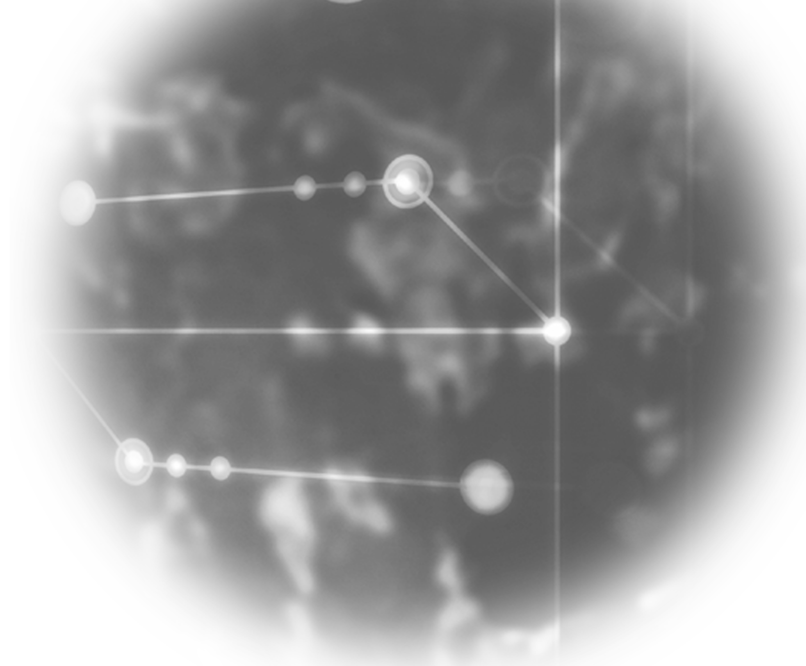
CHAPTER 1

Overview of Fixed Broadband Wireless Access Networks



The explosive rate of growth of the Internet has led to a high demand for bandwidth. Prior to 1996, Internet access for residential users was almost exclusively made via the public switched telephone network (PSTN). Such access was made via modems running at 28.8 kbps or less over the twisted copper pair. Unfortunately, even today anyone connecting to the Internet via slower telephone modem connections will not fully utilize and enjoy what the Internet has to offer. In particular, such new applications as video conferencing, streaming video, and dynamic Web pages demand high-speed broadband access. Also, accessing the Internet via the PSTN stresses the network switches, which are optimized for short holding times for voice calls and not designed for the long holding times associated with Internet access.

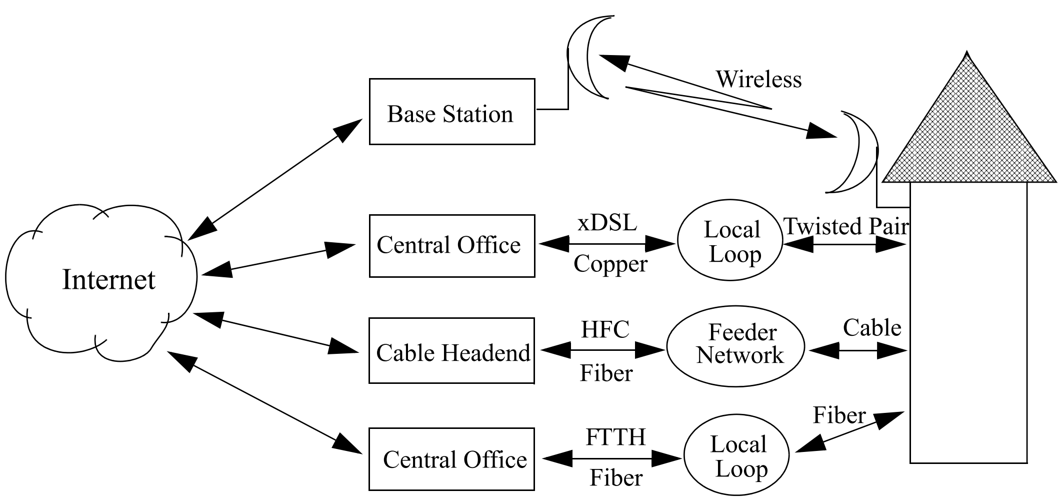
The Telecommunications Act of 1996, which triggered deregulation of the telecommunications industry in the United States and many countries around the world, led to the development of several last-mile solutions to relieve the PSTN switches of the data traffic. These solutions include the digital subscriber line group of technologies that are generally referred to as xDSL, hybrid fiber coaxial (HFC) network, fiber-to-the-home (FTTH), and the fixed broadband wireless access network. These solutions have one thing in common: They are broadband solutions, which means that they have the potential to provide data rates of at least 1 Mbps to the user. Also, they are *always-on* Internet access technologies. Thus, they have the potential to meet the growing demand for multimedia and voice applications.

