005
at the occasion of acceptance of duties as professor in the field of Wireless and Mobile Communications at the Faculty of Electrical Engineering, Mathematics and Computer Science of Delft University of Technology

by

I.G. Niemegeers

Cover illustration by SHED STUDIO, Brooklyn, NY, USA.

Opening Words

Mister Rector Magnificus, members of the Board of the University, dear colleagues, students and other members of the university community, friends, ladies and gentlemen.

Introduction

It is an honour for me to share with you some thoughts and perspectives on the field of wireless and mobile communication. It is a field which is at the crossroads of telecommunications and information technology, at the centre of what is designated by the acronym ICT: Information and Communication Technology. Being at the centre implies that you are surrounded by others, and that you may be hidden from the outside world. Being at the centre also means that you play a central role, that everybody needs you.

This will be a major theme in my oration: the central role of wireless and mobile systems in the future world, and the need to hide their workings from the users of such systems. Hence my title: "The Invisible Network", i.e., an invisible hand at work behind many of the ICT applications that will assist us in our personal and professional activities. These applications are designated by the term ubiquitous computing and communication.

In this oration we will sketch you a vision, a view of what in the coming decade will influence our lives, what our research agenda should be and what we should teach our students, so that they are well prepared to shape the technology and its applications for the better of society. To do this in an orderly way we will first give you a view of what are the main drivers for change: semiconductor technology and wireless. We will zoom in on the basic components of future wireless and mobile technology, for some this is called the Fourth Generation of wireless technology or 4G. We will next introduce new generic application classes where these technologies will increasingly find their application. We will focus on wireless and mobile systems that support person-centric and group-centric applications. We will do this by discussing two new concepts: Personal Networks and Fednets, the federation of Personal Networks to support group activities. We will touch on the relationship with Ambient Networks, networks supporting Ambient Intelligence. Finally we will say some concluding words regarding the way to approach our task.

It is not our aim, in this oration, to be comprehensive or exhaustive, but to convey some key ideas. The topics we will discuss are embedded in an environment of scientific and technical disciplines: Computer Science, Electrical Engineering, Business Science, Social Sciences and others. Luckily most of them are present at TU Delft and other Dutch universities with whom we cooperate. And of course, the playing field should be the world, because science, technology and business are global. Hence our partners in research and education should also be sought worldwide.

Drivers for Change: Semiconductor Technology and Wireless

Ubiquitous computing and communication is a vision that has come about primarily because of the evolution of semiconductor technology. In particular Moore's law is and has been for already 30 years the primary driving force. A popular formulation of Moore's law is that *the number of transistors on integrated circuits, which is a rough* *measure of computer processing power, doubles every 18 months* [1]. A corollary is that the price to make an integrated circuit of a given complexity is bound to drop dramatically as time goes on. Moore's law is illustrated in Figure 1 which graphically shows the growth in complexity of integrated circuits over a period of thirty years.

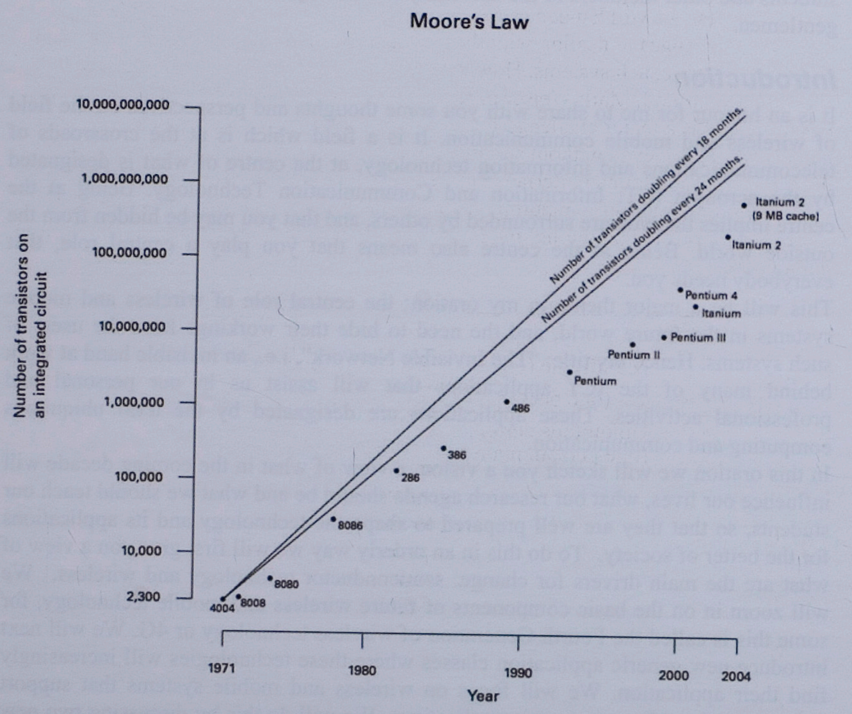

Fig. 1 An illustration of Moore's law

As a consequence, one can reliably predict that it will soon make sense to equip every new artefact with computing and communication capabilities, combined with sensors and eventually actuators. This is confirmed by recent predictions by market researchers. For example, according to Harbor, by 2010, 40 percent of all potentially networkable electronic or electromechanical devices will be connected [2]. According to Forrester Research, by the same year, the sales of network-enabling chips are likely to reach a number of 14 billion [3]. These chips will not only find their way in inanimate objects, but will also be implanted in humans for medical and health reasons and in animals for identification and tracking. Medical sensors and actuators with computing and radio communication are already commercial products. Active and passive Radio Frequency Identification Tags or RFIDs will, as soon as their reliability is high enough and a number of non-technical problems are solved, cause a wholesale replacement of bar code labels to identify and track products. This will lead to a huge market and eventually a revolution in applications.

In September 1991 the late Mark Weiser, Chief Technologist at the Xerox Palo Alto Research Center (PARC) and a visionary computer scientist, described in his paper "The computer for the 21st century", in Scientific American his vision of ubiquitous computing. We are approaching the age where computer technology is omnipresent but at the same time "recedes into the background of our lives" to quote Mark Weiser. This omnipresence will happen as a result of economics and will pose some major scientific challenges in dealing with the problems of mastering the connectivity and the complexity of such systems. However, making sure that this technology recedes into the background, Mark Weiser introduced the term "calm technology" for this phenomenon, is a major challenge for researchers, engineers and product developers, and cannot be achieved without seriously involving social scientists to tackle the human factors and human interface problems. Figure 2, taken from Weiser, illustrates the advent of ubiquitous computing. It shows the growth and saturation or decline of three generations in computing: the mainframe, the personal computer and ubiquitous computing.

