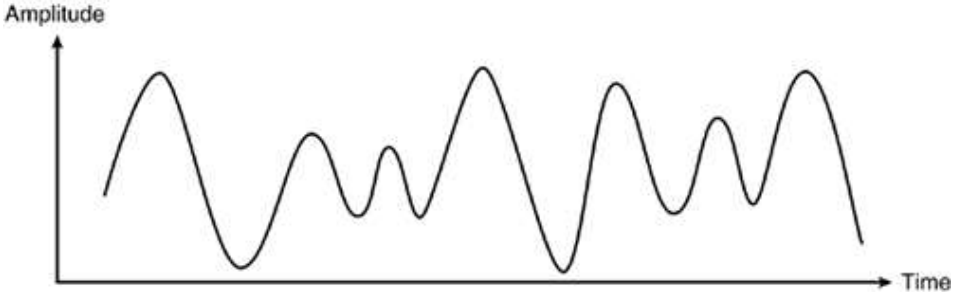
Figure 2-8. Analog Signals Carry Information Through the Air Medium



In the early days of electronic communication, most systems processed signals in analog form, mainly because their inputs were information coming from humans. An analog signal has amplitude, in units of voltage or power, and a frequency (having a specific number of cycles per second often referred to as Hertz). Wireless networks generally use analog signals at 2.4 GHz, which is in a band of frequencies referred to as radio waves. There are several different methods for describing the amplitude of wireless signals. Refer to **Chapter 3** for details on wireless analog signals.

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Flow of Information Through a Wireless Network

Certainly the reason for having a wireless network is to support the flow of information from one point to another without wires. As information flows through the network, the information changes form to efficiently traverse the network. Specific functions related to the transfer of information, such as medium access and error control, are common across the various types of wireless networks.

End Points of Information Flow

The flow of information often begins and ends with users. A business person might send an e-mail message from an airport, a doctor might review a patient's medical record from a wireless PDA, or a warehouse clerk might enter the number of items in a bin as part of inventory management. When users communicate information, they might use text, images, voice, or video through a computer device.

Initially, this information might simply be thoughts within a person's brain, which the user enters into a form of information, such as text or voice, and which the computer device stores as data. In the case of human users, the information is generally in an analog form; the information might be a digital signal when going between a nonhuman user, such as a robot, and a computer device.

Inputting, Storing, and Displaying Information

Information flows from the user to a computer device, which enables the inputting of information through a keyboard, keypad, microphone, or video camera. Newer input methods also allow information input

through eye movements and brain waves. Analog signals represent the information.

Before the computer device is capable of storing the information, however, the system must convert analog information signals into a digital form that is suitable for the computer device. Analog-to-digital (A/D) converters make this possible. Special circuitry samples the analog signal, resulting in pulses with amplitudes that binary numbers can represent. Likewise, digital-to-analog (D/A) converters translate digital signals into analog ones as part of presenting the information to users.

Inside a computer device, special codes represent information as data. The American Standard Code for Information Interchange (ASCII) code, for example, represents English characters as numbers. A computer stores these numbers as data. As examples, the ASCII code (in hexadecimal format) for the uppercase letter A is 41 and the lowercase h is 68. Most computers use ASCII encoding to represent textual information by representing the number in binary form, which includes only 1s and 0s. Other coding techniques symbolize video and audio information.

Interfacing with the Air Medium

After the user instructs the computer device to send information over the wireless network, the computer device negotiates a connection to the remote computer, which involves the use of transport and session layer functions. After establishing a connection, the computer device delivers the data in digital form to the wireless NIC. The wireless NIC generally sends a frame containing the information that conforms to a specific standard, such as IEEE 802.11, to the wireless NIC located within the remote computer device or access point.

The sending wireless NIC converts the data to an analog radio frequency or light wave signal before transmission through the antenna. This conversion requires modulation, which involves conversion of

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the signal from digital to analog. **Chapter 3** discusses particulars on how this is done. After modulation, the signal propagates through the air medium to the receiving wireless NIC, which demodulates and processes the received signal before handing the data up to higher network architectural layers.

