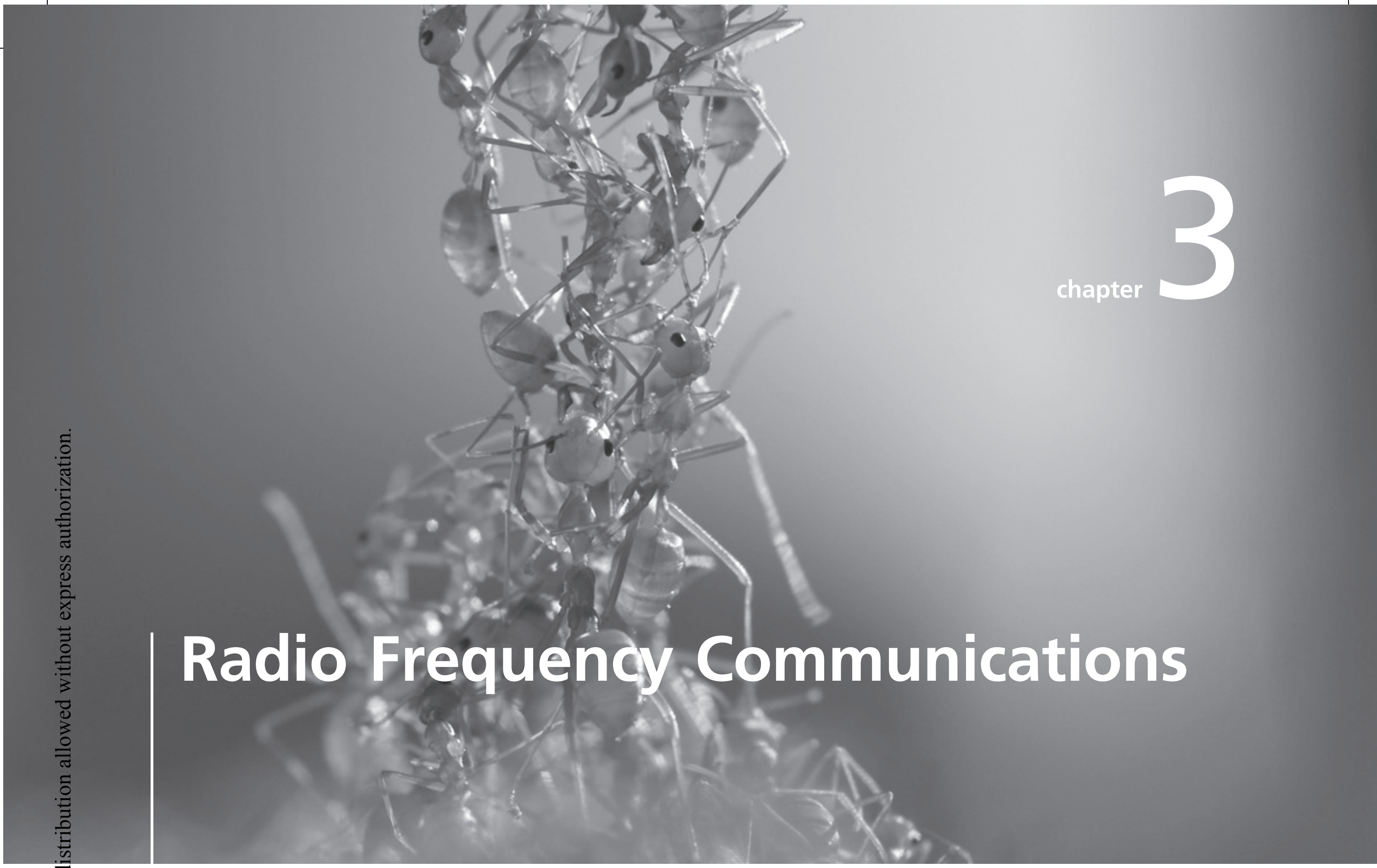

chapter 3

Radio Frequency Communications

After reading this chapter and completing the exercises, you will be able to:

- List the components of a radio system
- Describe the factors that affect the design of a radio system
- Discuss why standards are beneficial and list the major telecommunications standards organizations
- Explain the radio frequency spectrum

Radio frequency (RF) communications is the most common type of wireless communications. It comprises all the types of radio communications that use radio frequency waves, from radio broadcasting to wireless computer networks. In this book, we focus primarily on wireless data communications. Due to the convergence of technologies—for example, data transmission over cellular phones and satellites—we also cover these types of RF communications.

Unlike light-based communications, which is also wireless and is briefly discussed in this chapter, RF communications can cover long distances and is not always blocked by objects in the path of the signal, as light-based communications can be. RF is also a mature communications technology, the first radio transmission having been sent over 100 years ago.

RF communications can be very complex, but this chapter attempts to demystify the subject. First, we explore the basic components of RF communications. Then, we look at the issues regarding the design and performance of an RF system. Next, we explore the national and international organizations that create and enforce RF standards. Finally, we examine the RF spectrum allocation.

Components of a Radio System

Several hardware components are common to all radio systems, even though the functions of the radio systems may vary. These components include filters, mixers, amplifiers, and antennas. The first three are covered in this chapter. The fourth component, antennas, is important enough to warrant a chapter of its own (Chapter 4), especially given the accelerated growth of the wireless data communications field.

Filters

A **filter** does exactly what its name indicates: It gets rid of all the RF signals that are not wanted. The world around us is filled with RF signals that cover virtually every frequency in the electromagnetic spectrum (refer back to Figure 2-1). Most of these signals are generated by transmission equipment, such as cellular phones, communications satellites, and radio and television station transmitters; some reach us from outer space. After radio receivers have picked up these RF waves that are "flying" around us, a filter sifts out the frequencies that we do not want to receive. Think of a home-based water filter that removes particles and other impurities, or an automotive oil filter that prevents large contaminants from reaching the engine while allowing the oil itself to pass through. An RF filter either passes or rejects a signal based on the signal's frequency. The block diagram symbol for a filter is shown in Figure 3-1.

The block diagram symbols are universal and are commonly used to illustrate radio frequency as well as microwave components.

Figure 3-1 Filter symbol

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There are three types of RF filters: low-pass, bandpass, and high-pass. With a **low-pass filter**, a maximum frequency threshold is set and all signals below that value are allowed to pass through, as shown in Figure 3-2.

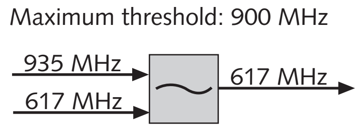

Figure 3-2 Low-pass filter

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A **high-pass filter**, instead of setting a maximum frequency threshold level, as a low-pass filter does, sets a minimum frequency threshold. All signals above the minimum threshold are allowed to pass through, whereas those below the minimum threshold are blocked. In addition, the process of modulating a signal with data to be transmitted creates "stray" signals called **harmonics**, which fall outside the range of frequencies we wish to transmit; these must also be filtered out. A high-pass filter is shown in Figure 3-3.

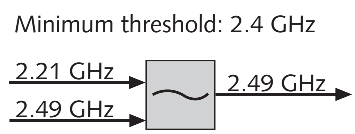

Figure 3-3 High-pass filter

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A **bandpass filter**, instead of setting either a minimum or maximum frequency threshold, sets a range called a **passband**, which includes both a minimum and a maximum threshold. Signals that fall within the passband are allowed through the bandpass filter. This is shown in Figure 3-4.

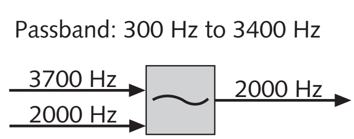

Figure 3-4 Bandpass filter

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Some of the figures depicting filters show multiple inputs. This is for the purpose of clarity only. A filter usually has a single input.

Filters are also found in transmitters, where they are used to eliminate unwanted frequencies called harmonic oscillations, which result from the process of modulating the signal before transmission. The way a filter functions in a transmitter is shown in Figure 3-5, which is a partial block diagram. The input is the information that needs to be sent; it can take the form of audio, video, or data. The transmitter takes the input data and modulates the signal (through analog or digital modulation) by changing the amplitude, frequency, or phase of the sine wave (see Chapter 2 to refresh your memory of RF signal modulation). The output from the modulation process is known as the **intermediate frequency** (**IF**) signal; it includes the frequencies between 8 MHz and 112 MHz. The IF signal is then filtered through a bandpass filter to remove any undesired high-frequency or low-frequency signals and produce an output with a frequency range of between 10 MHz and 100 MHz.

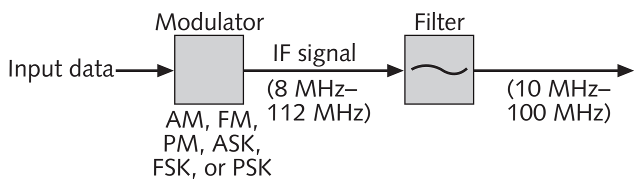

Figure 3-5 Filter function in a radio transmitter

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Mixers

The purpose of a **mixer** is to combine two inputs to create a single output. The mixer symbol is shown in Figure 3-6. The single output of a mixer is in the range of the highest sum and the lowest difference of the two frequencies. In Figure 3-7, the input signal—the information to be transmitted—is between 300 Hz and 3400 Hz, and the carrier frequency is 20,000 Hz.

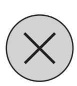

Figure 3-6 Mixer symbol

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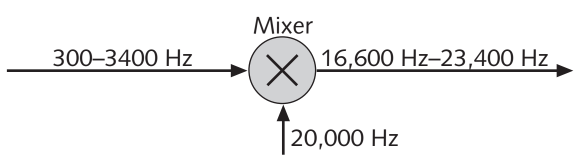

Figure 3-7 Mixer output

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The mixer adds the input frequencies to the mixed-in frequency to produce the sums:

20,000 Hz	20,000 Hz
+ 300 Hz	+3,400 Hz
20,300 Hz	23,400 Hz

In this example, 23,400 Hz is the highest sum. The mixer also determines the lowest difference between the input frequencies and the mixed-in frequency, for example:

20,000 Hz	20,000 Hz
– 300 Hz	–3,400 Hz
19,700 Hz	16,600 Hz

In this example, the lowest difference frequency would be 16,600 Hz. Therefore, the output from the mixer would be a frequency from 16,600 Hz to 23,400 Hz. The sum and the difference are known as the **sidebands** of the frequency carrier because they fall above and below the center frequency of the carrier signal.

One way to think about sidebands is by considering AM radio signals. AM broadcast radio is confined to a frequency range of 535 KHz to 1605 KHz. In an AM broadcast radio signal, the sidebands are typically 7.5 KHz wide, so a radio station on the AM dial uses a total of about 15 KHz of bandwidth to transmit a single audio channel or voice. An example of sidebands is shown in Figure 3-8.

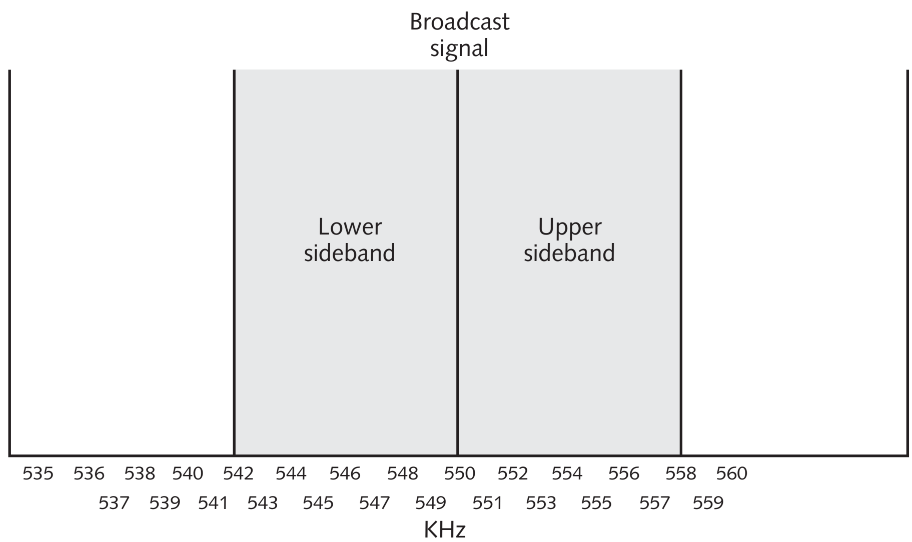

Figure 3-8 AM radio sidebands

Mixers are used to convert an input frequency to a specific desired output frequency. For example, let's say that you wish to transmit data using an 800 MHz carrier. Figure 3-9 illustrates how a mixer functions in a radio transmitter. The transmitter takes the input data and modulates the signal to produce an IF signal. In this example, the output from the modulator is a range of frequencies from 8 MHz to 112 MHz, which also includes some undesirable harmonic frequencies. This signal is then put through a bandpass filter to produce the desired IF signal range of 10 MHz to 100 MHz. This IF signal then becomes the input to the mixer along with the desired carrier frequency of 800 MHz. The output of the mixer is a signal with a frequency range between 698 MHz and 903 MHz, which is finally run through another bandpass filter to remove any frequencies outside the transmission range—in other words, those that fall outside the intended sideband limits.

