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Introduction

1.1 Introduction

Technological innovations by engineers during the past century have brought a deep change in our life style. Today, when we fly over a modern city at nighttime, we see a planet full of the footprints of the modern civilization made by engineers. The glowing lights below remind us of the impact made by electrical engineers, the planes we fly in and the moving cars under them remind us of the contributions of mechanical engineers, and high rise buildings and complex road systems remind us of what civil engineers have done. Through the eyes of an engineer, the glow of light, the movement of cars, and the complexity of civil infrastructure display the challenges in implementation and the size of the market for this industry and demonstrate the impact of this technology on human life. There is one industry, whose infrastructure is not seen from an airplane because it is mostly buried under the ground, but it is the most complex, it owns the largest market size, and it has enabled us to change our life style by entering the age of information technology. This industry is the *information networking industry*.

Perhaps the most prominent feature of the human species over other living species on the earth is the ability to create a sophisticated linguistic that allows us to generate information based on our experiences in life and to communicate that with others, store them in writing, and retrieve them by reading. As a result, while other species have little knowledge of their peers' experiences in other places or even living close to them, our lives are based on the retrieval of cumulative information that has been collected and stored over several thousands of years around the world. The availability of this vast treasure of information has allowed us to create an advanced civilization that is by far above the other species living on planet earth. Therefore, the availability of information has been the most important factor in the growth of our civilization. Information networks facilitate the transfer of information across the world. In the same way that highway systems facilitate the physical transfer of merchandise and people across the continents to nurture economic growth, information networks facilitate the transfer of merchandise descriptions and human thoughts to stimulate the economy. Highway systems facilitate their physical presence in diversified locations and information networks facilitate the close to instantaneous virtual presence of information about them in diversified locations. The importance of existent of information in diversified locations in the growth of our economies has resulted in huge investments in the infrastructure for information networking and the emergence of this industry as the largest industry made by engineers.

To have an intuitive understanding of the size of the information industry, it is illustrative to notice that the size of the budget of American Telephone and Telegraph (AT&T) Corporation in the early 1980s, before its divestiture, was close to the budget of the *fifth largest economy* of the world at that time. AT&T was the largest telecommunication company in the world and its core revenue at that time was generated mainly from wired connections to the public switched telephone network (PSTN) just for the basic telephone call application that was first patented in 1876. During the past three decades, the cellular telephone industry augmented the income of the prosperous circuit-switched telephone services with subscriber fees from approximately seven billion cellular telephone users worldwide. Today the income of the wireless industry has already surpassed the income of the wired telephone industry and this income is still dominated by the revenue from cellular telephone calls for wireless access to the PSTN and their recurring subscriber fees.

In the mid-1990s the Internet brought the data-oriented packet switched computer communication industry from a business-oriented office industry to an “everyone-use” home-oriented industry that soon generated an income comparable to that of the wired telephone and wireless access industries. At the time of writing, the *information networking industry* (including fixed and wireless telephones as well as Internet access industries) has annual revenues of a few trillion dollars and by far is the largest engineering industry in the world. The largest portion of earnings of the wireless industry is made from the revenue generated by cellular telephone calls. However, this trend is rapidly changing and the future of this industry relies on broadband wireless Internet access that has shown a rapid and continual growth to support the emerging multimedia communication networking industry and ad hoc wireless sensor networking. Sensor networks are becoming important for emerging cyber physical systems in different areas such as medicine and transportation.

The main forces behind the growth of the necessity for packet switched wireless data networks in the past few years were the sudden success of the smart phones that became an epidemic after their introduction and the unprecedented popularity of the iPhone in 2007. Smart phones, and in particular the iPhone, opened a new paradigm for a variety of data applications and nurtured the growth of social networking that was another revolution in networking applications. The exponential growth of the volume of information transfer using wireless data for multimedia and Internet browsing applications in the late 2000s caused an exponential growth in the wireless local area networking industry and forced the cellular telephone industry to shift its focus from the traditional telephone application and its quality of service to the emerging multimedia data applications which demand higher data rates but are more tolerant of delay.

The amount of information produced by these emerging devices is so vast that we need a method to filter them and capture the most useful parts for useful applications. The most popular filtering is through the association of information to the time and location (space). As a result, measuring time and location is an essential part of information processing, and engineers have tried to measure them ever more accurately throughout the centuries. In the past few centuries, we have found technologies for the precise measurement of time and the ways to make them available to a variety of applications. The localization industry for day-by-day use started in the past few decades by using radio frequency (RF) signals to measure the distance between a landmark and a mobile electronic device. First, Global Positioning System (GPS) was introduced for outdoor environments [Mis10], then the cell tower and Wi-Fi localization complemented that to extend the coverage to indoor areas [Pah02] and more recently localization is under research for inside the human body [Pah12a].

The iPhone, followed by other smart phones, also introduced the first popular and inexpensive wireless localization techniques on a massivescale. The availability of localization and the popularity of mobile computing initiated another round of growth in application development on smart devices using wireless localization. In early 2007, the localization for smart devices was built on a few popular applications such as turn by turn direction finding. By the year 2010 around 15%

of over 100 000 applications developed for the iPhone were using wireless localization [Mor10]. The popularity of multimedia and location-enriched applications on mobile smart devices has radically shifted the habits of humans in their communications and information processing and it has profoundly affected the way that we live and relate to others.

The purpose of this book is to provide the reader with a textbook for understanding the principles of wireless access and localization. Wireless access and localization is a multidisciplinary technology; to understand this industry we need to learn about a number of disciplines to develop an intuitive feeling of how these disciplines interact with one another. To achieve this goal we provide an overview of the important wireless access and localization applications and technologies, describe and classify their underlying science and engineering principles in a logical manner, give detailed examples of successful standards and products, and provide a vision of the evolving technologies. In this first chapter, we provide an overview of the wireless industry and its path of evolution. The next three chapters describe the fundamental principles of the radio propagation, transmission schemes, and medium access control techniques in wireless networks. The succeeding three chapters examine principles of wireless network infrastructure deployment, operation and security. The following three chapters describe the popular wireless local area networks and personal area networks that have evolved to complement them by supporting low-power sensor networking and high-speed gigabit wireless multimedia applications. The next three chapters provide the details of different generations of wireless wide-area cellular networks. The last three chapters of the book are devoted to wireless localization techniques.

In the remainder of this chapter, we first provide the elements of a wireless network and then we give a summary of the evolution of important standards and technologies for wireless networking as well as evolution of technologies for wireless localization. Finally, we give an outline of the chapters of this book and how they relate to one another.

1.2 Elements of Information Networks

Information networks have evolved to interconnect networking enabled devices over a geographical area to share information generated by an application in the device. Figure 1.1 illustrates the abstract of this basic concept. The information source could be the voice of a human being creating an electronic signal on a telephone device connected to a local public branch switch or the PSTN to transfer that information to another geographical location. The information source could be a video stream from a video camera or sensor data from a robot that is sent through a networking interface card to a local area network or the Internet to be delivered to another networking enabled device in a geographically separated location. The sensor data for example, could be used for remotely navigating the robot. The information could be a simple on-off signal generated by a light switch in one location to be transferred by a communication networking interface protocol to another location to turn a light bulb on. What is common among all of these examples is an *application* that needs the *transfer* of a certain amount of *information* from one location to another, a *network* that can carry the information and an *interface device* that shapes the information to a format or protocol suitable for a particular networking technology.

Figure 1.2 shows a diagram of the elements affecting information networks and the relationships among them. Information generated by an application is delivered to a communication device that uses the network and delivers that information to another location. When the network includes multiple service providers, the interface between the device and the network should be *standardized* to allow communication among different network providers and various user devices. Standardization also allows multivendor operation so that different manufacturers can design different parts of the

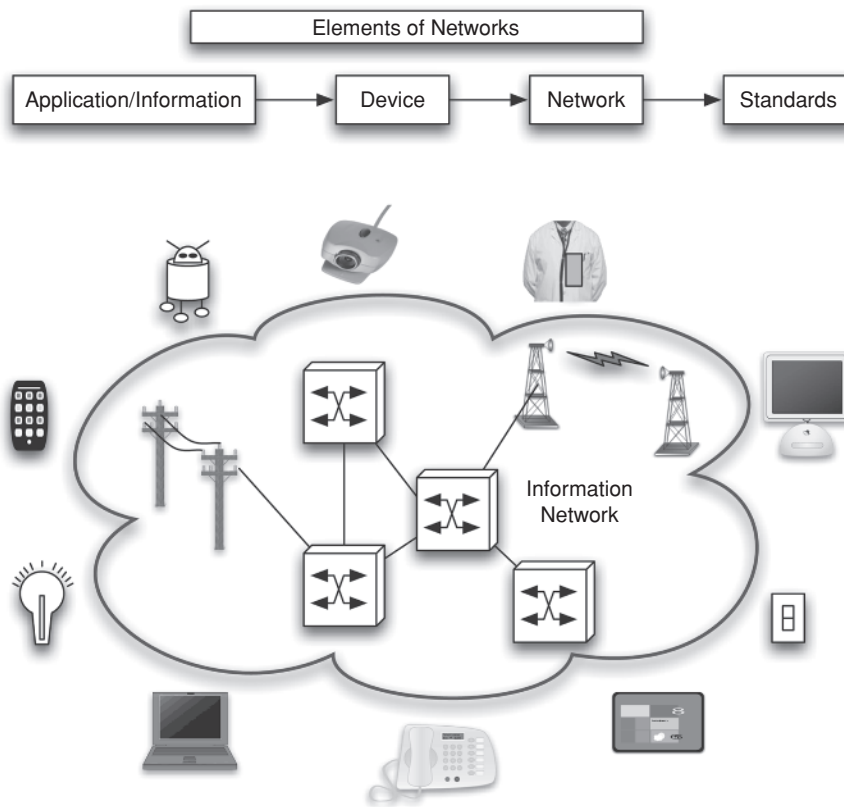


Figure 1.1 Abstract of the general concept of information networking.

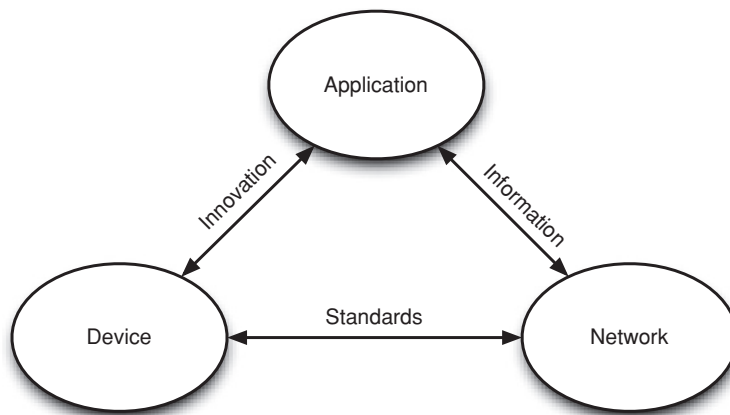


Figure 1.2 Elements of information networking.

applications can tolerate such delay to a certain extent. The transmission technique for the device was digital communication. Therefore, the telegraph could be considered the first packet switched digital network with human routers designed for data burst SMS applications.

The more popular telephone network, which was invented in 1876, operated using analog telephone devices. The user of the device would connect to the operator and the operator would communicate with other operators to establish a line between the source and the destination before conversation starts and information gets transferred along the network. The operator in this application had to work hard to establish the connection fast enough and to maintain that connection during the period of information transmission or streaming of the conversation in both directions. The operator in this case was a human switch that was expected to establish the connection quickly and to maintain that connection during the communication period. Therefore, the telephone network was an analog connection-based circuit-switched network originally designed for voice applications. The Morse pad that was the device used for the telegraph network needed a specialized operator capable of using the code for data communications; as a result the telegraph industry evolved as an office-based application with certain limitations on its size. The telephone devices, however, could be used by anyone and they penetrated the home market; thus orders of magnitude higher numbers of telephone devices were sold and the telephone network became much larger than telegraph network generating tremendously larger revenue for the company. By considering the telephone and telegraph networks, we observe that at the beginning of the twentieth century, the telecommunications industry had already been exposed to a number of important issues, which played similar roles during the entire course of the past century and culminated in the emergence of modern wireless networks. Among these important issues were analog versus digital, voice versus data, packet-switched versus circuit-switched networking, and home versus office networking.

The next popular telecommunication devices related to information networks were voice-band modems. These devices emerged after the Second World War to allow communication between computers and computer terminals located in geographically separated areas. Computer networks, which evolved that way, extended the SMS supported by the telegraph to other data applications such as file transfer and remote terminal access. The size of the computer communication industry was still very small compared to the telephone industry until the penetration of the Internet into homes and through the use of desktop and laptop computers. The evolution of computer networks opened up new applications and communication devices such as printers, scanners, fax machines, video cameras, and monitors that could attach to them.