Fixed broadband wireless access networks, which are sometimes referred to as *wireless DSL*, use high-frequency radio connections between two or more fixed sites to send and receive data, voice, and video traffic in a manner similar to wireline networks. These networks differ from mobile wireless by the fact that the endpoints in fixed wireless solutions are stationary and therefore less susceptible to the bandwidth and quality limitations associated with mobile wireless networks.

Benefits of Fixed Broadband Wireless Access Networks

As stated earlier, fixed wireless access networks represent one of many alternative last-mile solutions. Other solutions include xDSL, HFC, FTTH, and direct broadcast satellite. These solutions are illustrated in Figure 1.1.

The xDSL technologies are based on the twisted copper pair used to provide plain old telephone service. They can be provisioned for a distance of at most 18,000 feet (i.e., 3.4 miles) from the central office. However, this is not 3.4 miles as the crow flies, but 3.4 miles of cable run. Thus, a user may be within the



Fi e 1.1 Different last-mile access technologies.

3.4 miles from the central office and still not be qualified to receive xDSL service. Also, the bandwidth available to each user of the service depends on how far the user is from the central office. In general, the farther a user is from the central office, the smaller the bandwidth available to that user. Furthermore, the service depends on the telephone infrastructure, which, in most cases, involves aging lines that need to be reconditioned. Thus, even though telephone service is ubiquitous in many countries, xDSL may not be available to all telephone subscribers due to poor telephone line conditions. Finally, deployment of xDSL is predicated on the availability of twisted pair cable from the user's home to the central office. Any user whose signal has to pass through optical fiber before reaching the central office does not qualify for the service. Incumbent local exchange carriers (ILECs) are more likely to offer xDSL services than any other service provider.

HFC is derived from the cable TV network and provides a two-way communication between the headend and the subscriber. It is a shared-medium technology that is primarily a residential access technology. Like a conventional local area network (LAN), the performance is a function of the number of active users. Also, it provides asymmetric service, with more traffic coming downstream from the headend to the users. HFC network services are exclusively provided by the cable network operators.

FTTH can provide up to OC-3 data rates to a user. However, fiber is expensive to install. Moreover, many communities have very stringent trenching laws that make it difficult to deploy FTTH in such communities. Thus, its availability is currently limited.

Broadcast satellite uses a low-orbit satellite to provide Internet access. It has the advantage of being available almost anywhere, which makes it a good candidate for point-to-multipoint applications. However, while the downstream path is a direct broadcast from the satellite, the upstream path from the user to the service provider uses a conventional phone line. Thus, it provides asymmetric service. Also, it does not provide a large bandwidth in comparison to other technologies.

Fixed broadband wireless access networks have several advantages over these alternative solutions. First, there are many places that do not have access to the last-mile access technologies discussed earlier. These include rural areas with low population density, remote geographical areas, and urban areas with aged communication infrastructure. Many Third World countries lack the basic telecommunications infrastructure required to support advanced communications systems. This lack of basic infrastructure, which is sometimes coupled with inhospitable terrain, makes conventional solutions prohibitively expensive and slow to deploy. Such places are good candidates for the fixed wireless broadband access solution, which can be deployed more rapidly than any of the other technologies. Even in those places where the other access technologies can be deployed, it is always easier to set up a fixed wireless access network than any other solution.

Also, fixed wireless access networks are more flexible than other technologies. Because today's Internet traffic seems to be asymmetrical, with more traffic coming downstream to the user than going upstream, most of the other solutions have been designed for today's applications; that is, to provide asymmetrical traffic. If the traffic pattern should change in the future to a method such as voice over IP (VoIP), which generates symmetrical traffic, these services will require a major overhaul of the system. With fixed wireless access networks, the use of such channel sharing schemes as time division duplex (TDD) makes it possible to quickly assign more channel capacity to the direction where it is needed most. (TDD is discussed in Chapter 6.)

