Data Communications

Ch.04 Local Area Networks: LANs

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4.0 LAN

- 5계층이나 OSI 7계층은 인터넷이 보급되고 난 이후에 만들어진 구분법
- LAN의 계층을 세분화 하면 논리 연결 제어(LLC)와 매체 접근 제어(MAC)로 나눌 수 있음

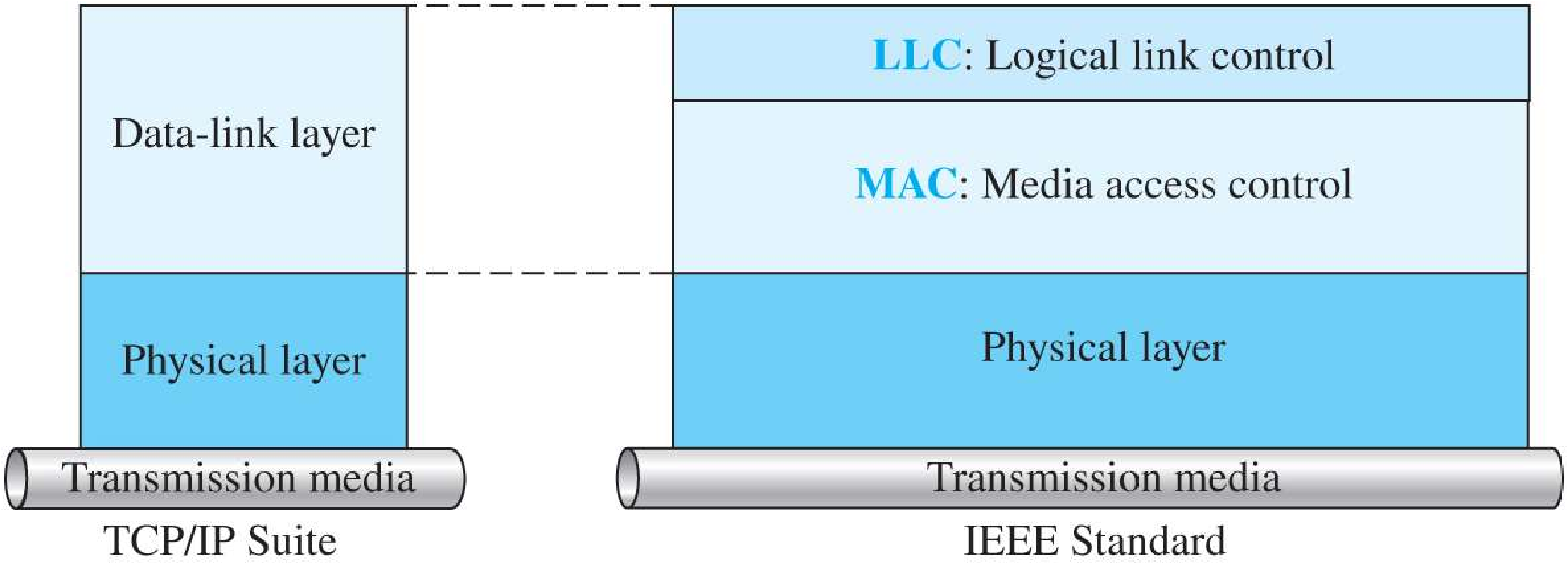


Figure 4.1 IEEE standard for LANs

4.0 LAN

- LAN에 관련된 표준들은 IEEE에 의해 표준화 (802 섹션)
- LLC는 802.2에 정의되어 있으며, 802.3부터 802.22까지가 MAC에 해당

표 7-1 IEEE 802(LAN) 표준

섹션	주제	비고
802.1	LAN Overview	LAN에 대한 규정 및 구조, LAN 간의 연결
802.2	LLC; Logical Link Control	제어 정보, 프레임 처리, 오류 제어
802.3	Ethernet	이더넷 표준
802.4	Token Bus	토큰 버스 표준(적게 사용됨)
802.5	Token Ring	토큰 링 표준
802.6	Distributed Queue Dual Bus	MAN에 사용되는 방식
802.7	Broadband Technologies	광역 통신 MAN 표준
802.8	Fiber Optic Technologies	광 통신 표준
802.9	Isochronous LAN	isoEthernet 표준
802.10	Virtual LAN and security	가상랜과 보안(2004년 철회)
802.11	Wireless LAN(WiFi)	와이파이 무선랜 표준
802.12		Demand Priority; 소멸
802.13		결번
802.14	Cable Modem	케이블 TV와 LAN 접속 표준
802.15	Wireless Personal Area Network	블루투스, Zigbee, RFID 등 표준
802.16	Wireless MAN	WiMAX와 같은 광대역 무선 접속 기술
802.17	Resilient Packet Ring	이더넷 기반 MAN 제어 기술
802.18	Radio Regulatory Technologies	IEEE 표준과 다른 표준과의 접근 정의
802.19	Coexistence Technologies	각 표준 간의 전파간섭 문제 정의
802.20	Mobile Broadband Wireless	모바일 광역 무선 접근 표준
802.21	Media Independent Handover	핸드오버 기능 정의
802.22	Wireless Regional Are Network	무선 소지역 네트워크 표준

4.0 LAN

- LLC 하부계층은 두 노드를 논리적으로 연결하는 계층
- LLC는 프레임을 송수신하는 방식을 정하고 상위계층(네트워크 계층)에 있는 프로토콜과의 인터페이스를 제공
- LLC 계층의 중요한 역할은 프레임을 에러 없이 전달하면서도 프레임 전송률을 높이는 것

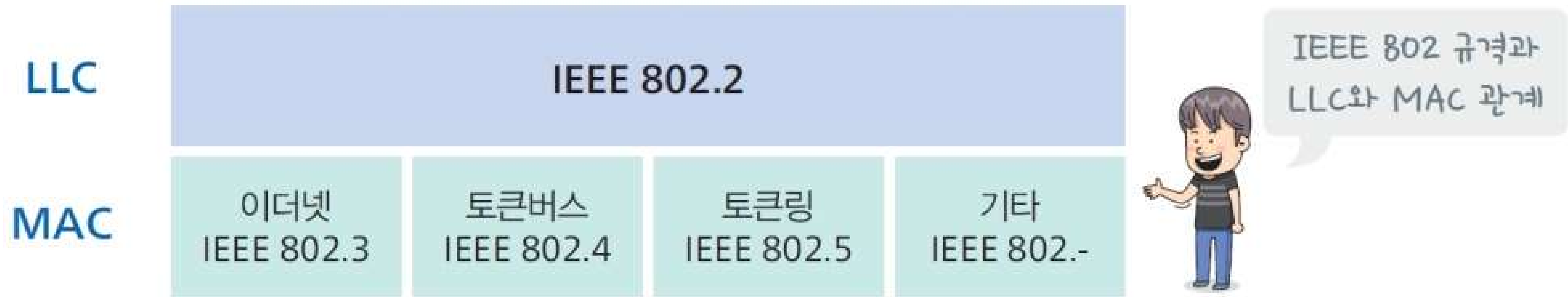


그림 7-2 IEEE 802에 규정된 LLC와 MAC

4.0 LAN - LLC

- LLC 계층에 사용되는 프로토콜에 따라 연결 서비스 혹은 비연결 서비스를 지원하며 연결 서비스의 유지관리를 담당
- LLC는 사용방식에 따라 다음과 같이 3가지의 종류로 나뉨

표 7-2 LLC 타입과 특징

Type	방식	특징	비고
1	비연결형	ACK를 사용하지 않음	이더넷
2	연결형	ACK 및 슬라이딩 윈도우 프로토콜 사용	HDLC
3	비연결 확인형	1대1 접속, Stop-and-Wait ARQ	거의 사용 안 함

4.0 LAN - MAC

- MAC 하부계층은 여러 종류 LAN의 연결형태, 데이터 전송방법, 헤더들을 정의하는 계층
- MAC에 대한 설명의 대부분은 Ethernet을 기준으로 함
- Ethernet은 star topology + CSMA/CD 프로토콜로 정의

표 7-3 대표적인 유선 LAN의 특징

LAN 이름	연결 형태 topology	프로토콜	충돌 처리 방식
토큰 링	링 ring 형태	토큰 링	예약을 통한 충돌 차단
이더넷	별 star 형태	CSMA/CD	경쟁 방식(충돌 허용 후 처리)

4.0 LAN

- MAC address : 6 bytes (48 bits)
  - IP 주소는 사용자가 변경할 수 있는 값이지만, MAC 주소는 통신기기가 만들어질 때 제조사가 임의로 부여한 값으로 변경 불가
- MAC 주소는 주민등록번호처럼 한번 만들어지면 바꿀 수 없는 값이기 때문에 physical address라고 부름
- 모든 통신기기는 MAC 주소와 IP 주소를 같이 가지고 있음

```
이더넷 어댑터 이더넷:

   연결별 DNS 접미사. . . . . . :
   설명. . . . . . . . . . . . : Intel(R) Ethernet Connection (2) I219-LM
   물리적 주소 . . . . . . . . . : 50-65-F3-4A-F5-33
   DHCP 사용 . . . . . . . . . : 예
   자동 구성 사용. . . . . . . . : 예
   링크-로컬 IPv6 주소 . . . . . : fe80::a5e2:5c85:862:c625%10(기본 설정)
   IPv4 주소 . . . . . . . . . : 192.168.31.178(기본 설정)
   서브넷 마스크 . . . . . . . . : 255.255.255.0
```

그림 7-3 IP 주소와 MAC 주소

4.1 ETHERNET

- Ethernet 일반적으로 LAN에서 가장 많이 활용되는 기술 규격이며 IEEE 802.3에 정의되어 있음
  - 초기에는 bus topology로 구성되었으며, 현재는 star topology로 구성
- Hub: Ethernet에서 각 호스트를 유선으로 연결하는 장치
- WiFi: 무선으로 연결할 수 있는 장치의 규격 (무선 공유기)