Medium Access

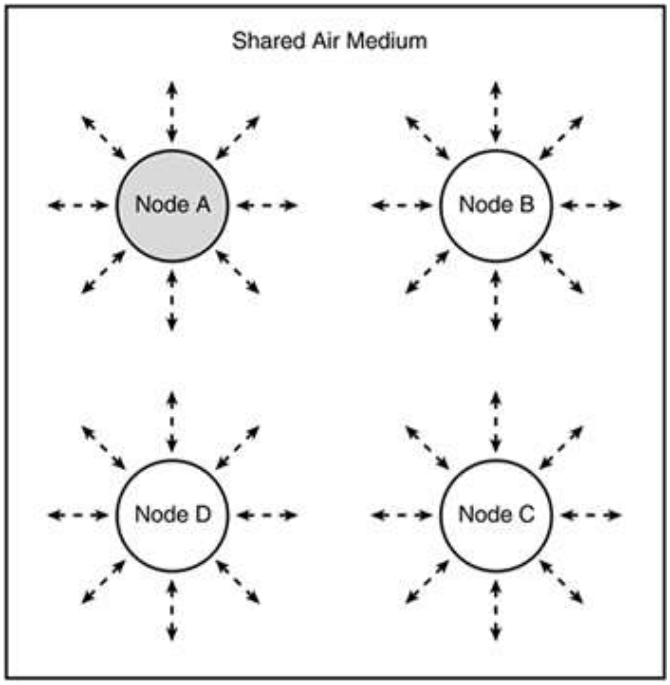
An important aspect of the transmission of data over a wireless network includes **medium access**, a data link layer function that comprises protocols that all wireless NICs must follow. These protocols ensure that wireless NICs coordinate the transmission of data, especially when only one can transmit at any particular time. Without this mechanism, several collisions would occur.

As with wired networks, CSMA is a common medium access protocol for wireless networks. CSMA implements a listen-before-talk protocol for regulating distributed access to a common medium. With CSMA, each wireless NIC has the capability of sensing transmissions from other devices.

If Node A has data to send, Node A first checks—senses—if any other nodes are transmitting data. (See **Figure 2-9**.) If the medium is clear—no transmission is heard—Node A will transmit one frame of data. If Node A senses transmissions from another node, Node A holds off transmitting and waits a period of time before sensing the channel again. The sensing operation continues until the node sends the data frame.

Figure 2-9. Node A Is Part of a Hypothetical Wireless Network Where Each Node Takes Turns Transmitting Data

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Collisions can occur with CSMA even though the transmitting node senses the channel first before sending data. The reason for this is the non-zero propagation delay between the nodes. The transmission coming from a particular node does not block all nodes from transmitting until the signal reaches all other nodes.

Node B, for example, starts to send a signal. Node A also needs to transmit a frame. It senses the medium and finds it clear because the signal from Node B has not arrived at Node A due to the propagation delay. As a result, Node A senses an idle medium and begins transmitting. Moments later, a collision between the two frames occurs, which causes significant errors in both data frames. Both nodes must retransmit the frames.

CSMA offers asynchronous access to the medium, which carries no guarantee that a particular NIC will be able to access the medium and send data within a particular span of time. Therefore, packet transmissions with CSMA are not constant.

This poses a problem for the transmission of real-time information, such as voice and video, because the network might not deliver pieces of information regularly enough to meet quality needs. In this case, QoS functions and higher throughput are necessary to improve performance.

Error Control

Information signals might encounter bit errors when propagating through the air medium. Noise and interference within the area of the wireless network causes these errors. As a result, wireless NICs implement error control mechanisms that detect and correct bit errors.

Noise from the sun's radiation and man-made devices cause damage to wireless information signals and is always present. The **noise floor**, however, is often low enough so that receivers are capable of distinguishing the information signal from the noise. At longer ranges, however, attenuation might reduce the information signal to a level that falls below the noise floor, and bit errors begin to occur.

The noise causing altered bits within wireless networks is usually Gaussian, or impulse noise. Theoretically, the amplitude of Gaussian noise is uniform across the frequency spectrum, and it normally triggers random errors that are independent of each other. Impulse noise, the most disastrous, is characterized by long quiet intervals of time followed by high-amplitude bursts. This noise results from natural causes— such as lightning— as well as man-made causes. Impulse noise is responsible for most errors in digital communication systems and generally provokes errors to occur dependently in groups. This distortion is referred to as burst errors.

