Part I

Introduction

Short-Range Wireless Communications: Emerging Technologies and Applications Edited by Rolf Kraemer and Marcos D. Katz
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Introduction

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Short-range communications systems characterize a wide range of scenarios, technologies and requirements. There is no formal definition of such systems though one can always classify short-range systems according to their typical reach or coverage. We define short-range communications as the systems providing wireless connectivity within a local sphere of interaction. Such a space corresponds to the first three levels of the multisphere model as discussed in the Book of Visions of the Wireless World Research Forum (WWRF) [1]. Figure 1.1 depicts the multisphere concept, highlighting the levels associated with short-range communications, namely Personal Area Network, Immediate Environment and Instant Partners [2–4]. Short-range systems involve transfer of information from millimeters to a few hundreds of meters. However, short-range communication systems are not only systems providing wireless connectivity in the immediate proximity, but in a broader perspectivethey also define technologies used to build service access in local areas. The WWRF envisions that by year 2017 there would be seven trillion wireless devices serving seven billion people. Certainly, the overwhelming majority of these devices will be short-range communication systems providing wireless connectivity to humans and machines.

Together with wide/metropolitan area cellular systems, short-range systems represent the two main developing directions in today's wireless communications scene. In terms of design rules and target capabilities, short-range systems have certain commonalities as well as marked differences from their counterparts, cellular systems. Maximizing the supported data throughput is quite often one of the main design targets for both types of wireless networks though a detailed comparison between them is not straightforward. Figure 1.2 shows the evolution of data rate support in cellular, metropolitan, Wireless Local Area Networks (WLAN) and very short-range systems. We can see that a steady increase in the supported throughput at a rate of approximately one order of magnitude every five years [5].

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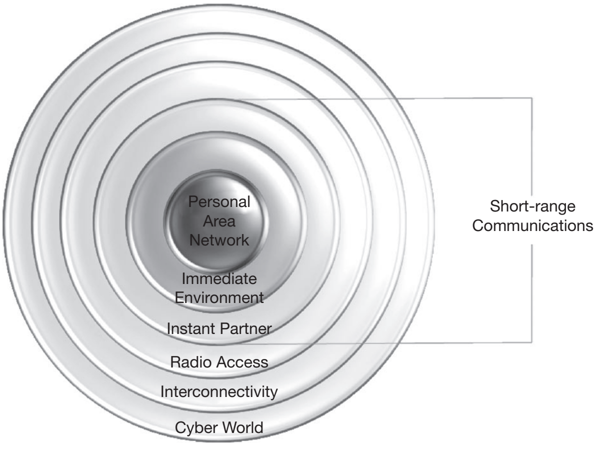

Figure 1.1 Short-range communications within the WWRF multisphere reference model.

There is a great deal of synergy between short-range and cellular networks, and in many cases exploiting their complementary characteristics results in very efficient solutions. The most important approaches to short-range are depicted in Figure 1.3, where a classification according to the operating range is shown. The short-range systems include Near Field Communications (NFC) for very close connectivity (range in the order of millimeters to centimeters), Radio Frequency Identification (RFID) ranging from centimeters up to a few hundred meters, Wireless Body Area Networks (WBAN) providing wireless access in the close vicinity of a person, a few meters typically, Wireless Personal Area Networks (WPAN) serving users in their surroundings of up to ten meters or so, Wireless Local Area Networks, the *de facto* local connectivity for indoor scenarios covering typically up to a hundred meters around the access point, Car-to-car communications (or Vehicle Area Networks) involving distances of up to several hundred meters and Wireless Sensor Networks, reaching even further.

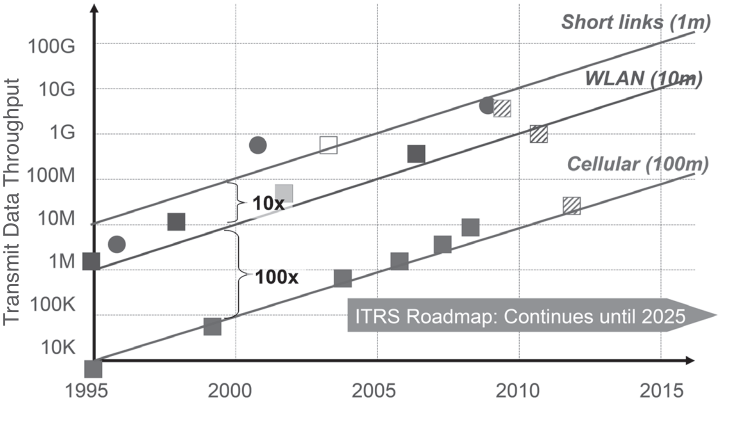

Figure 1.2 Data throughput evolution if mainstream communication systems [Courtesy of Wigwam project].

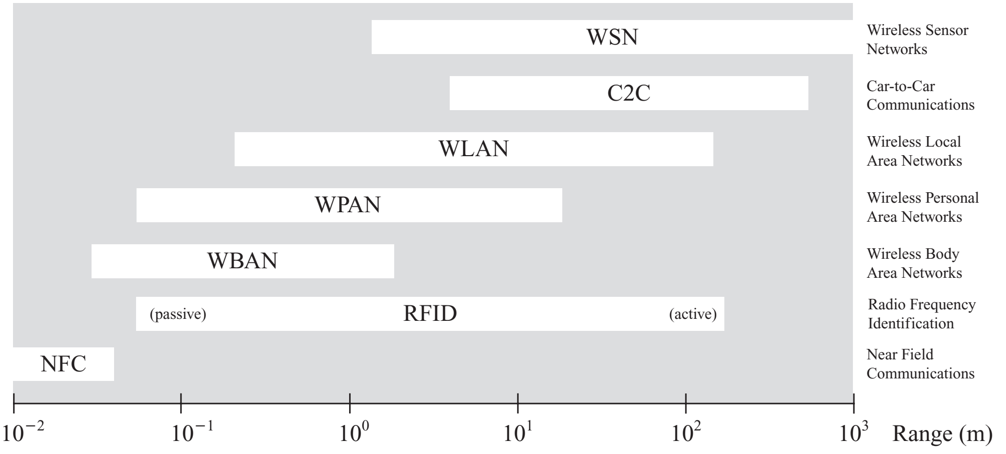

Figure 1.3 Short-range communications systems and their typical operating ranges.

Each of the aforementioned short-range approaches involves in general one or more specific air interface technologies (i.e. physical layer and medium access control layer) typically with the corresponding supporting standards defining most of the relevant technical details. A vast amount of literature exists for short-range technologies, in particular WLAN, WPAN, RFID and WSN are by far the most visible representative approaches. Ever since their inception, Wireless Local Area Networks (WLAN) and Wireless Personal Area Networks (WPAN) have had a leading role in the development and further diversification of short-range communications systems. Initial developments targeted simple point-to-point communication systems working as cable-replacements to connect wireless devices (e.g., computers, peripherals, appliances, etc.) Currently, there are several active and evolving standards particularly focused on short-range systems. The IEEE 802.11 standard series is the most popular example of coordinated and sustained development in short-range communications, particularly focused on WLAN. As for WPAN, the IEEE 802.15 series defines a family of wireless networking standards with different technologies, such as Bluetooth (802.15.1), High Speed (802.15.3) and Sensor Networks (802.15.4). There are several different physical layer descriptions in each of the 802.15 sections, for example 802.15.4a for UWB based wireless sensor networks or 802.15.3c Gigabit communication networks.

