Chapter 3. Radio Frequency and Light Signal Fundamentals: The Invisible Medium

What You Will Learn

After reading this chapter, you should be able to

- **Understand the general attributes of radio and light signals that affect propagation through the air medium**
- **Understand how wireless networks transform the representation of information for transmission through the air**

The primary difference between wireless and wired networks lies in the communications medium. Wired networks utilize cabling to transfer electrical current that represents information. With wireless networks, radio frequency (RF) and light signals have the job of carrying information invisibly through the air. This chapter continues the discussion on concepts common to all types of wireless networks, with emphasis on RF and light signal fundamentals.

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Wireless Transceivers

A wireless transceiver consists of a transmitter and a receiver. In the transmitter, a process known as **modulation** converts electrical digital signals inside a computer into either RF or light, which are analog signals. Amplifiers then increase the magnitude of the signals prior to departing an **antenna**. At the destination, a receiver detects the relatively weak signals and demodulates them into data types applicable to the destination computer. These elements, which **Figure 3-1** illustrate, are found in what's referred to as the transceiver. The transceiver is generally composed of hardware that is part of the wireless NIC.

Figure 3-1. In a Wireless Network, Signals Go Through a Process of Modulation and Amplification

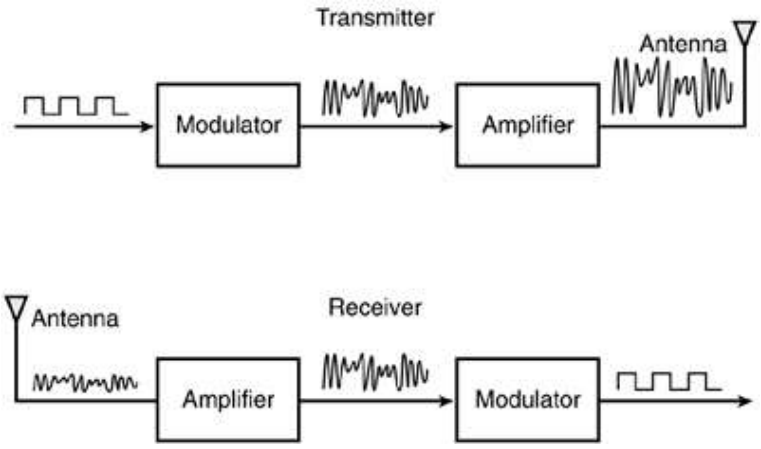


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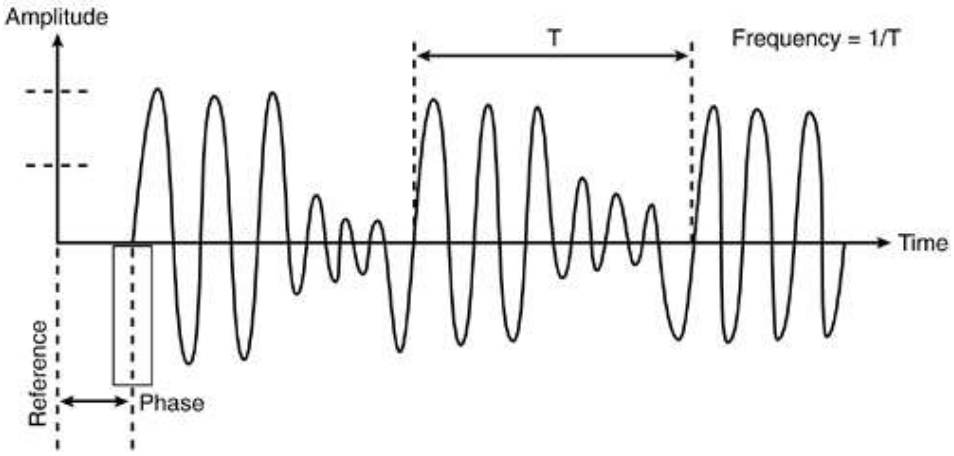
Understanding RF Signals

An **RF signal** is an electromagnetic wave that communications systems use to transport information through air from one point to another. RF signals have been in use for many years. They provide the means for carrying music to FM radios and video to televisions. In fact, RF signals are the most common means for carrying data over a wireless network.