Error control techniques highly reduce the number of transmission errors. Bit errors might still occur while data frames travel through the air medium, but error control mechanisms correct the errors. As a re-

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sult, the transmission of information through medium appears error-free to higher-layer protocols and the users.

The two primary types of error control are automatic repeat-request (ARQ) and forward error correction (FEC). With ARQ, which operates at the data link layer, the receiving wireless NIC detects errors and uses a feedback path to the sending wireless NIC for requesting the retransmission of frames having bit errors. There are two main events that must occur to correct errors with ARQ. First, a received frame must be checked at the receiver for possible errors, and then the sender must be notified to retransmit the frames received in error. In some protocols, such as 802.11, the receiver sends an acknowledgement to the sender if the received frame has no errors. The absence of an acknowledgement indicates to the sender to retransmit the frame.

Two approaches for retransmitting unsatisfactory blocks of data exist:

- Stop-and-wait ARQ
- Continuous ARQ

Stop-and-Wait ARQ

In the stop-and-wait method of transmission, the sending NIC transmits a block of data, then stops and waits for an acknowledgment from the receiving NIC on whether a particular frame was acceptable or not. If the sending side receives a negative acknowledgment, the previous frame will be sent again. The sending NIC will send the next frame after it receives a positive acknowledgment from the receiving NIC. The IEEE 802.11 standard specifies this form of error control.

One advantage of stop-and-wait ARQ is it does not require much memory space at the sending or receiving NIC. The outstanding transmitted frame needs only to be stored at the sender (in case of retransmission). On the other hand, stop-and-wait ARQ becomes inefficient as the propagation delay between the source and destination becomes large. For example, data sent on satellite links normally experience a round-trip

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delay of several hundred milliseconds; therefore, long block lengths are necessary to maintain a reasonably effective data rate. The trouble is that with longer data blocks the probability of an error occurring in a particular block is greater. Therefore, retransmission will occur often, and the resulting throughput will be lower.

Continuous ARQ

One way of improving the throughput on longer links is to use the continuous ARQ method. With this type of ARQ, the transmitter sends data blocks continuously until the receiving NIC detects an error. The sending NIC is usually capable of transmitting a certain number of frames and keeps a log of which frames have been sent. Once the receiving side detects a bad block, it will send a signal back to the sending NIC requesting that the bad frame be sent over again. When the receiver gets the signal to retransmit a certain frame, several subsequent frames might have already been sent because of propagation delays between the sender and receiver.

The sending NIC can retransmit frames with continuous ARQ in several ways. One method is for the source to retrieve the erred frame from the transmit memory and send the bad frame as well as the subsequent frames. This is called the go-back-n technique, and it can be more effective than the stop-and-wait ARQ because it makes better use of the channel bandwidth. One problem though is when n—the number of frames the transmitter sent after the erred frame plus one—becomes large, the method becomes inefficient. This is because the retransmission of just one frame means that a large number of good frames will also be resent, which decreases throughput.

The go-back-n technique is useful in applications where the receiver has little memory space because all that is needed is a receiver window size of one (ability to store one frame), assuming frames do not need to be delivered in order. When the receiving NIC rejects an erred frame —sends a negative acknowledgment—it does not need to store

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any subsequent frames for possible reordering while it is waiting for the retransmission. It need not wait because all subsequent frames will also be resent.

An alternative to the continuous go-back-n technique is a method that selectively retransmits only the erred frame and resumes normal transmission at the point just before getting the notification of a bad block of data. This is the selective repeat approach. Selective repeat is obviously better than continuous go-back-n in terms of throughput because the sending NIC only transmits the erred data block; however, the receiver must be capable of storing a number of data frames if they are to be processed in order. The receiver needs to buffer data that have been received after an erred frame was requested for retransmission as only the damaged frame will be resent.

All ARQ types depend on the detection of errors and the retransmission of the faulty data. Overall, ARQ is best for the correction of burst errors because this type of distortion normally occurs in a small percentage of frames, and does not invoke many retransmissions. Because of the feedback inherent in ARQ protocols, half-duplex or full-duplex lines must be in use since ARQ communication occurs in both directions. If only simplex links are available, it is impossible to use the ARQ technique because the receiver would not be able to notify the sending NIC of bad data blocks.