Figure 1.4 shows other aspects of short-range communication systems, highlighting the great diversity in possible air interface solutions, topologies as well as achievable data throughput and supported mobility. Physical layer technologies range from conventional radio (e.g., narrowband) to Ultra Wide Band (UWB) systems, exploiting single and multicarrier modulation schemes. Typical frequency bands span from some MHz to millimeter-wave systems (60 GHz and beyond). Moreover, optical communications are also attractive short-range technologies, including infrared and visible light communications. In general, short-range networks have *ad hoc* distributed architectures allowing direct and multi-hop connectivity among nodes. Centralized access is also possible, as in WLAN, which in fact supports both centralized and distributed topologies. Even though short-range systems are typically conceived for fixed or low-mobility environments, as in essentially all the indoor applications, new scenarios even foresee cases where high mobility is involved. Examples include car communications where

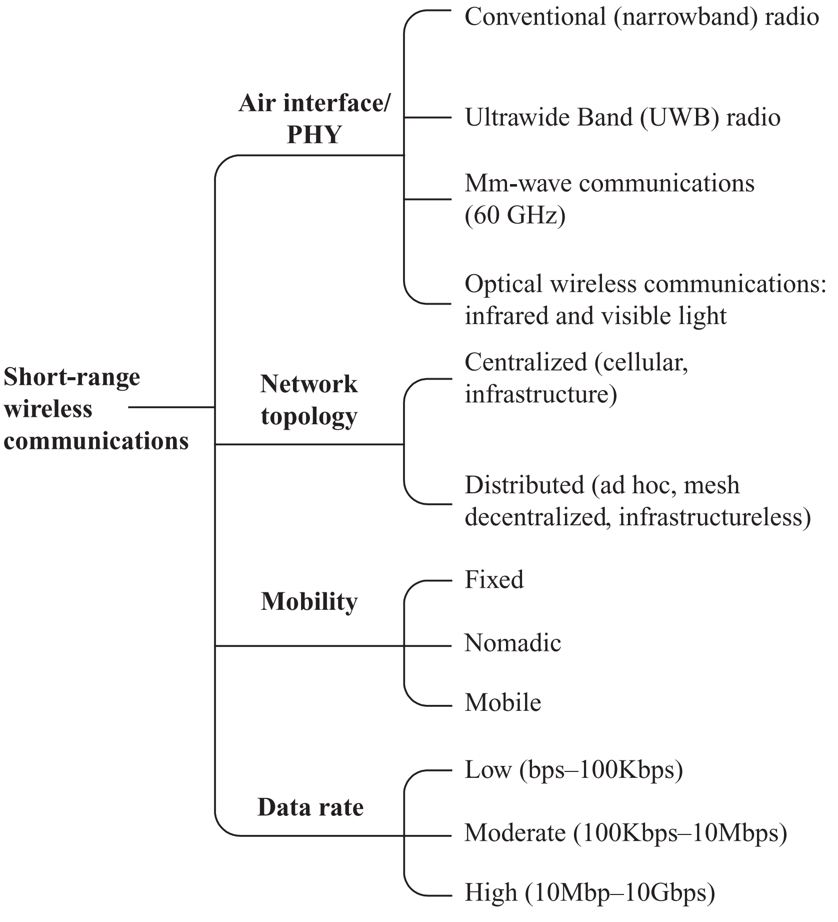

Figure 1.4 A general classification of short-range communications.

cars traveling in opposite directions attempt to exchange information, or information retrieval in the case of car-to-roadside communications. Data throughput requirements for short-range systems are also very broad, from some hundred bits per second in simple RFID systems up to 10 Gbps and beyond in WLAN systems, for instance.

In many cases low power consumption is one of the key requirements for short-range systems, particularly taking into account that transceivers are in many cases battery-driven. Particular attention is necessary when designing short-range devices while minimizing the power consumption at the three basic conditions of the transceiver, namely transmitting, receiving and idle states. Low cost is another important factor to take into consideration when designing short-range systems. Furthermore, minimizing size and weight are also quite often imperative engineering principles that need to be applied by the designer of such communication systems.

Another important aspect of short-range communications networks is their relationship to other existing wireless networks and their possible interaction. In very many scenarios it is indeed convenient to consider short-range networks as complementary to cellular networks, instead of the conventional approach considering the former in complete isolation from the rest of the networks. Countless efforts have been put into the research and development of *ad hoc* networks in the last twenty years. However, their presence today is effectively eclipsed by the omnipresent cellular network. It can be argued that one of the reasons for such a weak penetration is precisely the fact that these networks were designed largely ignoring the other mainstream network approach and their possible cooperation. As a matter of fact, these networks complement each other very well and a welldesigned cooperative strategy between both networks can bring significant benefits. Transmitting bits over short-range networks is much more energy efficient that doing it over cellular networks. In addition, short-range networks usually use spectrum-free bands (e.g., ISM bands).

WWRF has recognized the importance of short-range communications, creating a study group on this subject (WG5) back in 2004. Since then a number of highly relevant technologies have been actively explored jointly by academia and industry. The main focus of the short-range activities in WWRF is on air interface developments, and this is especially reflected in the contents of this book. Several white papers and briefings have been produced in recent years, dealing with the following subjects:

WWRF White Papers

- Multi-dimensional Radio Channel Measurements and Modelling for Future Mobile and Short-range Wireless Systems;
- UWB techniques and future perspectives;
- WBB over Optical Fiber;
- UWB Limits and Challenges;
- MIMO-OFDM for WLAN (TDD mode);
- Short-range Optical Wireless Communications;
- The Architecture of Mobile Internet;
- New Radio Interfaces for Short-range Communications;
- Gigabit LAN at 60 GHz;
- Cooperative Aspects of Short-range Systems.

WWRF Briefings

- Wireless Body Area Networks and Sensor Networks;
- High Throughput WLAN/WPAN;
- Gigabit WLAN Technologies;
- Visible Light Communications.

White papers and briefings on short-range communications at WG5 of WWRF

New research subjects are continuously identified, reflecting the interests of industry, academia and research institutes participating in WG5. The following subjects are currently being considered for further exploration in this group, leading to new briefing and white papers, thus becoming an integral part of the WWRF vision of future wireless communications.

New research subjects on short-range communications

- Car communications:
  - Car-to-Car,
  - Car-to-roadside,
  - Car-to-Infrastructure (jointly with WG4/cellular access group),
  - In-Car Communications.
- Ultra High Performance WLAN systems: Finding the limits of WLAN, targeting a bit rate of 100 GBps.
- Body Area Networks,
- Wireless Grids.

Identified new research items at WG5

The following chapters address aspects of the work on short-range communication of the last three years. They focus on several different aspects of UWB communications, ultra high speed communication at 60 GHz, visible light communication, UWB over fiber and also design rules for modern short-range communications systems. Our aim in publishing this book was to give a deeper insight in the important aspects and current research in short-range communication systems.