RF Signal Attributes

The RF signal propagates between the sending and receiving stations' antennae. As shown in **Figure 3-2**, the signal that feeds the antenna has an amplitude, frequency, and phase. These attributes vary in time in order to represent information.

Figure 3-2. Amplitude, Frequency, and Phase Are Basic Elements of RF Signal



The amplitude indicates the strength of the RF signal. The measure for amplitude is generally power, which is analogous to the amount of effort a person needs to exert to ride a bicycle over a specific distance. Power, in terms of electromagnetic signals, represents the amount of energy necessary to push the signal over a particular distance. As the power increases, so does the range.

As a radio signal propagates through the air, it experiences a loss in amplitude. If the range between the sender and receiver increases, the signal amplitude declines exponentially. In an open environment, one clear of obstacles, the RF signals experience what engineers call free-space loss, which is a form of attenuation. The atmosphere causes the modulated signal to attenuate exponentially as the signal propagates farther away from the antenna. Therefore, the signal must have enough power to reach the desired distance at a signal level acceptable that the receiver needs.

The ability of the receiver to make sense of the signal, however, depends on the presence of other nearby RF signals. For illustration, imagine two people, Eric and Sierra, whom are 20 feet apart and trying to carry on a conversation. Sierra, acting as the transmitter, is speaking just loud enough for Eric, the receiver, to hear every word. If their baby, Madison, is crying loudly, Eric might miss a few words. In this case, the interference of the baby has made it impossible to effectively support communications. Either Eric and Sierra need to move closer together, or Sierra needs to speak louder. This is no different than the transmitters and receivers in wireless systems using RF signals for communications.

The **frequency** describes how many times per second that the signal repeats itself. The unit for frequency is Hertz (Hz), which is the number of cycles occurring each second. For example, an 802.11b wireless LAN operates at a frequency of 2.4 GHz, which means that the signal includes 2,400,000,000 cycles per second.

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The phase corresponds to how far the signal is offset from a reference point. As a convention, each cycle of the signal spans 360 degrees. For example, a signal might have a phase shift of 90 degrees, which means that the offset amount is one quarter (90/360 = 1/4) of the signal. A variation in phase is often useful for conveying information. For example, a signal can represent a binary 1 as a phase shift of 30 degrees and a binary 0 with a shift of 60 degrees. A strong advantage of representing data as phase shifts is that impairments resulting from the propagation of the signal through the air don't have much impact. Impairments generally affect amplitude, not the signal phase.

RF Signal Pros and Cons

As compared to using light signals, RF signals have the characteristics defined in **Table 3-1**.

Table 3-1. Comparing the Pros and Cons of RF Signals

RF Signal Pros	RF Signal Cons
Relatively long range, up to 20 miles when line-of-sight is possible	Lower throughput, up to the Mbps range
Good operation in haze and foggy conditions, except heavy rain causes poor performance	High potential for RF interference from other external RF-based systems

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RF Signal Pros	RF Signal Cons
License-free operation (only for 802.11-based systems)	Limited security because of radio propagation to beyond the facilities

These pros make the use of RF signals effective for the bulk of wireless network applications. Most wireless network standards, such as 802.11 and Bluetooth, specify the use of RF signals.

RF Signal Impairments

RF signals encounter impairments, such as interference and multipath propagation. This impacts communications between the sender and receiver, often causing lower performance and unhappy users.

Interference

Interference occurs when the two signals are present at the receiving station at the same time, assuming that they have the same frequency and phase. This is similar to one person trying to listen to two others talking at the same time. In this situation, wireless NIC receivers make errors when decoding the meaning of the information being sent.