As an alternative to ARQ, FEC automatically corrects as many errors as it can within the physical layer at the receiving NIC without referring to the sending NIC. This is possible because the sending NIC includes enough redundant bits in case some are lost because of errors. This makes FEC well suited for simplex communications links, and cases where a return path to the sending NIC is not feasible.

For example, consider sending data wirelessly to control a space probe orbiting Pluto. By the time the sending NIC receives a negative acknowledgement from the probe and the corresponding retransmission

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of data reaches the probe, the probe would likely crash because of the significant propagation delay. Most wireless networks exist on Earth, but propagation delays can still be significant enough to warrant the use of FEC.

Despite the ability of FEC to correct errors without referring to the sending NIC, ARQ is still the most common method of error control. This is mainly because errors usually occur in clusters because of impulse noise. This places a requirement to correct large numbers of errors, which FEC typically cannot accomplish without excessive amounts of redundancy.

Many communications systems, however, are utilizing a combination of both ARQ and FEC. In this case, the physical layer devices attempt to correct a small number of errors to avoid a retransmission. If FEC corrects all the errors, the ARQ mechanism will not need to resend the data frame. If there are a large number of errors, ARQ steps in and the sender will resend the frame.

Transferring Wireless Data Signals

The air medium does not offer any active components to the wireless network. Several passive elements impact the appearance and effectiveness of the wireless information signals. While propagating through the medium, for example, the signals will encounter attenuation from solid objects and weather, as well as loss because of the distance between the sending and receiving NIC. In addition, the signals propagating through the medium can encounter interference, multipath propagation, and other elements that can impair the signal. Refer to **Chapter 3** for more details on these impairments.

Connecting with the Wireless Network Infrastructure

The base station, such as an access point, includes both a wireless and wired NIC, as well as software that interfaces the two networks. When a wireless user communicates with another wireless user, the base

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station might simply resend the data frame received from one user so that the other user is able to receive it. In this case, the base station is acting as a repeater. Alternatively, the base station might forward the data to the wired side of the base station if the destination is located somewhere on the wired side of the network.

Upon receiving a data frame, the wireless NIC within the base station converts the analog radio wave or light signal into a digital signal and performs error detection to ensure that the resulting data frame does not have any bit errors. The error control mechanism will cause the sending wireless NIC to retransmit the data frame if errors are present. After taking care of erred frames, the wireless NIC within the base station will either resend the frame or forward the frame to the wired side of the base station.

The wired NIC generally implements Ethernet, which interfaces directly with enterprise systems. The base station usually connects the wireless and wired networks at the physical layer and data link layer. Some base stations also include routing, which is a network layer function.

When traversing wire, the information signal remains in digital form, but different types of systems might convert the digital signal to a form suitable for transmission over the particular medium in use. The signal might undergo conversion to an analog form again if transmission over another wireless link, such as satellite, is necessary to reach the destination.

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Chapter Summary

Wireless networks include components that make mobile and portable application possible. Users are end points of the wireless network and utilize computer devices designed for a particular application. Wireless NICs and base stations are key components that communicate over the air medium. To provide roaming throughout a facility or city, a distribution system such as Ethernet interconnects base stations and interfaces users to servers and applications located on the wired network.

The seven-layer OSI reference model depicts functions necessary for a network, but wireless networks implement only functions defined by the bottom two layers—the physical and data link layer. These functions include medium access, error control, and formation of radio and light signals for propagation through the medium. When deploying wireless networks, however, it's important to ensure that protocols operating at higher layers have features that counter impairments found in wireless networks.

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Chapter Review Questions

You can find the answers to the following questions in **Appendix A**, "Answers to Chapter Review Questions."

1: Which wireless NIC form factors are best for small wireless computer devices?

2: What are examples of elements that impair the propagation of wireless communications signals through the air medium?

3: What is the primary purpose of a base station?

4: What are common features of wireless middleware?

5: On what layers of the OSI reference model do wireless networks operate?

6: How is throughput different from data rate?

7: True or false: A computer device stores data in analog form.

8: A wireless NIC must convert the information into what type of signal before transmission through the air medium?

9: Which medium access protocol is common with wireless networks?

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10: Explain how the ARQ form of error control works.

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