CHAPTER 10

INTRODUCTION TO WIRELESS LANs

10.1 Introduction

10.2 Historical Overview of the LAN industry

10.3 Evolution of the WLAN industry

10.3.1 Early Experiences
10.3.2 Emergence of Unlicensed Bands
10.3.3 Products, Bands, and Standards
10.3.4 Shift in Marketing Strategy

10.4 New Interest from Military and Service Providers

10.5 A New Explosion of Market and Technology

10.6 Wireless Home Networking

10.6.1 What Is a HAN?
10.6.2 Why Do We Need a HAN?
10.6.3 HAN Technologies
10.6.4 Home-Access Networks

Questions

Problems

10.1 INTRODUCTION

In the first part of the book, we provided an overview of wireless networks and the fundamental principles involved in their deployment and operation. In the third part of the book, we provided examples of the leading voice-oriented TDMA and CDMA cellular networks, as well as an overview of wide area data networks mostly operating in the licensed bands and designed for wide area coverage. In the fourth part of the book, we look into the wideband local wireless networks operating in unlicensed bands. WLAN were the first technology that was examined for wideband local access. More recently wireless personal area networks (WPAN) have attracted serious attention for local ad hoc wireless networking. Current standardization bodies differentiate a WLAN and WPAN based on their coverage area, data rate, and battery consumption. In practice, however, often WLANs and WPANs are considered as competing options for the implementation of various wireless indoor applications. Wireless LANs evolved in the data-oriented LAN industry and support data rates of up to several tens of Mbps in a coverage area of around 100 meters. The low-powered WPANs cover an order of magnitude smaller area with a maximum data rate of about order of magnitude lower than WLANs. The MAC layer of the popular standards for WLANs and WPANs are either voice- or data-oriented, which also plays a role in selection of a technology for a particular application.

Today the major standards for WLANs are IEEE 802.11 and HIPERLAN. The WPAN activitiy is under IEEE 802.16, which has chosen Bluetooth as the base standard, whereas HomeRF is another option for WPANs. In this chapter we discuss the overview of the WLANs and home networking industries. The next chapter is devoted to the IEEE 802.11 standard followed by a chapter on wireless ATM and HIPERLAN. The WLAN industry emerged as an extension to the wired LAN industry. To understand forces that shaped this industry, we first provide a short overview of the evolution of the wired LAN industry.

10.2 HISTORICAL OVERVIEW OF THE LAN INDUSTRY

The cost of infrastructure in WANs is very high, and the coverage is very wide. As a result, WANs are offered as a charged *service* to the user. The service provider invests a large capital for the installation of the infrastructure and generates revenue through monthly service charges. Local networks are sold as end products to the user, and there is no service payment for local communications.

Example 10.1: PBXs within Organizations

PBX networks are owned by the companies for their local communications. The only time that a company owning a PBX pays the PSTN service provider is when a call goes out of the local area using the service provider's infrastructure. Operation of LANs is very similar to a PBX in that the user owns them and pays monthly charges to the wide area Internet service providers for wide area communications.

The LAN industry emerged during the 1970s to enable sharing of expensive resources such as printers and to manage the wiring problem caused by increasing number of terminals in offices. By the early 1980s three standards were developed: Ethernet (IEEE 802.3), Token Bus (IEEE 802.4), and Token Ring (IEEE 802.5); they specified three distinct PHY and MAC layers and different topologies for networking over thick cable medium but shared the same management and bridging (IEEE 802.1) and LLC (IEEE 802.2). With the growing popularity of LANs in the mid-1980s, high-installation costs of thick cable in the office buildings moved the LAN industry toward using thin cables that are also referred to as "cheapernet." Cheapernet covered shorter distances of up to 185 m compared with the 500 m coverage of thick cables. In the early 1990s the star topology (often referred to as Hub and Spoke LANs), using easy-to-wire TP wiring with coverage of 100 m, was introduced. Figure 10.1 depicts the evolution of the wired LAN from thick to thin and finally TP networks. The interesting observation is that this industry has made a compromise on the coverage to obtain a more structured solution that is also easier to install. Twisted pair wiring, also used by PSTN service providers for telephone wiring distribution in homes and offices for over a hundred years, is much easier to install. The star network topology opened an avenue for structured hierarchical

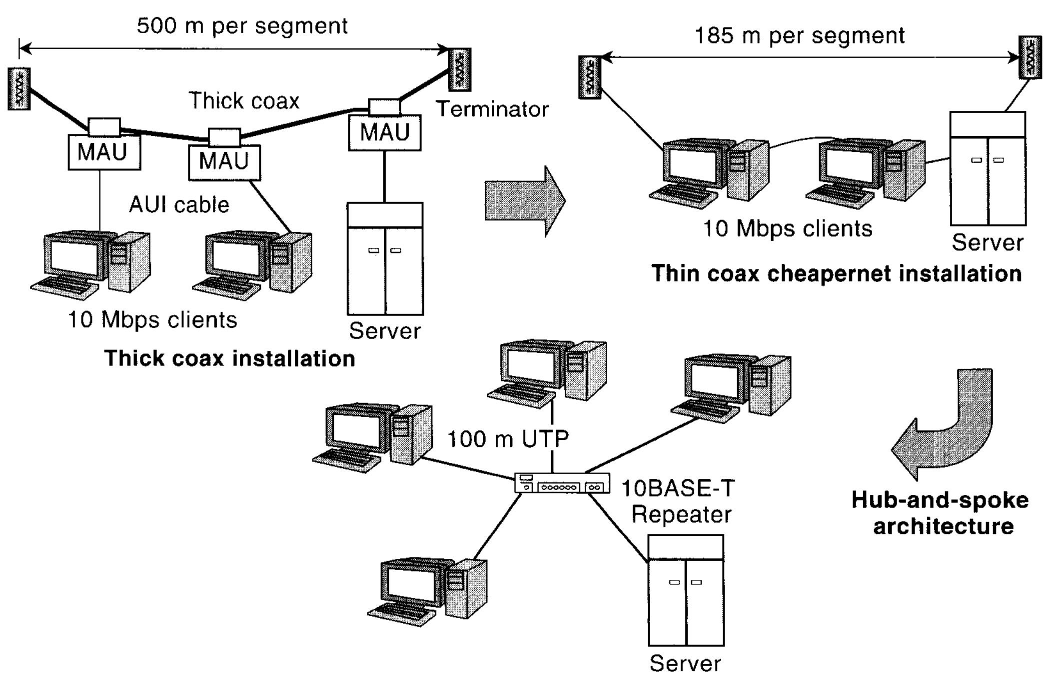

Figure 10.1 Evolution of the LANs from thick to thin cable and then to star topology using TP.

wiring, also similar to the telephone network topology. Today, IEEE 802.3 (Ethernet) using TP wiring is the dominant wired LAN technology.

The data rates of legacy Ethernet—thick, thin, and TP—were all 10 Mbps. The need for higher data rates emerged from two directions; (1) there was a need to interconnect LANs that are located in different buildings of a campus to share high-speed servers, and (2) computer terminals became faster and more capable of running high-speed, multimedia applications. To address these needs, several standards for higher data rate operations were introduced. The first fast LAN operating at 100 Mbps was the fiber distributed data interface (FDDI) that emerged in the mid 1980s as a backbone medium for interconnecting LANs. The ANSI published this standard directly. In the mid-1990s, 100 Mbps fast Ethernet was developed under IEEE 802.3 and 100VG-AnyLAN under IEEE 802.12. In the late 1990s, IEEE 802.3 approved the Gigabit Ethernet. All these high-speed LANs use multiple TP wiring to support faster transmission.

Example 10.2: Hierarchical TP Wiring in LANs

Figure 10.2 shows an example of a hierarchical wiring of a LAN. A variety of 10 and 100 Mbps terminals are connected with two levels of switches and repeaters to a router that connects the LAN to the rest of the world.

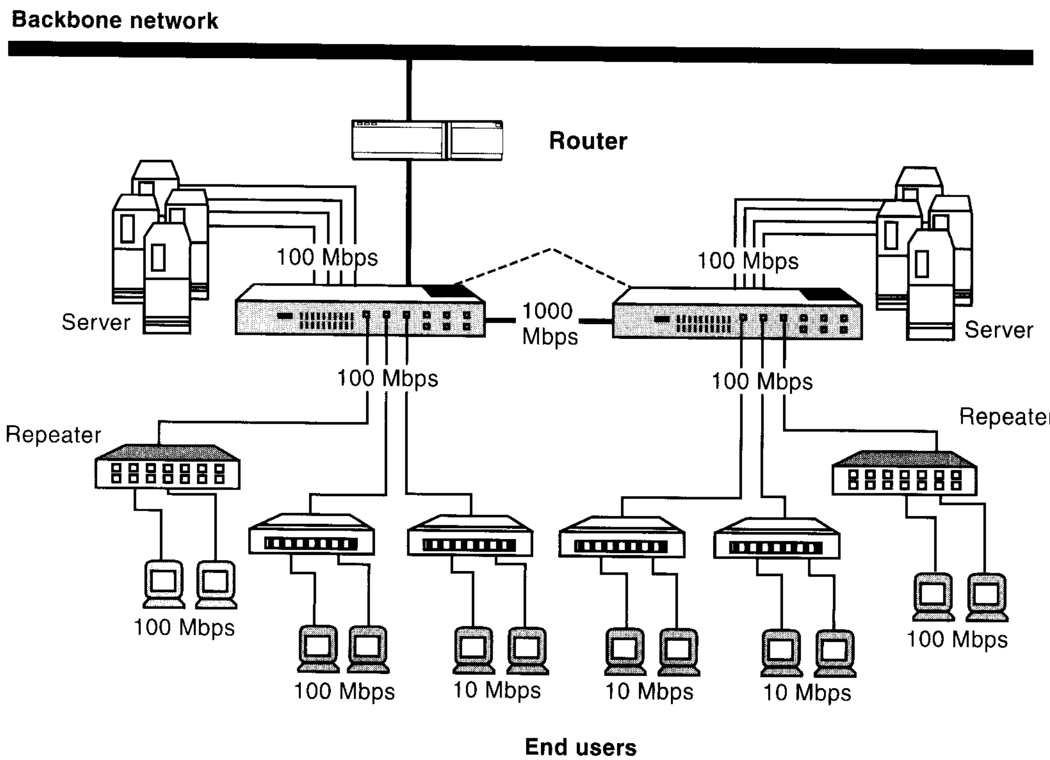

Figure 10.2 Hierarchical LANs [STA00].

In the mid 1990s when most people in the telecommunication industry believed that ATM would take over the entire emerging multimedia communications industry, ATM LAN emulation (LANE) was initiated. The purpose of ATM LANE was to adapt the existing legacy LAN infrastructures and applications to the then perceived end-to-end ATM network. The main technical challenge in implementing LANE was the adaptation of a connectionless legacy LAN to a connection-oriented ATM network. Details of the variety of LANs are available in [STA00]. More recently, a new wave of LANs is emerging for home applications that will be treated separately later on in this chapter.