The popularity of wireless networks started with cellular and cordless telephones during the 1980s, extending voice applications across local and wide area networks. During the 1990s, wireless local area networking (WLAN) technology emerged and nurtured mobile computing to connect laptops (which were the primary mobile computing devices at the time) in homes and small office networks. In the 2000s, wireless personal area networking (WPAN) technology allowed communications between and with sensors that can virtually connect the Internet to everything to create the Internet of Things.

The latest devices that heavily impacted the evolution of information networking technology were mobile smart devices. The introduction of the iPhone in 2007 opened a new horizon for wireless data applications that demanded more efficient networks to support these data applications. Smart phones, lead by the iPhone, created a platform for running data-consuming applications such as YouTube access and web browsing on a wireless platform. This demand further increased the popularity of WLANs and forced cellular telephone service providers to move to physical layer technologies used in WLANs to increase the supported data rates. At the time of writing cyber physical systems are emerging to facilitate the massive data processing collected from distributed sensors for medical, transportation, power distribution, and other applications.

1.2.2 Information Network Infrastructures and Wireless Access

To support the transmission of voice, data, and video, several wired information network infrastructures have evolved throughout the past century. Wireless networks allow a mobile wireless device to access these wired information network infrastructures. At first glance, it may appear that a wireless network is only an antenna site or a base station connected to one of the switches or routers in the wired information infrastructure that enables a mobile terminal to be connected to the backbone network. In reality, in addition to the antenna site, a wireless network also needs to add its own mobility-aware switches, databases, and base station control devices to be able to support mobility and manage scarce radio resources when a mobile terminal changes its connection point to the network. Therefore, a wireless network has its own fixed infrastructure with mobility-aware switches and networked connections, similar to other wired infrastructures, as well as antenna sites and mobile terminals.

When the geographical coverage area of a network is very large, the cost of deployment and maintenance of the infrastructure is very high and a service provider makes the investment to build the network infrastructure. To compensate for that large investment, the service provider leases the infrastructure access to subscribers. We refer to these large infrastructures as backbone or wide-area wired backbone networks. The two major examples of these backbone networks are the PSTN and the Internet, each having a number of service providers in different countries. Wireless access to these networks is either through wide-area wireless cellular networks, which allow for wireless access over a large area of coverage through a service provider, or smaller networks, owned by private enterprise or individuals. These smaller networks form the so-called local, personal, and body area networks. Local area networks are either wired or wireless and the backbone networks are mostly wired networks. In this book we address wireless networking technologies while details of wired wide and local area networks are addressed in [Pah09].

Figure 1.4 shows the overall picture for wired and wireless telephone services using PSTN. The PSTN, which was designed to provide wired telephone services, is augmented by a wireless fixed infrastructure to support the mobility of a mobile device that communicates with several base stations mounted over antenna posts. The PSTN infrastructure consists of switches, point-to-point connections, and computers used for the operation and maintenance of the network. The fixed infrastructure of the cellular telephone service has its own mobility-aware switches, point-to-point connections, and other hardware and software elements that are needed for the mobile network

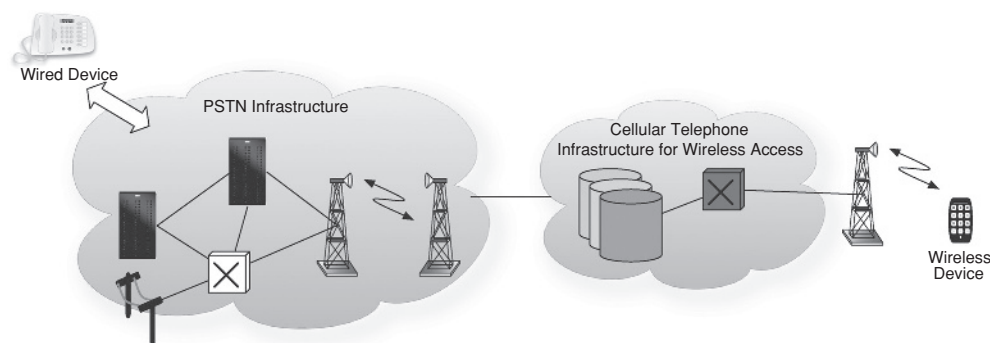


Figure 1.4 The PSTN and its extension to cellular telephone services.

operation and maintenance. A wireless telecommunication device, for example a smart phone, can connect to the PSTN infrastructure by replacing the wire attachment with radio transceivers. But, for the wireless device to change its point of contact, switches in the PSTN must be able to support mobility. Switches in the PSTN infrastructure were not originally designed to support mobility. To solve this problem, cellular telephone service providers have added their own fixed infrastructure with mobility-aware switches. The fixed infrastructure of the cellular telephone service provider is an interface between the base stations and the PSTN infrastructure that implements the environment to support mobility. The simplest wireless access to the PSTN is though a cordless telephone. This does not have any switch in the infrastructure and basically operates as a wireless connection between a handset and a telephone connected by wire to the PSTN and mostly through a standard or a proprietary protocol.

In the same way that a telephone service provider needs to add its own infrastructure to allow a mobile telephone to connect to the PSTN, a wireless data network provider needs its own infrastructure to support wireless Internet access. Figure 1.5 shows the traditional wireless data infrastructure and the additional wireless data infrastructure that allows wireless connection to the Internet. The traditional data network consists of routers, point-to-point connections, and computers for operation and maintenance. The elements of a wireless network include mobile devices, access points, mobility aware routers, and point-to-point connections. If the wireless data access intends to provide wide area coverage for the wireless data service, the new infrastructure has to support all the functionalities needed to support mobility. In simpler applications, such as a hot-spot or for home access, the wireless infrastructure does not necessarily need to be aware of mobility because connection to the Internet is through one access point only. However, to allow users with mobile devices to be able to connect to different access points, there is a need to support mobility through protocols and hardware.

The main difference between wireless access to the PSTN and the Internet is that wireless access to the PSTN, shown in Figure 1.4, is a connection-based voice-oriented network and wireless access to the Internet, shown in Figure 1.5, is a connectionless data-oriented network. A connection-based network needs a dialing process and, after dialing, a minimum quality of service is guaranteed to the user during the communication session. In connectionless networks, there is no dialing and the terminals are always connected to the network, but a uniform quality of service is not guaranteed. Figure 1.6 illustrates the basic difference between a packet-switched and a circuit-switched network in the handling and delivery of packets from a source to a destination terminal. In a connectionless

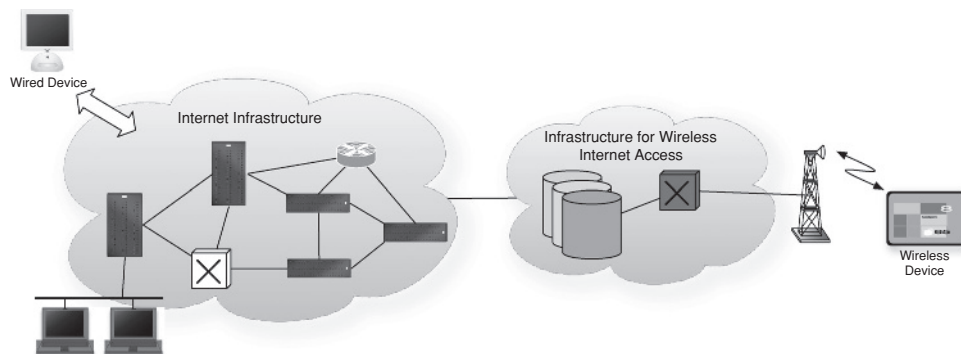
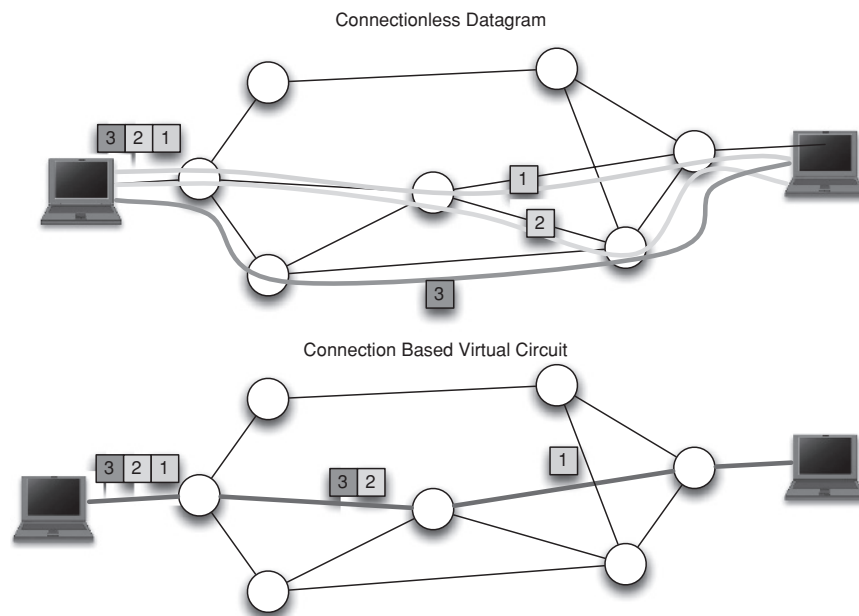


Figure 1.5 The Internet and its extension to cellular telephone services.



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Figure 1.6 Connection-less packet-switched Internet versus connection-based circuit-switched PSTN.

data gram network, information packets takes routes that are determined by the routers, hub-by-hub, as based on the traffic and resources arriving and leaving the hub. As a result, consequent packets from a single information source may take different paths to arrive at the receiver. This approach provides a more efficient method to utilize the transmission line capabilities but has no guarantee for the delay of the arriving packets with respect to one another, which challenges support to maintain a prescribed quality of service for the user. In connection-based networks a virtual path is established between the source and destination, and the consecutive data packets take the same route. This formation allows more control on the delay and consequently the quality of service provided to the user.

1.2.3 Connection Between Wireless Access and Localization

Wireless localization is tied with wireless access through two connections. First, popular wireless localization techniques, such as Wi-Fi localization and cell tower localization, use the existing infrastructure and the transmitted signals originally established for wireless access and communications, to localize a mobile terminal. The data base of the location of the Wi-Fi access points or cell tower base stations is used as the landmark and the received signal strength or the time of flight of the signal between the landmark and the mobile terminal is used to estimate the distance of the terminal from the landmarks. The distances from several landmarks are used to estimate the location of the terminal. Using the existing infrastructure and the received signal strength is the most inexpensive and commercially popular method currently used for wireless localization of smart devices.

The second tie between wireless access and localization lies in understanding the multipath channel characteristics that cause deformation of the transmitted waveforms due to multipath effects. As we will describe later in this book, this deformation of the transmitted waveform by the multipath characteristics of indoor and urban areas for wireless communications imposes restrictions on the highest symbol transmission rate for communication applications. In localization application using the time of flight of the transmitted waveform, which provides a more precise measure for ranging the distance from a landmark, deformation of the waveform caused by multipath causes errors in estimations of the time of flight. The time of flight of the signal is often calculated from a reference location of a feature of a waveform, for example, the peak of the transmitted waveform. In the multipath environment the peak of the received signal is dislocated by the effects of the multipath causing an unwanted error in estimations of the distances using the time of flight estimation. Therefore, both high-speed wireless access and precise localization techniques need a careful understanding of the nature of the multipath arrivals in wireless media that is one of the important subjects addressed in this book.

1.2.4 Standards Organizations for Information Networking

The increasing number of portable and mobile applications on different communication devices demands a variety of standardized wireless access technologies operating on different frequency bands. Frequency bands are regulated by national agencies such as the Federal Communication Commission (FCC) in the United States. Wireless technologies that are discussed in this book include cellular telephone and personal communication systems that are operating within licensed bands and WLAN and WPAN technologies that are operating in unlicensed bands. Licensed bands are like a privately owned backyard. The owner of the band needs to invest a substantial amount of money and effort to obtain permission for using that band in a certain geographical area. These bands usually allow higher transmission power but they are more restricted in the size of the bandwidth. Unlicensed bands are similar to public gardens; users of these bands have access to a wider bandwidth but with restrictions on their transmission power. Figure 1.7 illustrates several licensed and unlicensed bands in the United States that are used both for different generations of cellular networks and for cordless telephones and several unlicensed bands used for WLAN and WPAN applications.

Standards define interface specifications between elements of a wireless network infrastructure allowing a global multivendor operation, which facilitates the growth of the industry. Figure 1.8 provides an overview of the standardization process in information networking. The standardization process starts in a special interest group of a standards developing body such as the Institute of Electrical and Electronics Engineers (IEEE 802.11) or Global System for Mobile (GSM) communications, which defines the technical details of a networking technology as a standard for operation. The defined standard for implementation of the desired network is then moved for approval by a regional organization such as the European Telecommunication Standards Institute (ETSI) or the American National Standards Institute (ANSI). The regional recommendation is finally submitted to world-level organizations, such as the International Telecommunications Union (ITU), International Standards Organization (ISO), or International Electrotechnical Commission (IEC), for final approval as an international standard. There are a number of standards organizations involved in information networking. Table 1.1 provides a summary of the important standards playing major roles in shaping the information networking industry, which are also mentioned in this book.