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Design Rules for Future Short-range Communication Systems

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2.1 Introduction and Motivation

With the introduction and rapid spread of the mobile phone, access architectures with centralized topologies (e.g., Cellular) have become dominant in mobile communications. The main task of a mobile phone was to access to a predefined connection point whenever it was turned on. Throughout the evolution of the mobile phone, short-range technologies were gradually integrated into the phones, resulting in multi-mode devices. The first solutions, based on infrared (IRDA) [1] and Bluetooth [2] technologies, were mainly intended to serve as a cable replacement, typically for carrying out rather simple jobs such as printing, exchanging data or attaching wirelessly peripheral devices (mainly for Bluetooth). Following the evolutionary steps of cellular air interfaces, short-range technologies also developed rapidly, supporting increasingly higher data throughputs, multiple access and advanced services. Unfortunately, in many cases short-range systems are still considered to be just a handy cable substitute. In addition to the mentioned short-range technologies, several others have been introduced, such as IEEE802.11 [3], ZigBee [4], ultra low power (ULP) Bluetooth, formerly known as Wibree, near field communications [5], and so on.

Short-range technologies are nowadays used for more than just connecting a mobile phone to another one or a PC. Short-range technologies are in fact already used to, or envisioned

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to be used to:

1. form mobile social mobile networks,
2. to access wireless sensor networks and
3. to build cooperative wireless networks.

These application fields have different requirements for the short-range technology. In the following we briefly describe these application fields and derive the different requirements. It has to be noted that more application fields are emerging in these days, but the selected ones underline the need for specific technology features. Figure 2.1 summarizes the evolutive development of short-range communication systems. Clearly, the development of future short-range systems will focus on point-to-multipoint connectivity as well as on the interaction between short-range with other networks. One of the most exciting developments in short-range

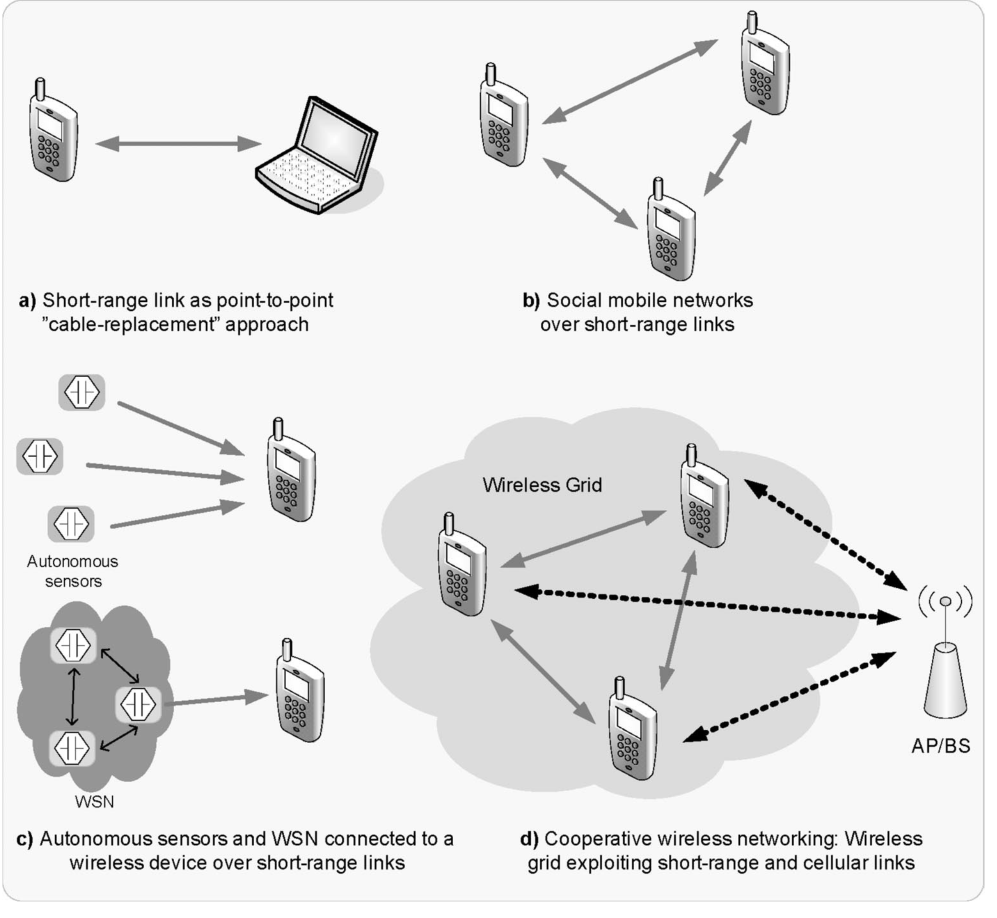

Figure 2.1 Evolutive aspects of short-range communication systems: from simple point-to-point systems to the concept of Wireless Grids.

communications results when such networks are connected to other networks, particularly cellular networks. In its simplest way, this could be realized by a network extension approach, where the short-range network is appended with the cellular network. A simple example of such a two-hop, dual-technology link would be the mobile phone in Figure 2.1(a, b or c) transmitting to the base station any information received over a short-range link. Figure 2.1(d) illustrates a more complex approach, exploiting rich and dynamic cooperation between the two networks, and aiming at improving communication performance as well as enhancing the efficiency in the utilization of resources. Such an approach, called *wireless grid*, has a lot of potential, and it will be discussed in the sequel.

2.2 Mobile Social Networks

Mobile social networks connect people that are within each other's proximity. The short-range technology is used to discover and connect other mobile phones in the range. This new kind of architecture is also referred to as mobile peer-to-peer. Multiple mobile peer-to-peer networks can coexist in the same place, as illustrated by Figure 2.2.

The first concrete applications of mobile social networks are on their way, and a very representative example of such is aka-aki [6], which enriches a conventional (web-based) social network such as Facebook [7], collecting information by short-range technology. Aka-aki users can access on the web at different profiles and add connections they made on their mobile life. The connections are collected by a mobile application running on the mobile phone. The application uses Bluetooth technology to identify known or new contacts using the same access technology. The mobile users can use the application either to get in contact right away or to contact those users later on the web. A similar approach is the Spider [8] application by Aalborg University. As illustrated in Figure 2.3, a mobile user can look at

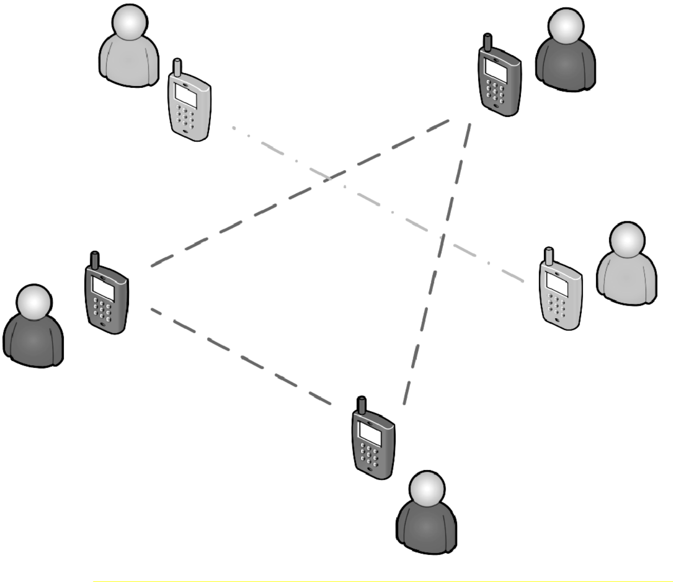

Figure 2.2 Mobile peer-to-peer architecture for mobile social networking.