In summary, the LAN industry has developed a number of standards, mostly under the IEEE 802 community. Figure 10.3 shows an overview of the important IEEE 802 community standards. The 802.1 and 801.2 parts are common for all the standards, 802.3, 802.4 and 802.5 are wired LANs, and 802.9 is the so called ISO-Ethernet that supports voice and data over the traditional Ethernet mediums. IEEE 802.6 corresponds to metropolitan area networking and the IEEE 802.11, 15, and 16 are related to wireless local networks. The IEEE 802.14 is devoted to cable modem–based networks providing Internet access through cable TV distribution networks operating over coaxial cable wiring and fiber originally installed for TV distribution. The IEEE 802.10 is concerned with security issues and operates at higher layers of the protocols. The existing LANs can be logically divided into four generations:[1] first generation legacy LANs, 802.3 and 802.5, that provided terminal-to-host connectivity and client-server architectures at moderate data rates of around 10 Mbps in offices; second generation LANs such as FDDI that responded to the need for backbone LANs and support of high-performance workstations;

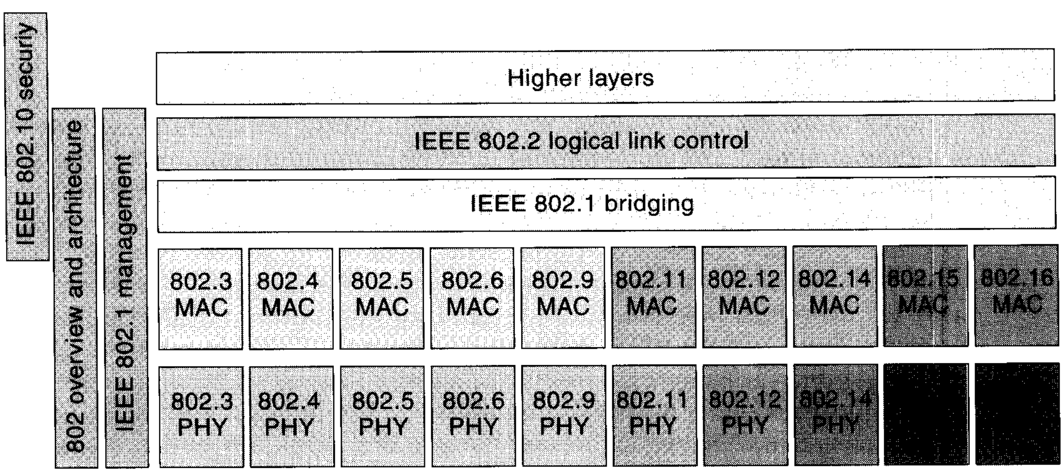

Figure 10.3 IEEE 802 standard series.

[1]The reader should not confuse these LAN generations with the generations in cellular systems.

third generation LANs such as ATM-LANE, Fast Ethernet, Gigabit Ethernet, and 100VG-AnyLAN that were designed for high throughput with delay control for multimedia applications; and fourth generation LANs such as IEEE 802.14 and the home phone-networking alliance (HPNA) that support networking in residences and home access and distribution. The two major drives of this industry have always been the ease of installation and increase of data rate.

10.3 EVOLUTION OF THE WLAN INDUSTRY

During the past two decades, as the vision of the WLAN industry evolved, WLANs were implemented based on a variety of innovative technologies and raised a lot of hopes for development of a sizable market several times. Today, the major differentiation of WLANs from wide area cellular services is the method of delivery of data to users, data rate limitations, and frequency band regulation. Cellular data services are delivered by operating companies as services, whereas the WLAN users belong to the organization that owns the network. At the time when the 3G cellular industries are striving for 2 Mbps packet data services, WLAN standards are working on 54 Mbps services. Another differentiation with other radio networks is that today almost all WLANs operate in the unlicensed bands where frequency regulations are loose and there is no charge or waiting time to obtain the band. To obtain a deeper understanding of all these issues, it is very educational to go over the history of the WLAN industry to see how all of these unique issues evolved.

10.3.1 Early Experiences

Gfeller at the IBM Rüschlikon Laboratories in Switzerland first introduced the idea of a WLAN in late 1970s [GFE80]. The number of terminals in manufacturing floors was growing and wiring them in that environment was difficult. In offices, wires are normally snaked under the suspended ceilings and through the interior partitions and walls, but these options are not available in manufacturing floors. In office environments, in extreme cases, it is possible to install wiring under the floor, using conduits, or even simply left over the floor with some cover. In manufacturing floors, the environment is rugged; under floor wiring is more expensive; and simply leaving wires on the floor is can be dangerous because heavy machinery may roll over them. The diffused IR technology was selected at IBM labs for the implementation of a WLAN to avoid interference with the electromagnetic signals radiating from machinery and to avoid dealing with long-lasting administrative procedures with frequency administration agencies. The principal researcher of this project abandoned the project because the goal of 1 Mbps with reasonable coverage did not materialize.

Ferrert at HP's Palo Alto Research Laboratories in California performed the second project on WLANs around the same time [FER80]. In this project a 100 kbps DSSS WLAN operating around 900 MHz was developed for office areas that used CSMA as the method of access. This project was conducted under an experimental license agreement from the FCC. The principal of this project failed to obtain the necessary frequency bands from the FCC, and discouraged with the administrative complexity, he also abandoned his project. A couple of years later, Codex, Motorola attempted to implement a WLAN at 1.73 GHz, and that project was also abandoned after negotiations with the FCC.

Although all the pioneering WLAN projects were abandoned, WLANs continued to attract attention, and negotiations continued with the FCC to secure frequency bands for this purpose [PAH85]. These projects revealed several important challenges facing the WLAN industry that remain to this day:

1. *Complexity and cost:* The alternatives for implementing WLANs such as IR, spread spectrum, or traditional radios are far more complex and diversified than the wired LANs.
2. *Bandwidth:* Data rate limitations of the wireless medium are more serious than those of wired media.
3. *Coverage:* The coverage of a WLAN operating within a building is less than that of a single cable (bus or ring) or even TP-based LANs.
4. *Interference:* WLANs are subject to interference from other overlaid WLANs or other users operating in the same frequency bands.
5. *Frequency administration:* Radio-based WLANs are subject to expensive and untimely frequency regulations.

10.3.2 Emergence of Unlicensed Bands

Wireless LANs need a bandwidth of at least several tens of MHz though they have not yet shown a market compatible in strength with the cellular voice industry that originally started with two pieces of 25 MHz bands that produced a huge market. Comparable sizes of bands for PCS applications were auctioned in the United States for tens of billions of dollars though the market for WLANs has not yet passed a billion dollars per year. The dilemma for the frequency administration agencies was to justify a frequency allocation for a product with a weak market.

In the mid-1980s, the FCC found two solutions for this problem. The first and the simplest solution was to avoid the 1–2 GHz bands used for the cellular telephone and PCS applications and approve higher frequencies at several tens of GHz where plenty of unused bands were available. This solution was first negotiated between Motorola and the FCC and resulted in Motorola's Altair, the first wireless LAN product operating in licensed 18–19 GHz bands. Motorola had actually established headquarters to facilitate user negotiation with the FCC for the usage of WLANs in different areas. A user who changed the location of operation of his/her WLAN substantially (from a town to another) contacted Motorola, and they would manage the necessary frequency administration issues with the FCC.

The second and more innovative approach was resorting to unlicensed frequency bands as the solution. In response to the applications for bands for WLAN projects mentioned in the previous section and motivated by studies for various implementations of wireless LANs [PAH85], Mike Marcus of the FCC initiated the release of the unlicensed ISM bands in May 1985 [MAR85]. The ISM bands were the first unlicensed bands for consumer product development and played a major role in the development of the WLAN industry. In simple words licensed and unlicensed bands can be compared with private backyards and public gardens. If one can afford it, he or she can own a private backyard (licensed band) and arrange a barbeque dinner (a wireless product). If one cannot afford to buy a house with a backyard, he or she simply moves the barbeque party to the public park (unlicensed band) where he/she should observe certain rules or *etiquette* that allows others to share the public resource as well. The rules enforced on ISM bands restricted the transmit power to 1 W and enforced the modems radiating more than 1 mW to employ spread spectrum technology. It was believed that spread spectrum communications would restrict interference and allow coexistence of several wireless applications in the same band. Table 10.1 provides a summary of the important features of the ISM bands.

10.3.3 Products, Bands, and Standards

Encouraged by the FCC ruling [MAR85] and some visionary publications in wireless office information networks summarizing previous works and addressing the future directions in this field [PAH85, PAH88, KAV87], a number of WLAN product development projects mushroomed almost exclusively over the North American continent. By the late 1980s the first WLAN products using three different technologies, licensed bands at 18–19 GHz, spread spectrum in the ISM bands around 900 MHz, and IR, appeared in the market. At around the same time, a standardization activity for WLANs under IEEE 802.4L was initiated that was soon converted into the independent IEEE 802.11 that was finalized in 1997! The early products consisted of shoe box sized APs and receiver boxes or PC installed cards that could connect workstations to LANs wherever wiring difficulties for the LANs justified using a more expensive WLAN connection. Today, we call this application LAN-extension [PAH94], [PAH95]. Market predictions at that time were estimating a shift of around 15 percent of the LAN market to WLANs that would generate a few billion dollars of sale per year by the first few years of the 1990s. In May 1991, to create a scientific forum for the exchange of knowledge on WLANs, the first IEEE-sponsored WLAN workshop was organized concurrent to the 802.11 meeting, in Worcester, Massachusetts [WOR91].

In 1992, as a follow up to the initial momentum for WLAN developments, lead by Apple, an industrial alliance called WINForum was formed aiming at obtaining more unlicensed bands from FCC for the so called Data-PCS activities. WINForum finally succeeded in securing 20 MHz of bandwidth in the PCS bands that was divided into two 10 MHz bands—one for isochronous (voice like) and one for asynchronous (data type) applications. The original aim of WINForum was to secure 40 MHz for asynchronous applications. WINForum also defined a set of rules or *etiquettes* for these bands that would allow the coexistence. Figure 10.4

Table 10.1 Properties of the ISM Bands

- Frequencies of operation: 902–928 MHz; 2.4–2.4835 GHz; 5.725–5.875 GHz
- Transmit power limitation of 1 W for DSSS and FHSS
- Low power with any modulation

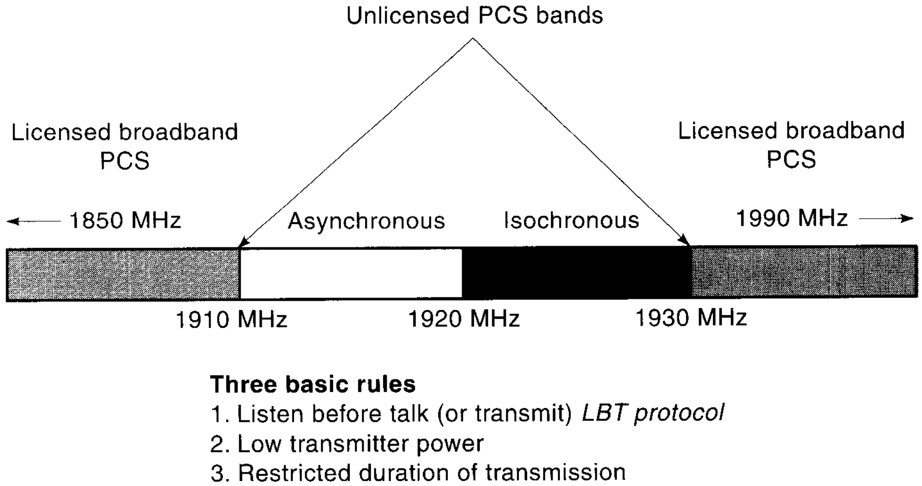

Figure 10.4 Unlicensed PCS bands and their spectrum etiquette.

shows the unlicensed PCS bands and the spectrum etiquette associated with them. The WINForum etiquette is based on CSMA rather than CDMA and spread spectrum communications used in ISM bands. This was a better choice because implementation of CDMA needed power control and larger bandwidth that was not feasible in uncoordinated, multiuser, multivendor WLANs and spread spectrum without CDMA offers a less bandwidth efficient solution.