The most important standard developing organizations for technologies described in this book are the IEEE 802-series standards for personal, local, and metropolitan area networking. The IEEE

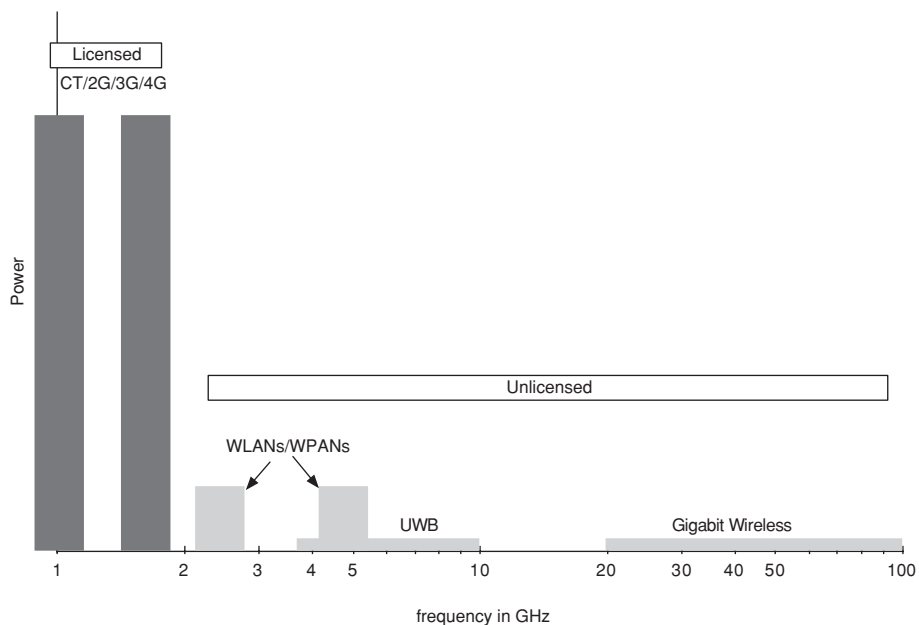


Figure 1.7 Samples of licensed and unlicensed band spectrums in the United States.

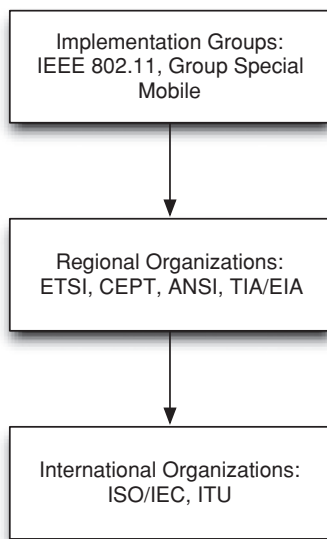


Figure 1.8 Standard development process.

Table 1.1 Summary of important standard organizations for information networking

FCC (Federal Communication Commission):	The frequency administration authority in the United States.
IEEE (Institute of Electrical and Electronics Engineers):	Publishes 802 series standards for WLAN and WPAN wireless applications.
GSM (Global System for Mobile):	Special group defined 2G TDMA standard sponsored ETSI.
ATM (Asynchronous Transfer Mode) Forum:	An industrial group working on a standard for ATM networks.
IETF (Internet Engineering Task Force):	Publishes Internet standards that include TCP/IP and SNMP. It is not an accredited standards organization.
EIA/TIA (Electronic/Telecommunication Industry Association):	United States national standard for North American wireless systems.
ANSI (American National Standards Institute):	Accepted 802 series and forwarded to ISO. Developed JTC models for wireless channels.
ETSI (European Telecommunication Standards Institute):	Published GSM, HIPERLAN-1, and UMTS.
CEPT (Committee of the European Post and Telecommunication):	Standardization body of the European Posts Telegraph and Telephone (PTT) ministries. Co-published GSM with ETSI.
IEC (International Electrotechnical Commission):	Publishes jointly with ISO.
ISO (International Standards Organization):	Ultimate international authority for approval of standards.
ITU (International Telecommunication Union formerly CCITT):	International advisory committee under the United Nations. The Telecommunication Sector, UTU-T, publishes ISDN and wide area ATM standards. Also works on IMT-2000.

is the largest engineering organization in the world, publishing a number of technical journals and magazines and organizing numerous conferences worldwide. The IEEE 802 community is involved in defining standard specifications for information networks. The number 802 was simply the next free number IEEE could assign to a committee at the inception of the group on February 1980, although “80-2” is sometimes associated with the date of the first meeting. Regardless of the ambiguity of the name, the IEEE 802 community has played a major role in the evolution of wireless information networks by introducing IEEE 802.11 WLANs, IEEE 802.15 WPANs, IEEE 802.16 WMAN, and other standards which are discussed in detail in this book.

Another important standard developing organization is the Internet Engineering Task Force (IETF) which was established in January 1986 to develop and promote Internet standard protocols around the Transmission Control Protocol/Internet Protocol (TCP/IP) suite for a variety of popular applications. In the 1990s, the Asynchronous Transfer Mode (ATM) Forum was an important standard developing group trying to develop standards for connection based fixed packet length communications for the integration of all services. This philosophy was in contrast with Internet/Ethernet networking using connection-less communications with variable and long length packets and it has lost its momentum.

The Telecommunication/Electronic Industry Association (TIA/EIA) is a United States national standards body defining a variety of wire specifications used in local, metropolitan and wide area networks. The TIA/EIA is a trade association in the United States representing several hundred telecommunications companies. The TIA/EIA has cooperated with the IEEE 802 community to define the media for most of the wired Local Area Networks (LANs) used in fast and gigabit Ethernet. TIA/EIA also defines cellular telephone standards such as Interim Standards (e.g., IS-95) or cdmaOne second generation (2G) cellular networks and the IS-2000 or CDMA-2000 third

generation (3G) cellular telephone networks. ETSI and the Committee of the European Post and Telecommunications (CEPT) are the European standardization bodies publishing wireless networking standards, such as GSM for the 2G cellular networks and Universal Mobile Telephone Standard (UMTS) for 3G cellular, in the European Union.

The most important international standards organizations are the International Telecommunication Union (ITU), the International Organization for Standardization (ISO), and the International Electrotechnical Commission (IEC); and they are all based in Geneva, Switzerland. Established in 1865, ITU is an international advisory committee under United Nations and its main charter includes telecommunication standardization and allocation of the radio spectrum. The Telecommunication Sector, ITU-T, has published, for instance, the Integrated Service Data Network (ISDN) and wide-area ATM standards, as well as International Mobile Telephone-2000 (IMT-2000) for 3G cellular networks.

In 2009, the Radio communication sector of ITU (ITU-R) defined the IMT-Advanced requirements for fourth generation (4G) cellular networks. At the time of writing, the so-called Long Term Evolution (LTE) of UMTS is becoming the favorite choice of this standard. The World Administrative Radio Conference (WARC) was a technical conference of the ITU where delegates from member nations of the ITU met to revise or amend the entire international Radio Regulations pertaining to all telecommunication services throughout the world. ISO and IEC are composed of the national standards bodies, one per member economy. These two standards often work with one another as the ultimate world standard organization. Established in 1947, ISO nurtures worldwide proprietary industrial and commercial standards that often become law, either through treaties or national standards. The ISO seven-layer model for computer networking was one of the prominent examples of ISO standards. The IEC started in 1906 and it is a non-governmental international standards organization for “electrotechnology” which includes a vast number of standards from power generation, transmission and distribution to home appliances and office equipment, to telecommunication standards. The IEC publishes standards with the IEEE and develops standards jointly with the ISO as well as the ITU.

1.2.5 Four Markets in the Evolution of Wireless Networking Standards

The market for wireless networks has evolved in four different segments that can be logically divided in two classes: *voice-oriented* and *data-oriented*. The voice-oriented market evolved around wireless connections to the PSTN for wireless telephone applications. These services further evolved into local and wide-area markets. The local wireless access to the PSTN is based on low-power, low-mobility devices with a higher quality of voice that evolved around the cordless telephone application. The wide-area wireless access to the PSTN market evolved around cellular mobile telephone services that are using terminals with higher power consumption, comprehensive coverage, and lower quality of voice. Figure 1.9 (a) compares several features of these two sectors of the wireless access to the PSTN market.

The wireless data-oriented market evolved around wireless access to the Internet and computer communication network infrastructure. The data-oriented wireless access services are divided into broadband local, ad hoc, and wide-area mobile data markets. The wide-area wireless data market provides for wireless Internet access for mobile users with a comprehensive coverage similar to that of the cellular telephone. Local broadband and ad hoc networks include wireless local and personal area networks that provide for high-speed Internet access as well as evolving ad hoc wireless consumer product markets with a local spot coverage similar to the cordless telephone systems. Figure 1.9 (b) illustrates several differences among the local and wide-area wireless data networks.

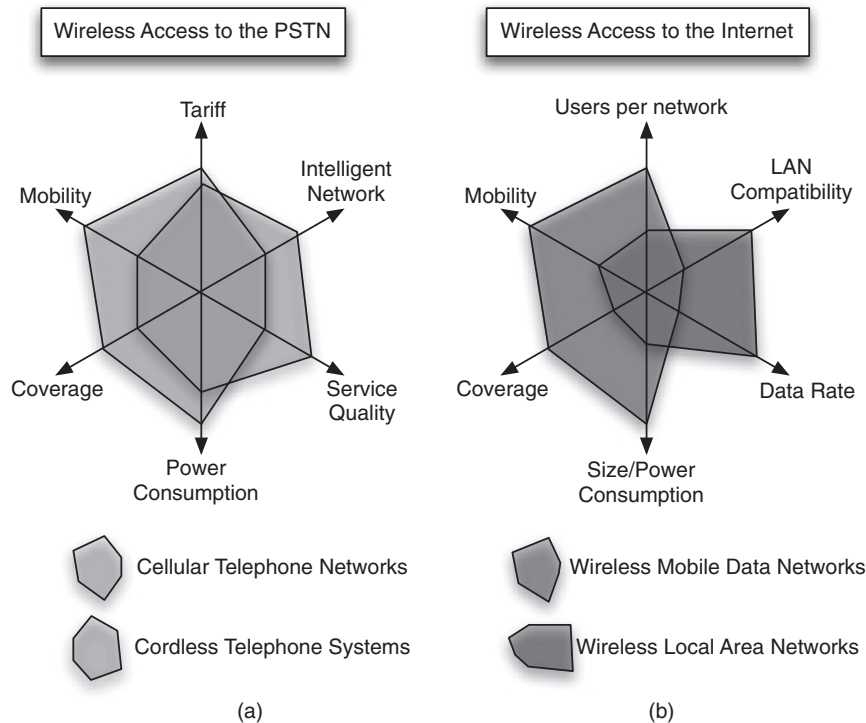


Figure 1.9 Wireless market sectors for wireless access to (a) the PSTN (b) the Internet.

Standards for wireless access to the PSTN and the Internet evolved around these four markets, described in Figure 1.9, for wireless telephone and wireless data applications. The evolutionary paths for these technologies were different because the market demand for data and voice applications was highly affected by the emergence of the Internet in the middle of the evolution of wireless networking technologies. The earlier standards were focused on voice and telephone applications using PSTN, which was the dominant source of revenue generation for the telecommunication network operating companies (and at the time of writing it still is). However, this trend started to change with the emergence of the popularity of data applications and the Internet in the late 1990s and the introduction of smart phones in the late 2000s. Smart phones increased the usage of the wireless data applications exponentially and that demand forced the cellular network providers to shift the focal point of the emerging wireless cellular networking systems toward data applications. As a result, as we will see in the following two sections, although the technologies for medium access control and physical layer in the four major markets differed substantially in the early days of this industry, they are evolving towards technologies that were originally explored for WLAN and wireless local data applications.