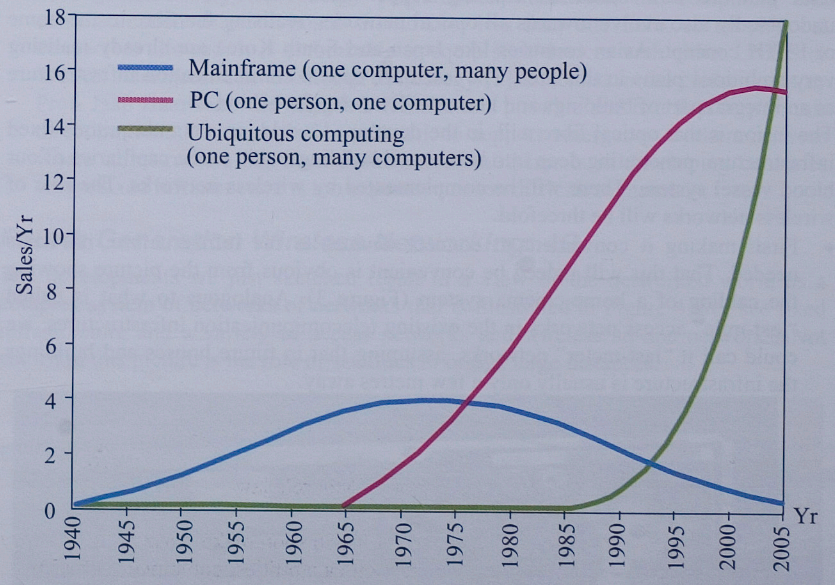

Fig. 2 The advent of Ubiquitous Computing from Mark Weiser)

A significant development driving ubiquitous computing, which is related to semiconductor technology, is the advent of very inexpensive sensors which are able to capture data about physical, chemical and biological phenomena, e.g., temperature, pressure, concentration of harmful chemicals in the environment, heart rate, etc.

Up to now we were stressing semiconductor technology as the driving force behind ubiquitous computing. An equally important enabling technology development is the advent of a range of wireless communication technologies. These are the essential links that interconnect the computing and sensing devices: on a small scale, through short range radio covering distances of the order of 10 m, on a local scale of the order of 100m, using Wireless Local Area Network (WLAN) technology, on a metropolitan scale using cellular radio technologies and fixed wireless access such as the new WIMAX technology, or on an even grander scale using terrestrial broadcasting systems such as DVB-T, satellite communication or potentially High Altitude Platforms or HAPs based on stratospheric balloons.

The essence of radio communication is that it is able to interconnect devices wirelessly. It makes it easy to physically interconnect devices; no infrastructure in the form of wires or optical fibres needs to be made. This, of course, is a must when the devices that one wants to interconnect are moving. Mobility requires wireless communication.

At the same time fixed infrastructure, i.e., wired networks will also develop and evolve. The main evolution here is towards all-optical networks, with their superior quality and capacity for data transmission. Already the core networks, which take care of national and intercontinental connectivity, are optical. The networks that connect homes and buildings to the core networks, the so-called access networks, e.g., the ones that are now based on existing copper lines and DSL technologies, will undoubtedly also evolve towards all optical networks, realising the fibre-to-the-home or FTTH concept. Asian countries like Japan and South Korea are already realising very ambitious plans in this area. The last step: optical communication infrastructure as an integral part of buildings and homes will not lag far behind.

The vision is that optical fibre will, in the developed world, create a ubiquitous fixed infrastructure, penetrating deep into homes and buildings, akin to the capillaries of our blood vessel system. These will be complemented by wireless networks. The role of wireless networks will be threefold.

- First: making it convenient to connect devices to the infrastructure: no wires needed. That this will indeed be convenient is obvious from the picture showing the cabling of a home-cinema system (Figure 3). Analogous to what is called "last-mile" access networks in the existing telecommunication infrastructures; we could call it "last-meter" networks, assuming that in future houses and buildings the infrastructure is usually only a few metres away.

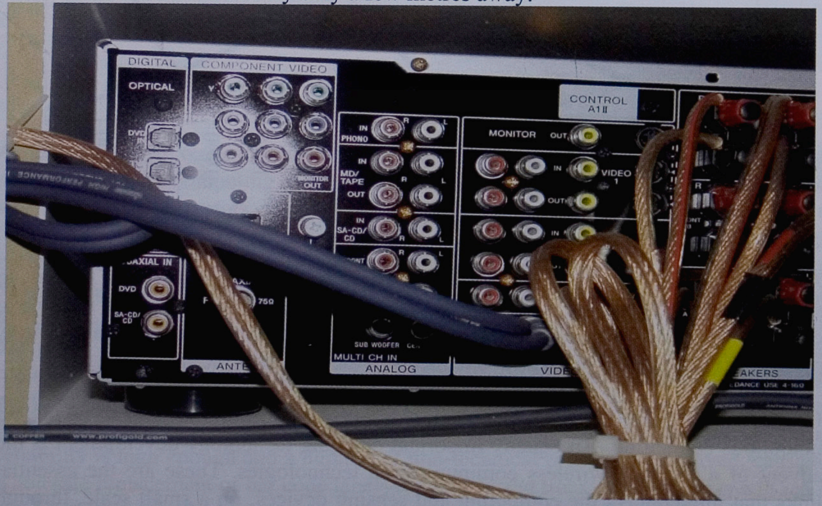

Fig. 3 A home cinema system in the process of being wired

- The second role is to allow objects or people to move while staying connected, this is analogous to the role of the present GSM network. Mobility needs to be supported in various areas and for various speeds of movement: locally, at pedestrian speeds in houses, buildings and within vehicles like trains, and, in wide areas, for communicating with moving vehicles. The latter is one of the primary aims of cellular infrastructures such as GSM and 3G networks. The two roles we just mentioned, untethered access to communication and supporting mobility are the classical roles.
- The third role is new. It is the ad hoc interconnection of devices, without relying on infrastructures. Where does this make sense? First of all in places and situations where infrastructure is not available or the right infrastructure from the perspective of cost and technical characteristics is not available. An example is our network for ubiquitous computing, where one wishes to interconnect many very low cost devices. These devices are likely to be battery powered, hence they have to have very low energy consumption, moreover, the computing and communication chips on-board should cost less than one Euro, so no physical connectors allowed. It is unthinkable to equip such devices with either UMTS or WLAN interfaces. The Bluetooth technology [5], invented in the Netherlands by Prof. Jaap Haartsen, was intended to make this possible and is a first step in this direction. Another example is a network to support emergency workers in areas where infrastructure has been destroyed. A third one is in developing countries where fixed infrastructure is too expensive or too difficult to maintain.

Fourth Generation Wireless Networking: 4G

The developments we just sketched result in a view of the networked world as a complex system of networks of networks that is illustrated in Figure 4. We see fixed infrastructure and a variety of access networks and wireless ad-hoc networks. Not shown in this picture is the role of satellites to bridge large distances.

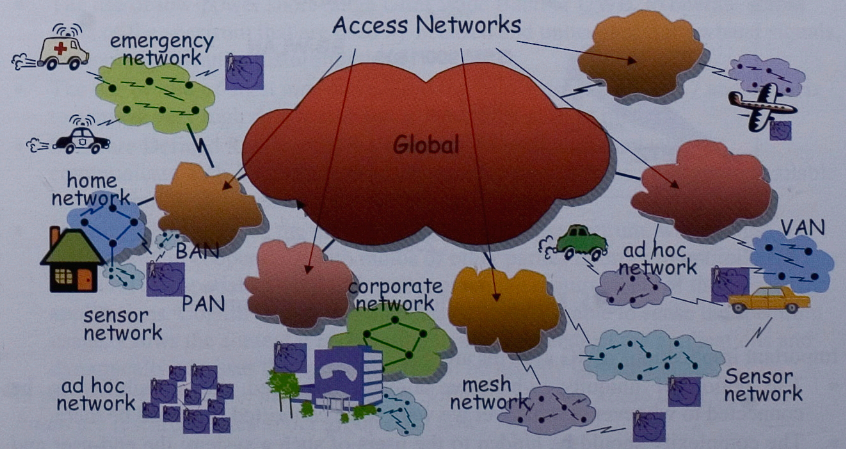

Fig. 4 A view of 4G wireless systems

Part of it exists already now and works well (e.g., the integration of various fixed access networks and core networks in the Internet), part of it is under construction (e.g., the seamless interworking of WLAN hotspots and UMTS), and part of it is not there yet.

