CHAPTER 1

OVERVIEW OF WIRELESS NETWORKS

1.1 Introduction

- 1.1.1 Information Network Infrastructure
- 1.1.2 Overview of Existing Network Infrastructure
- 1.1.3 Four Market Sectors for Wireless Applications
- 1.1.4 Evolution of Voice-Oriented Wireless Networks
- 1.1.5 Evolution of Data-Oriented Wireless Networks

1.2 Different Generations of Wireless Networks

- 1.2.1 1G Wireless Systems
- 1.2.2 2G Wireless Systems
- 1.2.3 3G and Beyond

1.3 Structure of the Book

- 1.3.1 Part One: Principles of Air-Interface Design
- 1.3.2 Part Two: Principle of Wireless Network Operation
- 1.3.3 Part Three: Wireless Wide Area Networks
- 1.3.4 Part Four: Local Broadband and Ad Hoc Networks

Appendix 1A Backbone Networks for Wireless Access

- 1A.1 Evolution of PSTN and Cellular Telephony
- 1A.2 Emergence of Internet
- 1A.3 The Cable TV Infrastructure

Appendix 1B Summary of Important Standards Organizations

Questions

1.1 INTRODUCTION

Technological innovations of engineers during the 20th century have brought a deep change in our lifestyle. Today, when we fly over a modern city at night we see the earth full of footprints made by engineers. The glowing lights remind us of the impact made by electrical engineers; the planes we fly in and the moving cars below remind us of the contributions of mechanical engineers; and high-rise buildings and complex roads remind us of what civil engineers have accomplished. From the eyes of an engineer, the glow of light, the movement of cars, and the complexity of civil infrastructure relates to the challenges in implementation, size of the market, and the impact of the technology on human life. There is, however, one industry whose infrastructure is not seen from the plane 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 lifestyle by entering the information technology age. This industry is the *telecommunications networking industry*.

To have an intuitive understanding of the size of the telecommunications industry, it is good to know that the size of the budget of AT&T in the early 1980s, before its divestiture, was nearly the budget of the fifth largest economy of the world. AT&T was the largest telecommunications company in the world, and its core revenue at that time was generated from plain old telephone service (POTS) that was first introduced in 1867.

During the past two decades, the cellular telephone industry augmented the income of the prosperous voice-oriented POTS with the subscriber fees of about 1 billion cellular telephone users worldwide [EMC01]. Today the income of the wireless industry has already surpassed the income of the wired telephone industry, and this income is by far dominated by the revenue of cellular phones. In the mid 1990s, the data-oriented Internet brought the computer communications industry from the of-

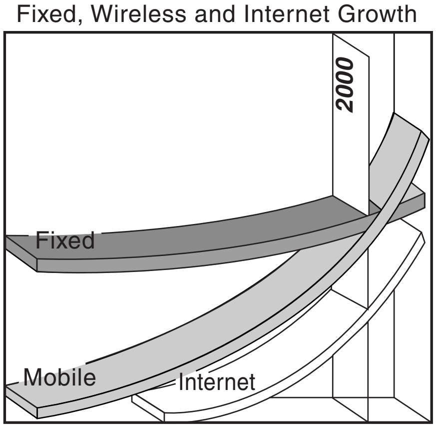

Figure 1.1 Worldwide growth of the fixed, wireless, and Internet communication industries in the past decade.

fice to the home, which soon generated an income comparable to that of the voice-oriented POTS and wireless industry. Figure 1.1 illustrates the growth of the fixed (POTS), wireless, and Internet industries in recent years. At the time of this writing, the *information exchange industry* that includes the fixed and wireless telephone as well as Internet access industries has an annual revenue of a few trillion dollars and is by far the largest industry in the world. The wireless networking industry makes up a third of the revenue of the information industry, and its share of the overall market is growing. Today this income is dominated by revenue from cellular telephone applications. The future of this industry relies on broadband wireless Internet access that is expected to develop a large market for emerging multimedia applications.

The purpose of this book is to provide the reader with a text for understanding the principles of wireless networks, which include the cellular telephone and wireless broadband access technologies. Wireless networking is a multidisciplinary technology. To understand this industry, we need to learn aspects of 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 standards and products, describe and classify their underlying technologies in a logical manner, give detailed examples of successful standards and products, and provide a vision of evolving technologies. In this first chapter, we provide an overview of the wireless industry and its path of evolution. The following five chapters describe principles of technologies that are used in wireless networks. The next three chapters discuss the details of wireless wide area networks (WANs), and the last four chapters describe short-range broadband and ad hoc wireless networks.

In this chapter we first provide an overview of the evolution of the wireless information network industry. We describe the meaning of a wireless network, and we give a summary of the important standards. Then we discuss the technical aspects and general structure of a wireless network. Finally we give an outline of the chapters of the book and how they relate to one another.

1.1.1 Information Network Infrastructure

An information network infrastructure interconnects telecommunication devices to provide them with means for exchanging information. Telecommunication devices are terminals allowing users to run applications that communicate with other terminals through the information network infrastructure. The basic elements of an information network infrastructure are a number of switches or routers that are connected via point-to-point links. Switches include fixed and variable rate voice-oriented circuit switches and routers that are low speed and high speed data-oriented packet switches. The point-to-point links include a variety of fiber, coaxial cable, twisted pair wires, and wireless connections.

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

Example 1.1: PSTN and Cellular

Figure 1.2 shows the overall picture for the wired and wireless telephone services. The public switched telephone network (PSTN), designed to provide wired telephone services, is augmented by a wireless fixed infrastructure to support mobility of the mobile terminal that communicates with several base stations mounted over antenna posts. The PSTN infrastructure consists of switches, point-to-point connections, and computers used for 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 operation and maintenance. A wireless telecommunications device, such as a cordless telephone, can connect to the PSTN infrastructure by replacing the wire attachment with radio transceivers. But, for the mobile terminal to change its point of contact (antennas) the PSTN switches must be able to support mobility. Switches in the PSTN infrastructure were not originally designed to support mobility. To solve this problem, the cellular telephone service providers add 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 requirements to support mobility.

In the same way 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.

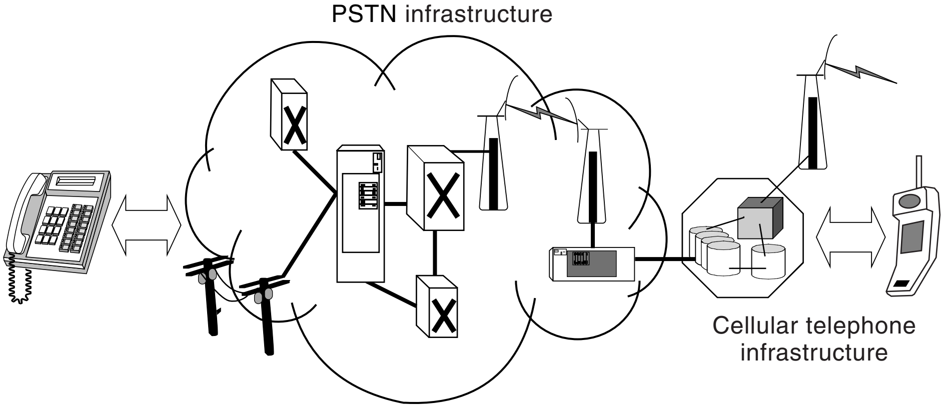

Figure 1.2 PSTN and its extension to cellular telephone services.

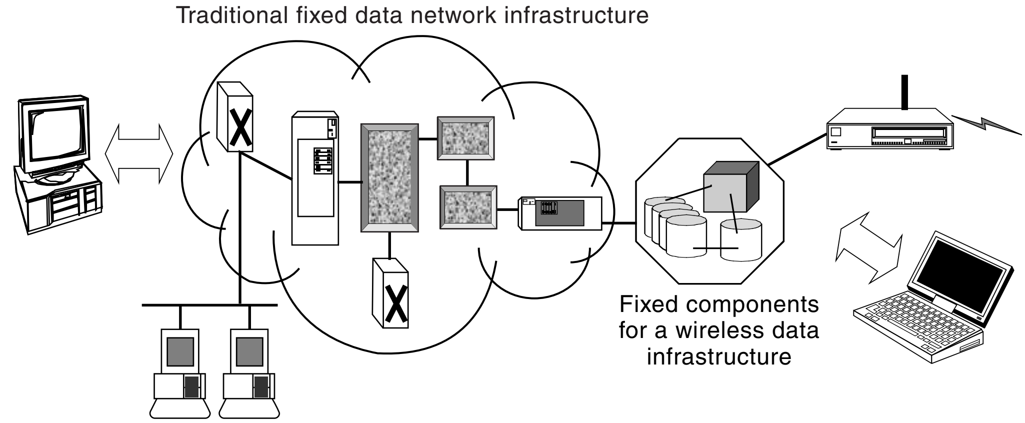

Figure 1.3 Internet and its extension to wireless data services.

Example 1.2: Wireless Internet

Figure 1.3 shows the traditional wired data infrastructure and the additional wireless data infrastructure that allow 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 terminals, access points, mobility-aware routers, and point-to-point connections. This new infrastructure has to support all the functionalities needed to support mobility.

The difference between Examples 1 and 2 is that the wireless network in Figure 1.2 is a connection-based, voice-oriented network, and the wireless network in Figure 1.3 is a connectionless data-oriented network. A voice-oriented network needs a dialing process, and after the dialing, a certain quality of service (QoS) is guaranteed to the user during the communication session. In data-oriented networks there is no dialing, and terminals are always connected to the network, but a definite QoS is not guaranteed.

1.1.2 Overview of Existing Network Infrastructure

Because the existence of the wireless networks heavily depends on the wired infrastructure that they connect to, in this section we provide an overview of the important types of wired infrastructure. More details on the evolution of these wired backbone infrastructures are provided in Appendix 1A. The most commonly used wired infrastructures for wireless networks are the PSTN, the Internet, and hybrid fiber coax (HFC), originally designed for voice, data, and cable TV distribution applications, respectively. Figure 1.4 provides an overall picture of these three networks and how they relate to other wired and wireless networks.