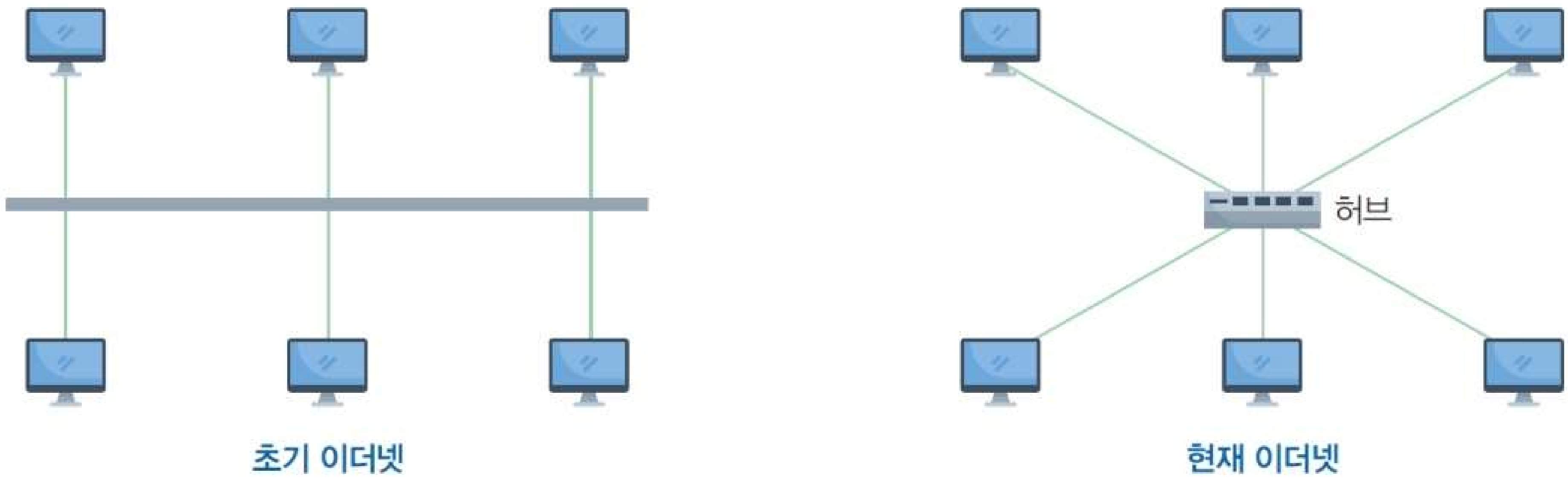


그림 7-4 이더넷 연결 형태

4.1 ETHERNET

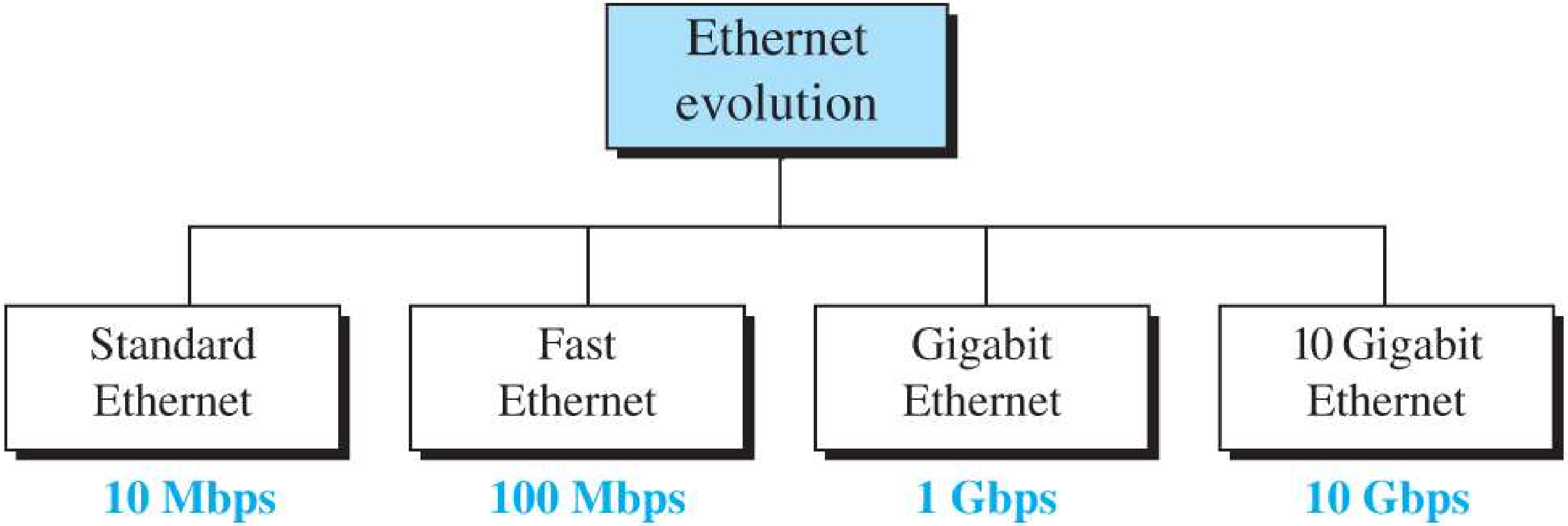


Figure 4.2 Ethernet evolution through four generations

4.1.1 Standard Ethernet (10 Mbps)

- We refer to the original Ethernet technology with the data rate of 10 Mbps as the Standard Ethernet
- Although most implementations have moved to other technologies in the Ethernet evolution, there are some features of the Standard Ethernet that have not changed during the evolution
- We discuss this standard version first

4.1.1 Standard Ethernet (10 Mbps)

- Connectionless and Unreliable Service
  - Ethernet provide a connectionless service, which means that the frames are sent independent of each other

- Frame Format
  - The Ethernet frame contains seven fields, as shown in Figure 4.3

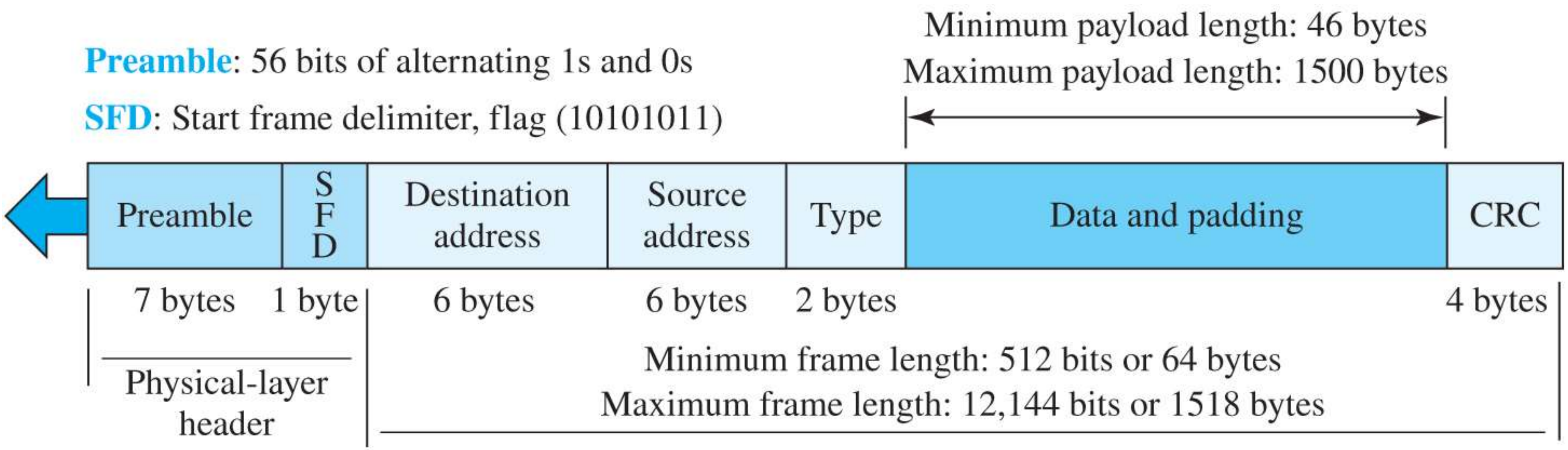


Figure 4.3 Ethernet frame

4.1.1 Standard Ethernet (10 Mbps)

Frame Length

- Ethernet has imposed restriction on maximum and minimum length to provide correct operation of CSMA/CD
- An Ethernet frame has minimum length of 64 bytes
- The maximum length limit is 1518 bytes (without preamble and SFD)
- This means that maximum payload is 1500 bytes

Addressing

- Each station on an Ethernet network (such as a PC, workstation, or printer) has its own network interface card (NIC)
- The NIC fits inside the station and provides the station with a link-layer address
- The Ethernet address is 6 bytes (48 bits), normally written in hexadecimal notation, with a colon between the bytes
- For example, the following shows an Ethernet MAC address:

4A:30:10:21:10:1A

4.1.1 Standard Ethernet (10 Mbps)

Transmission of Address Bits

- The way addresses are sent online is different from they way they are written in hexadecimal notation
  - Transmission is left to right, byte by byte; however, for each byte, the least significant bit that defines the address type is sent first

Example 4.1

The example shows how the address 47:20:1B:2E:08:EE is sent out online. The address is sent left to right, byte by byte; for each byte, it is sent right to left, bit by bit, as shown below:

Hexadecimal	**47**	**20**	**1B**	**2E**	**08**	**EE**
Binary	01000111	00100000	00011011	00101110	00001000	11101110
Transmitted ←	11100010	00000100	11011000	01110100	00010000	01110111

4.1.1 Standard Ethernet (10 Mbps)

Unicast, Multicast, and Broadcast Addresses

- Broadcast address is special case of the multicast address
- The recipients are all the stations on the LAN
- A broadcast destination address is forty-eight 1s

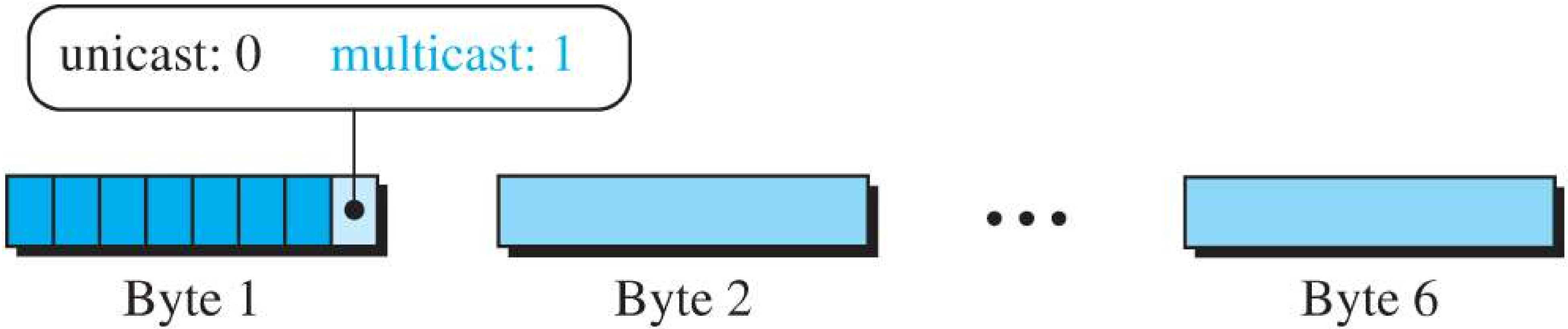


Figure 4.4 Unicast and multicast addresses

4.1.1 Standard Ethernet (10 Mbps)

- Example 4.2

Define the type of the following destination addresses:

a. **4A:30:10:21:10:1A**

b. **47:20:1B:2E:08:EE**

c. **FF:FF:FF:FF:FF:FF**

Solution

a. This is a unicast address because A in binary is 1010 (even).

b. This is a multicast address because 7 in binary is 0111 (odd).

c. This is a broadcast address because all digits are Fs in hexadecimal.