It illustrates the vision of what is called sometimes the Fourth Generation of wireless communication, or 4G. This is an ill-defined concept. The definition we refer is the following:

4G refers to a collection of technologies and standards that will find their way into a range of new ubiquitous computing and communications systems. 4G offers the promise of allowing users to connect to the Internet and one another through a variety of devices and standards anytime, anywhere, and at a wide range of speeds, from narrowband to broadband.

This is the dominant view from the country that is investing the most in developing and building 4G systems: South Korea.

Previous generations like 3G (e.g., UMTS) and 2G (e.g., GSM) referred to specific mobile communication standards. 4G on the other hand encompasses many existing and future standards. Figure 5 summarizes the characteristics of the different wireless systems generations.

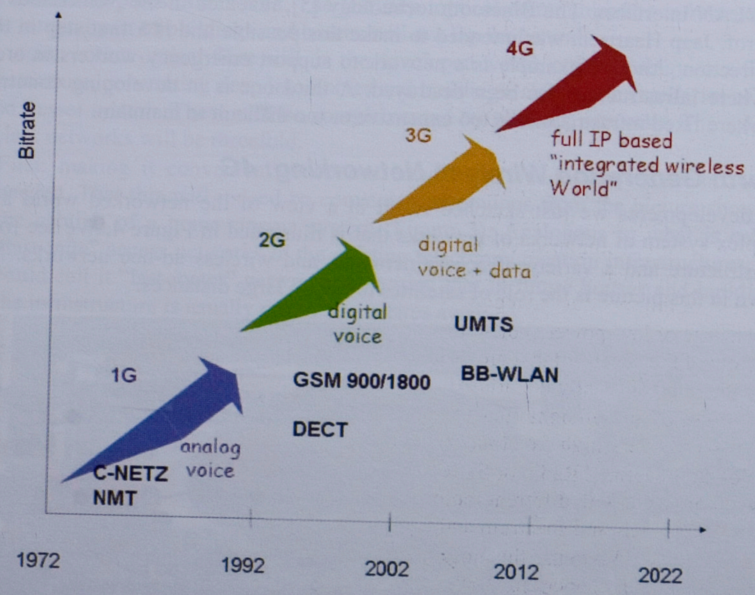

Fig. 5 Four generations of wireless systems

Important implications of 4G systems are:

- The notion of ubiquity, which we already discussed: the possibility to be connected to whoever or whatever we want to be connected to should be there.
- The complexity should be hidden to the users of such a system: the end-user and the application-builder. To the human user in particular the network should be **invisible**.

- It should always be available, so that it can become a substrate for a wide range of new applications that depend on ubiquitous dependable connectivity.
- It should be secure and safeguard the privacy of its users. This is becoming a major concern and a battleground for citizens, politicians and business.
- It should support a wide range of applications and open up opportunities to create new services and businesses in domains which do not belong to the traditional telecommunications world.

Let us now discuss the major technologies and technological challenges involved in 4G telecommunications. We will do this using the OSI Layered model as a guideline and briefly discuss: the Physical Layer, i.e., radio technology, the Link Layer technology and the Network and Higher Layers.

Technologies for 4G

Radio Technology

From a technical point of view, what is needed is cost-effective bandwidth over a very wide range of data transmission rates: from a few bit/s, e.g., in sensor networks measuring the temperature in a building, to Gbit/s radio links for transferring huge files in a short time, e.g., when high resolution pictures or HDTV movies stored in cameras, have to be transferred to a PC. Coverage is needed over a wide range of distances: from short-range, indoor pico-cells to outdoor cellular systems. Mobility of communicating users, objects and vehicles needs to be supported: from movement within buildings at pedestrian speeds to high-speed vehicle mobility for cars and trains. Since spectrum is a limited resource due to interference and regulations, better and cleverer, ways are needed to use and share the spectrum with others.

Some of the promising technologies that are researched to achieve these goals are:

- The use of smart antennas, Space-Time Processing and SDMA to achieve spatial reuse of the spectrum in a given area.
- The use of low-power short-range Ultra Wide Band or UWB, to operate across parts of the spectrum that are used by licensed and unlicensed narrowband signals, without significantly disturbing them.
- The use of line-of-sight mm-wave radio for indoor usage, e.g., at 17 and 60 GHz to achieve very high data transmission capacities at short range.
- Software Defined Radio or SDR to reconfigure radios dynamically to communicate with different radios belonging to other parties, to adapt to available radio channels and spectrum and to different standards.
- Cognitive Radio to use the most suitable parts of the spectrum, waveforms, coding, etc. in cooperation with radios of other parties in order to optimise the temporal and spatial spectral efficiency, given the requirements of the applications. Cognitive Radio implies that the radio is able to sense the spectrum usage, knows the context it is operating in and the needs of the applications and dynamically accesses the spectrum. It will be heavily software based.

In particular *UWB radio, mm-wave radio, Software Defined Radio and Cognitive Radio* are research topics in our group right now.

Link Layer Technology

A large number of Physical and Link layer technologies are available or are under development. These are the subject of standards specified by organisations such as

ETSI, 3GPP, for cellular 3G systems, and in particular IEEE for access networks, local area networks and short range networks. These standards are a prerequisite for creating mass markets that bring the cost of components down. The prospect of a mass market is essential for creating the applications that realise the vision of ubiquitous computing and communication.
Some challenges that need to be addressed here are:

- Achieving efficiency in multi-hop wireless communication
- Achieving low-power consumption to allow battery powered devices a long lifetime between battery replacements, this is in particular crucial for sensor networks which consist of throw-away or hard-to-reach devices
- Supporting Quality-of-Service, which in particular in ad-hoc networks is hard to achieve

We are addressing these challenges right now in the context of personal networks, home networks and emergency networks and based on UWB radio, mm-wave radio and cognitive radio.

Network and Higher Layers

The role of the Network Layer is to interconnect the different subnetworks consisting of different Link Layer technologies. Other functions are routing, support of mobility, and support of Quality-of-service. Increasingly the arena where these technologies are discussed and standardised is the Internet Engineering Task Force or IETF.
Some of the prominent technologies that are crucial for constructing 4G systems are:

- Mobile Ad-hoc Networks (IETF Working Group MANET), which addresses the network functions in ad hoc networks, in particular routing
- Network Mobility (IETF Working Group NEMO), addressing the mobility of entire networks with respect to infrastructure
- Network configuration (IETF Working Group ZeroCon), addressing the issues of automatic configuration of networks
- Wireless Mesh networks
- Integration of complementary wireless networks: Cellular-WLAN-WPAN

At the higher layers (Transport, Session and Application) major components are:

- Transport protocols for wireless networks
- Middleware technologies for mobile computing, e.g., Migrate
- The Session Initiation Protocol (SIP) and Host Identity Protocol (HIP) and cross-layer approaches to support mobile computing applications.

Network and higher layer research is an important part of our research in the context of personal networks, home networks and emergency networks.

