CONTROLLED ACCESS

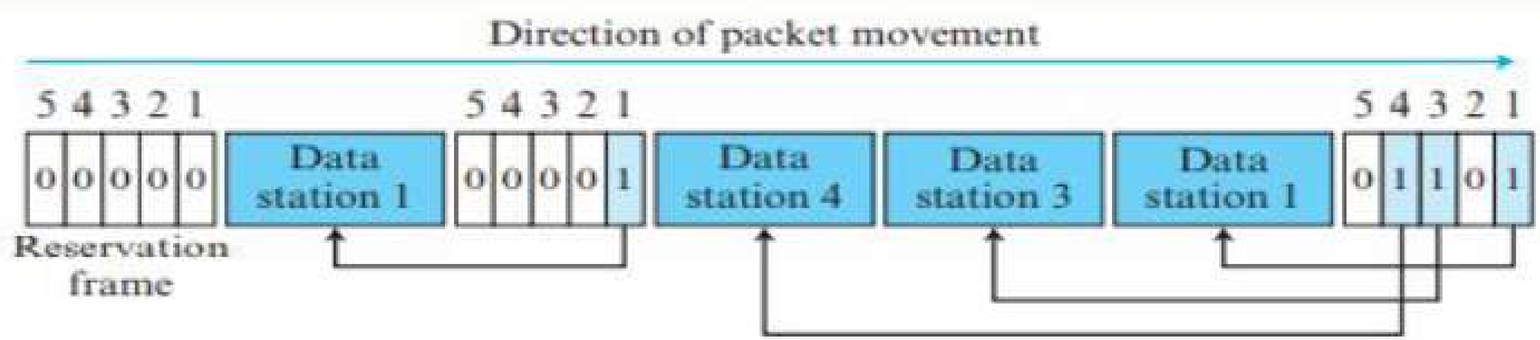
- In controlled access, the stations consult one another to find which station has the right to send.
- A station cannot send unless it has been authorized by other stations.
- We discuss three popular controlled-access methods.
  - Reservation
  - Polling
  - Token Passing

:

i) Reservation:

- A station needs to make a reservation before sending data.
- Time is divided into intervals.
- In each interval, a reservation frame precedes the data frames sent in that interval.
- If there are N stations in the system, there are exactly N reservation minislots in the reservation frame, each for a station.
- When a station needs to send a data frame, it makes a reservation in its own minislot.
- The stations that have made reservations can send their data frames after the reservation frame.

Figure 5.42 *Reservation access method*

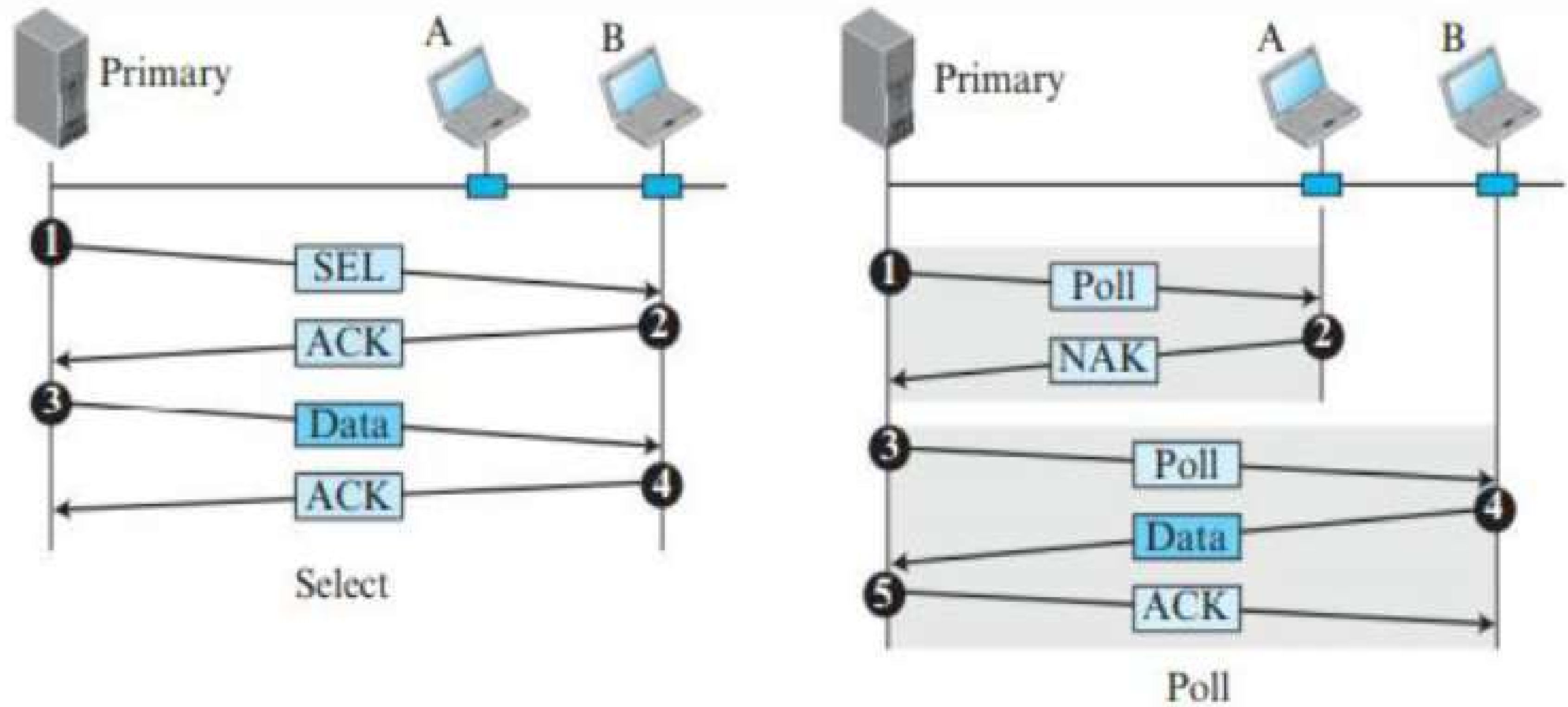


[Behrouz A Forouzan, Firouz Mosharraf, "Computer Networks: A top down Approach", McGraw Hill Education]

ii) **Polling:**

- One device is designated as a primary station and the other devices are secondary stations.
- The primary device controls the link; the secondary devices follow its instructions.
- It is up to the primary device to determine which device is allowed to use the channel at a given time.
- This method uses poll and select functions to prevent collisions.
- **Select** function: It is used whenever the primary device has something to send.
- **Poll** function:
  - When the primary is ready to receive data, it must ask (poll) each device in turn if it has anything to send.
  - The primary node polls each of the nodes in a round robin fashion.
  - Other nodes respond either with a NAK if they have nothing to send or with data if they have.
- If the primary station fails, the system goes down.

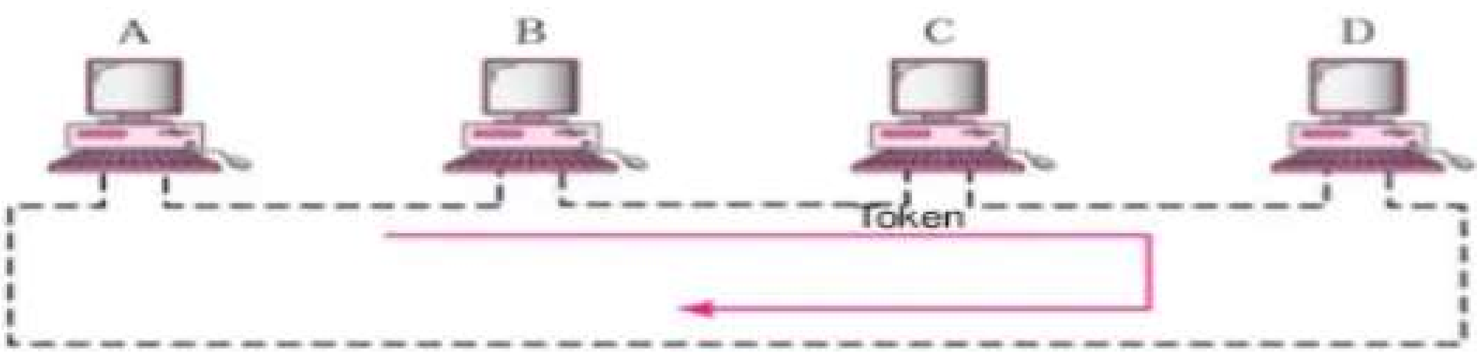
Figure *Select and poll functions in polling-access method*