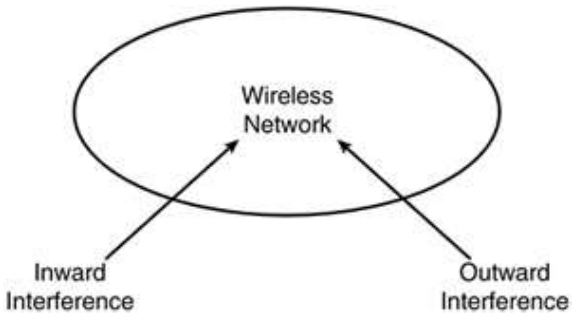
The Federal Communications Commission (FCC) regulates the use of most frequency bands and modulation types to avoid the possibility of signal interference between systems. However, radio interference can still occur, especially with systems operating in license-free bands.

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Users are free to install and utilize license-free equipment such as wireless LANs without coordinating usage and interference.

Figure 3-3 illustrates various forms of interference. Inward interference is where external signals interfere with the radio signal propagation of a wireless network. This interference can cause errors to occur in the information bits being sent. The receiver eventually discovers the errors, which invokes retransmissions and results in delays to the users. Significant inward interference might occur if another radio system is operating nearby with the same frequency and modulation type, such as two radio LANs operating in the license-free bands within close proximity.

Figure 3-3. Radio Signal Interference Can Be Inward or Outward



Other sources of inward interference are cordless phones, microwave ovens, and Bluetooth devices. When these types of RF devices are in use, the performance of a wireless network can significantly decrease because of retransmissions and competition on the network for use of the medium. This requires careful planning and consideration of other radio devices that might interfere with the wireless network.

One of the best ways to combat RF interference is to eliminate the sources of interference. For example, a company could set a policy for not using cordless phones that fall within the same frequency band as the wireless network. The problem, however, is that it is often impos-

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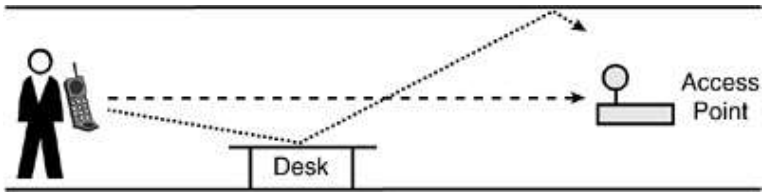
sible to completely restrict the usage of potential interferers, such as Bluetooth devices. If interference is going to be a big issue, consider choosing a wireless network that operates in a frequency band that doesn't conflict.

Outward interference happens when the signals from the radio signal system interfere with other systems. As with inward interference, significant outward interference can occur if a wireless network is in close proximity with another system. Because wireless network transmit power is relatively low, outward interference rarely causes significant problems.

Multipath

Multipath propagation occurs when portions of an RF signal take different paths when propagating from a source—such as a radio NIC—to a destination node, such as an access point. (See **Figure 3-4**.) A portion of the signal might go directly to the destination; and another part might bounce from a desk to the ceiling, and then to the destination. As a result, some of the signal encounters delay and travel longer paths to the receiver.

Figure 3-4. Obstacles Cause the Signal to Bounce in Different Directions

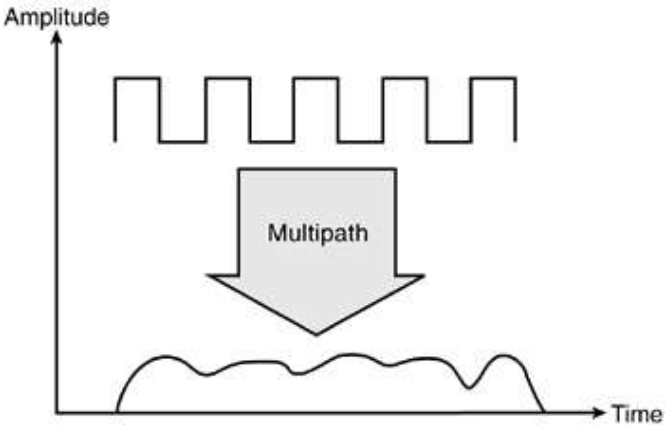


Multipath delays cause the information symbols represented in the radio signal to smear. (See **Figure 3-5**.) Because the shape of the signal conveys the information being transmitted, the receiver makes mis-

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takes when demodulating the signal's information. If the delays are great enough, bit errors in the packet occur, especially when data rates are high. The receiver won't be able to distinguish the symbols and interpret the corresponding bits correctly. When multipath strikes in this way, the receiving station detects the errors through an error-checking process. In response to bit errors, the sending station eventually retransmits the data frame.

