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The Vision of Personal Networks

Since the dawn of time, communication has been an integral part of human life and the need for better technology to support our communication has been growing continuously. Over the centuries, we have invented many different methods of communication to bridge the barrier of distance. With people becoming increasingly nomadic, the need for communication with business partners all over the world and with loved ones at home while on the move has never been greater. This is the basis of the worldwide success of mobile telephony. Migrant workers overseas may easily, for a relatively small cost, have voice conversations with their family on the other side of the planet. At the same time, the mode of communication has become richer and more varied. Today, nothing stops us from sending video and audio messages to any place on earth.

1.1 Past, Present, and Future Telecommunication

Telecommunication technologies, both wired and wireless, are what make rich communication, such as voice or video, possible for people on the move. Information and communication technology (ICT), which is the merger of telecommunication and computing, is the major enabling factor. However, rich communication is not limited to human interaction. Technology is increasingly used to automate many tasks. For example, with home automation, we can, in principle, control every electronic device in our homes. With electronic agendas accessible from everywhere, we can better plan our daily activities. By using sophisticated entertainment devices, we can listen to music, watch movies, or play games while waiting at the bus stop or at the airport.

From its roots in ARPANET (Abbate 1999), the Internet started in 1969 as a research project and grew into a worldwide network in the second half of the 1990s, connecting computers all over the world. Popular services such as e-mail, the World Wide Web, peer-to-peer file sharing, and more recently social networking evolved and made the Internet attractive for private citizens, business, and government alike. The growth of the Internet has been remarkable, and it has reached 60% of the population in the Western world (http://www.internetworldstats.com/). But it does not stop there. While the rate of Internet penetration is slowing down, the achievable data rates continue to increase and

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this will enable new services. Soon it will be possible to broadcast television and video on demand over the Internet to everyone everywhere.

Mobile telephony is yet another example of a very successful technology (Dornan 2001). The first successful mass market deployment of mobile telephone systems started in the 1980s. In less than 20 years, the mobile phone has gone from being a rare and expensive device, accessible only to business people with an interest in high-tech gadgets, to a pervasive low-cost personal item for everybody. In many countries, mobile phones now outnumber landline telephones, with most adults and many children owning mobile phones. In 2008, there were 4.02 billion mobile subscribers worldwide but only 1.27 billion landline subscribers (https://www.cia.gov/library/publications/the-world-factbook/geos/xx.html). While the Global System for Mobile Communication (GSM) and the various forms of 3G networks, such as the Universal Mobile Telecommunication System (UMTS), are currently the leading mobile technology standards, others, such as Long Term Evolution (LTE), will soon take over. These technologies offer better packet switching support as well as higher data rates with similar support for mobility. Another recent promising technology that can bring high data rates to the mobile user is IEEE 802.16 (IEEE 2004b, 2006a), also known as WiMAX. With these technologies we will soon be able to watch movies while on the move. However, this is probably just the start of the hunt for higher data rates for mobile devices. Better battery technology or other miniaturized energy sources, and energy harvesting techniques, more computational power, and improved radio technology will undoubtedly offer better data rates, higher quality, and more communication possibilities, enabling a vast range of high quality mobile services.

While Internet and mobile telephony have been developed side by side, there is a growing trend to integrate the two. Nowadays, there are plenty of websites on the Internet where one can send Short Message Service (SMS) or Multimedia Messaging Service (MMS) messages to mobile phones. Conversely, we have mobile phones that can send e-mails and connect to the Internet. Beyond any doubt, this trend will continue as normal users do not wish to have separate networks, for example one when on the move and another one when at home. Instead, users expect the two networks to be fully integrated.

The evolution of radio communication has also given birth to another trend: medium and short range wireless communication. One of the first successful mass market products in this segment was the wireless local area network (WLAN) standard IEEE 802.11 (IEEE 1999) originally released in 1997. It was designed to make the LAN wires redundant in an office and was much more successful in this than any of its predecessors, such as the Infrared Data Association (IrDA) (http://www.irda.org/). When the enhanced version IEEE 802.11b came onto the market, its deployment really took off. So-called hotspots were installed where an IEEE 802.11b (and later IEEE 802.11g) access point could offer wireless Internet connectivity with data rates of several Mbps to devices, such as laptops and personal digital assistants (PDAs), within a range of up to about 100 meters. Millions of hotspots have been installed worldwide in strategic locations where people congregate and need to communicate. Examples are airports, train stations, coffee shops, hotels, and convention centers.