New Applications

The availability of ubiquitous computing and communication capabilities, the fact that it will be economically feasible that every device is equipped with computing and wireless communication capabilities will be the basis for new applications and new business. Our claim is that many of these applications will be derived from societal needs, e.g., to help solve problems of an ageing population or to create a more secure environment. Those are the predictable ones. However we also expect that equally important will be new applications arising from the new possibilities the technology offers, combined with the creativity of people. Those are the disruptive ones, similar to the development of applications based on Web technology. When Sir Berners-Lee (the inventor of the World Wide Web) brought together in 1989 hypertext and the

Internet protocols, inventing the web, it was not created with the myriad of present-day applications that change the way we live, in mind. So be aware that there are two streams of progress, the predictable one and the disruptive one, which, by its nature is difficult to predict.
Major generic application domains, we expect, will be

- Ambient intelligence
- Sensorised universe
- Person-centric Personal Networks
- Group-centric Fednets

Let us briefly discuss these; later on we will focus on the latter two, because they are at the centre of our research activities at the moment.

Ambient intelligence represents a vision of the future where we shall be surrounded by electronic environments, that are sensitive and responsive to people. Ambient intelligence technologies will combine concepts of ubiquitous computing and communication, and intelligent systems. Intelligent user interfaces will enable the inhabitants of an ambient intelligent environment to control and interact with the environment in a natural (e.g., using voice and gestures) and personalised way (e.g., based on preferences and context). The vision of ambient intelligence has been aptly described in a book by Stefano Marzano and Emile Aarts, "The New Everyday View on Ambient Intelligence" [6]. A long-term vision has been developed by the EU's IST Advisory Group ISTAG in its report "Scenarios for Ambient Intelligence in 2010" [7].

The sensorised universe refers to the expectation that remote sensing will become an integral part of our lives as sensor technologies are introduced to monitor our surrounding space for a variety of applications such as security, health, education, comfort, environment, traffic, safety, etc. Sensor networks are the key technology here. Because of the specific characteristics of sensors, their small size, limited battery capacity, hard to reach location, restricted processing and communication capabilities and extremely low cost, the design of the complete protocol stack in combination with application level distributed processing, needs to be reconsidered. This is a very active field of research. For the state-of-the-art of sensor networking we refer to the recent PhD thesis by Stefan Dulman at the University of Twente [8] and a number of books that have been written on the subject lately [9].

Let us now discuss in more depth the concepts of Personal Networks and Fednets.

Personal Networks

The concept of a Personal Network extends the concept of a Personal Area Network or PAN. Personal Area Networks refer to a space of small coverage, typically less than 10 m, around a person where ad-hoc communication occurs, e.g., using Bluetooth radio. This is also referred to as the *personal operating space*. The standardization activities IEEE P802.15 [10] and Bluetooth SIG [11] in particular focus on the development of standards for PANs and short range wireless networks in general. PANs are intended to interconnect portable and mobile computing devices such as PCs, Personal Digital Assistants or PDAs, mobile phones, personal audio and video devices such as MP3 players, head sets and digital cameras.
Personal Networks is a new concept that was developed by us at TU Delft in cooperation with Sonia Heemstra de Groot (TI-WMC and the University of Twente)

[12]. It extends the local geographical scope of PANs to a global one by creating virtual personal environments that span a variety of infrastructure- as well as ad-hoc networks (Figure 6).

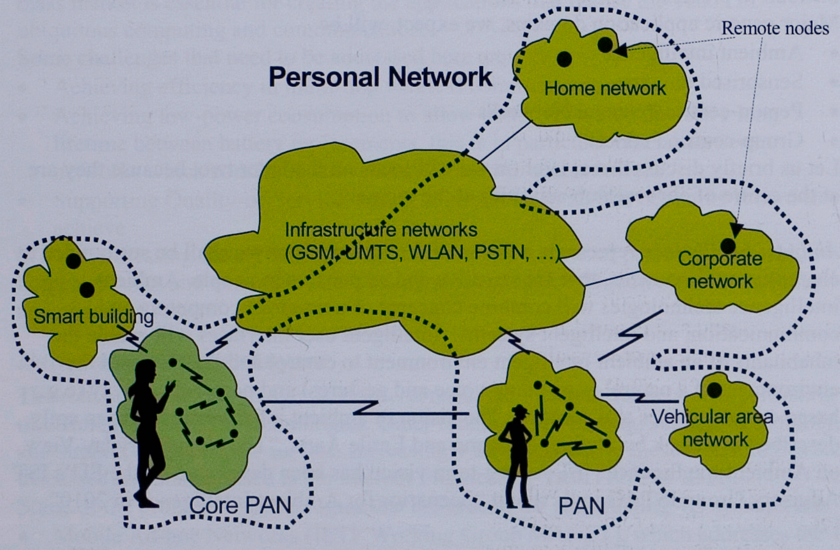

Fig. 6 A Personal Network: global interconnection of personal devices

Let us first describe some potential scenarios involving Personal Networks:

A health-monitoring application:

A disabled or elderly person has a PAN incorporating sensing devices linked to a health-monitoring server at home. As this person moves away from home to another location the server stays connected all the time to the sensing devices in a Personal Network which is formed by linking the PAN-connected devices via, e.g., a 3G network and the Internet to the Home Network where the health-monitoring server resides.

Walking through a building:

While a person walks through a smart building from room to room, a Personal Network accompanies him. It interacts with the building functions and controls the lighting, enables access to restricted areas, and activates building devices. For instance, it incorporates into the Personal Network a large wall-mounted display where the person can view an incoming video stream directed to him, which cannot be displayed properly on his PDA.

Business environment extended from the office to the car

A person leaves her office and enters her car. A Personal Network is established incorporating a number of car information accessories (via the on-board car network) so that she can listen to her corporate e-mail read by a computer, dictate and send replies. This could be realised for instance by temporarily extending the persons PAN containing a 3G-enabled PDA with on-board speakers, microphones and a voice-recognition and -synthesis system.

A way to envisage how these scenarios could happen is as follows. A person owns a PAN, we will call it core-PAN, consisting of networked personal devices in his close vicinity, e.g., attached to the body, part of his clothes or carried in a briefcase. This core-PAN is able to determine its context (e.g., where it is), interact and link up with devices in the environment or with remote devices in order to temporarily create a Personal Network. This Personal Network provides the functionality the individual wants at that very moment and in that particular context. For instance when he leaves the office and enters his car, he might want to hear his emails and dictate answers.

We envision a Personal Network to start from the core-PAN. This core PAN will, if its owner desires so, look out continuously for what the electronic environment has to offer; alternatively, if a user values privacy or isolation under given circumstances, his core-PAN will isolate itself from the environment. If not, the core-PAN will extend itself, on-demand and in an ad-hoc fashion with personal resources or resources belonging to people or organisations, driven by the opportunities that arise and the applications that one wants to run. The resources that can become part of a Personal Network will be very diverse; nowadays one could think of computers, PDAs, phones, headsets, displays, cameras, MP3 players, Internet-enabled appliances in the home, sensors and actuators, etc. There are many more devices with communicating and processing capabilities that will emerge in the coming years. This was the main rationale for the IPv6 protocol: to create a virtually unlimited address space for the myriad of devices that are likely to emerge in the near future. Many of these devices will be personal. Being personal could mean technically that they are impregnated with the identity of the person that owns them; some of them will be shared with other people. They may be free or one may have to pay for their usage.

The extension of the core PAN with remote devices will physically be made via infrastructure networks, e.g., the Internet, an intranet of an organisation or via a PAN belonging to another person or a home network.

Figure 7 shows an example of what present day devices and radio technologies could be part of a Personal Network.

