

CHAPTER 14

Wireless LANs

Wireless communication is one of the fastest-growing technologies. The demand for connecting devices without the use of cables is increasing everywhere. Wireless LANs can be found on college campuses, in office buildings, and in many public areas.

In this chapter, we concentrate on two promising wireless technologies for LANs: IEEE 802.11 wireless LANs, sometimes called wireless Ethernet, and Bluetooth, a technology for small wireless LANs. Although both protocols need several layers to operate, we concentrate mostly on the physical and data link layers.

14.1 IEEE 802.11

IEEE has defined the specifications for a wireless LAN, called IEEE 802.11, which covers the physical and data link layers.

Architecture

The standard defines two kinds of services: the basic service set (BSS) and the extended service set (ESS).

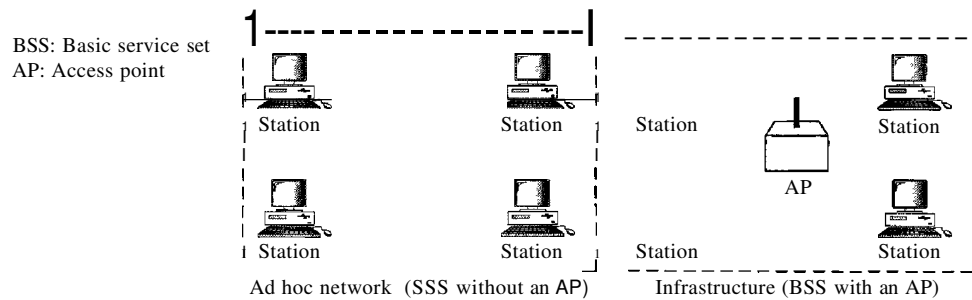
Basic Service Set

IEEE 802.11 defines the basic service set (BSS) as the building block of a wireless LAN. A basic service set is made of stationary or mobile wireless stations and an optional central base station, known as the access point (AP). Figure 14.1 shows two sets in this standard.

The BSS without an AP is a stand-alone network and cannot send data to other BSSs. It is called an *ad hoc architecture*. In this architecture, stations can form a network without the need of an AP; they can locate one another and agree to be part of a BSS. A BSS with an AP is sometimes referred to as an *infrastructure* network.

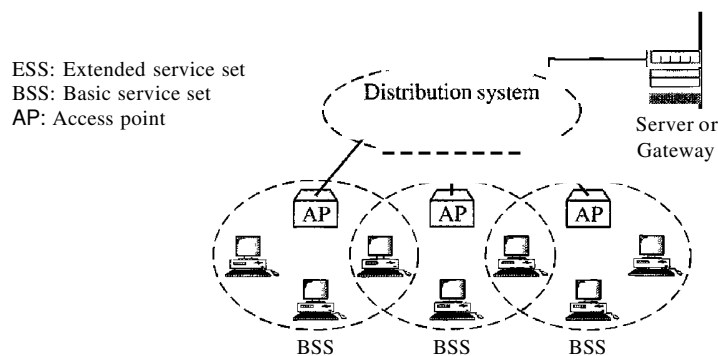
A BSS without an AP is called an ad hoc network;
a BSS with an AP is called an infrastructure network.

Figure 14.1 Basic service sets (BSSs)

*Extended Service Set*

An extended service set (ESS) is made up of two or more BSSs with APs. In this case, the BSSs are connected through a *distribution system*, which is usually a wired LAN. The distribution system connects the APs in the BSSs. IEEE 802.11 does not restrict the distribution system; it can be any IEEE LAN such as an Ethernet. Note that the extended service set uses two types of stations: mobile and stationary. The mobile stations are normal stations inside a BSS. The stationary stations are AP stations that are part of a wired LAN. Figure 14.2 shows an ESS.

Figure 14.2 Extended service sets (ESSs)



When BSSs are connected, the stations within reach of one another can communicate without the use of an AP. However, communication between two stations in two different BSSs usually occurs via two APs. The idea is similar to communication in a cellular network if we consider each BSS to be a cell and each AP to be a base station. Note that a mobile station can belong to more than one BSS at the same time.

Station Types

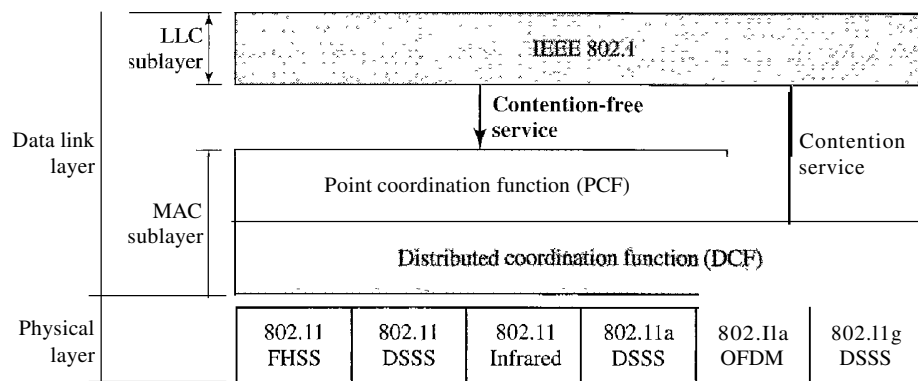
IEEE 802.11 defines three types of stations based on their mobility in a wireless LAN: no-transition, BSS-transition, and ESS-transition mobility. A station with no-transition

mobility is either stationary (not moving) or moving only inside a BSS. A station with BSS-transition mobility can move from one BSS to another, but the movement is confined inside one ESS. A station with ESS-transition mobility can move from one ESS to another. However, IEEE 802.11 does not guarantee that communication is continuous during the move.

MAC Sublayer

IEEE 802.11 defines two MAC sublayers: the distributed coordination function (DCF) and point coordination function (PCF). Figure 14.3 shows the relationship between the two MAC sublayers, the LLC sublayer, and the physical layer. We discuss the physical layer implementations later in the chapter and will now concentrate on the MAC sublayer.