Another standardization activity started in 1992 was the HIPERLAN. This ETSI based standard aimed at high performance LANs with data rates of up to 23 Mbps that was an order of magnitude higher than the original 802.11 data rates of 2 Mbps. To support these data rates, the HIPERLAN community was able to secure two 200 MHz bands: 5.15–5.35 GHz and 17.1–17.3 GHz for WLAN operation. This encouraged the FCC to release the so-called U-NII bands in 1997 when the original HIPERLAN standard (now called HIPERLAN-1) was completed. Table 10.2

Table 10.2 Properties of the U-NII bands

Band of Operation	Maximum Tx Power	Max. Power with Antenna Gain of 6 dBi	Maximum PSD	Applications: Suggested and/or Mandated	Other Remarks
5.15–5.25 GHz	50 mW	200 mW	2.5 mW/MHz	Restricted to indoor applications	Antenna must be an integral part of the device
5.25–5.35 GHz	250 mW	1,000 mW	12.5 mW/MHz	Campus LANs	Compatible with HIPERLAN
5.725–5.825 GHz	1,000 mW	4,000 mW	50 mW/MHz	Community networks	Longer range in low-interference (rural) environs

summarizes the U-NII bands and their restrictions. The WINForum etiquette was evaluated for the U-NII bands, but it was found not be suitable because research activities around that time favored wireless ATM that could not operate on a listen-before-talk etiquette. Today, U-NII bands are used by IEEE 802.11a and HIPERLAN-2 projects for the implementation of 54 Mbps OFDM-based WLANs. Table 1.8 in Chapter 1 provides a summary of the WLAN standards under IEEE 802.11 and HIPERLAN activities.

10.3.4 Shift in Marketing Strategy

In the first half of the 1990s, WLAN products were expecting a sizable market of around a few billions of dollars per year for shoebox-size products used for LAN-extension application in indoor areas. This did not materialize. Under this situation, two new directions for product development emerged. The first and the most simple approach was to take the existing shoebox-type WLANs, boost up their transmitted power to the maximum allowed under regulations, and equip them with directional antennas for outdoor interbuilding LAN interconnects. These technically simple solutions would allow coverage of up to a few tens of kilometers with suitable rooftop antennas. The new inter-LAN wireless bridges could connect corporate LANs that were within range. The cost of the inter-LAN wireless solution was much cheaper than the wired alternative, T1-carrier lines, leased from the PSTN service providers. The second alternative was to reduce the size of the design to a PCMCIA WLAN card to be used with laptops that were enjoying a sizable growth and demanded mobility for LAN connectivity. This approach was not available for all existing products, and it was more suitable for the spread spectrum products operating in lower frequencies. Figure 10.5 illustrates these three applications for the WLANs. Recently, there are new low-cost products for LAN extension that can convert a serial port or Ethernet connector to a WLAN interface for desktop PCs and workstations that operate at 11 Mbps.

The original marketing strategy for LAN-extension application was indeed a horizontal one aiming at selling individual WLAN components directly to the customers. Another major shift in the marketing strategy of a few successful companies in the mid 1990s was the move toward vertical markets where a wireless network was sold as a complete solution to an application. The major vertical markets approached by the WLAN industry were *"barcode" industries* providing a wireless inventory check and tracking in warehouses and manufacturing floors, *financial services* providing for wireless financial updates in large stock exchanges, *health care* networks providing wireless mobile services inside the hospitals, and *wireless campus area networks* (WCANs) providing for wireless classrooms and offices. All these efforts boosted the market for the WLAN to above half a billion dollars per year over the last few years of the 1990s.

Example 10.3: A WCAN in WPI

Figure 10.6 illustrates the schematic of an experimental NSF-sponsored WCAN that was design as a testbed for performance monitoring of WLAN products at CWINS, WPI in 1996. The testbed connects five buildings with inter-LAN bridges using different technologies. Inside each building APs provide coverage to the laptops that are carried by the students. The professor broadcasts his image

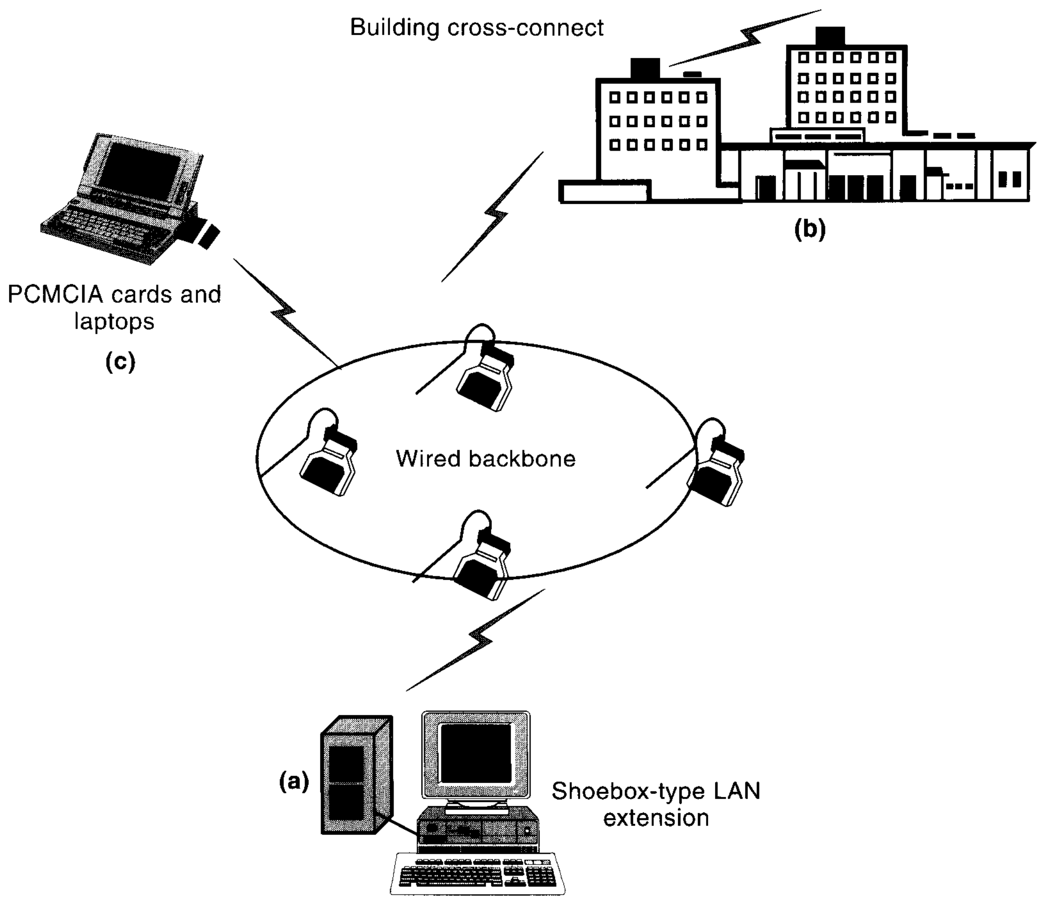

Figure 10.5 Different forms of WLAN products: (a) LAN-extension, (b) Inter-LAN bridge, and (c) PCMCIA cards for laptops.

and writing on the electronic board to allow students to participate in the wireless classroom from different buildings in the campus. The entire wireless network is connected to the backbone through a router to isolate the traffic for traffic monitoring experimentations.

Today the horizontal market for the WLAN industry is mainly focused on WLANs as an alternative to wiring additional LAN segments wherever the cost of the WLAN is justifiable. One example of this situation is installation with frequent relocations where the additional cost of the WLAN solution is justified by the relocation costs of the wired solution. Temporary networking situations such as registration sites in conferences or fairs (jobs, food, etc.) is another example where a wireless solution is preferred to the expensive but more reliable wired alternative. Buildings with difficult or impossible-to-wire situations, such as marble buildings or historical monuments where drilling for wiring is not favored, provide another example of situations where WLANs are justified. The most popular incentive for WLANs is the general use in the laptops in the home and in offices.

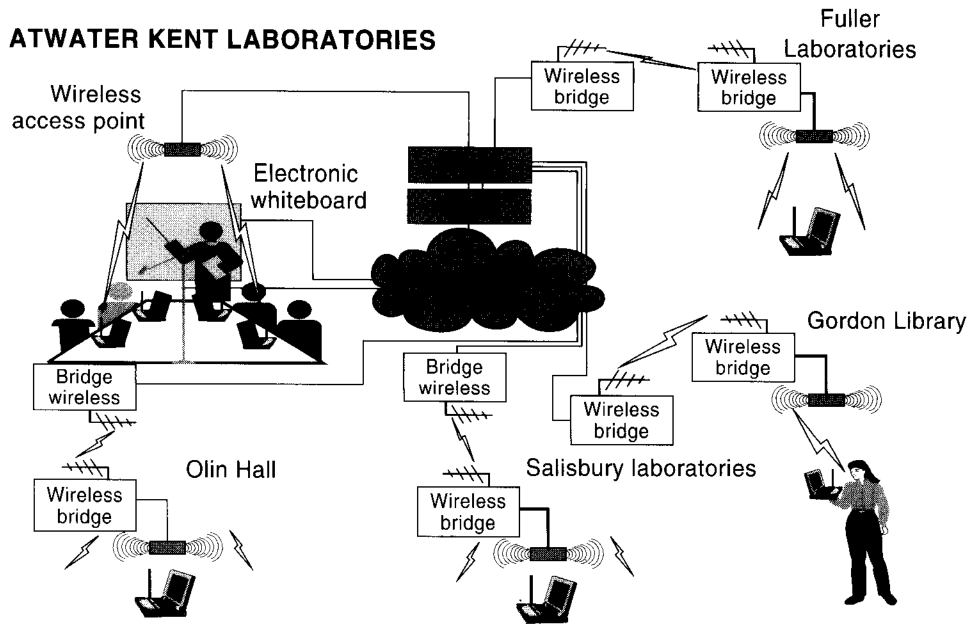

Figure 10.6 The experimental NSF-sponsored WCAN at Worchester Polytechnic Institute.

10.4 NEW INTEREST FROM MILITARY AND SERVICE PROVIDERS

In the mid-1990s, when the WLAN industry was struggling to find a market, a new wave of interest for WLAN was initiated in the United States for military applications and in the European Union (EU) for commercial applications. These projects poured a considerable amount of research investments in this field that further brightened the future of this industry [PAH97]. The incentive for the military was to discover new horizons for implementation of global mobile military networks that support integration with computing and positioning systems. Some examples of these projects will further clarify the situation.

Example 10.4: The InfoPAD Project

The InfoPAD project in the University of California, Berkeley was one of the early WLAN DARPA projects. Figure 10.7 represents the general application concept in this project. The environment is like a battleship equipped with a number of computing facilities. Soldiers in the environment are carrying InfoPADs that are small asymmetric communication devices carrying user instructions to the computing backbone to initiate computational operations whose results are downloaded to the PAD. The challenge in this project was the implementation of a PAD with a reasonable size and integration of multimedia applications in such a device [BRO98].