To connect wearable and handheld devices around a person, a range in the order of 10 meters is enough. This has led to the development of yet another branch of technologies that cover a wide range of data transmission rates, have low power consumption, but a limited range. They go under the term wireless personal area networks (WPANs) or just

personal area networks (PANs), of which IEEE 802.15.1 (IEEE 2005) (commonly known as Bluetooth) is currently the most common technology. These technologies interconnect mobile phones, laptops, PDAs, sensors and other personal devices located within 10 meters in a seamless way with low enough power consumption for normal battery-powered devices. Typical WPAN communication takes place between a person's mobile devices, such as a camera requesting time and location information from a Global Positioning System (GPS) receiver to tag a picture or a mobile phone sending voice to a wireless headset. It can also support information sharing between two persons meeting on the street. For instance, they can share recently taken pictures or interesting locations (geographical data) one of them just visited. Even in this segment, very high data rate versions are to be expected in the near future, such as the IEEE 802.15.3 family (IEEE 2003, 2006b). For the more distant future, data rates in the order of Tbps are the new target for research projects.

Current research and development will bring us more specialized communication technologies that are optimized for a particular niche. Figure 1.1 shows the current landscape of wireless communication technologies. It shows how each technology targets a specific area. It is clear that the variety of technologies we will have to cope with is likely to increase. The downside to this trend is the multitude of radio interfaces and protocols, between which there is currently a clear lack of integration. The advent of software defined radio and cognitive radio will to a certain extent help to address this issue, by providing radios that, depending on application and context, adapt themselves.

The major challenge that remains is to build wireless distributed systems providing a wide spectrum of applications on top of a multitude of devices using highly heterogeneous radio communication technologies. We cannot expect the end-user to deal with this issue. Therefore, it is important to use these technologies in a complementary way and make them work together seamlessly.

Regrettably, very little effort has been made to integrate these different technologies. One rare example is the attempt to integrate WLAN and cellular technologies (Vulić 2009).

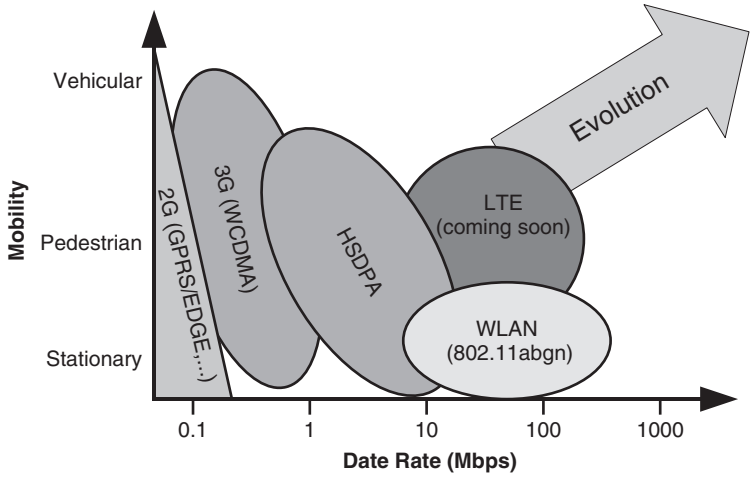

Figure 1.1 Wireless communication landscape.

Figure 1.2 Examples of personal electronic devices.

Furthermore, it is possible to send e-mails from a mobile phone and SMSs from an Internet-connected personal computer (PC), but the possibilities should go well beyond this. Instead, users nowadays are forced to learn each system and manually configure it to interoperate. In many cases, this is simply not possible because of software limitations. This problem is bound to become worse as people make more and more use of electronic devices. At the same time, device technology has made rapid progress in recent decades. Our mobile phones become smart mobile computers and still retain their original form. Even the cheaper mobile phones of today can play music, take and display photos and video clips, and even surf the Web.