4.1.1 Standard Ethernet (10 Mbps)

Implementation

- The standard Ethernet defines several implementation, but only four of them became popular

Implementation	*Medium*	*Medium Length(m)*	*Encoding*
10Base5	Thick coax	500 m	Manchester
10Base2	Thin coax	185 m	Manchester
10Base-T	2 UTP	100 m	Manchester
10Base-F	2 Fiber	2000	Manchester

Table 4.1 Summary of Standard Ethernet implementations

4.1.2 Fast Ethernet (100 Mbps)

- In the 1990s, Ethernet made a big jump by increasing the transmission rate to 100 Mbps, and the new generation was called the Fast Ethernet

- The designers of the Fast Ethernet needed to make it compatible with the Standard Ethernet
  - The MAC sublayer was left unchanged

- But the features of the Standard Ethernet that depend on the transmission rate, had to be changed

4.1.2 Fast Ethernet (100 Mbps)

- Access Method
  - We remember that the proper operation of the CSMA/CD depends on the transmission rate, the minimum size of the frame, and the maximum network length
  - If we want to keep the minimum size of the frame, the maximum length of the network should be changed
    - In other words, if the minimum frame size is still 512 bits, and it is transmitted 10 times faster, the collision needs to be detected 10 times sooner, which means the maximum length of the network should be 10 times shorter (the propagation speed does not change)
- Auto-negotiation
  - A new feature added to Fast Ethernet is auto-negotiation
  - It allows two stations to negotiate the mode or data rate of transmission
- Physical Layer
  - To be able to handle a 100 Mbps data rate, several changes need to be made at the physical layer

4.1.2 Fast Ethernet (100 Mbps)

- Summary
  - Fast Ethernet implementation at the physical layer can be categorized as either two-wire or four-wire
  - The two-wire implementation can be either shielded twisted pair (STP), which is called 100Base-TX, or fiber-optic cable, which is called 100Base-FX
  - The four-wire implementation is designed only for unshielded twisted pair (UTP), which is called 100Base-T4

Implementation	*Medium*	*Medium Length*	*Wires*	*Encoding*
100Base-TX	STP	100 m	2	4B/5B + MLT-3
100Base-FX	Fiber	185 m	2	4B/5B + NRZ-I
100Base-T4	UTP	100 m	4	Two 8B/6T

Table 4.2 Summary of Fast Ethernet implementations

4.1.3 Gigabit Ethernet (1000 Mbps)

- The need for an even higher data rate resulted in the design of the Gigabit Ethernet Protocol (1000 Mbps)
- The IEEE committee calls it the Standard 802.3z
- The goals of the Gigabit Ethernet were to upgrade the data rate to 1 Gbps, but keep the address length, the frame format, and the maximum and minimum frame length the same

4.1.3 Gigabit Ethernet (1000 Mbps)

- MAC Sublayer
  - A main consideration in the evolution of Ethernet was to keep the MAC sublayer untouched
  - However, to achieve a data rate of 1 Gbps, this was no longer possible
  - Gigabit Ethernet has two distinctive approaches for medium access: half-duplex and full-duplex
  - Almost all implementations of Gigabit Ethernet follow the full-duplex approach, so we mostly ignore the half-duplex mode
- Full-Duplex Mode
  - In the full duplex mode, there is a central switch connected to all computers
  - There is no collision in this mode
- Half-Duplex Mode
  - In this mode, a switch can be replaced by a hub

4.1.3 Gigabit Ethernet (1000 Mbps)

Physical Layer

- The physical layer in Gigabit Ethernet is more complex that the other version
- We have different implementations

Implementation	*Medium*	*Medium Length(m)*	*Wires*	*Encoding*
1000Base-SX	Fiber S-W	550 m	2	8B/10B + NRZ
1000Base-LX	Fiber L-W	5000 m	2	8B/10B + NRZ
1000Base-CX	STP	25 m	2	8B/10B + NRZ
1000Base-T4	UTP	100 m	2	4D-PAM5

Table 4.3 Summary of Gigabit Ethernet implementations

4.1.4 10-Gigabit Ethernet

- In recent years, there has been another look into the Ethernet for use in metropolitan areas
- The idea is to extend the technology, the data rate, and the coverage distance so that the Ethernet can be used as LAN and MAN (metropolitan area network)
- The IEEE committee created 10 Gigabit Ethernet and called it Standard 802.3ae

4.1.4 10-Gigabit Ethernet

Implementation

- 10 Gigabit Ethernet operates only in full-duplex mode, which means there is no need for contention; CSMA/CD is not used in 10 Gigabit Ethernet
- Four implementations are the most common: 10GBase-SR, 10GBase-LR, 10GBase-EW, and 10GBase-X4

Implementation	*Medium*	*Medium Length*	*Number of wires*	*Encoding*
10GBase-SR	Fiber 850 nm	300 m	2	64B66B
10GBase-LR	Fiber 1310 nm	10 km	2	64B66B
10GBase-EW	Fiber 1350 nm	40 km	2	SONET
10GBase-X4	Fiber 1310 nm	300 m to 10 km	2	8B10B

Table 4.4 Summary of 10-Gigabit Ethernet implementations

4.2 WIFI, IEEE 802.11 PROJECT

- IEEE has defined the specifications for a wireless LAN, called IEEE 802.11, which covers the physical and data-link layers
- It is sometimes called wireless Ethernet
- In some countries, including the United States, the public uses the term WiFi (short for wireless fidelity) as a synonym for wireless LAN
- WiFi is a wireless LAN that is certified by the WiFi Alliance

그림 8-1 와이파이 로고와 와이파이를 이용한 유무선 공유기

4.2 WIFI, IEEE 802.11 PROJECT

- WiFi의 가장 대중적인 규격으로는 802.11b, 802.11a, 802.11g, 802.11n, 802.11ac, 802.11ax가 있음
- WiFi는 다양한 암호화 기술을 채택하고 있으며, 초기 암호화 방식으로 WEP(Wired Equivalent Privacy)을 사용하였으나 쉽게 뚫리는 단점이 있어 더 높은 품질의 암호화방식(WPA, WPA2)들이 나중에 추가되었음

표 8-1 와이파이 규격과 특징

분류	IEEE 규격	특징
WiFi 1	802.11b	2.4GHz 사용, 11Mbps
WiFi 2	802.11a	5GHz 사용, 54Mbps
WiFi 3	802.11g	2.4GHz 사용, 최대 54Mbps, 스마트폰 및 노트북 탑재
WiFi 4	802.11n	a/b/g호환, 2.4GHz 및 5GHz 사용, 최대 600Mbps
WiFi 5	802.11ac	차세대 WiFi, 5GHz 주파수 대역만 사용하며 최대 3.7Gbps
WiFi 6	802.11ax	802.11ac의 후속 표준

4.2.1 Architecture

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

- Basic Service Set (BSS)
  - IEEE defines the basic service set as the building block of a wireless LAN. It also defines an optional base station known as the access point (AP)

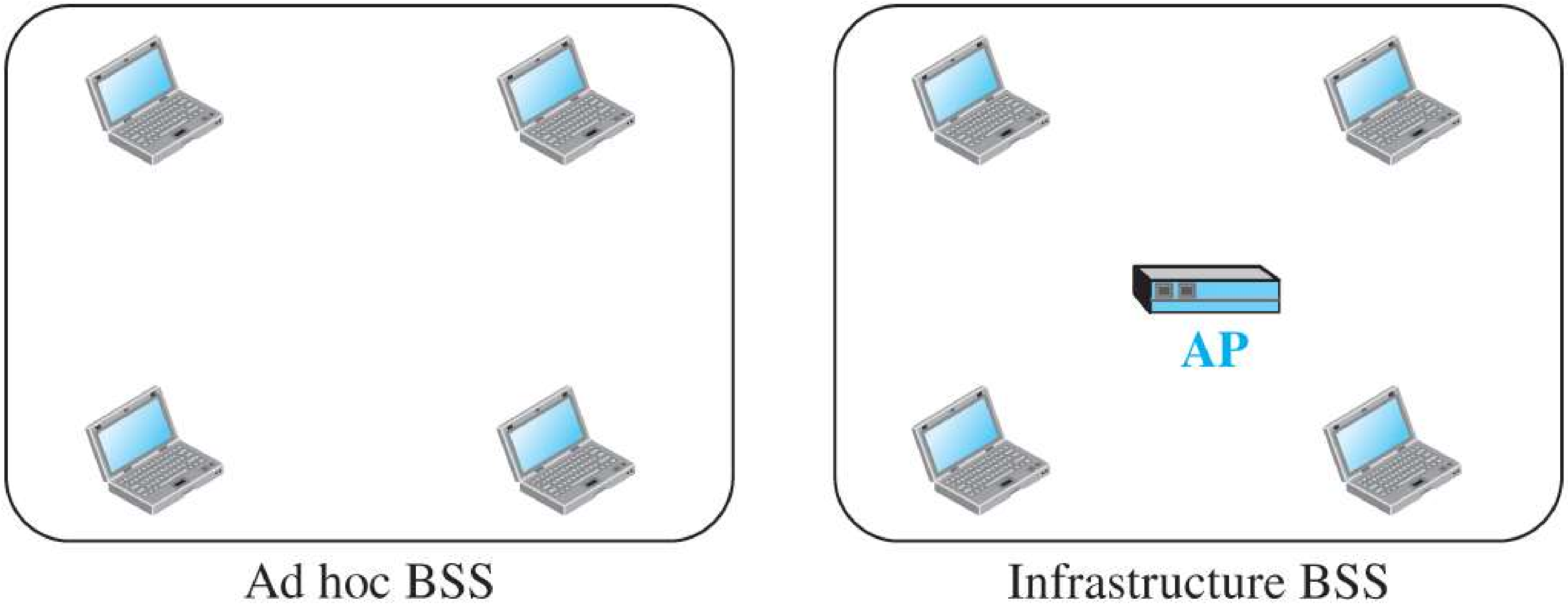


Figure 4.7 Basic service sets (BSSs)

4.2.1 Architecture

- Extended Service Set (ESS)

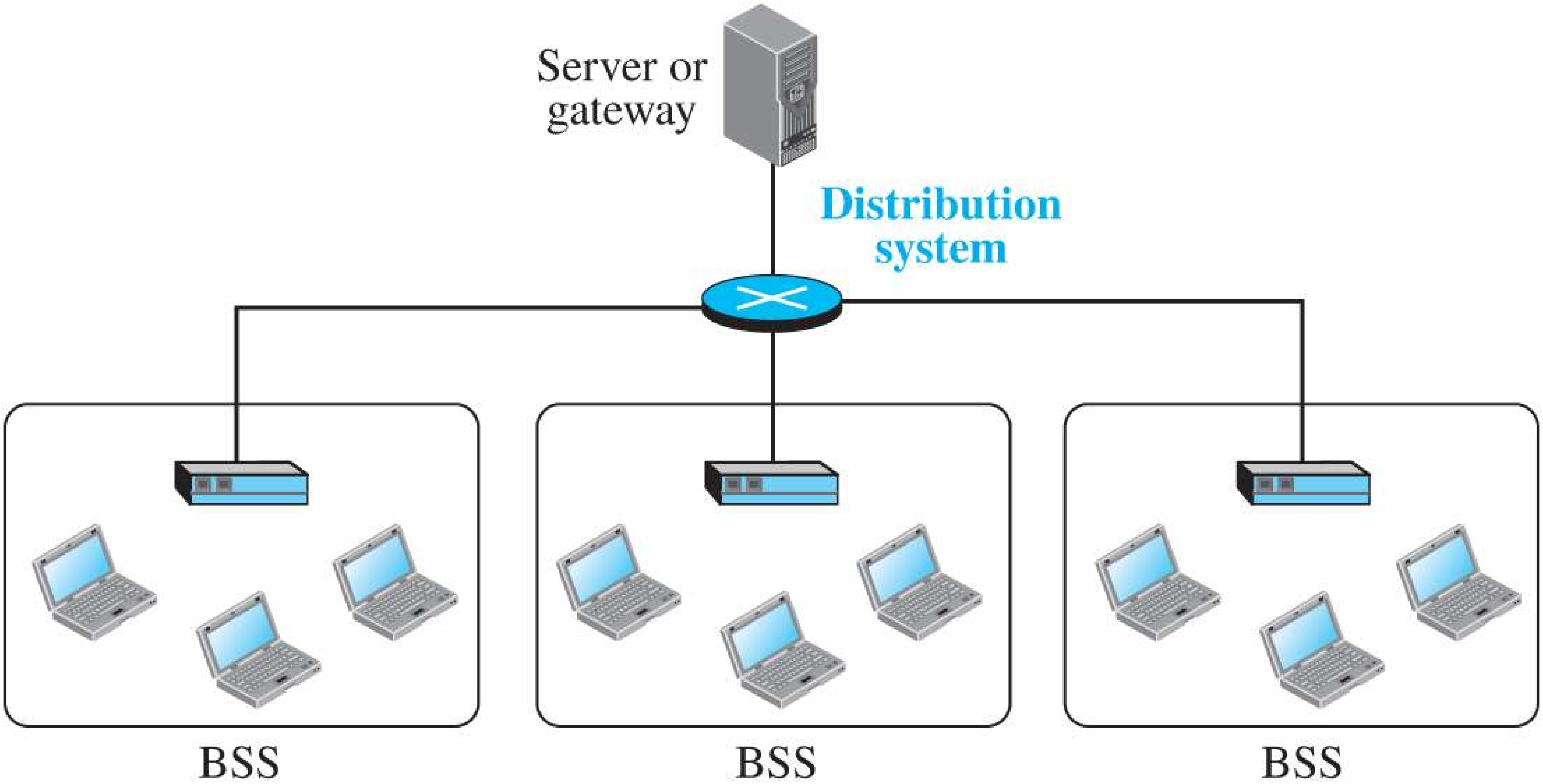


Figure 4.8 Extended service set (ESS)