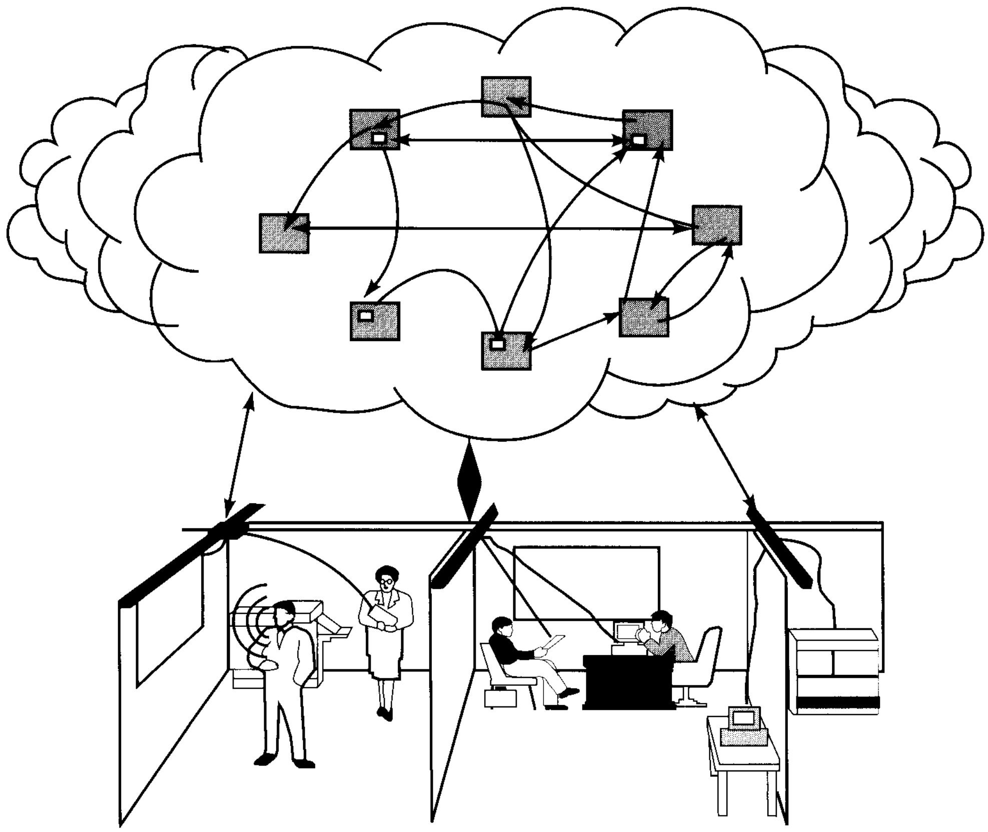

Figure 10.7 Fusion of computers and communications in the InfoPAD project at the University of California, Berkeley.

Example 10.5: The BodyLAN Project

The BodyLAN [BAR96] project sponsored by DARPA was initiated at BBN in Cambridge, Massachusetts. Figure 10.8 illustrates the operation of a BodyLAN. This project intended to design a low-power network that can monitor the vital information about the body conditions (heartbeat, temperature, etc.) and communicate it with nearby soldiers. As we will see later, the concept of this project motivated some of the work in the IEEE 802.15 WPAN activities.

Example 10.6: The SUO/SAS Project

A more recent DARPA project was the Small Unit Operations Situation Awareness Systems (SUO/SAS) [WIL01] that was aiming at an integrated telecommunication and geolocation network for modern fighting scenarios. Among the technical challenges in this project was the accurate indoor positioning [PAH98] that allows situation awareness information to be communicated with the war

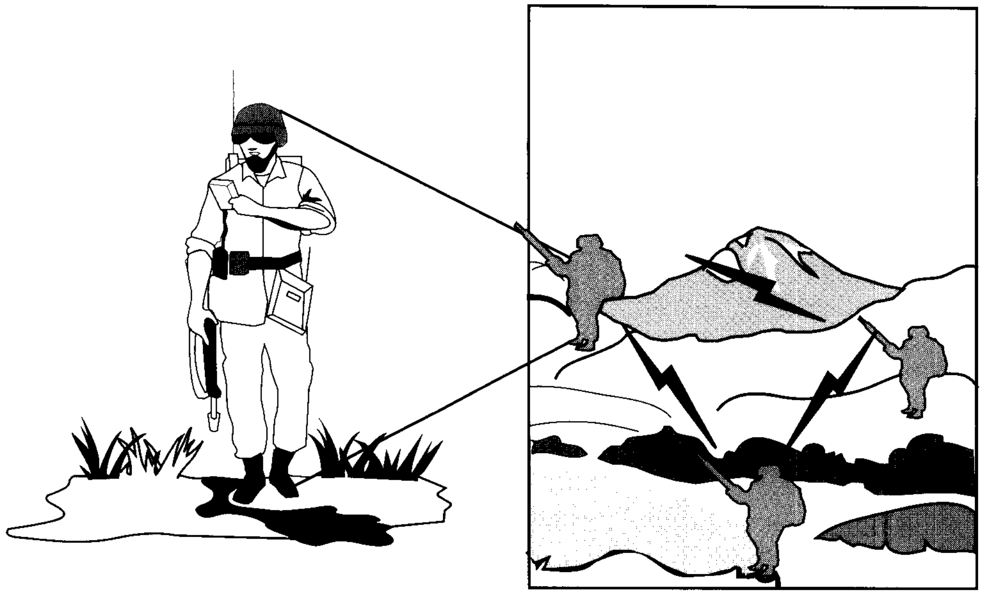

Figure 10.8 BodyLAN or wearable LAN.

fighters. Figure 10.9 provides a scenario for operation of such systems in urban area fighting. This system expects to provide a full communication and positioning link to a soldier operating inside a building.

Equipment manufacturers for service providers initiated the commercial interest of the European Union in WLANs. They were keen on incorporation of higher data rate services into the evolving rich cellular industry. In the mid-1990s, both commercial service providers and military network designers believed that the future of the backbone networks would be an end-to-end ATM based network. The technical impact of this perception of the wideband local networking industry was the start of the wireless ATM movement that we discuss in detail in the following chapters. From the application point of view, service providers intend to integrate WLAN products into their existing services. One popular scenario used by the HIPERLAN-2 project to represent the service providers' point of view is shown in Figure 10.10. In this scenario it is assumed that a WLAN user carries his/her laptop in the office, home, and public places (airports, train stations, etc.). In the home and the office, a laptop is connected to the free network whose infrastructure is owned by the user or his company. In public buildings or other places, either the service provider has a WLAN AP that provides high-speed access or there is a backbone wireless WAN that supports the connection with a lower data rate. In all public places, the service provider who owns the infrastructure will charge the user. One of the technical challenges for implementation of this scenario is the vertical roaming among different networks [PAH00a]. Another challenge is

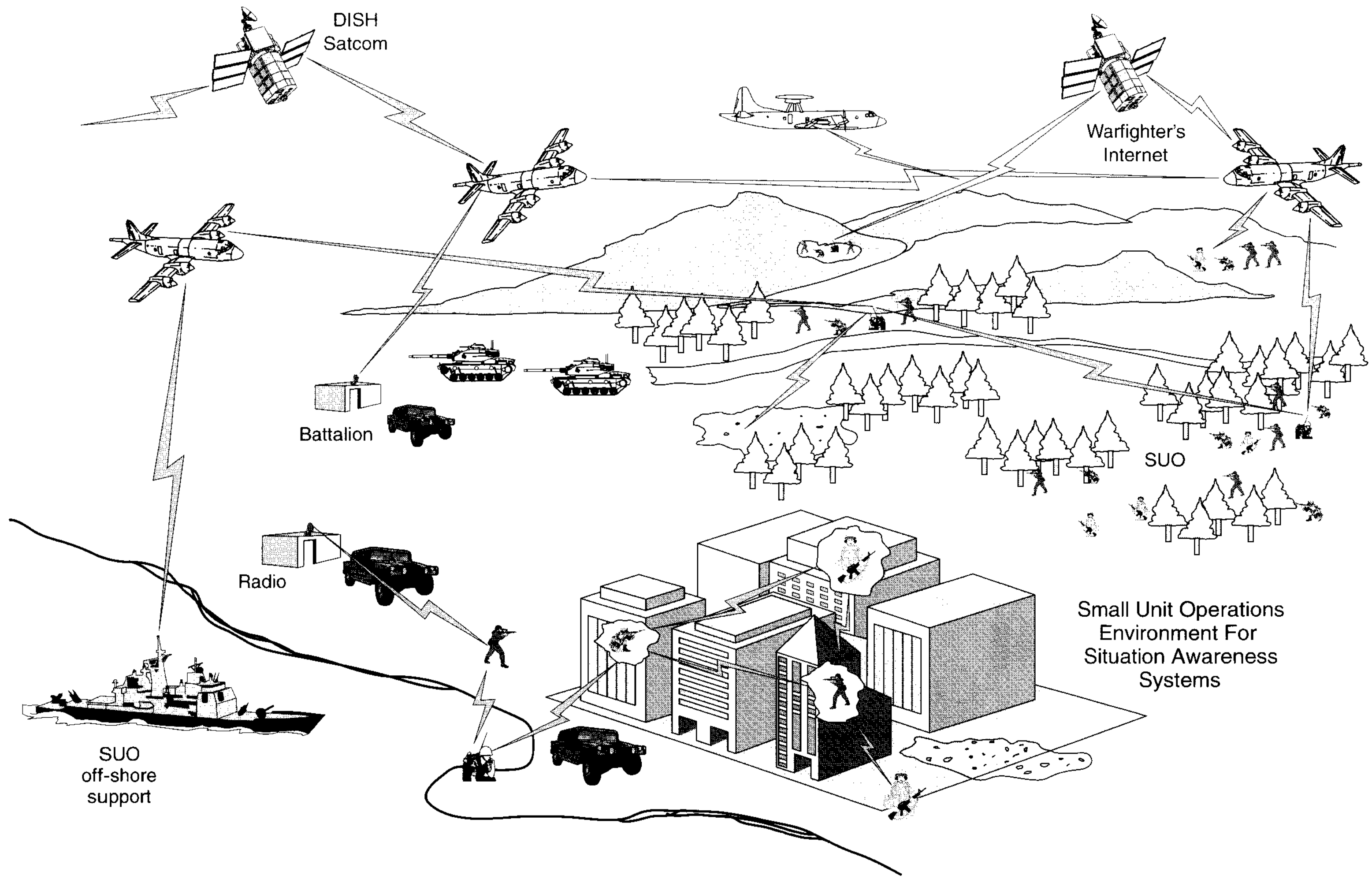

Figure 10.9 The urban/outskirts combat scenario for the SUO-SAS project.

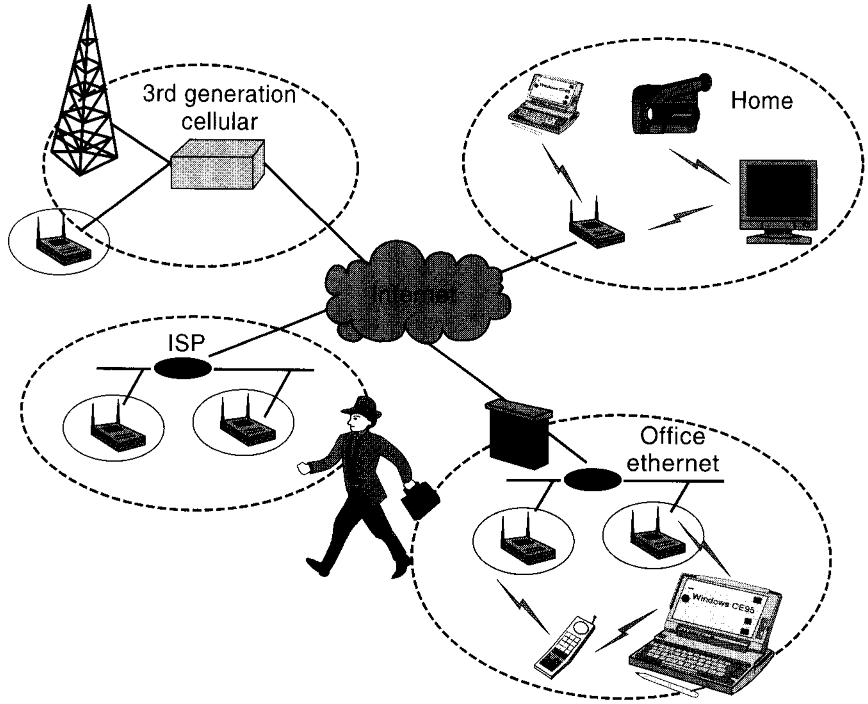

Figure 10.10 Service providers' view of the LANs.

to incorporate roaming and tariff mechanisms for WLANs. These issues are currently under investigation. It is interesting that commercial service with WLANs is now available in big airports in North America such as Dallas–Fort Worth.