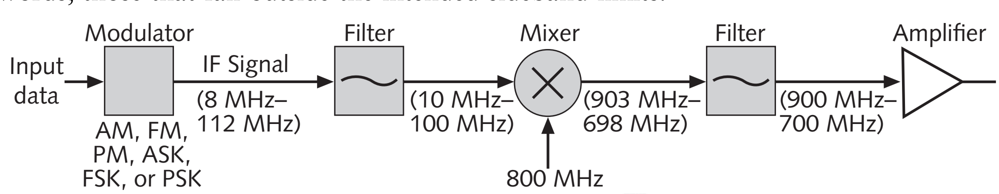

Figure 3-9 Mixer function in a radio transmitter

Amplifiers

An **amplifier** increases the amplitude of an RF signal. Figure 3-10 shows the symbol for an amplifier. In Figure 3-9, the amplifier is the last stage in a radio circuit and its function is to boost the power of the signal received from the last filter stage before it is transmitted. Amplifiers are critical components in a radio system because RF signals tend to lose intensity (amplitude) when they move through circuits or through air or space. Filters and mixers are passive devices, meaning that they do not add power to a signal; instead, they take power away from the signal. Likewise, when an electromagnetic wave carrying a modulated signal leaves the antenna and travels from the transmitter to the receiver antenna, a large portion of its power is lost or attenuated (reduced in amplitude) when it is absorbed by water particles in the air, walls, trees, and so on.

The amplifier is an active device. To work, though, it must be supplied with electricity. Amplifiers use this electricity to increase the input signal's intensity or strength and then output an exact copy of the input signal with a higher amplitude.

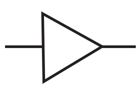

Figure 3-10 Amplifier symbol

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Antennas

For an RF signal to be transmitted or received, the transmitter or receiver must be connected to an antenna, the symbol for which is shown in Figure 3-11. Table 3-1 shows the list of radio system components along with their functions and block diagram symbols. Antennas will be discussed in greater detail in Chapter 4.

Figure 3-11 Antenna symbol

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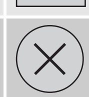
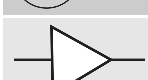
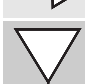
Component Name	Function	Block Diagram Symbol
Filter	Accept or block RF signal	
Mixer	Combine two radio frequency inputs to create a single output	
Amplifier	Boost signal strength	
Antenna	Send or receive an electromagnetic wave	

Table 3-1 Radio system components and their symbols

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Design of a Radio System

Filters, mixers, amplifiers, and antennas are necessary components of all radio systems, but designers need to consider how the systems will be used. In radio signal broadcasting, this may be as straightforward as determining the size and location of the antenna as well as a signal that will be strong enough to cover a very large area. However, in a radio system that incorporates two-way communications—for example, cellular phones connected via a wireless network—there are other considerations, including multiple user access, transmission direction, switching, and signal strength.

Multiple Access

Because the number of frequencies available for radio transmission is limited, conserving the use of frequencies is important. One way to do this is by sharing a particular frequency among multiple users, which reduces the number of frequencies needed. In Figure 3-12, a group of people is using walkie-talkies, all the users participating on the same channel. If the three people on the left transmit at the same time, the three on the right will not be able to understand the messages. The only way for all the users to share a channel is if they take turns transmitting.

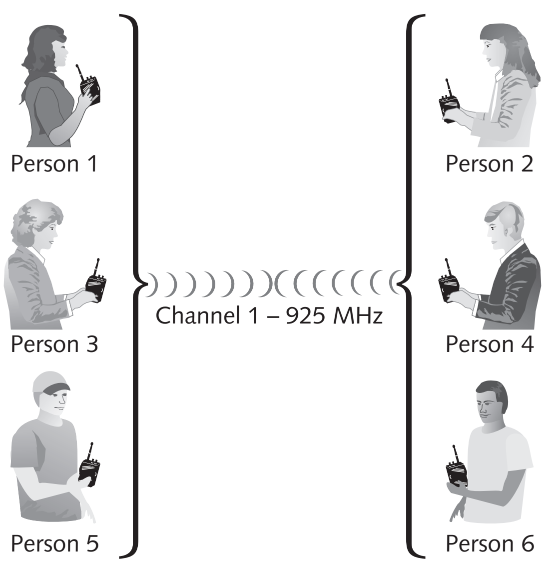

Figure 3-12 Multiple access

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Another example of multiple access is when employees of a company send multiple envelopes or packages from one office to another office. All the envelopes and packages are shipped at the same time and share space in the same courier truck on the same trip (multiple access). But when the truck arrives at the other office, the envelopes and packages are sorted and delivered to their respective recipients.

Several methods allow multiple access. The most significant, in terms of wireless communications, are Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), and Code Division Multiple Access (CDMA).

Frequency Division Multiple Access (FDMA) **Frequency Division Multiple Access (FDMA)** divides the bandwidth of a channel (a range of frequencies) into several smaller frequency bands (narrower ranges of frequencies, or channels). For example, a transmission band with a 50,000 Hz bandwidth can be divided into 1,000 channels, each with a bandwidth of 50 Hz. Each channel can then be dedicated to one specific user. This concept is illustrated in Figure 3-13. FDMA is most often used with analog transmissions.

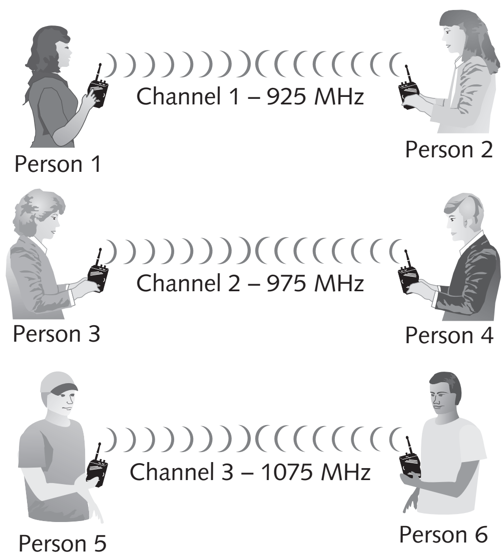

Figure 3-13 Frequency Division Multiple Access (FDMA)

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Cable television is transmitted using FDMA over coaxial cable. Each analog television signal uses 6 MHz of the 500 MHz bandwidth of the cable.

Think back to the example in Figure 3-12. If each of the three people on the left uses a different portion of the same frequency band by selecting a different channel on the walkie-talkie and if each of the three people on the right select one of the three transmitting channels, the people on the left can transmit simultaneously and each of the people on the right will receive the different transmissions.

One of the drawbacks of FDMA is that when signals are sent at frequencies that are grouped closely together, an errant signal from one frequency may encroach on its neighbor's frequency. This phenomenon, known as **crosstalk**, causes interference on the other frequency and may disrupt the transmission.

Time Division Multiple Access (TDMA) To overcome the problem of crosstalk, **Time Division Multiple Access (TDMA)** was developed. Whereas FDMA divides the bandwidth into several frequencies, TDMA divides the transmission time into several slots. Each user is assigned the entire frequency for a fraction of time on a fixed, rotating basis. Because the duration of each time slot is short, the delays that occur while others are using the frequency are not noticeable. Figure 3-14 illustrates TDMA for six users. TDMA is most often used with digital transmissions.

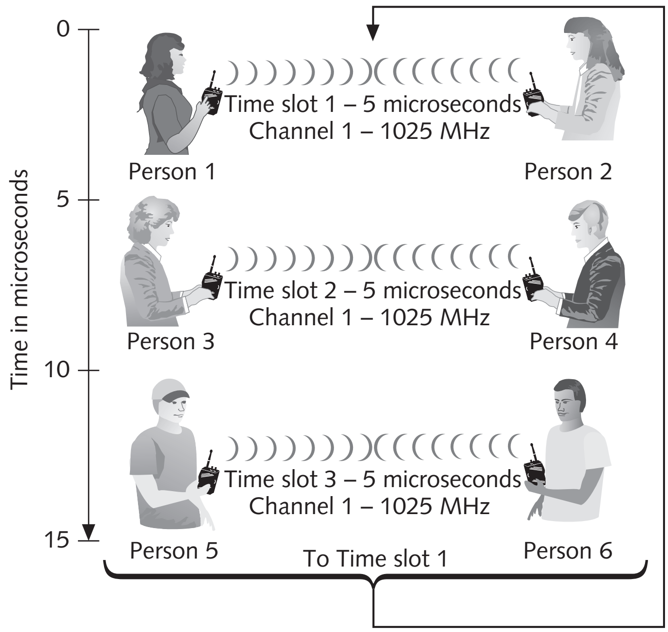

Figure 3-14 Time Division Multiple Access (TDMA)

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In traditional TDMA, if a user has no data to transmit during his or her assigned time slot with TDMA, the frequency remains idle—in other words, no one else uses that frequency. In more modern systems, the unused time slots can be assigned to users that are currently communicating.

Some types of cellular phones based on GSM technology, which until recently were the most common cellular technology used in Europe, transmit and receive using the TDMA method.

TDMA has two significant advantages over FDMA. First, it uses the bandwidth more efficiently. Studies indicate that when using a 25 MHz bandwidth, TDMA can achieve over 20 times the capacity of FDMA, meaning it can handle a much larger number of transmitters sharing the same frequency band. Second, TDMA allows data and voice transmissions to be mixed using the same frequency.

Code Division Multiple Access (CDMA) Code Division Multiple Access (CDMA) is another transmission method used in cellular telephone communications. Rather than separate RF frequencies or channels, CDMA uses direct sequence spread spectrum (DSSS) technology with a unique digital spreading code (called a **PN code**) to differentiate the multiple transmissions in the same frequency range. Before transmission occurs, the high-rate

PN code is combined with the data to be sent; this step spreads the signal over a wide frequency band.

CDMA is very similar to the spread spectrum transmission technique described in Chapter 2. What's different about CDMA is that, to implement multiple access, the transmission to each user begins on a subsequent chip of the PN code. Recall that, in DSSS, the 1s and 0s of the spreading code are referred to as "chips" to avoid confusing them with the data bits; this imprints a unique address on the data. Each "address" is then used only by one of the receivers sharing a frequency. Figure 3-15 illustrates the concept of the spreading code.

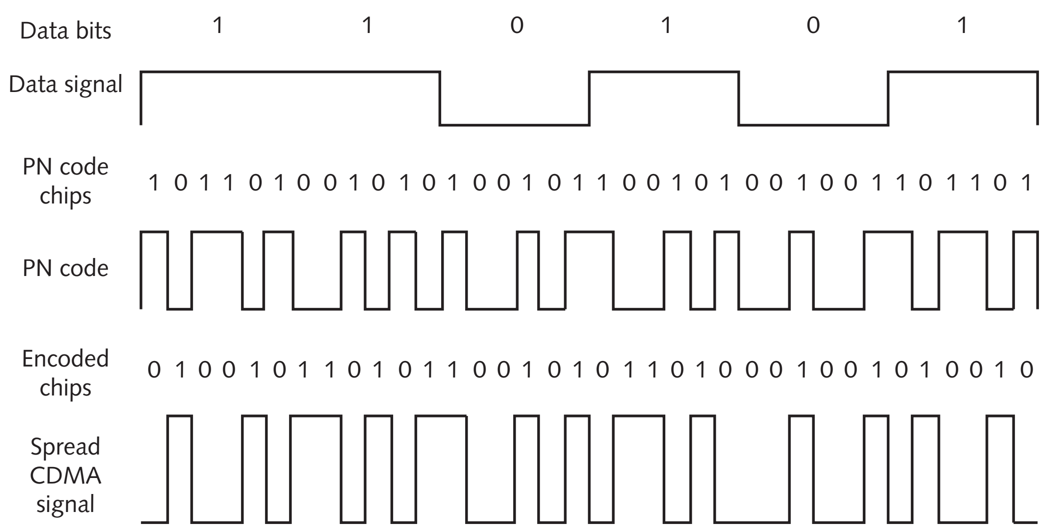

Figure 3-15 CDMA spreading of a data signal by a PN code

The unique-address concept works this way:

Channel 1: 1 0 0 1 1 0 1

Channel 2: 0 0 1 1 0 1 1

Channel 3: 0 1 1 0 1 1 0

and so on, until the sequence of chips wraps around.