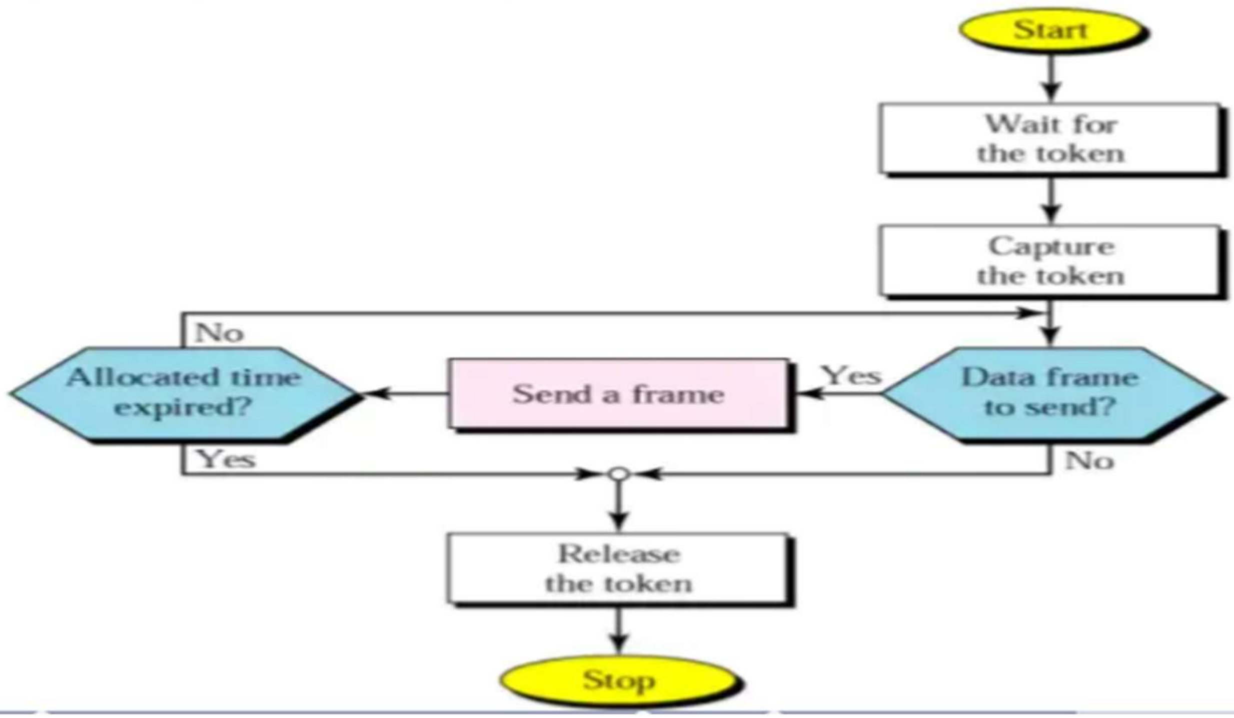
[Behrouz A Forouzan, Firouz Mosharraf, "Computer Networks: A top down Approach", McGraw Hill Education]

iii) **Token passing:**

- the stations are connected logically to each other in form of ring and access of stations is governed by tokens.
- A token is a special bit pattern or a small message, which circulate from one station to the next in the some predefined order.
- The possession of the token gives the station the right to access the channel and send its data.
- When a station has some data to send, it waits until it receives the token from its predecessor. It then holds the token and sends its data.
- When the station has no more data to send, it releases the token, passing it to the next logical station in the ring.
- If a node fails then it may affect the entire system.



TOKEN PASSING FLOW CHART :



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Channel Partitioning Protocols

- TDMA
- FDMA
- CDMA

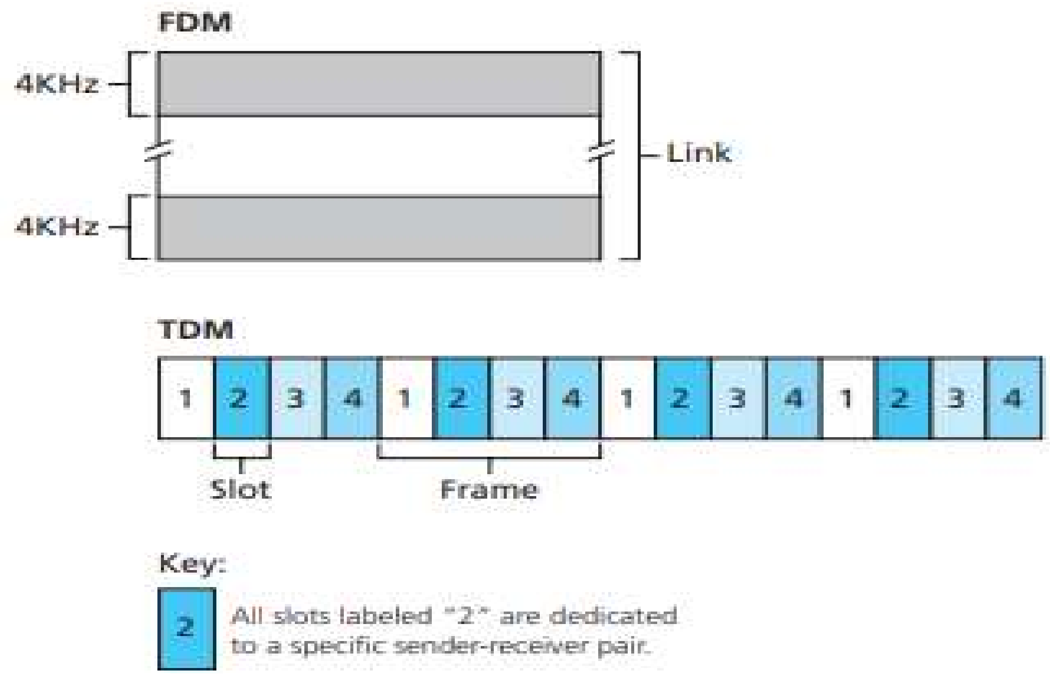


Figure 5.9 ♦ A four-node TDM and FDM example

James F Kurose and Keith W Ross, “Computer Networking: A Top - Down Approach”, Pearson Education; 6 th Edition (2017)