10.5 A NEW EXPLOSION OF MARKET AND TECHNOLOGY

In the last couple of years of the 1990s, a new explosive growth of interest stimulated the WLAN industry. The WLAN industry that owned an almost exclusively North American market with an income only equal to a fraction of the cellular industry has suddenly attracted widespread attention in Japan and the European Union and renewed interest in the United States hoping for a sizable market comparable with that of the cellular industry. In Japan, small office spaces promoted usage of laptops replacing desktop PCs. A natural networking solution for laptops is nothing but WLANs. In the European Union, the rich cellular industry started considering WLANs as a part of their next generation of high-speed packet data services. The interest is twofold, WLANs provide a practical higher speed solution, and they operate in the unlicensed bands that are free of charge though the cost of the licensed bands are constantly increasing. In the North American continent the successful growth of broadband Internet access to homes has opened a new window for

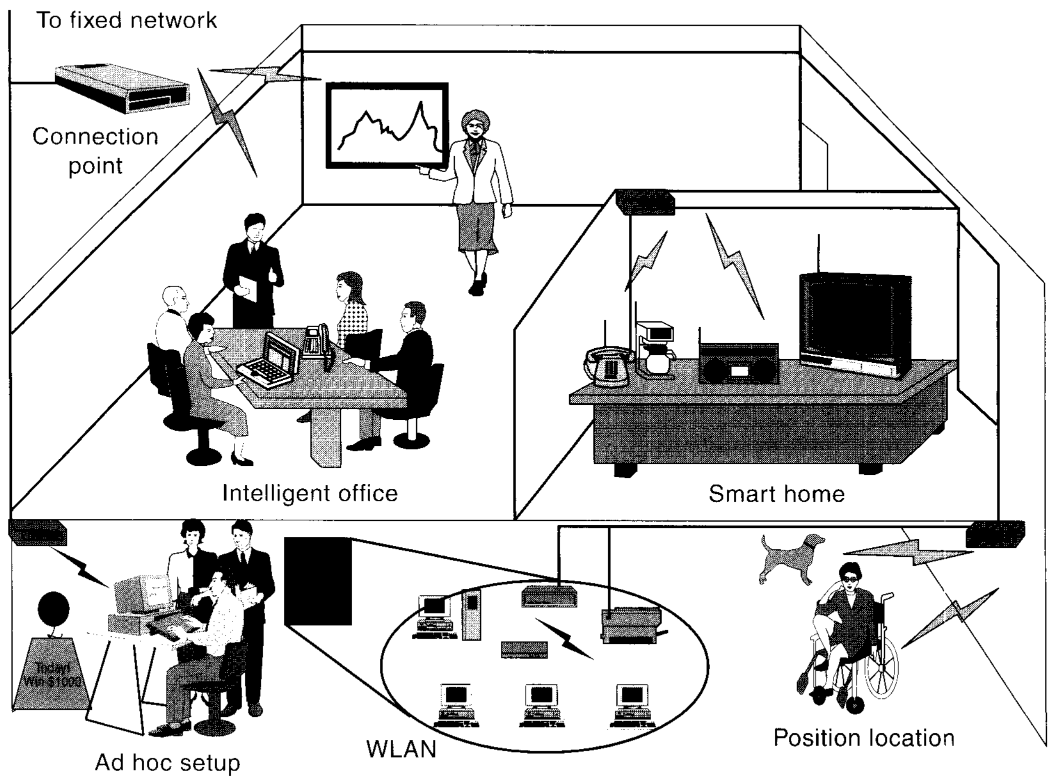

Figure 10.11 Wireless networks: 2000 and beyond.

a sizable market in home networking. These trends have been further catalyzed by the emergence of new low power personal area ad hoc wireless networking technologies such as Bluetooth and UWB for local distribution, LMDS for home access, and indoor positioning for a variety of applications. Availability of low-power, low-cost wireless chip sets started a new revolution in consumer product development raising hopes of sales exceeding hundreds of millions of these chip sets per year. All together these hopes initiated a *Gold Rush* in chip manufacturing for WLAN and WPAN applications that still continues. As far as technical directions in this industry are concerned, they continue to be toward providing higher data rates, comprehensive coverage, less interference, and lower cost. Figure 10.11 provides a visionary figure of the evolving applications for WLAN and WPAN networks.

10.6 WIRELESS HOME NETWORKING

Figure 10.12 illustrates the typical networking connections in most residences. The residence is connected to the PSTN for telephone services, the Internet for Web access, and a cable network for multichannel TV services. Within the home,

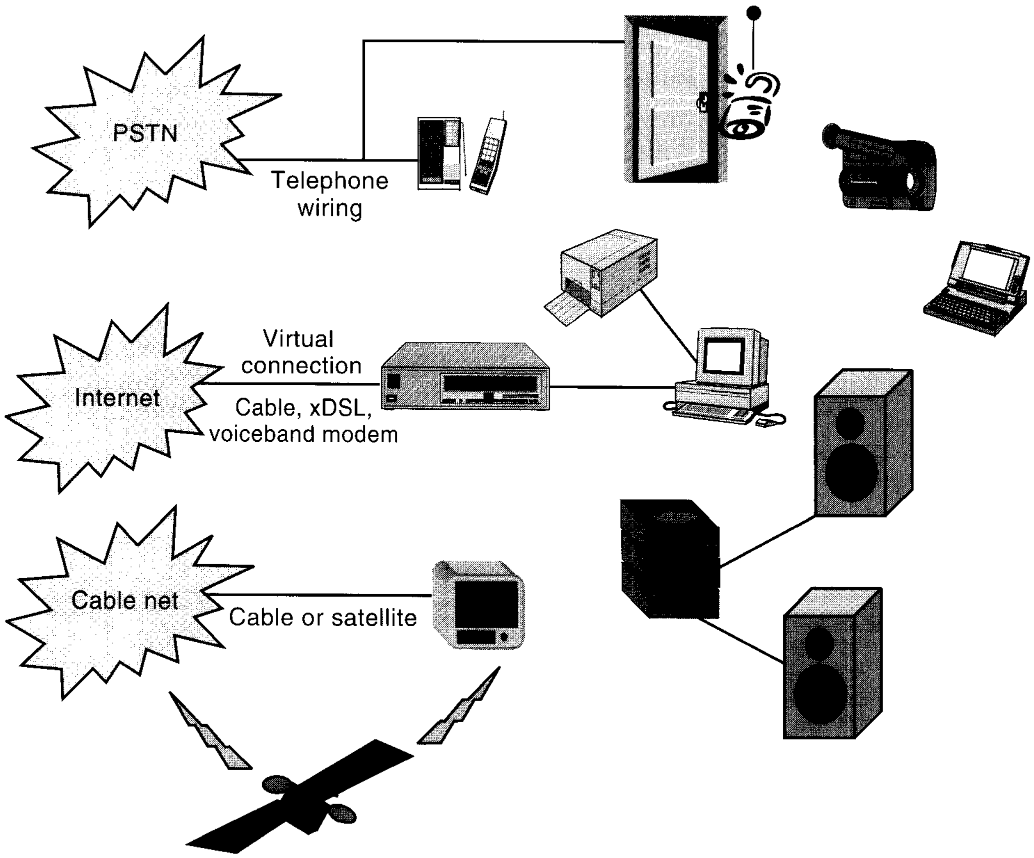

Figure 10.12 Today's fragmented home access and distribution networks.

computers and printers are connected to the Internet through voiceband modems, xDSL services, or cable modems. The telephone services and security systems are connected through PSTN wiring. The TV is connected to multichannel services through HFC cables or satellite dishes. The audio and video entertainment equipment such as video cameras and stereo systems and other computing systems such as laptops are either isolated or have proprietary wired connections. This fragmented networking environment has prompted a number of recent initiatives to create a unified home network. The home networking industry started in the last years of the 1990s by the design of the so-called home or residential gateways to connect the increasing number of information appliances at home through a single Internet connection.

Figure 10.13 shows the growth prediction for the home networks. The number of home networks in the United States is expected to almost double each year. As shown in Figure 10.14, this industry has two distinct segments, home access and home distribution. The home access technology employs different wireless and

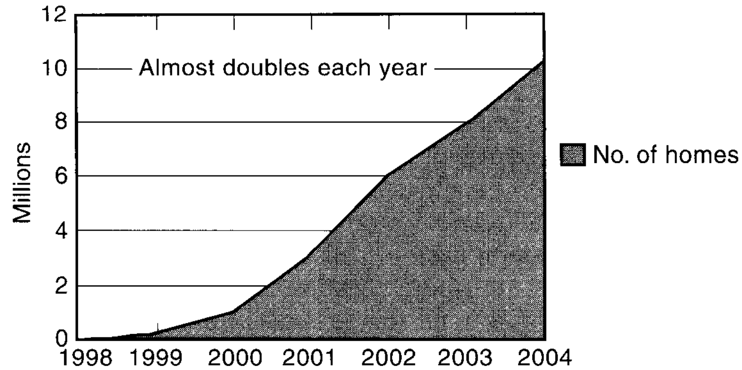

Figure 10.13 Growth of the home networking industry.

wired alternatives to secure a broadband Internet access to the home gateway to be distributed to the user's information appliances. The home distribution or home area network (HAN) interconnects all home appliances and connects them to the Internet through the home gateway. As far as access is concerned, it is expected that 80 percent of U.S. households will have a broadband data access by the year 2002. It is expected that the number of sold "information appliances" will exceed the sold number of PCs by the year 2002. It is also expected that to interconnect PCs and information appliances to the broadband services, 10 million home networks will be installed by the year 2004.

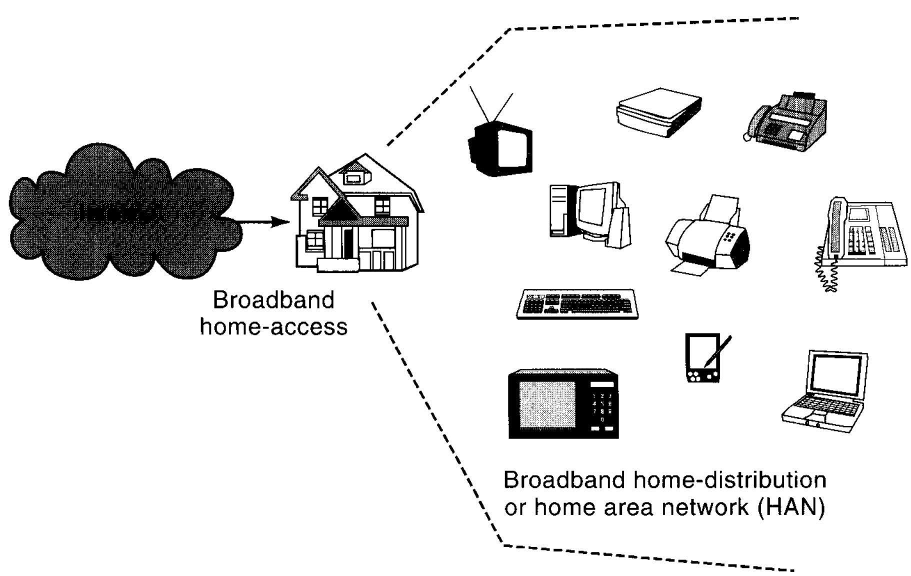

Figure 10.14 Two basic technologies needed for home networking.

10.6.1 What Is a HAN?

The HAN provides an infrastructure to interconnect a variety of home appliances and enable them to access the Internet through a central home gateway. A number of home appliances are emerging in the market that are in need of a HAN. Figure 10.15 provides an overview of these appliances classified into logical groups.

Home computing equipment, used for computing and Internet transaction interface access, includes PCs, laptops, printers, scanners, and Web cameras. If there is no home distribution network, all the equipment is connected together either through the PC or laptop ports. A home computing network allows multiple computers as well as multiple devices to connect with a network protocol. A wireless network allows flexibility in installation and relocation of these devices in different rooms of a home.