Figure 14.3 MAC layers in IEEE 802.11 standard



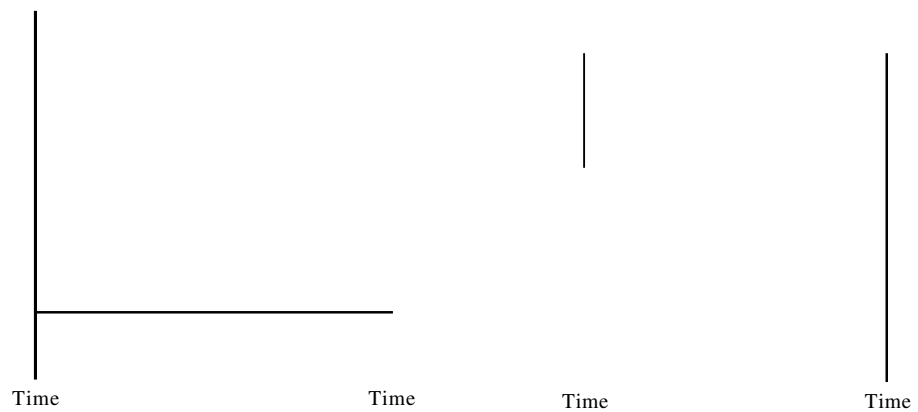
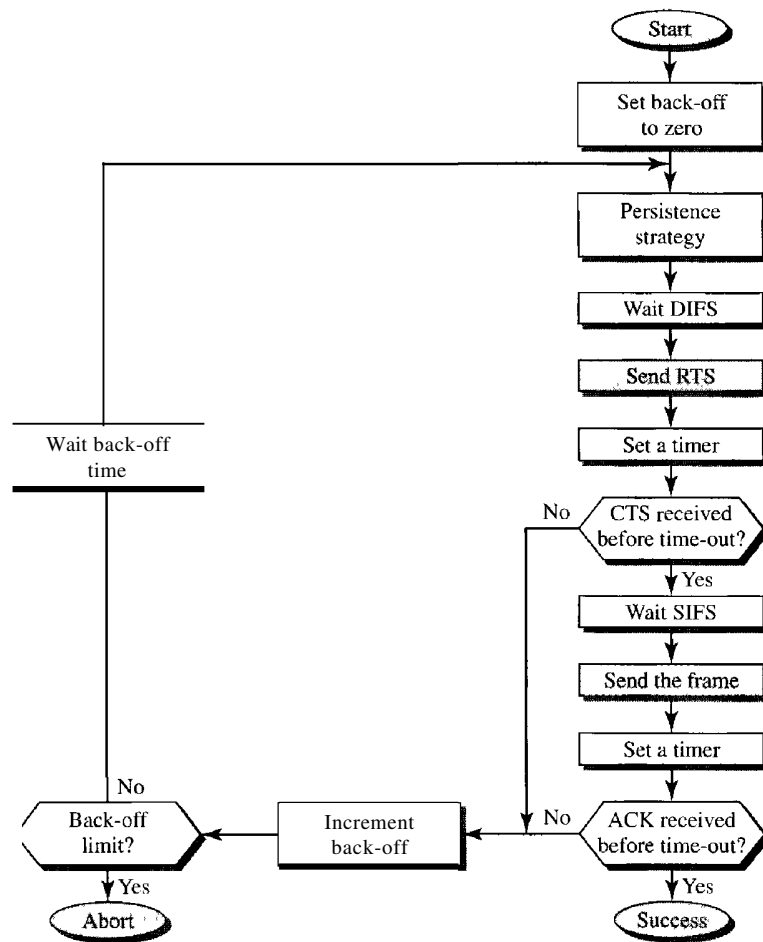
Distributed Coordination Function

One of the two protocols defined by IEEE at the MAC sublayer is called the distributed coordination function (DCF). DCF uses *CSMA/CA* (as defined in Chapter 12) as the access method. Wireless LANs cannot implement *CSMA/CD* for three reasons:

1. For collision detection a station must be able to send data and receive collision signals at the same time. This can mean costly stations and increased bandwidth requirements.
2. Collision may not be detected because of the hidden station problem. We will discuss this problem later in the chapter.
3. The distance between stations can be great. Signal fading could prevent a station at one end from hearing a collision at the other end.

Process Flowchart Figure 14.4 shows the process flowchart for *CSMA/CA* as used in wireless LANs. We will explain the steps shortly.

Frame Exchange Time Line Figure 14.5 shows the exchange of data and control frames in time.

Figure 14.4 CSMA/CA flowchart


1. Before sending a frame, the source station senses the medium by checking the energy level at the carrier frequency.
 - a. The channel uses a persistence strategy with back-off until the channel is idle.
 - b. After the station is found to be idle, the station waits for a period of time called the distributed interframe space (DIFS); then the station sends a control frame called the request to send (RTS).
2. After receiving the RTS and waiting a period of time called the short interframe space (SIFS), the destination station sends a control frame, called the clear to send (CTS), to the source station. This control frame indicates that the destination station is ready to receive data.
3. The source station sends data after waiting an amount of time equal to SIFS.
4. The destination station, after waiting an amount of time equal to SIFS, sends an acknowledgment to show that the frame has been received. Acknowledgment is needed in this protocol because the station does not have any means to check for the successful arrival of its data at the destination. On the other hand, the lack of collision in *CSMA/CD* is a kind of indication to the source that data have arrived.

Network Allocation Vector How do other stations defer sending their data if one station acquires access? In other words, how is the *collision avoidance* aspect of this protocol accomplished? The key is a feature called NAV.

When a station sends an RTS frame, it includes the duration of time that it needs to occupy the channel. The stations that are affected by this transmission create a timer called a network allocation vector (NAV) that shows how much time must pass before these stations are allowed to check the channel for idleness. Each time a station accesses the system and sends an RTS frame, other stations start their NAV. In other words, each station, before sensing the physical medium to see if it is idle, first checks its NAV to see if it has expired. Figure 14.5 shows the idea of NAV.

Collision During Handshaking What happens if there is collision during the time when RTS or CTS control frames are in transition, often called the handshaking period? Two or more stations may try to send RTS frames at the same time. These control frames may collide. However, because there is no mechanism for collision detection, the sender assumes there has been a collision if it has not received a CTS frame from the receiver. The back-off strategy is employed, and the sender tries again.

Point Coordination Function (PCF)

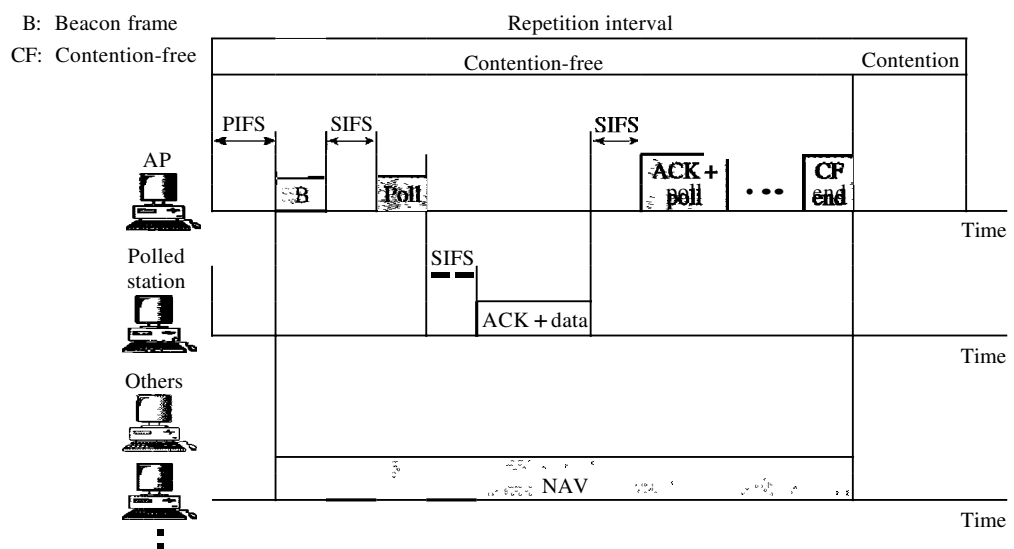
The point coordination function (PCF) is an optional access method that can be implemented in an infrastructure network (not in an ad hoc network). It is implemented on top of the DCF and is used mostly for time-sensitive transmission.