A fixed broadband wireless access network does not require twisted pair conditioning, and the service provider does not have to worry about the 18,000-foot distance limitation, which are two problems associated with xDSL. Similarly, a fixed broadband wireless access network does not require costly filters needed to subdivide the cable, as in HFC. Because fixed wireless access networks are deployed in cellular configurations, all that is required is a transceiver arrangement at the customer's premises that is pointing toward a transceiver at the base station.

The fixed broadband wireless access network infrastructure can be deployed rapidly since it does not require running cables or wires to individual customers. Also, it does not require investment in labor-intensive tasks, such as digging trenches to bury cables. Once the base station is set up, the service provider can begin providing service to customers. This means that the service provider generates revenue quicker with fixed broadband wireless access networks than with any other competing last-mile access technology.

The fixed broadband wireless access network infrastructure is scalable, because the service provider does not need to overbuild the infrastructure to make it possible to connect every potential customer in an area prior to delivering service. The service provider can start with one segment of the coverage area, which is called a sector. Then as the need arises, new sectors can be added at the base station without impacting the existing customers.

The fixed broadband access network is simpler to maintain, and problems are more easily isolated and corrected than in other last-mile technologies. It is more reliable because there are no wires between the headend and the user that can be cut either accidentally or intentionally. This is particularly advantageous in hostile environments where an enemy can disrupt communication by downing telephone poles or cutting cables and wires. Thus,

Table 1.1 Summary of Broadband Access Technologies

FEATURE	xDSL	HFC	FTTH	FIXED WIRELESS
Deployment	Slow	Slow	Slow	Fast
Market	Residential SOHO Business	Residential	Residential	Residential SOHO Business
Service Provider	ILECs CLECs with access to copper plant	Cable Operators	ILECs	ILECs CLECs

fixed broadband wireless access networks provide better customer service and lower maintenance costs.

The preceding facts account for the popularity of the fixed broadband wireless access network among the competitive local exchange carriers (CLECs) for both Internet and voice traffic services, as well as its increasing popularity in countries and areas that currently lack the basic telecommunication infrastructure. Table 1.1 summarizes the features of the various last-mile access technologies. In the table, SOHO stands for small office/home office.

Typical Applications

Like high-speed cable and xDSL services, but unlike a dial-up modem service, the fixed broadband wireless access network provides an always-on Internet-access service. Typical applications are discussed next.

Multitenant Unit/Multidwelling Unit (MTU/MDU) Services

With single customer premises equipment (CPE) on a single building and existing coaxial cable or telephone lines, a service provider can provide broadband wireless access to the Internet for the tenants of the building. As will be discussed in Chapter 8, using the current twisted pair telephone lines the service provider can use a mini-DSL access multiplexer in the basement of the building to provide xDSL services that are not encumbered by the distance limitations.

Corporate Converged Networks

Fixed broadband wireless access networks enable service providers to build converged networks that permit voice, video, and data to be integrated onto one network. This makes possible such advanced applications as unified messaging, Web conferencing, and enhanced call-center systems.

Wireless Local Loop

In its original meaning, wireless local loop (WLL) refers to the solution that uses fixed wireless access networks to provision local-loop services (or connect the user to the PSTN). WLL is particularly attractive in the following scenarios:

- Places that require rapid telephone deployment but lack basic telephone infrastructure to the customer premises
- Places where the terrain is hostile or rocky for laying telephone cables
- Places where CLECs are compelled to deploy local-loop facilities to bypass the ILECs

The fact that the fixed broadband wireless access network is a packet-switched network enables the service provider to provision voice over IP (VoIP) service, which is currently less expensive than traditional circuit-switched telephone service. Along with VoIP, the service provider can bundle enhanced services that are not easily available in traditional circuit-switched telephone service.

Television Service

Fixed wireless access networks can be used to provide wireless cable television service. One of the services defined for the multichannel multipoint distribution service (MMDS) is that of providing TV services in competition with the cable operators. MMDS is described later in this chapter.

System Overview

A fixed broadband wireless access network is essentially a sectorized network that consists of two principal components: the customer premises equipment that enables a user in the customer's network to access wide area network (WAN)–based services, where the WAN is usually the Internet, and the base station that controls the CPEs within a coverage area. The base station consists of many access points or wireless hubs, each of which controls the CPEs in one sector. The access points are connected to a multiplexer, such as a switch, which aggregates the traffic from the different sectors and forwards it to a router that is connected to the service provider's backbone IP network.