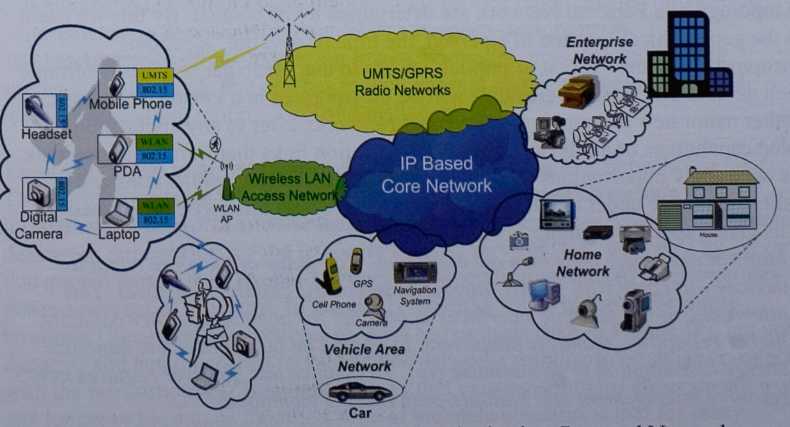

Fig. 7 Example of present-day technologies in a Personal Network

A corresponding, more technical view is given in Figure 8.

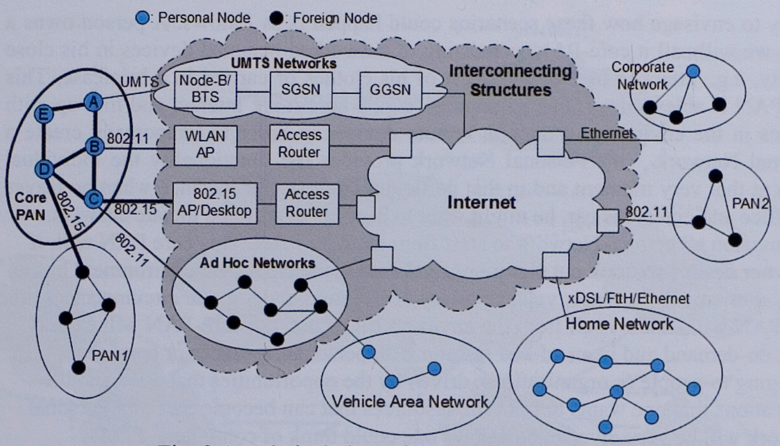

Fig. 8 A technical view of the same Personal Network

Looking at this figure we see that a Personal Network is composed of clusters of devices that are geographically disjoint. Each cluster is able to operate as an independent subnetwork. Examples of clusters are the core-PAN physically accompanying the owner of the Personal Network, or personal devices which are part of a home network or a car network. A cluster is a dynamic entity, created, modified and deleted as a result of the application needs or the opportunities that arise, or the movement of its components. Clusters communicate with each other via infrastructure networks such as the Internet, or a home network. Clusters need to be able to find each other and maintain contact when some of them move, e.g., when the person and its core-PAN move.

An important new element with respect to PANs is that the composition, organisation and topology of a Personal Network are determined by its context. By this we mean that the geographical location of a person, the time of day, the "electronic" environment, and the explicit or implicit wishes to use particular services determine which devices and network elements will be incorporated in a Personal Network. Another major new element is that Personal Networks offer to any application the pooled capabilities of all devices and communication links that form its ingredients. This opens new opportunities for achieving more dependable applications and offer Quality-of-service under circumstances where this would otherwise be impossible. Let us give a specific example:

> *Many devices have their own air interfaces, e.g., many of the more capable devices will come with WLAN interfaces and/or 3G cellular interfaces. This allows one to use multiple interfaces in parallel for achieving higher capacity, higher reliability, seamless handovers, to always be best connected, minimize energy consumption or to minimize cost. To achieve this however requires new resource management and multiple-path routing techniques.*

We conclude that a Personal Network will be a very dynamic system: the composition, configuration and connectivity will change depending on the time, place and circumstances, the resources required and the partners one wants to interact with. The concept of a Personal Network is closely related to the concept of Personal Distributed Environments [13] that is being researched in the UK Virtual Centre of Excellence on Mobile and Personal Communications. Both concepts originated in parallel. A major source of inspiration for personal networks was the work done in the MOPED project by Robin Kravets at the University of Illinois [14].

Let us now identify the research issues that need to be addressed in order to make full-fledged Personal Networks a reality.

Research on Personal Networks

Some major research issues need to be addressed in order to make Personal Networks a reality. Partial, limited or unsatisfactory solutions are available for some of these; we refer to our paper of 2003 [15] for a discussion of the state-of-the-art in relation to the requirements Personal Networks have to satisfy. We highlight here some major issues:

How to deal with the, in principle, unlimited *heterogeneity of the underlying link technologies, personal devices and applications*:
Personal Networks should be able to incorporate virtually every present and future personal device one might possess. This could range from very inexpensive, battery driven devices, with little capabilities, an example could be a simple sensor network embedded in a garment, to very powerful and capable devices, such as a PC. The radio links used to connect these devices may range from very low bit rates, e.g., for ZigBee equipped sensor systems, to Gb/s high bandwidth UWB radios.
Personal Networks are supposed to support any type of application as long as the resources are accessible and available. This could range from simple sensing tasks for monitoring somebody's health to complicated tasks like assisting in real-time somebody's memory through a search machine which operates on the person's email and agenda archives. Applications may differ widely in computational and communication resource usage, in Quality-of-service requirements, in real-time requirements, in dependability, security and privacy requirements.
The heterogeneity of the underlying link technologies, personal devices and applications, demands that one has to look anew at classical problems such as resource allocation, routing, QoS and management.

The involvement of *infrastructure-based networks* and *ad-hoc networks*:
There are two reasons why Personal Networks may want to co-operate with infrastructural networks and use their resources: to extend themselves with remote devices or remote clusters and to access specific services, e.g., delivered by servers that are not part of the Personal Network. Co-operation with fixed infrastructures poses a new set of problems. In Personal Networks we no longer have single terminals (like in cellular systems or WLANs) or hosts (like in Mobile IP), but very dynamic and heterogeneous mobile ad hoc networks wanting to establish co-operation with the infrastructures. This implies, e.g., that existing solutions either do not work any longer or have to be modified. One of the main concerns is that for many applications one would like that the establishment and maintenance of the co-operation is seamless.

The need for *self-organization* and *fast adaptation* to applications and context:
One of the goals and major challenges of Personal Network design is to make all the processes associated with establishing and managing a Personal Network largely invisible to its owner. This requires new techniques for self-organisation. Under self-organisation we understand methods and techniques to find devices, configure and adapt the configuration of the clusters and their components, and, to interconnect the clusters via infrastructures in a way that does not involve a user or system administrator. The Personal Network itself should be able to do this on its own, and thereby contribute to the unobtrusiveness and invisibility. A specific concern is the timeliness with which the organisation and adaptation processes take place, in order to reach the goal of "invisibility" of the Personal Network. This requirement is dictated by human perception and patience. We are extending the quantifiable set of Quality-of-Service (QoS) parameters for networks with a set of parameters characterizing the organisation and adaptation process. The requirements for these parameters should be derived from analysis of human perception of quality, a non-technical issue.