PCF has a centralized, contention-free polling access method. The AP performs polling for stations that are capable of being polled. The stations are polled one after another, sending any data they have to the AP.

To give priority to PCF over DCF, another set of interframe spaces has been defined: PIFS and SIFS. The SIFS is the same as that in DCF, but the PIFS (PCF IFS) is shorter than the DIFS. This means that if, at the same time, a station wants to use only DCF and an AP wants to use PCF, the AP has priority.

Due to the priority of PCF over DCF, stations that only use DCF may not gain access to the medium. To prevent this, a repetition interval has been designed to cover both contention-free (PCF) and contention-based (DCF) traffic. The repetition interval, which is repeated continuously, starts with a special control frame, called a beacon frame. When the stations hear the beacon frame, they start their NAV for the duration of the contention-free period of the repetition interval. Figure 14.6 shows an example of a repetition interval.

Figure 14.6 Example of repetition interval



During the repetition interval, the PC (point controller) can send a poll frame, receive data, send an ACK, receive an ACK, or do any combination of these (802.11 uses piggybacking). At the end of the contention-free period, the PC sends a CF end (contention-free end) frame to allow the contention-based stations to use the medium.

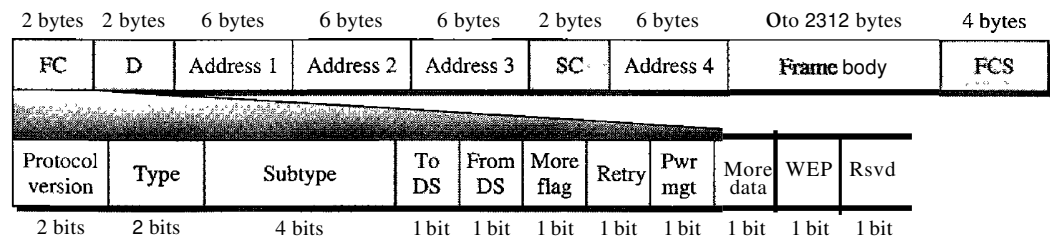
Fragmentation

The wireless environment is very noisy; a corrupt frame has to be retransmitted. The protocol, therefore, recommends fragmentation—the division of a large frame into smaller ones. It is more efficient to resend a small frame than a large one.

Frame Format

The MAC layer frame consists of nine fields, as shown in Figure 14.7.

- O** Frame control (Fe). The FC field is 2 bytes long and defines the type of frame and some control information. Table 14.1 describes the subfields. We will discuss each frame type later in this chapter.

Figure 14.7 *Frameformat*Table 14.1 *Subfields in FC field*

Field	Explanation
Version	Current version is 0
Type	Type of information: management (00), control (01), or data (10)
Subtype	Subtype of each type (see Table 14.2)
ToDS	Defined later
FromDS	Defined later
More flag	When set to 1, means more fragments
Retry	When set to 1, means retransmitted frame
Pwr mgt	When set to 1, means station is in power management mode
More data	When set to 1, means station has more data to send
WEP	Wired equivalent privacy (encryption implemented)
Rsvd	Reserved

- D D. In all frame types except one, this field defines the duration of the transmission that is used to set the value of NAY. In one control frame, this field defines the ID of the frame.
- D Addresses. There are four address fields, each 6 bytes long. The meaning of each address field depends on the value of the *To DS* and *From DS* subfields and will be discussed later.
- D Sequence control. This field defines the sequence number of the frame to be used in flow control.
- D Frame body. This field, which can be between 0 and 2312 bytes, contains information based on the type and the subtype defined in the FC field.
- D FCS. The FCS field is 4 bytes long and contains a CRC-32 error detection sequence.

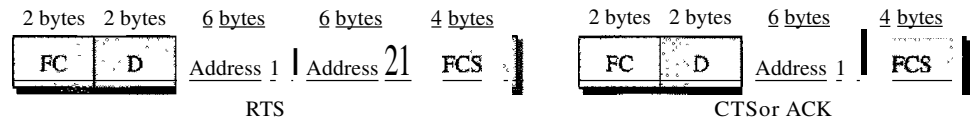
Frame Types

A wireless LAN defined by IEEE 802.11 has three categories of frames: management frames, control frames, and data frames.

Management Frames Management frames are used for the initial communication between stations and access points.

Control Frames Control frames are used for accessing the channel and acknowledging frames. Figure 14.8 shows the format.

Figure 14.8 *Controlframes*



For control frames the value of the type field is 0I; the values of the subtype fields for frames we have discussed are shown in Table 14.2.

Table 14.2 *Values of subfields in controlframes*

<i>Subtype</i>	<i>Meaning</i>
1011	Request to send (RTS)
1100	Clear to send (CTS)
1101	Acknowledgment (ACK)

Data Frames Data frames are used for carrying data and control information.

Addressing Mechanism

The IEEE 802.11 addressing mechanism specifies four cases, defined by the value of the two flags in the FC field, *To DS* and *From DS*. Each flag can be either 0 or 1, resulting in four different situations. The interpretation of the four addresses (address 1 to address 4) in the MAC frame depends on the value of these flags, as shown in Table 14.3.

Table 14.3 *Addresses*

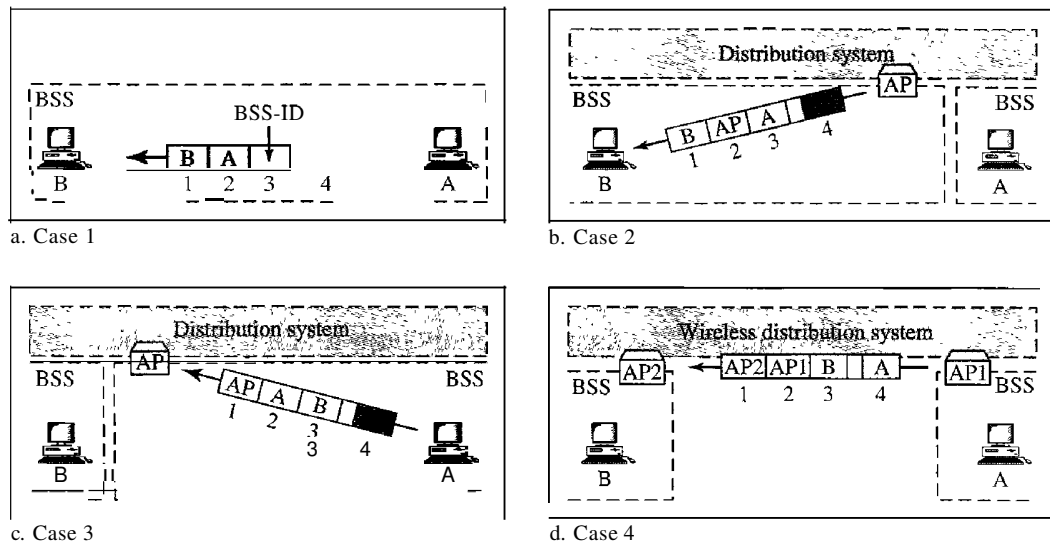
<i>To DS</i>	<i>From DS</i>	<i>Address 1</i>	<i>Address 2</i>	<i>Address 3</i>	<i>Address 4</i>
0	0	Destination	Source	BSS ID	N/A
0	1	Destination	Sending AP	Source	N/A
1	0	Receiving AP	Source	Destination	N/A
1	1	Receiving AP	Sending AP	Destination	Source

Note that address 1 is always the address of the next device. Address 2 is always the address of the previous device. Address 3 is the address of the final destination station if it is not defined by address 1. Address 4 is the address of the original source station if it is not the same as address 2.