The main sources of information transmitted through telecommunications devices are voice, data, and video. Voice and video are analog in nature, and data is digital. The dominant voice application is telephony, which is a bidirectional, symmetric, real-time conversation. To support telephony, telephone service

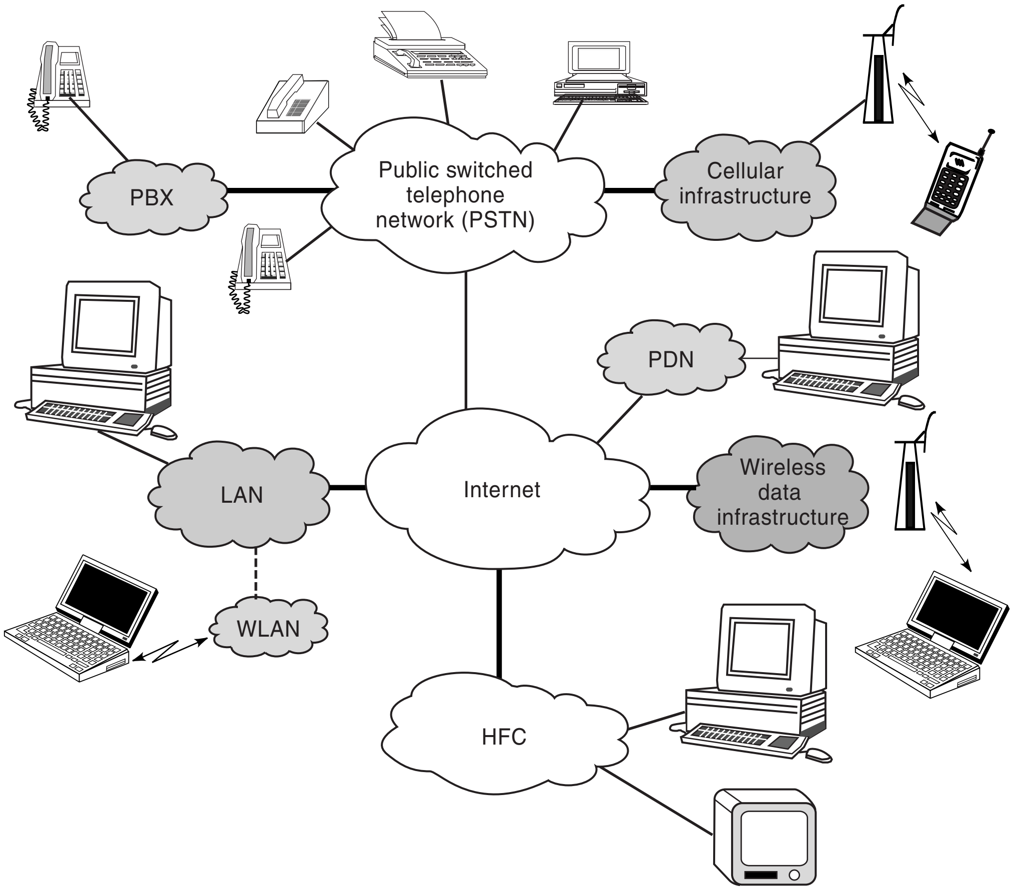

Figure 1.4 Backbone infrastructures: PSTN, Internet, and HFC.

providers have developed a network infrastructure that establishes a connection for a telephone call during the dialing process and disconnects it after completion of the conversation. As we saw in Example 1, this network is referred to as the PSTN. As shown in the top of Figure 1.4, the cellular telephone infrastructure provides a wireless access to the PSTN. Another network attached to the PSTN is the private branch exchange (PBX), which is a local telephone switch privately owned by companies. This private switch allows privacy and flexibility in providing additional services in an office environment. The PSTN physical connection to homes is a twisted-pair analog telephone wiring that is also used for broadband digital services. The core of the PSTN is a huge digital transmission system that allocates 64 kbps channels for each direction of a telephone conversation. Other network providers often lease the PSTN transmission facilities to interconnect their nodes.

The infrastructure developed for video applications is cable television, shown in the lower part of Figure 1.4. This network broadcasts wideband video signals to residential buildings. A cable goes from an end office to residential areas, and all users are provided service that is tapped from the same cable. The set-top boxes leased out by cable companies provide selectivity of channels depending on the charged rates. The end offices, where a group of distribution cables arrive, are connected to one another with fiber. For this reason, the cable TV network is also called hybrid fiber coax (HFC). More recently cable distribution has also been used for broadband home access to the Internet.

The data network infrastructure was developed for bursty applications and evolved into the Internet that supports Web access, email, file transfer, and telnet applications, as well as multimedia (voice, video, and data) sessions with a wide variety of session characteristics. The middle part of Figure 1.4 shows the Internet and its relation to other data networks. From the user's, point of view, the data-oriented networks are always connected, but they only use the transmission resources when a burst of information needs it. Sessions of popular data communications applications, such as Web browsing or file transfer protocol (FTP) are often asymmetric, and a short burst of upstream requests results in a downstream transmission of a large amount of data. Symmetric sessions such as Internet Protocol (IP) telephony over data networks are also becoming popular, providing an alternative to traditional telephony. The Internet access to home is a logical access that is physically implemented on other media such as cable TV wiring or telephone wiring. The distribution of the Internet in office areas is usually through local area networks (LANs). Wireless LANs (WLANs) in the offices are usually connected to the Internet through the LANs. These days all other private data networks, such as those used in the banks or airline reservation industries, are also connected to the Internet. As we saw in Example 2, the Internet is also the backbone for wireless data services.

1.1.3 Four Market Sectors for Wireless Applications

The market for wireless networks has evolved in four different segments that can be logically divided into two classes: *voice-oriented* market and *data-oriented* market. The voice-oriented market has evolved around wireless connections to the PSTN. These services further evolved into local and wide area markets. The local voice-oriented market is based on low-power, low-mobility devices with higher quality of voice, including cordless telephone, personal communication services (PCS), wireless PBX, and wireless telepoint. The wide area voice-oriented market evolved around cellular mobile telephone services that are using terminals with a higher power consumption, comprehensive coverage, and lower quality of voice. Figure 1.5(a) compares several features of these two sectors of the voice-oriented market. The wireless data-oriented market evolved around the Internet and computer communication network infrastructure. The data-oriented services are divided into broadband local and ad hoc and wide area mobile data markets. The wide area wireless data market provides for Internet access for mobile users. Local broadband and ad hoc networks include WLANs and wireless personal area networks (WPANs) which provide for high-speed Internet access, as well as evolving ad hoc wireless consumer products. Figure 1.5(b) illustrates several differences among the local- and wide-area wireless data networks.

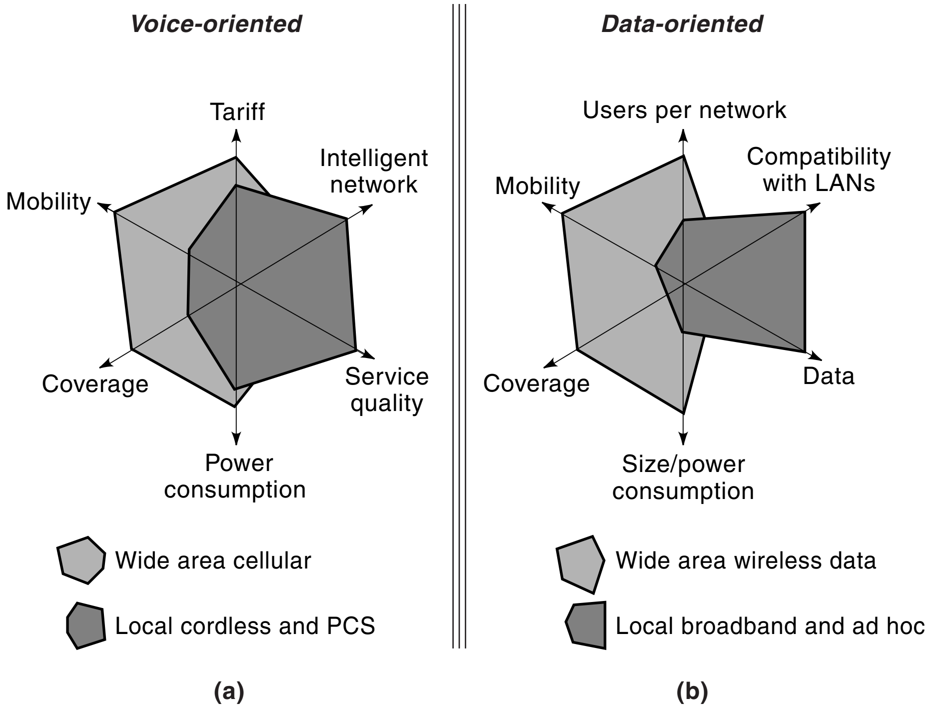

Figure 1.5 Wireless market sectors: (a) voice-oriented networks and (b) data-oriented networks.

1.1.4 Evolution of Voice-Oriented Wireless Networks

Table 1.1 shows a brief chronology of the evolution of voice-oriented wireless networks. The technology for frequency division multiple access (FDMA) analog cellular systems was developed at AT&T Bell Laboratories in the early 1970s. However, the first deployment of these systems took place in the Nordic countries as the Nordic Mobile Telephony (NMT) about a year earlier than the deployment of the Advanced Mobile Phone System (AMPS) in the United States. Because the United States is a large country, the frequency administration process was slower and it took a longer time for the deployment. The digital cellular networks started in Nordic countries with the formation of the Groupe Special Mobile standardization group that became the Global System for Mobile Communications (GSM). The GSM standard group was originally formed to address the international roaming, a serious problem for cellular operation in the European Union (EU) countries. The standardization group shortly decided to go for a new digital time division multiple access (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 its peak value, and there was a need for increasing it in the existing allocated bands. Although Nordic countries, led by Finland,

Table 1.1 History of Voice-Oriented Wireless Networks

Year	Event
Early 1970s	Exploration of first-generation mobile radio at Bell Labs
Late 1970s	First-generation cordless phones
1982	Exploration for second-generation digital cordless CT-2
1982	Deployment of first generation Nordic analog NMT
1983	Deployment of U.S. AMPS
1983	Exploration of the second-generation digital cellular GSM
1985	Exploration of wireless PBX, DECT
1988	Initiation for GSM development
1988	Initiation for IS-54 digital cellular
1988	Exploration of the QUALCOMM CDMA technology
1991	Deployment of GSM
1993	Deployment of PHS/PHP and DCS-1800
1993	Initiation for IS-95 standard for CDMA
1995	PCS band auction by FCC
1995	PACS finalized
1998	3G standardization started

have always maintained the highest rate of cellular telephone 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 code division multiple access (CDMA) that was originally perceived to provide capacity that was orders of magnitude higher than other alternatives, such as analog band splitting or digital TDMA.

While the debate between TDMA and CDMA was in progress in the United States, deployment of GSM technology started in the EC in the early 1990s. At the same time, developing countries started their planning for cellular telephone networks, and most of them adopted the GSM digital cellular technology over the legacy analog cellular. Soon after, GSM had penetrated into more than 100 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 POTS was slower than the growing demand for new subscriptions, and there was always a long waiting time to acquire a telephone line. As a result, in most of these countries telephone subscriptions were sold on the black market at a price several times the actual value. Penetration of cellular telephones in these countries was much easier because people were already prepared for a higher price for telephone subscriptions, and the expansion of cellular networks occurred much faster than POTS.