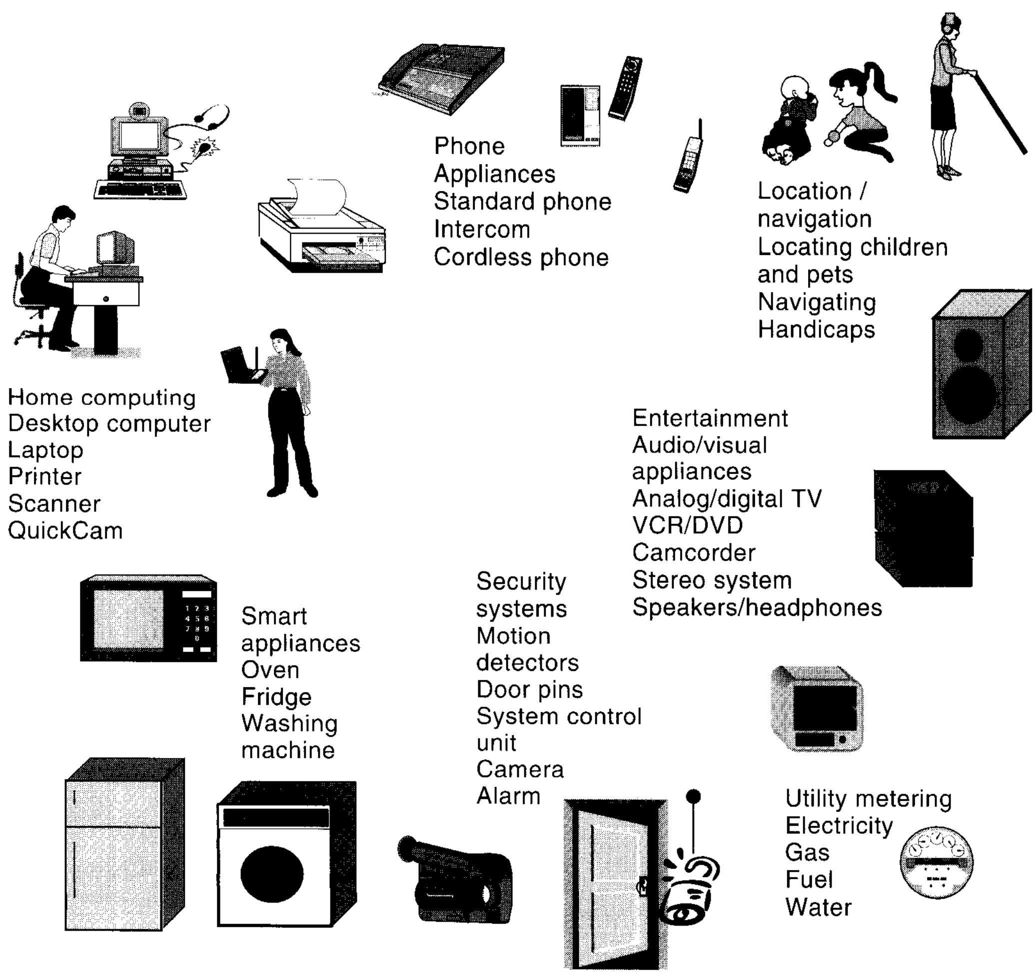

Figure 10.15 Classification of home equipment demanding networked operation.

Phone appliances, used for two-way conversations, include cordless telephones, intercom devices, and standard wired telephone sets. All telephone services have an interface to communicate with the PSTN. Currently they are connected through the home telephone wiring to the PSTN. With a HAN, these devices can share the home access medium (cable or TP), allowing one service provider to support both data and voice services.

Entertainment and audiovisual appliances include TV sets, stereo systems, CD players, VCRs, DVD players, tape recorders, camcorders, speakers, and headphones. These devices communicate through their own protocols such as IEEE 1394 or Firewire [FIRweb].

Security systems include motion detectors, door pins, system control panels, cameras, and alarms that are networked separately using protocols such as EIA-600 CEBus or EIA-709 Lon Works [LONweb]. Currently, the access to these systems is through the telephone lines that initiate emergency request alarms to the police stations.

Appliance manufacturers are working on *smart appliances* capable of communication. This intelligence allows remote checking test for maintenance (e.g., receiving alarm that a refrigerator's heat-pump needs to be replaced) and remote control of operation (e.g., dimming lights remotely). These devices use protocols such as Lon Works or WRAP. Another wave of interest in home network stems from utility companies for distance *utility metering.* The electricity, gas, water, and fuel companies would like to remotely read the utility meters at home for billing or other needs (e.g., refilling the gas tank). One of the solutions is to communicate this information through the HAN and its access to the Internet. More recently, a number of start-up companies are designing *indoor locating systems* that can be used for distance monitoring of children, elderly people, and pets or for navigating the blind. These systems are expected to be integrated with the home networks to provide access through the Internet.

10.6.2 Why Do We Need a HAN?

The existing LANs designed for office environment do not provide a good solution for home networking. The application diversity, network requirement, building infrastructure, and market size of the HANs are distinctly different from the LANs. In homes, the number of users of the network is much smaller than in offices but the diversity of device types and their bandwidth requirements is much larger than that in offices. The diversity of the bandwidth requirement of the large appliance list introduced in the previous section includes multichannel video up to monthly meter reading. Offices mostly employ computing devices. The home environment includes new applications such as positioning/navigation and audio/video broadcasting that were not applications for traditional office LANs. Offices are larger than residential homes, and they are made of more concrete material than homes. Therefore physical wiring and wireless coverage in homes is easier than in offices. Homeowners are more reluctant to allow service workers to enter their home, and they cannot afford a network manager to operate their network. The number of homes is orders of magnitude larger than the offices so the market for home networking is expected to be much larger than the LAN market.

These specific requirement on home applications imposes certain constrains on the design of HANs. A HAN needs to be *user-friendly* because it is used and managed by nonprofessionals with limited technical skills and a small budget size. A HAN must be low cost, easy to install and relocate, and easy to upgrade. In terms of *performance* a HAN should enable multimedia applications and be capable of accommodating legacy voice and data services. A HAN also needs to be *flexible* and *scalable* to allow location independence and easy reconfigurability of networks without significant performance degradation. To avoid eavesdropping or session hijacking, a HAN also needs *security* and *privacy* provisions.

10.6.3 HAN Technologies

In an office, a company sees the need for networking, decides on the installation of a network, opens a budget for expensive wiring, and installs the LAN infrastructure. In the case of home networking, users gradually build their networks at their leisure with an investment that is spread over a relatively long period. An average consumer does not spend a sizable budget on wiring to develop an infrastructure. Therefore, the trend for today's HANs is to either use existing wires or try a wireless solution. The existing wiring at homes consists of TP telephone wires, powerlines, and cable from cable TV. The *phone line* wiring has a relatively good distribution and in most modern homes at least you can locate one telephone outlet in every room. The wiring for phone lines is voice-grade TP that is suitable for Ethernet connections. However, the same line is also used for telephony and xDSL transmissions which interfere with the Ethernet signal. *Power line* wiring is even better distributed because every room has several power outlets. However, the quality of the line is poor, and the level of the noise in power lines much more than TP phone line wiring. Figure 10.16 shows a typical transfer function and noise level in a power line. The power line is a frequency selective channel that suffers from impulsive noise in the frequency domain. These characteristics impose limitations on the data rate that can be overcome only by using more complex transmission techniques. Existing *cable TV* wiring has a very restricted distribution, and only a few outlets are available in each household. This wiring is used for multichannel TV distribution that interferes with the baseband data signal. The expensive broadband cable TV modems can be used to overcome this problem. Because of its limited distribution and expensive modem requirement, cable TV wiring is not considered seriously for home distribution. A *wireless* solution appears ideal for home networking. The ease of installation and relocation provides an excellent solution. Challenges for wireless are reliability, bandwidth, coverage, security, and interference. Comparing wired and wireless solutions, wired HANs can be implemented over less expensive cards, and they can support higher data rates. Wireless HANs provide an ideal ad hoc solution that supports portability.

10.6.3.1 HPNA

All networked home computers have Ethernet cards, and PCMCIA laptop cards are almost exclusively made for Ethernet. However, as we mentioned before, TP phone line wiring at home is used for analog voice and distribution access and DSL access. The HPNA [HPNAweb] is an Ethernet-compatible LAN over

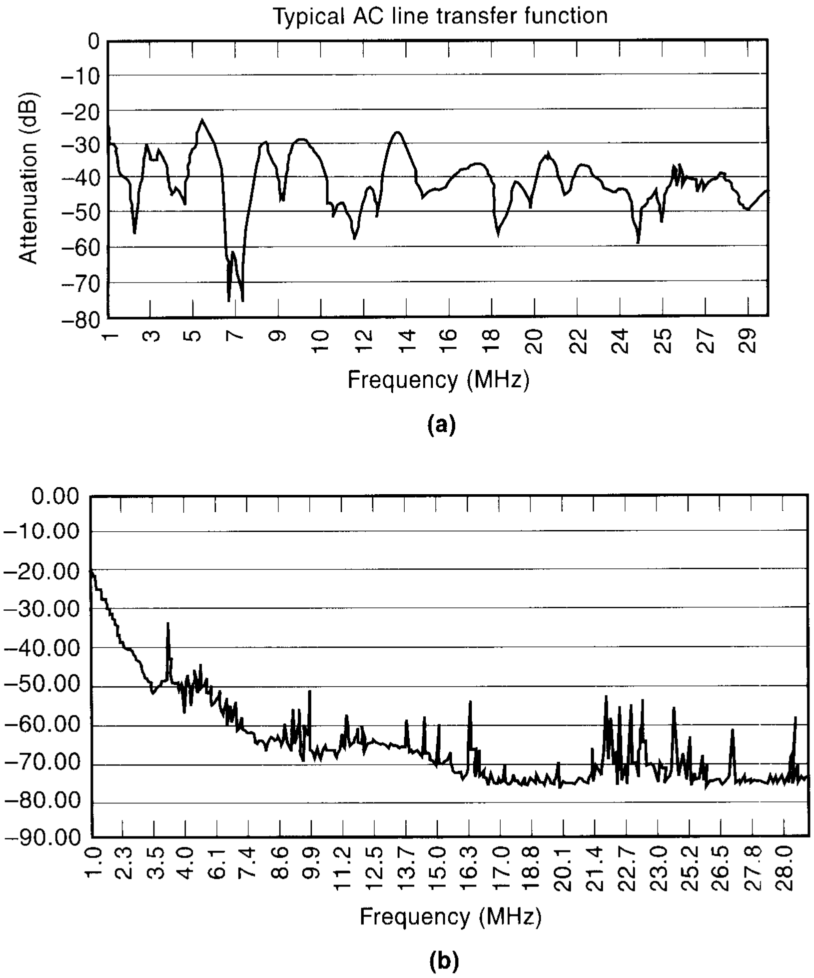

Figure 10.16 (a) Typical power line transfer function and (b) typical noise level in the power lines.

random-tree home phone lines. It uses a stand-alone adapter to connect any device having an Ethernet 10Base-T interface card, operating at 10 Mbps over TP lines, directly to the in-home telephone jacks. Figure 10.17 shows an example of HPNA applications where a number of data terminals and analog voice terminals share the home TP telephone wiring. The data equipment also receives Internet access through a home gateway.