Driven by Moore's law (Moore 1965), the microelectronics industry has created ever smaller chips that are consuming less energy, are less costly, and yet are more powerful and capable of things one could hardly imagine before. This has led to a large variety of different devices and terminals, everything from small and simple mobile phones and music players to PDAs, tablet PCs, and computers embedded in virtually every artifact, to advanced mobile multimedia or entertainment platforms. Figure 1.2 shows some current examples. Hence, there is no reason why future terminals should be a limiting factor for enhanced interoperability.

1.2 Personal Networks

According to the Wireless World Research Forum (WWRF), by the year 2017, there will be 1000 wireless devices per person on earth (Jefferies 2007). These devices will vary from sophisticated multimedia systems to very simple sensor systems. Many of them will be intimately linked to people. They will be an important ingredient of what has been called 'the Internet of things' (Dodson 2003). In principle, this opens up the perspective of using this vast number of personal resources to enhance people's lives, professional and personal, regardless of where they are. However, the shortcomings of current wireless

communication technologies are hampering the development of seamless communication between the multitude of devices a person will own. The careful reader will notice that most devices in Figure 1.2 have screens. These are needed because communication is cumbersome and forces us to interact directly with every single device, using screens and other input and output means.

In order to be successful, future information and communication technology should be centered on the user, improving the quality of life of and adapted to the individual, without the need for the user to be aware of the technical details. In order to achieve this, devices and environments need to become smarter, more responsive, and to accommodate the needs of the individual. Further, personalization and ubiquitous access to information and communication will be essential. Ideally, such a system must adapt to the situation and allow its users to use the most suitable means of communication and to access the most relevant information. As a consequence, new fields of research have emerged that aim to provide users with the same experience independent of user interfaces, terminal capabilities, communication technologies, and network and service providers. Examples of such fields are pervasive and ubiquitous computing (see Section 3.4) as well as ambient intelligence and ambient networking (see Section 3.5).

The personal network (PN) (Niemegeers and Heemstra de Groot 2003) is such a concept and technology. It is related to pervasive computing with a strong user-focused view. While a PAN connects a person's devices around her, a PN extends that PAN with other devices and services farther away. This extension will physically be made via any kind of wired or wireless network. This can include devices and networks around her in the car, office, or any other place. However, a PN is more than connectivity. A person's PN must support her applications and take into account her context, location and, of course, her communication possibilities. A PN must adapt to changes in the surroundings, be self-configuring and be able to incorporate many different types of networks and devices to be as useful as possible. Figure 1.3 shows what a PN could look like for a user. It shows how the user has electronic devices around her that can communicate with each other using WPAN technologies. It also shows how those devices can communicate with the devices of friends in the close vicinity as well as devices in smart buildings. The PN also incorporates devices elsewhere, such as in the office and at home.

There are many different ways of integrating the various communication technologies to achieve one unified system. The best and most complete integration approach is to define a common network layer to be used by all, which is similar to the approach taken by the Internet with the Internet Protocol (IP). Such a general and common network layer architecture that imposes minimal changes to the underlying network types, can bridge different communication technologies and offer a homogeneous and clear view to the end-user. At the same time, the network architecture needs to be future proof, that is able to accommodate all kinds of present and future applications and technologies. In order to be successful, a PN should cater for all of a person's communication needs. The PN must include not only the person's wearable and wireless devices but also devices at home, in the car, in the office, or any place where the user may have personal devices. This means that the network layer of the PN must work as a home network at home, a car network in the car, a PAN around a person and glue all these networks together in one PN. At the same time, it must cooperate with existing networks such as the Internet and other infrastructure networks.