In the beginning of the race between TDMA and CDMA, CDMA technology was deployed in only a few countries. Besides, experimentation had shown that the capacity improvement factor of CDMA was smaller than expected. In the mid 1990s when the first deployment 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 banners like “you cannot believe your ears” started marketing this technology in the United States, which soon became very popular with the users. Meanwhile, with the huge success of digital cellular all manufacturers worldwide started working on the next generation IMT-2000 wireless networks. Most of these manufacturers adopted wideband CDMA (W-CDMA) as the technology of choice for the IMT-2000, assuming that W-CDMA eases integration of services, provides better quality of voice, and supports higher capacity.

The local voice-oriented wireless applications started with the introduction of the cordless telephone, which 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 technology for implementation of a cordless telephone is similar to the technology used in walkie-talkies which had 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 tens of millions of units and generating an income exceeding several billion dollars. The success of the cordless telephone encouraged further developments in this field. The first digital cordless telephone was CT-2, a standard developed in the United Kingdom in the early 1980s. The next generation of cordless telephones was the wireless PBX 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 cordless telephone, neither CT-2 nor DECT has yet been considered a very commercially successful system. These local systems soon evolved into PCS, which was a complete system with its own infrastructure, very similar to the cellular mobile telephone.

In the technical communities of the early 1990s, PCS systems were differentiated from the cellular systems as presented in Figure 1.5(b). A PCS service was considered 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 as personal handy system (PHS), introduced in Japan in 1993. At that time, the technical differences between PCS services and cellular systems were perceived to be smaller cell size, better quality of speech, lower tariff, lesser power consumption, and lower mobility. However, from the user's point of view the terminals and services for PCS and cellular looked very similar; the only significant differences were marketing strategy and the way that they were introduced to the market. For instance, around the same time in the United Kingdom DCS-1800 services were introduced as PCS services. The DCS-1800 was using GSM technology at a higher frequency of 1,800 MHz, but it employed a different marketing strategy. The last PCS standard was the personal access communications system (PACS) in the United States, finalized in 1995. All together, none of the PCS standards became a major commercial success or a competitor with cellular services.

In 1995, the Federal Communications Commission (FCC) in the United States auctioned the frequency bands around 2 GHz as the 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 at PCS bands. Although the more advanced and complex PCS services evolving from simple cordless telephone application did not succeed and were merged into the cellular telephone industry, the simple cordless telephone industry itself still remains active. In more recent years, the frequency of operation of cordless telephone products has shifted into unlicensed industrial, scientific, and medical (ISM) bands rather than the licensed PCS bands. Cordless telephones in the ISM bands can provide a more reliable link using spread spectrum technology.

1.1.5 Evolution of Data-Oriented Wireless Networks

Table 1.2 provides the chronology of data-oriented wireless networks. As shown in Figure 1.5(b), data-oriented wireless networks are divided into the wide area wireless data and local broadband and ad hoc networks. Wireless local networks support higher data rates and ad hoc operation for a lower number of users. The broadband wireless local networks are usually referred to as WLANs and the ad hoc local networks as WPANs. The concept of WLANs was first introduced around 1980. However, the first WLAN products were completed about 10 years later. Today a key feature of the local broadband and ad hoc networks is operation in the unlicensed bands. The first unlicensed bands were the ISM bands released in the United States in 1985. Later in 1994 and then in 1997, unlicensed PCS and U-NII (Unlicensed National Information Infrastructure) bands were also released in the United States. The major WLAN standard is the IEEE 802.11 started in the late 1980s and completed in 1997. The IEEE 802.11 and 802.11b operate in the ISM bands and the IEEE 802.11a in the U-NII bands. The competing European standard for WLANs is the HIgh PErformance Radio LAN (HIPERLAN). The HIPERLAN-1 was completed in 1997, and the HIPERLAN-2 is currently under development. In 1996, the wireless ATM working group of the ATM (Asynchronous Transfer Mode) Forum was formed to merge ATM technology with wideband local access. More recently, after the announcement of Bluetooth technology in 1998, WPANs have attracted tremendous attention. The coverage of WPANs is

Table 1.2 History of Data-Oriented Wireless Networks

Date	Event
1979	Diffused infrared (IBM Rueschlikon Labs—Switzerland)
1980	Spread spectrum using SAW devices (HP Labs—California)
Early 1980s	Wireless modem (Data Radio)
1983	ARDIS (Motorola/IBM)
1985	SM bands for commercial spread spectrum applications
1986	Mobitex (Swedish Telcom and Ericsson)
1990	IEEE 802.11 for Wireless LAN standards
1990	Announcement of wireless LAN products
1991	RAM mobile (Mobitex)
1992	Formation of WINForum
1992	ETSI and HIPERLAN in Europe
1993	Release of 2.4, 5.2, and 17.1–17.3 GHz bands in EU
1993	CDPD (IBM and 9 operating companies)
1994	PCS licensed and unlicensed bands for PCS
1996	Wireless ATM Forum started
1997	U-NII bands released, IEEE 802.11 completed, GPRS started
1998	IEEE 802.11b and Bluetooth announcement
1999	IEEE 802.11a/ HIPERLAN-2 started

smaller than traditional WLANs, and they are intended for ad hoc environments to interconnect such personal equipment as the laptop, cell phone, and headset together. At the time of this writing, the IEEE 802.11 products generated around half a billion dollars per year. In the past couple of years, huge investments have been poured into WLAN and WPAN chip set developments all over the world. These investments expect sizable incomes from the possible incorporation of WLANs into the prosperous cellular industry and a large WPAN market for consumer products and home networking. A more complete history of WLANs and WPANs is provided in Chapter 10.

Mobile data services were first introduced with the ARDIS (now called DATATAC) project between Motorola and IBM in 1983. The purpose of this network was to allow IBM field crew to operate their portable computers wherever they want to deliver their services. In 1986, Ericsson introduced Mobitex technology, which was an open architecture implementation of the ARDIS. In 1993, IBM and nine operating companies in the United States started the CDPD (cellular digital packet data) project, expecting a huge market by the year 2000. In the late 1990s the GPRS (general packet radio service) data services that are integrated in the successful GSM systems and can support an order of magnitude higher data rates than previous technologies attracted considerable attention. These higher data rates are perceived to be essential for wireless Internet access, the most popular wireless data application. The third generation (3G) cellular systems are planning to provide up to 2 Mbps mobile data service that is substantially higher than the GPRS data rates. These data rates, however, would not have the comprehensive coverage of GPRS. The early mobile data networks, ARDIS and Mobitex, were independent networks owning their infrastructure. As time passed, CDPD overlaid its infrastructure over the AMPS systems, and GPRS was actually integrated within the GSM infrastructure. This gradual assimilation of the mobile data industry into the cellular telephone industry will be completed in the next-generation cellular systems.

With the integration of PCS and mobile data industries in the next-generation cellular systems we see the emergence of two industries: the next-generation traditional cellular systems operating in licensed bands and the local broadband and ad hoc networks operating in unlicensed bands.

1.2 DIFFERENT GENERATIONS OF WIRELESS NETWORKS

It is customary among the cellular telephone manufacturers and service providers to classify wireless communication systems into several generations. The first-generation (1G) systems are voice-oriented analog cellular and cordless telephones. The second-generation (2G) wireless networks are voice-oriented digital cellular and PCS systems and data-oriented wireless WANs and LANs. The third-generation (3G) networks integrate cellular and PCS voice services with a variety of packet-switched data services in a unified network. In parallel to the unified 3G standardization activities, broadband local and ad hoc networks attracted tremendous attention, and they developed their own standards. One of the major current differences between these two waves is that the 3G systems use licensed bands, and broadband and ad-hoc networks operate in unlicensed bands. The manner in which broadband local access in unlicensed bands and 3G standards in licensed bands may be integrated forms the core of the forthcoming generations of wireless networks.

1.2.1 1G Wireless Standards

Table 1.3 shows the worldwide 1G analog cellular systems. All these systems use two separate frequency bands for forward (from base station to mobile) and reverse (from mobile to base station) links. Such a system is referred to as a frequency division duplex (FDD) scheme. The typical allocated overall band in each direction, for example, for AMPS, TACS, and NMT-900, was 25 MHz in each direction. The dominant spectra of operation for these systems were the 800 and 900 MHz bands. In an ideal situation, all countries should use the same standard and the same frequency bands, however, in practice, as shown in Table 1.3, a variety of frequencies and standards were adopted all over the world. The reason for the different frequencies of operation is that the frequency administration agencies in each country have had previous frequency allocation rulings that restricted the assignment

Table 1.3 Existing 1G Analog Cellular Systems

Standard	Forward Band (MHz)	Reverse Band (MHz)	Channel Spacing (kHz)	Region	Comments
AMPS	824–849	869–894	30	United States	Also in Australia, southeast Asia, Africa
TACS	890–915	935–960	25	EU	Later, bands were allocated to GSM
E-TACS	872–905	917–950	25	UK	
NMT 450	453–457.5	463–467.5	25	EU	
NMT 900	890–915	935–960	12.5	EU	Freq. overlapping; also in Africa and southeast Asia
C-450	450–455.74	460–465.74	10	Germany, Portugal	
RMTS	450–455	460–465	25	Italy	
Radiocom 2000	192.5–199.5 215.5–233.5 165.2–168.4 414.8–418	200.5–207.5 207.5–215.5 169.8–173 424.8–428	12.5	France	
NTT	925–940 915–918.5 922–925	870–885 860–863.5 867–870	25/6.25 6.25 6.25	Japan	First band is nationwide, others regional
JTACS/ NTACS	915–925 898–901 918.5–922	860–870 843–846 863.5–867	25/12.5 25/12.5 12.5	Japan	All are regional

TACS: Total Access Communication System
E-TACS: Enhanced TACS
NTT: Nippon Telephone and Telegraph

choices. The reason for adopting different standards was that at that time cellular providers assumed services to be mainly used in one country, and they did not have a vision for a universal service. The channel spacing or bandwidth allocated to each user was either 30 kHz or 25 kHz or a fraction of either of them. The 25 kHz band was previously used for mobile satellite services and the 30 kHz band was something new used for cellular telephone applications. All the 1G cellular systems were using analog frequency modulation (FM) for which the transmission power requirement depends on the transmission bandwidth. On the other hand, power is also related to the coverage and size of the radios. Therefore, one can compensate for the reduction in transmission bandwidth per user by reducing the size of a cell in a cellular network. Reduction in size of the cell increases the number of cells and the cost of installation of the infrastructure.

Example 1.3: Infrastructure Density versus Channel Size in Analog Cellular Systems

> The AMPS system in North America uses 30 kHz band whereas C-450 in Germany uses 10 kHz spacing that is ⅓ of the 30 kHz. Therefore, one expects a heavier infrastructure density for deployment of C-450.

Example 1.4: Cell Size and Channel Bandwidth in Analog Cellular Systems

> The Japanese use 25 kHz, 12.5 kHz, and 6.25 kHz bands in their systems that support the entire band, ½, and ¼ of the band, respectively. The size of the cells for split-band operation is smaller than the size for full-band operation.

Band splitting obviously allows more subscribers at the expense of more investment in the infrastructure. In Chapter 5, where we address deployment of the cellular networks, we introduce a technique to improve the capacity of a cellular network with the same number of base stations using band splitting.