The distance between the CPE and the base station depends on how the system is designed and the frequency band in which it operates. If it is designed as a line-of-sight (LOS) system, the distance is generally less than 5 miles. Typically systems that operate above the 20-GHz band are LOS systems. However, most of the early deployments of fixed broadband wireless access networks were based on LOS technologies because, even at the time of writing, non–line-of-sight (NLOS) systems were still very expensive to deploy. If the system is designed as an NLOS system, the distance between the CPEs and the base station can be up to 35 miles. NLOS systems use more advanced modulation schemes to overcome the transmission impairments that are discussed later in the book.

The air link capacity available to each sector depends on the modulation scheme used. As will be discussed later in the book, the most commonly used modulation schemes are the quaternary phase-shift keying (QPSK) and different variations of the quadrature amplitude modulation (QAM), the more commonly used being 16-QAM and 64-QAM. QPSK is mainly used in the upstream direction, which is the direction from the CPE to the base station, and 64-QAM is used in the downstream direction (or the direction from the base station to the CPEs). The 16-QAM can be used for either direction. In the QAM nomenclature, the numeral is called the modulation order; thus, the higher the modulation order used, the greater the data rate that the system can support. QPSK is functionally identical to 4-QAM, which means that it has a lower modulation order than 16-QAM.

Figure 1.2 shows the fixed broadband wireless access network architecture. It illustrates the components of a typical sector of the network. The wireless hub provides a wireless interface for receiving data from and transmitting data to the CPEs. The wireless hub is connected to the backhaul router via a switch. The switch can be an Ethernet switch or an asynchronous transfer

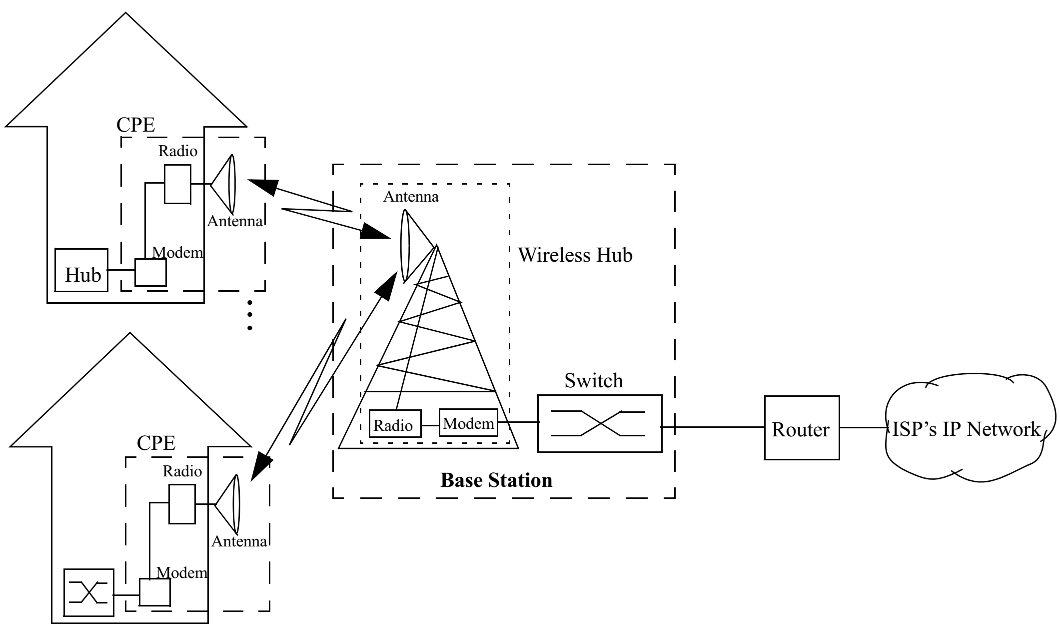


Figure 1.2 Fixed broadband wireless access network architecture.

mode (ATM) switch. The router is the default gateway to the Internet and to the service provider's IP backbone network. Note that there are three component parts of the CPE: the modem, the radio, and the antenna. The modem provides an interface between the customer's network and the fixed broadband wireless access network, while the radio provides an interface between the modem and the antenna. Some vendors integrate two or all of these components to form a compact CPE, while others have the three units as standalone systems. When the antenna is integrated with the radio, the patch antenna is often used. (Antennas are discussed in Chapter 3.) Similarly, the wireless hub consists of a modem, radio, and antenna, all of which can be integrated into one box or can exist as standalone systems.