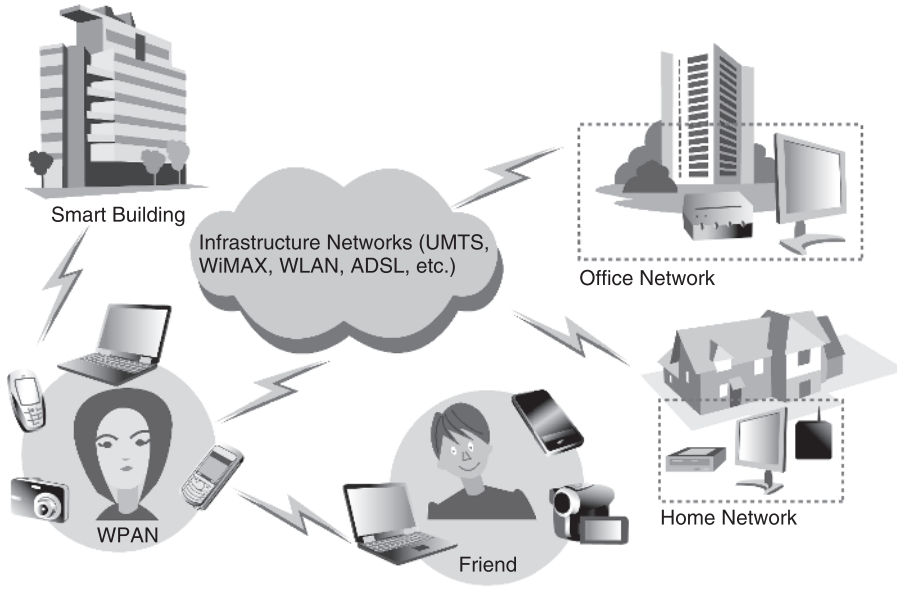

Figure 1.3 The concept of personal networks.

1.3 Some Typical PN Use-Case Scenarios

The success of PNs requires not only seamless integration at the network layer, but also, and more importantly, the development of new types of interesting and useful applications that exploit the full potential of PNs. To better introduce the concept of a PN, some use-case scenarios are given below that demonstrate the possibilities of a PN and what types of applications can benefit from a PN.

1.3.1 Introducing Jane

Let us meet Jane, who will pop up throughout this book to help us explain various PN concepts and how they apply to real users. When we refer to this example, we use indented and italic text.

> *Jane is a salesperson who travels a lot. For her, it is important to always be able to access her own data and services, regardless of their locations. Frequently, she needs to access information stored on computers in her office when she is on a company visit or on the way to the next meeting. To do this, Jane is equipped with a mobile phone, a laptop, a headset, and a navigation system.*
>
> *Furthermore, Jane has a family with two children. To be away from home for extended periods of time can be demanding. However, screens, cameras, speakers, and microphones in her home enable her to have a richer form of communication with her family. The devices at home can provide her with a virtual home environment through which Jane can virtually see her family, talk to them, and even play games.*

Sara is Jane's mother. Sara is aging, but still lives by herself, not far from Jane. However, Sara needs more and more attention, especially with household tasks such as cleaning and grocery shopping. Jane shares the task of helping her mother with her brother and one of Sara's neighbors. However, this requires a lot of coordination to, for instance, ascertain that Sara does not suddenly end up without food. To this end, Jane shares her agenda with the others so that better coordination can be achieved.

However, Jane has one problem with all this. There are so many applications, devices, and networks to keep track of and getting them to cooperate is a major task. Jane does not want to spend time on these sorts of issues and has therefore decided to create a PN for herself.

1.3.2 The Traveling Saleswoman

One major potential benefit of using PNs is seamless access to resources anywhere. For instance, personal files stored at home or in an office can be obtained by one's devices as long as there is network access. Figure 1.4 shows Jane during a company visit.

Jane's PN offers a framework that enables her devices to seamlessly cooperate and to communicate with distant devices, such as desktop computers, company servers, customer services, and home multimedia systems.

