CHAPTER 1

Introduction

1.1 Introduction to Wireless Communication

Wireless communication involves any form of communication without using wires. Information may be transferred between two or more points that are not physically connected. The distance between the points could be as short as a few centimeters or meters like in the case of near field communication and remote controls to as long as thousands of kilometers in the case of Global Positioning System (GPS) and deep space communications.

Wireless communication has existed for ages. In early days people used smoke signals to communicate over long distances and pass encoded messages. Carrier pigeons were used to deliver written messages. These were also forms of wireless communication and were used much before wired communication was invented.

In modern times, wireless communication is found almost everywhere. We are surrounded by devices like mobile phones, remote controls, wireless keyboards, headsets, FM radios, satellite television, broadcast television, cordless phones, sports equipment, wireless toys, GPS units, key fobs, smartcards, and many more. All these devices use wireless communication to exchange data.

Wireless communication has changed the dynamics of how people work and how they communicate. People no longer needed to be constrained by wires to exchange information. Some of the major benefits that wireless communications provide include the following:

- *Mobility*: The communication is not restricted by the length of the wires. Wireless devices can be easily moved around offering users the flexibility to move while still being connected.
- *Convenience*: It is much more convenient to use devices like remote controls, cordless phones, and keyboards compared to their wired counterparts. Users are freed up from clumsy wires that hamper movement.
- *Almost zero setup time:* In most cases, setting up a wireless device involves just switching it on and using it. There are no cables to set up.

- *Reduced cost*: No cost for setting up expensive cabled infrastructure. For example, in many countries the mobile connections have now surpassed the landline connections because of reduced infrastructure costs.
- *Connectivity in remote areas*: It is much easier to provide connectivity in remote areas like deserts, oceans, forests, and remote villages using wireless technologies compared to building wired infrastructures. In many cases, wired infrastructures may not be even feasible.
- *Enhanced productivity*: Wireless communication improves productivity for a mobile workforce by providing the possibility to stay connected to the workplaces while on the move. Workers, students, and professionals can stay connected and work at their convenience thus enhancing productivity.
- *Newer possibilities:* Wireless communication makes possible scenarios like deep space communication, satellite navigation, location-based services, and communication in remote locations, which are not possible with wired communication.
- *Safety and security:* Wireless communications makes emergency services like E911 possible where users can seek help from any remote location and can be tracked and assisted in case of emergency.
- *No compromises on speed:* Wireless communications offer almost equivalent and sometimes higher speeds compared to the wired counterparts.

1.2 Data Rates and Coverage

Wireless technologies find applications in various scenarios involving data transfer rates ranging from a few kilobits per second (Kbps) to several gigabits per second (Gbps). At the lower end of the data rate spectrum are technologies like NFC, Bluetooth Low Energy, Zigbee, radio frequency identification (RFID), and ANT that offer data rates in the range of few hundred Kbps or less. At the higher end there are technologies like wireless USB, WiFi, and ultrawideband (UWB) that may offer data rates in the range of several hundred Mbps to even few Gbps.

Figure 1.1 shows the typical data range and coverage of various wireless technologies. Each technology is suited to a particular set of applications that need specific data rates and coverage areas.

Wireless (and wired) technologies can be classified into several categories depending on the distances over which these are used. Some of these categories are outlined below.

1.2.1 Wide Area Network

A wide area network (WAN) covers a broad geographical distance that can range from a few kilometers to thousands of kilometers. This includes technologies such as GSM (originally Groupe Spécial Mobile, also referred to as Global System for Mobile Communications), general packet radio service (GPRS), 3G, and code division multiple access (CDMA).