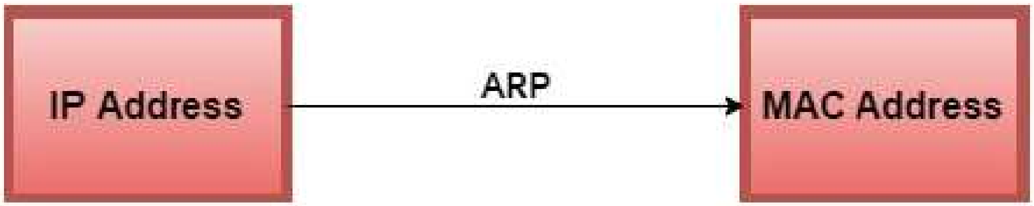
Channel Partitioning Protocols

CDMA

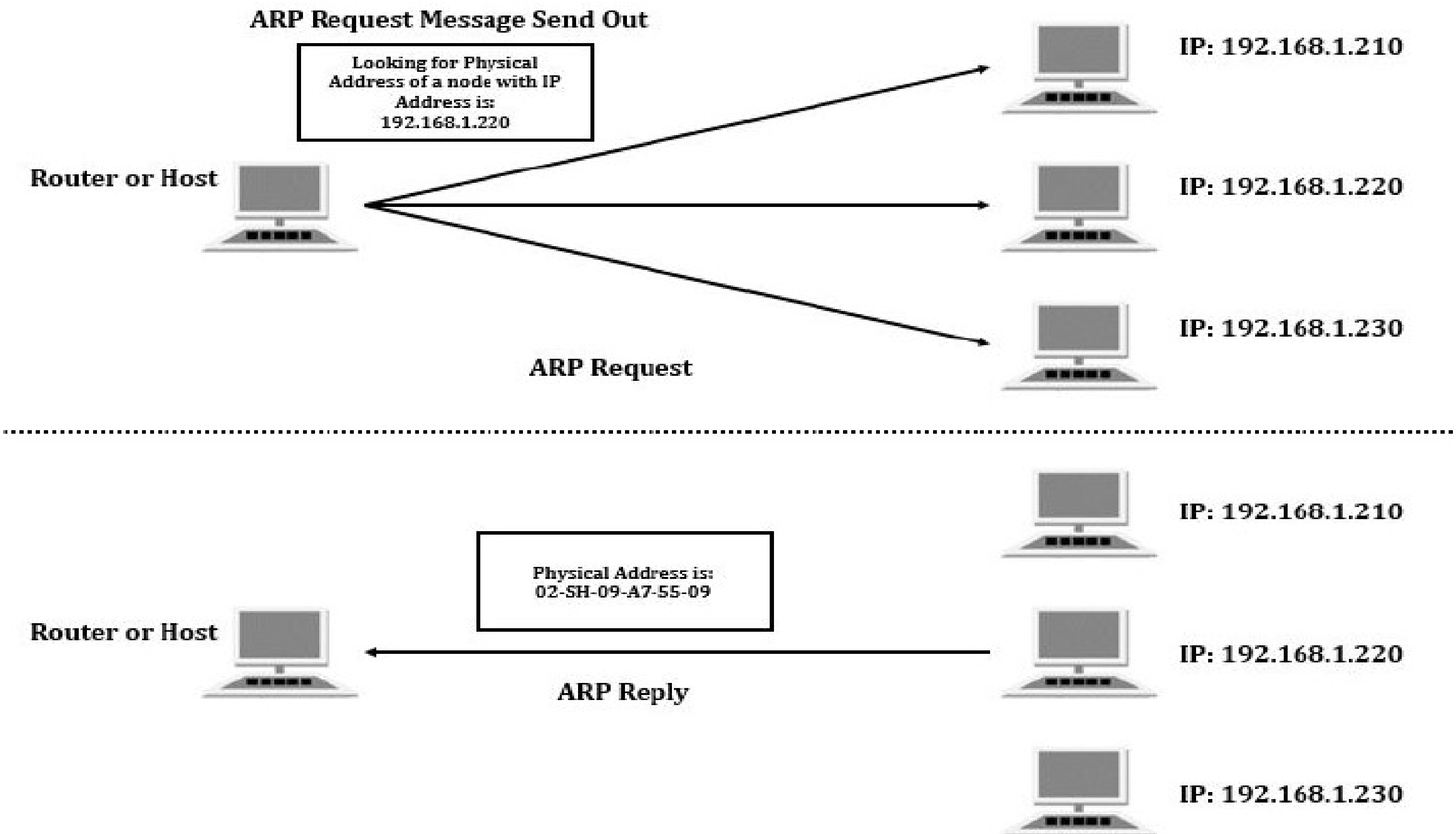
- A third channel partitioning protocol is code division multiple access (CDMA).
- While TDM and FDM assign time slots and frequencies, respectively, to the nodes, CDMA assigns a different code to each node.
- Each node then uses its unique code to encode the data bits it sends.
- Different nodes can transmit simultaneously and the respective receivers correctly receive a sender’s encoded data bits (assuming the receiver knows the sender’s code) in spite of interfering transmissions by other nodes.

ADDRESS RESOLUTION PROTOCOL (ARP)

- It belongs to the OSI data link layer (Layer 2).
- Before a host can send any data, it must know the Layer 3 (IP) and Layer 2 (MAC) addresses to correctly construct a frame.
- ARP is used to dynamically learn the MAC address of a receiver, when the IP address is known.



- Each device on the network is having an ARP table which consists of different devices on the network.
- The entries in this table are dynamically added and removed.



ARP Request Message Send Out
Looking for Physical Address of a node with IP Address is: 192.168.1.220
Router or Host
IP: 192.168.1.210
IP: 192.168.1.220
IP: 192.168.1.230
ARP Request
Physical Address is: 02-SH-09-A7-55-09
Router or Host
IP: 192.168.1.210
IP: 192.168.1.220
IP: 192.168.1.230
ARP Reply

ARP

- If a node (A) wants to find out the MAC address of another node (B), it will broadcast an ARP request message containing B's IP address.
- All nodes on the network receives this message but only B responds to A with ARP response, giving its MAC address.
- Now A receives B's reply and updates its ARP table with B's MAC address.

MAC

- A link-layer address is variously called a LAN address, a physical address, or a MAC address.
- Link-layer addresses is MAC addresses.
- LANs (including Ethernet and 802.11 wireless LANs), the MAC address is 6 bytes long, giving 2^{48} possible MAC addresses.
- These 6-byte addresses are typically expressed in hexadecimal notation, with each byte of the address expressed as a pair of hexadecimal numbers.

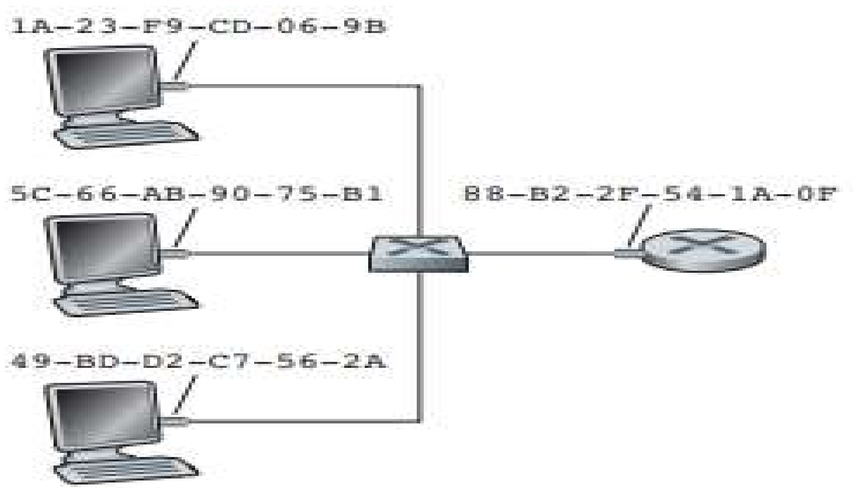


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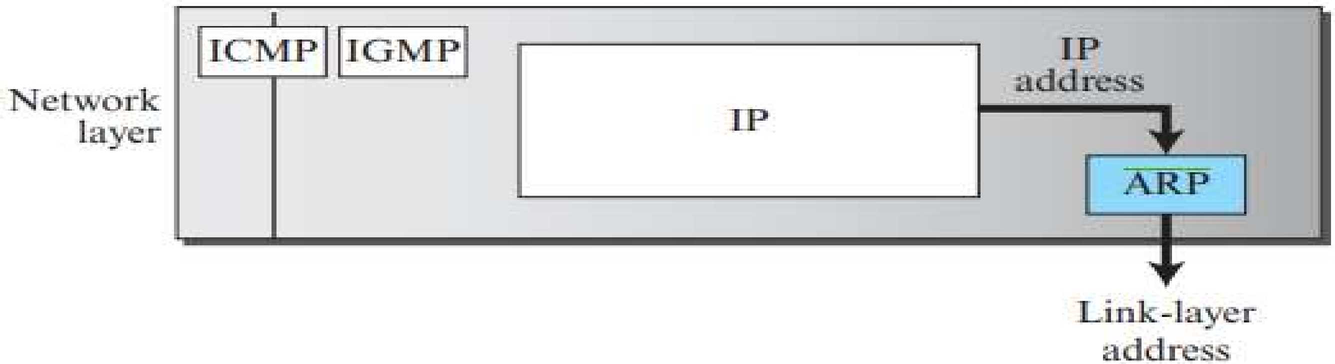
Figure 5.46 *Position of ARP in TCP/IP protocol suite*



[Behrouz A Forouzan, Firouz Mosharraf, "Computer Networks: A top down Approach", McGraw Hill Education]

- The ARP protocol is one of the auxiliary protocols.
- ARP accepts an IP address from the IP protocol, maps the address to the corresponding link-layer address, and passes it to the data-link layer.