Figure 2.3 Screenshot of a virtual meeting room in the Spider application [8].

a virtual world where its own virtual character is mobile. As soon as Bluetooth detects other close-by mobile phones that are also running the same application, more characters start to fill the virtual meeting room. Each mobile user can now steer its own character close to other characters and start some actions such as chatting, exchanging profiles or just looking at a real photo image of the actual user. The Spider approach is based on the concept of SMARTEX [9]. The idea behind SMARTEX is to exchange digital content among mobile phones, introducing a new concept of digital ownership [10]. Also here the Bluetooth technology is used to form the mobile peer-to-peer network.

Wireless technology brings an important extension to social networking. Users can be networked on the move, by cellular or short-range networks. The latter approach is particularly appealing as close-by users are likely to share some commonalities, interests or background.

2.3 Wireless Sensor Networks

In parallel with the evolution of cellular networks and mobile phones, wireless sensor networks (WSN) have attracted a lot of attention in recent years. The first research efforts were mainly focused on military applications, but wireless sensors have shown their great potential in civil environments too. A wireless sensor is composed of a wireless communication facility, sensor elements as well as a source of energy, typically a battery. A great array of different physical phenomena can be measured by the sensors, such as light, temperature, pressure, distance and many others. There are also some passive sensors such as RFID and UHF devices that do not need a battery as they are remotely powered by the electromagnetic waves from the requesting device.

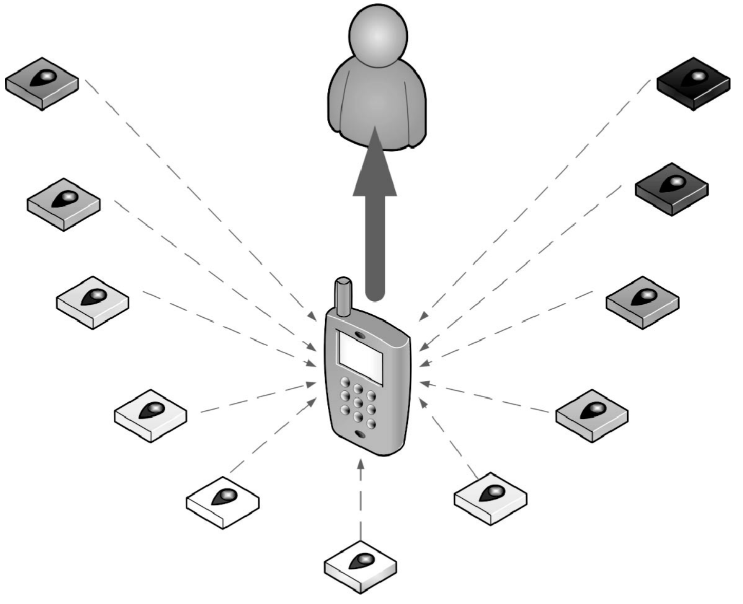

Figure 2.4 Mobile device gathering information from a Wireless Sensor Network.

Even though the combination of mobile phones with wireless sensors, see Figure 2.4, appears to be quite obvious and straightforward, its full potential has not been exploited yet. By linking a wireless sensor network to a wireless device such as a mobile phone, the user can control the networks as well as getting access to measured data. A wireless device equipped with cellular and short-range interfaces then becomes an extremely flexible tool for monitoring and controlling the sensor network, both remotely and locally. Some concrete examples of current developments in that direction include the joint development by Apple and Nike of sport shoes with integrated sensors measuring and transmitting relevant information (e.g., number of steps) to an access point held or worn by the user, for example an iPod using propriety technology. Other sensors are able to retrieve heart beat information or blood pressure and convey the data to a dedicated place such as a wrist watch. It is expected that the variety of external sensors is much larger than that of the embedded ones. In particular, external sensors will lead to new applications in the area of health care, intelligent housing and others. The advantage of omnipresent sensors is that complete measurement campaigns can be carried out, which are more meaningful than instant measurements points. An example is health parameters such as blood pressure or insulin levels, where the instantaneous value has almost no meaning, but values over a longer time period are more meaningful. Therefore sensors could help medical doctors to retrieve the value over a long time, without being dependent on the instantaneous value that they measureon the date they see the patient.

There are already some sensor platforms on the market. Nevertheless, in collaboration with the Technical University of Berlin, the mobile device group of Aalborg University (AAU) has designed their own platform, called *opensensor*. The main reason for this development was to have as much flexibility on the platform as possible. Flexibility refers to the number of connectable sensor parts as well as the wireless part. As the opensensor is to be used for

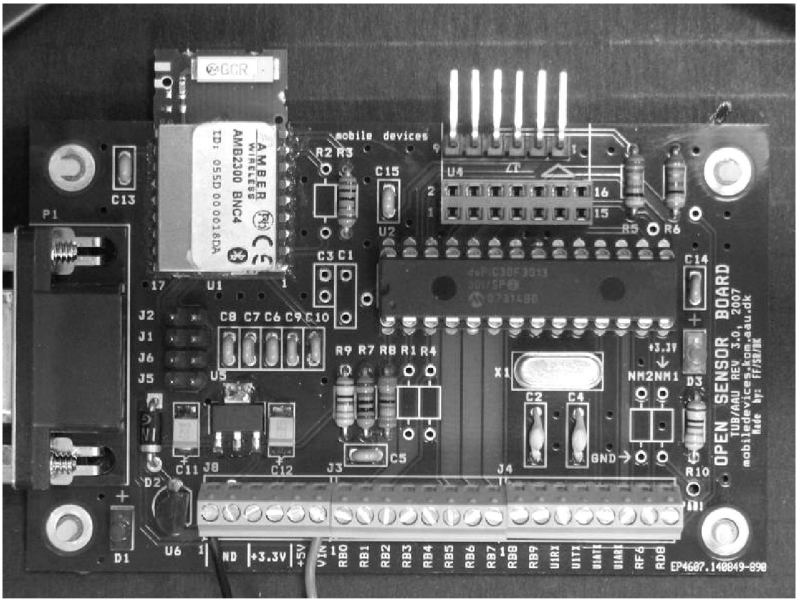

Figure 2.5 Opensensor hardware [10].

ongoing and future research projects as well as for teaching purposes, the design of the board was kept as simple as possible. Throughout the evolution of the opensensor, surface-mount devices (SMD) technology was deliberately avoided, designing the board for easy-to-mount standard components. In addition, this results in a low-cost solution, enabling researchers and students to implement their ideas in the field of wireless sensor networking on a real platform. As the convergence of wireless sensors with mobile phones is one of the design goals of the mobile device group at AAU, the opensensor offers the possibility to communicate with commercial mobile phone.

In Figure 2.5 a view of the opensensor hardware is depicted [11]. The opensensor initiative makes available to anyone detailed hardware specifications, software, as well as teaching material. The opensensor can be used for classical WSN implementation such as MAC design, routing, energy saving, and so on. The opensensor is powered up with a 9 V battery block and it has several interfaces to connect to the outer world. Two LEDs are on the board, the red one showing the operational phase of the opensensor while the green one, controlled by DSP, is used for monitoring purposes. The core of the opensensor is a 16 bit architecture dsPIC30f3013 processor produced by Microchip. It has low power consumption, features 24 KB of program memory, 2.048 B of RAM and has 28 pins, 20 of which can be used as in/output pins. For communication purposes the chip has two UARTS and one SPI port. The chip is capable of performing Analog to Digital conversion in 12 bit, 200 Ksps for measurement purposes, it has three timers and is also able to provide pulse-width modulation (PWM) which can be utilized for motor control. The opensensor board has up to five interfaces that allow communicating and programming the sensor. While the connection bar, the RS232 and the PICKIT pins are part of the board, the wireless communication interfaces nRF905 and Bluetooth are optional.