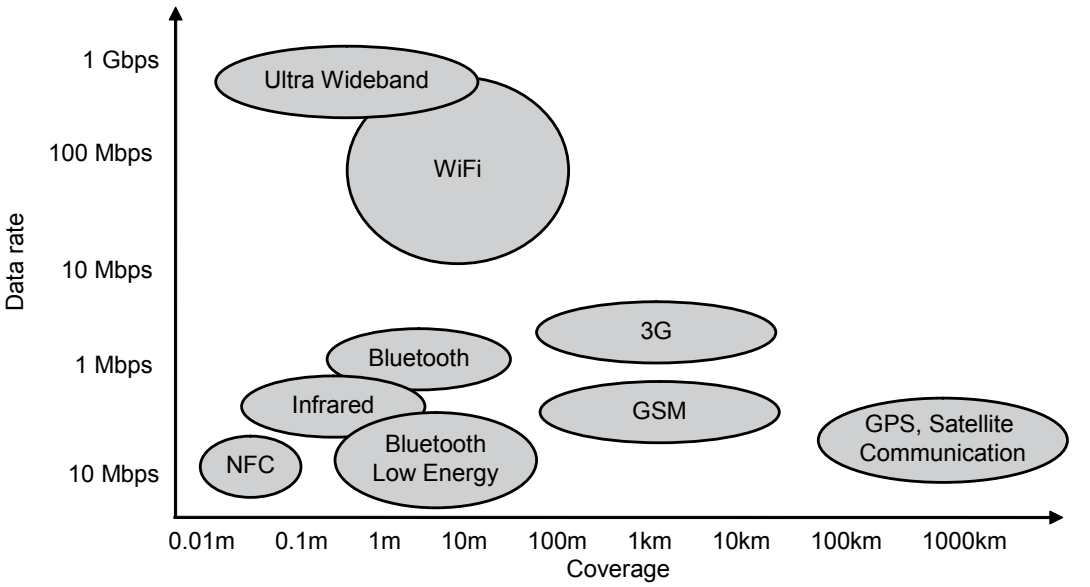

Figure 1.1 Typical data rates and coverage of various wireless technologies.

1.2.2 Metropolitan Area Network

A metropolitan area network (MAN) covers a smaller area than a WAN. Typically this could be a small town or a metropolis. This includes technologies like Worldwide Interoperability for Microwave Access (WiMAX) that cover several kilometers.

1.2.3 Local Area Network

A local area network (LAN) typically covers distances in the range of a few hundred meters. This can be a building, a campus, and so forth. This includes technologies such as WiFi.

1.2.4 Personal Area Network

A personal area network (PAN) encompasses communication between personal devices like mobile phones, PDAs, remote controls, keyboards, printers, and cameras. The range of PANs is typically a few meters. This includes technologies like Infrared Data Association (IrDA), Bluetooth, Wireless Universal Serial Bus (USB), Near Field Communication (NFC), and Zigbee.

1.2.5 Body Area Network

A body area network (BAN) encompasses communication between devices that are supposed to be carried or worn by people. These include devices like mobile phones, headsets, watches, and fitness equipment like blood pressure and heart rate sensors. This includes technologies like Bluetooth, RFID, NFC, and ANT.

1.3 Why Have Standards?

Industry standards play a vital role in research and development, worldwide adoption, standardization of products, ensuring interoperability of products from one vendor to another and protection from patent infringement. Several organizations have come together to form task forces and standards bodies to contribute to the development of the standards and ensure their wide acceptance.

Standards help the consumer by driving down prices by helping to build an ecosystem of companies that contribute to the innovation, mass manufacturing of the products, and a fair competition amongs suppliers. Consumers don't get bound to one single supplier and can have flexibility to choose a vendor based on price versus feature comparison.

Standards also help in ensuring worldwide regulatory compliance. This is especially true in the wireless world since wireless products may contain transmitters and there might be regulatory restrictions on the frequencies on which transmissions are allowed.

There are several organizations which are working on defining standards and regulations. Some of these organizations are mentioned below. The information presented here about these organizations has been picked up from the Web site of the respective organizations. For details, see the references.

3rd Generation Partnership Program (3GPP) [1]

- 3GPP unites six telecommunications standard development organizations: Association of Radio Industries and Businesses (ARIB); Alliance for Telecommunications Industry Solutions (ATIS);China Communications Standards Association (CCSA); European Telecommunications Standards Institute (ETSI); Telecommunications Technology Association (TTA); and Telecommunication Technology Committee (TTC). These organizational partners provide their members with a stable environment to produce the highly successful "Reports and Specifications" that define 3GPP technologies.

Bluetooth Special Interest Group (SIG) [2]

- Bluetooth SIG is a privately held, not-for-profit trade association. The main tasks for Bluetooth SIG are to publish Bluetooth specifications, administer the qualification program, protect the Bluetooth trademarks, and evangelize Bluetooth wireless technology.