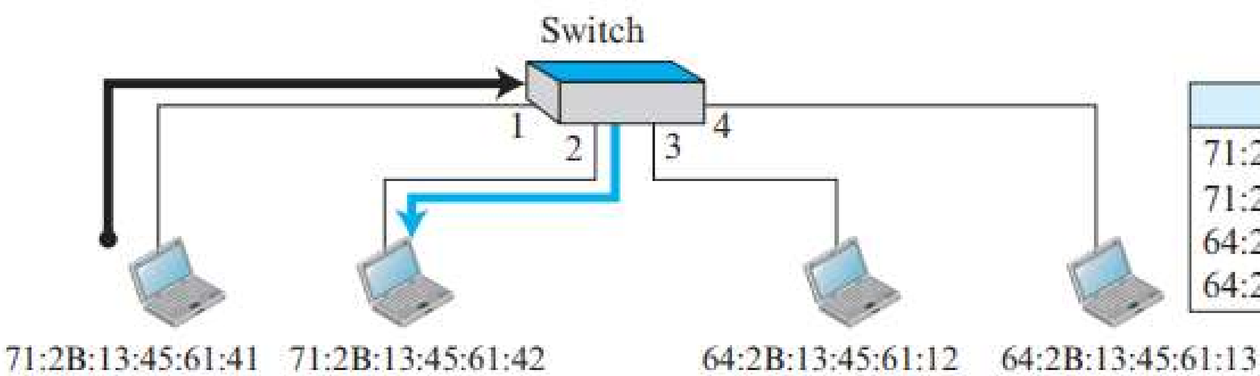
Ethernet Switch

- A link-layer switch operates in both the physical and the data-link layers.
- As a physical-layer device, it regenerates the signal it receives.
- As a link-layer device, the link-layer switch can check the MAC addresses (source and destination) contained in the frame.

Filtering:

- It can check the destination address of a frame and can decide through which outgoing port the frame should be sent.

Figure 5.85 *Link-Layer Switch*



Switching table

Address	Port
71:2B:13:45:61:41	1
71:2B:13:45:61:42	2
64:2B:13:45:61:12	3
64:2B:13:45:61:13	4

[Behrouz A Forouzan, Firouz Mosharraf, "Computer Networks: A top down Approach", McGraw Hill Education]

Transparent Switches:

- It is a switch in which the stations are completely unaware of the switch's existence.
- If a switch is added or deleted from the system, reconfiguration of the stations is unnecessary.

Learning:

- A learning switch uses a dynamic table that maps addresses to ports (interfaces) automatically.
- To make a table dynamic, we need a switch that gradually learns from the frame movements.
- To do this, the switch inspects both the destination and the source addresses.
- The destination address is used for the forwarding decision (table lookup); the source address is used for adding entries to the table and for updating purposes.

Figure 5.86 *Learning switch*

Gradual building of Table

Address	Port

a. Original

Address	Port
71:2B:13:45:61:41	1

b. After A sends a frame to D

Address	Port
71:2B:13:45:61:41	1
64:2B:13:45:61:13	4

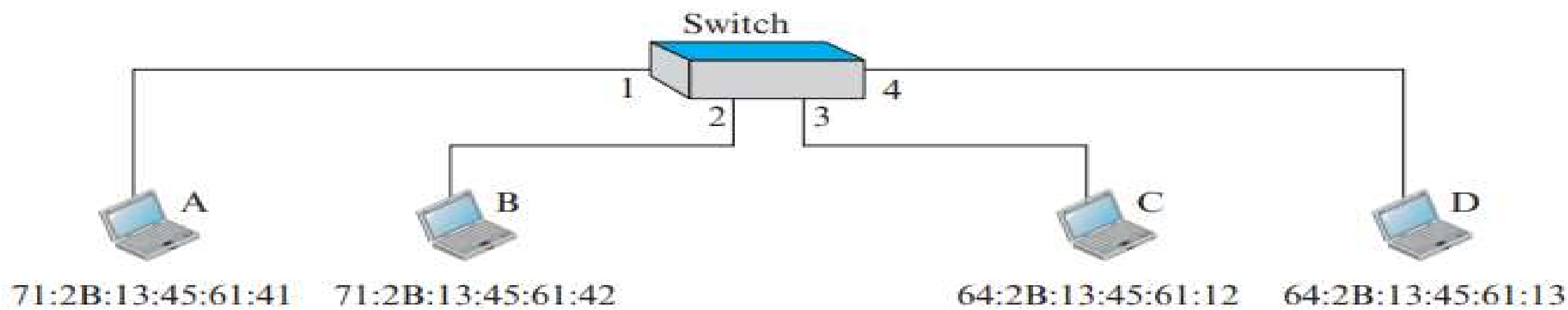
c. After D sends a frame to B

Address	Port
71:2B:13:45:61:41	1
64:2B:13:45:61:13	4
71:2B:13:45:61:42	2

d. After B sends a frame to A

Address	Port
71:2B:13:45:61:41	1
64:2B:13:45:61:13	4
71:2B:13:45:61:42	2
64:2B:13:45:61:12	3

e. After C sends a frame to D



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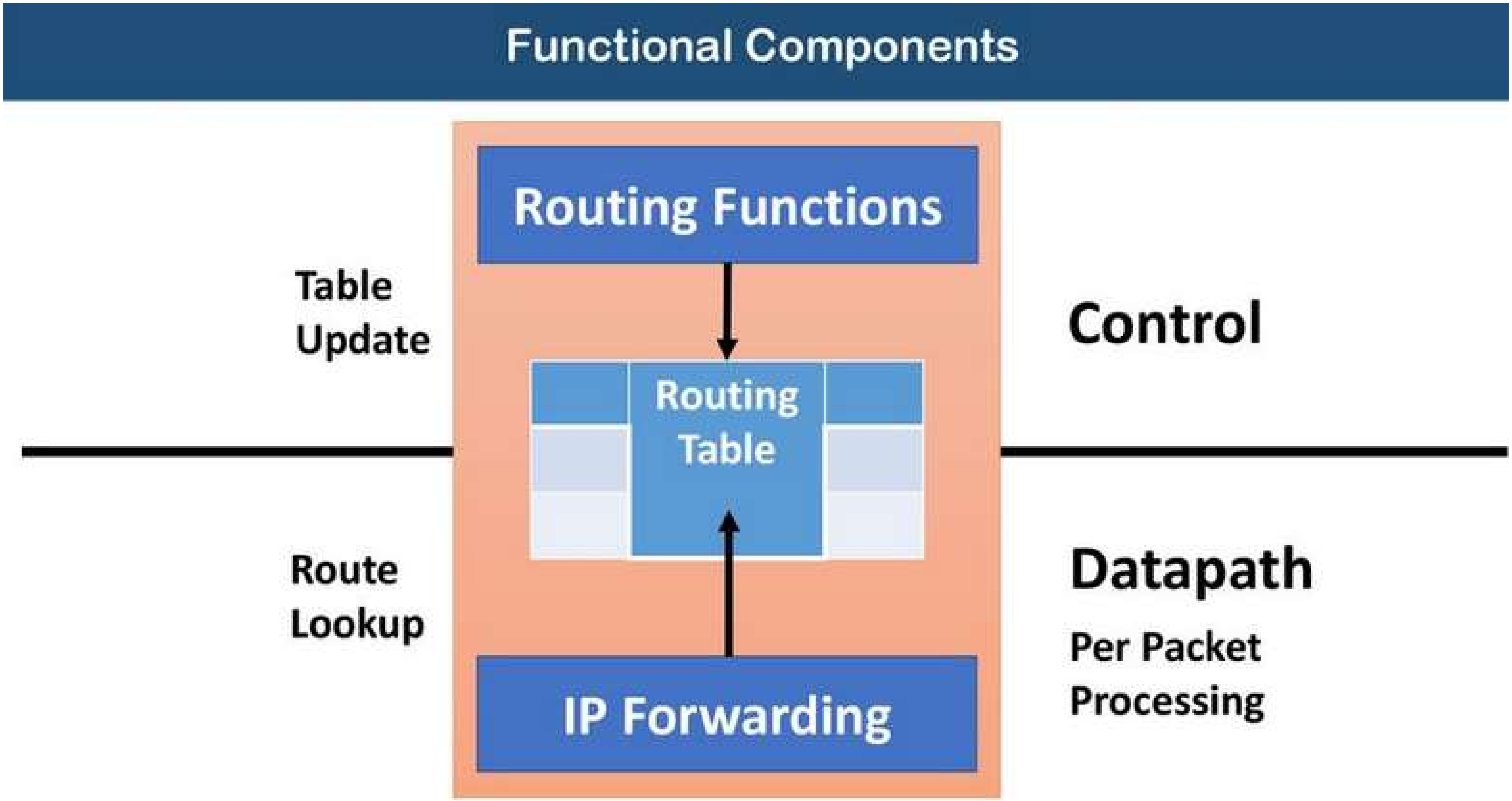
ROUTERS AND FIB (Forwarding Information Base)

Router Hardware

- Processor is responsible for control functions **(route processors)**
  - Construct the routing table based on the routing algorithm