Note that each of these codes starts on a different chip of the same sequence of 1s and 0s. The code for channel 2 begins on the second chip of channel 1. The code for channel 3 begins on the second chip of channel 2, and so on, until there are no more unique codes available and the sequence of chips wraps around. The longer the code is, the larger the number of users who will be able to share a channel. In the previous unique-address example, there are seven chips per code, which allows for seven unique codes.

The number of chips in the code determines the amount of spreading or bandwidth that the transmitted signal will occupy. Because the amount of spreading is limited by the bandwidth allocated to the system, the length of the spreading code also determines the number of unique code sequences and, consequently, the number of users that can share that frequency band.

In CDMA technology, the spreading code is called a pseudo-random code (PN code), because the code appears to be a random sequence of 1s and 0s, but it actually repeats itself over and over.

The spreading process is reversed at the receiver, and the code is de-spread to extract the original data bit transmitted. Because all receivers are on the same frequency, they all receive the same transmission. The PN code is designed so that when a receiver picks up a signal that was spread with the PN code that's being used by another receiver and then attempts to recover the original data, the decoded signal still looks like a high-frequency signal instead of data, so it is ignored. Figure 3-16 illustrates the decoding of the data in CDMA, and Figure 3-17 shows an example of what happens when a receiver attempts to de-spread another receiver's signal and recover the data bits.

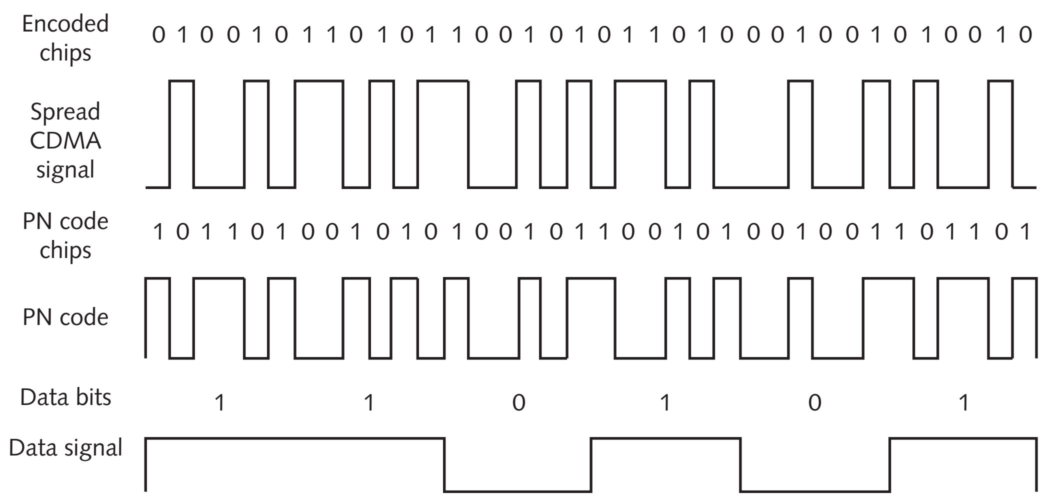

Figure 3-16 De-spreading a CDMA signal to recover the data bits

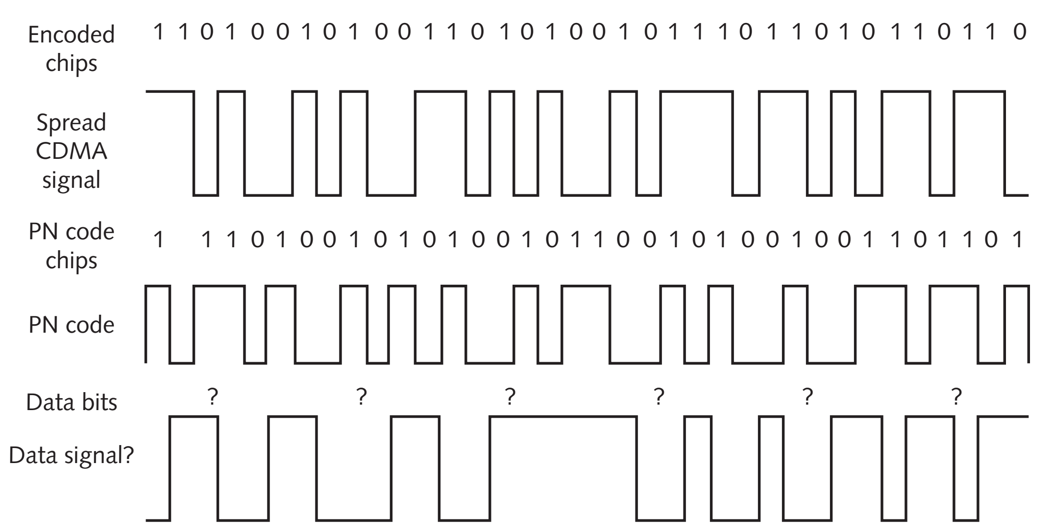

Figure 3-17 Attempting to de-spread another receiver's CDMA signal

To understand CDMA, imagine a room with 20 people in it who are having 10 simultaneous one-on-one conversations. Now suppose that all the pairs are talking at the same time but in different languages. Ignoring the issue of the noise level in the room, because none of the listeners understands any language other than that of the individual with whom they are speaking, the other nine conversations don't bother them.

There are several advantages to CDMA:

- It can carry up to three times the amount of data as TDMA.
- Transmissions are much harder to eavesdrop on, because a listener would have difficulty picking out a single conversation spread across the entire spectrum.
- A would-be eavesdropper must know the exact chip in which a particular transmission starts, and the PN code changes if the user is moving when his cellular phone connects to a different tower, thus making eavesdropping extremely difficult.

CDMA-based cellular technology is extremely complex. Because this book is not specifically focused on CDMA technology, the preceding description is included merely to provide an overview of this multiple access method.

Transmission Direction

In most wireless communications systems, data must flow in both directions, and the flow must be controlled so that the sending and receiving devices know when data will arrive or when it needs to be transmitted. There are three types of data flow: simplex, half-duplex, and full-duplex.

Simplex transmission occurs in only one direction, from device 1 to device 2, as shown in Figure 3-18. A broadcast radio station is an example of simplex transmission: The signal goes from the radio transmitter to the listener's radio, but the listener has no way of communicating with the station using the same radio signal. Except for broadcast radio and television, simplex is rarely used in wireless data communications today. That's because the receiver is unable to give the sender any feedback regarding the transmission, such as whether it was received correctly or if it needs to be resent. Such reliability is essential for successful data exchange.

Figure 3-18 Simplex transmission

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Half-duplex transmission occurs in both directions, but only one way at a time, as shown in Figure 3-19. This type of communications is typically used in consumer devices such as citizens band (CB) radios or walkie-talkies. In order for User A to transmit a message to User B, he must hold down the "talk" button while speaking. While the button is being pressed, User B can only listen and not talk. User A must release the "talk" button before User B can press her "talk" button. Both parties can send and receive information, but only one at a time.

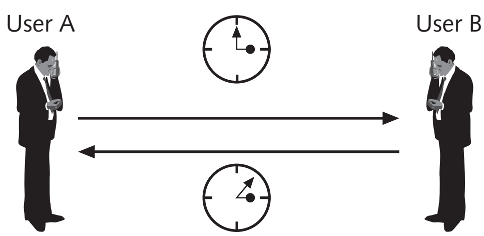

Figure 3-19 Half-duplex transmission

Full-duplex transmission occurs in both directions simultaneously, as shown in Figure 3-20. A telephone system is a type of full-duplex transmission. Both parties to a telephone call can speak at the same time, and they are able to hear each other throughout the call. Most modern wireless systems, such as cellular telephones, use full-duplex transmission.

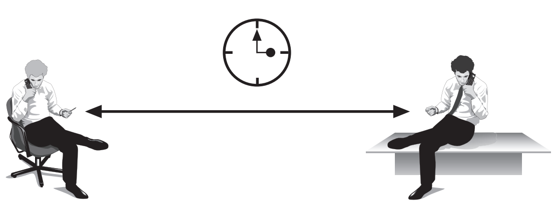

Figure 3-20 Full-duplex transmission

If the same antenna is used for wireless transmission and reception, a filter can be used to handle full-duplex transmissions. Most RF communications equipment that works in full-duplex mode sends and receives on different frequencies. A transmission picked up by the antenna on the receiving frequency passes through a filter and is sent to the receiver, while the transmission signal on the sending frequency is passed on to the same antenna. This is shown in Figure 3-21.

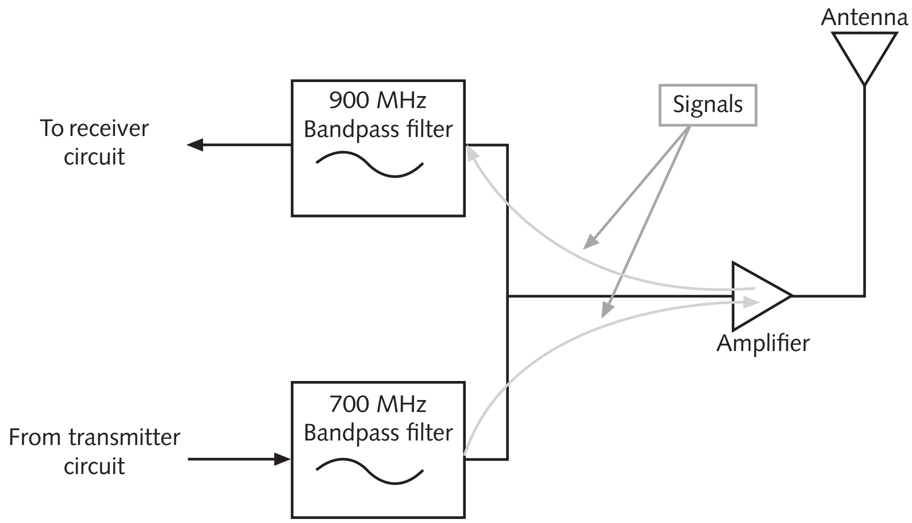

Figure 3-21 Using a single antenna in full-duplex RF communications

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Switching

The concept of **switching** is essential to all types of telecommunications, wireless as well as wired. Switching involves moving the signal from one wire or frequency to another. Consider for a moment the telephone in your home. You can use that one telephone to call a friend across the street, a classmate in another town, a store in a distant state, or anyone else who also has a phone. How can one single telephone be used to call any other telephone in the world? This is accomplished through a switch at the telephone company's central office. The signal from your phone goes out your telephone's wire all the way to a telephone company's switching office and is then switched or moved to the wire of the telephone that belongs to your friend across the street. This process is shown in Figure 3-22.

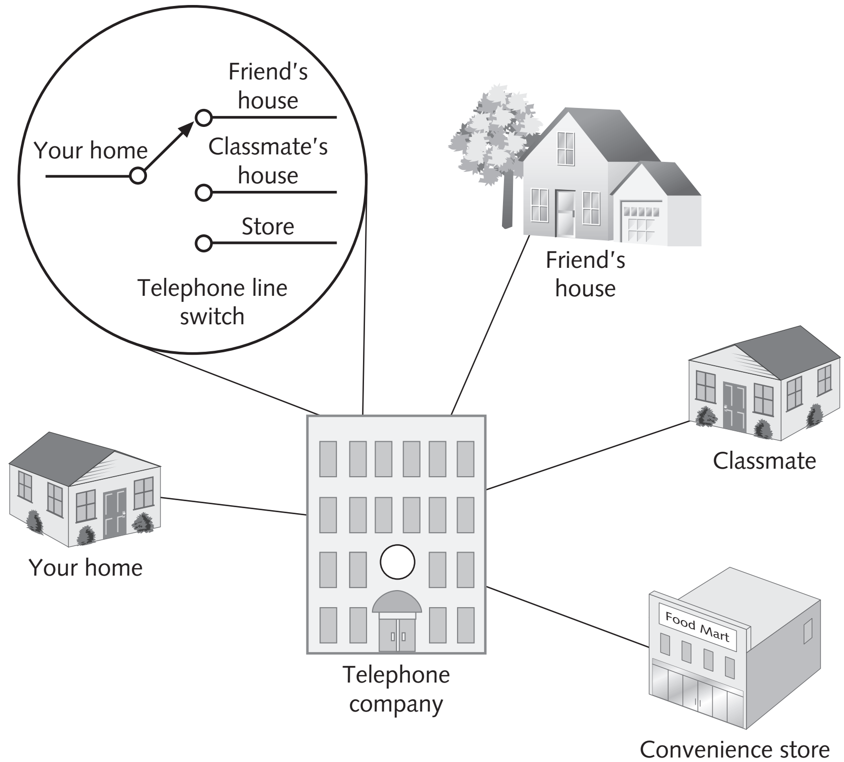

Figure 3-22 Telephone call switching

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The first telephone switches were not automatic. Human operators connected (switched) each two lines manually. Today, the telephone system is known as the Public Switched Telephone Network (PSTN), and the collection of equipment used in this network, including the home telephone sets, is commonly referred to in the data communications field as the Plain Old Telephone System (POTS).