European Commission for Standardization (CEN) [3]

- CEN was officially created as an international nonprofit association based in Brussels on October 30, 1975. CEN is a business facilitator in Europe, removing trade barriers for European industry and consumers. Its mission is to foster the European economy in global trading, the welfare of European citizens, and the environment. Through its services it provides a platform for the development of European Standards and other technical specifications.

European Telecommunications Standard Issue (ETSI) [4]

- ETSI produces globally applicable standards for information and communications technologies (ICT), including fixed, mobile, radio, converged, broadcast, and Internet technologies.

Federal Communications Commission (FCC) [5]

- The FCC regulates interstate and international communications by radio, television, wire, satellite, and cable in all 50 states, the District of Columbia and U.S. territories.

International Electrotechnical Commission (IEC) [6]

- The IEC is the world's leading organization that prepares and publishes international standards for all electrical, electronic, and related technologies. Over 10,000 experts from industry, commerce, government, test and research labs, academia, and consumer groups participate in IEC standardization work.

Institute of Electrical and Electronics Engineers (IEEE) [7]

- IEEE is the world's largest professional association dedicated to advancing technological innovation and excellence for the benefit of humanity. IEEE and its members inspire a global community through IEEE's highly cited publications, conferences, technology standards, and professional and educational activities.

International Organization for Standardization (ISO) [8]

- The ISO is the world's largest developer of voluntary international standards. International standards give state-of-the-art specifications for products, services, and good practice, helping to make industry more efficient and effective. Developed through global consensus, they help to break down barriers to international trade.

International Telecommunications Union (ITU) [9]

- The ITU is the United Nations specialized agency for information and communication technologies (ICTs). They allocate global radio spectrum and satellite orbits, develop the technical standards that ensure networks and technologies seamlessly interconnect, and strive to improve access to ICTs to underserved communities worldwide.

Wi-Fi Alliance [10]

- The Wi-Fi Alliance is a global nonprofit organization with the goal of driving adoption of high-speed wireless local area networking.

Near Field Communication (NFC) Forum [11]

- The Near Field Communication Forum was formed to advance the use of NFC technology by developing specifications, ensuring interoperability among devices and services, and educating the market about NFC technology.

ZigBee Alliance [12]

- ZigBee Alliance is an open, nonprofit association of members that has created a thriving global ecosystem of a growing family of innovative, reliable, and easy-to-use ZigBee standards.

1.4 Introduction to Bluetooth and Bluetooth Low Energy

Bluetooth is a global standard for short-range, low-power, low-cost, small-form-factor wireless technology that allows devices to communicate with each other over radio links. It originated as a cable replacement technology mainly to replace the serial data cables that connect various devices. Over the years, the use cases have grown to exchanging files between PCs, mobiles, listening to music, printing documents, browsing, taking mobile calls on Bluetooth headsets and car kits, and several more.

Today the attach rate of Bluetooth is almost 100% for mobile phones, tablets, and laptops. Bluetooth is also widely used in wireless headsets, speakers, cameras, car kits, gaming consoles, and peripherals like keyboards, mouses, printers, and scanners.

Bluetooth Low Energy (also referred to as LE) is one of the latest enhancements to the Bluetooth technology that was added as a part of Bluetooth 4.0 specification. As the name suggests, it is aimed at "ultra" low power devices. This technology was known as Wibree and Ultra Low Power (ULP) in the past. The terms Bluetooth Low Energy and LE will be used interchangeably in this book to refer to Bluetooth Low Energy.

Bluetooth Low Energy extends the low power feature of Bluetooth even further. Devices compliant with this standard are expected to consume very low power so that they can operate for months or even years on coin cell or smaller batteries without the need of recharging or replacing batteries. This is very useful in applications where it may be difficult to recharge frequently and longer battery life is important. Data communication is generally in short bursts that do not need to be very frequent. It is best suited for devices that do not require high throughput or streaming of data.