- Forwarding is done at the interface card
  - Route match needs to be very fast
  - Specialized hardware – Ternary Content-Addressable Memory (TCAM)


Functional Components
Routing Functions
Table
Update
Routing
Table
Control
Datapath
Route
Lookup
Per Packet
Processing
IP Forwarding

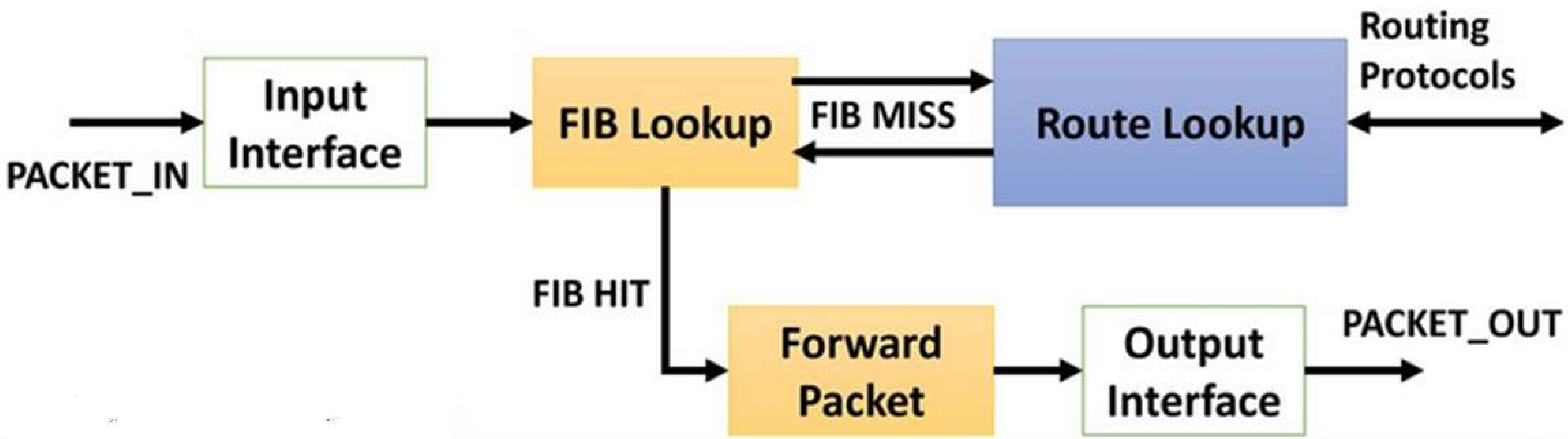
Routing Functions

- **Route Calculation**
- **Maintenance of the routing table**
- **Execution of the routing protocol**

- On commercial routers, routing functions are handled by a single general purpose processor, called the **route processor**

Forwarding Information Base (FIB)

- The interfaces maintains a *forwarding information base* (FIB) – a mapping from input interface to output interface
- A replica of the routing table used at the interfaces for making the forwarding decision

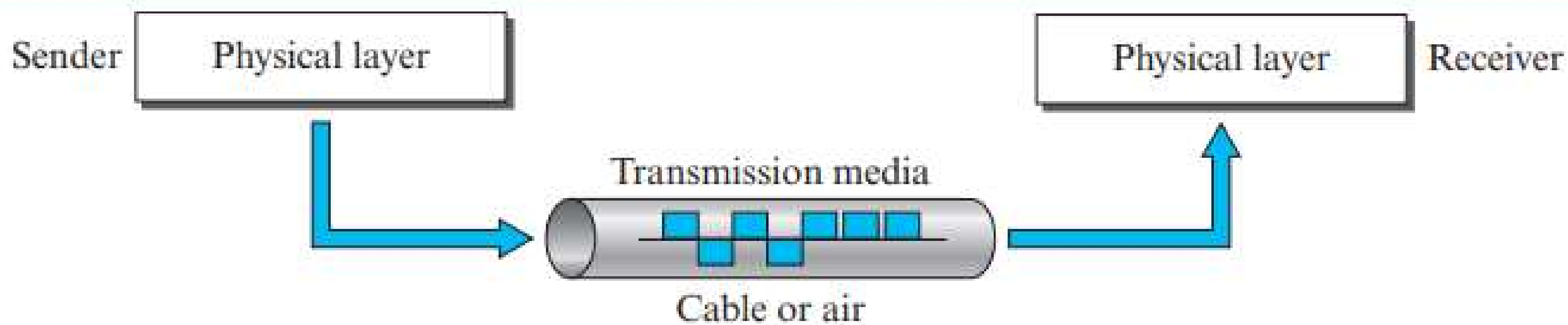


Difference between RIB and FIB

- **Routing Information Base (RIB)** – The routing table, implemented in software, is maintained at the control plane
- **Forwarding Information Base (FIB)** – The copy of the required routes maintained in interface TCAM hardware
- RIB is dynamic and maintains entire routing information, FIB is updated whenever required

TRANSMISSION MEDIA

Figure 7.58 *Transmission media and physical layer*



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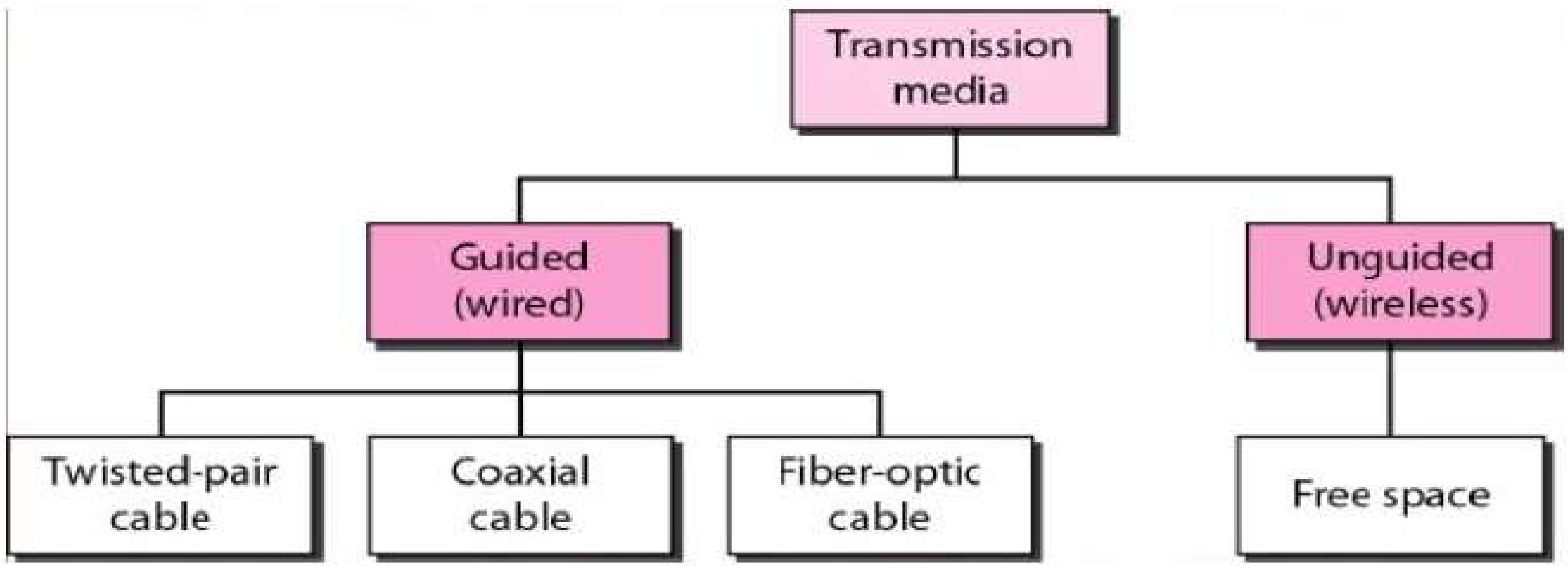
[See the slides Transmission media](#)