To better understand why switches are necessary, imagine a telephone network in which each telephone must be wired to every other telephone without using switches. If this network had 500 telephones, each telephone would require 499 cables to connect to all the others, and a total of 124,750 cables would be needed to connect all the telephones to one another. If you draw a simple network of five telephones on a piece of paper, you'll notice that you need 10 cables to interconnect all of them. This type of connection is called a "mesh network."

You can quickly calculate how many cables would be required to interconnect several telephones or computers in a mesh network by using the formula n(n-1)/2, where n is the total number of devices you want to connect. Of course, this is not a very practical solution. To connect all the telephone sets in a city with 100,000 telephones would require that each be connected to an enormously large number of wires.

The type of switching used by telephone systems today is known as **circuit switching**. When a telephone call is placed, a direct physical connection is made, through the switch, between the caller and the recipient of the call. While the telephone call is taking place, the connection is "dedicated" and remains open only to these two users. Ignoring, for the moment, some of the advanced features available in today's telephone networks, such as call waiting and conference calling, no other calls can be made from or received by the two connected phones while this conversation is taking place, and anyone who calls that phone will receive a busy signal. This direct connection lasts until the end of the call, at which time the switch drops the connection and makes the two telephone lines available once more to receive or make calls.

Circuit switching is used for both wired telephone systems and second-generation wireless cellular telephone systems.

Circuit switching is ideal for voice communications. However, it is not efficient at transmitting data, because data transmission occurs in "bursts," with periods of delay in between. The delay would result in wasted time while nothing is transmitted. Instead of using circuit switching, data networks use **packet switching**. Packet switching requires that the data transmission be broken into small units called **packets**. Each packet is then sent independently through the network to reach the destination, as shown in Figure 3-23.

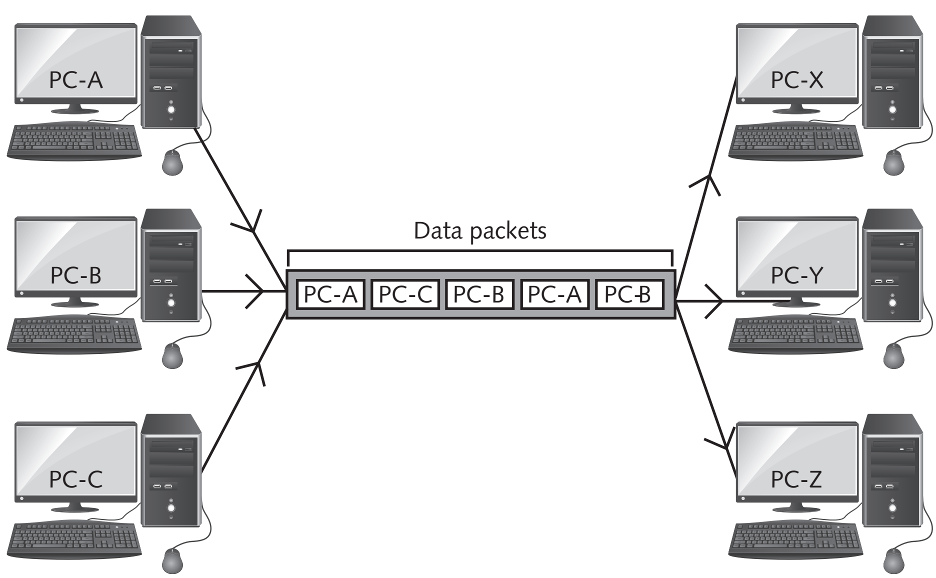

Figure 3-23 Packet switching

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Packet switching has a couple of important advantages for data transmissions. One advantage is that it allows better utilization of the network. In Figure 3-23, if PC-A does not have any data to send, PC-B and PC-C can use the available bandwidth on the network to send more data. Circuit switching ties up the communications line until the transmission is complete, whereas packet switching allows multiple computers to share the same line or frequency. That's because packets from several different computers can be intermingled while being sent. Another advantage has to do with error correction. If a transmission error occurs, it usually affects only one or a few packets. Only those packets affected must be resent, not the entire message.

3

Signal Strength

In a radio system, a signal's strength must be sufficient for the signal to reach its destination with enough amplitude for it to be picked up by the antenna and for the information to be extracted from it. Managing signal strength is much more complicated in a wireless system than in a wired network. Because the signal is not confined to a pair of wires, many types of electromagnetic interference can wreak havoc with the transmission. In addition, many types of objects, both stationary and moving, can impact the signal by blocking it or causing it to reflect. Examples of electromagnetic interference include high-voltage power lines, various types of radiation emitted by the sun, and lightning (see Figure 3-24).

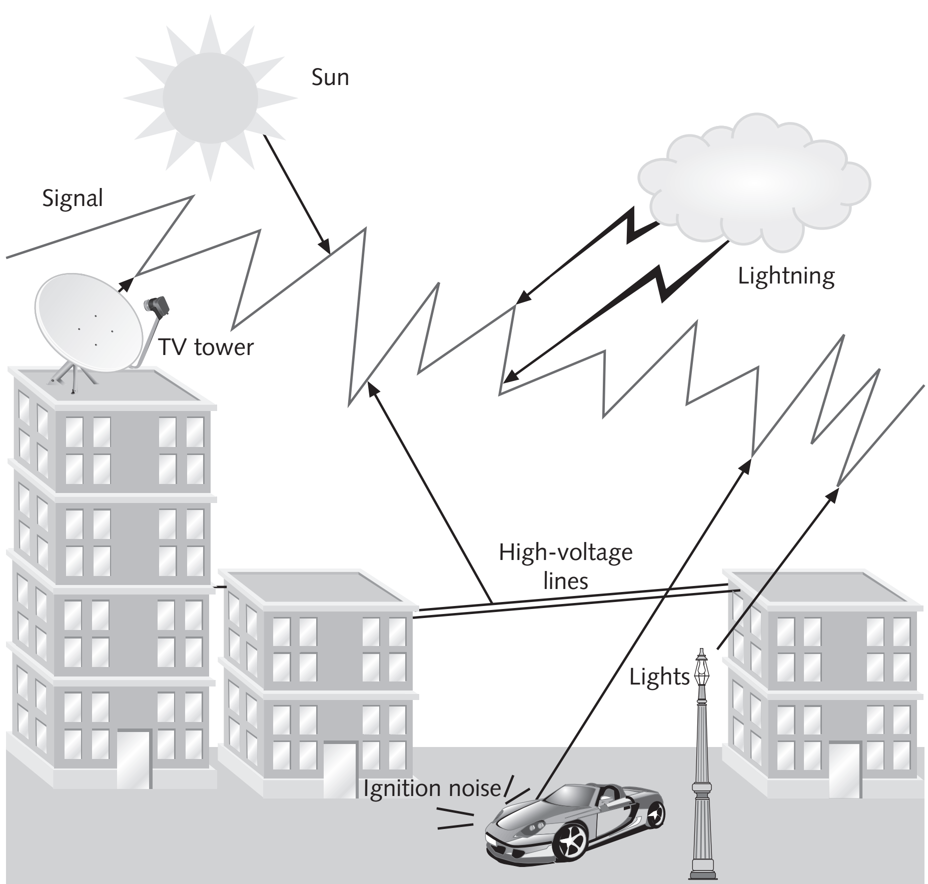

Figure 3-24 Sources of EMI or noise (interference)

Electromagnetic interference (**EMI**) is also called **noise**. Consider a room with 20 people in it who are having 10 one-on-one conversations. If everyone talks freely, there is a great deal of "racket" or background noise, which interferes with all conversations. With radio waves, background electromagnetic "noise" of various types can impede a signal.

A measurement called **signal-to-noise ratio** (**SNR**) compares the signal strength with the background noise (see Figure 3-25). When signal strength falls close to or below the level of noise, interference can take place. However, when the strength of the signal is well above the noise, interference can be easily filtered out. Consider again the example of the room with 20 people having 10 conversations. Someone who moves closer to her partner so she can be heard above the background noise is trying to achieve a higher SNR.

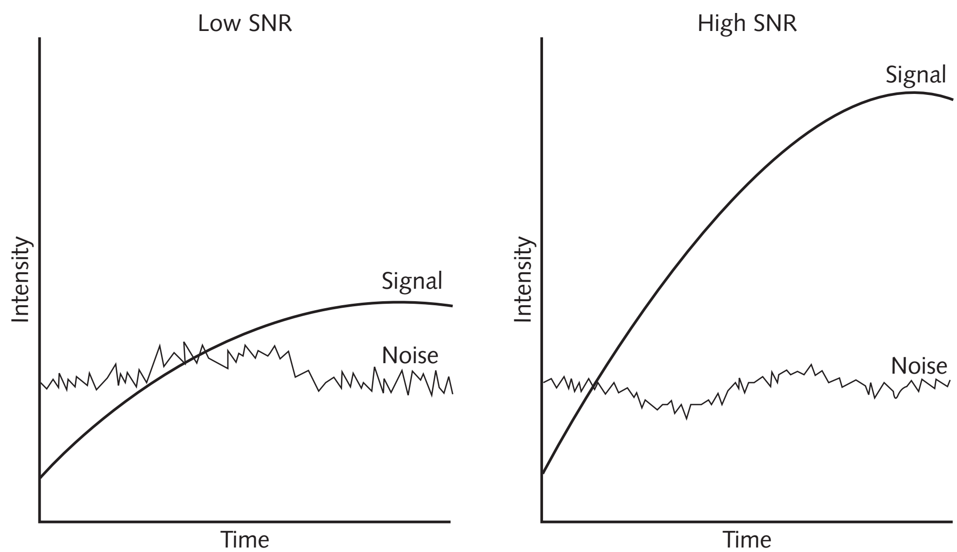

Figure 3-25 Signal-to-noise ratio (SNR)

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There are various ways to reduce the interference caused by noise, thereby creating an acceptable SNR. You can use more powerful amplifiers to boost the signal strength, you can filter the signal on the receiving end, or you can use techniques such as frequency hopping spread spectrum.

With a highly complex and expensive device, such as an extremely sensitive radio telescope receiver, the temperature of the circuits is lowered to –459 degrees Fahrenheit to maximize the performance and minimize the noise and attenuation generated by the circuits themselves. Recall that filters and mixers are passive devices that tend to reduce the amplitude or strength of the signal. Cooling these circuits down to –459 degrees Fahrenheit virtually eliminates the attenuation and dramatically reduces the noise. However, it is not practical to do this in a handheld transmitting device.

Loss of signal strength, or **attenuation**, is caused by various factors, but objects in the path of the signal, including man-made objects such as walls, are what cause the most attenuation. Table 3-2 shows examples of different building materials and their effects on radio transmissions. Amplifying a signal both before it is transmitted (to increase the power level) and after it is received helps to minimize attenuation.

Type of Material	Use in a Building	Impact on Radio Waves
Wood	Office partition	Low
Plaster	Inner walls	Low
Glass	Windows	Low
Bricks	Outer walls	Medium
Concrete	Floors and outer walls	High
Metal	Elevator shafts and cars	Very high

Table 3-2 **Materials and their effects on radio waves**

At certain frequencies, attenuation can also be caused by precipitation, such as rain or snow. Consequently, attenuation decreases as the altitude increases because of the decrease in air and water vapor density at higher altitudes.

As a radio signal is transmitted, the electromagnetic waves spread out. Some of these waves may reflect off distant surfaces and continue toward the receiver. This results in the same signal being received not only from several different directions but also at different times, since it takes longer for the wave that bounced off a distant surface to reach the receiver (see Figure 3-26).