Fixed Wireless Networks versus Mobile Wireless Networks

The term wireless network is generally associated with mobile communication systems, which are usually optimized for providing voice connections at very low data rates. However, mobile wireless networks are not the only wireless networks. Fixed wireless networks have the potential to deliver very high data rates because, unlike mobile wireless networks, which use basic modulation schemes to provide data rates on the order of kilobits per second, they can use more advanced modulation schemes to provide data rates on the order of megabits per second.

Mobile wireless networks generally use omnidirectional antennas, while fixed wireless networks use highly directional high-gain antennas. Also, fixed wireless networks used for broadband applications generally operate in the so-called ultrahigh-frequency and superhigh-frequency bands of the frequency spectrum, while mobile wireless networks operate in the very high frequency band. Thus, mobile wireless networks deal with meter waves, while fixed broadband wireless networks deal with centimeter and millimeter waves. (See Table 1.1 for the various frequency bands.)

Licensed versus Unlicensed Frequency Bands

Different frequency bands are used to deliver fixed broadband wireless services. While different countries have different allocations, the most commonly used bands in the United States are the following: 2.1 GHz, 2.4 GHz, 2.5 GHz, 5 GHz, 24 GHz, 28 GHz, and 31 GHz. Some of these frequencies are licensed while others, such as 2.4 GHz and 5 GHz, are unlicensed. The rationale for designating some frequency bands as unlicensed is to enable service providers to deploy services quickly and at lower cost since there are no license fees involved. An overview of the various broadband services, along with the frequency bands associated with them, is presented later in this chapter.

Model of a Radio Communication System

The components of a radio communication system include the following:

- A transmitter, which converts the information to be transmitted into a radio-frequency (RF) signal.
- A transmitting antenna, which converts the RF signal into an electromagnetic wave.
- A transmission medium, which is free space.
- A receiving antenna, which intercepts the electromagnetic wave and converts it back to an RF signal that is ideally the same as the RF signal generated by the transmitter.
- A receiver that converts the received RF signal into a form that can used by the intended recipient.

Figure 1.3 shows the components of a typical radio communication system.

An RF signal is characterized by its frequency and wavelength. The frequency, f, and wavelength, , are related by the following equation:

$$f\lambda = v$$

where v is the velocity of the wave in the medium where propagation is taking place. In free space, $v = c$, where c is the speed of light, which is 3×10^8 m/s. Frequency is measured in Hertz (Hz), which is equal to 1 cycle per second. Wavelength is measured in meters. Practical radio communications take place from

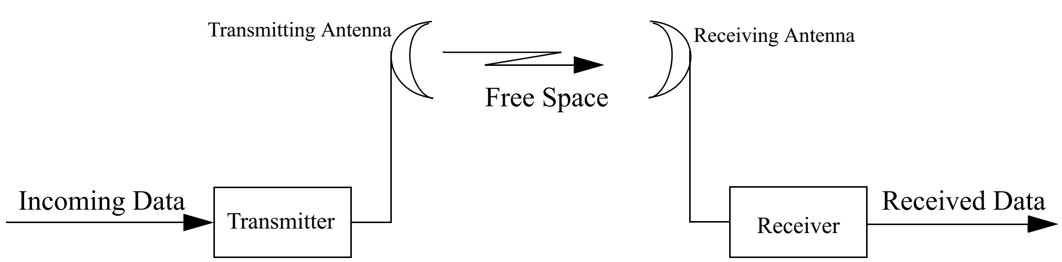


Figure 1.3 Typical radio communication system.

frequencies of about 3 kHz to 300 GHz. This corresponds to free-space wavelengths from 100 km to 1 mm.

There are three basic processes that affect the radio wave as it propagates through free space. These include reflection by smooth surfaces, diffraction by apertures, and scattering by rough surfaces. These phenomena are discussed in Chapter 2.