1.2.6 Trends in Wireless Data Applications

Wireless access and localization techniques are multidisciplinary systems engineering fields. During the evolution of these technologies the focal point of applications and the market as well as

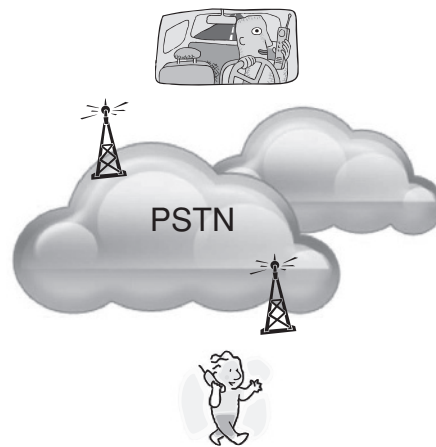


Figure 1.10 Mobile and personal users of voice telephone applications.

research and development have shifted over time. During the 1990s and early 2000s the cellular telephone network industry was growing exponentially. The cellular telephone industry runs a connection-based telephone voice application with a bandwidth per user of around 10 Kbps but numerous simultaneous users each running a telephone call for a few minutes. Figure 1.10 shows the main two application environments for personal and mobile radio communications. The main applications are connected to the network for only a few minutes, they are moving around and they are sensitive to real-time delay. Thus, the wireless access network providers focus on increasing the number of simultaneous users and the steadiness of the quality of service during the connection time, as the users are moving around. As a result of that growth and these requirements the Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA) medium access technologies emerged and frequency administration agencies released more bands for these applications to support the growth of the number of users. Service providers who had started their business by installing macro-cells to cover tens of kilometers at an approximate cost of around a million dollars per cell started deploying smaller micro-cells for dense urban areas that cover several hundred meters at a cost that was an order of magnitude lower than the cost of a macro-cell for dense urban areas; and then they shifted to pico-cells, for inside large buildings, which covers and costs about an order of magnitude less than the micro-cells. More recently the number of telephone voice users reached its steady large value of around seven billion users worldwide.

As shown in Figure 1.11, with the emergence and immediate popularity of smart phones in late 2000's, wireless data applications started to grow exponentially and this growth is expected to continue for the next few decades. At the time of writing, over 70% of this data is carried through Wi-Fi connections that are deployed randomly by individual users and private institutions to cover their work space area, not by the service providers. Service providers provide a complementary coverage in the areas that Wi-Fi does not cover and a more reliable connection for mobile data users. As shown in Figure 1.12 data applications are dominated by downloading from a cloud somewhere in the Internet into a stationary or semi-stationary device. The Internet is made of a fiber optics backbone and can provide the data pipe from the cloud up to the wireless access point; the bottleneck is the fast transmission from the access point to the user. Data applications are keen on speed of transmission because their applications are often bursts of data with a wide variety of sizes, from a short message to streaming videos. This demand for higher data rates resulted in the emergence of Orthogonal Frequency Division Multiplexing (OFDM), space-time coding, and

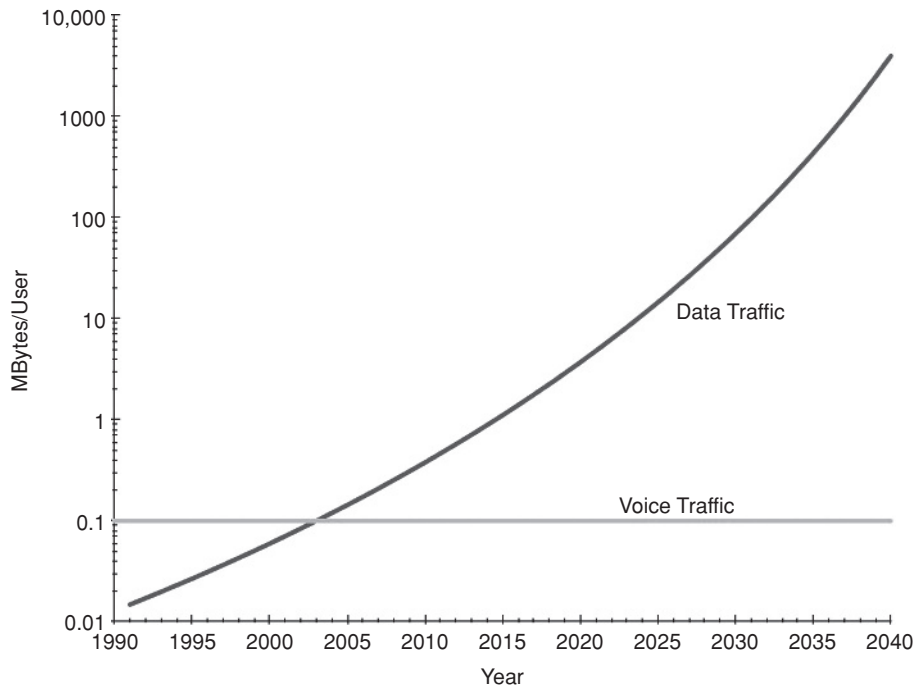


Figure 1.11 Trends in the growth of voice and data applications in the next few decades.

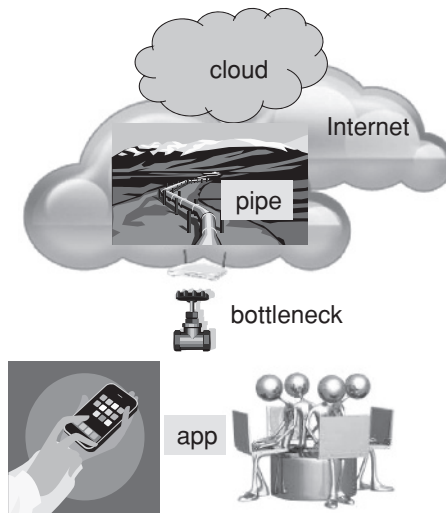


Figure 1.12 Stationary and semi-stationary users of wireless data applications.

Multiple-Input-Multiple-Output (MIMO) antenna system technologies first in Wi-Fi and then in LTE systems in 4G cellular networks. Wi-Fi supports local wireless data access and 4G is designed for the wide-area backup support of data applications. To support the growth of data more bandwidth efficient modulation techniques, release of wider bands from frequency administration agencies, and using smaller cells are the trends of the future. The wireless local industry is searching for gigabit wireless and the cellular networking industry is examining femto-cell technology.

1.3 Evolution of Wireless Access to the PSTN

Wireless access to the PSTN evolved around two applications, the cordless telephone for local access and the cellular telephone for wide-area wireless access. Table 1.2 shows a brief chronology of the evolution of wireless access networks to connect to the PSTN. The local area networks for wireless access to PSTN, mostly for home and small office applications, started with the introduction of the cordless telephone that appeared in the market in the late 1970s. A cordless telephone provides a wireless connection to replace the wire between the handset and the telephone set. The radio technology for implementation of a cordless telephone was similar to the technology used in walkie-talkies that existed since the Second World War. The important feature of the cordless telephone was that, as soon as it was introduced to the market, it became a major commercial success, selling on the order of tens of millions in numbers and generating a gross sales income exceeding several billions of dollars. The success of the cordless telephone encouraged further developments in this field. The first digital cordless telephone was cordless telephone (CT) and CT-2, a standard developed in the United Kingdom in the early 1980s. The next generation for cordless telephones was wireless multichannel local cordless telephone with a higher transmission rate to

Table 1.2 History of voice-oriented wireless networks

Exploration of first generation mobile radio at Bell Laboratories: early 1970s
First generation cordless phones: late 1970s
Exploration for second generation digital cordless CT-2: 1982
Deployment of first generation NORDIC analog NMT: 1982
Deployment of United States AMPS: 1983
Exploration of the second generation digital cellular GSM: 1983
Exploration of wireless PBX; DECT: 1985
Initiation for GSM development: 1988
Initiation for IS-54 TDMA digital cellular: 1988
Exploration of the QUALCOMM CDMA technology: 1988
Deployment of GSM: 1991
Deployment of PHS/PHP and DEC-1800: 1993
Initiation for IS-95 standard for CDMA: 1993
PCS band auction by FCC: 1995
PACS finalized: 1995
3G Standardization started: 1998 (add WiMax and LTE)
WiMax Forum formed: 2001
WiMax fixed: 2004
WiMax mobile: 2005
LTE products: 2006
LTE-advanced standardization: 2009

support wireless data using the digital European cordless telephone (DECT) standard. Both CT-2 and DECT had minimal network infrastructures to go beyond the simple cordless telephone and cover a larger area and multiple applications. However, in spite of the huge success of the traditional cordless telephone, neither CT-2 nor DECT became a commercially successful system immediately. These local systems soon evolved into the so-called Personal Communication Systems (PCS) that were complete systems with their own infrastructure, very similar to the cellular mobile telephone.

1.3.1 Cordless Telephone Systems

In the technical communities of the early 1990s, PCS systems were differentiated from the cellular systems in the way they are presented in Figure 1.9 (a). A PCS service was considered as the next generation cordless telephone designed for residential areas, providing a variety of services beyond the cordless telephone. The first real deployment of PCS systems was the Personal Handy Phone (PHP), later renamed the Personal Handy System (PHS), introduced in Japan in 1993. At that time, the technical difference between PCS services and cellular systems was perceived to be smaller cell size, better quality of speech, lower tariff, less power consumption, and lower mobility. However, from the user's point of view the terminals and services for PCS and cellular looked very similar and the only significant difference was marketing strategy and the way that they were introduced to the market. For instance, around the same time, in the United Kingdom, Digital European Cordless DEC-1800 services were introduced as a PCS service. The DEC-1800 service was using the second generation (2G) cellular GSM-like technology at a higher frequency of 1800 MHz but it employed a different marketing strategy. The last PCS standard was Personal Access Communications System (PACS) in the United States, finalized in 1995. Altogether, none of the PCS standards became a major commercial success and a competitor to cellular services.

In 1995 FCC in the United States auctioned the frequency bands around 2 GHz as PCS bands but PCS specific standards were not adopted for these frequencies. Eventually, the name PCS started to appear only as a marketing pitch by some service providers for digital cellular services, in some cases not even operating in the PCS bands. While the more advanced and complex PCS services evolving from the simple cordless telephone application did not succeed and eventually merged into the cellular telephone industry, the simple cordless telephone industry itself still remains active. In the early 2000s the frequency of operation of cordless telephone products was shifted into unlicensed industrial, scientific and medical (ISM) bands rather than the licensed PCS bands. Cordless telephones in the ISM bands could provide a more reliable link using spread spectrum technology. With the growing popularity of WLAN technology for home networking, interference between cordless telephones and wireless Internet access in the home and small offices captured the attention of manufacturers in this area. More recently, the DECT standard has attracted considerable renewed attention for the implementation of cordless telephones and DECT devices are flooding this market, replacing cordless telephones in the ISM bands. These devices are using 1.8 and 1.9 GHz PCS bands, which do not interfere with the ever-growing popular WLAN application for wireless networking inside residences and small offices. The DECT standard uses TDMA technology with a Time Division Duplex (TDD) option, in which a single carrier frequency carries multiple handset streams between the handsets and the base station in both directions.

1.3.2 Cellular Telephone Networks

The wide area wireless access to the PSTN started with the analog cellular telephone. The technology for the analog cellular first generation (1G) systems was developed at the AT&T Bell

Laboratories in the early 1970s. However, the first deployment of these 1G systems took place in the Nordic countries using Nordic Mobile Telephone (NMT) technology about a year earlier than the deployment of the Advanced Mobile Phone Services (AMPS) in the United States. Since the United States was a large country, frequency administration and other regulation in the process was slower, so it took a longer time for the deployment. All 1G systems used traditional analog FM transmission and frequency division multiple access (FDMA) to share the medium among different users. The digital cellular networks in the Nordic countries started with the formation of the Groupe Speciale Mobile or GSM standardization group. The GSM standards group was originally formed to address international roaming, a serious problem for cellular operation in the European Union countries. The standardization group shortly decided to go for a new digital TDMA technology because it could allow integration of other services to expand the horizon of wireless applications [Hau94]. In the United States, however, the reason for migration to digital cellular was that the capacity of the analog systems in major metropolitan areas such as New York City and Los Angeles had reached their peak value and there was a need for increasing the capacity in the existing allocated bands. Although the Nordic countries, led by Finland, maintained the highest rate of cellular penetration in the early days of this industry, the United States was by far the largest market. By 1994, there were 41 million subscribers worldwide, 25 million of them in the United States. The need for higher capacity motivated the study of CDMA technology in the United States that was originally perceived to provide a capacity up to two orders of magnitude higher than other alternatives such as analog band splitting or digital TDMA. The CDMA technology used in the cellular network utilizes direct sequence spread spectrum (DSSS) technique for transmission and different users are differentiated using different spread-spectrum codes.

In the early 1990s, while the debate between TDMA and CDMA capacity for 2G cellular networks was in progress in the United States, deployment of the GSM technology started in the European Union that was looking for a technology to solve the roaming problem between a number of countries ready to form the European Union. Around the same period, developing countries, which had not yet deployed any cellular networks, started their planning for cellular telephone networks and most of them adopted the 2G GSM TDMA digital cellular technology over the legacy analog cellular systems. Soon after, GSM had penetrated into more than 180 different countries. An interesting phenomenon in the evolution of the cellular telephone industry was the unexpected rapid expansion of this industry in developing countries. In these countries, the growth of the infrastructure for wired telephone was slower than the growth of the demand for the new subscriptions and always there were long waiting times to acquire a wired telephone line. As a result, in most of these countries, telephone subscriptions were sold on the black market at a price several times its actual value. Penetration of cellular telephone in these countries was much easier because people were already prepared for a higher price for a telephone subscription. In addition, original deployment, maintenance, and expansion of cellular networks could be done in a manner that was much faster than that with wired telephones, resulting in a rapid penetration of cellular telephones in the world market.