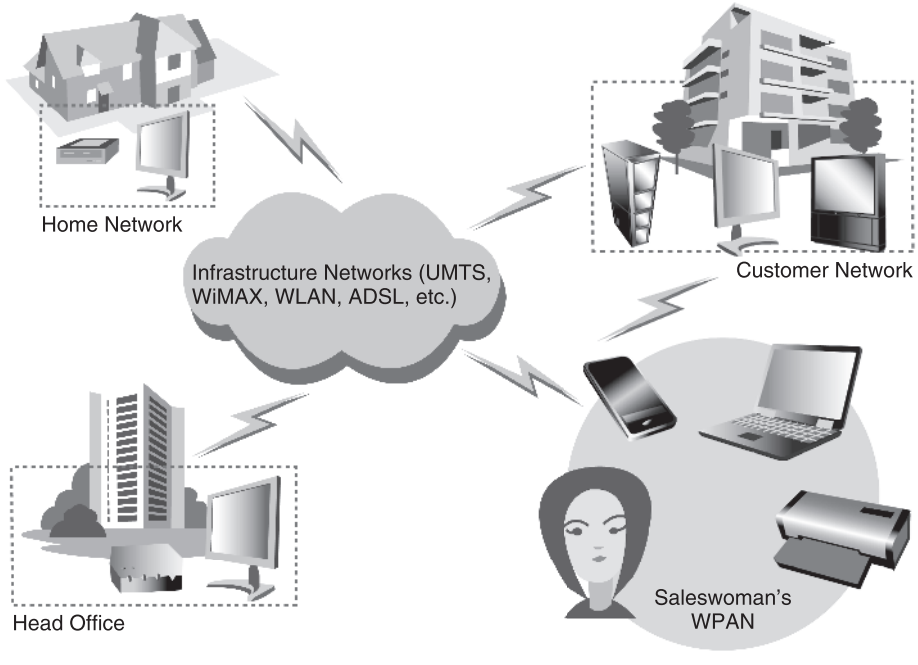

Figure 1.4 Traveling saleswoman scenario.

With a PN, Jane can easily access her agenda from any device wherever she is and at the same time make sure her secretary has an up-to-date copy as well. The same holds for personal and shared files. When at a client site, Jane can share some of these files with the client in order to be able to present products, make offers, etc. These are very simple applications, yet very important ones. They must work with whatever network access is available. For instance, when she is visiting a client, they should be able to use the client's network to improve transmission speed.

Furthermore, Jane's PN lets her communicate with her family using the equipment at home. The PN enables her to use the devices that she carries to communicate with the devices in her home and thereby offer her the ability to interact with her family in a rich way.

Depending on the communication requirements, she could also continue all this while traveling. She could listen to streamed music from the home multimedia system while driving, or play a game while waiting for an airplane, etc. If she meets a friend somewhere, a temporary network can be established, to share files, services or just to play a multi-player game for a while.

While several existing technologies can offer solutions to parts of this scenario, very little work has yet been done to combine these technologies into a seamless integrated solution for a normal user. Today, employers have experts who set up servers and configure wireless devices to interoperate with their enterprise software on behalf of their employees. Even so, these solutions are typically application-specific and will not work for new applications without proper integration. For the end-user, such as Jane, they are far from seamless. Complex settings cause frustrations and make people wonder whether it will work on the next customer visit. PNs try to address this issue by being easy to use, set up, configure, and maintain, as well as being fast and secure.

1.3.3 Care for the Elderly

PNs can be an even more powerful tool for personal communication if they are designed to interact with other PNs as well as existing networks and services. With an aging population, this may prove to be a very important function. An elderly person could be equipped with a PN consisting of various medical sensors to continuously allow monitoring of her health. Such sensors could include blood pressure and heartbeat sensors, activity sensors, accelerometers, and positioning devices. When something happens, the PN could alert any interested parties. Figure 1.5 illustrates this scenario.

Sara's doctor decides that it would be a good idea to monitor Sara more closely in case something happens and arranges for a wearable fall detector and some activity sensors to be placed in Sara's home. With PN technology, these sensors can trigger an alarm on some other predefined PNs. In this case, the system is configured to notify the PNs of Sara's daughter Jane, Sara's neighbor, and a special care organization. Using a camera in the home, any of these persons can try to make contact and find out more details when an incident occurs.