Radio-Frequency Spectrum

The electromagnetic spectrum is the fundamental resource in a wireless communication system. This spectrum is divided into several bands that are used for specific applications. The frequency band associated with an application determines the propagation characteristics of the RF channel. In particular, the frequency band determines how much energy density is left in the signal at a given distance from the transmitter under given terrain, foliage, and weather conditions. Also, propagation perturbation phenomena (or impairments) vary according to the frequency band.

Table 1.2 shows the naming convention for the electromagnetic spectrum. The table shows both the frequency ranges and wavelengths, given that propagation takes place in free space. Note that the wavelength decreases as the frequency increases.

Commonly, LF waves are also called long waves, MF waves are called medium waves, HF waves are called short waves, SHF waves are called centimeter waves, and EHF waves are called millimeter waves. As will be shown in the next section, the broadband wireless systems that are the subject of this book are either centimeter (SHF) waves or millimeter (EHF) waves.

Table 1.2 Naming Convention for the Electromagnetic Spectrum

BAND NAME	FREQUENCY RANGE	WAVELENGTH RANGE
Very Low Frequency (VLF)	3–30 kHz	100–10 km
Low Frequency (LF)	30–300 kHz	10–1 km
Medium Frequency (MF)	0.3–3 MHz	1 km–100 m
High Frequency (HF)	3–30 MHz	100–10 m
Very High Frequency (VHF)	30–300 MHz	10–1 m
Ultrahigh Frequency (UHF)	0.3–3 GHz	1 m–10 cm
Superhigh Frequency (SHF)	3–30 GHz	10–1 cm
Extra High Frequency (EHF)	30–300 GHz	1 cm–1 mm

Fixed Broadband Wireless Network Frequency Bands

One of the general rules regarding the use of the radio-frequency spectrum is that as new applications are developed, the frequencies assigned for handling them tend to increase. This is due to the fact that use of the spectrum is regulated by the government, which is responsible for licensing the use of the bands of the spectrum. Thus, it is only in the higher end of the frequency spectrum that very large bandwidth can be made available for these new applications. Unfortunately, the technology for supporting applications at these very high frequencies becomes more challenging as the propagation impairments become very severe. Also, it takes a long time to develop economically viable semiconductor devices that can operate at higher frequencies. Until recently, SHF and EHF devices were fairly exotic. However, one major advantage is that dimensions of the antennas used in these very high frequencies become smaller as the frequency increases.

This observation holds true for services defined for fixed wireless networks. The frequencies associated with these networks are in the UHF to the EHF bands. In the United States, some of the services use the licensed frequency bands, while others use the unlicensed frequency bands. Also, some of the services are provided via point-to-point connections, while others are offered via point-to-multipoint connections.

A point-to-point (PTP) network provides a connection between two points with fixed bandwidth on a permanent basis. A PTP network usually involves the use of high-gain antennas that concentrate the radio power in a particular direction. Similarly, a point-to-multipoint (PMP) network is one that involves a base station and a number of remote stations. In a PMP network, the base station sends a broadcast to the remote stations in the downstream direction and receives transmissions from the remote stations in the upstream direction. Such a network involves a well-defined multiple access scheme to ensure that transmissions from two or more remote stations do not collide. Various multiple access schemes that can be used in fixed broadband wireless access networks are discussed in Chapter 6.

Because different countries assign the frequency bands differently, the following discussion is based on frequency allocations in the United States. The major fixed broadband wireless access network frequency bands are as follows:

- Unlicensed national information infrastructure (U-NII)
- Multichannel multipoint distribution service (MMDS)
- International wireless local loop
- Local multipoint distribution service (LMDS)

In order to meet the growing customer demand for broadband service, the service providers offer these services in cellular manner. This enables them to use a sectorized scheme that permits reusing the same frequency at multiple sites. A brief overview of each of these bands is presented next.

U-NII Band

The U-NII frequencies cover a bandwidth of 300 MHz, and span three bands, which are defined as follows:

- Lower band, which covers 5.15 to 5.25 GHz, is reserved for indoor use and the transmitter output power is limited to 200 milliwatts.
- Mid band, which covers 5.25 to 5.35 GHz, is for outdoor use. The transmitter output power is limited to 1 watt.
- Upper band, which covers 5.725 to 5.825 GHz, is also for outdoor use. The transmitter output power is limited to 4 watts.