The need for *context awareness and cognition*:
New techniques involving proactive behaviour of Personal Networks, driven by context awareness and using cognitive techniques need to be explored. The idea is that the Personal Network is context aware, e.g., knows where the person is, what the time of the day is and what his or her agenda is. It should use this information to predict what the person will need and act on it, by setting up the Personal Network to provide particular services. Cognitive methods may help, e.g., in learning patterns of behaviour of the owner to predict what services will be needed and learning about state and availability of resources in a given context. A simple example is the following:

> *A person gets up in the morning and likes to watch or listen to the news when using the bathroom, get dressed, have breakfast, walk to the car and drive to work. If we realise that homes and cars will have displays and audio systems in every room, we can imagine that, as the person moves through the house, his personal news broadcast will automatically accompany him from room to room and into the car, where of course, for safety reasons, only audio should be used. This requires timely multimedia session transfers from one group of audio devices to another: this is called session mobility. These processes should be controlled by the intelligence of the Personal Network, which has learned the movement patterns of its owner and is assisted by cues from its own sensors and the intelligent ambient home environment which also contains sensor networks that identify and track a person as he or she walks through the home. This intelligence should through its predictive power and the cues it receives be able to take measures proactively. The aim should be that the owner of the Personal Networks has the experience that his favourite broadcast follows him in a seamless way, without noticing any hiccups, without requiring any intervention from his side. The Personal Network should be working hard to achieve this, but at the same time its actions should be invisible to its owner. This is what, in the words of Mark Weiser, is called "calm technology".*

The need for *dependability*, *security* and *privacy*:
Personal Networks should deserve the trust of their users by being dependable and secure and respecting a person's privacy. Personal Networks rely to a large extent on wireless links, which makes them vulnerable to eavesdropping and malicious interference. However, this is the same problem as faced by all wireless communication. Solutions developed in wireless LANs, short range and cellular radio link technologies will be part of the security measures in Personal Networks. The ad-hoc nature of Personal Networks will pose serious challenges for authentication and authorization. In particular security threats are posed by the incorporation of foreign devices, remote clusters through third party networks, the linking up or merging with other Personal Networks and with infrastructure networks. Personal Networks are nomads with respect to the infrastructure; this implies that they in turn also pose a threat to other networks. They will have to be properly authenticated and authorized. Because of the ad-hoc and distributed nature of Personal Networks distributed solutions need to be found that are efficient in bandwidth usage and at the same time are able to deal with the large variety of handheld and other portable devices and their constraints.

The research on Personal Networks is taking place in three projects, which we co-initiated: a major European IST integrated project MAGNET and its successor MAGNET Beyond [16], a major Dutch project, the Freeband project Personal Network Pilot 2008 [17], and the Dutch IOP GenCom project Quality-of-Service for PNs [18].

Fednets: Federation of Personal Networks

Many of the activities we undertake are group activities, e.g., among members of a family or groups of professionals. This asks for a concept which goes beyond Personal Networks; a concept which builds on people and their Personal networks, and exploits their capabilities. We call this a federation of Personal Networks or short: Fednets [19]. Let us discuss two examples of Fednets.

Sharing personal resources

A simple example of a Fednet is the federation of Personal Networks belonging to a group of friends or family members that want to share and enjoy together personal items, e.g., pictures or movies of an event they participated in. This is illustrated in Figure 9, where families physically meet at a restaurant and two Fednets are formed, one for sharing vacation pictures among adults and a second Fednet for the children to play computer games together. A select subset of each person's Personal Network resources is involved in each Fednet; some resources, e.g., a laptop serving as a communication hub, may be involved in both Fednets. Note that the federation of Personal Networks does not require that the people are present at the same location. They could be anywhere as long as their Personal Networks have the opportunity to communicate, e.g., by having Internet access.

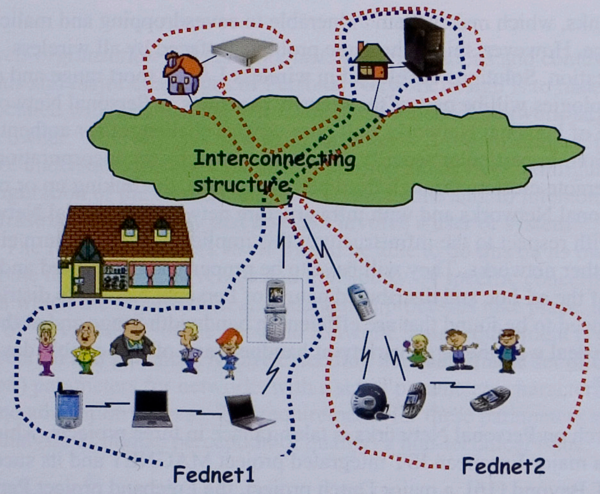

Fig. 9 Fednets for sharing personal resources

Emergency networks

Imagine an emergency situation where fire fighters, policemen, medical personnel, environmental specialists, etc. each have at their disposal a diversity of devices to assist them in monitoring and observing (Figure 10). These devices could be, e.g., sensors, cameras and communication equipment. They are part of their individual Personal Networks. It would be useful if these monitoring and observation devices could be shared in a common Fednet to enhance the capabilities of each professional involved, e.g., to give the policeman or medical personnel a view of the situation inside a burning building by using helmet-mounted cameras of firemen. This example is illustrated in Figure 10.

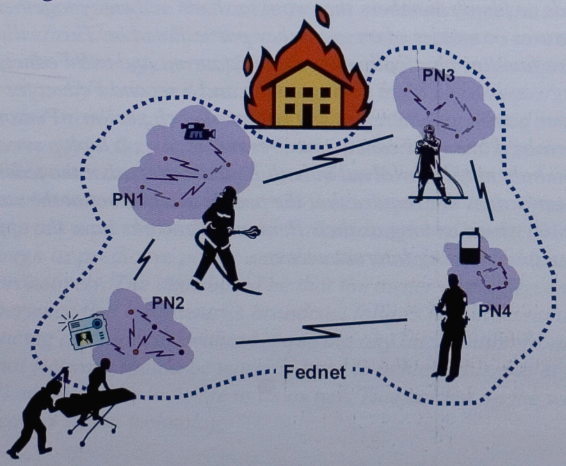

Fig. 10 Fednet for emergency handling

The idea of federation in distributed systems has been around for a while. In 1994, the ANSA consortium on open dependable distributed computing has defined federation as "*facilitating co-operation between autonomous organizations for the purpose of sharing services and resources*". The principal federation issue was seen as the problem of dealing with establishing authority in a large distributed system spanning boundaries of authority, while maintaining local control [20]. The ANSA approach has up to now not been adopted widely, but contains potentially useful ideas for Fednets.

More recently, the idea of federation has come up again in the context of networks and grid computing. These new developments are concerned with access control [21] resource allocation [22], load management [23] and security [24]. They have a different intention in the sense that they are based on the paradigm of a (single) service-user service-provider paradigm; the grid is an example thereof. Our perspective is a new one: *autonomous systems cooperating and sharing selected resources to achieve a group goal.*

Another development related to federation is identity management for e-commerce. The aim here is to simplify identity management across organizational boundaries, allowing users to consolidate many local identities into ideally a single federated identity. It provides the user access to the services offered by a range of systems through what is called single sign-on, without requiring the user's personal information to be stored centrally. It relies on groups of service providers that have established trust relationships. This work is carried out in the Liberty Alliance Project [25] and the OASIS standardisation activity [26].

The starting point for our concept of a Fednet is the idea of an independent person-centric network such as a Personal Network, in which there is a strong concept of ownership and trust. Person-centric could be extended to virtual persons or agents. It could even be networks enhancing the capabilities of robots.