In the cellular industry, often 1G only refers to analog cellular systems because it is the only system implemented based on popular standards such as AMPS or NMT. However, we can generalize the 1G systems to other sectors of the wireless services. The analog cordless telephone that appeared on the market in the 1980s can be considered the 1G cordless telephone. Paging services that were deployed around the same time frame as analog cellular systems and cordless telephones can be referred to as 1G mobile data services providing one-way short data messages. In the early 1980s before the release of ISM bands and start of the WLAN industry, a couple of small companies in Canada and the United States developed low-speed connectionless WLANs using voiceband modem chip sets and commercially available walkie-talkies. These products were operating at the speed of voice-band modems (< 9,600 bps) but using medium-access control techniques used in data-oriented LANs. Because of their low speed they do not comply with the IEEE 802 definition of LANs, but one may refer to them as 1G WLAN products.

1.2.2 2G Wireless Systems

The 2G systems supported a complete set of standards for all four sectors of the wireless network industry. As we discussed in the history of voice-oriented and data-oriented networks, we have a number of digital cellular, PCS, mobile data, and WLAN standards and products that can be classified as 2G systems. In the remainder of this section, we cover each of these four sectors of 2G systems in a separate subsection.

1.2.2.1 2G Digital Cellular

Table 1.4 summarizes the major 2G digital cellular standards. There are four major standards in this category: GSM, the pan-European digital cellular, the North American Interim Standard (IS-54) that later on improved into IS-136 and Japanese digital cellular (JDC)—all of them using TDMA technology and IS-95 in North America, which uses CDMA technology. Like the 1G analog systems, the 2G systems are all FDD and operate in the 800–900 MHz bands. The carrier spacing of IS-54 and JDC is the same as the carrier spacing of 1G analog systems in their respective regions, but GSM and IS-95 use multiple analog channels to form one digital carrier. GSM supports eight users in a 200 kHz band; IS-54 and JDC support three users in 30 and 25 kHz bands, respectively. As we explain in Chapter 4, the number of users for CDMA depends on the acceptable quality of service; therefore, the number of users in the 1,250 kHz CDMA channels cannot be theoretically fixed. But this number is large enough to convince the standards organization to adopt CDMA technology for next generation 3G systems. By looking into these numbers, one may jump to the conclusion that GSM uses 25 kHz for each bearer, and IS-54 uses 10 kHz per user. Therefore GSM supports 2.5 times less the number of users in the given bandwidth. The reader should be warned that this is an illusive conclusion because when the network is deployed, the ultimate quality of voice also depends on the frequency reuse factor and signal-to-noise/interference

Table 1.4 2G Digital Cellular Standards

System	GSM	IS-54	JDC	IS-95
Region	Europe/Asia	United States	Japan	United States/Asia
Access method	TDMA/FDD	TDMA/FDD	TDMA/FDD	CDMA/FDD
Modulation scheme	GMSK	π/4-DQPSK	π/4-DQPSK	SQPSK/QPSK
Frequency band (MHz)	935–960 890–915	869–894 824–849	810–826 940–956 1,477–1,489 1,429–1,441 1,501–1,513 1,453–1,465	869–894 824–849
Carrier spacing (kHz)	200	30	25	1,250
Bearer channels/carrier	8	3	3	Variable
Channel bit rate (kbps)	270.833	48.6	42	1,228.8
Speech coding	13 kbps	8 kbps	8 kbps	1–8 kbps (variable)
Frame duration (ms)	4.615	40	20	20

requirements that will change these calculations significantly. These issues are addressed in Chapter 5.

The channel bit rate of GSM is 270 kbps whereas IS-54 and JDC use 48 and 42 kbps, respectively. Higher channel bit rates of a digital cellular system allow simple implementation of higher data rates for data services. By assigning several voice slots to one user in a single carrier, one can easily increase the maximum supportable data rate for a data service offered by the network. How the higher channel rate of GSM allows support of higher data rates is discussed in Chapter 9, when we discuss GPRS mobile data services. Using a similar argument, one may notice that the 1228.8 kcps channel chip rate of IS-95 provides a good ground for integration of higher data rates into IS-95. This fact has been exploited in IMT-2000 systems to support data rates up to 2 Mbps.

The speech coding technique of 2G systems are all around 10 kbps. As shown in Table 1.4, cellular standards assume large cell sizes and a large number of users per cell, which necessitates lower speech coding rates. On the other hand, cellular standards were assuming operation in cars for which power consumption and battery life were not issues. The peak transmission power of the mobile terminals in these standards can be between several hundreds of mW up to 1W [PAH95] and on the average they consume around 100 mW. All of these systems employ central power control, which reduces battery power consumption and helps in controlling the interference level. In digital communications, information is transmitted in packets or frames. The duration of a packet/frame in the air should be short enough so that the channel does not change significantly during the transmission and long so that the required time interval between packets is much smaller than the length of the packet. A frame length of around 5 to 40 ms is typically used in 2G networks.

1.2.2.2 2G PCS

As we discussed in the history of wireless voice-oriented networks, the 2G PCS standards evolved out of the 1G analog cordless telephone industry and merged into the 3G cellular systems. Figure 1.5(a) illustrates the difference between these two industries during the evolution of the 2G networks; before they

Table 1.5 Quantitative Comparison of PCS and Cellular Philosophies

System Aspects	PCS	Cellular
Cell size	5–500 m	0.5–30 km
Coverage	Zonal	Comprehensive
Antenna height	< 15 m	> 15 m
Vehicle speed	< 5 kmph	< 200 kmph
Handset complexity	Low	Moderate
Base station complexity	Low	High
Spectrum access	Shared	Exclusive
Average handset power	5–10 mW	100–600 mW
Speech coding	32 kb/s ADPCM	7–13 kb/s vocoder
Duplexing	Usually TDD	FDD
Detection	Non-coherent	Coherent

were integrated into one in 3G systems. Table 1.5 illustrates a more quantitative comparison of PCS and cellular industries that at the time was used to justify the existence of two separate voice-oriented standards. The basic philosophy was that PCS is for residential applications, the cell size is small, coverage is zonal, antennas are installed on existing posts (such as electricity or telephone posts), it is not designed to be used in the car, and the complexity of the handset and base station is low. These standards preferred 32 kbps speech coding to support wireline quality and shared the same spectrum in different zones; time-division-duplex (TDD) and noncoherent modulation techniques were mostly used to support simpler implementation.

Table 1.6 provides a summary of the specifications of the four major PCS standards. CT-2 and CT-2+ were the first digital cordless telephone standards; PHS, which later on became PHP, was the first and the only nationwide deployment of these systems; and PACS is the last standard developed with this philosophy. Except for CT-2+ all these standards were designed for 1.8 and 1.9 GHz frequency bands, which are commonly referred to as PCS bands; all systems use TDMA/TDD except PACS, which adopted FDD. To support wireline quality of voice, speech coding at 32 kbps is used in all of these standards. This rate is around three times higher than the speech coding rate of digital cellular systems. The carrier bit rate of 1,728 kbps in DECT is even higher than GSM, which had the highest carrier rate of all TDMA digital cellular systems. This carrier bit rate is even higher than the chip rate in IS-95, the 2G CDMA standard. This feature provides an edge to DECT in supporting high-speed data connections for Internet access. Perhaps this is the major reason why DECT is the only PCS standard that is still considered in new technologies like HomeRF. The power consumption of PCS standards is almost one order of magnitude less than that of the digital cellular standards because PCS systems are designed for smaller cells. If digital cellular systems were deployed with the same cell sizes, the average power consumption could be comparable to PCS systems. Modulation techniques used for PCS standards, GFSK and DQPSK, are less bandwidth efficient and more power efficient than modulation schemes used in digital cellular systems. These modulation techniques can be implemented with simpler noncoherent receivers reducing the size of the handset. The shorter propagation

Table 1.6 2G PCS Standards

System	CT-2 and CT-2(+)	DECT	PHS	PACS
Region	Europe/Canada	Europe	Japan	United States
Access Method	TDMA/TDD	TDMA/TDD	TDMA/TDD	TDMA/FDD
Frequency band (MHz)	864–868 944–948	1,880–1,900	1,895–1,918	1,850–1,910 1,930–1,990
Carrier spacing (kHz)	100	1,728	300	300
Bearer channels/carrier	1	12	4	8 per pair
Channel bit rate (kbps)	72	1,152	384	384
Modulation	GFSK	GFSK	$\pi/4$-DQPSK	$\pi/4$-DQPSK
Speech coding (kbps)	32	32	32	32
Average handset Tx power (mW)	5	10	10	25
Peak handset Tx power (mW)	10	250	80	200
Frame duration (ms)	2	10	5	2.5

time for the smaller-cell PCS standards allows shorter packet frames which help the quality of voice in spite of the wireless channel impairments.

1.2.2.3 Mobile Data Services

As shown in Figure 1.5(b), mobile data services provide moderate data rate and wide coverage area access to packet-switched data networks. The mobile data networks emerged after the success of the paging industry to provide a two-way connection for larger messages. Table 1.7 provides a comparison among a number of important mobile data services. ARDIS and Mobitex use their own frequency bands in 800–900 MHz, terrestrial European trunked radio (TETRA) uses its own band at 300 MHz, CDPD shares the AMPS bands and site infrastructure, GPRS shares the GSM's complete radio system, and Metricom uses the unlicensed ISM bands. The early systems, ARDIS, Mobitex, and CDPD, were developed before the popularity of the Internet, and the dominant design criteria was coverage and cost rather than data rate. These systems were a wireless replacement for voiceband modems operating at data rates up to 19.2 kbps, which was the rate of modems at that time. TETRA is designed for pan-European civil service application and has its own features for that purpose. Metricom and GPRS support data rates more suitable for Internet access. The advantage of GPRS is that it is incorporated in the popular GSM digital services with large numbers of terminals all over the world. Except for Metricom, the channel spacing of the rest of the mobile data services is based on the channel spacing of cellular telephone networks with 25 or 30 kHz bands or a fraction (12.5 kHz) or a multiple of them (200 kHz). These services are designed to use multiple carriers in an FDMA format and use different versions of random access techniques such as DSMA, BTMA, or ALOHA, which are explained in Chapter 4. Modulation techniques for these systems are like digital cellular and PCS systems explained in Chapter 3. A more detailed comparison of mobile data services is provided in Chapter 9.