As per ABI research [16]:

> … In the first 10 years of its life (up to 2010) cumulative shipments of Bluetooth enabled devices reached 5 billion. Growth has been largely driven by its use in mobile phones and accessories. This market is still growing overall but it will start to plateau out over the next five years…
>
> …The introduction of Bluetooth v4.0, with low energy as its pivotal enabler, will drive a second wave of Bluetooth enabled device shipment growth. The market is expected to achieve cumulative shipments over 20 billion by 2017…

Some of the key features of Bluetooth Low Energy are:

- Ultra low power, which enables months or even years of operation on coin cell or smaller batteries;
- Small size;
- Low cost;
- Short range;
- Faster connections (link setup time reduced to 3 ms);
- Small chunks of data;
- Infrequent transfers;
- Secure;
- Interoperable.

Bluetooth Low Energy finds a wide variety of applications including the following:

- Internet of Things;
- Health care devices such as thermometers, blood pressure monitors, and glucose meters;
- Sports and fitness equipment such as smart watches, pedometers, GPS locators, and heart rate monitors;
- Home automation;
- Home entertainment, remote controls, wireless keyboards;
- Smart energy (meters and displays);
- Advertisements;
- Mobile payments;
- Automotive devices such as vehicle tire pressure sensors, motion sensors, temperature sensors, and pollution sensors;
- Security.

What is the Internet of Things?

More and more devices are being embedded with sensors and have the ability to communicate. This enables a network of devices that can identify themselves, collect data, and also communicate with each other. The Internet of Things is the next radical transformation in the communications era where the gadgets talk to each other without any need for human intervention.

Some examples are smart energy meters that report electricity and gas usage to the utility company, vending machines with cellular modems to update inventory and pricing, vehicle fleet management systems that report location of all vehicles in the fleet to a central server, and so forth.

One of the key advantages that LE has over other similar technologies is that it will be able to build onto the existing Bluetooth infrastructure, especially smartphones, tablets, and laptops. At present the attach rate of Bluetooth to these devices is almost 100%. Once these devices get upgraded to use LE chips, they can act as gateways to the LE sensors. A wide variety of use cases can be enabled with a very low incremental cost for the end user. Therefore, LE is expected to be a significant contributor to the overall wireless sensor market.

The Bluetooth 4.0 core specification [13] that introduced enhancements related to LE was released in July 2010. Since then several devices have hit the market and several more are already being developed and announced. This has also opened up several requirements for both hardware and software developers. Newer devices and uses are being developed that will need both hardware implementation and software applications.

1.5 Applications

This section describes some possible real-world uses of LE.

1.5.1 Finding and Alerting Devices

LE can be used to find misplaced devices. Some example scenarios are:

1. If the remote control of a home appliance or car keys is misplaced, they can be found from a mobile device. The user will press a button on the mobile and the misplaced device will start giving an audio or visual alert. For example it may start beeping or an LED on it may start flashing.
2. The microwave oven or washing machine will send an alert to the mobile phone or wrist watch once the food is cooked or the clothes are washed.

This is shown in Figure 1.2.

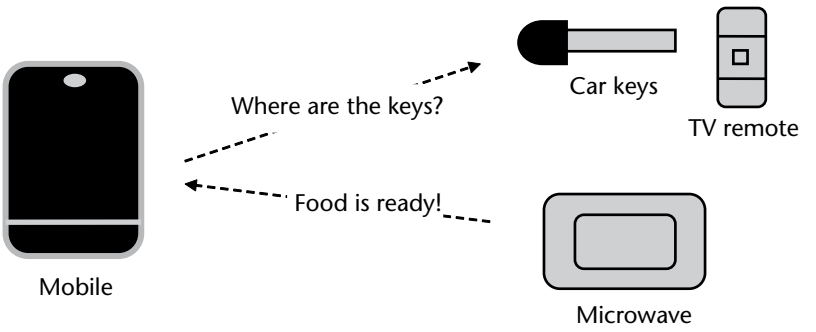

Figure 1.2 Finding and alerting devices.