4.2.1 Architecture

- Station Type
  - IEEE defines three types of stations: no-transition, BSS-transition, and ESS-transition
  - 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

4.2.2 MAC Sublayer

- IEEE 802.11 defines two MAC sublayers: the distributed coordination function (DCF) and point coordination function (PCF)
- Figure 4.9 shows the relationship between the two MAC sublayers, the LLC sublayer, and the physical layer

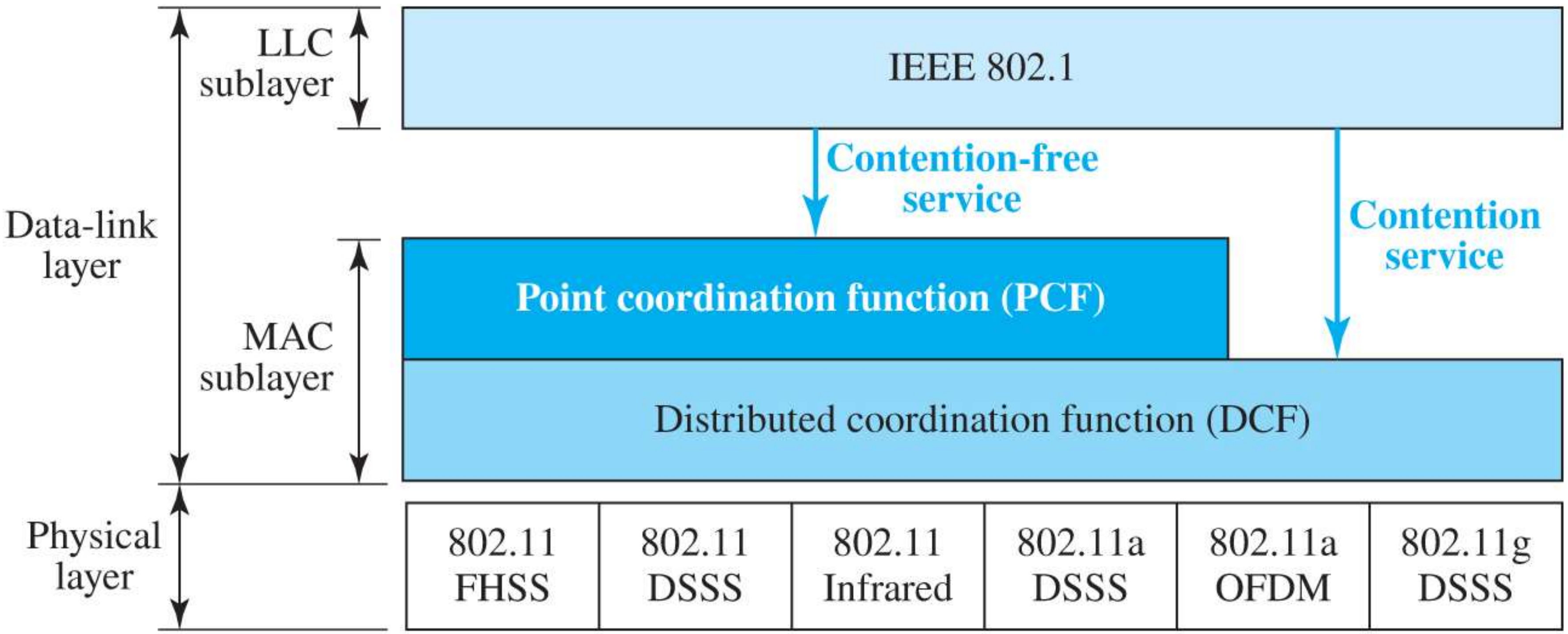


Figure 4.9 MAC layers in IEEE 802.11 standard

4.2.2 MAC Sublayer

■ Distribution Coordination Function (DCF)

- One of the two protocols defined by IEEE at the MAC sublayer is called distribution coordination function (DCF), which uses CSMA/CA
- Owing to the different communication ranges, host A cannot hear the host D's signal → Hidden terminal problem can occur

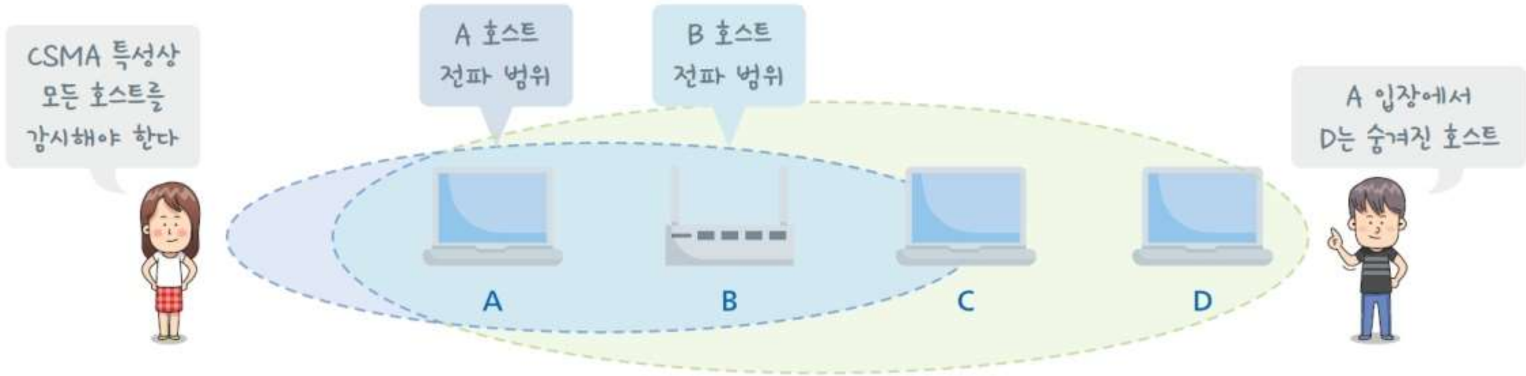


그림 8-2 서로 다른 전파 범위의 문제

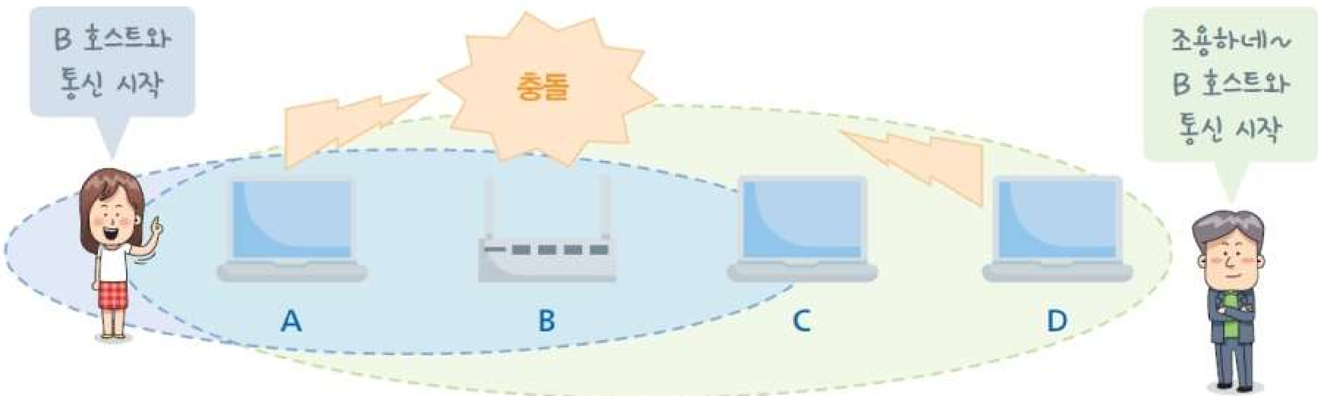


그림 8-3 숨겨진 호스트 문제

4.2.2 MAC Sublayer

- Distribution Coordination Function (DCF)
  - One of the two protocols defined by IEEE at the MAC sublayer is called distribution coordination function (DCF), which uses CSMA/CA

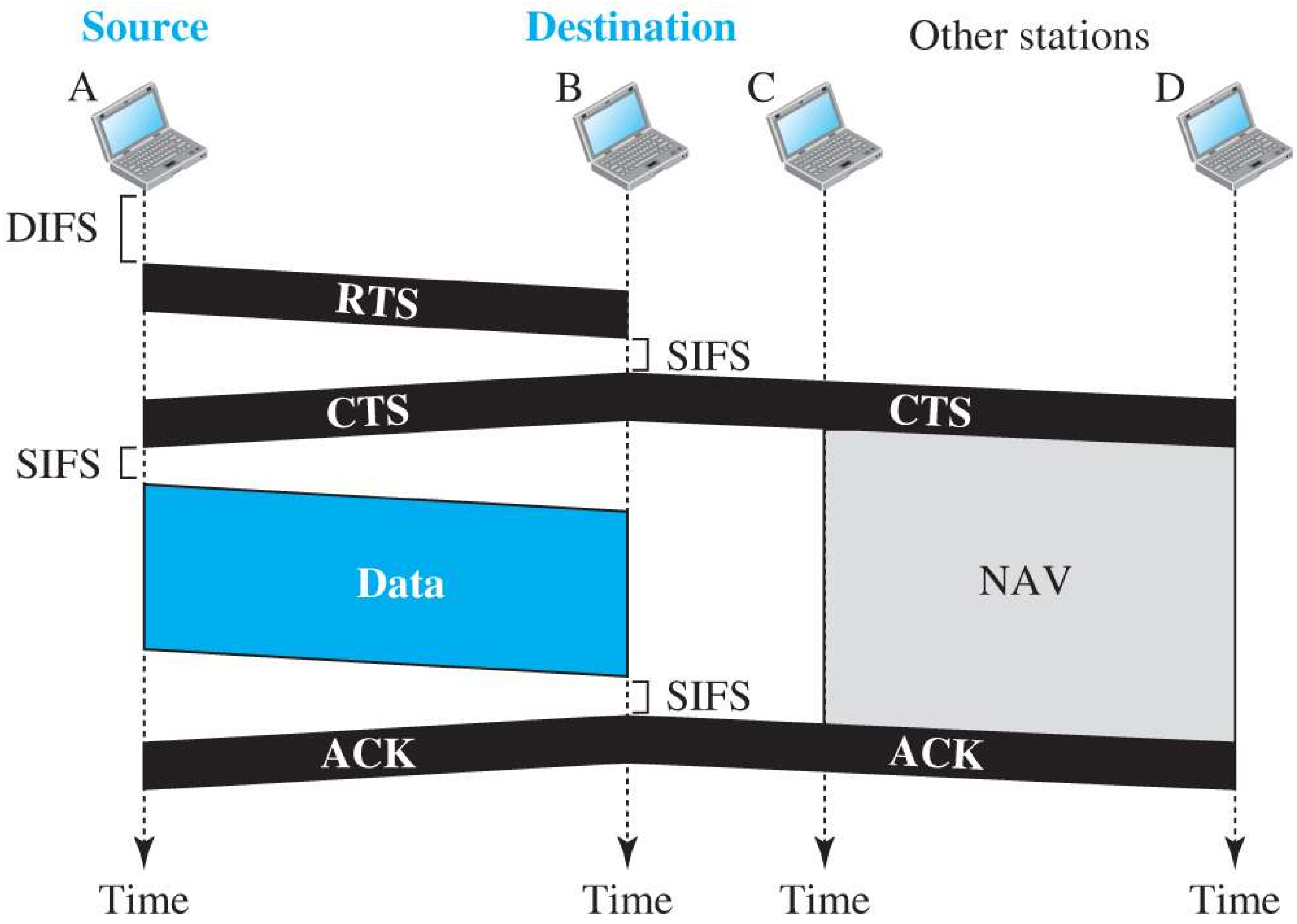


Figure 4.10 CSMA/CA and NAV

4.2.2 MAC Sublayer

■ Distribution Coordination Function (DCF)