Figure 3-5. Smearing of the Signals Because of Multipath Causes Confusion and Bit Errors in Receivers



Because of retransmissions, users encounter lower performance when multipath is significant. As examples, 802.11 signals in homes and offices might encounter 50 nanoseconds (ns) multipath delay while a manufacturing plant could be as high as 300 ns. Based on these values, multipath isn't too much of a problem in homes and offices. Metal machinery and racks in a plant, however, provide a lot of reflective surfaces that cause RF signals to bounce around and take erratic paths. As a result, be wary of multipath problems in warehouses, processing plants, and other areas full of irregular, metal obstacles.

What can you do if multipath is causing problems? Aside from clearing desks and chairs from your building, diversity seems to be the best solution to combat the perils of multipath. Diversity is the use of two

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antennae for each radio NIC to increase the odds of receiving a better signal on either of the antennae.

Diversity antennae have physical separation from the radio to ensure that one will encounter fewer multipath propagation affects than the other. In other words, the composite signal that one antenna receives might be closer to the original than what's found at the other antenna. The receiver uses signal-filtering and decision-making software to choose the better signal for demodulation. In fact, the reverse is also true: The transmitter chooses the better antenna for transmitting in the opposite direction.

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Understanding Light Signals

Light signals have been in use with communications systems for even longer than RF systems. Lanterns would provide a source of light to use with sending codes between ships at sea hundreds of years ago. Light guns are still in use today at many airports as a backup communication with aircraft having malfunctioning radio gear.

Wireless networks that utilize light signals, however, are not as common as these that use radio signals. Light signals generally satisfy needs for special applications, such as building-to-building links and short-range personal-area networks. Some wireless LANs and inter-building products use laser light to carry information between computers.

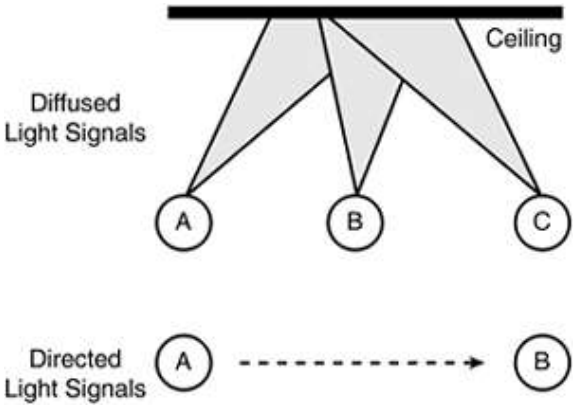
Light Signal Attributes

A light signal is analog in form and has a very high frequency that's not regulated by the FCC. Most wireless networks that use light for wireless signaling purposes utilize infrared light, which has a wavelength of approximately 900 nanometers. This equates to 333,333 GHz, which is quite a bit higher than RF signals and falls just below the visual range of humans.

Diffused and direct infrared are two main types of light transmission. Figure 3-6 illustrates these two concepts. Diffused laser light is normally reflected off a wall or ceiling, and direct laser is directly focused in a line-of-sight fashion. Most laser LANs utilize diffused infrared; inter-building modems and PDAs use the direct infrared technique.

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Figure 3-6. Both Diffused and Directed Light Signals Offer a Basis for Wireless Networks



Infrared light has very high bandwidth; however, the diffusing technique severely attenuates the signal and requires slow data transmissions (less than 1 Mbps) to avoid significant transmission errors. In addition, this technique limits wireless component spacing to around 40 feet, mainly because of the lower ceilings indoors and resulting signal path geometry. The advantage is relatively easy installation with inexpensive components.