1.2.2.4 WLANs

As shown in Figure 1.5(b), WLANs provide high data rates (minimum of 1 Mbps) in a local area (< 100 m) to provide access to wired LANs and the Internet. Today all successful WLANs operate in unlicensed bands that are free of charge

Table 1.7 Mobile Data Services

System	ARDIS	Mobitex	CDPD	TETRA	GPRS	Metricom
Frequency band (MHz)	800 bands 45 kHz sep	935–940 896–961	869–894 824–849	380–383 390–393	890–915 935–960	902–928 ISM bands
Channel bit rate (kbps)	19.2	8.0	19.2	36	200	100
RF channel spacing	25 kHz	12.5 kHz	30 kHz	25 kHz	200 kHz	160 kHz
Channel access/ Multiuser access	FDMA/ DSMA	FDMA/ Dynamic S-ALOHA	FDMA/ DSMA	FDMA/ DSMA	FDMA/ TDMA/ Reservn.	FHSS/ BTMA
Modulation technique	4-FSK	GMSK	GMSK	$\pi/4$-QPSK	GMSK	GMSK

Table 1.8 Wireless LAN Standards

Parameters	**IEEE 802.11**	**IEEE 802.11b**	**IEEE 802.11a**	**HIPER-LAN/2**	**HIPER-LAN/1**
Status	Approved, Products	Products	Approved, Products in development	Approved	Approved, No products
Freq. Band	2.4 GHz	2.4 GHz	5 GHz	5 GHz	5 GHz
PHY, modulation	DSSS: FHSS:	DSSS: CCK	OFDM	OFDM	GMSK
Data rate	1, 2 Mbps	1, 2, 5.5, 11 Mbps	6, 9, 12, 18, 24, 36, 54 Mbps		23.5 Mbps
Access method	Distributed control, CSMA/CA or RTS/CTS			Central control; reservation-based access	Active contention resolution; priority signaling

and rigorous regulations. Considering that PCS bands were auctioned at very high prices, in the past few years WLANs have attracted a renewed attention. Table 1.8 provides a summary of the IEEE 802.11 and HIPERLAN standards for WLANs. IEEE standards include 802.11 and 802.11b operating at 2.4 GHz and 802.11a, which operates at 5 GHz. Both HIPERLAN-1 and -2, developed under the European Telecommunication Standards Institute (ETSI), operate at 5 GHz. The 2.4 GHz products operate in ISM bands using spread spectrum technology to support data rates ranging from 1 to 11 Mbps. HIPERLAN-1 uses GMSK modulation with signal processing at the receiver that supports up to 23.5 Mbps. IEEE 802.11a and HIPERLAN-2 use the orthogonal frequency division multiplexing (OFDM) physical layer to support up to 54 Mbps. The access method for all 802.11 standards is the same and includes CSMA/CA, PCF, and RTS/CTS, which are described in Chapters 4 and 11. The access method of the HIPERLAN-1 is on the lines of the 802.11, but the access method for HIPERLAN-2 is a voice-oriented access technique that is suitable for integration of voice and data services. The details of these transmission techniques and access methods are described in Chapters 3 and 4. IEEE 802.11, IEEE 802.11b, and HIPERLAN-1 are completed standards, and IEEE 802.11 and 11.b are today's dominant products in the market. IEEE 802.11a and HIPERLAN-2 are still under development. The IEEE 802.11 and HIPERLAN-1 standards can be considered 2G wireless LANs. The OFDM wireless LANs are forming the next generation of these products. The last four chapters of this book are focused on wideband local access systems which describe these systems in further detail.

1.2.3 3G and Beyond

The purpose of migration to 3G networks was to develop an international standard that combines and gradually replaces 2G digital cellular, PCS, and mobile data services. At the same time, 3G systems were expected to increase the quality of the voice, capacity of the network, and data rate of the mobile data services. Among several radio transmission technology proposals submitted to the International Telecommunication Union (ITU), the dominant technology for 3G systems was W-CDMA, which is discussed in detail in Chapter 11. Outside the 3G standards, WLAN and WPAN standards are forming the future for the broadband and ad hoc wireless networks. Figure 1.6 illustrates the relative coverage and data rates of 2G, 3G, WLAN, and WPANs. WPANs, studied in Chapter 13, are formed under the IEEE 802.15 standard. This community has adopted Bluetooth technology as its first standard. Bluetooth is a new technology for ad hoc networking which was introduced in 1998. Like WLANs, ad hoc Bluetooth-type technologies operate in unlicensed bands. Bluetooth operates at lower data rates than WLANs but uses a voice-oriented wireless access method that provides a better environment for integration of voice and data services. The WPAN ad hoc networking technologies are designed to allow personal devices such as laptops, cellular phones, headsets, speakers, and printers to connect together without any wiring.

From the point of view of cellular service providers, 3G provides multimedia services to users everywhere, WLANs provide broadband services in hot spots where a short proximity is needed, and WPANs connect the personal devices together. The telecommunications industry is a multidisciplinary industry, and it has always been difficult to predict its future. However, there are certain current trends that one may perceive as important. In terms of frequency of operation, 3G systems use licensed bands whereas WLANs and WPANs use unlicensed bands. Unlicensed bands are wider and free of charge and rigorous rules, but there is no regulation to control the interference in these bands. Some researchers and vision-

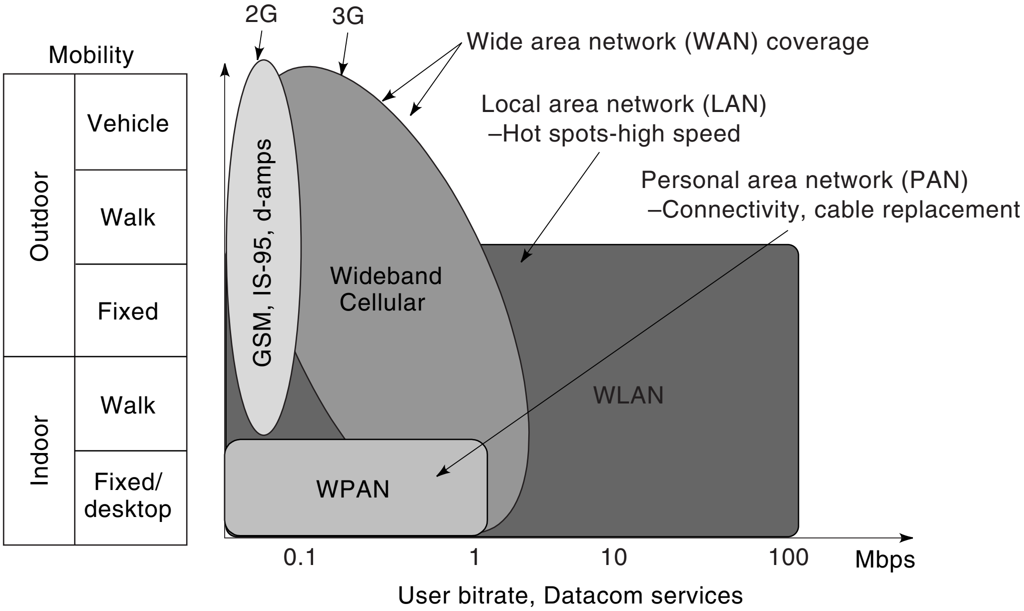

Figure 1.6 Relative coverage, mobility, and data rates of generations of cellular systems and local broadband and ad hoc networks.

aries have gone too far to state that the future is "everything unlicensed," but it is safer to say that recent years have witnessed an immense growth of hope for an increase in using unlicensed bands. Wideband CDMA is the dominant transmission technology for 3G systems and OFDM is becoming very popular in broadband WLANs operating in 5 GHz. Again some visionaries also state that the next-generation systems will be based on OFDM; however, it is safe to say that OFDM appears to play an increasing role in the future of broadband wireless access. Another important evolving technology is the ultra wide band (UWB) which is expected to support a myriad of users with noiselike impulses with a spectrum spreading over several GHz [SCH00]. We address this evolving technology in Chapter 3. There are some visionaries who predict that UWB may be the next step to OFDM, but it is safe to state that it is an evolving, promising technology. Another evolving technology is position finding, in particular in indoor areas, which is becoming an integral part of the wireless networks for the next generations. We address location finding in the last chapter of this book. The FCC in the United States has already mandated the integration of position location systems with cellular systems; however, the extent and method of integration is not yet clear.

1.3 STRUCTURE OF THE BOOK

Wireless networks are very complex multidisciplinary systems; to describe these networks, we need to divide the details into several categories to create a logical organization for presentation of important material. This book is organized in five sections: one introduction chapter and four parts. The introductory material presented in Chapter 1 defines the meaning and sketches the path of evolution of the 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 1 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 1 should motivate the reader to study the details provided in the remainder of the book.

Each of the four parts of the book consists of several chapters directed toward the description of certain aspects of wireless networks. Parts One and Two are devoted to the principles of wireless network operations. These parts provide the technical background needed for understanding wireless networks. The technical aspects are either related to the design of the air-interface or issues related to deployment and operation of the infrastructure. Part One consists of three chapters describing technical aspects of the air-interface. Part Two has two chapters devoted to the technical aspects of the wireless network infrastructure. Parts Three and Four are devoted to describing the details of typical wireless networks in a comparative manner. Part Three consists of three chapters describing both voice- and data-oriented wireless WANs. Part Four consists of four chapters on local broadband and ad hoc wireless networks, including WLAN, WPAN, and indoor positioning.

1.3.1 Part One: Principles of Air-Interface Design

Wired terminals connect to power 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, unreliable, and band limited. The design of the physical connection and access method and understanding of the behavior of the medium for wireless operation is far more complicated than wired operation scenarios. The design of air-interface for wireless connections needs a far deeper understanding of the behavior of the channel and a more complex physical and medium access control mechanism. The behavior of the wireless medium is more complex than the wired medium because in wireless channels the received signal strength suffers from extensive power fluctuations caused by temporal and spatial movements. Wireless transmission and access techniques are more complex because they have to be power and bandwidth efficient, and they need to employ techniques to mitigate the fluctuations caused by the medium. Part One of the 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 in voice- and data-oriented networks in Chapter 4.

Chapter 2 describes modeling of the path-loss, 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 with the base station. These models are used in deployment of the networks to determine the coverage of a base station. The received power at the receiver is not fixed, and it changes in time as the mobile moves or the environment changes. Models for the variations of the channel are used to design the adaptive elements of the receiver, such as synchronization circuits or equalizers, to cope with the variation of the channel. Models for multipath characteristics allow the design of a receiver that can handle the interference of the signals arriving from different paths to the receiver.

The second chapter related to air-interface is Chapter 3, which describes transmission techniques that are used for the physical (PHY) layer of wireless networks. The diversity and complexity of transmission techniques in wireless systems are far more complex than those in wired networks. This chapter provides a comprehensive coverage of all transmission techniques that are employed in voice-oriented cellular and PCS systems, as well as data-oriented mobile data and WLAN and WPAN systems. The transmission techniques are divided into pulse transmission techniques used in infrared (IR) networks and UWB systems, traditional modulation techniques mostly used in digital cellular and mobile data networks, and spread spectrum technologies used in CDMA cellular, as well as WLANs and WPANs. More advanced techniques such as CCK used in 802.11b and OFDM used in 802.11a and HIPERLAN-2 are also described in this chapter.