- One of the two protocols defined by IEEE at the MAC sublayer is called distribution coordination function (DCF), which uses CSMA/CA

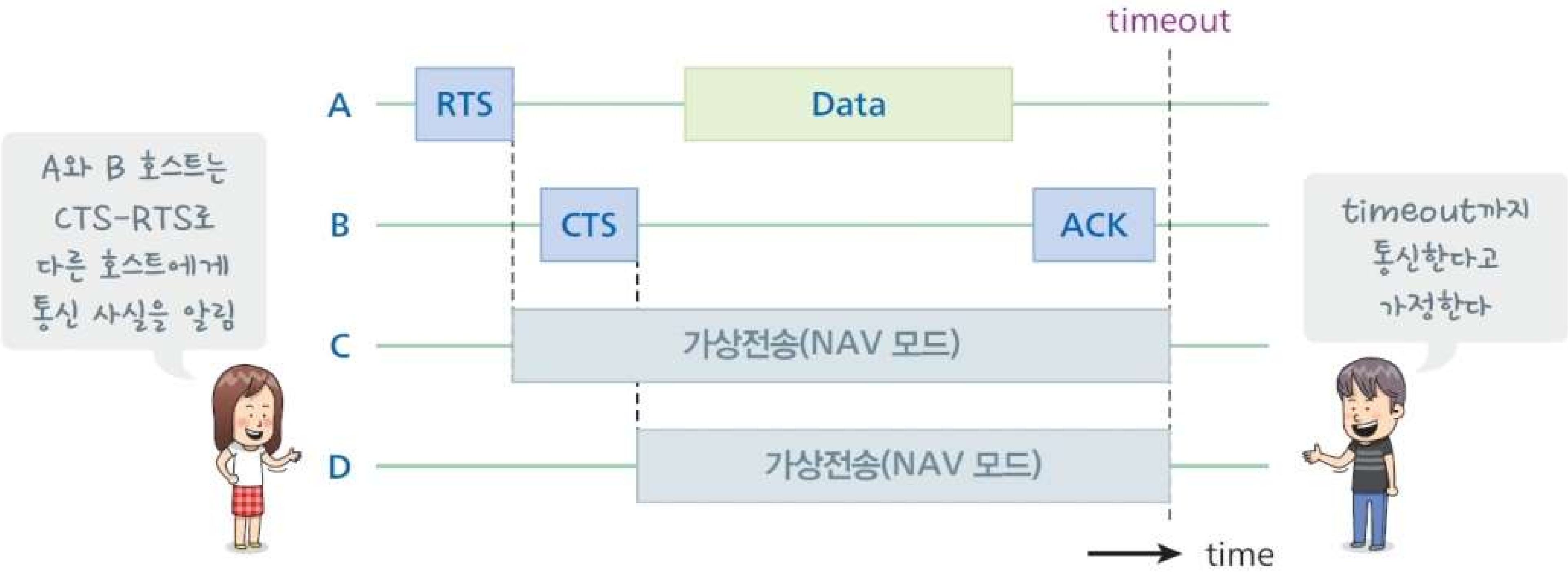


그림 8-5 CSMA/CA 프로토콜

4.2.2 MAC Sublayer

- DCF – Frame Exchange Time Line
  - 1. Before sending a frame, the source station senses the medium by checking the energy level at the carrier frequency
    - Channel uses a persistence strategy with backoff until the channel is idle
  - 2. After the station is found to be idle, the station waits for a period of time called the **DCF interframe space (DIFS)**; then the station sends a control frame called the **request to send (RTS)**
  - 3. 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
    - CTS indicates that the destination station is ready to receive data
  - 4. The source station sends data after waiting for a period of the SIFS
  - 5. The destination station, after waiting an amount of time equal to the SIFS, sends an **acknowledgment (ACK)** to show that the frame has been received
    - ACK is needed because the station does not have any means to check for the successful arrival of its data at the destination.

4.2.2 MAC Sublayer

- DCF – Network Allocation Vector (NAV)
  - 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 include the **duration** field, which is the duration of time that it needs to occupy the channel
  - The stations that are affected by this transmission create a timer called a 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

4.2.2 MAC Sublayer

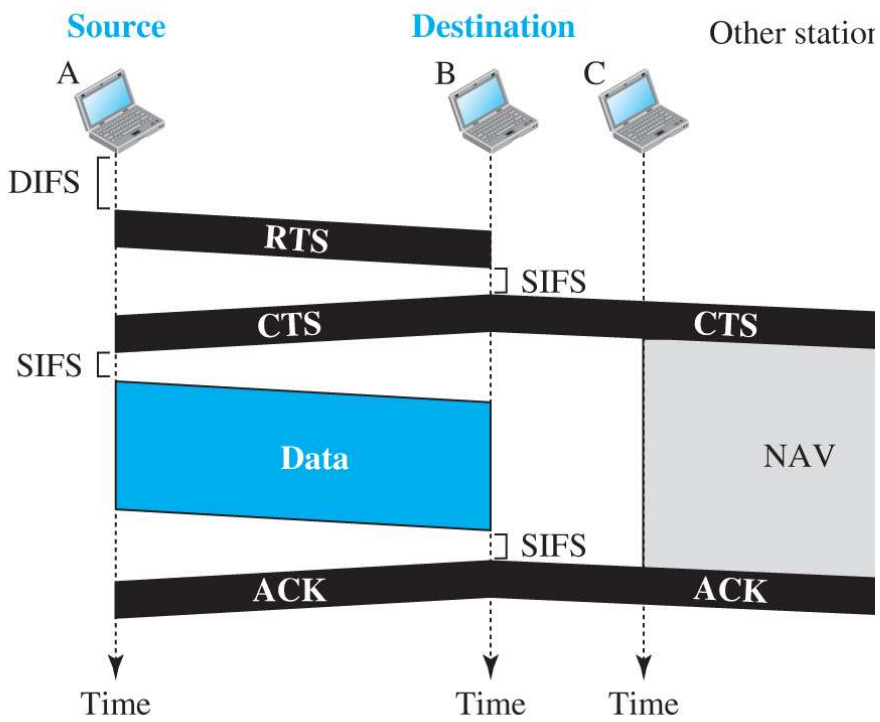
- DCF – Collision During Handshaking
  - What happens if there is a collision during the time when RTS or CTS control frames are in transition, often called the handshaking period?
  - Two or more stations may try to send RTS frames at the same time and these control frames may collide
  - However, because 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 backoff strategy is employed, and the sender tries again

4.2.2 MAC Sublayer

- DCF – Hidden-Station Problem
  - (a.k.a.) **Hidden terminal problem** or **hidden node problem**
  - Problem of a collision caused by the hidden node
    - Neither A nor C know each other
    - A is a hidden node of C / C is also a hidden node of A
  - Unlike wired networks, a sender cannot directly recognize the collision at a receiver in wireless networks

4.2.2 MAC Sublayer

- DCF – Hidden-Station Problem (Cont.)
  - To prevent a collision by the hidden node, the solution is the use of the handshake frames (RTS and CTS)
    - RTS message from B reaches A, but not C
    - However, because both A and C are within the range of B, the CTS message, which contains the duration of data transmission from A to B, reaches C
    - Station C knows that some hidden station is using the channel and refrains from transmitting until that duration is over



4.2.2 MAC Sublayer

- Point Coordination Function (PCF)
  - This is an optional access that can be implemented in an infrastructure network
  - PCF has priority over DCF
  - However, to allow DCF frame to get access to the network repetition interval has been added to the network as shown in Figure 4.11

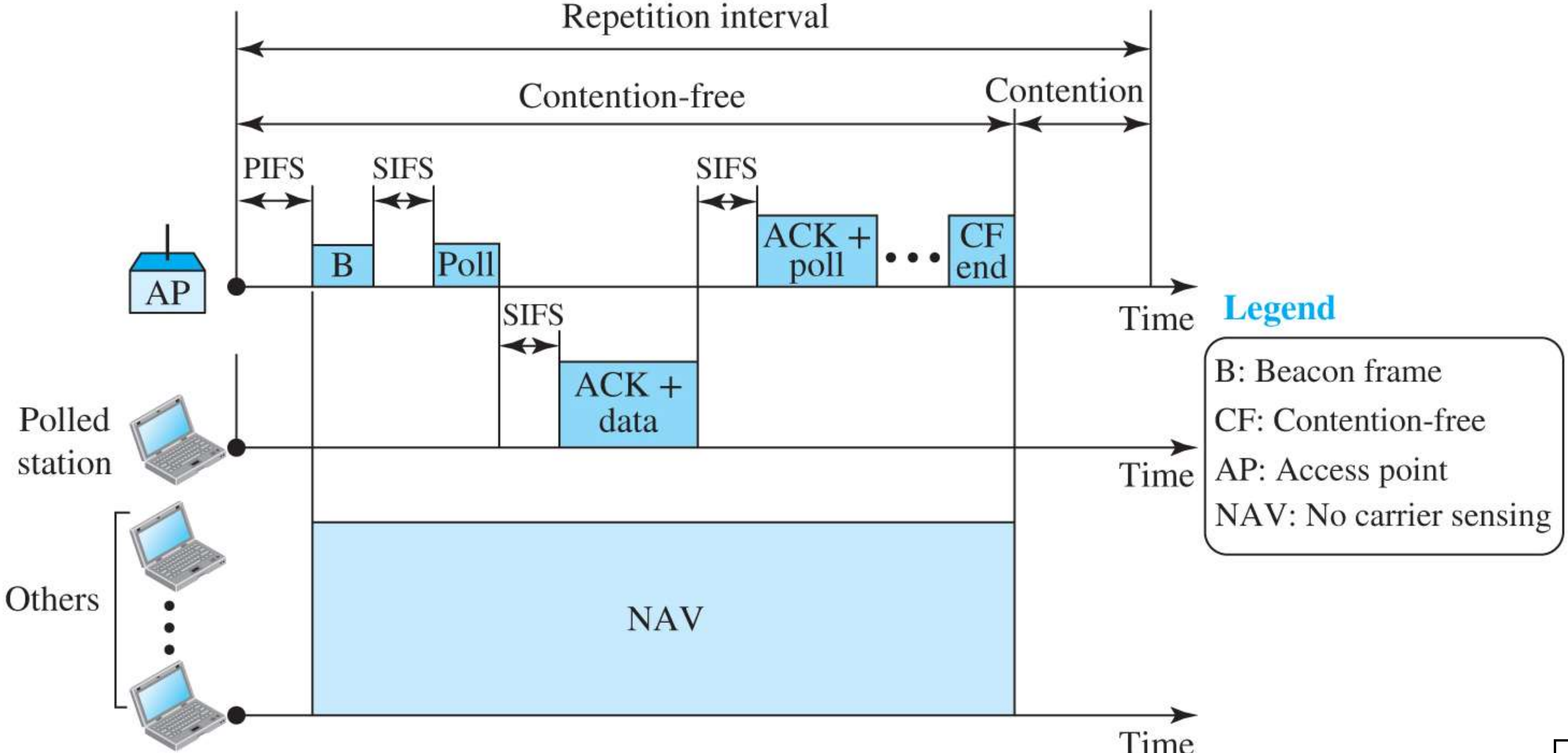


Figure 4.11 Example of repetition interval

4.2.2 MAC Sublayer

- Fragmentation
  - The wireless environment is very noisy, so frames are often corrupted
  - A corrupted frame has to be retransmitted
  - The protocol recommend fragmentation – the division of a large frame into smaller ones
  - It is more efficient to resend a small frame than a large one (why?)