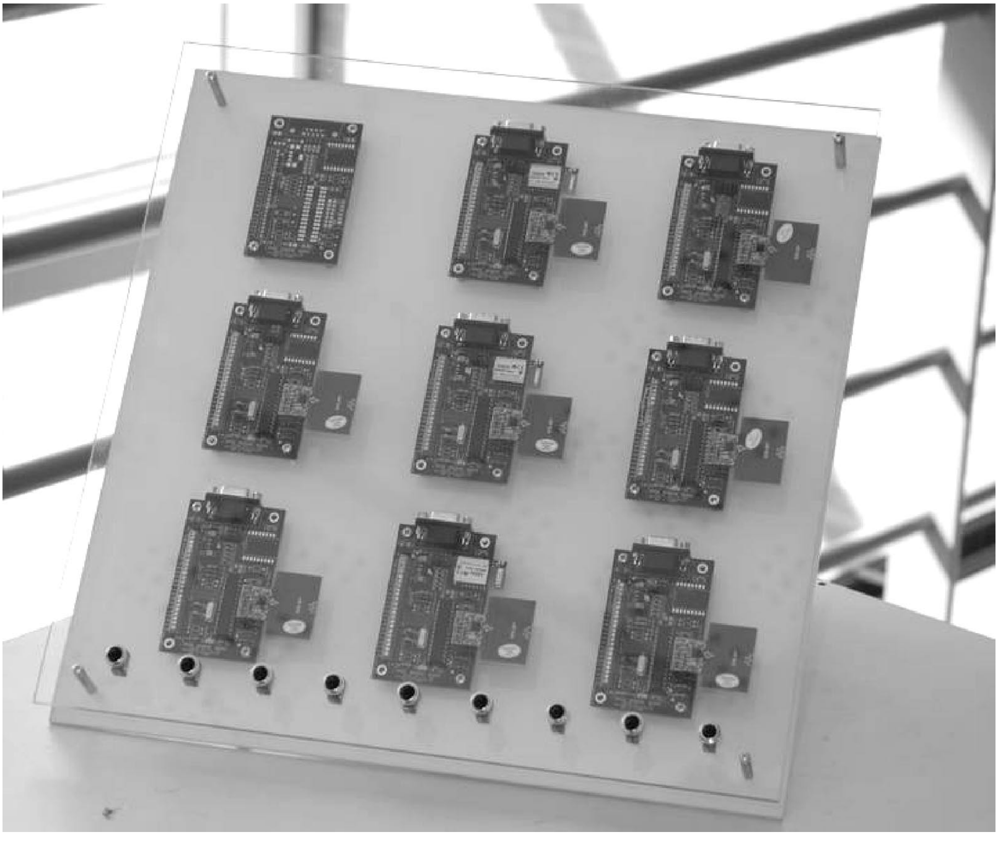

Figure 2.6 Practical implementation of an opensensor grid.

The opensensors can communicate among each other using the nRF905 or Bluetooth. In Figure 2.6 an opensensor grid with nine nodes is shown. This grid was used to demonstrate distributed storage approaches and network coding [12–14].

As mentioned before, the opensensor is also envisioned to ease the convergence of mobile phones and external wireless sensors, building up contextual information for the user, as previously mentioned. An example of external sensors and mobile phones, namely the *Parksensor* is shown in Figure 2.7. Here four external proximity sensors capable of measuring distance between objects are mounted at the corners of a car. The individual distance measurements are sent to the driver's mobile phone inside the car. The mobile phone can then display the situation in an appealing way, even supporting the driver with audio and sound information, ultimately resulting in a more comfortable and safer parking operation.

2.4 Cooperative Wireless Networking

Another field of application for short-range technology is cooperative wireless networking, where mobile phones connect with other phones in their proximity, forming so-called *wireless*

Figure 2.7 Parksensor with mobile phone application [15].

grids. Wireless grids can use their capabilities and resources in a much more efficient way than any stand alone device could ever do. In general, a wireless grid exploits not only the short-range links among the local cooperative cluster, but also the cellular links of the interacting wireless devices. This combination of access approaches with many complementary characteristics creates a novel framework for distributing information. The advantages of wireless grids include better utilization of radio and other shared resources, enhancement of communication capabilities such a data throughput and quality of service and a natural support for new types of cooperative services and applications. For instance, when the mobile phones are connected to the cellular overlay network as given in Figure 2.8, the wireless grid is able to provide high peak data throughput by accumulating the data rates of each single mobile phone. The wireless grid can use the accumulated data rate for better service support, less energy consumption and less cost for the user [16–18]. The concept of wireless grids is very flexible and has a lot of potential to become one of the paradigms of future wireless communications.

2.5 Top Ten Design Rules For Short-range Communications

As seen by the classification discussed in the previous sections, short-range technology can be used in various scenarios and for different applications. The demands for this technology differ from those in a cellular concept dramatically. In the following we identify and discuss the top ten design rules for short-range communications, particularly taking into account the emerging applications and novel scenarios for the future. The rules can be interpreted also as a wish list, where the need for each individual issue arises from a certain requirements for future communication architectures such as social-mobile networks, wireless grids and cooperative wireless networking. In many cases these individual issues are not totally separated and will overlap. Nevertheless, the following list aims at highlighting the key design issues to take into