The third chapter related to air-interface is Chapter 4, which is devoted to multiple access alternatives applied to wireless networks. This chapter starts with a description and comparison of the voice-oriented FDMA, TDMA, and CDMA access methods. The second part of this chapter is devoted to CSMA- and ALOHA-based random access techniques used in data-oriented wireless networks. The last part analyzes the applied access methods for integration of the voice and data that has evolved to operate in the voice- and data-oriented networks.

1.3.2 Part Two: Principles of Wireless Network Operation

In Part One of the book, technical issues related to design of the air-interface are presented. In Part Two we address technical aspects of fixed infrastructure of the wireless networks. This part consists of Chapters 5 and 6, addressing deployment and operation, respectively. Service providers often start with minimal infrastructure and antenna sites to keep the initial investment low. As the number of subscribers grows, service providers expand the wireless infrastructure to increase the capacity and improve the quality. The technology related to the deployment and expansion of the cellular infrastructure is discussed in Chapter 5, which is the first chapter related to technical aspects of the network infrastructure. This chapter discusses different topologies for wireless networks, describes cellular infrastructure deployment, and addresses issues related to the expansion of the size and migration to new technologies.

Chapter 6 is devoted to functionalities of the fixed network infrastructure to support the mobile operation. These functionalities include mobility management, radio resource and power management, and security management. These issues are addressed in three separate parts of Chapter 6. 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 mobile as it changes its access to the network from one antenna to another. The radio resource and power management part of Chapter 6 is devoted to the technologies used for controlling the transmitted power of the terminals. Voice-oriented networks control the transmitted power of the mobile station to minimize the interference with other terminals using the same frequency and to maximize the life of the battery. Data-oriented networks also use the sleep mode to avoid unnecessary consumption of power. Explanation of the methodologies and examples of how to implement power control and sleeping modes are provided in this part of Chapter 6. The last section of Chapter 6 is devoted to security in wireless networks. Wireless connections are inherently vulnerable to fraudulent connections and eavesdropping and need security features. 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 6.

1.3.3 Part Three: Wireless Wide Area Networks

After completion of the overview of the standards in Chapter 1 and study of the technical aspects in Parts One and Two, we start detailed descriptions of specific wireless networks. These detailed descriptions are divided into two parts addressing WANs and LANs. The third part of the book is devoted to the description of important voice- and data-oriented wireless wide area networks. In Chapter 7 we describe GSM as an example for TDMA systems, and in Chapter 8 we describe IS-95 and

IMT-2000 as examples of CDMA technology. The obvious reason for these selections is the current worldwide popularity of the GSM and emergence of the IMT-2000 and CDMA technologies as the choice of the emerging 3G systems. The last chapter in this part of the book is Chapter 9 which is devoted to mobile data networks.

Details of the architecture, mechanisms to support mobility, and layered protocols adopted by the GSM standard are described in Chapter 7. GSM is a complete standard that includes specification of the air-interface as well as fixed wired infrastructure to support the services. Other TDMA digital cellular standards, such as IS-136 or JDC, are very similar to GSM. Chapter 7 provides the most comprehensive coverage of a standard in this part of the book. First we describe all elements of the network architecture. Then we address mobility support mechanism 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 channel. The study of this chapter introduces the reader to the complexity and diversity of the issues involved in development of a wireless standard.

Chapter 8 is devoted to the CDMA and IMT-2000 technology that is the direction of the immediate future of 3G cellular systems. After a brief description of IS-41 and IS-634, which are the standards for communication between cellular switches and base stations in North America, details of the air-interface, IS-95, for cmdaONE that was developed by Qualcomm will be described. Then the 3G systems and how they differ from IS-95 are described. This chapter is completed with a summary of ITU's IMT-2000 standard. Because the wired backbone of the TDMA and CDMA systems are very similar, most of our attention is paid to the air-interface that is completely different from TDMA systems such as GSM. The details of GSM, IS-95, and IMT-2000 conclude our description of popular voice-oriented wide area systems.

The last topic in this part is the description of mobile data networks provided in Chapter 9. This is a comprehensive coverage of all mobile data services including short messaging and application programming for wireless data networks. Although a number of technologies have been examined for mobile data services, the market for this industry has not yet reached the market size of the popular cellular telephone industry. The delay in formation of the market has created a fragmented industry. To cover the details of this fragmented industry, we first provide an overview of all technologies and classify them into logical groups. Then we provide details of CDPD, a data-oriented network overlaid on AMPS infrastructure, and GPRS, which is embedded in the voice-oriented GSM system. In spite of small growth of the mobile data industry, recently short messaging systems (SMS) and application protocols for mobile data networks have attracted considerable market attention. As a result, we have devoted the last two sections of this chapter to SMS and application protocols, respectively.

1.3.4 Part Four: Local Broadband and Ad Hoc Networks

As we discussed earlier, 3G systems integrated cellular telephone, PCS, and mobile data services into one standard system operating in licensed bands. However, WLAN and WPAN have their own standards for broadband and ad hoc networking in unlicensed bands. At the time of this writing, most visionaries in wireless technology developments believe that the future is shaping with the merger of the broadband and ad hoc networking and 3G systems. In addition, there is a trend for integration of geolocation features into the next generation wireless networks. These networks support broadband wireless access to the backbone infrastructure, as well as ad hoc wireless networking. The last part of the book is devoted to these short-range local wireless networks. This part consists of five chapters, three of them devoted to WLAN, one to WPAN, and one to wireless geolocation principles.

The first of the three chapters on WLAN is Chapter 10 which provides an overview of the WLAN industry. This chapter analyzes the evolutionary path of the WLAN and explains how it started for office and manufacturing environments and is currently heading toward home area networking (HAN). Chapter 11, which describes details of the IEEE 802.11 standard for WLAN, follows the introduction to WLAN. Chapter 11 plays the same role as Chapter 7 on GSM was playing in Part Three; it provides details of the IEEE 802.11 to demonstrate all aspects of a data-oriented wireless standard operating in unlicensed bands. The medium access technology for the IEEE 802.11 is CSMA/CA which sets this standard as a connectionless, data-oriented standard. This feature eases the Internet access either by direct connection or connection through an existing wired LAN. The contents of this chapter describe the objective of the standard, explain specifications of the physical (PHY) and medium access control (MAC) layer alternatives supported by this standard, and provide the details of mobility support mechanisms such as registration, handoff, power management, and security. The next chapter, Chapter 12, is devoted to wireless ATM activities and the HIPERLAN standard. HIPERLAN-1 and IEEE 802.11 are considered data-oriented WLANs. Wireless ATM and HIPERLAN-2 are considering integration of voice and data from the point of view of the voice-oriented networks. The medium access for these standards is keen on supporting QoS for voice applications, which makes them suitable for integration into the existing prosperous cellular telephone networks. This chapter starts with an overview of the technical aspect of wireless ATM, then provides a short description of HIPERLAN-1, and at last describes the necessary details of HIPERLAN-2.

Chapter 13 describes WPANs with particular emphasis on details of Bluetooth technology. As discussed earlier, WPANs are ad hoc networks designed to connect personal equipment to one another. However, today's personal devices need to be connected to both voice- and data-oriented networks. The access method for these systems are designed to accommodate that need. Beyond that, WPANs are perceived to have lower power consumption which makes them compromise on the highest supportable data rate as compared with WLANs. This chapter starts by describing the IEEE 802.15 standards committee on WPAN and HomeRF activities under this standard. Then details of Bluetooth technology are described in some depth. The last part of this chapter analyzes the interference between IEEE 802.11 and Bluetooth, both operating in the 2.4 GHz ISM bands.

Chapter 14 is devoted to indoor geolocation and cellular positioning as emerging technologies to complement the local and wide local area wireless services. This chapter provides a generic architecture for the wireless geolocation services, describes alternative technologies for implementation of these systems, and gives examples of evolving location-based services. Location-based services provide a fertile environment for the emergence of E- and M-commerce applications.

APPENDIX 1A BACKBONE NETWORKS FOR WIRELESS ACCESS

Table 1A.1 provides a brief history of important developments in the telecommunications industry. The telecommunications industry started with the simple wired telegraph that used Morse code for digital data communication over long distance wires between the two neighboring cities of Washington, D.C., and Baltimore in 1839 [COU01]. It took 27 years, until 1866, for engineers to communicate over the ocean. In 1900, 34 years after the challenging task of deploying cables in the ocean and three years after the first trial of wireless telegraph, Marconi demonstrated wireless transoceanic telegraph as the first wireless data application. In 1867, Bell started the telephone industry, the first wired analog voice telecommunication service. It took 47 years for the telephone to become a transoceanic service in 1915, and it took almost 100 years for this industry to flourish into the wireless cellular telephone. The wireless telegraph was a point-to-point solution that eliminated the tedious task of laying very long wires in harsh environments. The wireless telephone was a network that had to support numerous mobile users. The challenge for wireless point-to-point communications is the design of a radio; the challenge for a wireless network is the design of a system that allows many mobile radios to work together. The telegraph was a manual SMS that needed a skilled worker to decode the transmitted message.

The first computer communication networks started after the Second World War by using voiceband modems operating over the PSTN infrastructure to exchange large amounts of data among computers located a far distance from one another [PAH88]. Approximately two decades after the era of circuit switched computer communication networks around 1970, wide area packet switched networks (DARPAnet) and wideband local area networks, which were tailored for bursty data applications, were invented.

By the end of the 20th century, multimedia wireless networks emerged to integrate all networks and provide wireless and mobile access to them. SMS services, E- and M-commerce are becoming very popular. It is interesting to note that SMS provides a similar service as the wireless telegraph using the telephone keypad as the terminal. Finally, after more than 100 years, when a terminal with easy user interface became available, the market for the same service started to explode. In the late 1990s, income from SMS in Finland, the current leader in development and consumption of wireless services, is 20% of the income from cellular telephones in that country. This phenomenon also reflects the trends in change of habits, as user-friendly terminals become available for an old application.

Connection to the wired infrastructure is a very important issue for implementation of a wireless network. In the rest of this appendix, we give a brief description of the evolution of the three major existing wired telecommunications network infrastructures: PSTN, the Internet, and cable TV.