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DATA ENCODING

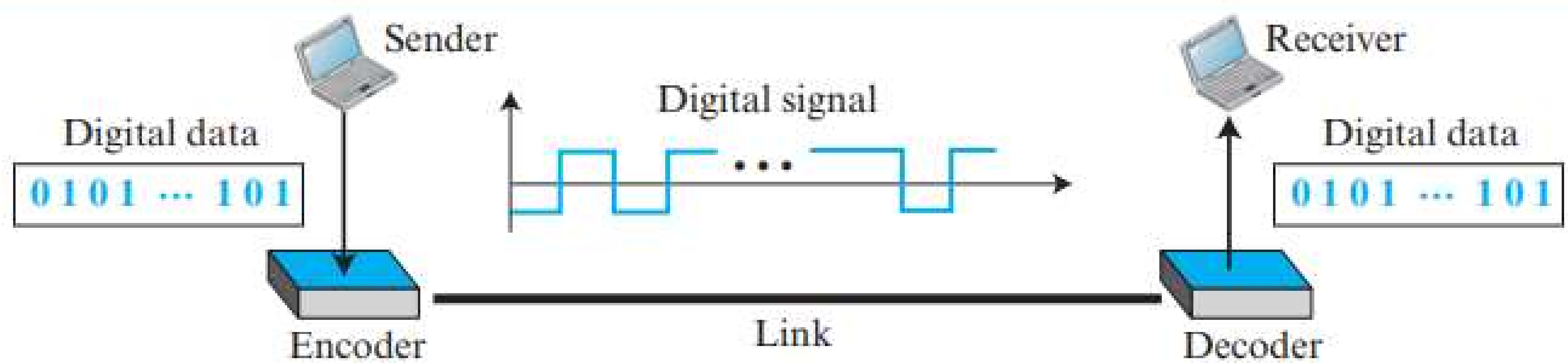
Digital Data, Analog Signals
Digital Data, Digital Signals
Analog Data, Digital Signals
Analog Data, Analog Signals

Digital-to-Digital Conversion

1. Digital-to-Digital Conversion

- Line Coding Line coding is the process of converting digital data to digital signals.
- Can divide common line coding schemes into three categories, polar, bipolar, and multilevel

Figure 7.19 *Line coding and decoding*



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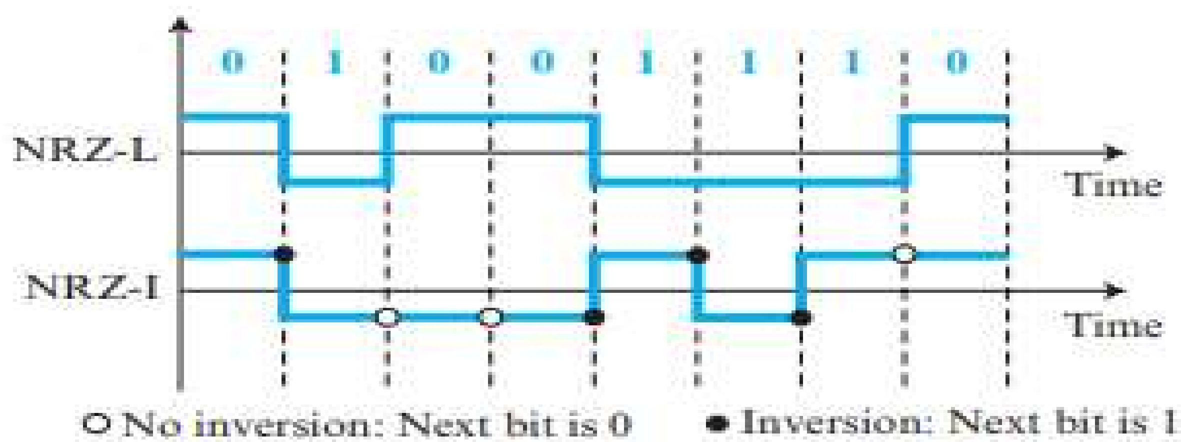
1. Digital-to-Digital Conversion

Polar Schemes

- In polar schemes, the voltage level oscillates between a positive value and a negative value although it may remain at zero level between the two values.

Figure 7.20 *Polar schemes*



- NRZ-L (NRZ-Level)
- NRZ-I (NRZ-Invert)

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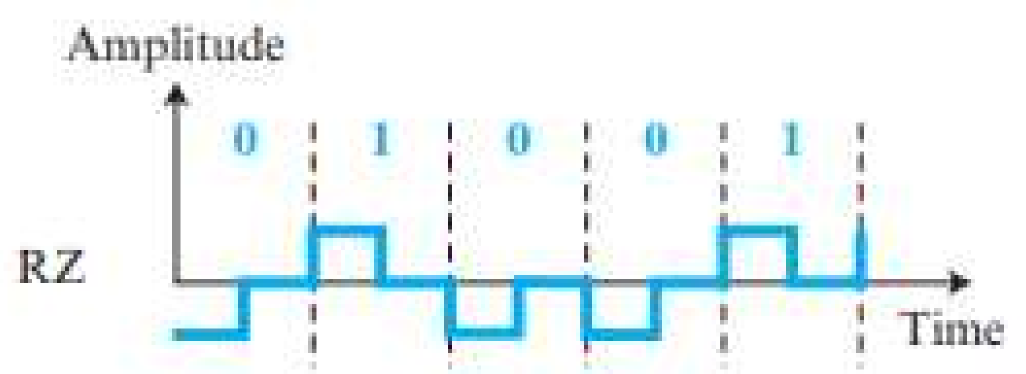
1. Digital-to-Digital Conversion

Polar Schemes

- The main problem with NRZ encoding occurs when the sender and receiver clocks are not synchronized.
- The receiver does not know when one bit has ended and the next bit is starting.
- One solution is the return-to-zero (RZ) scheme, which uses three values: positive, negative, and zero.



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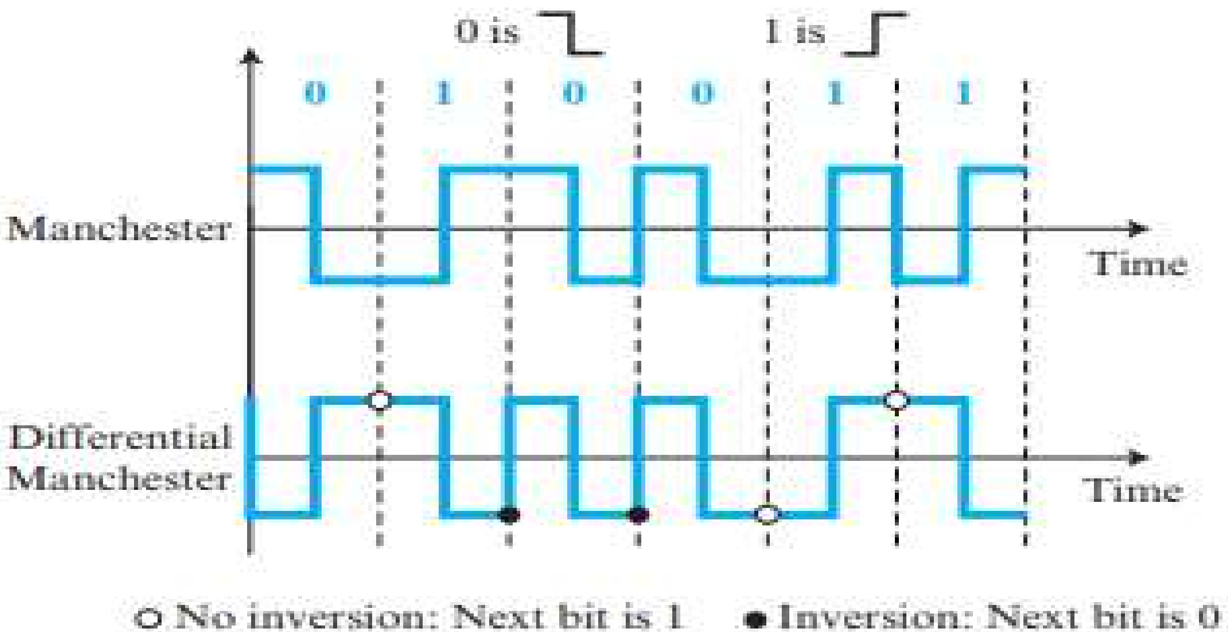
1. Digital-to-Digital Conversion

Polar Schemes

- The idea of RZ (transition at the middle of the bit) and the idea of NRZ-L are combined into the Manchester scheme
- Differential Manchester, combines the ideas of RZ and NRZ-I.