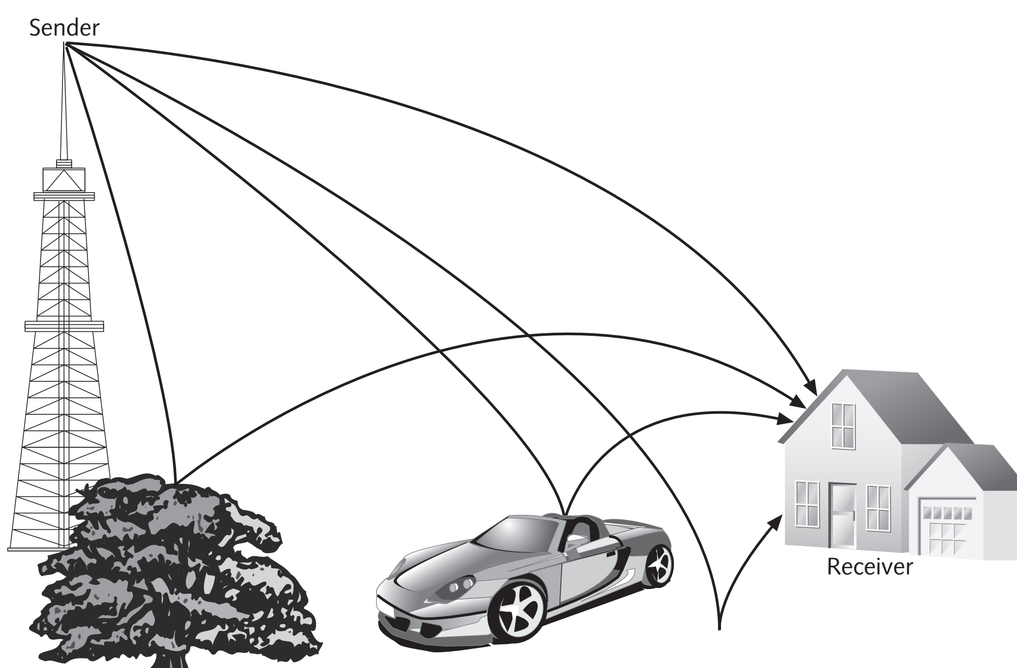

Figure 3-26 Multipath interference or distortion

This phenomenon, known as **multipath distortion**, can cause interference problems that affect the strength of the signal. This can prevent the receiver from picking up a signal strong enough for reliable reception (see Figure 3-27).

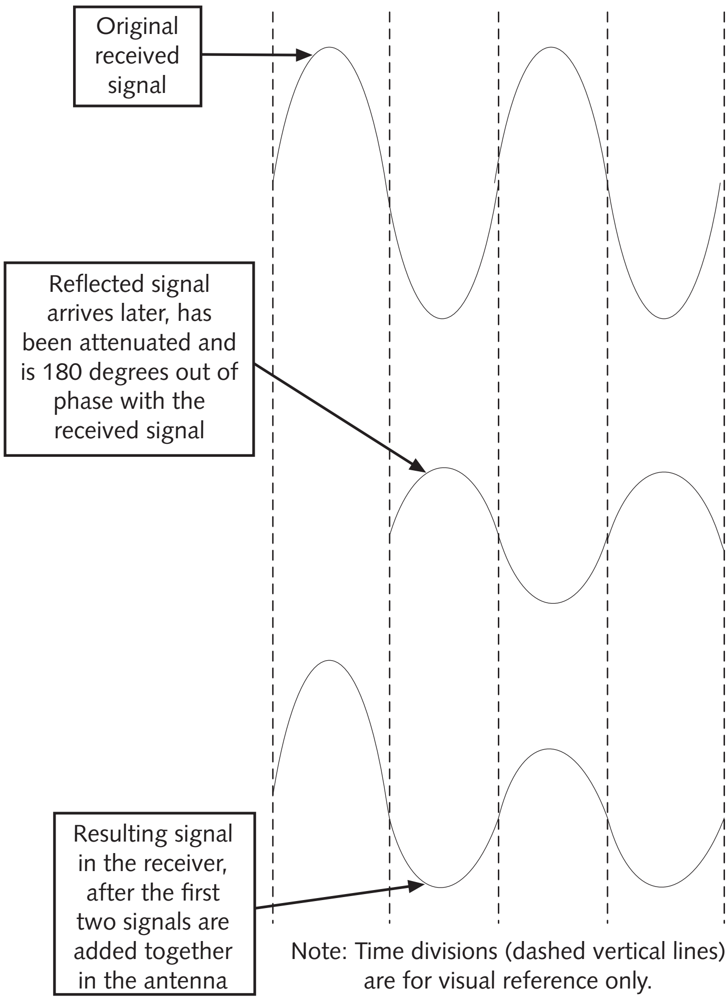

Figure 3-27 Effect of multipath distortion in a signal

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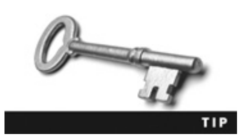
Multipath distortion gets its name from the fact that some of the waves get reflected, travel different paths between the transmitter and the receiver, and arrive at the receiver antenna at different times and out of phase with a signal that travels a more direct path. The resulting signal at the input of the receiver gets distorted because the peaks of the waves of both signals—one positive and one negative, for example—get added to each other. The result can be a reduction or an increase in the amplitude of the signal at the receiver's antenna, both of which can cause problems. Multipath distortion is a very complex topic, and a full discussion of it is beyond the scope of this book. However, some new standards—such as 802.11n—actually take advantage of multiple signals arriving at the receiver at different times to improve reception.

There are various ways to minimize multipath distortion, including using a **directional antenna**, or multiple receiver radios and antennas, where possible, or changing the height of the transmitter antenna to provide a stronger signal with a clear line of sight to the receiver's antenna. Directional antennas radiate the electromagnetic waves in one direction only and can help reduce or eliminate the effect of multipath distortion if there is a clear line of sight between the receiver and transmitter antennas. Other methods include using a more powerful amplifier in front of the receiver circuit to help increase the SNR, or transmitting the same signal on separate frequencies (see the discussion about OFDM in Chapter 8). Multipath distortion is particularly problematic in cities with large buildings and structures where the receiver is in constant motion, such as in cellular telephony.

Multipath distortion affects FM reception as well, particularly in the downtown districts of metropolitan areas. FM stations are usually free from noise; however, if you have ever been riding in an automobile in the downtown area of a large city you may have noticed occasional static-like noise while listening to an FM station. This noise is caused by the signal reflecting off large buildings and reaching the receiver out of phase, sometimes canceling the signal for very brief moments.



Multipath distortion in RF communications works very similarly to the way an echo affects sound. A good way to simulate multipath distortion is to use an audio editor such as Audacity (on a computer running Windows) or Garageband (on an Apple Macintosh running OS X) to record a sentence like "This is what happens when multipath affects a wireless transmission," then add an echo effect to the recording. Experiment with different degrees of echo. When you play the recording with a lot of echo, try to pick out the individual words in the middle of the sentence.

Understanding Standards

In place almost from the beginning of the telecommunications industry, standards have played an important role in its rapid growth. Today, a knowledge of which standards apply (and how they apply) to the wireless communications systems you are working on will enhance your ability to read and understand industry news, technical articles, and system specifications as well as design and deploy multi-vendor systems that offer excellent compatibility and scalability.

Need for Standards

Some IT people believe that the standards set for computer technologies stifle growth in this fast-paced field—that waiting for standards to catch up slows everything down. Nevertheless, standards do ultimately benefit both manufacturers and consumers. The very nature of the telecommunications industry, in which pieces of equipment from one manufacturer interact with equipment from other manufacturers, requires that standards exist for the design, implementation, test, and operation of the equipment. For example, using your laptop computer on virtually any network worldwide would be next to impossible without standards.

NOTE

The world's first telecommunications standard was published by the International Telegraph Union (ITU) in 1885. The standard originated from a desire by the governments of many countries to have a compatible telegraph operation. It took 20 years for the first telegraph standard to be created and published.

Advantages and Disadvantages of Standards

There are pros and cons to developing and applying standards in the telecommunications industry. The advantages have to do with interoperability and corporate competition, whereas the disadvantages are primarily political in nature.

Advantages of Standards One advantage of telecommunications standards is the guarantee that devices from one vendor will interoperate with those from other vendors. Devices that are not based on standards may not be able to connect and communicate with similar devices from other vendors. Standards ensure that a transmitter purchased from Vendor A can be seamlessly integrated into a communications network that contains a receiver from Vendor B.

A second advantage of standards is that they create competition. Standards are open to everyone; any vendor who wants to enter a marketplace can do so. Thus, standards can result in competition between vendors; and competition has several benefits. It results in lower costs for consumers and better-developed products. A vendor who has created a proprietary device gains no benefit from reducing his prices because he has no competition. Instead, with a captive market, he may raise prices at will. However, vendors making products based on the same standards may reduce their prices in order to compete in the marketplace. The competition usually results in lower costs to consumers.

Competition also results in lower costs for manufacturers. Because standards have already been established, manufacturers do not have to invest large amounts of capital in research and development. Instead, they can use the standards as a blueprint for their manufacturing. This reduces startup costs as well as the amount of time needed to bring a product to the market. Also, because standards increase the market for products that follow those standards, manufacturers tend to employ mass production techniques and gain economies of scale in manufacturing and engineering. As a result, production costs stay low, and these savings are passed on to the consumer.

A third advantage of standards is that they help consumers protect their investments in equipment. It is not uncommon for a manufacturer of a proprietary device to phase out a product line of equipment. Businesses that purchased that line are left with two choices. They can continue to support this now-obsolete legacy system, although the costs will dramatically escalate as replacement parts (and support specialists) become more difficult to locate. Or they can throw everything away and buy an up-to-date system. Both choices are very expensive.

Standards can help create a migration path. The organization that creates the initial standards continues to incorporate new technologies by regularly revising its standards. Generally, these revisions are backward-compatible, which reduces the risk of obsolete "orphan" systems that are incompatible with newer technologies.

Disadvantages of Standards International standards can be perceived as a threat to large countries such as the United States because their domestic markets become subjected to overseas competition. Manufacturers in smaller countries may have lower overhead costs, allowing them to produce a device more cheaply than larger manufacturers. Standards allow those manufacturers to produce and sell their products abroad, often threatening a domestic manufacturer's market share. Another way to look at this, of course, is that standards can benefit industries in smaller countries.

Another disadvantage of standards is that although they are intended to create unity, they can have the opposite effect. Periodically, a country will create a standard and offer it to other countries as a global standard. However, another country, for political reasons having nothing to do with technology, may reject the standard and attempt to create its own. Television broadcasting standards provide an example of this. Countries around the world have created various standards as a way of protecting their internal markets as well as their cultural heritages. With the advent of the Internet and global commerce, this type of protectionism appears to be on the way out, but multiple TV standards continue to be in effect, forcing many manufacturers to design and produce television sets and video recorders that support multiple standards. The consumer ultimately has to pay the cost of maintaining these more complex devices.

Most experts agree that the advantages of standards far outweigh the disadvantages and that standards are vital in industries such as telecommunications.

Types of Standards

There are two major types of standards in the telecommunications industry: de facto standards and de jure standards. A third type, consortia standards, is increasingly influencing how standards are set.

De Facto Standards **De facto standards** are not official standards. They are simply common practices that the industry follows for various reasons—because they're easy to use, perhaps, or because they've traditionally been used or they're what the majority of users have adopted. For the most part, de facto standards are established by their success in the marketplace. For example, most industry experts would agree that Microsoft Windows has become the de facto standard for personal-computer operating systems. By one estimate, approximately 85 percent of computer users worldwide run Windows on their computers (as of November 2011). No organization proclaimed Windows the standard; its widespread use has created what amounts to a standard.

The term "de facto" comes from Latin and means "from the fact." As it applies to computer and communications technologies, those technologies that are adopted by the market voluntarily become known as de facto standards.

De Jure Standards **De jure standards**, also called **official standards**, are those that are controlled by an organization or body that has been entrusted with that task. Each standards group has its own rules regarding membership. You will read about some of these groups in the next section.

The process for creating standards can be very involved. Generally, the organization develops subcommittees responsible for specific technologies. Each subcommittee is composed of different working groups, which are teams of industry experts given the task of creating the initial draft of a standard's documentation. The draft is then published to the members, both individuals and companies, and requests for comments (RFCs) are solicited. These members are developers, potential users, and other people with an interest in the field. The original committee reviews the comments and revises the draft. This final draft is then reviewed by the entire organization and is usually put to a vote before the final standards are officially published and made available to the public.