- **Case 1: 00** In this case, *To DS* = 0 and *From DS* = 0. This means that the frame is not going to a distribution system (*To DS* = 0) and is not coming from a distribution

system ($From DS = 0$). The frame is going from one station in a BSS to another without passing through the distribution system. The ACK frame should be sent to the original sender. The addresses are shown in Figure 14.9.

Figure 14.9 Addressing mechanisms



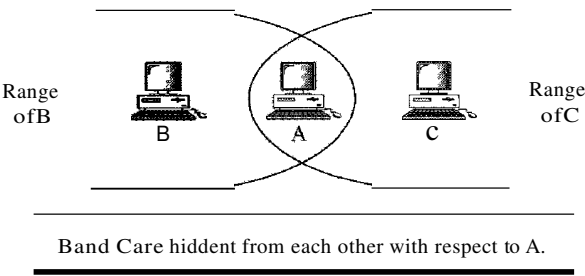
- Case 2: 01 In this case, $To DS = 0$ and $From DS = 1$. This means that the frame is coming from a distribution system ($From DS = 1$). The frame is coming from an AP and going to a station. The ACK should be sent to the AP. The addresses are as shown in Figure 14.9. Note that address 3 contains the original sender of the frame (in another BSS).
- Case 3: 10 In this case, $To DS = 1$ and $From DS = 0$. This means that the frame is going to a distribution system ($To DS = 1$). The frame is going from a station to an AP. The ACK is sent to the original station. The addresses are as shown in Figure 14.9. Note that address 3 contains the final destination of the frame (in another BSS).
- Case 4: 11 In this case, $To DS = 1$ and $From DS = 1$. This is the case in which the distribution system is also wireless. The frame is going from one AP to another AP in a wireless distribution system. We do not need to define addresses if the distribution system is a wired LAN because the frame in these cases has the format of a wired LAN frame (Ethernet, for example). Here, we need four addresses to define the original sender, the final destination, and two intermediate APs. Figure 14.9 shows the situation.

Hidden and Exposed Station Problems

We referred to hidden and exposed station problems in the previous section. It is time now to discuss these problems and their effects.

Hidden Station Problem Figure 14.10 shows an example of the hidden station problem. Station B has a transmission range shown by the left oval (sphere in space); every station in this range can hear any signal transmitted by station B. Station C has

Figure 14.10 *Hidden station problem*



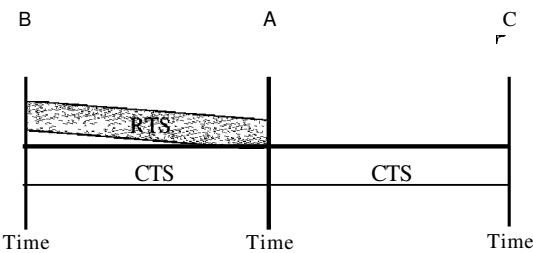
a transmission range shown by the right oval (sphere in space); every station located in this range can hear any signal transmitted by C. Station C is outside the transmission range of B; likewise, station B is outside the transmission range of C. Station A, however, is in the area covered by both B and C; it can hear any signal transmitted by B or C.

Assume that station B is sending data to station A. In the middle of this transmission, station C also has data to send to station A. However, station C is out of B's range and transmissions from B cannot reach C. Therefore C thinks the medium is free. Station C sends its data to A, which results in a collision at A because this station is receiving data from both B and C. In this case, we say that stations B and C are hidden from each other with respect to A. Hidden stations can reduce the capacity of the network because of the possibility of collision.

The solution to the hidden station problem is the use of the handshake frames (RTS and CTS) that we discussed earlier. Figure 14.11 shows that the RTS message from B reaches A, but not C. However, because both B and C are within the range of A, the CTS message, which contains the duration of data transmission from B to A reaches C. Station C knows that some hidden station is using the channel and refrains from transmitting until that duration is over.

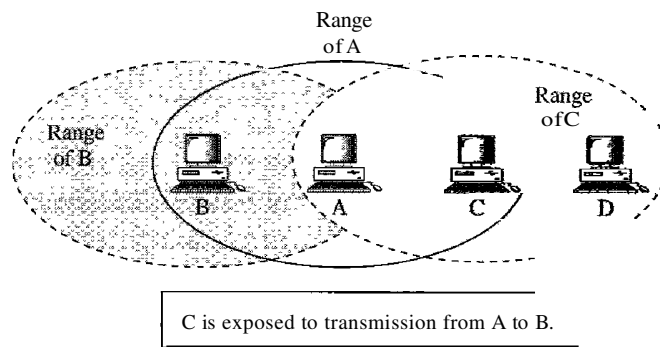
The CTS frame in CSMA/CA handshake can prevent collision from a hidden station.

Figure 14.11 *Use of handshaking to prevent hidden station problem*



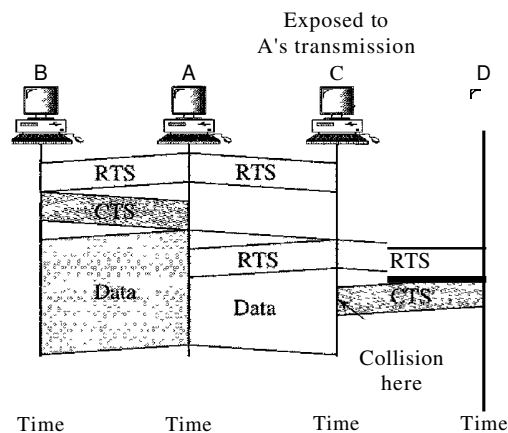
Exposed Station Problem Now consider a situation that is the inverse of the previous one: the exposed station problem. In this problem a station refrains from using a channel when it is, in fact, available. In Figure 14.12, station A is transmitting to station B. Station C has some data to send to station D, which can be sent without interfering with the transmission from A to B. However, station C is exposed to transmission from A; it hears what A is sending and thus refrains from sending. In other words, C is too conservative and wastes the capacity of the channel.

Figure 14.12 *Exposed station problem*



The handshaking messages RTS and CTS cannot help in this case, despite what you might think. Station C hears the RTS from A, but does not hear the CTS from B. Station C, after hearing the RTS from A, can wait for a time so that the CTS from B reaches A; it then sends an RTS to D to show that it needs to communicate with D. Both stations B and A may hear this RTS, but station A is in the sending state, not the receiving state. Station B, however, responds with a CTS. The problem is here. If station A has started sending its data, station C cannot hear the CTS from station D because of the collision; it cannot send its data to D. It remains exposed until A finishes sending its data as Figure 14.13 shows.