In the beginning of the race between the TDMA and CDMA, CDMA technology was deployed only in a few countries. Besides, the experimentation had shown that the capacity improvement factor of CDMA was smaller than expected. In the mid-1990s when the first deployments of CDMA technology started in the United States, most companies were subsidizing the cost to stay in race with TDMA and analog alternatives. However, from day one, the quality of voice using CDMA was superior to that of TDMA systems installed in the United States. As a result, CDMA service providers under the banners like “you cannot believe your ears” started marketing this technology in the United States that soon become very popular with the users. Meanwhile, with the huge success of digital cellular telephony, all manufacturers worldwide started working on 3G cellular

International Mobile Telephone IMT-2000 wireless networks. Most of these manufacturers adopted wideband CDMA (W-CDMA) as the technology of choice for IMT-2000, assuming that W-CDMA eases integration of services, provides better quality of voice, and supports higher data rates of up to 2 Mbps for wireless Internet access.

In the early 2000s, Internet access to the home opened a new horizon for wireless data applications as WLAN became the choice for local access in home, office, and hot spots. The sporadic nature of WLAN coverage demanded the attention of cellular providers to provide wide-area high-speed wireless data access. The technology adopted in these efforts was no longer CDMA and these technologies evolved out of OFDM and MIMO technologies that had matured in the WLAN industry. This movement first started with WiMax (Worldwide Interoperability for Microwave Access) that was an extension to the WLAN technologies originally specified by IEEE 802.11. WiMax did not gain the expected market success and, at the time of writing, long-term evolution LTE has been more successful. Further, LTE provides an enhancement more suited to fragmented frequency bands used by cellular networks compared to WiMax. These technologies are referred to as fourth generation (4G) wireless technologies. LTE-advanced is the latest standard emerging in this area aiming at maximum data rates on the order of a gigabit per second. The basic physical layer of these technologies is similar to the physical layer of WLANs that better suits emerging data applications. The implementation of medium access control is adjusted to the specifics of cellular networks that are designed for comprehensive wide-area coverage and a fragmented bandwidth allocations. Figure 1.13 provides a chart depicting the evolution of different technologies for

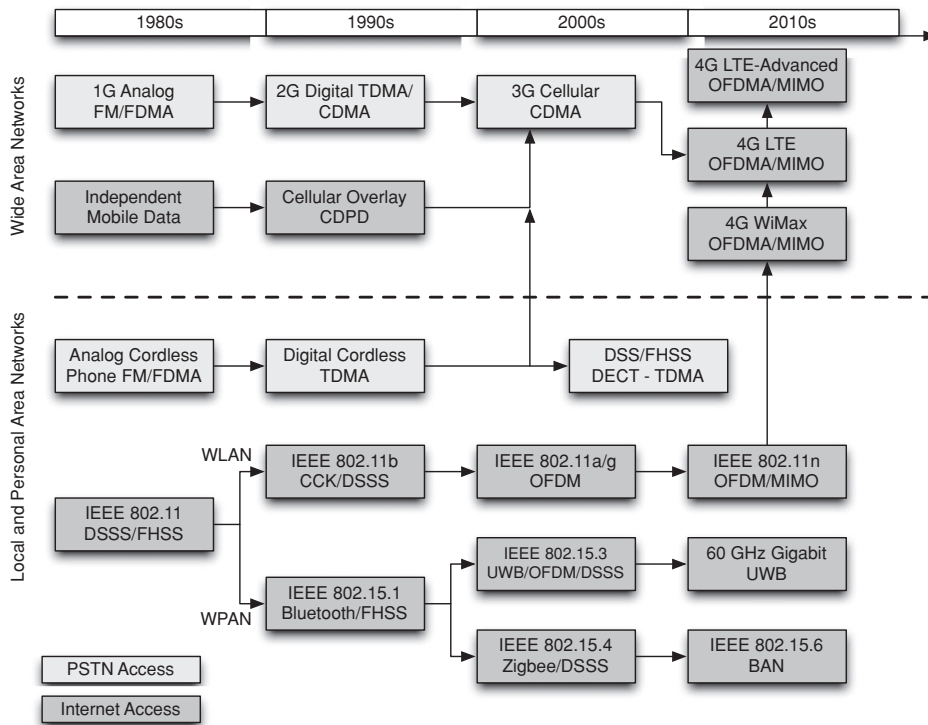


Figure 1.13 Evolution of networking technologies for wireless access to the PSTN and the Internet.

the original first four applications for local and wide-area voice and data applications shown in Figure 1.9.

1.4 Evolution of Wireless Access to the Internet

The main difference between wireless access to the Internet and wireless access to the PSTN is that the PSTN is a connection-based network primarily designed for telephone voice applications and the Internet is a connectionless network primarily designed for data applications. The telephony application generates massive amounts of data for two-way communication for a few minutes of real-time streaming at a low speed of around 10 Kbps per user that demands a steady quality of service during the conversation. These features require a simpler transmission technique but a more predictable medium access control method. Therefore, the focal points for the design of wireless access to these networks were the medium access control techniques and how they can support more numbers of users with a better quality of voice over a given bandwidth. Data applications are best described by bursts of information and these bursts of information need to percolate over the network in the fastest way, to incur minimal delay, and for that reason the highest achievable data rate dominates the design of the data-oriented networks. Therefore, the evolution of wireless data networks has focused on achieving the highest data rate in a given bandwidth that is achieved by innovations at the physical layer used for transmission of the bit streams in the wireless medium.

Table 1.3 provides the chronology of data-oriented wireless networks. As shown in Figure 1.9 (b) data-oriented wireless networks are divided into wide-area wireless mobile data networks and wireless local and personal area networks. Wireless local networking started with WLANs and later extended into WPAN technologies. WLANs originally emerged to support high data rates of above 1 Mbps (at that time) compared to mobile data networks that would support data rates of less than 10 kbps. In three decades of evolution, the WLAN industry changed significantly in developing innovative technology and marketing to the extent that, today, the WLAN standardization committee, IEEE 802.11, is evaluating gigabit wireless for the future of this technology and the sales of the WLAN chip sets exceeds several billions units per year. WPAN technology evolved under the IEEE 802.15 standardization process as a complement to WLAN technology to address application areas that are not fully covered by WLAN technology. They have already introduced popular standards such as Bluetooth for short-range communications between devices and ZigBee for low-power sensor networking applications. This group has worked on 3.4–10.6 GHz bands and more recently the 60 GHz spectrum for the implementation of higher data rates (gigabit wireless technologies) for short-distance connection such as wireless Universal Serial Bus (USB), three dimensional (3D) gaming, or cable replacement for multichannel high-definition television applications.

1.4.1 Local Wireless Data Networks

The lower part of Figure 1.13 illustrates the evolutionary path of WLAN and WPAN technologies. The concept of using the spread spectrum and infrared technologies to implement WLANs was first introduced around 1980 [Pah85], the first IEEE 802.11 standard using these technologies released in 1997 and the IEEE 802.15 for WPAN was formed in the following year. However, the sizeable market of several billion chipsets per year, which is comparable to the cellular chip set market, emerged only in recent years. A key feature of the WLAN and WPAN industry is operation in the unlicensed bands. The first unlicensed bands were the Industrial, Scientific and Medicine (ISM) bands at 900 MHz, 2.4, and 5.2 GHz, released in the United States in 1985 [Mar85]. Later in 1994 the unlicensed PCS bands and in 1997 unlicensed National Information Infrastructure

Table 1.3 Chronology of wireless data networks

Diffused Infrared WLAN: 1979 (IBM Rueschlikon Laboratories, Switzerland)
Spread Spectrum WLAN: 1980 (HP Laboratories, California)
ARDIS: 1983 (Motorola/IBM)
ISM bands for commercial spread spectrum applications: 1985
Mobitex: 1986 (Swedish Telecom and Ericsson)
IEEE 802.11 for WLAN standards: 1987
HIPERLAN-1: (High PERFORMANCE LAN) in Europe: 1992
Release of 2.4, 5.2, and 17.1–17.3 GHz bands in the European Community: 1993
PCS licensed and unlicensed bands for PCS: 1994
CDPD: 1993 (IBM and nine operating companies)
U-NII bands released, IEEE 802.11 completed, GPRS started: 1997
IEEE 802.11b with 11 Mbps: 1998
IEEE 802.15 for WPAN with Bluetooth as 15.a: 1998
IEEE 802.11a/HIPERLAN-2 started: 1999
IEEE 802.16 Metropolitan Area Networks: 1999
GPRS (General Packet Radio Services): Late 1990s
EDGE (Enhanced Data rates for GSM Evolution): Early 2000s
EV-DO (Evolution-Data Optimized or Evolution-Data Only): Mid-2000s
IEEE 802.15.3a for UWB Technology: 2003
IEEE 802.15.4 ZigBee: 2003
Mobile Wi-Max (Worldwide Interoperability for Microwave Access): 2005
HSPA (High Speed Packet Data): 2008
LTE (Long Term Evolution): 2009
Femtocell technology: Early 2010s
IEEE 802.11ad and IEEE 802.15.3c for Gigabit wireless: Early 2010s

(U-NII) bands were also released in the United States. The original legacy IEEE 802.11 used direct sequence spread spectrum (DSSS) and frequency hopping spread spectrum (FHSS) operating at 2.4 GHz, as well as a diffused infrared technology with 1 and 2 Mbps options. The DSSS and FHSS became the popular options and the enhanced versioned of the DSSS option using Complementary Code Keying (CCK) became the 802.11b standard, completed in 1998, that could support up to 11 Mbps with backward compatibility to the legacy DSSS option. The IEEE 802.11a standard, completed in 1999, operated in the ISM and U-NII bands at 5 GHz and used orthogonal frequency division multiplexing (OFDM) for the first time in a standard for wireless networking to support up to 54 Mbps.

The IEEE 802.15 WPAN standardization committee evolved from the IEEE 802.11 WLAN community and indeed it started in that community and then turned to an independent committee in 1998 [Hei98]. The first successful standard of this community was the IEEE 802.15.1 standard, popularly known as Bluetooth, which was released in the first year of the formation of IEEE 802.15. Bluetooth was designed for low-power ad hoc sensor networking using lower transmission power and FHSS technology. The FHSS transmission technology of Bluetooth is very similar to the FHSS technology used in legacy 802.11 but its medium access control is centralized, that better suits voice applications. As a result, Bluetooth has captured the market for wireless telephone connections over very short distances, such as the connection of cellular handsets or headphones to a base computer or a telephone base inside a car. The ZigBee technology was introduced by IEEE 802.15.4 in 2003

as a low-power WPAN technology for simple short data packet transmission applications in sensor networking. ZigBee, similar to legacy 802.11 DSSS option, uses DSSS for transmission with a contention-based medium access control that is a simplified version of IEEE 802.11 and better suits bursty and low-power connection applications. One can classify Bluetooth and ZigBee WPAN technologies as the low-power, smaller coverage area extensions of legacy IEEE 802.11 that have evolved for voice and data applications, respectively.

In addition to the low-power sensor complement of IEEE 802.11, IEEE 802.15 has also addressed higher data rate technologies at higher frequencies of operation as well. The first of these efforts was initiated by the IEEE 802.15.3a subcommittee, defining standard specifications for WPANs operating in the 3.1–10.6 GHz unlicensed ultra-wideband (UWB) bands released by the FCC in 2002. The entire band for the IEEE 802.11 community at 2.4 GHz is 84 MHz and at around that time the popular IEEE 802.11b WLANs specifications occupied a bandwidth of 26 MHz per carrier to support a maximum data rate of 11 Mbps. That had an enormous amount of overhead, leaving the highest achievable data rates at approximately 5.5 Mbps. The UWB system specifications could be envisioned to occupy a bandwidth on the orders of a few gigahertz and support data rates on the orders of gigabits per second. In practice, IEEE 802.15.3 began by completing a preliminary standard for 11 and 55 Mbps operation in the UWB spectrum in 2003. Fairly soon after this, the IEEE 802.15.3a group was formed that was aiming at using the UWB band and the technology to increase the effective data rate to several hundred Mbps to Gbps (that was at that time an order of magnitude higher than the corresponding data rates with IEEE 802.11b operating at 11 Mbps). In IEEE 802.15.3a, several options were evaluated for UWB communications, among which were the historical impulse radio technology, as well as Direct Sequence UWB (DS-UWB) and Multi Band OFDM (MB-OFDM) systems. This standard lost its momentum later and was dissolved in January 2006. However, the technical work produced by the committee was later transferred to activities in the 60 GHz band.