The U-NII bands are unlicensed bands, and there is no defined modulation scheme or multiple access scheme. Because they are unlicensed bands, many CLECs use them to offer different types of services, particularly Internet access. The bands are also included in the range of frequency bands that are at the center of an ongoing IEEE 802.16 standards activity for point-to-multipoint broadband wireless access that can support data, voice, and video for residential, small and medium enterprise (SME), and SOHO locations. The U-NII bands are generally not susceptible to rain, fog, and snow.

MMDS

MMDS, which is also called *wireless cable* because it was originally used to provide a one-way analog TV broadcast service, operates in the following frequency bands: 2.150 to 2.162 GHz and 2.50 to 2.69 GHz for a total bandwidth of about 200 MHz. It has the ability to deliver multichannel television programming, Internet access, data transfer service, and other interactive services. It is not usually susceptible to rain, fog, and snow. Consequently, it can provide service to an area with a radius of up to 35 miles when operated in a non–line-of-sight manner. Finally, because it uses licensed bands it is not as prone to interference as the U-NII band.

MMDS is the oldest of all the fixed broadband wireless access services; it has been around for more than 20 years. Although it has hitherto existed as a one-way distribution technology, it is a better understood service than the other services.

International Wireless Local Loop

The international wireless local loop is a service that is generally available in the rest of the world outside the United States in the 3.5 GHz frequency band. In some countries it is available as unlicensed band, while it is licensed in others. Like MMDS and U-NII, this band is not usually susceptible to rain, fog, and snow, as the LMDS bands are.

LMDS

LMDS is offered in two bands: LMDS Band A includes 27.50 to 28.35 GHz, 29.10 to 29.25 GHz, and 31.075 to 31.225 GHz. LMDS Band B includes 31.000 to 31.075 GHz and 31.225 to 31.300 GHz. Thus, the total available bandwidth is 1,300 MHz, which is the largest bandwidth dedicated to any one service.

There is no restriction on the duplex method used for LMDS. However, at these frequencies signal strength is adversely affected by the weather conditions, and rain fade becomes a major issue. Because of its susceptibility to weather conditions, the radius of an LMDS cell is much smaller than that of either MMDS or U-NII. Typical LMDS transmission radius is 2 to 3 miles. Thus, it is not a good choice for providing wide area coverage of digital TV service. Instead, it is good for point-to-point interconnection of base stations that use the other services.

Overview of the Book

This book deals with the technologies for fixed broadband wireless access networks. It does not promote any product; rather, it attempts to present the technologies as they stand at the time of writing, especially as they apply to MMDS, U-NII, WLL, and LMDS services. The remainder of the book is organized as follows.

Chapter 2 presents an introduction to radio communications. It discusses how a radio wave propagates through space and the impairments that it suffers as it moves from the transmitter to the receiver. Also, it provides basic definitions of many of the terms used in the rest of the book.

Chapter 3 discusses fundamentals of antennas. This includes the hypothetical antenna called *isotropic radiator*, monopole and dipole antennas, and directional microwave antennas.

Chapter 4 discusses different modulation schemes used in wireless broadband systems, which include single-carrier modulation schemes like quadrature amplitude modulation and quaternary phase-shift keying, and multicarrier modulation schemes like orthogonal frequency division multiplexing and multicarrier code division multiple access.

Chapter 5 discusses ways to improve wireless channel reliability. This includes diversity transmission; equalization; and error control, which includes automatic repeat request and forward error correction.

Chapter 6 discusses wireless medium access control (MAC) protocols. It presents an overview of multiple access techniques, including frequency division multiple access; time division multiple access; and spread-spectrum multiple access, which includes code division multiple access. It discusses MAC protocols of the cable TV network-based DOCSIS, the IEEE 802.14 and IEEE 802.16 standards, and the wireless ATM.

Chapter 7 discusses radio systems engineering issues. It attempts to put the different pieces together to deal with real-life fixed broadband wireless access network deployment.

Chapter 8 discusses fixed broadband wireless access network services. It discusses how network services can be deployed in both ATM-based networks and DOCSIS-based networks.

Chapter 9 discusses fixed broadband wireless access network planning issues. These include regulatory considerations, such as whether to use licensed or unlicensed bands; which channel sharing scheme to use; and site survey, frequency planning, link budget, and backhaul considerations.

Chapter 10 discusses network management principles and how they apply to the fixed broadband wireless access networks. The topics discussed in the chapter include the Telecommunication Management Network, the Simple Network Management Protocol, and policy-based network management.