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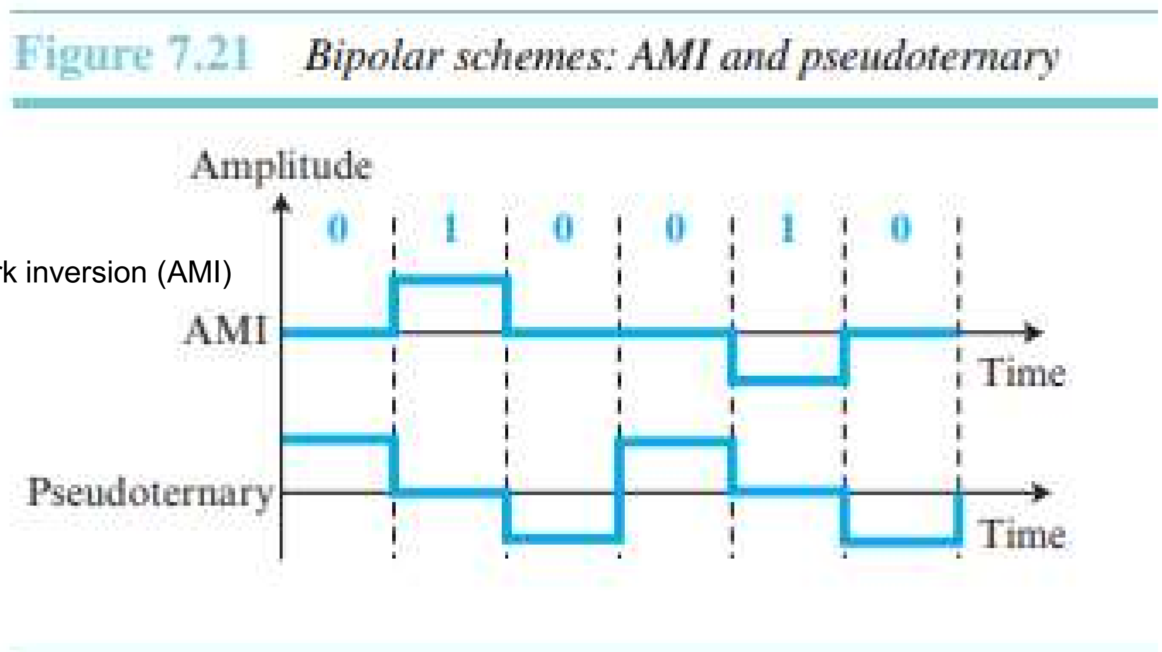
1. Digital-to-Digital Conversion

Bipolar Schemes

- In bipolar encoding (sometimes called multilevel binary) there are three voltage levels: positive, negative, and zero.

Alternate mark inversion (AMI)



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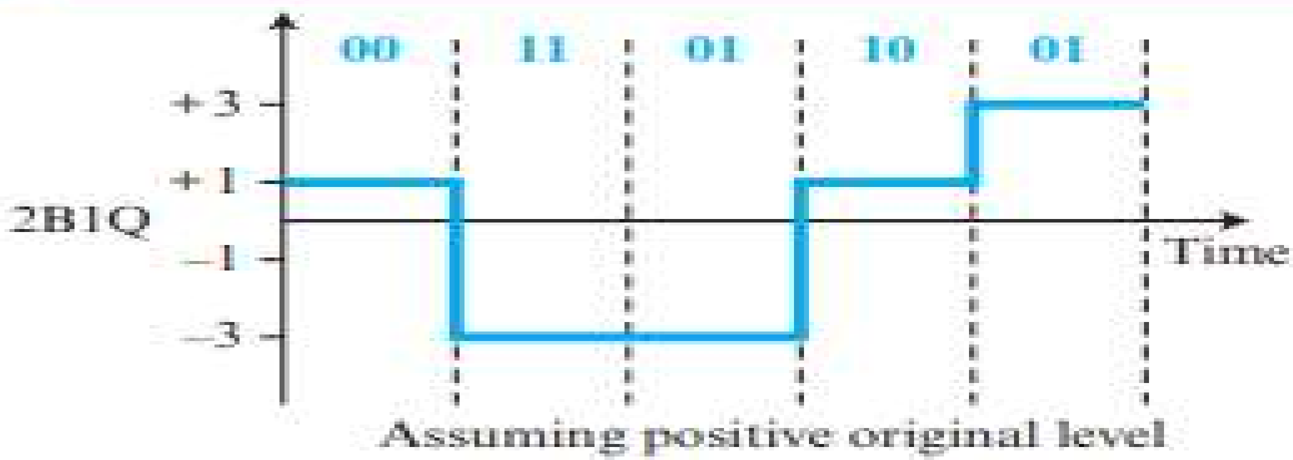
1. Digital-to-Digital Conversion

Multilevel Schemes

- The two binary, one quaternary (2B1Q) scheme uses data patterns of size 2 and encodes the 2-bit patterns as one signal element belonging to a four-level signal.
- In 2B1Q, encoding is +1, +3, −1, and −3 for the patterns 00, 01, 10, and 11.
- If the previous level is negative, the sign of the signal is inverted (−1, −3, +1, and +3).

Figure 7.22 *Multilevel: 2B1Q and 8B6T*



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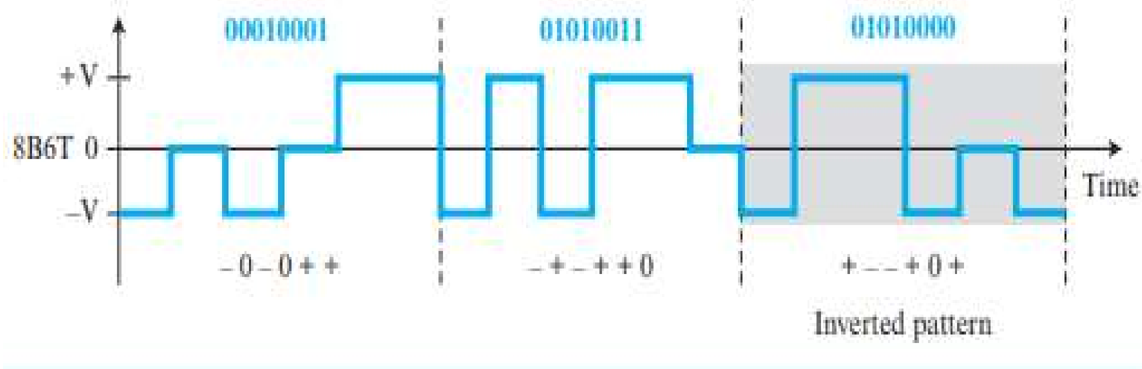
1. Digital-to-Digital Conversion

Multilevel Schemes

- Eight binary, six ternary (8B6T)
- The idea is to encode a pattern of 8 bits as a pattern of 6 signal elements, where the signal has three levels (ternary).
- In this type of scheme, we can have $2^8 = 256$ different data patterns and $3^6 = 729$ different signal patterns. There are $729 - 256 = 473$ redundant signal elements that provide synchronization and error detection.



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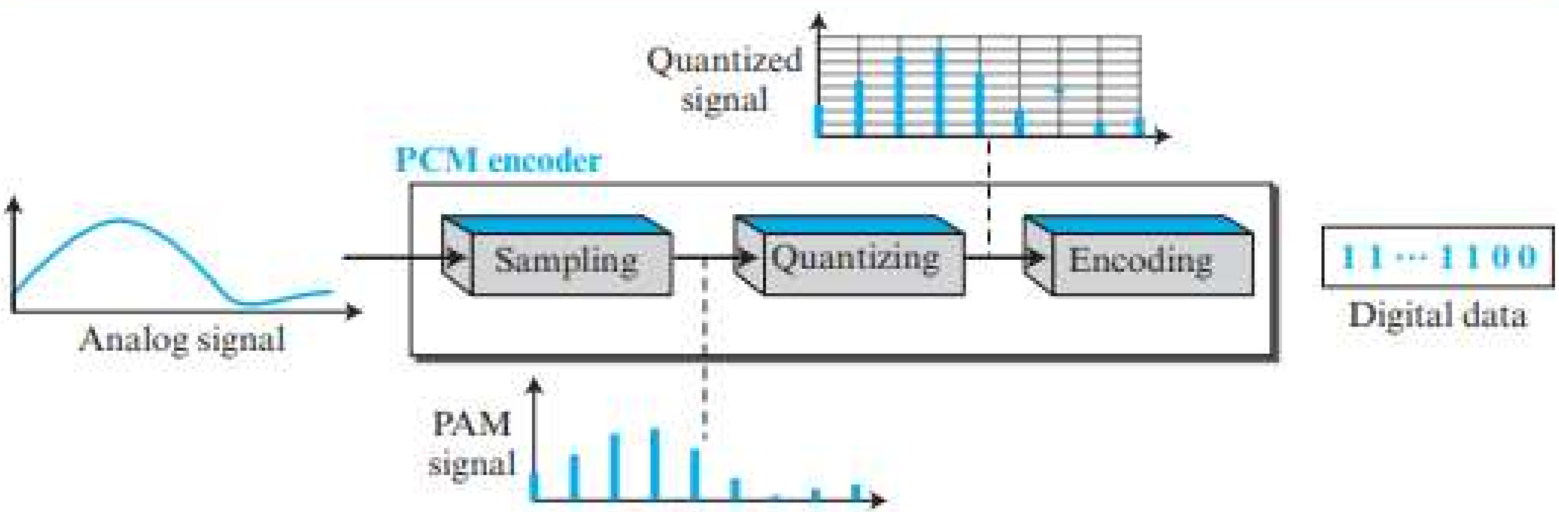
Analog-to-Digital Conversion

2. Analog-to-Digital Conversion

- The most common technique to change an analog signal to digital data (digitization) is called pulse code modulation (PCM).