In 2001, the FCC released unlicensed bands at 57–66 GHz and this band opened another wave of standardization activities for gigabit wireless applications. The research and development community in this field argues that the millimeter wave frequencies have several advantages over the UWB bands. First, the UWB regulation in different countries is not the same. Second, the UWB spectrum overlaps with other technologies, causing potential interference with popular applications such as 802.11a WLANs and other consumer products such as cordless telephones operating at 5.2 GHz. The IEEE 802.15c group was formed to specify another PHY alternative to the original 802.15.3 WPAN standard released in 2003, which uses millimeter waves at 60 GHz. This group was formed in March 2005 and defined new MAC and PHY layer standards for the 60 GHz channel in September 2009 [IEEE09]. This technology is expected to accommodate coexistence with other WPANs and support high definition video streaming and other streaming applications that need data rates larger than 2 Gbps. Yet another alternative approach for Gbps wireless is being pursued by the IEEE 802.11ad group, which is building on the legacy of IEEE 802.11 and its commercial success in using MIMO/OFDM technology to achieve similar data rates. The IEEE 802.11ad group was expecting to complete its standard by December 2011 [Per10].

The lower parts of Figure 1.13 illustrate the evolution of local and personal area networking standards and technologies from the original concept of the WLAN for wireless Internet access. The evolution of wireless local Internet access in the past three decades is an excellent example of evolution for a successful and complex technology. This evolution experienced a huge swing from the early days of desperations for WLAN market in the early 1990s to the unexpected worldwide prosperity and growing popularity of Wi-Fi technology as the dominant technology for the wireless Internet access in the emerging smart phones, tablets and other devices at the time of this writing. Throughout this evolution, spread spectrum, OFDM, and MIMO technologies found

their first popular applications in the wireless networking industry. Spread spectrum has emerged as the technology of choice for low-power applications and MIMO/OFDM for supporting the highest possible data rates. Another useful application of WLANs is the use of this technology for opportunistic wireless localization in indoor areas [Pah10]. WiFi localization is expected to emerge as one of the most popular wireless localization approaches for tens of thousands of location-dependent applications in smart phones and wireless tablets.

1.4.2 Wide Area Wireless Data Networks

In the wide area, mobile packet switched wireless data services were first introduced with the Advanced Radio Data Information Service (ARDIS) project between Motorola and IBM in 1983 that covered a number of metropolitan areas in the United States at a data rate of 4800 bps [Pah94]. The purpose of this network was to allow the IBM field crew to operate their portable computers wherever they wanted to deliver their services. In 1986, Ericsson introduced the Mobitex technology that was an open architecture implementation of ARDIS at a data rate of 8000 bps. In 1993, IBM and the nine Bell operating companies in the United States started the Cellular Digital Packet Data (CDPD) project operating at 19,200 bps, expecting a huge market by the year 2000. ARDIS and Mobitex were independent networks that owned their infrastructure and frequency bands and were using their own transmission technique and contention based medium access control. The CDPD infrastructure, however, was overlaid over the existing AMPS antennas and frequency bands with a separate physical layer and contention-based medium access control. This arrangement would allow a comprehensive coverage to the CDPD and would save in the cost of infrastructure that is heavily influenced by the cost of the land, tower and the frequency band. In the early 1990s CDPD was perceived to be the future of the mobile data industry, which at that time supported low-speed applications such as remote access to computers, file transfer, and email.

In the mid-1990s, the Internet started to penetrate the home market and the speed of operation and memory size of personal computers connected to the Internet opened a new horizon for evolution of a number of bandwidth-hungry applications that needed much higher data rates than those supported by the emerging wireless mobile data services such as CDPD at that time. This movement directed the cellular telephone community to consider integration of high-speed packet switched data networks into the 3G cellular networks and the IMT-2000 specifications for the 3G cellular networks set a data rate of 2 Mbps on a wireless packet switched network as its goal.

While 3G standards were under progress, 2G standardization activities responded to the market demand for higher-speed packet switched data with extensions to existing 2G digital cellular networks. The popular 2G networks included circuit switched packet data applications for low speeds of less than a couple of tens of kilobits per second and were interfacing to the PSTN. These new services would modify the infrastructure with new hardware elements that would direct the packet switched data to the Internet and would focus on increasing the data rate transmission over the air interface. In the late 1990s, General Packet Radio Services (GPRS) that was integrated in the successful GSM cellular systems was introduced with a theoretical data rate of up to around hundred Kbps. This is an order of magnitude higher data rate than previous technologies used for mobile data services. The GPRS system used the same physical air interface as the GSM but assigned more TDMA slots to a single user. In the early 2000s, Enhanced Data rates for GSM Evolution (EDGE) was released as a standard that used more bandwidth efficient transmission techniques to increase the data rate by several times to reach several hundred Kbps. EDGE still used the GSM infrastructure and TDMA framing. The real limitation of the data rate for GPRS and EDGE was due to the bandwidth of the carrier, that is 200 KHz for GSM.

The bandwidth per carrier of the 2G cdmaOne (IS-95) and the 3G CDMA2000 (IS-2000) is 1.25 MHz, allowing theoretical data rates of around several Mbps that was the goal of 3G cellular networks. In the mid-2000s, the Evolution-Data Optimized or Evolution-Data Only (EV-DO) standard was introduced that could achieve these data rates over the original QUALCOMM 2G CDMA technology by dedicating a 1.25 MHz carrier to packet data services. To achieve higher data rates, in a manner similar to GPRS and EDGE, multiple voice user channels (now separated in code) are devoted to a data user to transmit its burst of data at high speed. The data occupies the same bandwidth as voice but, similar to EDGE, can use a more bandwidth-efficient transmission to achieve even higher data rates. The same idea, when applied to Universal Mobile Telecommunications System (UMTS) using wideband CDMA technology with a bandwidth of 5 MHz, can allow another growth in the data rate for data burst transmissions. In the late 2000s, the High Speed Packet Data (HSPA) was introduced that could achieve several tens of Mbps. When these technologies are combined with MIMO technology, literally allowing multiple streams of the signal over the same bandwidth, another increase in data rate allows the achievement of several hundred Mbps for wireless mobile data access that is the highest one can expect from CDMA-based technologies.

Another path of evolution for cellular data networks came as an offspring of the IEEE 802.11 WLAN technology. In the early 1990s, while the European Union industry, lead by Nokia and Ericsson, was dominating the cellular telephone industry by capitalizing on the success of the GSM standard and its worldwide adoption, a smaller group initiated the idea of the High PERFORMANCE LAN (HIPERLAN) [Wil95a,b] to achieve higher data rates than the other LANs at that time. HIPERLAN-1 was the first standard to employ 5 GHz unlicensed bands with non-spread spectrum technologies for the next generation of WLANs. Spread spectrum technology that was mandated by FCC for the original unlicensed ISM bands sacrifices bandwidth to achieve resistance to interference and with lower power consumption. The focal point of the LAN industry, however, has always been the achievement of higher transmission rates. HIPERLAN-1 was considering an adaptive equalization of the channel that could achieve data rates an order of magnitude higher than those achievable with spread spectrum technologies adopted by the legacy IEEE 802.11 at that time [Sex89]. This standard did not gain popularity in commercialization and it was continued by HIPERLAN-2 that merged its physical layer activities with IEEE 802.11a. As mentioned earlier, they adopted OFDM technology that can achieve the highest data rates in multipath-rich indoor environments. An early comparison of all these transmission technologies for WLAN applications is available at [Fal96]. The differentiation between HIPERLAN-2 and IEEE 802.11a was medium access control. HIPERLAN-2 was devoted to centralized medium access, rather than the contention-based medium access used in IEEE 802.11, which is better in supporting quality of service in heavy traffic and was favored by cellular manufacturers making all their income at that time from cellular telephone applications.

HIPERLAN-2 did not meet commercial success either. However, close to the end of the 1990s, the idea of centralized medium access for better quality of service and using transmission techniques similar to WLANs extended to the IEEE 802.16 for metropolitan area networking for multipoint fixed access as a backbone for wireless networking. These activities later evolved into the mobile Wi-Max standard using OFDM with MIMO technology with a centrally assigned medium access control that gained significant attention in the late 2000s and received reasonable worldwide deployments. The next step in this evolutionary path was the Long Term Evolution (LTE) that at the time of writing is being followed by LTE-Advanced. The objective of these wireless technologies is to achieve gigabit per second data rates for wide area coverage.

The stimulus behind these technologies in the past few years has been the enormous success of the iPhone, followed by other smart phones and tablet computers demanding tremendous amount of bandwidth for data applications. The popularity of these devices is shifting the habits of people from

using the telephone as the main medium for communications to email, short messaging, and social networking. New multimedia applications such as YouTube access are gaining rapid increases in usage. These data applications with high data rate demands have forced the service providers to re-design their networks for the emerging world of data communications and have been the force behind the emergence of WiMAX and LTE standards. Adapting these technologies for the emerging smart device is the key for the future success of these networks. However, smart devices prefer using WiFi because it is mostly free of charge, provides higher data rates per user, and consumes less battery. To take advantage of these features for cellular applications, this industry is considering Femtocell technology that uses traditional cellular technologies for integrated voice and data in an all-IP environment, such as WiMAX and LTE, to design base stations with a smaller coverage similar to WLANs. The future of the local wireless access industry could be a struggle between Femtocell technology and the existing WLAN technologies for local wireless access. Femtocells may be deployed by the service provider or by a user and they have their own feature of better quality of service for voice applications. WLANs are mostly deployed by individuals randomly but at a low-cost. If it happens, it would be one of those rare cases that a successful trend for the growth of a data communication network technology is reversed in favor of a voice-oriented technology. For wide area coverage, 3G and 4G technologies are competing to win their adoption by smart phone, tablet, and laptop manufacturers.

Figure 1.14 sketches a comparison among different wide, local, and personal area wireless networks. The vertical axis shows the degree of mobility and the horizontal axis the data rate per user. Since the coverage of a cell tower may span several tens of kilometers, while a WLAN access point covers less than 100 m and WPANs cover around 10 m, the number of users sharing a carrier is much higher for the larger areas that restrict the data rate delivered to each user. Another hidden factor in this comparison is the issue of battery life for the mobile terminal. Larger areas demand higher power consumption and consequently lower battery life for the mobile terminal.

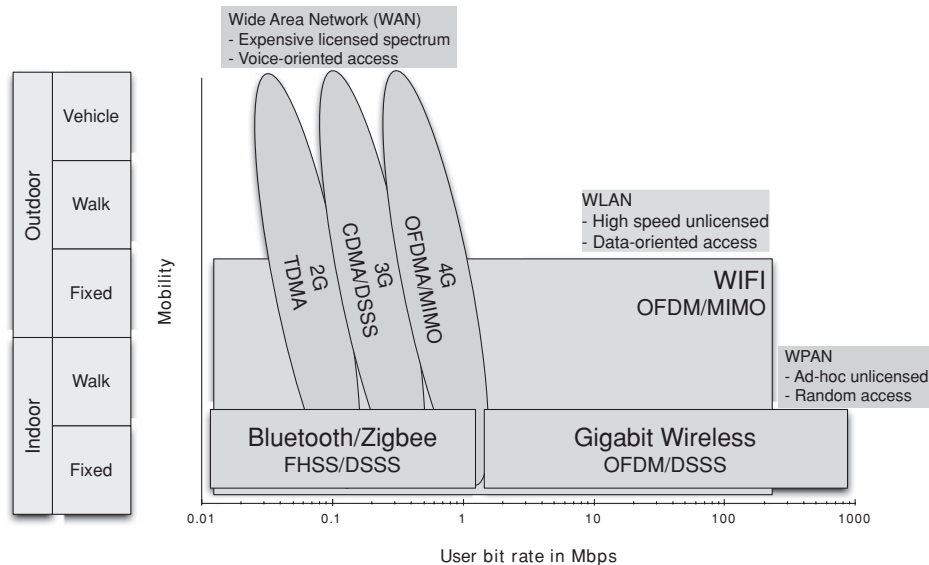


Figure 1.14 Overview of wireless technologies from a user perspective.

These issues are critical in the adoption of technologies for the future of this industry. For example, a smart phone manufacturer may consider 3G with lower data rates but lesser power consumption over 4G with higher data rates, but more power consumption.