De facto standards sometimes become de jure standards by being approved by a committee. The TCP/IP network communications protocol that is so widely used today is an example of a de facto standard that later became an official standard, when the Internet Engineering Task Force (IETF) became an official standards body.

Consortia One of the major complaints against de jure standards is the amount of time it takes for a standard to be completed. For example, the initial standard for wireless local area networks took seven years to complete. In the telecommunications and IT industries, this represents an extremely long period of time before products can be brought to the marketplace; and, in some cases, manufacturers release products long before the standards are approved, as was the case with the latest high-speed WLAN standard.

Responding to this criticism, consortia are often used today to create standards. **Consortia** are industry-sponsored organizations with the goal of promoting a specific technology. Unlike with de jure standards bodies, membership in consortia is not open to everyone. Instead, specific high-profile companies create and serve on consortia. The goal of consortia is to develop a standard that promotes their specific technology in a shorter period of time than what official standards organizations take.

One of the most well-known consortia is the World Wide Web Consortium (W3C), which is composed of industry giants such as Microsoft, Netscape, Sun, and IBM. The W3C is responsible for creating the standards that are widely used on the Internet today, including hypertext markup language (HTML), cascading style sheets (CSS), and the Document Object Model (DOM).

Telecommunications Standards Organizations

In the telecommunications field, standards organizations exist at the national, multinational, and international levels. The following sections discuss each of these levels.

National Standards Organizations In the United States, there are several standards organizations, each of which plays a role in setting telecommunications standards. The **American National Standards Institute (ANSI)** functions largely as a clearinghouse for all kinds of standards development in the United States. Most ANSI standards are developed by one of its over 270 affiliated organizations, which include diverse groups such as the Water Quality Association and the Telecommunications Industry Association, as well as the group that originally created the ASCII code for use in computers and data communications. As of 2011, ANSI represents the interests of over 125,000 companies and 3.5 million professionals.

One of the ANSI-affiliated organizations is the **Telecommunications Industries Association (TIA)**. It is made up of industry vendors from telecommunications, electronic components, consumer electronics, and electronic information. Working with vendors, the TIA publishes Recommended Standards (RS) for the industry to follow. For example, the TIA developed and published a standard that defines how a computer's serial port, connector pin-outs, and electrical signaling should function. This standard is generally known as TIA RS-232. More information on the TIA can be found at *www.tiaonline.org*.

The TIA represents more than 600 companies that manufacture or supply the products and services used in global communications. The function of the TIA is to advocate policies to legislative bodies and to establish standards in five areas: user-premises equipment, network equipment, wireless communications, fiber optics, and satellite communications.

Two other organizations play roles in establishing national standards for telecommunications technology. The **Internet Engineering Task Force (IETF)** is a large, open (to anyone interested in joining) community of network designers, operators, vendors, and researchers concerned with the evolution of the Internet's architecture and the smooth operation of the Internet. Although it is a United States organization, it accepts members from any country in the world and focuses on the upper layers of telecommunications protocols; it is the organization that designs and develops practically all of the protocols used on the Internet. The IETF existed informally for many years, and it was not an official standards body until 1986, when it was formalized by the **Internet Architecture Board (IAB)**.

The IAB is responsible for defining the overall architecture of the Internet; it also serves as the technology advisory group for the **Internet Society (ISOC)**, a professional-membership organization of Internet experts that comments on policies and practices and oversees a number of other boards and task forces dealing with network policy issues. You can find out more about the IETF and its parent organizations at *www.ietf.org*.

The **Institute of Electrical and Electronics Engineers (IEEE)**, like the IETF, establishes standards for telecommunications. However, it also establishes a wide range of other IT standards. The IEEE's most well-known standards include IEEE 802.3, which covers local area network Ethernet transmissions, and IEEE 802.11, which covers the lower protocol layers of wireless local area network transmissions.

You can learn more about the IEEE at *www.ieee.org*. You can also obtain a no-cost copy of the IEEE 802 standards that relate to networking and wireless networking, provided that these have been published for longer than six months, at the following Web site: *standards.ieee.org/getieee802/portfolio.html*.

Multinational Standards Organizations Multinational standards organizations span more than one country; many of them are based in Europe. For example, the **European Telecommunications Standards Institute (ETSI)** develops telecommunications standards for use throughout Europe. Its membership consists primarily of European companies and European government agencies, but they also interface with organizations in other countries, including the United States. You can learn more about ETSI at *www.etsi.org*.

International Standards Organizations Because telecommunications technology is truly global, there are also global organizations that set industry standards. The best known is the **International Telecommunication Union** (**ITU**), an agency of the United Nations that is responsible for telecommunications. The ITU is composed of over 200 governments and private companies that coordinate global telecommunications networks and services. Unlike other bodies that set standards, the ITU is actually a treaty organization. The regulations set by the ITU are legally binding on the nations that have signed the treaty.

Two of the ITU's subsidiary organizations prepare recommendations on telecommunications standards. The ITU-T focuses on telecommunications networks, and the ITU-R focuses on RF-based communications, including the radio frequencies that should be used and the radio systems that support them. Although these recommendations are not mandatory and are not binding on the countries that have signed other treaties, almost all of the countries elect to follow the ITU recommendations, and these essentially function as worldwide standards. You can learn more about the ITU at *www.itu.int*.

NOTE

ITU-T replaced a standards body known as the CCITT, whose origins date back to work on standards for telegraphs in the 1860s.

The **International Organization for Standardization** (**ISO**) is based in Geneva, Switzerland. (Note that it uses the acronym "ISO" instead of "IOS." That's because "iso" means "equal" in Greek, and the organization wanted to use the same acronym worldwide, regardless of language.) Started in 1947, the ISO promotes international cooperation and standards in the areas of science, technology, and economics. Today, groups from over 100 countries belong to the ISO. You can learn more about it at *www.iso.org*.

NOTE

Several of the groups that belong to the ISO are actually national standards bodies. For example, the TIA interfaces with the ISO.

It might seem like there are too many standards organizations, but all these organizations, including the ones in the United States, tend to cooperate with one another, seldom stepping over one another's authority or geographical jurisdiction. You will read more about this cooperation in the upcoming chapters.

Regulatory Agencies

Although setting standards is important for telecommunications, enforcing telecommunications regulations is equally important. In a sense, the nature of national and international commerce enforces some standards. A company that refuses to abide by standards for cellular telephone transmissions will find that nobody buys its products. Telecommunications regulations, however, must be enforced by an outside regulatory agency, whose role is to ensure that all participants adhere to the prescribed standards. These regulations typically involve defining who can use a specific frequency when broadcasting a signal. Almost all countries have a national organization that functions as the regulatory agency to determine and enforce telecommunications policies. Some small countries simply adopt the regulations used by another country.

In the United States, the **Federal Communications Commission (FCC)** serves as the primary regulatory agency for telecommunications. The FCC is an independent government agency that is directly responsible to Congress. It was established by the Communications Act of 1934 and is charged with regulating interstate and international communications by radio, television, wire, satellite, and cable. The FCC's jurisdiction covers the 50 states, the District of Columbia, and U.S. territories.

In order to preserve its independence, the FCC is directed by five commissioners who are appointed by the President and confirmed by the Senate for five-year terms. Only three commissioners may be members of the same political party, and none of them can have a financial interest in any FCC-related business.

The FCC's responsibilities are very broad. In addition to developing and implementing regulatory programs, it processes applications for licenses and other filings, analyzes complaints, conducts investigations, and takes part in congressional hearings. The FCC also represents the United States in negotiations with foreign nations about telecommunications issues.

The FCC plays an important role in wireless communications. It regulates radio and television broadcast stations as well as cable and satellite stations. It also oversees the licensing, compliance, implementation, and other aspects of cellular telephones, pagers, and two-way radios. The FCC regulates the use of radio frequencies to fulfill the communications needs of businesses, local and state governments, public safety service providers, aircraft and ship operators, as well as individuals.

The RF spectrum is a limited resource, meaning that only a certain range of frequencies can be used for radio transmissions. Because of this limitation, frequencies are often licensed by regulatory agencies in the different countries around the world. In the United States, the regulatory agency is the FCC, which has the power to allocate portions of the spectrum. Broadcasters are required to transmit only in the frequency or frequencies for which they obtained a license. Commercial companies such as radio and television stations must pay fees (which are sometimes quite large) for the right to use a frequency; and, naturally, they do not want anyone else to be allowed to transmit on the same frequency within their coverage area. The FCC and other countries' agencies continually monitor transmissions to ensure that no one is using a frequency without a license or is transmitting with more power than their license allows.

Radio Frequency Spectrum

The **radio frequency spectrum** is the entire range of all radio frequencies that exist, from 10 KHz to over 30 GHz. The spectrum is divided into 450 different sections, or **bands**. Table 3-3 lists the major bands, their corresponding frequencies, and some typical uses.

Band (Acronym)	Frequency	Common Uses
Very low frequency (VLF)	10 KHz to 30 KHz	Maritime ship-to-shore
Low frequency (LF)	30 KHz to 300 KHz	Radio location such as LORAN (Long Range Navigation) Time signals for clock synchronization (WWVB)
Medium frequency (MF)	300 KHz to 3 MHz	AM radio
High frequency (HF)	3 MHz to 30 MHz	Short wave radio, CB radio
Very high frequency (VHF)	30 MHz to 144 MHz 144 MHz to 174 MHz 174 MHz to 328.6 MHz	TV channels 2–6, FM radio Taxi radios TV channels 7–13
Ultra high frequency (UHF)	328.6 MHz to 806 MHz 806 MHz to 960 MHz 960 MHz to 2.3 GHz 2.3 GHz to 2.9 GHz	Public safety: Fire, Police, etc. Cellular telephones Air traffic control radar WLANs (802.11b/g/n)
Super high frequency (SHF)	2.9 GHz to 30 GHz	WLANs (802.11a/n)
Extremely high frequency (EHF)	30 GHz and above	Radio astronomy

Table 3-3 Radio frequency bands

Radio frequencies of other common devices include:

- Garage door openers, alarm systems: 40 MHz
- Baby monitors: 49 MHz
- Radio-controlled airplanes: 72 MHz
- Radio-controlled cars: 75 MHz
- Wildlife tracking collars: 215 MHz–220 MHz
- Global positioning system (GPS): 1.227 GHz and 1.575 GHz

The United States is obligated to comply with the international spectrum allocations established by the ITU. However, the United States' use of its domestic spectrum may differ from the international allocations as long as those uses do not conflict with international regulations or agreements.

Until 1993, the ITU held conferences at 20-year intervals to review the international spectrum allocations. Since then, ITU conferences are convened every two to three years.

The U.S. Commerce Department's National Telecommunications and Information Administration (NTIA), serves as the principal advisor to the President on domestic and international communications and information issues. It also represents the views of the executive branch before Congress, the Federal Communications Commission, foreign governments, and international organizations.

Although a license from the FCC is required to send and receive on a specific frequency, there is a notable exception. This is known as the **license exempt spectrum**, or **unregulated bands**. Unregulated bands are, in effect, radio spectra that are available to any users nationwide without charge and without a license. Devices that use these bands can be either fixed or mobile. The FCC designated the unregulated bands to promote the development of a broad range of new devices and stimulate the growth of new industries.

NOTE

The FCC does impose power limits on devices using the unregulated bands, which in effect reduces their ranges. This prevents manufacturers of devices such as long-range walkie-talkies from using these frequencies instead of the regulated frequencies intended for these products.

Table 3-4 outlines a subset of the unregulated bands used by many of the technologies discussed in this book. The ITU-R has published recommendations for many additional unregulated bands; but as you learned earlier, not every country's domestic market follows all of the ITU-R's recommendations. One unregulated band is the **Industrial, Scientific and Medical (ISM) band**, which was approved by the FCC in 1985. Today, devices such as WLANs that transmit at speeds between 1 Mbps and 300 Mbps use this band. Another unlicensed band is the **Unlicensed National Information Infrastructure (U-NII)**, approved in 1996. The U-NII band is intended for devices that provide short-range, high-speed wireless digital communications. U-NII devices provide a means for educational institutions, libraries, and health care providers to connect to basic and advanced telecommunications services. Wireless networks working in unlicensed frequency bands are already helping to improve the quality and reduce the cost of medical care by allowing medical staff to obtain on-the-spot patient data, X-rays, and medical charts, and by giving health care workers access to telecommunications services.