1.5.2 Proximity and Presence Detection

LE can be used to detect the presence or absence of a device and take actions accordingly. It can also be used to detect when the device is moving away from a predefined range. Some example scenarios are (see Figure 1.3):

1. As soon as a car comes close to the garage the car keys will automatically instruct the garage door to open without the need to press any buttons.
2. While a person parks the car, the devices in the home will detect his or her presence and automatically take some action. The lights could be switched on and temperature control (air conditioner or heater) could be activated.
3. As soon as a person leaves the home the lights would switch off, the doors would lock, and the temperature control would adjust automatically.
4. If a person is in a crowded place and his or her mobile is stolen, as the thief runs away with the mobile device, the distance from the owner would

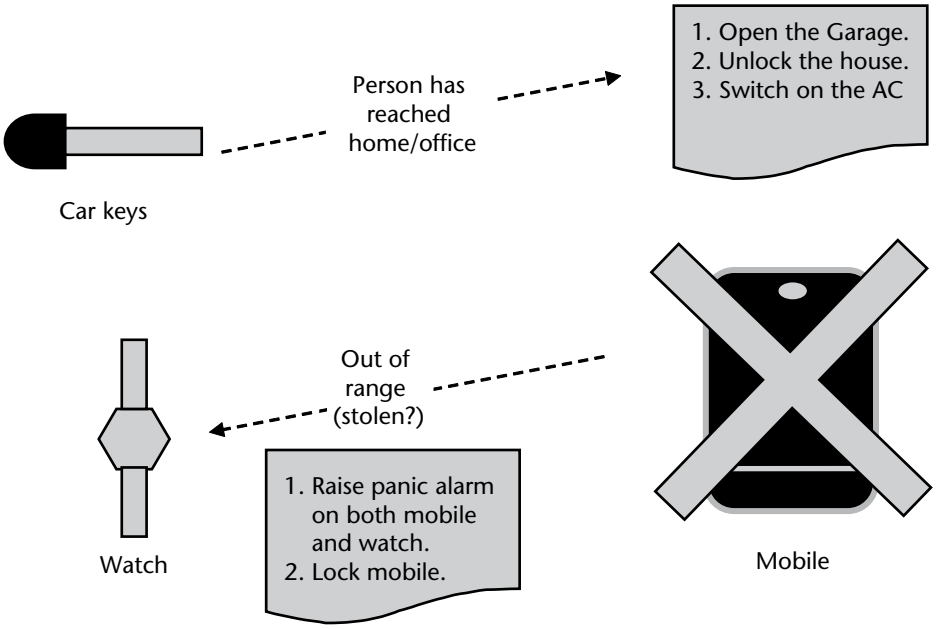

Figure 1.3 Proximity and presence detection.

increase. In this situation, both the owner's watch and the mobile would start raising an alarm and the mobile would lock itself. If the owner is lucky, the thief may panic, throw the mobile down, and run away! At least automatically locking the mobile will ensure that the sensitive data stored on the mobile is not misused.

1.5.3 Health Care

One of the major markets intended for LE is the health care domain. Some applications in this area are (see Figure 1.4):

1. Health care devices like thermometers, heart rate monitors, glucose monitors, and scales can take measurements and send the data to the smartphone or laptop. The smartphone or laptop can perform some analysis of the data like historical trends and alert the user if any parameters are beyond the prescribed limits. It may also send the data through Internet to the doctor.
2. The health care devices can be programmed to take measurements at various intervals depending on the condition of the patient. These can also be programmed to report data in various units (like Celsius or Fahrenheit).

1.5.4 Sports and Fitness Equipment

LE can be used in several sports and fitness applications. Some example applications are (see Figure 1.5):

1. Wearable heart rate monitors to monitor the heart rate during cardio exercises.
2. Pedometers and speedometers to track the exercise done.