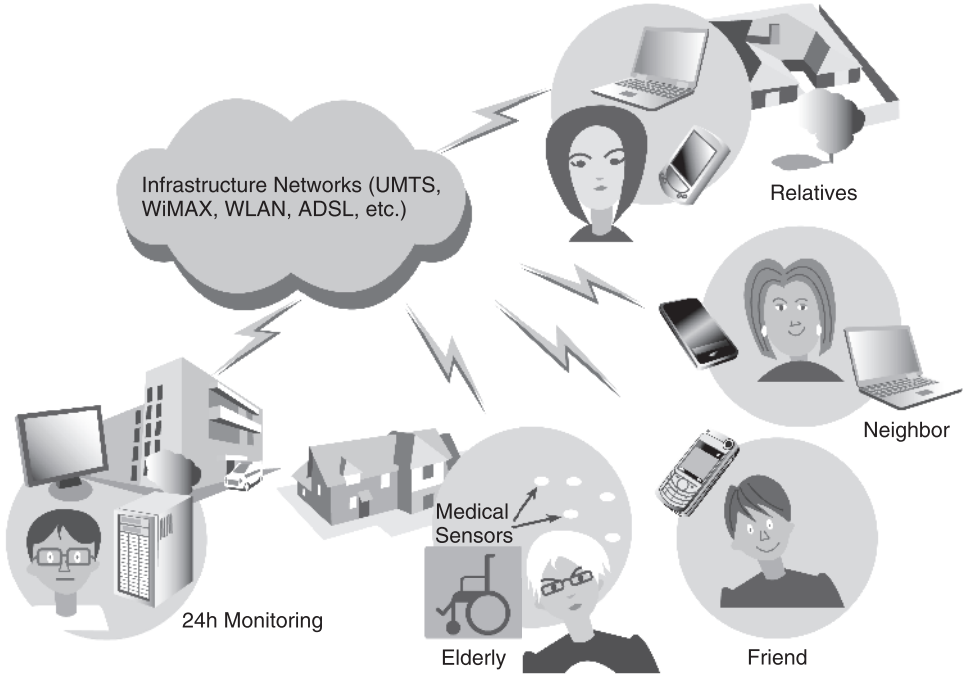

Figure 1.5 Care for an elderly person.

Sara is also offered a device that can trigger the alarm at the push of a button. That device can also track the location. When the button is pressed, the location can also be sent with the notification so that medical staff can be sent to the correct location immediately. Such a device may allow Sara to leave the house, knowing that help is still available if something happens.

A PN can also improve an elderly person's capability to communicate with friends, who might also be elderly, or it can remind them about various things, such as when to take certain medicines for those whose memory is fading. However, designing a PN for the elderly is even more challenging because of an even greater requirement for usability. Such a PN must work for people who may not be accustomed to modern electronic devices or have lost their ability to deal with complexities. Further, it must also be usable for people who have reduced audiovisual capabilities and/or movement disorders, such as tremors in arms and hands.

This area of application poses a significant challenge since it requires ease of use for several very different groups of people, efficient and reliable communication, and also security. The system must be dependable, particularly in emergency situations. Privacy is another complex issue that cannot be neglected. While the elderly person wants a fast response in emergencies, he may not want to be monitored in detail all the time by unscrupulous relatives or neighbors.

1.3.4 More Use-Case Scenarios

Obviously, we can imagine many more PN use-case scenarios and applications. Here is a short list of some additional use-case scenarios.

Walking through smart buildings. While a person walks through smart buildings from room to room, her PN accompanies her. It interacts with building functions and controls lighting, enables access to restricted areas, and activates building devices. For instance, the PN can incorporate a large wall-mounted display where she can view an incoming video stream directed to her, which otherwise cannot be displayed properly on her PDA.

Business environment extended from the office to the car. A person leaves his office and gets into his car. A PAN is established incorporating a number of car information accessories (via the on-board car network) so that he can listen to his corporate e-mail text read by a computer, dictate, and send replies. This could be realized, for instance, by linking up and temporarily extending the person's PAN containing a 3G-enabled PDA with on-board speakers, microphones, and a voice-recognition and speech-synthesis system.

A tele-presence session. One or more video cameras and high quality displays that surround a person in the office and at home can be used to set up a video conference or tele-presence session with someone else. The devices are incorporated, automatically and invisibly, into the person's PN as he enters the office or sits down on a couch in his living room. They allow him to start up a tele-presence session via a PDA, for instance, in which he can have a virtual meeting with other people for business as well as for social occasions. Alternatively, a person on the move could carry around some high quality portable wireless screens and cameras. Again, this would involve the automatic establishment of a PN involving local and remote devices.