Figure 10.18 illustrates how HPNA shares the medium through FDM with POTS and DSL. In the same home wiring, POTS uses the 20 Hz–3.4 kHz band for analog voice transmission, xDSL uses the 25 kHz–1.1 MHz band to provide high-speed Internet access to the home, and HPNA uses the 2 MHz–30 MHz band for home distribution networking. HPNA is based on a patented physical layer that up converts the differential Manchester-coded Ethernet physical layer to the HPNA band. This physical layer is more immune to high-noise conditions in the home

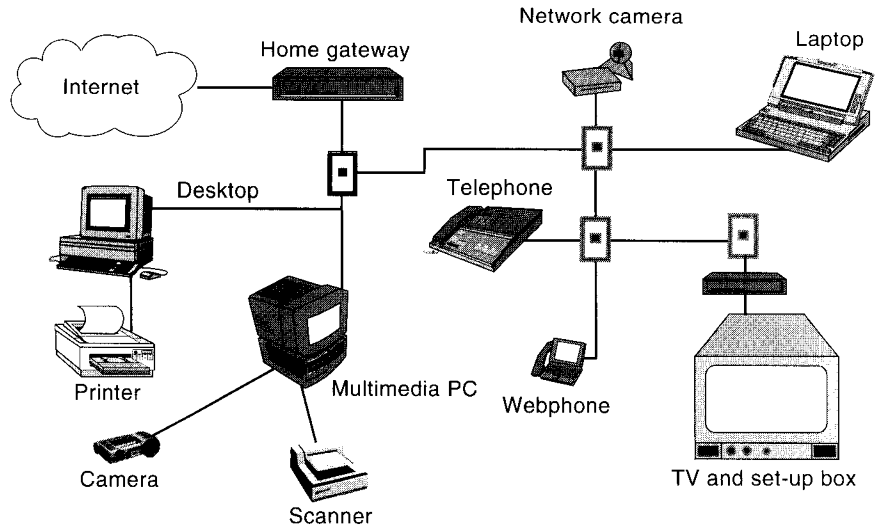

Figure 10.17 An example of an HPNA network.

telephone wiring. The MAC layer for the HPNA is the same as the MAC layer of the IEEE 802.3 Ethernet. From the user's point of view, the HPNA network accommodates the existing legacy Ethernet software and hardware. Only an adaptor is placed between the Ethernet connection and the phone plugs. The next step for the HPNA is to boost the data rate to accommodate video applications.

10.6.3.2 Power Line Modems

Compared with telephone wiring, power lines have the best wiring distribution in homes because they reach every corner of a building. In outdoor areas, the PSTN network has two parts: the TP analog access wiring and the backbone digital

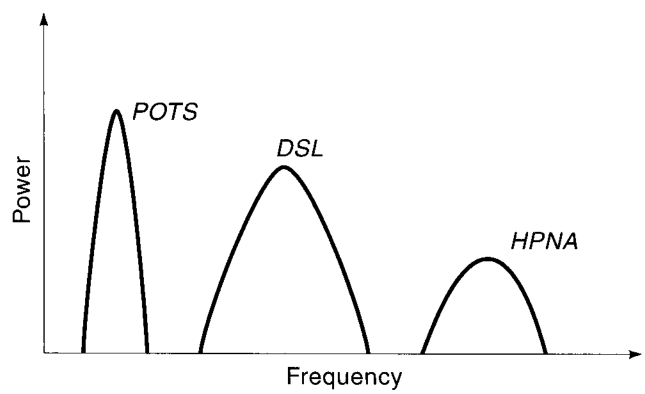

Figure 10.18 Phone line wirings shared among three technologies using FDM: (a) POTS uses 20 Hz–3.4 kHz, (b) DSL uses 25 kHz–1.1 MHz, and (c) HPNA uses 2–30 MHz.

wiring connecting switches together. The digital segment of the PSTN fully utilizes the wiring. The traditional access wiring uses around 4 kHz of the band for analog POTS and the rest was unexplored until DSL and HPNA were introduced. Comparing external PSTN wiring with the power line wiring, we can say that the entire power line wiring is used for transmissions of 50–60 Hz waveforms, and the rest is available for other applications. For many years power lines were used for low data rate (< 100 kbps) control and security networks operating below 500 kHz. These systems were using X-10, CEBus/CAL, and Lonworks standards [LONweb]. More recently, power lines are being considered for high data rates (> 1 Mbps) that operate above a frequency of 1 MHz to provide adequate speeds for computer networking. This area is still in the preliminary stages of development with no clear standard initiative. The only constraint by regulation on power lines is that they should not interfere with AM radio systems. AM radios in the United States operate between 9 and 490 kHz and in the EU between 3 and 148.5 KHz. Figure 10.19 shows the typical band separation in the power line applications. Low frequencies of up to a few kHz are used for low data rate applications such as security. The frequencies in the range of the AM radios are not used to avoid interference with AM radios. The frequency band of 1–30 MHz is used for high-speed data communications.

Recently smart appliances are emerging in the market that have some built-in intelligence, can sense other appliances on the power lines, and can be accessed through the Internet. Electric companies are investigating using the outside AC lines to deliver various services such as meter reading, energy management, and even Internet access to homes. The main current research thrust is to enable the access to control and security systems through the Internet. Figure 10.20 illustrates a number of potential applications that are emerging for the wire line systems. These applications include traditional low-speed security systems, remote control through the Internet, smart appliances, and meter reading operating in lower bands of the power lines and high-speed computing networks operating in higher bands. Power lines suffer from tremendous interference from electrical appliances, high attenuation, reflection caused from varying input impedance, and multipath phenomena that makes communication over this medium as challenging as communication

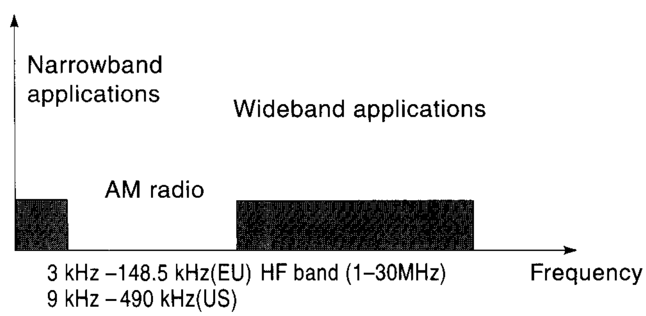

Figure 10.19 Frequency bands for low- and high-speed data communications over power lines.

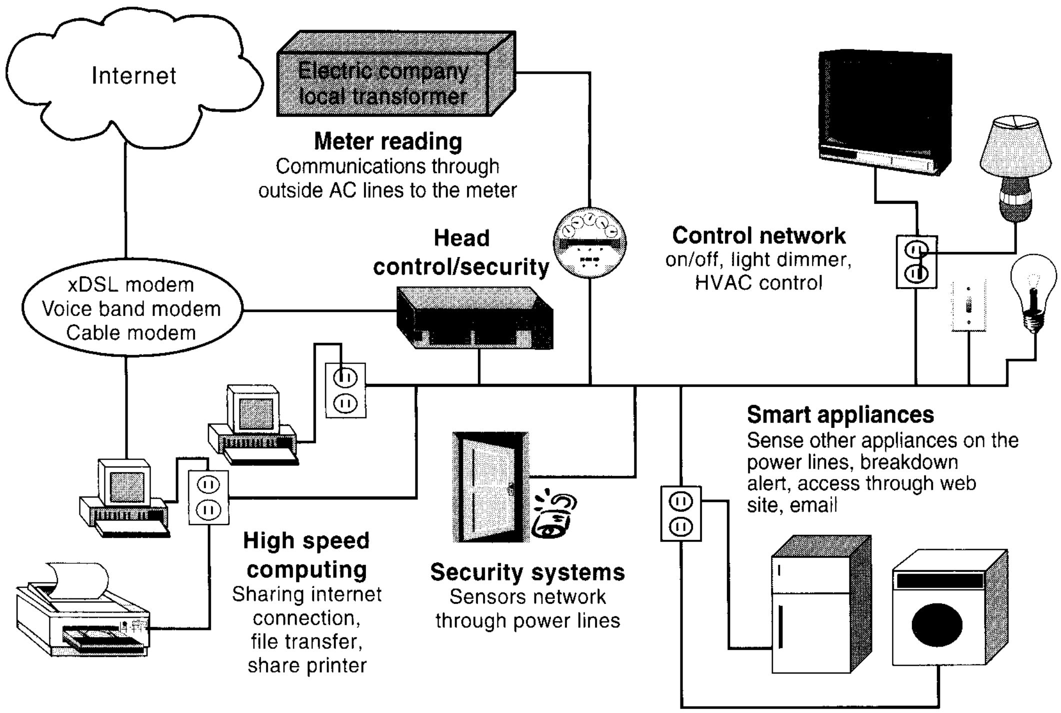

Figure 10.20 Potential applications for power lines.

over radio channels. As a result, a variety of complex transmission techniques and medium access protocols has been examined for different power line applications. Traditional FSK and QPSK are used in lower frequency bands and more complex spread spectrum and OFDM modems are used in the higher bands. DSMA and CSMA access methods, discussed in wireless data networks, are commonly used in the power line systems. The difficulty of the medium has kept the cost at higher rates which is a draw back in the growth of the market in this medium.

10.6.3.3 Wireless Solution Alternatives

A common advantage of wireless solutions over a wired network is that the wireless solution provides mobility and it covers the home as well as the yard.

Example 10.7: Coverage of a Wireless Cordless Telephone

As we explained in Chapter 1, cordless telephones were very successful from the early days of their appearance in the market. Because cordless telephones provide mobility and cover a larger area at home, users have paid higher prices to purchase cordless telephones in addition to a wired phone.

Other advantages of the wireless solution are that wireless is easy to install, relocate, scale, and maintain.

Example 10.8: Wireless Home Security Solutions

Introduction of wireless solutions to home security systems resulted in a sizable growth of that industry. From the user's point of view, wireless security systems are installed very quickly without additional holes in the walls or wires distributed in the home. Besides, selecting the location for placing a wireless product is more flexible which allows a better blending with the decoration of the home. Other advantages are that the wireless solutions are easier for expansion, moving to new homes, maintenance, and upgrading.

These examples are selected applications where a wireless solution is certainly necessary. As we discussed earlier, we have numerous home applications, and wireless may not be as important for all of them.

Example 10.9: Applications Where a Wireless Solution May Not Be Important

Smart appliances need a very low data rate for communication. These days manufacturers prefer to use power lines for networking so that by plugging the appliance to the wall, the user connects to the power and the network at the same time.

Certainly it is not difficult to find examples for cases where phone lines are the preferred home networking solution. The important conclusion from this discussion is that in home networking, we want to avoid new wiring, and therefore we need to use all the existing media that provide a nonhomogeneous environment for networking. Figure 10.21 provides a near future visionary portrayal of the evolving home networking solutions. Appliances are connected through a power line network, fixed computing equipment through HPNA, laptops and cordless phones through evolving wireless home networking, and security systems use their own proprietary network. A home server box connects all these networks together and to the Internet. Figure 10.22 represents a broader view of the home networking from the point of view of the now defunct Home RF group at the IEEE 802.15 standards group that will be discussed later on in Chapter 13. This is a more comprehensive view which also includes integration of entertainment systems using the IEEE 1394 standard. In this vision, wireless is only used for computing and cordless phones. New approaches for wireless networking was the scope of the EU workshop on wireless home networking [WIR00].