We define a Fednet as a

> *federation of independent Personal Networks, created ad-hoc for achieving a specific task a group wants to carry out. It does this by allowing each other access to specific services and the usage of specific resources for performing the task.*

The independence of networks means that each constituent network does not need the others for performing non-common tasks.

Examples of constituent networks are Personal Networks, distributed robotic systems, and on-board networks of a vehicle. We will further concentrate on Fednets based on Personal Networks.

The Fednet has authority over the shared resources used in the cooperation, only for the time and purpose of the federation. It is formed on purpose when the need for achieving a common task arises or when the opportunity to federate presents itself, e.g., when the Personal Networks of people with strong common interests detect each other and see opportunities to cooperate. The Fednet, in principle, uses only a subset of the resources of the constituent networks. What particular subset is part of the federation depends on the specific application(s) that needs to be supported and the agreed rules and policies. The concept of Fednet is illustrated in Figure 11 where three Personal Networks federate into a single Fednet involving a subset of the nodes that constitute each Personal Network.

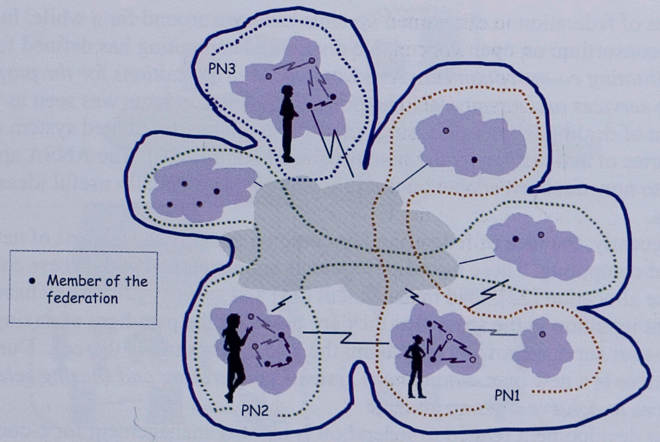

Fig. 11 Fednets: ad-hoc federation of personal networks

Research on Fednets

Let us look at some of the technical questions to be answered to make Fednets work. Before a Fednet is formed, rules and policies are needed to define under what conditions and circumstances (context), a person is willing to share which personal resources belonging to his Personal Network. One should be able to describe, communicate, interpret and agree on the rules or policies for federation. Mechanisms and formalisms are needed to describe, communicate and negotiate the resources Personal Networks are willing to contribute to a Fednet.

The Fednets should have an identity. They should be able to be reached, e.g., using an IP address of a federation agent; again privacy concerns are important here, e.g., depending on context and application, the full identity and location of the person and his Personal Network should only be revealed after a sufficient level of trust has been established. Of course the complexity of the Fednet mechanisms should be made invisible to the users.

As was the case for Personal Networks, algorithms and protocols should be distributed and should take into account the heterogeneous nature of the components of the Fednet, the mobility of the components and in general the dynamics of the topologies of the constituent Personal Networks and their interconnections. This complicates the problem. Therefore, in order to get dependable, secure and privacy respecting technical solutions, new algorithms and protocols have to be found and proven.

In line with the ideas of incorporating a knowledge plane in networking design proposed by Clark et al. in [27], we believe that cognitive techniques could help to deal with the complexity of management and control of Fednets. We started to investigate in which specific problem domains cognitive technology can assist.

Research on Fednets will take place in MAGNET Beyond, a major European 6th Framework IST integrated project which we co-initiated.

Interaction Personal Networks/Fednets – Ambient Networks

We envision a world where people will be assisted by Personal Networks and Fednets. We have already mentioned some of the potential applications and

application areas. At the same time our environment, the houses we live in, the streets we walk, the buildings we work in, the cars we drive or public transportation systems we use, will be equipped with Ambient Networks. These Ambient Networks will connect devices, sensors and actuators in our environment, to create the platform for ambient intelligence we discussed earlier. From a person's point of view, his capabilities will be enhanced by his own Personal Network facilities, interaction with other people through Fednets, and with the electronic environment, the surrounding Ambient Networks. For example the Ambient Network could tell a person's Personal Network, its exact location inside a building and help guide the person to a destination.

From a technical point of view, the Personal Network will be aware of its environment, locally and globally. This is called environment awareness: it knows what services and resources are available. More generally it will be context aware. At the same time the ambient intelligence surrounding it, will be able to detect and react to the presence of people and interact with them. It should assist the user as much as possible in what he wants to achieve, in protecting him against potentially dangerous situations or preventing him from undertaking undesirable actions. Hence we need a two-way interaction between Personal Networks and Ambient Networks. This is illustrated in Figure 12.

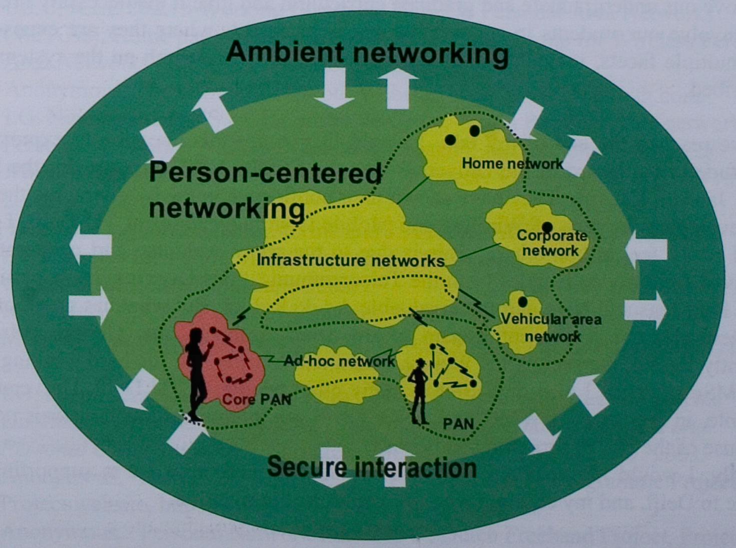

Fig. 12 Interaction of Personal Networks and Ambient Networks

The unobtrusive, i.e., invisible interaction of Personal Networks, Fednets and Ambient Networks will be a major new research area, that up to now has not been charted well, and that we will explore in our projects.

Conclusion

In this oration we have tried to give you a flavour of where we are going in our research and teaching. We have presented a vision of a new world of wireless and mobile communication, one which is centred on persons and their needs; a world in which technology will be assisting people, amplifying their capabilities without being intrusive. We introduced the new concepts of Personal Networks and Fednets, "invisible networks", that we expect will become major instruments in bringing this vision about. We have discussed the challenges that arise from the wireless, heterogeneous and dynamic nature of these future systems, and their need to be invisible, dependable and secure. This requires an approach that is different from the classical layered way of thinking about network design. We need to take into account the properties and characteristics of all system layers in a cross-layer approach. To do this well requires knowledge and skills to do the research that spans all system layers from the radio layers up to the application layer. We are happy to work in an enthusiastic group and research institute, the IRCTR Centre for Wireless and Personal Communication, where this is the case. To make sense it is also mandatory that the research is embedded in projects where applications, human factors and business aspects are examined. We are pursuing this through cooperation with partners inside and outside TU Delft.

Our principal task however is to educate people so that they are very well prepared to be researchers and engineers designing the products, systems and applications that will help people in their private lives and in their profession. These engineers and researchers should have a wide span of interest. We intend to work with others to improve our undergraduate and graduate curriculum and give it the necessary breadth. We involve our students in cooperative research projects where they are exposed to the multiple facets, including non-technical ones, of the research on the systems we described.