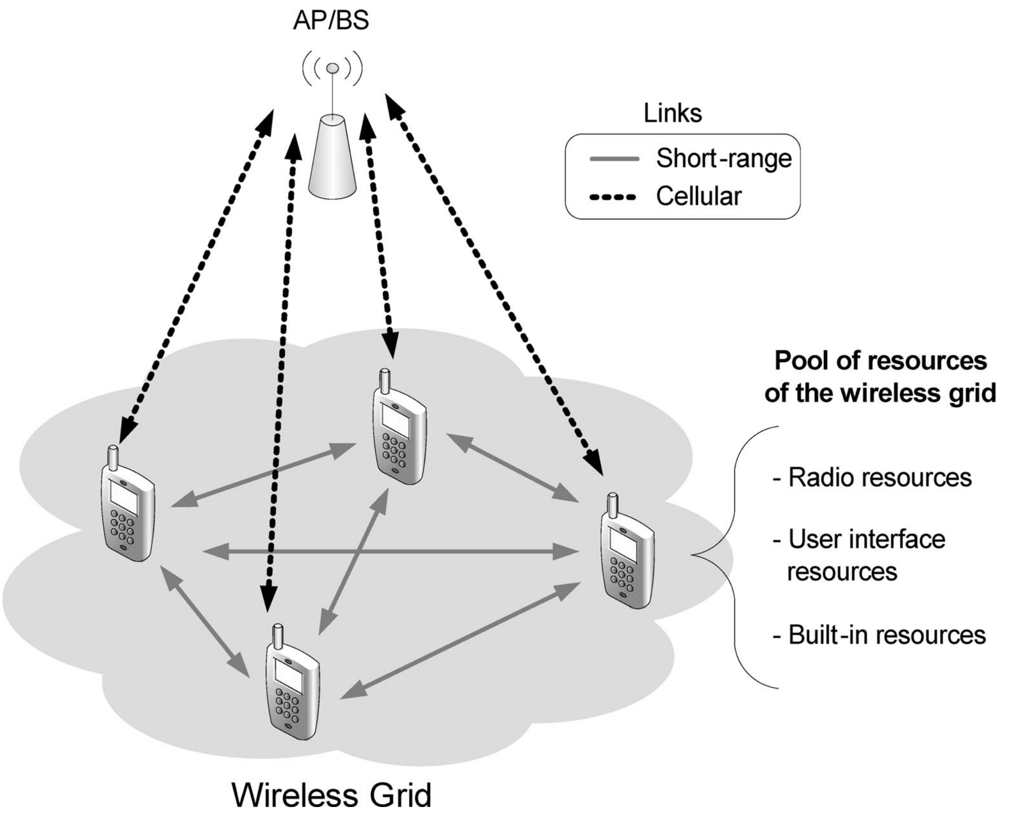

Figure 2.8 Wireless Grids: a cooperative cluster formed over short-range links, while connected to the cellular network.

account when designing short-range communication systems for future wireless networks. The top ten design rules are listed below in Table 2.1 and are explained in the following sections. Each listed topic is equally important.

2.5.1 Communication Architecture

As mentioned earlier the state-of-the-art communication architecture is dominated by point-to-point links. In the cellular environment the base station communicates with individual mobile devices and vice versa. Broadcast by the base station is envisioned, but rarely used. Even for multicast services, mostly unicast traffic channels are used. The only exceptions are technologies such as digital multimedia broadcasting (DMB) [19] and digital multimedia broadcasting-handheld (DVB-H) [20]. Those are in fact real broadcast communication systems without any feedback channel. Certainly, the mobile devices themselves use only unicast transmission towards the base station. It is convenient to extend this somewhat conservative thinking to the short-range world. With IrDA the first point-to-point optical short-range wireless communication was introduced. Even Bluetooth followed this path, being originally conceived as a wireless cable replacement. The Bluetooth architectures foresee one master

Table 2.1 Top ten design rules

Rank	Short-range Topic
1	Communication architecture
2	Energy awareness
3	Signaling and traffic channels
4	Scalability and connectivity
5	Medium access control and channel access
6	Self-organizing and presence
7	Service discovery
8	Security and privacy and authentication
9	Flexible spectrum
10	Software defined radio

node communicating with up to seven active slave nodes. The slave nodes cannot communicate directly with each other and therefore they need to relay their information via the master, in a centralized fashion. The master has the possibility to communicate in a point-to-point way with the slaves. Moreover, some Bluethooth chipsets even allow the master to broadcast its information. In the IEEE802.11 standard each node can directly communicate with any other node in its proximity. If this is done in a point-to-point way the transmitted packet will be acknowledged on successful reception. In case the sender receives no acknowledgment, it will do link level retransmission for a certain number of times. Each node can also broadcast or multicast its packet to other nodes, but such operations have some implications. First, the data rate is reduced on most chipsets to enable all nodes in the coverage area to receive the message. In addition, there is no feedback from the recipients, nor back-off in case of packet collisions.

It would be highly beneficial that future short-range communication systems have both point-to-point as well as point-to-multipoint communication capabilities. In particular point-to-multipoint capabilities are essential for service discovery, presence and self-organization. Furthermore, point-to-multipoint communications is the natural access paradigm for social and cooperative networking.

2.5.2 Energy Awareness

One of the fundamental challenges of battery-driven mobile devices is their energy consumption. The more energy is consumed the less operational time of the mobile device is available for the user. This is not desirable from the viewpoint of the users, but also from the service provider, as shorter operational times involve less use of the provided services and consequently less revenue. Furthermore, if too much energy is consumed in a short time, this will end up in a dramatic heating of the mobile device, particularly taking into account the small form factor of wireless devices. Nowadays the materials of a mobile device are chosen to distribute the generated heat over the whole mobile device in an attempt to dissipate it as much as possible. In Figure 2.9 temperature distributions of a commercial mobile phone are shown. The device heats up by nearly 8 °C just by changing the phone from offline mode to WLAN transmissions.

Manufacturers are certainly interested in reducing power consumption, as longer autonomy will make their products attractive, improving their competitive edge. Indeed, operational

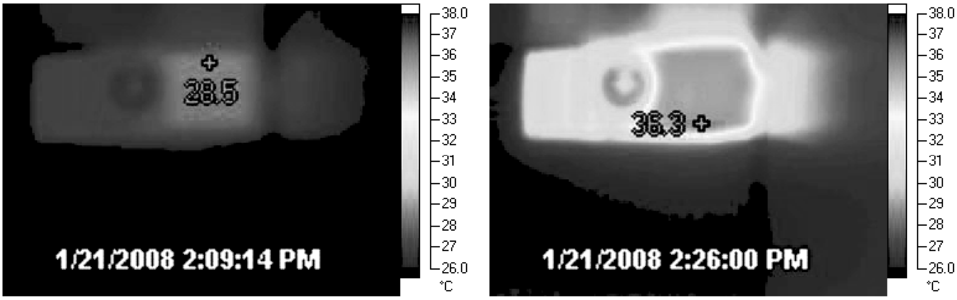

Figure 2.9 Internal temperature distribution in a commercial mobile phone: Maximum temperatures are 28.5 °C (offline mode) and 36.3 °C (WLAN on).

time is also a critical selling point for mobile phones and consequently manufacturers should continue developing techniques for achieving lower power consumption. The power drain resulting from the communicational functionalities of a typical mobile phone could be half or even two-thirds of the overall power consumption of the device [18, 21]. So, the designer of future air interfaces has a large margin of power to reduce. Consuming less energy can be achieved by using less complex system components, more efficient medium access schemes, and other issues addressed in the following. Most of the wireless technologies have four basic states, namely *sending*, *receiving*, *idle* and *sleep*. A wireless device can be characterized by a given average power consumptions associated with each of these states. The energy consumed in each state depends on the power level and the related time that state is active. For instance, if two sending data rates R1 and R2 are available to transmit a given data chunk of size D with sending power P1 and P2 respectively, R1 should be used for transmission if $R1 < R2 \times P2/P1$ and R2 otherwise. The power levels for the different states change according to the technology and the implementation of different distributors. In the following table the power levels for 3G, WLAN and Bluetooth are given for a typical commercial mobile phone. In general, the power levels for sending are larger than those of the receiving state which are in turn larger than the power during the idle state (Table 2.2).

A lesson learned from our previous research work [22–24] is that one of the dominating factors for the overall energy consumption is in fact the idle power state. This is particularly true for scenarios where the wireless link is not used in an on-off model as cable replacement. The idle power state could be eliminated easily if the incoming traffic could be known beforehand or somehow signaled in an energy-efficient way. For streaming services, where data is coming from an access point or a neighboring device with a predefined traffic pattern (e.g., video frames every 40 ms), the mobile devices should be able to switch off the RF chain and

Table 2.2 Power levels for different wireless technologies [22–24]

	Sending	Receiving (W)	Idle (W)
3G	—	1.3	0.6
WLAN	1.6 W	1.2	0.9
Bluetooth	0.4 W	0.3	0.1

baseband circuitry among the activity phases, a procedure that is known from DVB-H to save energy. More problematic are the cases where the traffic pattern is unknown and the inactivity phase is very long. For example, a mobile device using IEEE802.11 would significantly waste energy just by waiting for an incoming call, while the call itself may take only a short while compared with the inactivity phase. Switching off the RF/BB stages in this case would not be a good idea as incoming calls cannot be received. In this case other solutions should be found, and some possible ideas are discussed in the following section.