1.5 Evolution of Wireless Localization Technologies

The RF localization industry started by addressing the problem of locating mobile radios used for military operations during World War II to locate soldiers in emergency situations. About 20 years later, during the Vietnam War, the United States Department of Defense launched a series of Global Positioning System (GPS) satellites to support localization during military operations in combat areas. In 1990, the signals from GPS satellites were made accessible to the private sector for commercial applications such as fleet management, navigation, and emergency assistance. Today, GPS technology is widely available in the civilian market for personal navigation applications. GPS receivers are designed to determine the locations of boats, planes, or mobile vehicles in open areas such as waterways, skyways, and highways. However, the accuracy of GPS positioning is significantly impaired in urban and indoor areas, where received signals can suffer from extensive multipath effects and additional path loss. In the past decade or so, to remedy this situation wireless localization technologies using signals other than GPS have emerged. We may refer to these localization technologies using signals of opportunity. A full description of the GPS system is beyond the scope of this book, but the interested reader can find much information in the open literature [Kap96]. In this book we address wireless localization techniques using time-of-arrival (TOA) and received signal strength (RSS) of the signals of opportunity.

1.5.1 TOA-based Wireless Localization

The GPS receivers measure the TOA of the received signal to measure the distance to satellite landmarks and from that locating itself on the Earth within a few meters. However, it does not work properly in urban and indoor areas where a number of computer-related applications can benefit from the location information. In the mid-1990s the Defense Advanced Research Projects Agency (DARPA) launched its small unit operation situation awareness system (SUO/SAS) program aiming at one-meter accuracy for indoor geolocation in military and public safety operations. About the same time, venture capitalists started funding startup companies such as PinPoint (in Woburn, Massachusetts) and WhereNet (based in Santa Clara, California), both seeking to develop and implement indoor geolocation technologies with accuracies comparable to those required for SUO/SAS.

The success of TOA-based techniques used in GPS positioning led military and commercial researchers to think in that direction. The idea sounded very straightforward. Using the operating frequency, bandwidth, and signal strength found in GPS systems, accuracies around several meters can be achieved within the course of a few minutes. If we want to extend this technology to practical indoor geolocation, we must overcome four challenges:

1. We need a positioning accuracy of better than a few meters to identify objects in different rooms of a building.
2. We need to cope with around 20–30 decibels of additional path loss to penetrate into the building.
3. We need algorithms to cope with multipath conditions.
4. We need to reduce the time to first fix to just a few seconds.

The pioneering military and commercial TOA-based systems designed in the late 1990s did not meet these challenges. DARPA had to compromise on its accuracy requirements and the commercial startups simply failed.

Radio propagation studies conducted for the SUO/SAS project revealed that the primary source of the problem for indoor geolocation was severe multipath conditions in obstructed line of sight (OLOS) environments that frequently caused large ranging errors [Pah98]. To remedy the situation, the developers of military and public safety applications resorted to such methods as UWB (ultra-wideband), super-resolution, multipath diversity, and cooperative localization [Pah06]. More recently, inertial navigation systems and other sensors have been added to some systems in an effort to overcome the deficiencies of RF indoor geolocation; and hybrid localization using a variety of sensors complementing TOA-based RF localization is under development [Moa11]. The specifics of technologies for military and public safety applications are that these technologies are designed for first responder situations where minimal information about the environment is available because such environments are either unknown, such as a military target, or under rapid change, such as a disaster sight. In commercial applications, maps of the buildings are known and the site can be surveyed for the RF signature of the existing infrastructure in the building. The results of these RF surveys of the areas can be used later to localize the devices using less complex RSS-based localization.

1.5.2 RSS-based Localization

For commercial applications, other major problems include the cost of new proprietary hardware and the deployment of infrastructure. These cost factors led the industry to develop indoor geolocation techniques leveraging existing Wi-Fi and cellular networking infrastructures, which were growing rapidly in a variety of indoor environments. The accuracy of RSS-based localization is on the order of the coverage of the access points or base stations. Since the coverage of Wi-Fi is on the order of a few tens of meters while base stations cover several kilometers, Wi-Fi localization techniques using RSS have become a very important opportunistic localization technique to complement the GPS shortcoming in indoor areas. At the time of writing, RSS-based Wi-Fi localization is the most popular localization engine in smart devices such as iPhone, iPad, Kindle, and other similar devices. The database of leading Wi-Fi localization companies for smart devices, Skyhook (Boston, Massachusetts), receives several hundreds of millions of location request from smart devices per day.

The concept of using Wi-Fi infrastructure for TOA- and RSS-based localization in indoor areas was first introduced in 2000 [Li00; Bah00]. RSS-based localization needs a sight survey to create a data base as a reference for the RSS pattern of Wi-Fi devices at different locations in a building [Roo02a,b]. In the early days of this industry the data base was collected in indoor areas using a sight map. The locations where each data point was collected was marked on the map. This approach had three drawbacks: (1) the maps of indoor areas were not publicly available, (2) the data collection was very time-consuming, and (3) the coverage of the system was limited to a few uncoordinated buildings. The market for these application was certain buildings such as hospitals, museums, and warehouses in which localizing needs for equipment, merchandise, or people were in high demand.

In the mid-2000s Wi-Fi localization in urban areas emerged in the market. In these systems the data collection consisted of driving the streets of an urban area, with the receiver tagging the location where the RSS of access points were measured by the GPS reading in those locations [Pah10]. These systems are referred to as wireless positioning systems (WPS) and they cover the metropolitan areas. The WPS systems are those that were first adopted in the iPhone, the leading popular smart device, which revolutionized communication applications and networks to support

those applications. The advantage of these systems is their comprehensive coverage using Google satellite maps. More recently Google started a collection of indoor maps for popular public places such as airports and shopping malls; and this has stimulated a number of new startup companies working on indoor geolocation applications in those areas.

1.6 Structure of this Book

Wireless access and localization is a very complex multidisciplinary systems engineering discipline. To describe these networks we need to divide their details into several categories to create a logical organization for the presentation of important material. From the material presented in the previous section on the evolution of wireless networks, we observe that the essential material needed for students to understand these systems in a comparative manner are the details of applied transmission techniques and the medium access control methods. Comparison of these techniques needs an understanding of radio propagation in urban and indoor areas that suffers extensively from the existence of multipath conditions. To make the book suitable for teaching in an engineering or science curriculum we need to present useful quantitative and analytical examples that are relevant for a comparative evaluation of these systems. In textbooks and associated courses in specific fields such as digital communications or signal processing, it is common to present the details of the derivation of techniques for transmission or design of filters and transforms that are useful for processing the signal. Multidisciplinary fields such as wireless networking, robotics engineering, or bio-engineering however *use* the results of several other disciplines and merge them for the creation of a new field. The analytical examples used for students in such fields are more diversified and they have to be selected carefully to avoid excessive complexity and yet remain useful and non-trivial to carry educational values. Therefore, a clear organization of the presented material and depth of discussion on the variety of issues is needed because the multidisciplinary nature of the material plays a significant role in the properness of the book.

This book is intended to describe technologies presented in the previous section and summarized in Fig. 1.13 during the evolution of wireless access techniques and to provide an understanding of the principles of emerging wireless localization techniques. It is intended to provide an overview of the standards and technologies, the basic fundamental science behind these technologies, and examples of popular standards using these fundamental technologies to explain the “why” and “where” of their applications. The book is organized into an introduction chapter and five parts. The introductory material presented in Chapter one defines the meanings and sketches the evolutionary path of wireless networks. This chapter also provides an overview of the important wireless systems and outlines the details of the rest of the book. The material presented in Chapter one identifies different sectors of the wireless market, familiarizes the reader with the forces behind the growth of these sectors, and provides an overview of the standards developed to address them. The material presented in Chapter one motivates the reader to study the details provided in the remainder of the book.

The five parts of this book each consists of several chapters directed toward a description of certain aspects of wireless networks. The first and second parts of the book are devoted to the principles of air–interface design and the principles of wireless network operations. These parts provide the technical background needed for an understanding of wireless networks. The technical aspects are either related to the design of the air–interface or issues related to the deployment and operation of the infrastructure. The first part consists of three chapters describing technical aspects of the air–interface. The second part comprises three chapters devoted to the technical aspects of the wireless network infrastructure. The third and fourth parts of the book are devoted to a description of the details of typical wireless networks in a comparative manner. The third part comprises three chapters on local broadband and ad hoc wireless networks, describing popular WLANs

and WPAN technologies. The fourth part consists of three chapters describing technologies used for the implementation of wireless wide-area networks. The fifth part of the book is devoted to RF localization and includes three chapters that describe system aspects, analytical bounds, and practical implementation, respectively.

1.6.1 Part I: Principles of Air-Interference Design

Wired terminals are powered and connect to transmission lines; and wired access to information networks is reliable, fixed, and relatively simple. Wireless mobile terminals are battery operated and wireless access is through the air that is unreliable and band-limited. The design of the physical layer connection and access method and an understanding of the behavior of the medium for wireless operation is far more complicated than for wired operation scenarios. Design of the air-interface for wireless connections needs a far deeper understanding of the behavior of the channel and more complex physical and medium access control mechanisms. The behavior of the wireless medium is more complex than that of the wired medium because in a wireless channel the received signal strength suffers from extensive power fluctuations caused by temporal and spatial channel dynamics. Transmission techniques used for wireless access are more complex because they have to be power- and bandwidth-efficient and they need to employ techniques to mitigate the received power fluctuations caused by the medium. Part I of this book is devoted to the analysis of the behavior of the channel in Chapter 2, an overview of the applied wireless transmission techniques in Chapter 3, and a description of the medium access control techniques used for wireless access to the PSTN and the Internet in Chapter 4.

Chapter 2 describes path-loss modeling, fluctuation of the channel, and the multipath arrivals of the signal. Path-loss models describe the relation between the average received power in a mobile station and its distance from a base station. These models are used in the deployment of networks to determine the coverage of a base station. In communication over the wireless medium the received power is not constant and it changes in time as the mobile moves or the environment changes. Models for variations of the channel are used to design the adaptive elements of the receiver, such as synchronization circuits or equalizers, to cope with variations of the channel. Models for multipath characteristics allow the design of a receiver that can handle the interference from signals arriving along different paths at the receiver.

The second chapter related to the air-interface is Chapter 3, which describes the digital transmission techniques used for the implementation of a variety of wireless networks. The diversity and complexity of transmission techniques in a wireless system is greater than that observed in wired networks. This chapter provides an overview of the principles of transmission techniques that are used for wireless access to the PSTN and the Internet. We first provide a brief description of the effects of multipath on the performance of wireless networks. Then we describe traditional transmission technologies, multipath resistant transmission techniques, the coding techniques used in wireless networks, and a brief description of cognitive radio and dynamic spectrum management.

The third chapter related to the air-interface is Chapter 4, devoted to the applied multiple access alternatives for packet transmission over the wireless medium. This chapter starts with a description and comparison of the assigned access schemes, such as TDMA, and CDMA, evolved for wireless access to the PSTN. The second part of this section is devoted to CSMA and ALOHA based random access techniques, such as ALOHA and Carrier Sense Multiple Access (CSMA), used for wireless access to the Internet. The last part of this section analyzes the applied access methods for the integration of voice and data that has evolved for wireless access to the PSTN and the Internet.

1.6.2 Part II: Principle of Network Infrastructure Design

In Part II of the book we address technical aspects of the design of the fixed infrastructure of wireless networks. This part consists of Chapters 5, 6 and 7, respectively addressing the deployment, operation, and security of wireless networks. Wireless networks share the medium and when they operate at the same or an overlapping frequency band, they interfere with each other. As a result, an understanding of the nature of the interference is essential for the deployment of a wireless network infrastructure. The frequency bands used by different wireless networks are either unlicensed, commonly used by WLANs and WPANs, or they are licensed to a service provider in a region, which is popular in cellular telephone networks. Unlicensed bands are open to the public, and as a result deployment of the network and interference between devices are not practically controllable. In licensed bands the service provider owns the bands as well as the network infrastructure; therefore, it can control the interference and use it to its advantage to provide an efficient and comprehensive coverage. In Chapter 5, we discuss interference between WLAN and WPAN products operating in uncontrolled unlicensed bands as well as frequency management in licensed bands to control the interference. Service providers using licensed bands often start with a minimal infrastructure and few antenna sites, to keep the initial investment low. As the number of subscribers grows, the service providers expand their wireless infrastructure to increase capacity and improve quality. The technology related to the deployment and expansion of the cellular infrastructure is also discussed in Chapter 5. This chapter is the first chapter related to the technical aspects of network infrastructure. It discusses interference in general, different topologies for wireless networks, frequency management in cellular infrastructure deployment, and issues related to expansion and migration to new technologies.