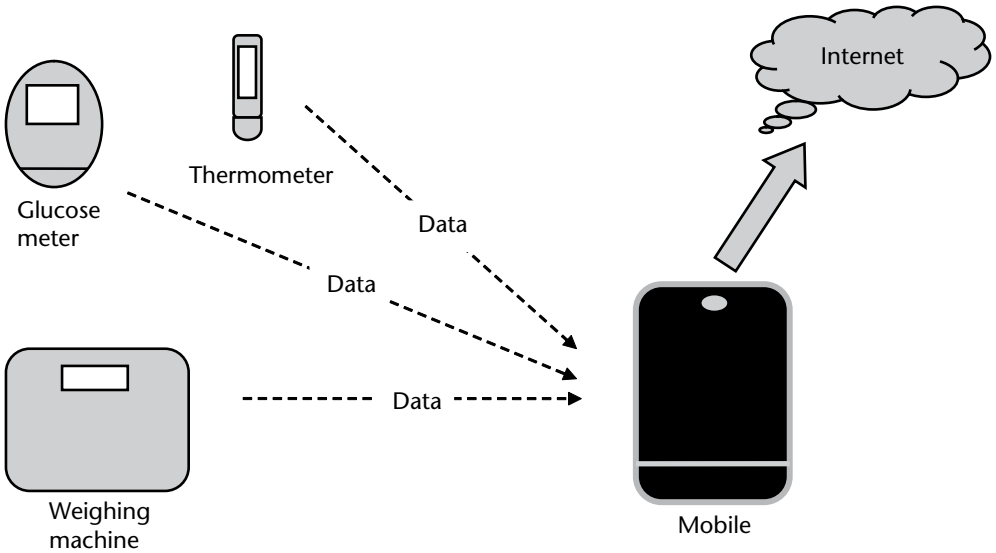

Figure 1.4 Health care.

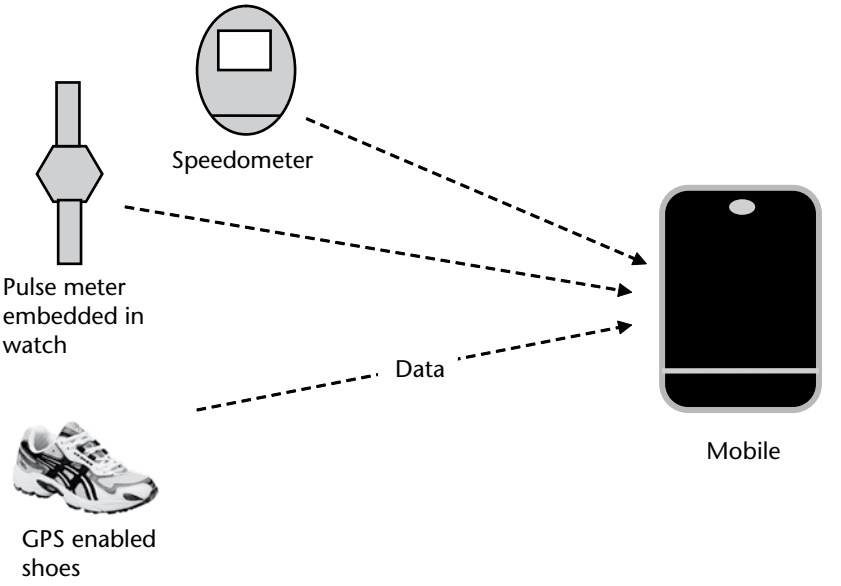

Figure 1.5 Sports and fitness equipment.

3. GPS locators enabled with LE sensors to provide information on the speed, distance traveled, current location, etc.

1.5.5 Mobile Payments

LE can be used be used in electronic wallet applications for making mobile payments. Some example scenarios are (see Figure 1.6):

1. The user could walk into a store and select merchandise to buy. Instead of using a credit card to make payments, the user could use the LE-enabled mobile phone. The mobile phone would establish a secure link with the retail terminal in the shop for PIN verification, and so forth. The verification and acceptance of the financial transaction could be cloud-based.

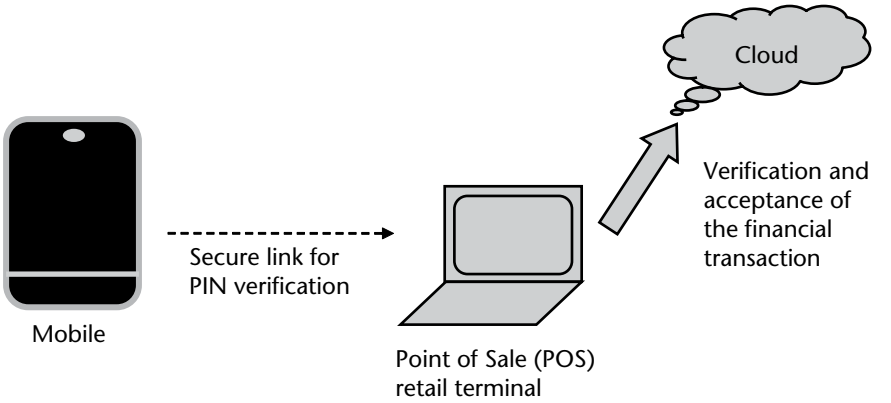

Figure 1.6 Mobile payments.