4.2.2 MAC Sublayer

■ Frame Format

- Frame control (FC): 2bytes long and defines the type of frame and some control information
- D: Duration of transmission (used to set the value of NAV)
- Addresses: four address fields, each 6 bytes long
  - The meaning depends on the value of the *To DS* and *From DS* subfields
- Sequence control (SC): this field defines a 16-bit value
  - First 4 bits: the fragment #; 12 bits: sequence # (Same in all fragments)
- Frame body: this field contains information based on the type and the subtype defined in the FC field (0 ~ 2312 bytes)
- FCS: 4 bytes long and contains a CRC-32 error-detection sequence

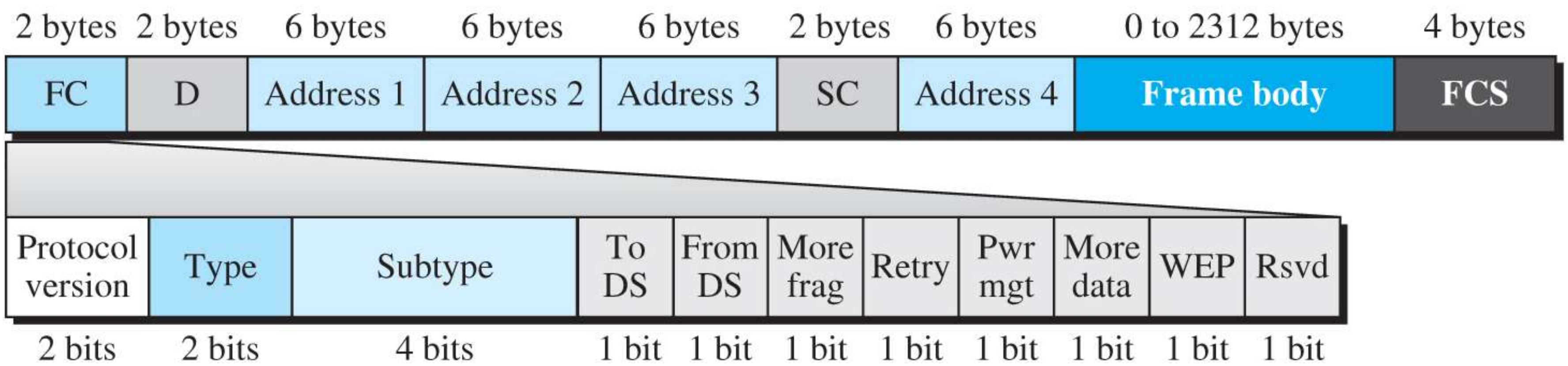


Figure 4.12 Frame format

4.2.2 MAC Sublayer

- Frame Format (Cont.)
  - 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 4.6)
To DS	Defined later
From DS	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

Table 4.5 Subfields in FC field

4.2.2 MAC Sublayer

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

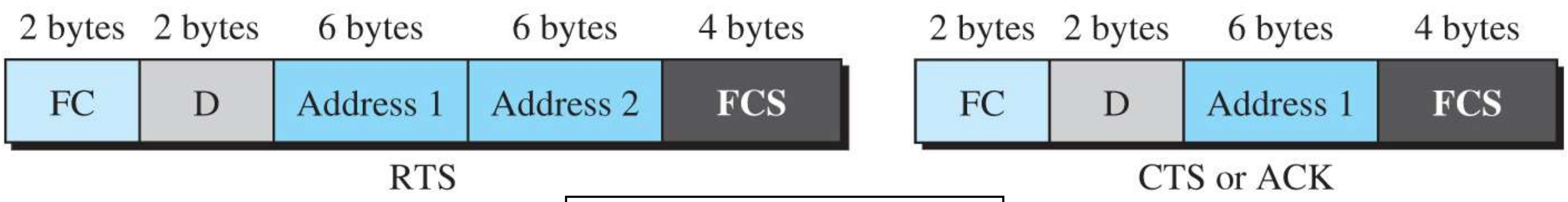


Figure 4.13 Control frames

Subtype	*Meaning*
1011	Request to send (RTS)
1100	Clear to send (CTS)
1101	Acknowledgment (ACK)

Table 4.6 Values of subfields in control frames

4.2.3 Addressing Mechanism

- IEEE 802.11 addressing mechanism
  - Four cases defined by two flags in the FC field, To DS and From DS
    - Case 1: 00 / Case 2: 01 / Case 3: 10 / Case 4: 11

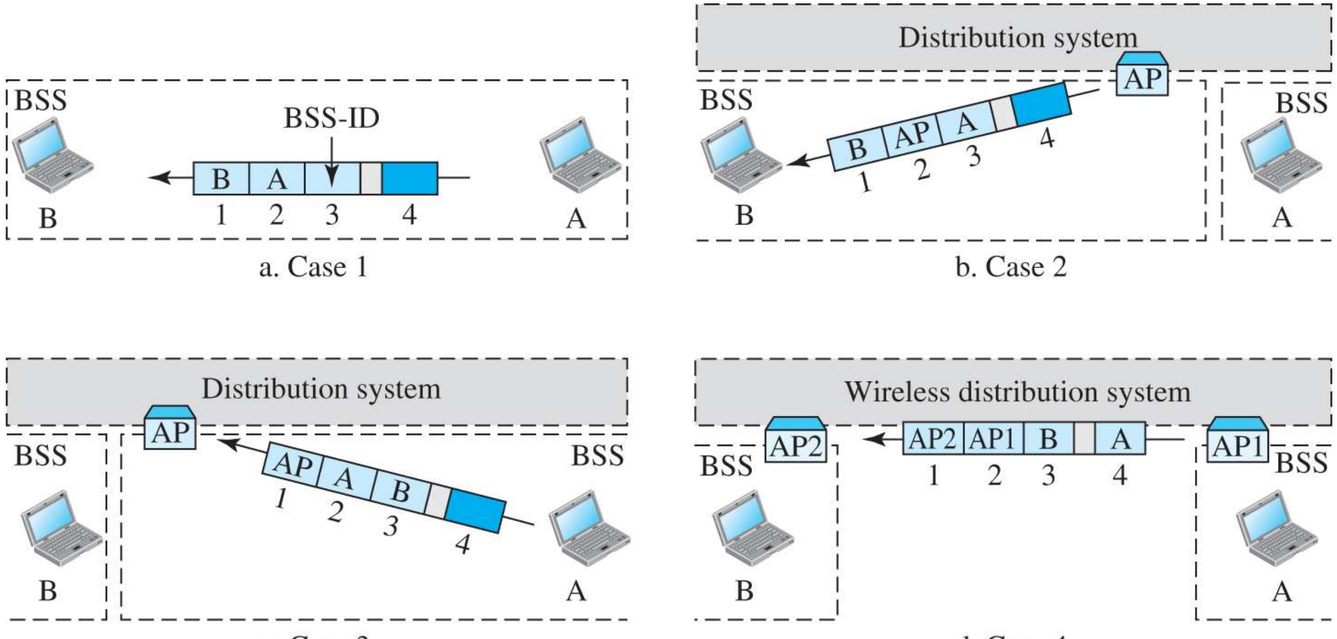


Figure 4.14 Addressing mechanisms

To DS	*From DS*	*Address 1*	*Address 2*	*Address 3*	*Address 4*
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

4.2.3 Addressing Mechanism

- IEEE 802.11 addressing mechanism (Cont.)
  - Each flag can be either 0 or 1, resulting in four different situations
  - The interpretation of the four addresses in the MAC frame depends on the value of these flags
    - Address 1: the address of the next device that the frame will visit
    - Address 2: the address of the previous device that the frame has left
    - Address 3: the address of the final destination if it is not defined by address 1 or the original source if it is not defined by address 2
    - Address 4: Original source when the DS is also wireless

To DS	*From DS*	*Address 1*	*Address 2*	*Address 3*	*Address 4*
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

4.2.3 Addressing Mechanism

- Exposed Station Problem
  - A station refrains from using a channel when it is available
    - 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
      - C is the exposed station of A
      - In other words, C is too conservative and wastes the capacity of the channel

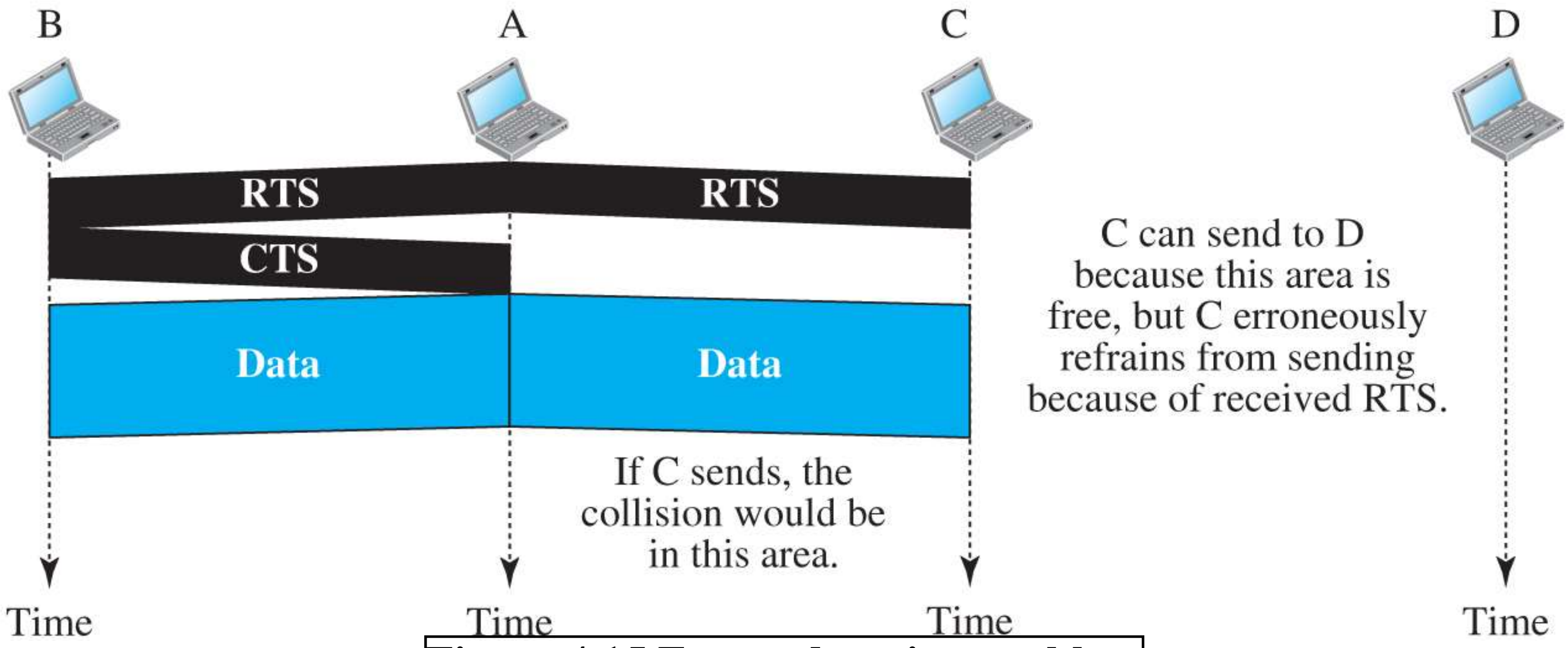


Figure 4.15 Exposed station problem

4.2.4 Physical Layer

- We discuss six specifications, as shown in Table 4.8
- 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