I have reached the end of my talk. I would like to use this occasion to express my gratitude to the Board of the University and the Faculty EWI, in particular the Dean Prof. Jan van Katwijk. They have shown their confidence in me by giving me the task of developing the area of Wireless and Mobile Communications at TU Delft. I must say I really feel at home here. This is due to the warm welcome and cooperation I received from my colleagues from the Telecommunications Department, in particular Leo, Piet, Jens and Nico and the invaluable Ad de Ridder. But what has given me the greatest pleasure is the enthusiasm of my team Anthony, Jos, Gerard and most recently Ramin, the secretaries Wendy, Laura and Marjon and the hard working PhD and MSc students. I also owe a lot to many other people, at TU Delft, University of Twente, in industry, TI-WMC and TNO. I will not attempt to mention their names, because of the risk of forgetting somebody.

Finally, I would like to thank my wife Mimi, who gave up a lot in supporting my move to Delft, and my children who are a source of motivation.

References

[1] G. Moore, "Cramming more components onto integrated circuits", *Electronics Magazine*, 19, April 1965.

[2] F. Hapgood, "Thousands of "dumb devices" are coming to a network near you", *Swantech Media Clips*, http://www.swantech.com//mediaclip_cio1.html, 2002.

[3] F. Hapgood, The Device Internet, http://fhapgood.fastmail.fm/devices.htm, 2002.

[4] M. Weiser, "The computer for the 21st Century", *Scientific American*, September 1991.

[5] J. C. Haartsen, "Bluetooth - The Universal Radio Interface for Ad-hoc Wireless Connectivity", *Ericsson Review*, 3:110-117, 1998.

[6] Stefano Marzano and Emile Aarts, "The New Everyday View on Ambient Intelligence", *Uitgeverij 010 Publishers*, ISBN 90-645-0502-0, February 2003.

[7] ISTAG, "Scenarios for Ambient Intelligence in 2010", Final Report, EC 200, http://www.cordis.lu/ist/istag.htm, February 2001.

[8] S.O. Dulman, "Data-centric Architecture for Wireless Sensor Networks", PhD Dissertation, University of Twente, ISBN 90-365-2262-5, October 2005.

[9] C. S. Raghavendra, K. M. Sivalingam and T. Znati (Editors), "Wireless Sensor Networks", Springer, ISBN 1402078838, 2005.

[10] IEEE, IEEE 802.15 Working Group for Wireless Personal Area Networks (WPANs), Home page of the IEEE 802.15 Working Group for Wireless Personal Area Networks (WPANs), www.ieee802.org/15/.

[11] Anonymous, The Official Bluetooth Website, http://www.bluetooth.com/.

[12] I.G. Niemegeers and S.M. Heemstra de Groot, "From Personal Area networks to Personal Networks: A User-Oriented Approach", *International Journal of Wireless and Personal Communications*, Springer, Vol. 22 No.2, pp. 175-186, 2002.

[13] Dunlop, J., Atkinson, R. C., Irvine and J., Pearce, "A Personal Distributed Environment for Future Mobile Systems", *IST Mobile & Wireless Communications Summit*, June 2003.

[14] R. Kravets, C. Carter and L. Magalhaes, "A Cooperative Approach to User Mobility", *Computer Communication Review*, Vol.31, No.5, October 2001, pp. 57-69.

[15] I.G. Niemegeers and S.M. Heemstra de Groot, "Research Issues in Ad-Hoc Distributed Personal Networking", *International Journal of Wireless and Personal Communications*, Springer, Vol. 26, No. 2-3, pp 149-167, 2003.

[16] Anonymous, "MAGNET", European IST 6th Framework Programme Project, Project website, http://www.telecom.ece.ntua.gr/magnet/.

[17] Anonymous, "Personal Network Pilot 2004", Dutch Freeband Project, Project website, http://www.freeband.nl/project.cfm?id=530&language=en.

[18] Anonymous, "QoS for Personal Networks at Home", Dutch IOP GenCom Project, Project website, http://www.irctr.tudelft.nl/cwpc/IOPGENCOM-QoS

[19] I.G. Niemegeers and S.M. Heemstra de Groot, "FEDNETS: Context-aware Ad-hoc Network Federations", *International Journal of Wireless and Personal Communications*, Springer, Vol. 33, No. 3-4, pp 319-325, 2005.

[20] N.J. Edwards, "An ANSA Analysis of Open Dependable Distributed Computing", ANSA, Cambridge, UK, 1994.

[21] N. Furmento, S. Newhouse, and J. Darlington, "Building Computational Communities from Federated Resources", in R. Sakellariou et al. (eds.), Euro-Par 2001, *Lecture Notes on Computer Science 2150*, Springer, 2001, pp.855-863.

9. Grassmann, H., Die Wissenschaft der extensiven Grösse oder die Ausdehnungslehre, etc.; Erster Teil, 1844, O. Wigand, Leipzig.
10. Bottema, O., Steen en Schelp, pg. 31 e.v., 1971; Keuze uit redevoeringen en opstellen van Dr. O. Bottema.
11. Hilbert Gedenkband, herausgegeben von K. Reidemeister, Springer Verlag, Berlin etc. 1971.
12. Todhunter, I., A history of the mathematical theories of attraction and the figure of the earth, 1873. Dover Publications, New York.
13. Thomson, W. and Tait, P. G., Principles of mechanics and dynamics in two parts (formerly titled Treatise on natural philosophy), last revised 1912 ed.; Dover Publications, New York.
14. Courant, R. and Hilbert, D., Methods of Mathematical Physics; Volume I, 1953, Volume II, 1962; Interscience Publishers, Inc. New York.
15. Poincaré, H., Science and hypothesis, 1905, Dover Publications, New York.
16. Zie (14) Volume I, pag. 62 e.v.
17. Bruins, G. J. and Bisselink, L. G. J., Computation of precision of distances in two- and three-dimensional figures. Assembly International Association of Geodesy, 18–25 August 1975, Grenoble.
18. Zie (14) Volume I, pag. 105 e.v.
19. Weitzenböck, R., Invariantentheorie; P. Noordhoff, Groningen, 1923.
20. Zie (12) pag. 100 e.v.
21. Clairaut, A. C., Théorie de la figure de la terre, tirée des principes de l'hydrostatique. Paris 1743.
22. Bruins, G. J.; Het nieuwe geodetische referentiesysteem 1967. Tijdschrift voor Kadaster en Landmeetkunde, 84e jaargang, no. 4, augustus 1968.
23. Moritz, H. e.a., Geodetic reference system 1967. Publication spéciale du Bulletin Géodésique; Association Internationale de Géodésie.
24. Sakuma, A., A permanent station for the absolute determination of gravity approaching one micro-gal accuracy, pg. 674 e.v. Proceedings of symposium on earth's gravitational field and secular variations in position, 26–30 november 1973, Sydney Australia.
25. Gaposchkin, E. M. e.a., Determination of the geopotential, pag. 901 e.v. Proceedings of the international symposium on the use of artificial satellites for geodesy and geodynamics, 14–21 May, 1973, Athens (Editor: George Veis).
26. Misner, Ch. W., Thorne, K. S., Wheeler, J. A., Gravitation, pag. 400 e.v. W. H. Freeman and Co., San Francisco, 1973.
27. Lloyd, I. D., On the scale and orientation of Geodetic Reference Systems by Very Long Baseline Interferometry, pag. 406. Proceedings: zie (24).