Figure 14.13 *Use of handshaking in exposed station problem*



Physical Layer

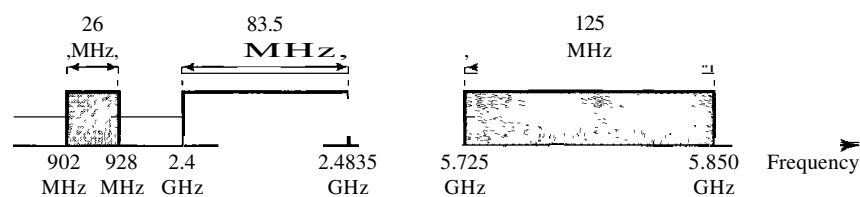
We discuss six specifications, as shown in Table 14.4.

Table 14.4 *Physical layers*

<i>IEEE</i>	<i>Technique</i>	<i>Band</i>	<i>Modulation</i>	<i>Rate (Mbps)</i>
802.11	FHSS	2.4 GHz	FSK	1 and 2
	DSSS	2.4 GHz	PSK	1 and 2
		Infrared	PPM	1 and 2
802.11a	OFDM	5.725 GHz	PSK or QAM	6 to 54
802.11b	DSSS	2.4 GHz	PSK	5.5 and 11
802.11g	OFDM	2.4 GHz	Different	22 and 54

All implementations, except the infrared, operate in the *industrial, scientific, and medical (ISM)* band, which defines three unlicensed bands in the three ranges 902-928 MHz, 2.400-4.835 GHz, and 5.725-5.850 GHz, as shown in Figure 14.14.

Figure 14.14 *industrial, scientific, and medical (ISM) band*



IEEE 802.11 FHSS

IEEE 802.11 FHSS uses the frequency-hopping spread spectrum (FHSS) method as discussed in Chapter 6. FHSS uses the 2.4-GHz ISM band. The band is divided into 79 subbands of 1 MHz (and some guard bands). A pseudorandom number generator selects the hopping sequence. The modulation technique in this specification is either two-level FSK or four-level FSK with 1 or 2 bits/ baud, which results in a data rate of 1 or 2 Mbps, as shown in Figure 14.15.

IEEE 802.11 DSSS

IEEE 802.11 DSSS uses the direct sequence spread spectrum (DSSS) method as discussed in Chapter 6. DSSS uses the 2.4-GHz ISM band. The modulation technique in this specification is PSK at 1 Mbaud/s. The system allows 1 or 2 bits/ baud (BPSK or QPSK), which results in a data rate of 1 or 2 Mbps, as shown in Figure 14.16.

IEEE 802.11 Infrared

IEEE 802.11 infrared uses infrared light in the range of 800 to 950 nm. The modulation technique is called pulse position modulation (PPM). For a 1-Mbps data rate, a 4-bit

Figure 14.15 Physical layer of IEEE 802.11 FHSS

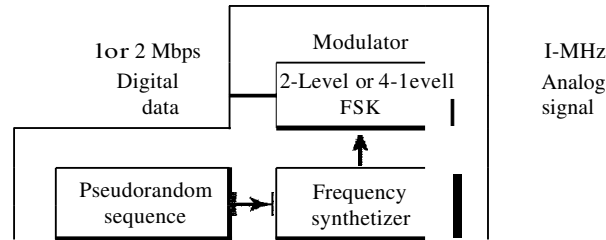
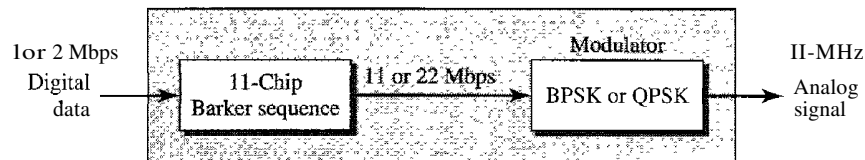
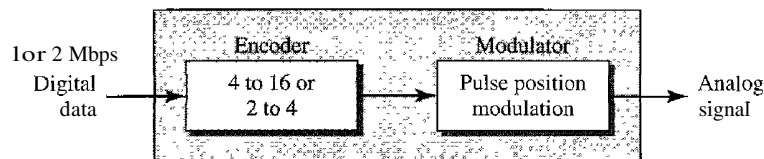


Figure 14.16 Physical layer of IEEE 802.11 DSSS



sequence is first mapped into a 16-bit sequence in which only one bit is set to 1 and the rest are set to 0. For a 2-Mbps data rate, a 2-bit sequence is first mapped into a 4-bit sequence in which only one bit is set to 1 and the rest are set to 0. The mapped sequences are then converted to optical signals; the presence of light specifies 1, the absence of light specifies 0. See Figure 14.17.

Figure 14.17 Physical layer of IEEE 802.11 infrared



IEEE 802.11a OFDM

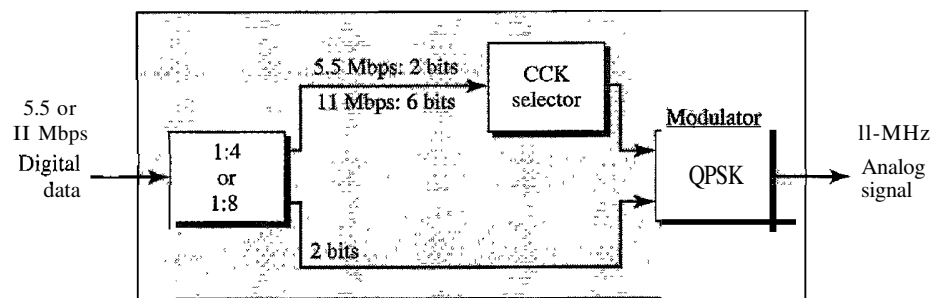
IEEE 802.11a OFDM describes the orthogonal frequency-division multiplexing (OFDM) method for signal generation in a 5-GHz ISM band. OFDM is similar to FDM as discussed in Chapter 6, with one major difference: All the subbands are used by one source at a given time. Sources contend with one another at the data link layer for access. The band is divided into 52 subbands, with 48 subbands for sending 48 groups of bits at a time and 4 subbands for control information. The scheme is similar to ADSL, as discussed in Chapter 9. Dividing the band into subbands diminishes the effects of interference. If the subbands are used randomly, security can also be increased.

OFDM uses PSK and QAM for modulation. The common data rates are 18 Mbps (PSK) and 54 Mbps (QAM).

IEEE 802.11b DSSS

IEEE 802.11b DSSS describes the high-rate direct sequence spread spectrum (HR-DSSS) method for signal generation in the 2.4-GHz ISM band. HR-DSSS is similar to DSSS except for the encoding method, which is called complementary code keying (CCK). CCK encodes 4 or 8 bits to one CCK symbol. To be backward compatible with DSSS, HR-DSSS defines four data rates: 1, 2, 5.5, and 11 Mbps. The first two use the same modulation techniques as DSSS. The 5.5-Mbps version uses BPSK and transmits at 1.375 Mbaud/s with 4-bit CCK encoding. The 11-Mbps version uses QPSK and transmits at 1.375 Mbaud/s with 8-bit CCK encoding. Figure 14.18 shows the modulation technique for this standard.

Figure 14.18 *Physical layer of IEEE 802.11b*



IEEE 802.11g

This new specification defines forward error correction and OFDM using the 2.4-GHz ISM band. The modulation technique achieves a 22- or 54-Mbps data rate. It is backward-compatible with 802.11b, but the modulation technique is OFDM.