2.5.3 Signaling and Traffic Channels

In general, short-range communication systems employ the same physical and logical resource for signaling and traffic transportation. This has some serious drawbacks. The first is that normal traffic channels can block important and even critical signaling messages. The second is that the same amount of energy per bit is spent for the signaling and the traffic transportation. So, one design rule is to split the signaling from the main data exchange. Coming back to the previously presented example of the IEEE802.11 technology used for VoIP, instead of wasting energy for waiting an incoming call, the RF/BB should be switched off. Then, a special procedure to wake the mobile device up and listen for incoming calls is required. Two possible approaches are discussed next:

1. *Overlay Concept*: The originating SIP server calls the mobile device over the cellular network (e.g., 2G/3G). Next, the mobile device, spending only a small amount of energy by powering up the 2G/3G, will receive the incoming call, identifying the number, suppressing the ring tone and switching on the WLAN to receive the call over WLAN. Figure 2.10 depicts the underlying concept of overlay wake up.

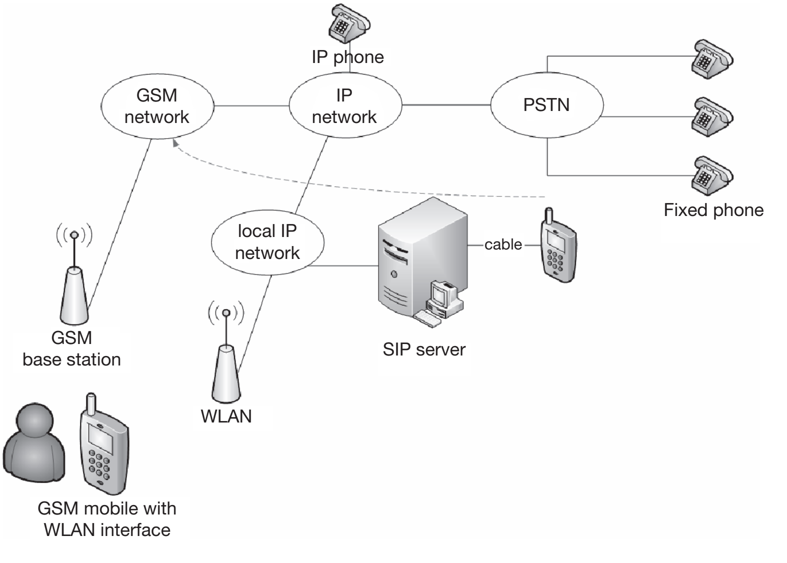

Figure 2.10 Overlay concept for energy saving with wake up calls.

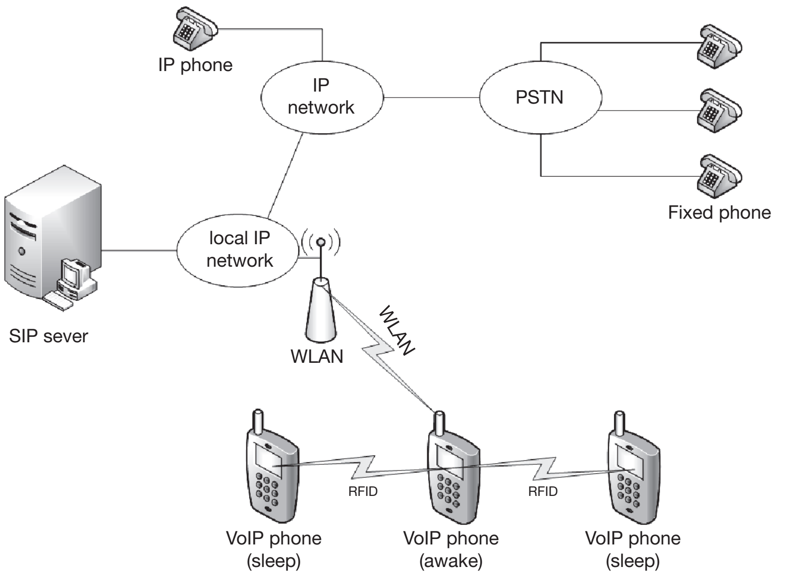

Figure 2.11 Cooperative concept for energy saving with wake up calls.

2. *Cooperative Concept:* A group of mobiles in an office scenario is waiting for incoming VoIP calls over WLAN. To save energy some of the mobile devices switch off their WLAN, while other mobile devices, referred to as watchdogs, will listen on the WLAN AP. Whenever there is an incoming call for a mobile under their responsibility, they need to wake them up. Here RFID or UHF technology comes into the picture. The watchdog will initiate a radio wave that carries enough energy to wake up the neighbouring mobile devices after receiving SIP messages over the WLAN AP. With coded RFID or UHF it might be even possible to wake up dedicated mobile devices. In order to balance the energy expenditure of all cooperating mobile devices, the role of the watchdog should be changed among the mobile devices in a round robin fashion. The concept of cooperative wake up is shown in Figure 2.11.

2.5.4 Scalability and Connectivity

It is highly important that the whole wireless communication system scales. In other words, scalability should not be limited to a certain number of participating devices, as we see it today in Bluetooth. As the foreseen scenarios are highly dynamic and heterogeneous, the number and type of participating devices in a short-range network can vary dramatically. In particular, wireless grids offer a wirelessly scalable architecture. Indeed, the more cooperating units, the larger is the resource pool that can be formed, as each wireless device can contribute with its resources. These resources, for example radio resources, built-in resources, user-interface resources, and so on can not only be shared by all cooperating devices, but they can also be moved or borrowed to particular node or nodes of the network that may need them.

The concept of network connectivity is related to network scalability. Connectivity here refers to the capability of the short-range network to be connected to another network. This is a highly desired feature in very many scenarios. In fact, a short-range network can be extended to another network, for example the cellular network. Information generated within the short-range network is made available widely, for instance for monitoring purposes. Moreover, the short-range network can be controlled remotely with this approach. Network connectivity to any complementary wireless/mobile network increases the capabilities and operating domain of the short-range network considerably. Such a connectivity, leading to cooperation between networks, is one of the underlying principles of wireless grids. One or more nodes of the short-range network can serve as the interface or gateway to another network.

2.5.5 *Medium Access Control and Channel Access*

The medium access control (MAC) has the biggest impact on the short-range performance, whereas performance refers to all other top ten requirements. From the energy saving perspective, a slotted system would be desirable such that mobile devices can go to a deep sleep more or even better switch-off their air interface if not needed to save the largest possible amount of energy. Even though the channel is slotted, the MAC should support high and low data rates equally efficiently. For the self-organization the amount of data to be exchanged is small, but the messages need to be exchanged very quickly to perform fast self organization. The MAC should be different for the signaling and data channel if there is such a separation. If the signaling is separated from the data channel, the requirement of being slotted can be dropped on the signaling domain.