A remote babysitting application. Consider the case of a mother visiting a friend's house while her child is asleep at home. She might want to remotely watch and observe the child. She does this by using a PN consisting of some personal devices, for example a UMTS and Bluetooth capable PDA and a headset she carries with her, and a remote pair of eyes and ears in the child's bedroom at home. The latter consist of a digital video camera, a microphone, and a UMTS phone, forming a cluster of cooperating devices. But since the friend's living room is equipped with a wall display including speakers, hooked up to the friend's home network and accessible to authorized guests via a Bluetooth link into the home network, she might want to use these to observe the child instead of her PDA and headset.

A way to envisage how these scenarios could happen is as follows. An individual owns a PAN, consisting of networked personal devices in his close vicinity, for example attached to the body or carried in a briefcase. This 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 PN. This PN provides the functionality (e.g. office functions in the car) that the individual wants at that very moment and in that particular context.

These scenarios highlight some of the potential application areas of PNs. More scenarios that reflect the vision of PNs have also been defined elsewhere (Jacobsson et al. (2004); MAGNET (2005g); Niemegeers and Heemstra de Groot (2003)).

1.4 Federations of Personal Networks

The services and resources of a PN need not be confined to a single user. There are many situations in which it may be desirable to extend the boundaries of a single PN. A PN federation (Niemegeers and Heemstra de Groot 2005) is an extension of the concept of the PN that allows resources to be shared among different PNs. A PN federation is defined as a temporal, ad hoc, opportunity- or purpose-driven, secure group-oriented network where the users may be the producers and consumers of the services, content, and resources. In principle, only a subset of the resources of each constituent PN is committed to the PN federation. Only those resources are visible to the members of the PN federation.

The cooperation of PNs gives opportunities for different types of group-oriented applications in health care, education, business, entertainment, emergencies and more. Examples are distributed classrooms, sharing resources amongst project members, cooperative inter-vehicle networks, emergency networks, gaming and family networks. We will discuss PN federations in detail in Chapter 10.

1.5 Early Personal Network Implementations

Since PNs were first proposed, work has been going on to develop an architecture and solutions for them. In this book, we will introduce this architecture and the solutions along with some alternatives. This work has not just been theoretical, but also practical. A large part of it has been devoted to implementing prototypes. At the time of writing this book, at least three PN prototypes have been developed by different research projects, in particular the European MAGNET and MAGNET Beyond (http://magnet.aau.dk/) projects and the Dutch Freeband PNP2008 project (http://pnp2008.freeband.nl/).

The very first prototypes, which were developed within the PNP2008 project, were designed to demonstrate and test potential PN applications. Only very limited support systems were developed. Some of the prototypes were used in trials with real users. Based on user feedback, we were able to better understand what was really needed and the PN concept evolved accordingly. One example is the Medicam prototype, which was a demonstration of PNs in a professional setting – the medical profession. It showed how PNs and PN federations could be used to easily and reliably tie devices together in an area where errors are unacceptable.

Later implementations, such as those developed by MAGNET as well as PNP2008, were far more complete. They contain a good amount of support for networking, security, auto-configuration, context awareness, etc. Here, the focus was on the PN support systems and on testing them.

All these implementations clearly demonstrate that PNs can become a reality and that it need not take long. For all the details of these prototypes, we refer the reader to Chapter 11.

1.6 Expected Impact

The true impact of a new concept, such as the personal network, and the technology that underpins it is difficult to gauge quantitatively. It depends on many factors, such as user acceptance, market conditions, technology roadmaps, and regulatory frameworks, which

are beyond the scope of this book. They will determine when and to what extent PNs might become a reality.

It should be remarked that PNs that have been prototyped in the different projects but they only address the basic functionality of PNs. We cannot yet talk about full-fledged PNs. The potential of PNs will grow as more advanced features, such as resource virtualization, context awareness, and cognition, become available for developing applications that go beyond what is presently possible. What we can point out, however, are the qualitative impacts that PNs might have in different domains.

PNs are based on personal devices, many of them consumer products from different manufacturers. Essential for the integration of these devices into a PN is that they can be software-enhanced to become PN-capable. One should be able to download and install PN software that incorporates the necessary PN protocols and functionalities into these devices. Therefore, it is necessary to define a core set of standards, an endeavor that has already begun.