IEEE	*Technique*	*Band*	*Modulation*	*Rate (Mbps)*
802.11	FHSS	2.400–4.835 GHz	FSK	1 and 2
	DSSS	2.400–4.835 GHz	PSK	1 and 2
	None	Infrared	PPM	1 and 2
802.11a	OFDM	5.725–5.850 GHz	PSK or QAM	6 to 54
802.11b	DSSS	2.400–4.835 GHz	PSK	5.5 and 11
802.11g	OFDM	2.400–4.835 GHz	Different	22 and 54
802.11n	OFDM	5.725–5.850 GHz	Different	600

Table 4.8 Specifications

4.3 BLUETOOTH

- Bluetooth is a wireless LAN technology designed to connect devices of different functions when they are at a short distance from each other
- 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
- Applications: wireless mouse or keyboard, sensor for health care, home security devices, etc
- IEEE 802.15 WPAN

Bluetooth™

그림 8-6 블루투스 로고와 지원 기기

4.3.1 Architecture

- Bluetooth defines two types of networks: piconet and scatternet
  - Piconet
    - A Bluetooth network is called a piconet (a small net)
    - It can have up to 8 stations, one of which is called the primary; the other are called the secondaries
    - **Parked state**: Although a piconet can have a maximum of 7 secondaries, additional secondaries can be in the parked state (active/parked state)
  - Scatternet
    - Piconets can be combined to create a scatternet
    - A secondary station in one piconet can be a primary in another one

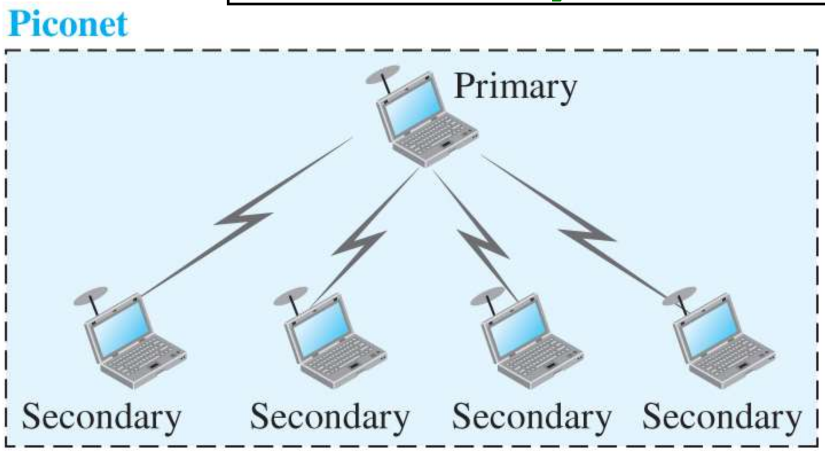


Figure 4.20 Piconet

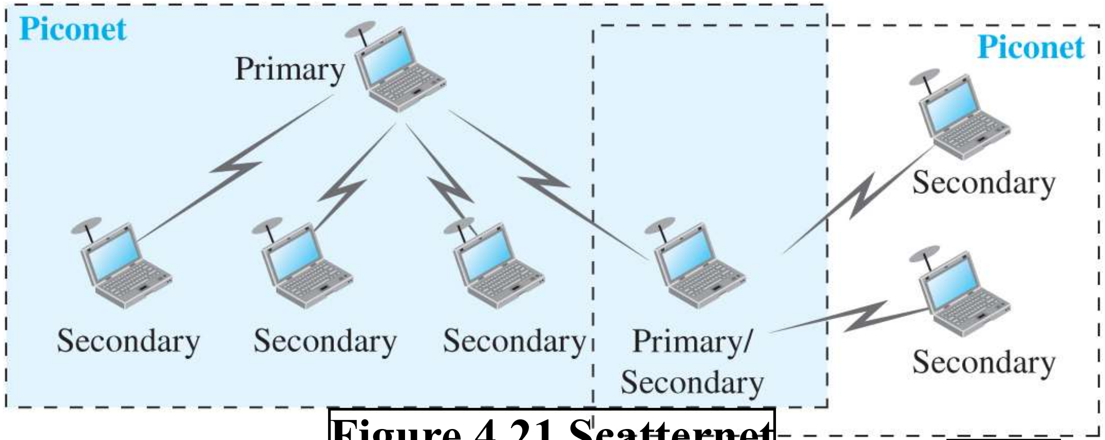


Figure 4.21 Scatternet

4.3.1 Architecture

■ 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
- Possibility of interference between IEEE 802.11b wireless LANs and Bluetooth LANs

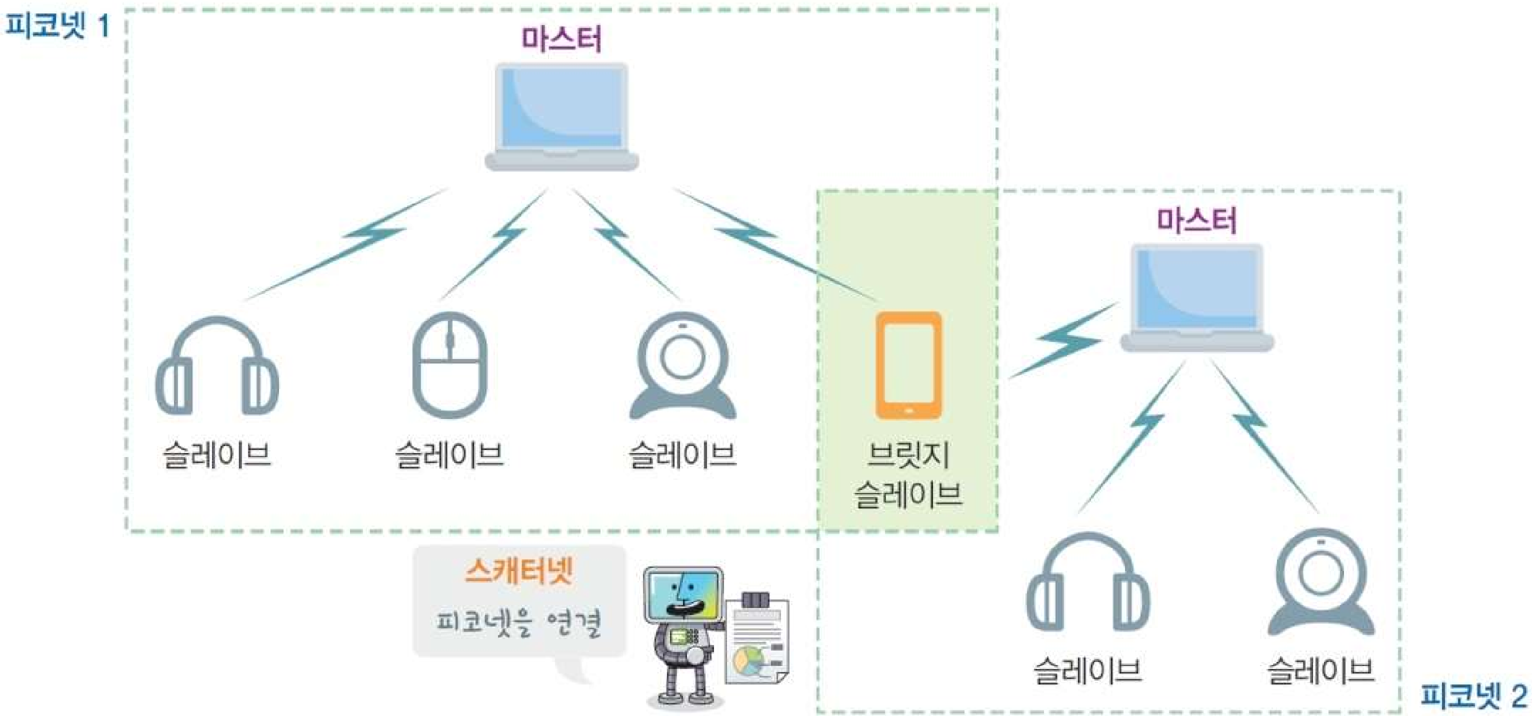


그림 8-8 스캐터넷

4.3.2 Bluetooth Layers

- Bluetooth uses several layers that do not exactly match those of the Internet model

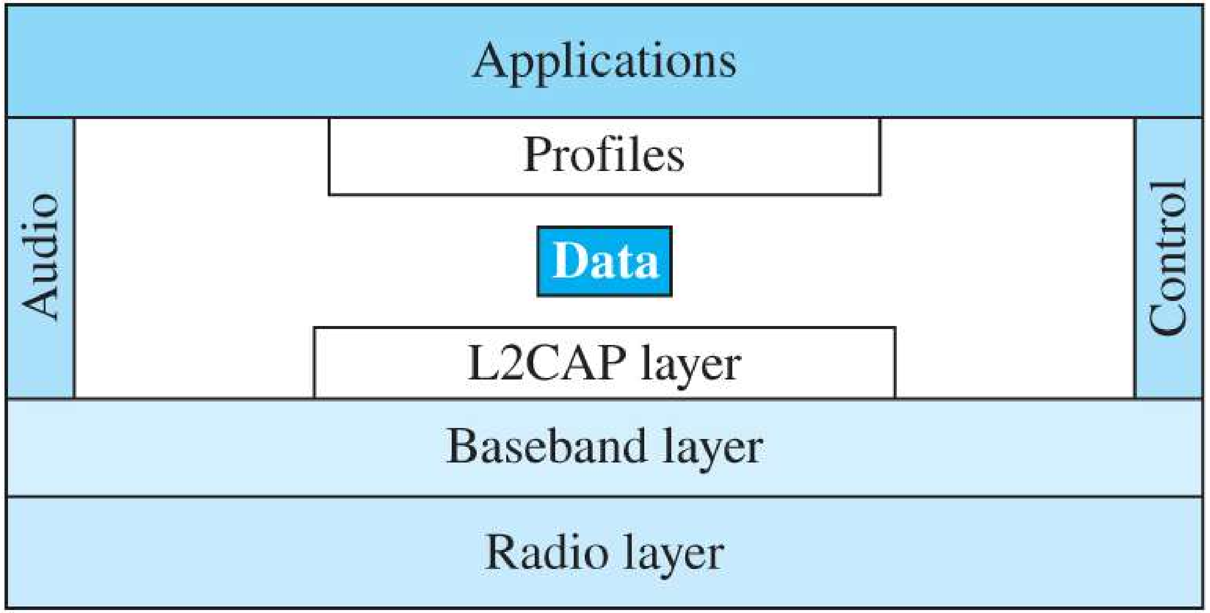


Figure 4.22 Bluetooth layers

4.3.2 Bluetooth Layers

- L2CAP
  - Logical Link Control and Adaption Protocol (L2CAP) is roughly equivalent to the LLC sublayer in LANs
  - 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
  - Channel ID (CID) defines a unique identifier for the virtual channel created at this level