2.5.6 *Self-organizing and Presence*

One important factor of short-range technology is that it has, most of the time, no structure and no continuity over time. Therefore short-range networks need the capability of self- organization. The first step towards self-organization is presence, where the device can announce its existence to the other devices in proximity to it. Though the concept of presence can be implemented now with existing technologies, it results, on the other hand, in a highly inefficient solution, particularly in terms of energy and spectrum usage. Note that presence need not necessarily be announced by means of signaling from the device willing to be taken into account. In fact, such devices, their resources and capabilities can be sensed by the network in many different ways, including in a centralized fashion by the access point or base station, or cooperatively, involving several nodes that sense relevant information. Future cognitive networks will have implemented a cognitive cycle, extending the sensing of spectrum (as in cognitive radios) to include the other shared resources, as discussed in [17].

2.5.7 *Service Discovery*

Short-range networks are set up with a certain goal in mind. For example if we assume a wireless grid with heterogeneous wireless devices, each device may want to use remote capabilities (e.g., possessed by other devices in the grid) whenever these are not implemented onboard or the available capabilities are not sufficient. To understand the available capabilities within the wireless grid, a given device needs somehow to announce the capabilities it is willing to share. Thus service discovery is an essential capability for upcoming short-range technologies.

2.5.8 *Security and Privacy and Authentication*

Security is nowadays already implemented in most wireless technologies and users are aware of the risks of not using it. But all implemented solutions so far have a centralized entity to assure security, mostly based in the core network. In the future, with upcoming mobile peer-to-peer networks becoming one of the key communication paradigms, security needs to be established among two entities with no external referee. Another trend in security is that it tends to be implemented at lower protocol layers. Security started with HTTP security (HTTPS) and solutions such as IPsec and WEP came later.

2.5.9 *Flexible Spectrum*

In order to have enough bandwidth and to assure coexistence among the large number of wireless technologies, the available spectrum needs to be assigned in a flexible manner. Spectrum is a limited and highly valuable radio resource, the scarcity and value of which will increase with the emergence of advanced bandwidth-eager services as well as the increasing number of wireless subscribers. Considerable efforts are being put into developing new techniques to enhance the spectral efficiency of the network. Cognitive radio is perhaps the most representative solution to that challenge. The concept of wireless grids is attractive from the standpoint of spectrum usage. In fact, the composite topology involving the combination of centralized and distributed access architectures can help to improve the spectral usage of the network. The cellular network uses licensed spectrum while the short-range networks typically exploits license-free spectrum. Cooperative strategies exploiting this synergy can be devised to maximize the use of the short-range network, aiming ultimately to minimize the amount of licensed spectrum.

2.5.10 *Software Defined Radio Design*

For some of the envisioned scenarios mobile devices might use multiple air interfaces at the same time. In accordance with the flexible spectrum section, the hardware of the mobile device needs to be flexible. Instead of just accumulating multiple wireless technologies, there should be a platform that can flexibly adjust to the needs of the mobile device and transform to the need technology. This can be done by software designed radio (SDR).

2.6 Conclusion

After having introduced the top ten design-rules (or wish list) for wireless short-range communications, we summarize these requirements in Table 2.3, for the three initial scenarios, namely social-mobile networks, wireless sensor networks and cooperative networking. For each individual scenario not all of the requirements are needed.

Table 2.3 Top ten design rules applied to different scenarios

	Social Mobile Networks	Wireless Sensor Networks	Cooperative Wireless Networks
Communication architecture	P2P, P2MP	P2P, P2MP	P2P, P2MP
Energy awareness	Yes	Yes	Yes
Signaling and traffic channels	Yes	Yes	Yes
Scalability and connectivity	Yes	Yes	Yes
Medium access control and channel access	SoA	Advanced for energy	Advanced
Self-organizing and presence	Yes	Yes	Yes
Service discovery	Must	Maybe	Must
Security and privacy and authentication	Must	Must	Must
Flexible spectrum usage	No	No	Yes
Software defined radio	No	No	Yes

2.7 Outlook

As mentioned beforehand the top ten design rules for short-range systems can also be seen as a wish list. Nevertheless, if we have a look at the development of Bluetooth technology, we will see that some of the points discussed are addressed there already. Indeed, besides the actual version of Bluetooth v2.x, two further developments are on their way. The ultra

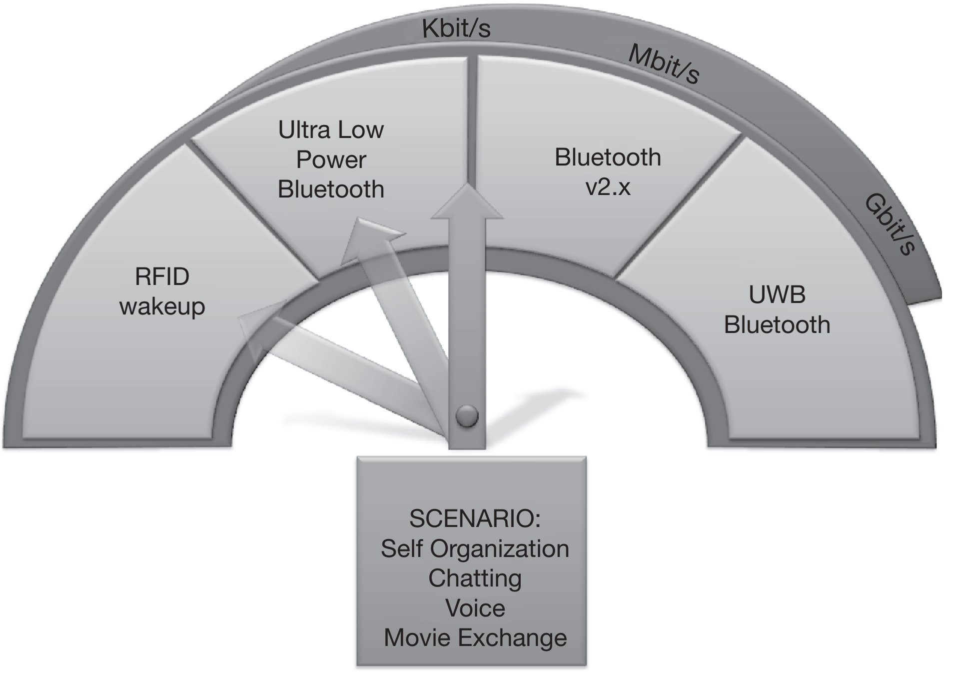

Figure 2.12 Composition of several Bluetooth technologies.

wide band (UWB) Bluetooth supporting very high data rates of up to 400 Mbit/s over short distances and the ultra low power (ULP) Bluetooth (formerly known as WiBree) with low data rates, but extremely low energy consumption. The ULP Bluetooth will be an integral part of the standard Bluetooth chip. This will help to penetrate the market very quickly. The UWB Bluetooth on the other hand will be realized by an additional chipset in the beginning. From a mobile device's point of view some of the top ten requirements are fulfilled already.

The ULP Bluetooth can be used to do the initial detection of neighboring devices or wireless sensors. In case of short data exchange or signaling conventional Bluetooth technology can be used. If larger data files need to be exchanged among the devices UWB Bluetooth can be then used. This *troika* can be extended by a simple RFID, UHF, or NFC entity to carry out rudimentary wake ups.

As given in Figure 2.12, this would end up in four short-range technologies appropriate to the needs and scenarios. These technologies are just like gears in an engine, to change the operating point of the system to the best possible solution.

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