A faster introduction and market penetration might take place in the professional domain. An example is the public safety and security domain, where professionals, such as firefighters, policemen, environmental specialists, ambulance personnel, security specialists, etc., might be equipped with specialized PNs to enhance their personal capabilities and allow them to federate with other professionals handling a particular incident. Other examples can be found in health care, for example (ETSI 2009). The community of players that have to agree on a common approach is much smaller and the urgency for adopting PN-like technology to increase professional capabilities and cooperation is much stronger. Moreover, the additional cost of making devices PN-capable may be small compared to the cost of professional equipment. Hence, an initial penetration of PN technology in these sectors could start in the short term, perhaps within a few years.

From the point of view of the consumer product manufacturers, PN technology should be seen as a product enhancement that allows devices to be embedded in a much more powerful distributed environment. This should extend the usage of these devices in space and time, and enable new distributed applications not yet foreseen. This in turn could be a sales argument for PN-capable consumer devices.

A significant impact will, we expect, be caused by the user experience created by PNs. The fact that a user has access, in a seamless way, to his personal devices and their services, wherever he is and with minimal user intervention, should be an unrivaled experience, especially given the growing numbers of ICT devices and services that are surrounding us.

PNs will be an enabler for the development of new distributed applications, exploiting the combined power and synergy of all the personal devices the user owns. In the light of the rapidly growing number and heterogeneity of these devices, from simple sensor and actuator devices to sophisticated computing systems, this may be a significant boost to the ICT sector in a new domain of applications and services.

PNs may also create new business roles for PN and service providers. This has been explored in the PNP2008 project (PNP2008 2008b,e), where the role of a PN provisioning party was defined, in conjunction with a supporting PN architecture. In such an approach, the provisioning of a number of the PN functionalities is outsourced to a trusted PN and/or service provider.

The PN concept and some of its supporting technologies can also be used in different domains. One can think of the concept of personalization and cooperation, and the supporting functionalities proposed in PNs as organizational principles for any future complex network that supports the functioning of one particular entity. Examples are networks for managing smart homes or buildings, for managing large vehicles such as ships, and for managing industrial structures such as power plants. To a certain extent, the principles of PNs could alleviate some of the issues raised by the Internet of things (ITU 2005).

Some of the technologies developed for PNs might be adopted in other ICT systems. Examples include the concept of personalization, which may be used to build grid-like systems in which secure cooperation among different entities is needed, or the self-organizational principles of PNs to form various types of overlay networks (Hoebeke 2007).

Finally, it is not only expected that PNs will have an impact on standardization, but also necessary. This process has started and may lead to a profile of standards for building PNs so that equipment from different manufacturers can fully coexist in a PN. This is likely to consist of a mix of existing standards and newly developed ones that together prescribe what is needed to implement PNs. This process is currently ongoing in an editing group within Ecma International (http://www.ecma-international.org/memento/TC32-PNF-M.htm).

1.7 Summary

In this chapter, we have introduced the vision of personal networks and how it creates the opportunity to exploit the possible synergy of the many personal devices a person will own in the near future. We discussed how the computer industry and the telecommunications industry have converged and now need to work together more closely in order to enable new applications that will be easy to use. Internet technologies and wireless communication will together allow seamless communication between a person's devices. Better computational capabilities allow for more intelligent and exciting applications. However, in order to achieve this, all devices need to be extended with software that allow them to seamlessly cooperate with each other. Personal networks were introduced to achieve this.

We highlighted the possibilities of PNs with some use-case scenarios. The scenarios show that PNs are beneficial in a large range of different situations, such as home networking, business, and health monitoring.

We also introduced the concept of federations of PNs. This broadens the user-centric concept of PNs into a group-centric concept. Federations allow the sharing of resources among different users and their PNs. The cooperation of PNs gives opportunities for different types of group-oriented applications in different areas, such as health care, education, business, entertainment, and emergency response.

Finally, we discussed current PN implementations as well as the potential impact of PNs. We discussed how a concept such as personal networks affects the development of new technologies and how the concept can become a reality, and argued that standardization is vital for the success of personal networks.