Figure 4.23 L2CAP data packet format

4.3.2 Bluetooth Layers

- Baseband Layer
  - The Baseband layer is roughly equivalent to MAC sublayer in LANs
  - The access method is TDMA
  - The primary and secondary stations communicate with each other using time slots
  - The length of a time slot is exactly the same as the dwell time, 625 μs

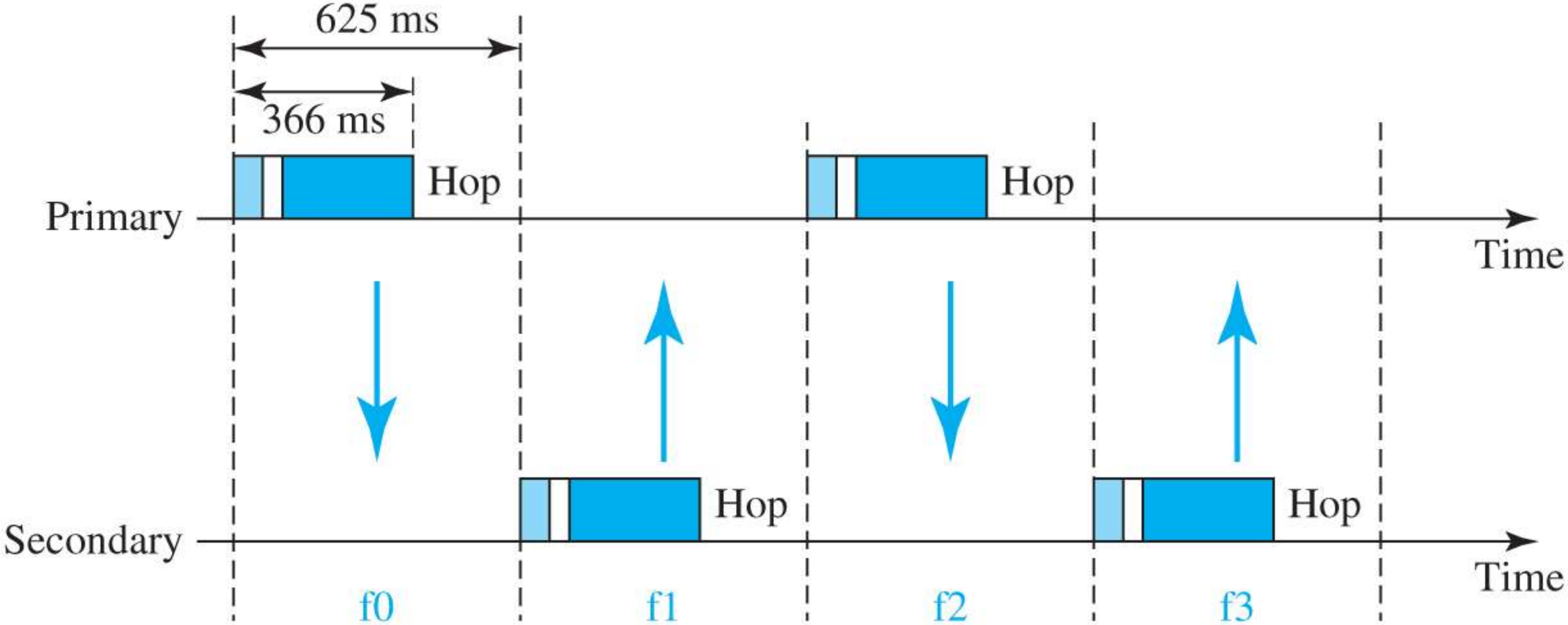
4.3.2 Bluetooth Layers

- Baseband Layer – TDMA
  - Bluetooth uses a form of TDMA that is called TDD-TDMA (time-division duplex TDMA)
  - TDD-TDMA is a kind of half-duplex communication in which the sender and receiver send and receive data, but not at the same time (half-duplex)
  - However, the communication for each direction uses different hops

4.3.2 Bluetooth Layers

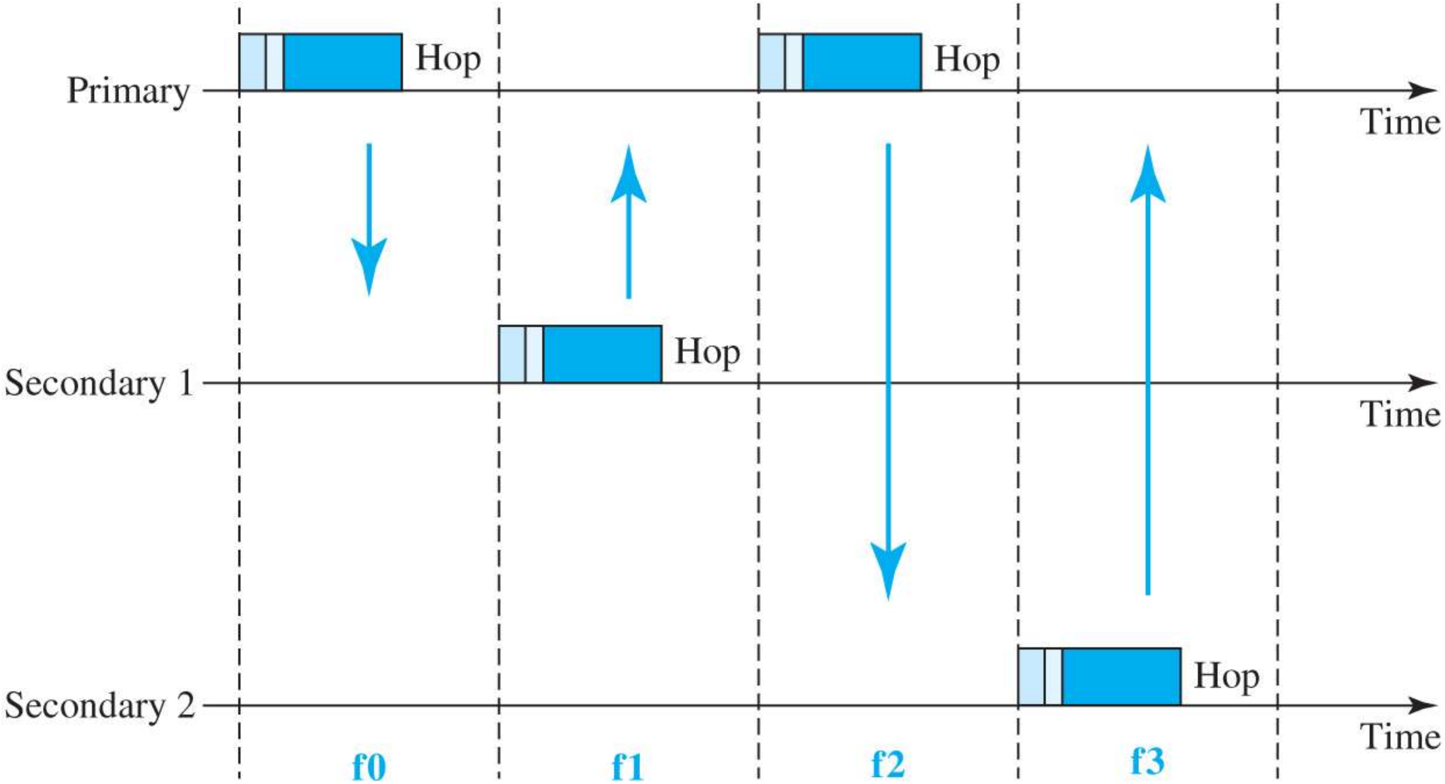
■ Baseband Layer – TDMA (Cont.)

- Single-secondary communication
  - If the piconet has only one secondary, the TDMA operation is very simple
  - The time is divided into slots of 625 μs
  - The primary uses even-numbered slots (0, 2, 4, …); the secondary uses odd-numbered slots (1, 3, 5, …)



4.3.2 Bluetooth Layers

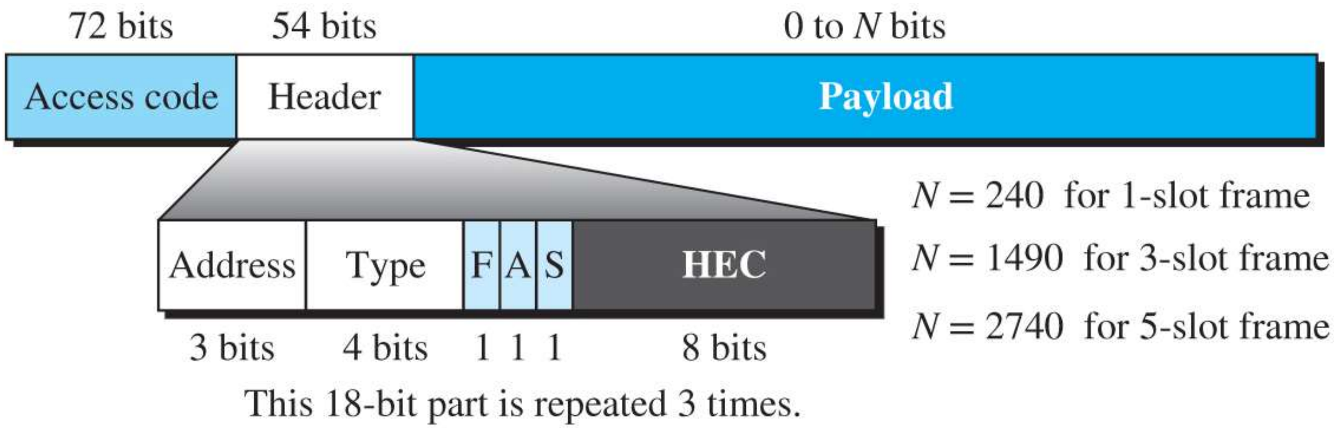
- Baseband Layer – TDMA (Cont.)
  - Multiple-secondary communication
    - The process is a little more involved if there is more than one secondary in the piconet
    - Primary uses the even-numbered slots, but a secondary sends in the next odd-numbered slot if the packet in the previous slot was addressed to it
    - All secondaries listen on even-numbered slots, but only one secondary sends in any odd-numbered slot



4.3.2 Bluetooth Layers

Baseband Layer – Frame Format

- Three types of a frame in the baseband layer: 1-slot, 3-slot, or 5-slot
- A slot is 625 μs
- One-slot frame
  - In a one-slot frame, 259 μs is needed for hopping and control mechanism
  - This means that a one-slot frame can last only 625 – 259, or 366 μs
  - With a 1-MHz bandwidth and 1 bit/Hz, the one-slot frame size is 366 bits
- Three-slot frame
  - The length of the frame : 3 × 625 – 259 = 1616 μs or 1616 bits
  - A device that uses a three-slot frame remains at the same hop for 3 slots
- Five-slot frame
  - The length of the frame : 5 × 625 – 259 = 2866 μs or 2866 bits



4.3.2 Bluetooth Layers

- Radio Layer
  - Band
    - Bluetooth uses a 2.4-GHz ISM band divided into 79 channels of 1MHz each
  - FHSS (Frequency-hopping spread spectrum)
    - Bluetooth uses the 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 μs (1/1600 s) before it hops to another frequency; the dwell time is 625 μs
  - Modulation
    - To transform bits to a signal, Bluetooth uses a sophisticated version of FSK, called GFSK (Gaussian FSK)
    - The first channel uses carrier frequency 2402 MHz (2.402 GHz), and the second channel uses carrier frequency 2403 MHz (2.403 GHz)

$$f_c = 2402 + n \ \text{MHz}, n = 0,1,2,\cdots,78$$

Q & A