14.2 BLUETOOTH

Bluetooth is a wireless LAN technology designed to connect devices of different functions such as telephones, notebooks, computers (desktop and laptop), cameras, printers, coffee makers, and so on. A Bluetooth LAN is an ad hoc network, which means that the network is formed spontaneously; the devices, sometimes called gadgets, find each other and make a network called a piconet. A Bluetooth LAN can even be connected to the Internet if one of the gadgets has this capability. A Bluetooth LAN, by nature, cannot be large. If there are many gadgets that try to connect, there is chaos.

Bluetooth technology has several applications. Peripheral devices such as a wireless mouse or keyboard can communicate with the computer through this technology. Monitoring devices can communicate with sensor devices in a small health care center. Home security devices can use this technology to connect different sensors to the main

security controller. Conference attendees can synchronize their laptop computers at a conference.

Bluetooth was originally started as a project by the Ericsson Company. It is named for Harald Blaatand, the king of Denmark (940-981) who united Denmark and Norway. *Blaatand* translates to *Bluetooth* in English.

Today, Bluetooth technology is the implementation of a protocol defined by the IEEE 802.15 standard. The standard defines a wireless personal-area network (PAN) operable in an area the size of a room or a hall.

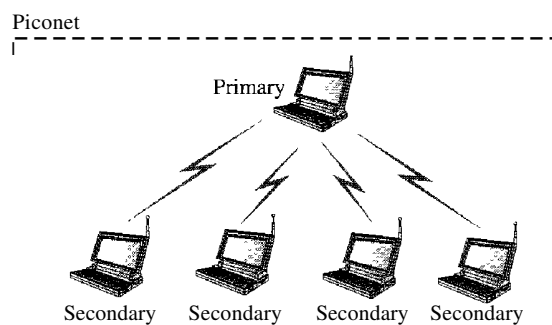
Architecture

Bluetooth defines two types of networks: piconet and scatternet.

Piconets

A Bluetooth network is called a piconet, or a small net. A piconet can have up to eight stations, one of which is called the primary; the rest are called secondaries. All the secondary stations synchronize their clocks and hopping sequence with the primary. Note that a piconet can have only one primary station. The communication between the primary and the secondary can be one-to-one or one-to-many. Figure 14.19 shows a piconet.

Figure 14.19 *Piconet*



Although a piconet can have a maximum of seven secondaries, an additional eight secondaries can be in the *parked state*. A secondary in a parked state is synchronized with the primary, but cannot take part in communication until it is moved from the parked state. Because only eight stations can be active in a piconet, activating a station from the parked state means that an active station must go to the parked state.

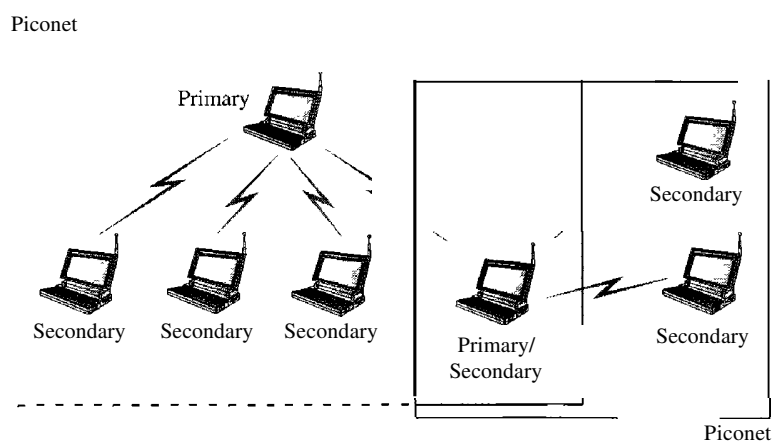
Scat/ernet

Piconets can be combined to form what is called a scatternet. A secondary station in one piconet can be the primary in another piconet. This station can receive messages

^tThe literature sometimes uses the terms *master* and *slave* instead of *primary* and *secondary*. We prefer the latter.

from the primary in the first piconet (as a secondary) and, acting as a primary, deliver them to secondaries in the second piconet. A station can be a member of two piconets. Figure 14.20 illustrates a scatternet.

Figure 14.20 Scatternet



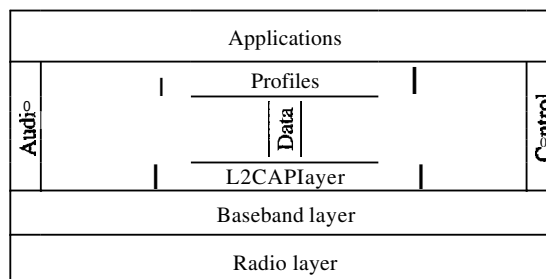
Bluetooth Devices

A Bluetooth device has a built-in short-range radio transmitter. The current data rate is 1 Mbps with a 2.4-GHz bandwidth. This means that there is a possibility of interference between the IEEE 802.11b wireless LANs and Bluetooth LANs.

Bluetooth Layers

Bluetooth uses several layers that do not exactly match those of the Internet model we have defined in this book. Figure 14.21 shows these layers.

Figure 14.21 Bluetooth layers



Radio Layer

The radio layer is roughly equivalent to the physical layer of the Internet model. Bluetooth devices are low-power and have a range of 10 m.

Band

Bluetooth uses a 2.4-GHz ISM band divided into 79 channels of 1 MHz each.

FHSS

Bluetooth uses the frequency-hopping spread spectrum (FHSS) method in the physical layer to avoid interference from other devices or other networks. Bluetooth hops 1600 times per second, which means that each device changes its modulation frequency 1600 times per second. A device uses a frequency for only 625 μ s (1/1600 s) before it hops to another frequency; the dwell time is 625 μ s.

Modulation

To transform bits to a signal, Bluetooth uses a sophisticated version of FSK, called GFSK (FSK with Gaussian bandwidth filtering; a discussion of this topic is beyond the scope of this book). GFSK has a carrier frequency. Bit 1 is represented by a frequency deviation above the carrier; bit 0 is represented by a frequency deviation below the carrier. The frequencies, in megahertz, are defined according to the following formula for each channel:

$$f_c = 2402 + n \quad n = 0, 1, 2, 3, \dots, 78$$

For example, the first channel uses carrier frequency 2402 MHz (2.402 GHz), and the second channel uses carrier frequency 2403 MHz (2.403 GHz).

Baseband Layer

The baseband layer is roughly equivalent to the MAC sublayer in LANs. The access method is TDMA (see Chapter 12). The primary and secondary communicate with each other using time slots. The length of a time slot is exactly the same as the dwell time, 625 μ s. This means that during the time that one frequency is used, a sender sends a frame to a secondary, or a secondary sends a frame to the primary. Note that the communication is only between the primary and a secondary; secondaries cannot communicate directly with one another.