Chapters 6 and 7 are devoted to the functionalities of the fixed network infrastructure to support a mobile operation. These functionalities include mobility, radio resource, power and security managements. These issues are addressed in two separate parts of Chapter 6 and in Chapter 7. The mobility management part of Chapter 6 describes how a mobile terminal registers with the network at different locations and how the network tracks the location of the mobile as it changes its access to the network from one antenna site to another. The radio resource and power management part of Chapter 6 is devoted to the technologies used for controlling the quality and transmitted power of the terminals. Voice-oriented networks control the transmitted power of the mobile station to minimize interference with other terminals using the same frequency and to maximize battery life. Data-oriented networks use the sleep mode to avoid unnecessary consumption of power. Explanations of the methodologies and examples of how to implement power control and sleeping modes are provided in this part of Chapter 6. Chapter 7 is devoted to security in wireless networks. Wireless connections are inherently vulnerable to fraudulent connections and eavesdropping and need security features to avoid them. The security of wireless networks is provided by authentication and ciphering. When a wireless terminal connects to a network, an authentication process between the network and the terminal checks the authenticity of the terminal. When the connection is established, the transmitted bits are scrambled with a ciphering mechanism to prevent eavesdropping. Algorithms used for these purposes are discussed in the last part of Chapter 7.

1.6.3 Part III: Wireless Local Access

After completion of the overview of the standards in Chapter one and a study of the overview of technical aspects in Parts I and II, we provide detailed descriptions of practical wireless access techniques in Parts III and IV. These detailed descriptions are divided into two parts, addressing wireless local access (Part III) and wide area wireless access (Part VI).

Part III of the book describes WLAN and WPAN technologies used for wireless local access in unlicensed bands, and it consists of three chapters. The first chapter of these three is Chapter 8, which provides an overview of the WLAN industry and the IEEE 802.11 standardization committee. This chapter provides the details of IEEE 802.11 to demonstrate all aspects of the packet switching wireless standards operating in unlicensed bands. The medium access technology for IEEE 802.11 is CSMA/CA (CSMA with Collision Avoidance) that sets this standard as a connectionless packet switched standard. This feature eases Internet access, either by direct connection or by connection through an existing wired LAN. The contents of this chapter describe the objective of the standard, explain the specifications of packet framing, physical and medium access control layer alternatives supported by this standard, and provides the details of mobility support mechanisms, such as registration, handoff, power management, and security.

Chapter 9 is devoted to low-power WPAN technologies operating at data rates that are lower than those of WLANs, with particular emphasis on the details of Bluetooth and ZigBee technologies. This chapter starts by describing the IEEE 802.15 standards committee and low-power versus gigabit wireless technologies for WPANs. Then details of Bluetooth and ZigBee technology are described in reasonable depth. These types of WPANs are ad hoc networks designed for operating over short distances to connect personal equipment or sensors to one another. These personal devices or sensors ultimately provide wireless communications for voice- or data-oriented applications. The physical layer and medium access control methods for these systems are designed to suit one of these applications. Bluetooth access is centralized, which is more suited for the quality control needed for real-time streaming for voice applications and consequently it has gained more popularity in applications such as wireless headphones or wireless microphones. The ZigBee access method is a light version of the contention-based CSMA/CA, originally used in IEEE 802.11, which is better suited for data burst applications leading this technology towards sensor networking applications for low-power low-rate packet transmissions. After a description of Bluetooth and ZigBee as established WPAN standards, we conclude Chapter 9 with a short description of another low-power emerging standard, IEEE 802.15.6 for Body Area Networking (BAN), which is an active area of research at the time of writing.

Chapter 10 is devoted to technologies to support data rates beyond the existing WLANs and refers to these technologies as gigabit wireless networks for local and personal area networking. At the time of writing, a super high-speed WPAN industry is not as established as low-power WPANs and it is experiencing its evolutionary path waiting for a sizable market to emerge in the near future. However, those engaged in research and development in this industry believe that it will serve a number of applications, including high-definition video streaming, wireless gigabit Ethernet, wireless docking stations, desktop point to multipoint connections, wireless back haul, and wireless ad hoc networks [Guo07; Per10; Dan10; Kum11]. We start the Chapter 10 with the UWB technology for 3.4–10.6 GHz bands and we continue this discussion into gigabit wireless technologies evolving for 57–64 GHz bands for short-distance gigabit wireless. The objective of this chapter is to provide an overview of the evolution of this industry and to provide some detailed examples of the fundamentals for the design and operation of these networks.

1.6.4 Part IV: Wide Area Wireless Access

The fourth part of the book is devoted to a description of the important wide area networking technologies used for wireless access to the PSTN and the Internet. As explained in Section 1.2, cellular networks were originally designed for cellular telephone applications and connection to the circuit switched PSTN. Therefore, the center of attention for the design of 1G, 2G, and 3G cellular networks was connection to the PSTN for cellular telephone applications. The cellular telephone needs a low data rate of around 10 kbps for each of numerous simultaneous users engaged is

two-way conversations. The quality of service for mobile users as they change their connection from one to different antennas in the network is very important for users. These requirements demand simple transmission techniques and more robust and centrally controlled medium access techniques. The cellular network technologies evolved for cellular telephone application using FDMA, TDMA, and CDMA techniques for 1G, 2G, and 3G cellular networks, respectively, to address this demand. In the late 2000s, and with the beginning of the popularity of smart phones, the cellular network providers started paying attention to all-IP 4G networks for Internet connection, and consequently OFDM and MIMO technologies evolved for wireless Internet access. In this part of the book we have three chapters to explain the principles of operation of TDMA and CDMA cellular networks primarily designed for wireless access to the PSTN and the differences between the 4G cellular networks and the WLANs that are designed for wireless Internet access.

In Chapter 11 we describe the overall infrastructure of a wide-area wireless access network to connect to the PSTN and details of the TDMA air-interface used in the popular 2G TDMA digital cellular network, the GSM. In Chapter 12 we describe the details of wireless access to the PSTN using CDMA technology used in original 2G cdmaOne and its extension to 3G cellular networks. The obvious reason for these selections is the worldwide popularity of GSM and the emergence of CDMA technology as the choice for 3G cellular systems. The last chapter in this part of the book is Chapter 13, devoted to the implementation of OFDM and MIMO technologies for 4G cellular networks.

Details of the architecture, the mechanisms to support mobility, and the layered protocols in a cellular telephone network are described in Chapter 11. This description is completed by including the specification of the air-interface of GSM as an example of a TDMA air-interface. Other TDMA digital cellular standards such as DECT, currently popular in cordless telephone applications, are very similar in nature to the GSM. In Chapter 11 we first describe all the elements of a cellular network architecture. Then, we address mobility support mechanisms with details of registration, call establishment, handoff, and security. The last part of this chapter provides details of how packets are formed and transmitted over the TDMA air-interface. The study of this chapter introduces the reader to the complexity and diversity of the issues involved in the development of a wireless cellular network.

Chapter 12 is devoted to CDMA and WCDMA technology that is adapted for 3G cellular systems. Since the wired backbone of the TDMA and CDMA systems are very similar, most attention is paid to the air-interface that is completely different from TDMA systems such as GSM. In this chapter, we describe the reasons for employing CDMA, the way users are separated within and across cells using spread spectrum codes, and how spread spectrum helps in exploiting multipath diversity. Details of how spread spectrum influences the design of the air-interface in 2G and 3G systems, as well as special challenges with CDMA such as soft handoffs and power control are also explained in this chapter. The evolution to HSPA through changes in the network architecture and air-interface concludes this chapter.

The last topic in this part is a description of 4G cellular networks that is provided in Chapter 13. This chapter is devoted to details of Wi-Max and LTE technologies for cellular networks. In this chapter, we explain the reasons for using OFDM as the primary transmission scheme with MIMO technology for higher data rates. We also describe the flattening of the network architecture with WiMax and LTE compared to the traditional hierarchical architecture used in GSM and CDMA networks. We finally discuss the evolution of this technology to LTE-Advanced.

1.6.5 Part V: Wireless Localization

The fifth and last part of the book is devoted to wireless localization techniques. A fundamental element of localization is a map and a means to find the distances from landmarks that can be

identified on the maps. If we use an RF signal to find the distance from a landmark, we may call the system an RF localization system. The first popular RF localization system was GPS, designed originally for military applications and later available for commercial applications. GPS does not work properly indoors and in highly dense urban areas, it has a relatively long warm-up time, and it is a piece of hardware that has its own toll on the battery life of mobile devices. To extend the coverage of GPS to indoor and urban areas for both military and commercial applications wireless localization techniques using signals other than the GPS signals started in more recent years. The technical connection between wireless localization techniques and wireless networks is an understanding of channel behavior and its impact on waveform transmission on different media for wireless transmission and the fact that wireless localization techniques often use wireless infrastructures and signals for the purpose of localization. In Part V we have three chapters addressing different aspects of wireless localization. Chapter 14 provides an introduction to wireless localization systems, Chapter 15 covers the fundamentals of wireless localization, and Chapter 16 addresses the practical aspects of wireless localization.

Chapter 14 is devoted to an introduction to indoor geolocation and cellular positioning as emerging technologies to complement local and wide-area wireless services. This chapter provides a generic architecture for wireless geolocation services, describes alternative technologies for the implementation of these systems, and gives examples of evolving location-based services that are becoming necessary for a variety of applications.

Chapter 15 starts with modeling of the RF sensors used for localization technologies. This behavior modeling is important to understand the complexity of the technologies that evolved for wireless localization in indoor and urban areas. The next part of this chapter is devoted to the calculation of the Cramer–Rao Lower Bound (CRLB) for performance evaluation of wireless localization techniques. These bounds enable us to compare the performance of different wireless sensors in a quantitative manner. The last section of Chapter 14 is devoted to a survey of fundamental algorithms used for localization using different RF sensing techniques.

Chapter 16 is devoted to practical aspects of wireless localization techniques. We begin this chapter by addressing issues related to RSS-based Wi-Fi localization, which is the most popular wireless localization technique currently used in smart devices for numerous popular location-based applications. Then we address more precise indoor positioning using TOA-based localization by introducing challenges in measurement of the TOA with particular emphasis on the large errors that are caused when the direct path between the transmitter and the receiver is blocked. This discussion is followed by introducing localization using multipath diversity and cooperative localization for situations when the direct path between the transmitter and the receiver is blocked. The last section of this chapter is devoted to localization inside the human body as the latest localization technique that is emerging at the time of writing. The human body is a non-homogeneous liquid-like medium for RF propagation with extensive path loss and a blurred map because the objects inside it are constantly moving. As localization transforms from outdoors to indoors and then to inside the human body, we explain the challenges facing the research community to discover this medium for RF localization needed for emerging wireless health applications.

Questions

1. Why is a wired network usually part of the wireless infrastructure?
2. How is a wireless network different from a wired network? Explain at least five differences.
3. What is the difference between a licensed and an unlicensed band? Give one example wireless technology standard that operates in licensed and one that operates in unlicensed bands.

4. What are the differences among WLAN and 4G (WiMax and LTE) data services in terms of regulation for frequency of operation, data rate, coverage, and cost charging mechanism?
5. What is Wi-Fi localization and how does Wi-Fi localization complement GPS technology?
6. Name the original four categories of markets that have evolved for the wireless networks.
7. Explain why standardization is important for wide, local, and personal area wireless networks.
8. What are the main differences between the characteristics of technologies needed for wireless access to the PSTN and the Internet?
9. How does a standard evolve for wireless networks and what type of organizations are involved in the process?
10. What are the differences among connection-based and connectionless networks? Give an example for each of the two networks.
11. What is WPAN? What is the difference between WPANs and WLANs? Name the two major standardization organizations writing the draft standards for these networks.
12. When the ISM bands were released, what was new about them, and what are the available ISM bandwidths at 0.9, 2.4, and 5.7 GHz?
13. What is ZigBee technology and how does it differ from Bluetooth technology? Which standardization organization is working on these technologies?
14. What does BAN stands for? Name two popular applications using BAN technology and one standards organization that is devoted to this technology?

Project 1.1

Search Chapter 1 and the Internet (IEEE Explore, Wikipedia, Google Scholar, ACM Digital Library) to identify one area of research and one area of business development which you think are the most important for the future of the wireless information networking industry. Give your reasoning why you think the area is important and cite at least one paper or a website to support your statement.

Project 1.2

Go over the technical program presentations and synapses of the WPI workshop on Body Area Networking Technology and Applications on 20 June, 2011: <http://www.cwins.wpi.edu/workshop11/program.html>. Do a Google scholar search for each category of fundamental challenges itemized in the synapses and find one paper in that area that you think is interesting. List the authors, title, publisher, and date of your selected papers for each category. Also, print and attach one paper that you enjoyed most and read through. Explain why you liked that attached paper.

Project 1.3

Read the following articles:

<http://www.intomobile.com/2011/12/23/were-top-mobile-trends-2011-infographic/>

<http://www.businessweek.com/magazine/map-apps-the-race-to-fill-in-the-blanks-01122012.html>

<http://www.insidegnss.com/auto/may10-Pahlavan.pdf>

and write a one-page essay on the current and future directions in Wi-Fi localization. You need to address the business aspects, technology challenges, and future directions of this area.