Unlicensed Band	Frequency	Total Bandwidth	Common Uses
Industrial, Scientific and Medical (ISM)	902–928 MHz 2.4–2.4835 GHz 5.725–5.875 GHz	259.5 MHz	Cordless phones, WLANs, wireless public branch exchanges
Unlicensed Personal Communications Systems	1910–1930 MHz	20 MHz	WLANs, wireless public branch exchanges
Unlicensed National Information Infrastructure (U-NII)	5.15–5.25 GHz 5.15–5.25 (Low) 5.25–5.35 GHz (Mid) 5.47–5.725 (Worldwide) 5.725–5.825 GHz (Upper)	555 MHz	WLANs, wireless public branch WLANs wireless public branch exchanges, campus applications, long outdoor links
Millimeter Wave	59–64 GHz	5 GHz	In-home networking applications

Table 3-4 Unregulated bands

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Two recent developments have had an impact on the crowded radio frequency spectrum. The first involves the direction of radio signals. Currently, when radio signals leave the sender's antenna, they spread or radiate out (the word "radio" comes from the term "radiated energy") and can be picked up by multiple recipients. A new technique known as **adaptive array processing** replaces a traditional antenna with an array of antenna elements. These elements deliver RF signals to one specific user instead of sending signals out in a scattered pattern. This helps prevent eavesdropping by unapproved listeners and also allows more transmissions to take place in a given range of frequencies.

The second development is known as **ultra-wideband transmission** (**UWB**). UWB does not use a traditional radio signal carrier sending signals in the regulated frequency spectrum. Instead, UWB uses low-power, precisely timed pulses of energy that operate in the same frequency spectrum as low-end noise, such as that emitted by computer chips, TV monitors, automobile ignitions, and fans. UWB is currently used in limited radar and position-location devices. The IEEE has ratified standards for its use in wireless network communications. One example is IEEE 802.15.3c, which is used in WirelessHD and WiGig.

Chapter Summary

- Several hardware components are essential for communicating using radio frequencies (RF): filters, mixers, amplifiers, and antennas. A version of each of these components is found on all radio systems.
- A filter is used to either accept or block a radio frequency signal. With a low-pass filter, a maximum frequency threshold is set. All signals that are below that maximum threshold are allowed to pass through. Instead of setting a maximum frequency threshold, as with a low-pass filter, a high-pass filter sets a minimum frequency threshold. All signals that are above the minimum threshold are allowed to pass through, whereas those below the minimum threshold are turned away. A bandpass filter sets a passband, which is both a minimum and maximum threshold.
- The purpose of a mixer is to combine two inputs to create a single output. The single output is the highest sum and the lowest difference of the frequencies.
- An amplifier increases a signal's intensity or strength, whereas an antenna converts an RF signal from the transmitter into an electromagnetic wave, which carries the information through the air or empty space.
- Although filters, mixers, amplifiers, and antennas are all necessary components for a radio system, there are other design considerations that must be taken into account when creating a radio system. Because there are only a limited number of frequencies available, conserving the use of frequencies is important. One way to conserve is by sharing a frequency among several individual users.
- Frequency Division Multiple Access (FDMA) divides the bandwidth of the frequency into several narrower frequencies. Time Division Multiple Access (TDMA) divides the bandwidth into several time slots. Each user is assigned the entire frequency band for his transmission but only for a small fraction of time on a fixed, rotating basis. Code Division Multiple Access (CDMA) uses spread spectrum technology and unique digital spreading codes called PN codes, rather than separate RF frequencies or channels, to differentiate between the different transmissions.

- The direction in which data travels on a wireless network is important. There are three types of data flow. Simplex transmission occurs in only one direction. Half-duplex transmission sends data in both directions, but only one way at a time. And full-duplex transmission enables data to flow in both directions simultaneously.

- Switching involves moving the signal from one wire or frequency to another. Telephone systems use a type of switching known as circuit switching. When a telephone call is made, a dedicated and direct physical connection is made between the caller and the recipient of the call through the switch. Instead of using circuit switching, data networks use packet switching. Packet switching requires that the data transmission be broken into smaller units called packets, and each packet is then sent independently through the network to reach the destination.

- Managing a signal's strength is much more complicated in a wireless system than in a wired system. Electromagnetic interference (EMI), sometimes called noise, comes from a variety of man-made and natural sources. The signal-to-noise ratio (SNR) refers to the measure of signal strength relative to the background noise. A loss of signal strength is known as attenuation. Attenuation can be caused by a variety of factors (such as walls) that can decrease the signal's strength. As a radio signal is transmitted, the electromagnetic waves spread out. Some of these waves may reflect off surfaces and slow down. This results in the same signal being received not only from several different directions but at different times. This is known as multipath distortion.

- Telecommunications standards have been in place almost since the beginning of the industry and have played an important role in the rapid growth of the field. There are several advantages of having standards, including interoperability, lower costs, and a migration path. De facto standards are not standards per se, just common practices that the industry follows. Official standards (also called de jure standards) are those that are controlled by an organization or body that has been entrusted with that task. Consortia are often used today to create standards. Consortia are industry-sponsored organizations that have the goal of promoting a specific technology.

- Some standards organizations span more than one country. And because telecommunications is a truly global phenomenon, there are also multinational organizations that set standards. In the United States, the Federal Communications Commission (FCC) serves as the primary regulatory agency for telecommunications. The FCC is an independent government agency that is directly responsible to Congress.

- The radio frequency spectrum is the entire range of all radio frequencies that exist. This range extends from 10 KHz to over 30 GHz and is divided into 450 different bands. Although a license from the FCC is normally required to send and receive on a specific frequency, unregulated bands are available for use without a license in the United States and many other countries. Two unregulated bands are the Industrial, Scientific and Medical (ISM) band and the Unlicensed National Information Infrastructure (U-NII).

- Two recent developments have had an impact on the crowded radio frequency spectrum. A new technique known as adaptive array processing replaces a traditional antenna with an array of antenna elements. These elements deliver RF signals to one specific user instead of sending signals out in a scattered pattern. Ultra-wideband transmission (UWB) does not use a traditional radio signal carrier to send signals in the regulated frequency spectrum. Instead, it uses low-power, precisely timed pulses of energy that operate in the same frequency spectrum as low-end noise, such as that emitted by computer chips and TV monitors.

Key Terms

adaptive array processing A radio transmission technique that replaces a traditional antenna with an array of antenna elements.

American National Standards Institute (ANSI) A clearinghouse for standards development in the United States.

amplifier A component that increases a signal's intensity.

attenuation A loss of signal strength.

bandpass filter A filter that passes all signals that are between the maximum and minimum threshold.

circuit switching A switching technique in which a dedicated and direct physical connection is made between two transmitting devices—for example, between two telephones during a call.

Code Division Multiple Access (CDMA) A technique that uses spread spectrum technology and unique digital codes to send and receive radio transmissions.

consortia Industry-sponsored organizations that have the goal of promoting a specific technology.

crosstalk Signals from close frequencies that may interfere with other signals.

de facto standards Common practices that the industry follows for various reasons.

de jure standards Standards that are controlled by an organization or body.

directional antenna An antenna that radiates the electromagnetic waves in one direction only. As a result, it can help reduce or eliminate the effect of multipath distortion if there is a clear line of sight between the two antennas.

electromagnetic interference (EMI) Interference with a radio signal; also called noise.

European Telecommunications Standards Institute (ETSI) A standards body that develops telecommunications standards for use throughout Europe.

Federal Communications Commission (FCC) The primary U.S. regulatory agency for telecommunications.

filter A component that is used to either accept or block a radio frequency signal.

Frequency Division Multiple Access (FDMA) A radio transmission technique that divides the bandwidth of the frequency into several smaller frequency bands.

full-duplex transmission Transmissions in which data flows in either direction simultaneously.

half-duplex transmission Transmission that occurs in both directions but only one way at a time.

high-pass filter A filter that passes all signals that are above a maximum threshold.

harmonics Stray oscillations that result from the process of modulating a wave and that fall outside the range of frequencies used for transmission. Harmonics also occur when a signal goes through a mixer and must be filtered out at several points before the signal is finally fed to the antenna for transmission.

Industrial, Scientific and Medical (ISM) band An unregulated radio frequency band approved by the FCC in 1985.

Institute of Electrical and Electronics Engineers (IEEE) A standards body that establishes standards for telecommunications.

intermediate frequency (IF) The output signal that results from the modulation process.

International Organization for Standardization (ISO) An organization to promote international cooperation and standards in the areas of science, technology, and economics.

International Telecommunication Union (ITU) An agency of the United Nations that sets international telecommunications standards and coordinates global telecommunications networks and services.

Internet Architecture Board (IAB) The organization responsible for defining the overall architecture of the Internet, providing guidance and broad direction to the IETF. The IAB also serves as the technology advisory group to the Internet Society and oversees a number of critical activities in support of the Internet.

Internet Engineering Task Force (IETF) A standards body that focuses on the lower levels of telecommunications technologies.

Internet Society (ISOC) A professional-membership organization of Internet experts that comments on policies and practices and oversees a number of other boards and task forces dealing with network policy issues.

license exempt spectrum Unregulated radio frequency bands that are available in the United States to any users without a license.

low-pass filter A filter that passes all signals that are below a maximum threshold.

mixer A component that combines two inputs to create a single output.

multipath distortion What occurs when the same signal reflects and arrives at the receiver's antenna from several different directions and at different times.

noise Interference with a signal.

official standards *See* de jure standards.

packet A smaller segment of the transmitted signal.

packet switching Data transmission that is broken into smaller units.

passband A minimum and maximum threshold that spells out which range of frequencies will pass through a filter.

PN code Pseudo random code; a code that appears to be a random sequence of 1s and 0s but actually repeats itself. Used in CDMA cellular telephone technology.

radio frequency (RF) communications All types of radio communications that use radio frequency waves.

radio frequency spectrum The entire range of all radio frequencies that exist.

sidebands The sum and the differences of the frequency carrier that serve as buffer space around the frequency of the transmitted signal.

signal-to-noise ratio (SNR) The measure of signal strength relative to the background noise.

simplex transmission Transmission that occurs in only one direction.

switching Moving a signal from one wire or frequency to another.

Telecommunications Industries Association (TIA) A group of more than 600 companies that manufacture or supply the products and services used in global communications.

Time Division Multiple Access (TDMA) A transmission technique that divides the bandwidth into several time slots.

ultra-wideband transmission (UWB) Low-power, precisely timed pulses of energy that operate in the same frequency spectrum as low-end noise, such as that emitted by computer chips and TV monitors.

Unlicensed National Information Infrastructure (U-NII) An unregulated band approved by the FCC in 1996 to provide for short-range, high-speed wireless digital communications.

unregulated bands *See* license exempt spectrum.

Review Questions

1. Each of the following is a type of RF filter except ______________.
   a. low-pass
   b. high-pass
   c. passband
   d. bandpass
2. A(n) ______________ combines two inputs to create a single output.
   a. mixer
   b. codex
   c. filter
   d. amplifier
3. A(n) ______________ actively increases a signal's intensity or strength.
   a. transmitter
   b. demodulator
   c. amplifier
   d. antenna
4. The result of using a PN code is that ______________.
   a. it adds a unique address to the signal
   b. it spreads the signal over a wider range of frequencies
   c. it mixes the signal with the IF
   d. it decodes the signal
5. ______________ is a method of transmission in which the information is broken up into smaller units.
   a. Error correction
   b. Circuit switching
   c. Electromagnetic interference
   d. Packet switching

6. A passband has both a minimum and maximum threshold. True or False?
7. The resulting output from the modulation process is known as the middle frequency (MF) signal. True or False?
8. When mixing two signals, the highest sum and the smallest difference between the carrier frequency and the range of frequencies at the other input define two limits known as the sidebands of the frequency carrier. True or False?
9. TDMA can carry three times the amount of data that CDMA can. True or False?
10. Without switching, 1,225 cables would be required to interconnect 50 telephones. True or False?
11. When using the same antenna for full-duplex communications, the same frequency can be used for transmitting and receiving simultaneously. True or False?
12. ______________ divides the bandwidth of the frequency into several narrower frequencies. Each user then transmits using its own narrower frequency channel.
    a. TDMA
    b. OFDM
    c. FDMA
    d. CDMA
13. When signals are sent at frequencies that are closely grouped together, an errant signal may encroach on a close frequency, causing ______________.
    a. frequency conflict
    b. crosstalk
    c. time conflict
    d. channel mixing
14. Which of the following divides the bandwidth of the frequency channel into several time slots?
    a. FDMA
    b. OFDM
    c. CDMA
    d. TDMA
15. A ______________ transmission uses spread spectrum technology and unique spreading codes for each user.
    a. CDMA
    b. FDMA
    c. TDMA
    d. OFDM

16. List and describe the three types of data flow.

17. List and discuss the advantages of standards.

18. What is switching? What type of switching is used with telephone transmissions, and what type is used for data transmissions?