The direct infrared approach, commonly referred to as free-space optics, intensifies the light signal power similarly to a directive radio signal antenna. This increases the range of low-power laser systems to a mile or so at data rates up in the Gbps range.

As with RF signals, the amplitude of light also decreases as distance between the sending and receiving stations increase. The range of an infrared light system can vary from a few feet with PDA applications to 1 mile with direct infrared systems. This is significantly less range than with RF systems.

Light Signal Pros and Cons

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As compared to RF signals, light signals have the characteristics defined in **Table 3-2**.

Table 3-2. Comparing the Pros and Cons of Light Signals

Light Signal Pros	Light Signal Cons
Extremely high throughput, up to the Gbps range	Variable, unreliable performance in the presence of significant smog, fog, rain, snow, and other airborne particulate matter
High inherent security because of narrow laser beam	Relatively short-range (1 mile) capability
License-free operation	Requirement for line-of-sight operation, free from obstructions such as buildings, trees, and telephone poles
Extremely low potential for RF interference from external systems	Issues dealing with alignment because of building swaying

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These characteristics make the use of light signals most effective for specialized applications where extremely high performance is necessary. For example, a company can install an infrared communications link between two nearby buildings in order to facilitate high-speed server backups over a wireless network.

Light Signal Impairments

Light signal propagation is not free from difficulties. Impairments, such as interference and obstructions, limit the performance of the wireless network that uses light signals.

Interference

Light signals are free from RF sources of interference such as cordless phones, and microwave ovens. In fact, the FCC doesn't regulate light signals because of extremely limited potential interference among systems. Light signals have such a high frequency that their emissions are well outside the spectrum of RF systems, which means that the FCC doesn't regulate light signals.

Interference from other sources of light, however, can still be a problem for systems that use light signals. For example, the installation of a point-to-point infrared transmission system aimed in an easterly or westerly direction can receive substantial interference from infrared light found within sunlight because the sun is low to the horizon. This interference can be high enough in some cases to completely disrupt transmission of data on the infrared link. When installing these types of systems, be certain to follow the manufacturer's recommendations when orienting the antennae.

Attenuation Because of Obstructions and Weather

Obstructions such as buildings, mountains, and trees offer substantial amounts of attenuation to light signals as they propagate through the air. Most of these objects are composed of materials that readily ab-

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sorb and scatter the light. As a result, be sure that the path between the end points of a light-based communications system are completely clear of obstacles.

Even if the communications path is open, weather can still impress large amounts of attenuation to light signals. The problem with weather is that it varies. For example, heavy fog might be present, and then the skies might be completely clear the following hour. This makes planning link budgets for light-based systems, especially those operating near the range limits, extremely difficult. Planners must be certain that the attenuation imposed by weather will not disrupt communications.

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Modulation: Preparing Signals for Propagation

Modulation creates a radio or light signal from the network data so that it is suitable for propagation through the air. This involves converting the digital signal contained within the computer into an analog signal. As part of this process, modulation superimposes the information signal onto a carrier, which is a signal having a specific frequency. In effect, the information rides on top of the carrier. In order to represent the information, the modulation signal varies the carrier in a way that represents the information.

This is done because it's generally not practical to transmit the information signal in its native form. For example, consider Brian, who wants to transmit his voice wirelessly from Dayton to Cincinnati, which is about 65 miles. One approach is for Brian to use a really high-powered audio amplifier system. The problem with this is that the intense volume would probably deafen everyone in Dayton. Instead, a better approach is to modulate Brian's voice with a radio frequency or light **carrier signal** that's out of range of human hearing and suitable for propagation through the air. The information signal can vary the amplitude, frequency, or phase of the carrier signal, and amplification of the carrier will not bother humans because it's well beyond the hearing range.

The latter is precisely what modulation does. A modulator mixes the source information signal, such as voice or data, with a carrier signal. The transceiver couples the resulting modulated and amplified signals to an antenna. The modulated signal departs the antenna and propagates through the air. The receiving station antenna couples the modu-

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