1A.1 Evolution of PSTN and Cellular Telephony

The invention of the telegraph in 1834 started wired data communication, and the invention of telephone in 1876 was the start of analog telephone networking. At

Table 1A.1 A Brief History of Telecommunications

Year	Event
1834	Wired telegraph for manually digitalized data (Gauss & Weber)
1839	First demonstration of telegraph between Washington DC and Baltimore (Morse)
1858	First transoceanic cable for telegraph (second working version in 1866)
1867	Manually switched telephone for analog voice (Bell)
1897	Wireless telegram (Marconi)
1900	Transoceanic wireless telegraph (Marconi)
1905	Radio transmission (Fessenden)
1908	Idea of TV (Campbell-Swinton)
1915	Transcontinental telephone (Bell)
1920	Commercial radio broadcast (KDKA); also sampling in comm (Carson)
1926	TV demonstration (Baird, England, and Jenkins)
1933	FM modulation invented (Armstrong)
1941	TV broadcast starts in the United States
1946	First computer (University of Pennsylvania)
1950	Time division multiplexing (TDM), microwave radio, and voice band modems were used in PSTN
1953	Color TV and transoceanic telephone
1957	First satellite (Sputnik I)
1962	Transoceanic satellite TV (Telstar I)
1965	Videotape (Sony)
1968	Cable TV development
1968	ARPANET started (first node at UCLA)
1971	9600 bps voice band modems (Codex)
1972	Demonstration of cellular systems (Motorola)
1973	Ethernet was invented (Metcalfe); also international ARPANET
1980	Fiber optic systems were applied to the PSTN
1995	Netscape introduced and Internet industry started to evolve as the first popular data communications network competing with the legacy PSTN
Recently	Introducing broadband services (cable modems and xDSL), IP switching, home networking, pervasive networking, and incorporation of positioning systems into wireless networks

that time, operators were used to manually switch or route a session from one terminal to another. At the beginning of 20th century, the telecommunications industry had already been exposed to a number of important issues, which played different roles, culminating in the emergence of modern wireless networks. Among these important issues were analog versus digital, voice versus data, wireless versus wired, local versus long haul communications, and personal versus group services.

Example 1A.1: Cabling

It took 28 years for telegraphy to provide transoceanic services after the first on-land service. On the other hand, it took only three years for wireless telegraphy to become transoceanic after a local installation. This reflects the disadvantages of laying cables for wired communications compared with wireless services. To install a wireline in a town, one needs to get wiring permits which take extremely long processing times; conduct expensive, long, and laborious digging to lay the wire; and maintain a service organization for wiring maintenance. The PSTN has emerged as the expert of these details, and as we will later discuss, all networks that emerged use this expertise in one way or another for developing their own network infrastructure. The telephone service providers have the requisite knowledge for laying wires of three types: first, they know how to connect long-haul networks; second, they know how to provide a twisted pair line to homes and offices; and last, they know how to wire a home or office. Wiring of homes and offices is an expertise shared between telephone companies and electricians.

Example 1A.2: Personal Services

The telegraph infrastructure evolved as a private network not directly accessible to the public user. Each end terminal of a telegraph network supported a community whereas the telephone end terminals supported a home or an office with at most a few users. As a result, the number and the usage periods of the telephone terminal were orders of a magnitude larger than the telegraph network, resulting in a far more prosperous telephone industry. This fact reflects the importance of the extension of a service to the home or even further to the user himself/herself as a personal service. In order to develop an intuitive understanding of the size of the telephone market, it is noteworthy to remember that by the mid-1980s, before AT&T's divestiture, its annual budget was comparable to the budget of the fifth largest economy of the world.

By the 1950s, the PSTN had more than 10 million customers in the United States, and those interested in long-haul communication issues also needed PSTN services to solve their problems. Although end users are still mostly connected to the PSTN with twisted-pair analog lines, to provide flexibility and ease of maintenance and operation of the PSTN, the core network gradually changed to digital switches and digital wired lines connecting switches together. A hierarchy of digital lines (the T-carriers in the United States) evolved as trunks to connect switches of different sizes together.

Another advancement in the PSTN was the development of private branch exchanges (PBXs) as privately owned local telephone networks for large offices. A PBX is a voice-oriented local area network owned by the end organization itself, rather than the telephone service provider. This small switch allows the telephone company to reduce the number of wires that are needed to connect all the lines in an office to the local office of the PSTN. This way, the service provider reduces the number of wires to be laid to a small area where large offices with many subscribers are located. The end user also pays less to the telephone company. The organization thus has an opportunity to enhance services to the end users connected to the PBX.

In the 1920s, Bell Laboratories conducted studies to use the PSTN facilities for data communications. In this experiment the possibility of using analog telephone lines for transferring transoceanic telegrams was examined. Researchers involved in this project discovered several key issues that included the sampling theorem and effects of phase distortion on digital communications. However, these discoveries did not affect applications until after World War II when Bell Laboratories developed voice band modems for communication among air force computers in air bases that were geographically separated by large distances [PAH98]. These modems soon found their way into commercial airlines and banking industries, resulting in the associated private long-haul data networks. These pioneering computer communications networks consisted of a central computer and a bank of modems operating over four-wire commercial grade leased telephone lines to connect several terminals to the computer. In late 1960s, the highest data rate for commercial modems was 4,800 bps. By the early 1970s, with the invention of quadrature amplitude modulation (QAM), the data rate of four-wire voice band modems reached 9,600 bps. In the early 1980s, trellis-coded modulation (TCM) was invented which increased data rates to 19.2 kbps and beyond.

In parallel with the commercial four-wire modems used in early long haul computer networks, two-wire modems emerged for distance connection of computer terminals. The two-wire modems operate over standard two-wire telephone lines, and they are equipped with dialing procedures to initiate a call and establish a POTS line during the session. These modems started at data rates of 300 bps. By the early 1970s, they reached 1,200 bps, and by the mid 1980s, they were running at 9,600 bps. These two-wire voice band modems would allow users in the home and office to have access to a regular telephone to develop a data link connection with a distant modem also having access to the PSTN. Voice band modems using two-wire telephone connections soon found a large market in residential and small office remote computer access (telnet), and the technology soon spread to a number of popular applications such as operating a facsimile machine or credit card verification device. With the popularity of Internet access, a new gold rush for higher speed modems began, which resulted in 33.6 kbps full-duplex modems in 1995 and 56 kbps asymmetric modems by 1998. The 56 kbps modems use dialing procedures and operate within the 4 kHz voice band, but they directly connect to the core pulse code modulated (PCM) digital network of the PSTN that is similar to digital subscriber lines (DSLs). DSLs use the frequency band between 2.4 kHz and 1.1 MHz to support data rates up to 10 Mbps over two-wire telephone lines.

More recently cellular telephone services evolved. To connect a cellular telephone to the PSTN, the cellular operators developed their own infrastructure to support mobility. This infrastructure was connected to the PSTN to allow mobile-to-fixed telephone conversations. The addition of new services to the PSTN demanded increases in the intelligence of the core network to support these services. As this intelligence advanced, the telephone service provider added value features such as voice mail, autodialing through network operators, call forwarding, and caller identification to the basic POTS service traditionally supported. Figure 1A.1 shows a simplified representation of today's PSTN network.

1A.2 Emergence of Internet

Data networks that evolved around voice band modems connected a variety of applications in a semiprivate manner. The core of the network was still the PSTN, but the application was for specific corporate use and was not offered privately to individual users. These networks were private data networks designed for specific applications, and they did not have standard transport protocols to allow them to interconnect with one another. Another irony of this operation was that the digital data was first converted to analog to be transmitted over the telephone network; then within the telephone network, it was again converted to digital format for

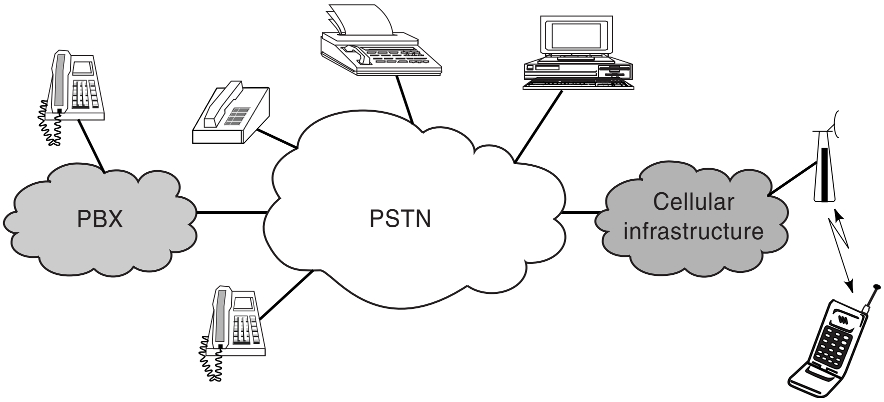

Figure 1A.1 Simplified representation of PSTN and surrounding voice networks.

transmission over long distances using the digital subcarrier system. To avoid this situation, starting in the mid 1970s, telephone companies started to introduce digital data services (DDS) which provided a 56 kbps digital service directly delivered to the end user. The idea was great because at that time the maximum data rate for voice band modems was 9,600 bps. However, like many other good and new ideas in telecommunications, this idea did not become popular. A large amount of capital was already invested in the existing voice band based data networks. It was not practical to replace them at once, and DDS services were not interoperable with the analog modems. The DDS services later emerged as integrated services digital network (ISDN) services providing two 64 kbps voice channels and a 16 kbps data channel to individual users. Penetration rates of ISDN services were not as expected, but laid a foundation for digital cellular services. Digital cellular systems can be viewed as a sort of wireless ISDN technology that integrates basic digital voice with a number of data services at the terminal.

The major cost for operation of a computer network over the four-wire lines was the cost of leasing lines from the telephone company. To reduce the operation cost, multiplexers were used to connect several lower speed modems and carry all of them at once over a higher speed modem operating over a long distance line. The next generation of multiplexers consisted of statistical multiplexers that multiplexed flows of data rather than multiplexing individual modem connections. Statistical multiplexer technology later evolved into router technology, which are generalized packet data switches.

In the early 1970s, the rapid increase in the number of terminals at the offices and manufacturing floors was the force behind the emergence of LANs. LANs provided high-speed connections (greater than 1 Mbps) among terminals facilitating the sharing of printers or mainframes from different locations. LANs provided a local medium specifically designed for data communication that was completely independent from the PSTN. By the mid 1980s, several successful LAN topologies and protocols were standardized, and LANs were installed in most large offices and manufacturing floors connecting their computing facilities. However, the income of the data communication industry, both LANs and public data networks (PDNs), was far below that of the PSTN still leaving the PSTN as the dominant economical force in the information networking industry.

Another important and innovative event in the 1970s was the implementation of ARPANET, the first packet-switched data network connecting 50 cities in the United States. This experimental network used routers rather than the PSTN switches to interconnect data terminals. The routers were originally connected via 56 kbps digital leased lines from the telephone company. This way, ARPANET interconnected several universities and government computers around a large geographic area. This network was the first packet-switched network supporting end-to-end digital services. This basic network later upgraded to higher speed lines and numerous additional networks. To facilitate a uniform communication protocol to interconnect these disparate networks, transmission control protocol/Internet protocol (TCP/IP) evolved that allowed LANs, as well as a number of other PDNs, to interconnect with one another and form the Internet. In the mid 1990s with the introduction of popular applications such as Telnet, FTP, email, and Web browsing, the Internet industry was created. Soon, the Internet penetrated the home market, and the number of Internet users became comparable with that of the PSTN, creating another economical power, namely, computer communications applications, which compete with the traditional PSTN. The IP-based Internet provides a cheaper solution than circuit switched operations, and today people are thinking of employing IP to capture a large share of the traditional telephony market served by the PSTN. The Internet provides a much lower-cost alternative to PSTN for support of multimedia applications. With the growth of the wireless industry in the past two decades, wireless LANs, wireless WANs, and wireless access to the Internet have become very popular.