1.6 Competing Technologies

There are many other wireless technologies that are competing in the same space as Bluetooth Low Energy. Each of these technologies has its own pros and cons and some of the uses overlap with those of Bluetooth Low Energy. Some of these technologies are briefly mentioned here. This information has been picked up from the respective Web sites of the relevant technologies (see the references).

The intention here is not to compare technologies but to introduce these technologies to the reader so that details of these technologies can be looked up in the references. There are already some good resources on the Internet that provide an in-depth comparison of these technologies both from a technical perspective as well as from a commercial perspective.

1.6.1 ANT and ANT+

ANT™ [16] is a proven ultra-low power (ULP) wireless protocol that is responsible for sending information wirelessly from one device to another in a robust and flexible manner. With millions of deployed nodes, ANT is perfectly suited for any kind of low data rate sensor network topologies—from peer-to-peer or star, to practical mesh—in personal area networks (PANs) that are well-suited for sports, fitness, wellness, and home health applications. ANT is a practical solution for local area networks (LANs) in homes and industrial automation applications.

ANT is specifically designed for wireless sensor networks (WSNs) that require:

- Ultra low power (runs on a coin cell for years of operation);
- Highly resource optimized (fits into a compact-sized memory);
- Network flexibility and scalability (self-adaptive and able to do practical mesh network;
- Easy to use with low system cost (operates independently with a single chip).

ANT+ represents an interoperability function that can be added to the base ANT protocol. This facilitates collection, automatic transfer, and tracking of sensor data. ANT+ is finding applications in sports and wellness equipment like heart rate monitors, sports watches, bikes, temperature sensors, and so forth.

1.6.2 ZigBee

ZigBee is a standards-based wireless technology designed to address the unique needs of low-cost, low-power wireless sensor and control networks in just about any market. Since ZigBee can be used almost anywhere, is easy to implement, and needs little power to operate, the opportunity for growth into new markets, as well as innovation in existing markets, is limitless. Here are some facts about ZigBee from the ZigBee Web site:

- With hundreds of members around the globe, ZigBee uses the 2.4-GHz radio frequency to deliver a variety of reliable and easy-to-use standards anywhere in the world.
- Consumer, business, government, and industrial users rely on a variety of smart and easy-to-use ZigBee standards to gain greater control of everyday activities.
- With reliable wireless performance and battery operation, ZigBee gives people the freedom and flexibility to do more.
- ZigBee offers a variety of innovative standards smartly designed to help people be green and save money.

1.6.3 Near Field Communication (NFC)

NFC technology makes life easier and more convenient for consumers around the world by making it simpler to make transactions, exchange digital content, and connect electronic devices with a touch. A standards-based connectivity technology, NFC harmonizes today's diverse contactless technologies, enabling current and future solutions in areas such as:

- Access control;
- Consumer electronics;
- Health care;
- Information collection and exchange;
- Loyalty and coupons;
- Payments;
- Transport.

NFC provides a range of benefits to consumers and businesses, such as:

- *Intuitive:* NFC interactions require no more than a simple touch.
- *Versatile:* NFC is ideally suited to the broadest range of industries, environments, and uses.
- *Open and standards-based:* The underlying layers of NFC technology follow universally implemented ISO, ECMA, and ETSI standards.
- *Technology-enabling*: NFC facilitates fast and simple setup of wireless technologies such as Bluetooth and Wi-Fi.
- *Inherently secure:* NFC transmissions are short-range (from a touch to a few centimeters).
- *Interoperable:* NFC works with existing contactless card technologies.
- *Security-ready:* NFC has built-in capabilities to support secure applications.

1.7 Summary

Wireless technologies have become an important part of our lives. Depending on the application requirements, wireless technologies offer ample choice in terms of data rates and coverage. There are several standard bodies that help in developing specifications for these technologies.

Bluetooth Low Energy finds applications in several fields. It builds onto the existing ecosystem of Bluetooth devices and addresses use cases where ultra-low power consumption is needed. These include scenarios where it may be difficult to replace or recharge the batteries. LE devices are expected to work for several months to several years without need of a recharge.

References

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[2] Bluetooth SIG Web site, http://www.bluetooth.org.
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