19. Explain multipath distortion and how it can be minimized.

20. What does the Federal Communications Commission do regarding the licensing of radion frequencies?

Hands-On Projects

Project 3-1

In Figure 3-28, fill in the dashed lines on the right with the resulting output frequency ranges from the various filters. Begin by converting the input frequencies to a common unit: KHz, MHz, or GHz. Then, show the results in the unit of your preference. (Recall that filters usually have only a single input but are shown here, for reasons of clarity, with two inputs.)

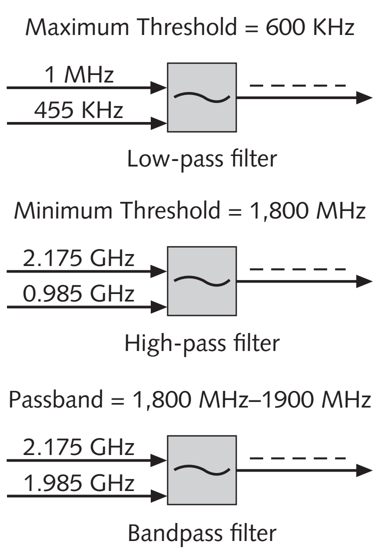

Figure 3-28 Filters (1)

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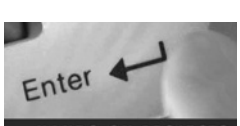

Project 3-2

In Figure 3-29, fill in the dashed lines at the right with the resulting output frequencies or ranges. Begin by converting the input frequencies to a common unit: KHz, MHz, or GHz. Then, show the results in the unit of your preference.

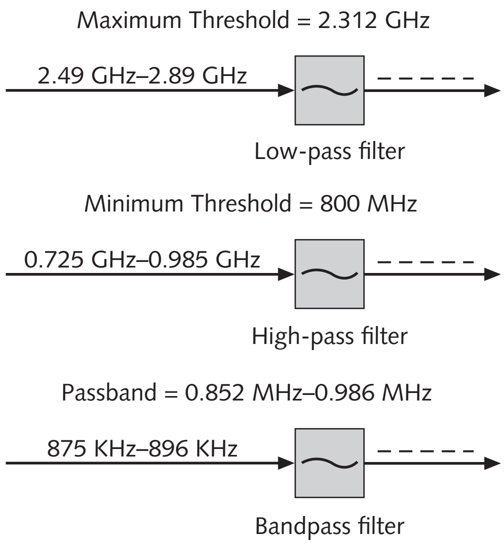

Figure 3-29 Filters (2)

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Project 3-3

In Figure 3-30, fill in the dashed lines at the right with the resulting output frequency ranges. Begin by converting the frequencies to a common unit: KHz, MHz, or GHz. Then, show the results in the unit of your preference.

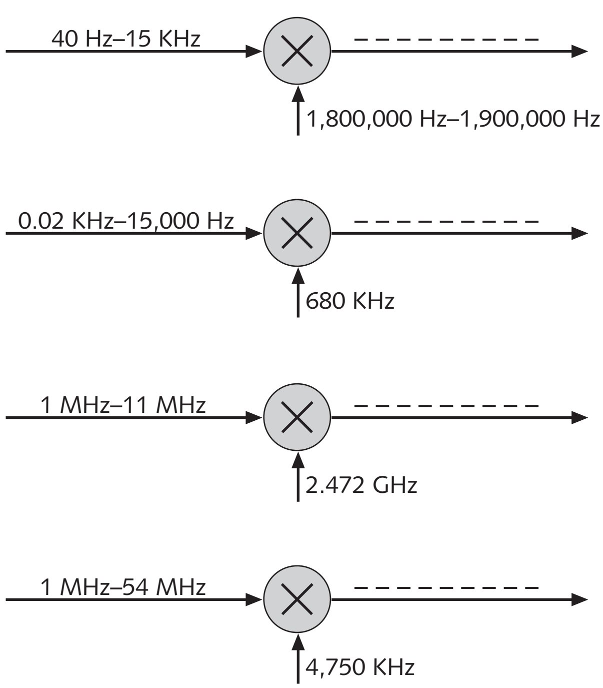

Figure 3-30 Mixers

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Project 3-4

Both natural and man-made objects located in a radio signal's path can cause attenuation—that is, a loss of signal strength. For this project, you will need a notebook computer equipped with a wireless LAN interface that is connected to an AP or wireless residential gateway. You will download, install, and configure inSSIDer to monitor the signal strength of the network that your computer is connected to.

1. In a Web browser, enter the address **www.metageek.net**.
2. Click **Downloads**. The inSSIDer download page should open automatically. If it doesn't, click **inSSIDer** in the menu on the left side of the page.
3. Save the file in the location of your preference, then locate the file inSSIDer-Installer-*x.x.x.x*.exe, in which *x.x.x.x* is the latest version of the program. Double-click the file to install the utility on your computer. Accept all the default settings.
4. Once the program has finished installing, click **Start, All Programs, Metageek,** then click **inSSIDer**.
5. inSSIDer will open and display a screen similar to the one in Figure 3-31. Maximize the inSSIDer application window. By default, inSSIDer will detect and display a list of all the wireless networks your computer has detected around your current location.

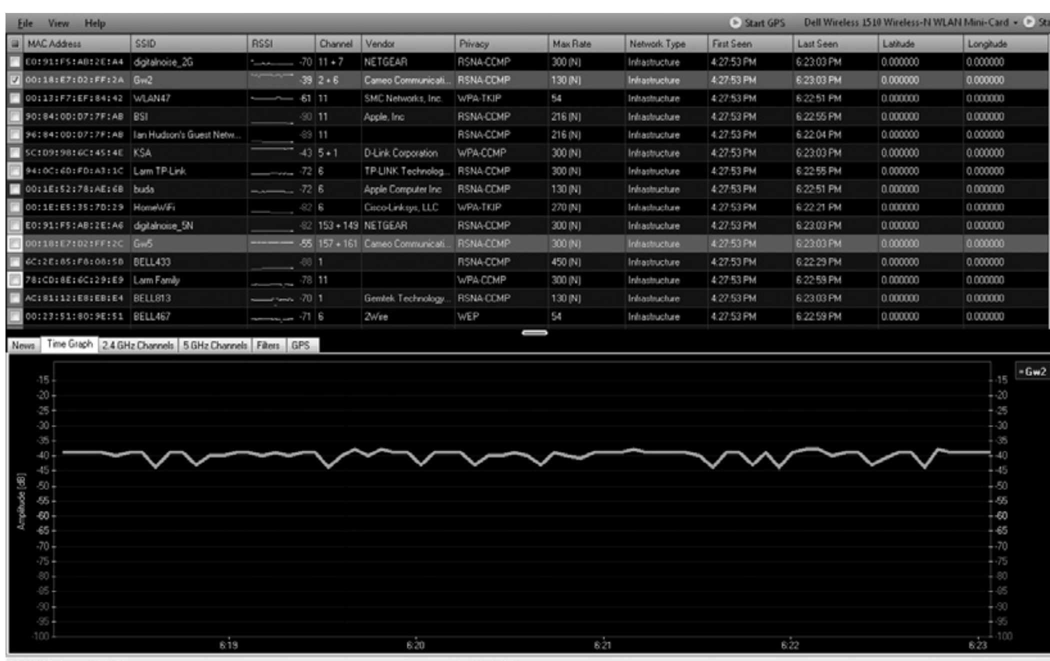

Figure 3-31 inSSIDer window

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6. Click the box to the left of "MAC Address" (just below the menu bar in the inSSIDer window) to remove the checkmarks in the column below. In the next project, you will monitor only the wireless network to which your computer is connected.

7. If you don't know it yet, ask your instructor to provide you with the SSID of the network. Locate it in the SSID column of the inSSIDer window and click the box to the left of the MAC Address of your network's SSID. A checkmark should appear in the box, with the row highlighted.
8. In the middle of the inSSIDer window, you will find a series of tabs. Click the **Time Graph** tab.

NOTE: You will use inSSIDer in the following projects as well as in other chapters of this book.

Project 3-5

In this project, you will use inSSIDer to monitor the signal strength of your AP.

1. The line in the Time Graph graph tab at the bottom of the inSSIDer window (see Figure 3-31) displays the strength of the signal that your computer is receiving from the AP. It will appear near the top of the graph if the signal strength is high and near the bottom of the graph if the signal strength is low.

Don't worry about the meaning of the numbers on either side of the inSSIDer Time Graph window for now. You will learn what they mean and how to use them in Chapter 4.

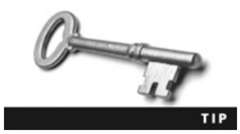
2. Monitor the strength of the signal while roaming away from the access point with the computer. Try to determine how far you can move from the access point before the signal is too weak for the connection to work reliably. To do this, you will need to attempt to open a Web page or download a file.

TIP: You can estimate the distance between you and the AP by any method available to you, such as counting tiles on the floor and multiplying by the size of the tiles or measuring your stride and counting the number of paces between the notebook computer and the AP.

3. As you move away from the AP, record all the obstacles between the computer and the AP, such as walls, doors, windows, and partitions. As you monitor the signal strength, record which items appear to have the greatest impact on the strength of the signal.
4. Record the distance at which the connection to the AP drops or becomes too slow or unreliable, such as when you can no longer access Web pages or when a file download appears to stop for a minute or longer.

5. Monitor the strength of the signal while standing between 50 ft. (15 meters and 100 ft. (30 meters) from the AP and covering the antenna of the network interface card with the following items:

- your hand (for a short period of time)
- a piece of aluminum foil
- a sheet of paper
- a sheet of plastic (like a shopping bag)
- a purse or briefcase with some metalic objects inside



If the NIC is built into the notebook computer, try using both hands to cover the back of the screen or the bottom of the computer until you see a definite reduction in the strength of the signal.

Project 3-6

Research the Web sites of the organizations listed in the left column of the table below and list some of the standards that they publish. Using Row 1 as a guide, identify other types of standards published by the same organization.

ISO – International Organization for Standardization *www.iso.org*	Screw threads, freight containers, computer protocols
IEEE – Institute of Electrical and Electronic Engineers *www.ieee.org*	
ITU – International Telecommunication Union *www.itu.int*	
ANSI – American National Standards Institute *www.ansi.org*	
ETSI – European Telecommunications Standards Institute *www.etsi.org*	

Real-World Exercises

The Baypoint Group (TBG), a company of 50 consultants who work with organizations and businesses on issues involving network planning and design, has again requested your services as a consultant. This time, the Good Samaritan Center, which assists needy citizens in the area, needs to modernize its office facilities. As part of its community outreach program, TBG has asked you to donate your time to help the Good Samaritan Center.

The Good Samaritan Center wants to install a wireless network in its offices. One local vendor has been trying to sell the center a proprietary system based on five-year-old technology that does not follow any current standards. The price given for the product and its installation is low and is therefore attractive to the center. However, managers at the center have asked TBG for advice.

Exercise 3-1

Create a PowerPoint slide presentation that outlines the different types of standards, the advantages and disadvantages of standards, and why they are needed. Include examples of products that did not follow standards and have vanished from the marketplace. Because the Good Samaritan Center is on the verge of buying the product, TBG has asked you to be very persuasive in your presentation. You are told that presenting the facts is not enough at this point; you must convince them why they should purchase a product that follows standards before you leave the room.

Exercise 3-2

Your presentation casts a shadow of doubt over the vendor's proprietary product, but the Good Samaritan Center is still not completely convinced it should go with a standard product. TBG has just learned that the vendor's proprietary product uses a licensed frequency that will require the center to secure and pay for a license from the FCC. TBG has asked you to prepare another presentation regarding the advantages and disadvantages of unregulated frequency bands. Because an engineer who sits on the Board of the Good Samaritan Center will be there, this PowerPoint presentation should be detailed and technical in its scope. Avoid focusing on the disadvantages of the vendor's proposal. Be prepared to answer questions related to potential interference by other wireless network users in nearby offices and what measures can be taken either to avoid such interference altogether or to deal with any problems that may arise.

Challenge Case Project

A local engineering user's group has contacted The Baypoint Group requesting a speaker to discuss multiple access technologies (FDMA, TDMA, and CDMA). Form a team of two or three consultants and research these technologies in detail. Specifically, pay attention to how they are used, and address their strengths and weaknesses. Provide an opinion about which technology will become the dominant player in the future of wireless.