In a manner similar to cellular telephony, wireless data network infrastructures have evolved around the existing wired data network infrastructures. Wireless LANs are designed mostly for in-building applications to cover a small area, and the network has a minimal infrastructure. Wireless LANs are usually connected to the existing wired LANs as an extension. Mobile data services are designed for low-speed wireless data applications with metropolitan, national, and, global coverage. These networks sometimes have their own infrastructure (e.g., ARDIS, Mobitex), sometimes use the existing cellular infrastructure but their own radio interface (e.g., CDPD), and sometimes use the infrastructure, as well as air-interface, of a cellular telephone service (e.g., GPRS). In all cases ultimately they connect to the Internet and run its popular applications. The 3G systems also provide competing packet-switched service. Figure 1A.2 provides a simplified sketch of the overall data networks surrounding the Internet. As compared with the PSTN, the Internet provides a cheaper and easier means to connect and expand networks. However, the telephone company owns the wires connecting the Internet and the telephone wires that can, among other alternatives, bring the Internet to the home or office.

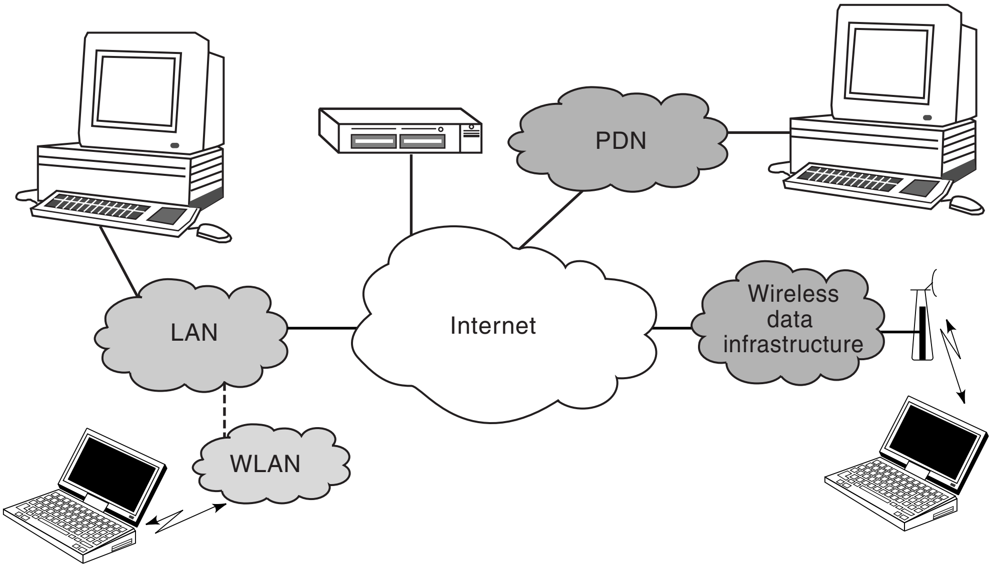

Figure 1A.2 Simplified representation of the Internet and surrounding data networks.

1A.3 The Cable TV Infrastructure

Another competing wired infrastructure that evolved in the last few decades of the 20th century was the cable television network. Installation of cable TV distribution networks in the United States started in 1968 and has penetrated more than 60 percent of the residential homes. This penetration rate is getting close to that of the PSTN. The cable TV network consists of three basic element: a regional hub, a distribution cable bus, and a fiber ring to connect the hubs to one another. Because of the hybrid usage of fiber and cable, this network is also referred to as the hybrid fiber coax (HFC) network. The signals containing all channels at the hub are distributed through the cable bus in a residential area, and each home taps the signal off the bus. This is radically different in many ways from home access through twisted pair wires provided by the PSTN. The bandwidth of the coaxial cable supports about 100 TV channels, each around 6 MHz, whereas the basic telephone channel is around 4 kHz. The extended telephone channel using DSL uses about 1 MHz of bandwidth. The cable access is via a long bus originally designed for a one-way multicast that has a number (up to 500) of taps, creating a less controllable medium. The twisted pair star access for the PSTN is designed for two-way operation and is easier to control. The HFC channel is noisier than the telephone channel, and despite its wider bandwidth, its current supported broadband data rate is at the same range as the digital subscriber line (DSL) services operating on telephone wiring.

Figure 1A.3 shows a general picture of a futuristic HFC and the way it connects to the PSTN and Internet. The cable TV network was also considered a backbone for wireless PCS systems, and it is considered the leading method for broadband home access to support the evolving home networks. Some of the cable TV providers in the United States also offer telephone services over this medium.

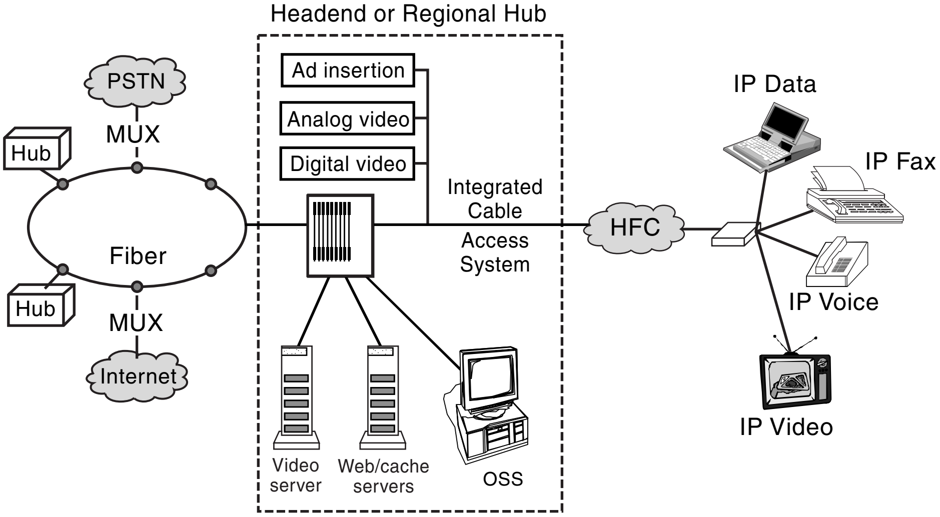

Figure 1A.3 General overview of HFC networks.

In the late 1990s, success of cable in broadband access encouraged some of the PSTN providers, such as AT&T, to acquire cable companies such as MediaOne.

APPENDIX 1B SUMMARY OF IMPORTANT STANDARDS ORGANIZATIONS

Figure 1B.1 provides an overview of the standardization process. The process starts in a group, for example, IEEE 802.11 or GSM, which implements the standard. The implemented standard is then moved for the approval of a regional organiza-

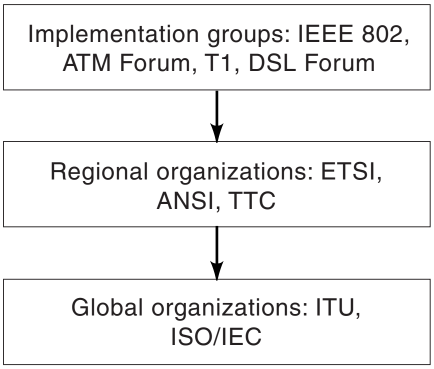

Figure 1B.1 Standard development process.

Table 1B.1 Summary of Important Standards

IEEE: Publishes 802 series standards for LANs and 802.11, 802.15, and 802.16 for wireless applications.
T1: Sponsored by Alliance for Telecommunications Information Solutions (ATIS) telecommunication standards body working on North American standards.
ATM (Asynchronous Transfer Mode) Forum: An industrial group working on a standard for ATM networks.
DSL (Digital Subscriber Loop) Forum: An industrial group working on xDSL services.
CableLab: Industrial alliance in America to certify DOCSIS compatible cable modems.
UNII (formerly SUPERNet): Industrial alliance for unlicensed bands for wireless LANs in 5.2 and 5.7 GHz.
IETF (Internet Engineering Task Force): Publishes Internet standards that include TCP/IP and SNMP. It is not an accredited standards organization.
FCC (Federal Communication Commission): The frequency administration authority in the United States.
EIA/TIA (Electronic/Telecommunication Industry Association): U.S. national standard for North American wireless systems.
ANSI: Accepted 802 series and forwarded to ISO. Also published FDDI, HIPPI, SCSI, and Fiber Channel. Developed JTC models for wireless channels.
ETSI: 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.
TTC (Telecommunication Technology Committee): Japanese national standard organization that approved JTC.
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 United Nations. The Telecommunication Sector, ITU-T, published ISDN and wide area ATM standards. Also works on IMT-2000.

tion such as the European Telecommunications Standards Institute (ETSI) or the American National Standards Institute (ANSI). The regional recommendation is finally submitted to world-level organizations, such as ITU or ISO/IEC, for final approval as an international standard. There are a number of standards organizations involved in wireless networking. Table 1B.1 provides a summary of the important standards playing major roles in shaping the wireless networking industry. This table helps the reader as a reference point while reading the text.

QUESTIONS

1.1 Draw a diagram showing the positioning of wireless networks vis a vis wired networks. Why is a wired network usually part of the wireless infrastructure?

1.2 Differentiate between portability, nomadicity, and mobility.

1.3 How is a wireless network different from a wired network? Explain at least five differences.

1.4 Distinguish between horizontal and vertical applications. Which of these two types of applications will reduce device and service costs? Why?

1.5 Name the four categories of 2G wireless networks and explain how they are related to 3G and WLAN systems.

1.6 What is the difference between the 3G cellular networks and WLANs in terms of frequency of operation, orientation of the application over the network, and supported rates for data services?

1.7 Name the three major telecommunication services that dominate today's commercial services and give the approximate time when they were first introduced.

1.8 Name five mobile data services, data rates supported by them, worldwide coverage, and frequency of operation.

1.9 Name the three major cellular standards in the United States and give the name of their wireless access technology.

1.10 What is the difference between the bandwidth per user of the analog cellular telephone systems in United States, European Union, and Japan? Which one has employed bandwidth-splitting techniques?

1.11 Name five WLAN standards and identify the transmission techniques and supported data rates of each of them.

1.12 Why do PCS standards such as CT-2 and DECT use 32 kbps ADPCM rather than the lower rate speech codes used in digital cellular standards such as GSM or IS-95?

1.13 What is WPAN? What is the difference between WPAN and WLAN? Name two example technologies for WPAN.

1.14 What is the difference between registration and call establishment in a cellular network?

1.15 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?

1.16 What is the difference between connectionless and connection-oriented packet data network protocols?

1.17 Create a kiviat chart like the one shown in Figure 1.5 comparing ARDIS and Metricom with respect to carrier spacing, data rate per carrier, number of channels, and ease of implementation.