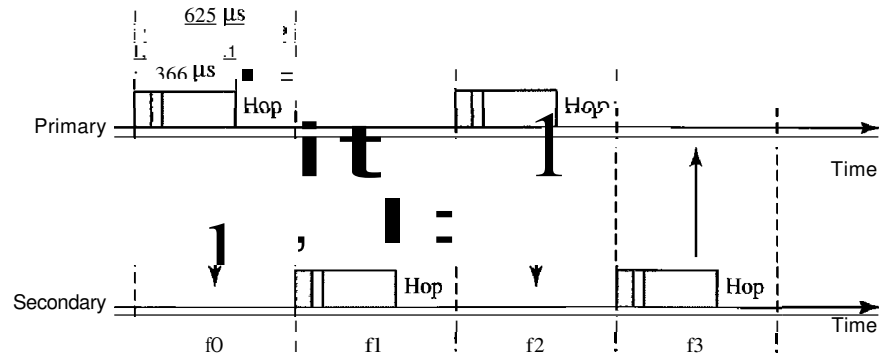
TDMA

Bluetooth uses a form of TDMA (see Chapter 12) that is called TDD-TDMA (time-division duplex TDMA). TDD-TDMA is a kind of half-duplex communication in which the secondary and receiver send and receive data, but not at the same time (half-duplex); however, the communication for each direction uses different hops. This is similar to walkie-talkies using different carrier frequencies.

Single-Secondary Communication If the piconet has only one secondary, the TDMA operation is very simple. The time is divided into slots of 625 μ s. The primary uses even-numbered slots (0, 2, 4, ...); the secondary uses odd-numbered slots (1, 3, 5, ...). TDD-TDMA allows the primary and the secondary to communicate in half-duplex mode.

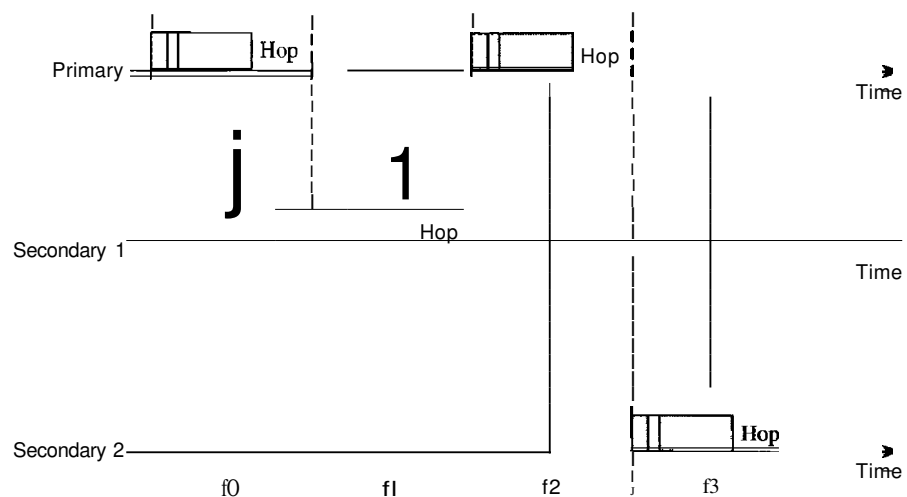
In slot 0, the primary sends, and the secondary receives; in slot 1, the secondary sends, and the primary receives. The cycle is repeated. Figure 14.22 shows the concept.

Figure 14.22 *Single-secondary communication*



Multiple-Secondary Communication The process is a little more involved if there is more than one secondary in the piconet. Again, the primary uses the even-numbered slots, but a secondary sends in the next odd-numbered slot if the packet in the previous slot was addressed to it. All secondaries listen on even-numbered slots, but only one secondary sends in any odd-numbered slot. Figure 14.23 shows a scenario.

Figure 14.23 *Multiple-secondary communication*



Let us elaborate on the figure.

1. In slot 0, the primary sends a frame to secondary 1.
2. In slot 1, only secondary 1 sends a frame to the primary because the previous frame was addressed to secondary 1; other secondaries are silent.

3. In slot 2, the primary sends a frame to secondary 2.
4. In slot 3, only secondary 2 sends a frame to the primary because the previous frame was addressed to secondary 2; other secondaries are silent.
5. The cycle continues.

We can say that this access method is similar to a poll/select operation with reservations. When the primary selects a secondary, it also polls it. The next time slot is reserved for the polled station to send its frame. If the polled secondary has no frame to send, the channel is silent.

Physical Links

Two types of links can be created between a primary and a secondary: SCQ links and ACL links.

sca A synchronous connection-oriented (SeQ) link is used when avoiding latency (delay in data delivery) is more important than integrity (error-free delivery). In an SCQ link, a physical link is created between the primary and a secondary by reserving specific slots at regular intervals. The basic unit of connection is two slots, one for each direction. If a packet is damaged, it is never retransmitted. SCQ is used for real-time audio where avoiding delay is all-important. A secondary can create up to three SCQ links with the primary, sending digitized audio (PCM) at 64 kbps in each link.

ACL An asynchronous connectionless link (ACL) is used when data integrity is more important than avoiding latency. In this type of link, if a payload encapsulated in the frame is corrupted, it is retransmitted. A secondary returns an ACL frame in the available odd-numbered slot if and only if the previous slot has been addressed to it. ACL can use one, three, or more slots and can achieve a maximum data rate of 721 kbps.

Frame Format

A frame in the baseband layer can be one of three types: one-slot, three-slot, or five-slot. A slot, as we said before, is 625 μ s. However, in a one-slot frame exchange, 259 μ s is needed for hopping and control mechanisms. This means that a one-slot frame can last only 625 - 259, or 366 μ s. With a 1-MHz bandwidth and 1 bit/Hz, the size of a one-slot frame is 366 bits.

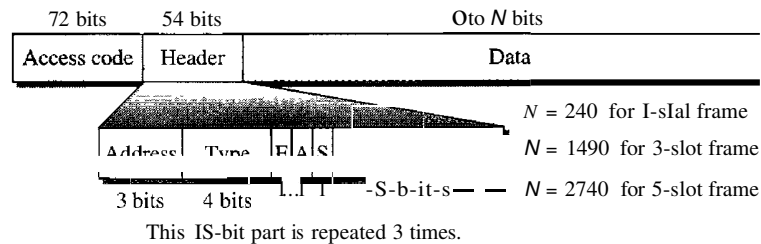
A three-slot frame occupies three slots. However, since 259 μ s is used for hopping, the length of the frame is $3 \times 625 - 259 = 1616 \mu$ s or 1616 bits. A device that uses a three-slot frame remains at the same hop (at the same carrier frequency) for three slots. Even though only one hop number is used, three hop numbers are consumed. That means the hop number for each frame is equal to the first slot of the frame.

A five-slot frame also uses 259 bits for hopping, which means that the length of the frame is $5 \times 625 - 259 = 2866$ bits.

Figure 14.24 shows the format of the three frame types.

The following describes each field:

- O** Access code. This 72-bit field normally contains synchronization bits and the identifier of the primary to distinguish the frame of one piconet from another.

Figure 14.24 *Frame format types*

❑ **Header.** This 54-bit field is a repeated 18-bit pattern. Each pattern has the following subfields:

1. **Address.** The 3-bit address subfield can define up to seven secondaries (1 to 7). If the address is zero, it is used for broadcast communication from the primary to all secondaries.
2. **Type.** The 4-bit type subfield defines the type of data coming from the upper layers. We discuss these types later.
3. **F.** This 1-bit subfield is for flow control. When set (1), it indicates that the device is unable to receive more frames (buffer is full).
4. **A.** This 1-bit subfield is for acknowledgment. Bluetooth uses Stop-and-Wait ARQ; 1 bit is sufficient for acknowledgment.
5. **S.** This 1-bit subfield holds a sequence number. Bluetooth uses Stop-and-Wait ARQ; 1 bit is sufficient for sequence numbering.
6. **HEC.** The 8-bit header error correction subfield is a checksum to detect errors in each 18-bit header section.