Wireless solutions for home networking include WLANs and WPANs which are discussed in detail in the following chapters. There are a number of home specific challenges for wireless networking. Using multiple devices allows operation of several different wireless solutions operating in the same unlicensed band. Handling interference in such a case is an important issue in wireless home networks. As we move to higher frequencies of operation at 5 GHz to support higher data rates, the coverage of the wireless solution may become a challenge. Wireless home networking needs designing inexpensive reconfigurable devices and Internet working between different media using different protocols. Incorporating cable TV into the network demands high transmission rates and a change in the access method to deliver video to the TV set. Today the cable that delivers the signal to the cable

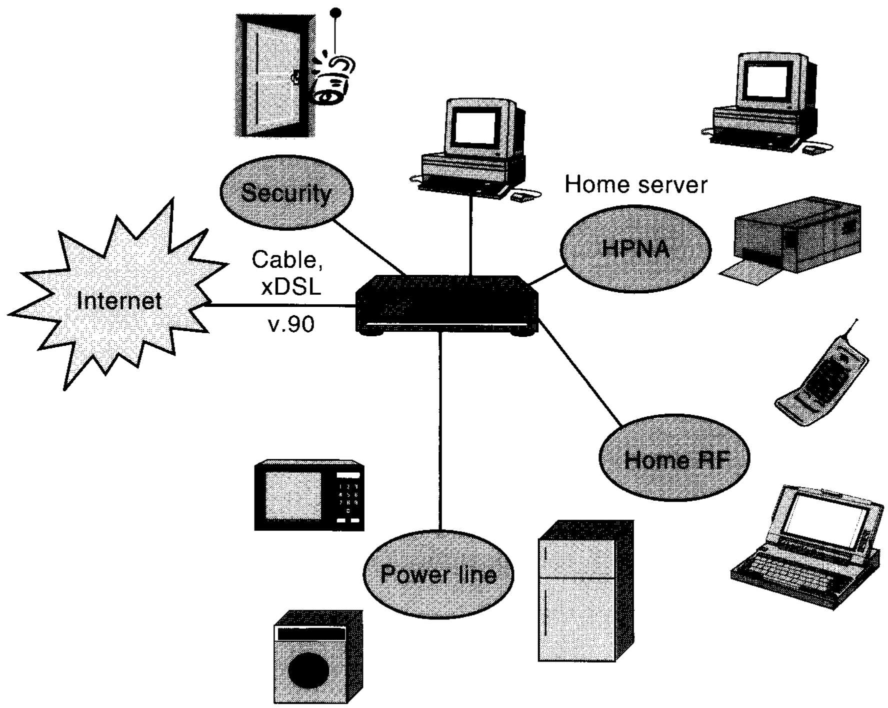

Figure 10.21 Evolving HANs.

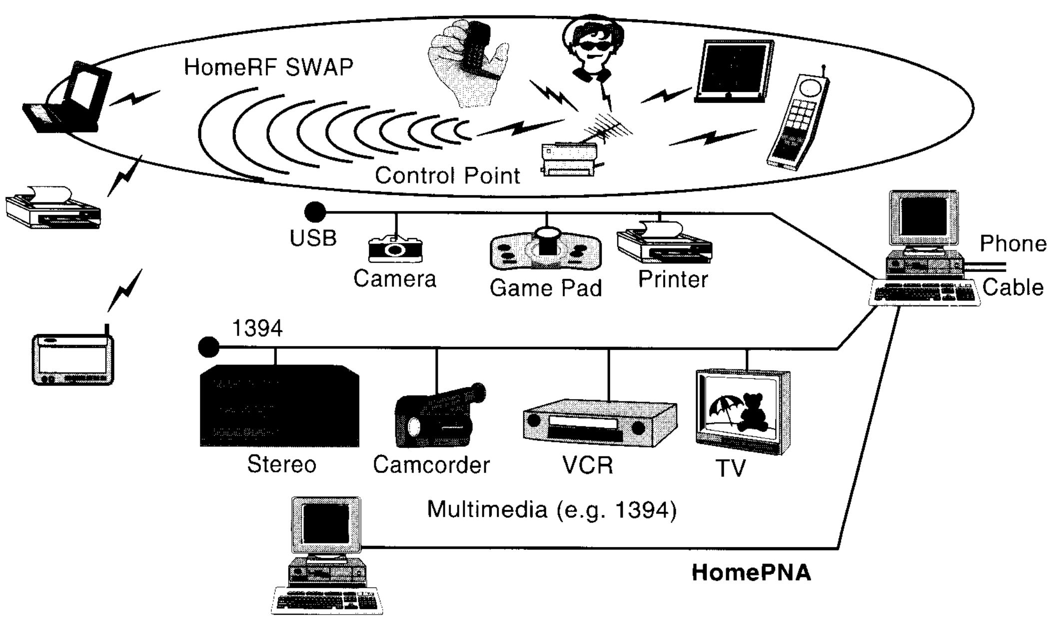

Figure 10.22 Vision of the home RF group at IEEE 802.15.

box, carries around a hundred analog video channels. Such bandwidths are not feasible over the wireless medium. Therefore, the entire system needs to be redesigned.

10.6.4 Home-Access Networks

The early home access technology was based on voice-band modems. Today broadband home access (with data rates on the order of 10 Mbps) is provided through cable modems and DSL services over the telephone lines. Cable modems operate on the cable TV wiring. The bandpass channel allocated to the TV channels is used by the cable modem which uses QAM modulation to provide higher data rate for transmission. The cable distribution in the residential areas has a bus topology that is optimally designed for one-way TV signal distribution. The bus carries all the stations in the neighborhood, and the cable TV box selects the station for the TV. If it is a scrambled paid channel, it also descrambles the signal. To control the set-top boxes, a reverse channel is available in all modern cable wiring. Broadband cable services use one of the video channels and the reverse channel to establish a two-way communication and access to Internet. The xDSL services use the 25 kHz–1.1 MHz bands on the telephone wirings and multisymbol QAM modulation to support high data rates to the users. The topology of the telephone line is a

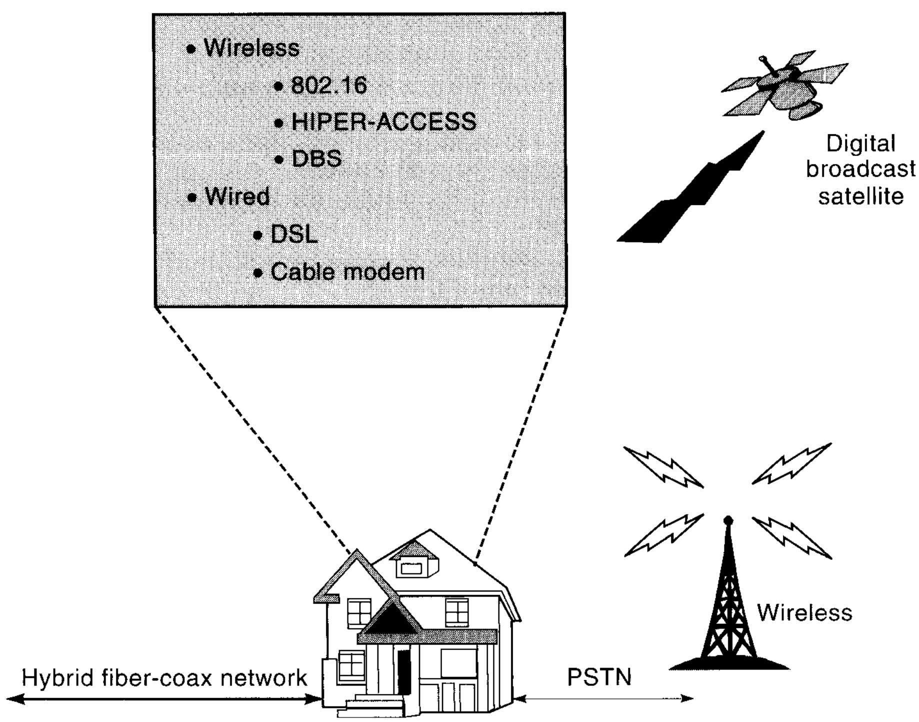

Figure 10.23 Broadband home access alternatives.

star topology that connects every user directly to the end-office where the DSL data is directed to Internet through a router.

Higher speed wireless home access uses LMDS or even existing WLAN inter-LAN bridges to provide the service. The advantage of using fixed-wireless solutions is that it does not involve wiring the streets. If there is no available wiring in the neighborhood, a wireless solution is certainly the main solution. The IEEE 802.16 in the United States and HIPER-ACCESS program in the EU are studying the next generation of networks in this area. Other wireless alternatives are direct satellite TV broadcasting and 3G wireless networks. Direct broadcast usually suffers from lack of a reverse channel and high delay that challenges the implementation of broadband services on this medium. The high-speed 3G wireless packet data services are expected to provide up to 2 Mbps which is very suitable for Internet access. The data rates on these systems are lower, and they are using licensed bands that ultimately may be expensive. Figure 10.23 summarizes the existing solutions for the home access technologies.

QUESTIONS

10.1 What is the difference between nomadic access and ad hoc networking?

10.2 Name three categories of unlicensed bands used in the United States and compare them in terms of size of the available band and coverage.

10.3 Explain the differences between WLAN and WPAN.

10.4 What are the IEEE 802.3, 802.4, and 802.5 standards and what are the differences between them?

10.5 Name the three IEEE 802 standard groups that are working on wireless networks and briefly explain the objective of each of them.

10.6 How does the current state of the art data rate of the wired and wireless LANs compare with one another?

10.7 Name the five major challenges for implementation of wireless LANs that existed from the beginning of this industry.

10.8 Why are unlicensed bands essential for the WLAN and WPAN industries?

10.9 Explain the difference between wireless Inter-LAN bridges and WLANs.

10.10 What are the differences between IEEE 802.11 and HIPERLAN standards?

10.11 Explain the differences among WCAN and WHAN technologies.

10.12 Why does the military show more interest in the wireless ATM approach?

10.13 Name three military projects related to broadband wireless local access.

10.14 Why did service providers become interested in WLAN and WPAN?

10.15 Name different alternatives for Internet access to the home and different mediums for home distribution.

10.16 What are the differences between LANs and HANs?

10.17 Explain the specifics challenges for the design of a HAN.

10.18 Name the classes of home appliances that are emerging in the home networking market.

10.19 What are the differences between HPNA and Ethernet?

10.20 How do HPNA, DSL, and POTS share the telephone wirings?

10.21 Compare telephone wiring, cable TV wiring, and power lines as media for home networking.

10.22 Compare wireless and wired solutions for home access and in-home distribution.

PROBLEMS

10.1 The IEEE 802.11 operates at 2.4 GHz, transmits 100 mW, and the minimum acceptable received signal strength for its proper operation is −80 dBm.

- **a.** Using the JTC model, determine its approximated coverage in a three-floor office building.
- **b.** If it is used as an Inter-LAN bridge in an open area in a large city to connect two 30 m tall buildings that are 1 km apart, what is the path loss that the transmitted signal will suffer? Can this Inter-LAN bridge operate properly? (Assume that antennas are installed on top of the roof and use the Okumura-Hata macro-cell model for prediction).

10.2 We want to install a LAN in a 5-story office building with identical floor plans. Each floor of the building is a 80m × 80m square with a height of 4 m. There are 15 terminals on each floor of the building and the external wiring comes to the first floor.

- **a.** What is the total cost of wiring, equipment, and installation of the entire network if an IEEE 802.3 star network with one 240-port switch in the first floor connects all terminals to each other and the external connection? Assume a charge of $150 per run of wiring between two locations, a $6,000 cost for the switch, and a $35 per terminal cost for the network interface card.
- **b.** To avoid wiring costs, assume that we use an IEEE 802.11 WLAN access point with a 100 mW (20dBm) transmitter power and a −80dBm receiver sensitivity in the center of the third floor. What is the total cost of the WLAN if the access point is $800 and each network interface card is $120?
- **c.** Use the JTC model to calculate the coverage of the access point. Can we cover the entire building with one access point?
- **d.** Compare the advantages and disadvantages of the two solutions.

10.3 You are designing a WLAN for an office building. You are not able to perform measurements or site surveys and have to rely on statistical models and certain other information. There are also certain constraints on where you can actually place the access point(s). You have the following information available to you:

Maximum number of walls between an access point and a mobile terminal = 4
Maximum number of floors between an access point and the mobile terminal = 2
Transmit power possibilities = 250 mW and 100 mW
Sensitivity of receiver is −80 dBm
Maximum distance from access point to building edge = 30m
Building has office walls, brick walls, and metallic doors
Shadow fading margin = 8 dB

What would be a conservative estimate of the number of access points required for the WLAN set-up? State your assumptions, models, and provide reasons for all your assumptions and calculations. Explain why. (*Hint:* Use path loss models from chapter 2 that are applicable to indoor areas.)