The header has three identical 18-bit sections. The receiver compares these three sections, bit by bit. If each of the corresponding bits is the same, the bit is accepted; if not, the majority opinion rules. This is a form of forward error correction (for the header only). This double error control is needed because the nature of the communication, via air, is very noisy. Note that there is no retransmission in this sublayer.

○ **Payload.** This subfield can be 0 to 2740 bits long. It contains data or control information coming from the upper layers.

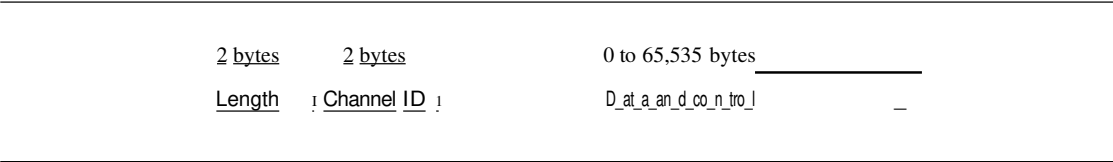
L2CAP

The Logical Link Control and Adaptation Protocol, or L2CAP (L2 here means LL), is roughly equivalent to the LLC sublayer in LANs. It is used for data exchange on an ACL link; SCQ channels do not use L2CAP. Figure 14.25 shows the format of the data packet at this level.

The 16-bit length field defines the size of the data, in bytes, coming from the upper layers. Data can be up to 65,535 bytes. The channel ID (CID) defines a unique identifier for the virtual channel created at this level (see below).

The L2CAP has specific duties: multiplexing, segmentation and reassembly, quality of service (QoS), and group management.

Figure 14.25 L2CAP data packet format



Multiplexing

The L2CAP can do multiplexing. At the sender site, it accepts data from one of the upper-layer protocols, frames them, and delivers them to the baseband layer. At the receiver site, it accepts a frame from the baseband layer, extracts the data, and delivers them to the appropriate protocol layer. It creates a kind of virtual channel that we will discuss in later chapters on higher-level protocols.

Segmentation and Reassembly

The maximum size of the payload field in the baseband layer is 2774 bits, or 343 bytes. This includes 4 bytes to define the packet and packet length. Therefore, the size of the packet that can arrive from an upper layer can only be 339 bytes. However, application layers sometimes need to send a data packet that can be up to 65,535 bytes (an Internet packet, for example). The L2CAP divides these large packets into segments and adds extra information to define the location of the segments in the original packet. The L2CAP segments the packet at the source and reassembles them at the destination.

QoS

Bluetooth allows the stations to define a quality-of-service level. We discuss quality of service in Chapter 24. For the moment, it is sufficient to know that if no quality-of-service level is defined, Bluetooth defaults to what is called *best-effort* service; it will do its best under the circumstances.

Group Management

Another functionality of L2CAP is to allow devices to create a type of logical addressing between themselves. This is similar to multicasting. For example, two or three secondary devices can be part of a multicast group to receive data from the primary.

Other Upper Layers

Bluetooth defines several protocols for the upper layers that use the services of L2CAP; these protocols are specific for each purpose.

14.3 RECOMMENDED READING

For more details about subjects discussed in this chapter, we recommend the following books and sites. The items in brackets [...] refer to the reference list at the end of the text.

Books

Wireless LANs and Bluetooth are discussed in several books including [Sch03] and [Gas02]. Wireless LANs are discussed in Chapter 15 of [For03], Chapter 17 of [Sta04], Chapters 13 and 14 of [Sta02], and Chapter 8 of [Kei02]. Bluetooth is discussed in Chapter 15 of [Sta02] and Chapter 15 of [For03].

14.4 KEY TERMS

access point (AP)	Logical Link Control and Adaptation Protocol (L2CAP)
asynchronous connectionless link (ACL)	network allocation vector (NAV)
basic service set (BSS)	no-transition mobility
beacon frame	orthogonal frequency-division multiplexing (OFDM)
Bluetooth	piconet
BSS-transition mobility	point coordination function (PCF)
complementary code keying (CCK)	primary
direct sequence spread spectrum (DSSS)	pulse position modulation (PPM)
distributed coordination function (DCF)	repetition interval
distributed interframe space (DIFS)	scatternet
ESS-transition mobility	secondary
extended service set (ESS)	short interframe space (SIFS)
frequency-hopping spread spectrum (FHSS)	synchronous connection-oriented (SCO)
handshaking period	TDD-TDMA (time-division duplex TDMA)
high-rate direct sequence spread spectrum (HR-DSSS)	wireless LAN
IEEE 802.11	

14.5 SUMMARY

- The IEEE 802.11 standard for wireless LANs defines two services: basic service set (BSS) and extended service set (ESS).
- The access method used in the distributed coordination function (DCF) MAC sublayer is *CSMA/CA*.
- The access method used in the point coordination function (PCF) MAC sublayer is polling.
- The network allocation vector (NAV) is a timer used for collision avoidance.
- The MAC layer frame has nine fields. The addressing mechanism can include up to four addresses.
- Wireless LANs use management frames, control frames, and data frames.

- IEEE 802.11 defines several physical layers, with different data rates and modulating techniques.
- Bluetooth is a wireless LAN technology that connects devices (called gadgets) in a small area.
- A Bluetooth network is called a piconet. Multiple piconets form a network called a scatternet.
- A Bluetooth network consists of one primary device and up to seven secondary devices.

14.6 PRACTICE SET

Review Questions

1. What is the difference between a BSS and an ESS?
2. Discuss the three types of mobility in a wireless LAN.
3. How is OFDM different from FDM?
4. What is the access method used by wireless LANs?
5. What is the purpose of the NAV?
6. Compare a piconet and a scatternet.
7. Match the layers in Bluetooth and the Internet model.
8. What are the two types of links between a Bluetooth primary and a Bluetooth secondary?
9. In multiple-secondary communication, who uses the even-numbered slots and who uses the odd-numbered slots?
10. How much time in a Bluetooth one-slot frame is used for the hopping mechanism? What about a three-slot frame and a five-slot frame?

Exercises

- 1]. Compare and contrast *CSMA/CD* with *CSMA/CA*.
12. Use Table 14.5 to compare and contrast the fields in IEEE 802.3 and 802.11.

Table 14.5 Exercise 12

<i>Fields</i>	<i>IEEE 802.3 Field Size</i>	<i>IEEE 802.11 Field Size</i>
Destination address		
Source address		
Address 1		
Address 2		
Address 3		
Address 4		
FC		

Table 14.5 Exercise 12 (continued)

<i>Fields</i>	<i>IEEE 802.3 Field Size</i>	<i>IEEE 802.11 Field Size</i>
<i>D/ID</i>		
SC		
PDU length		
Data and padding		
Frame body		
FCS (CRC)		