Figure 7.29 *Components of PCM encoder*



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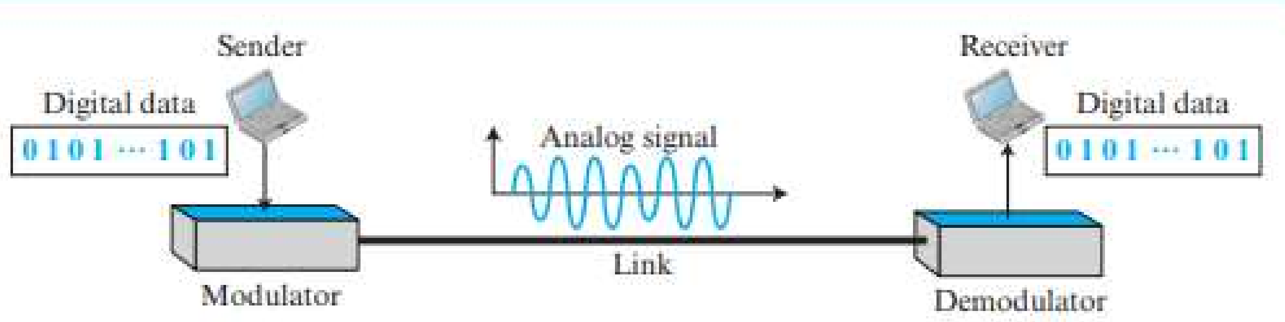
Digital-to-Analog Conversion

3. Digital-to-Analog Conversion

- Amplitude shift keying (ASK), frequency shift keying (FSK), and phase shift keying (PSK)
- In addition, there is a fourth (and better) mechanism that combines changing both the amplitude and phase, called quadrature amplitude modulation (QAM)

Figure 7.35 *Digital-to-analog conversion*



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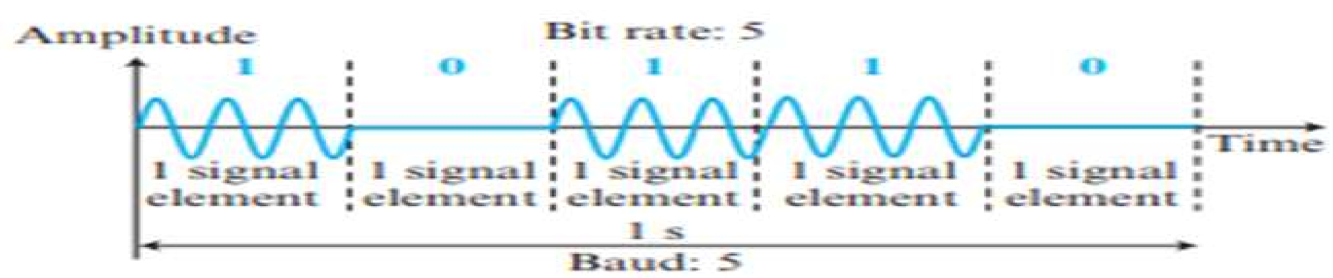
3. Digital-to-Analog Conversion

- Amplitude Shift Keying
- In amplitude shift keying, the amplitude of the carrier signal is varied to create signal elements. Both frequency and phase remain constant while the amplitude changes.
- Binary ASK (BASK)
- ASK is normally implemented using only two levels. This is referred to as binary amplitude shift keying or on-off keying (OOK)
- Multilevel ASK

Figure 7.36 *Binary amplitude shift keying*



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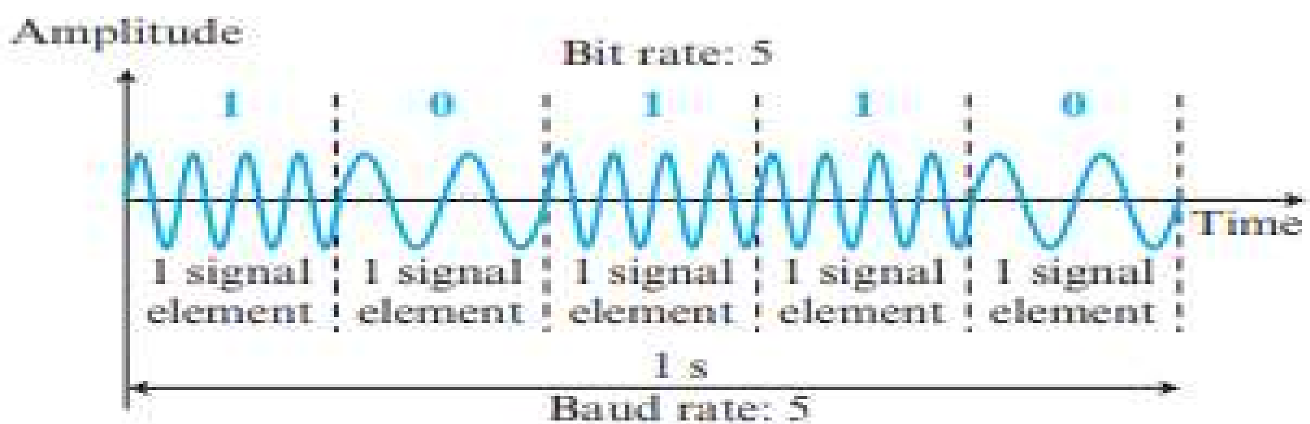
3. Digital-to-Analog Conversion

- Binary FSK (BFSK)
- Multilevel FSK

Figure 7.37 *Binary frequency shift keying*



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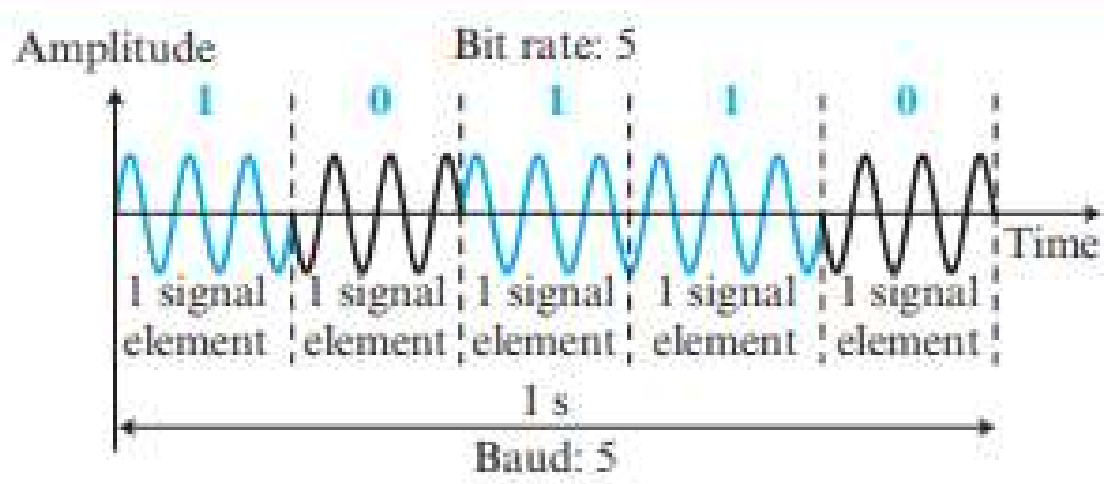
3. Digital-to-Analog Conversion

- Phase Shift Keying

In phase shift keying, the phase of the carrier is varied to represent two or more different signal elements

Figure 7.38 *Binary phase shift keying*



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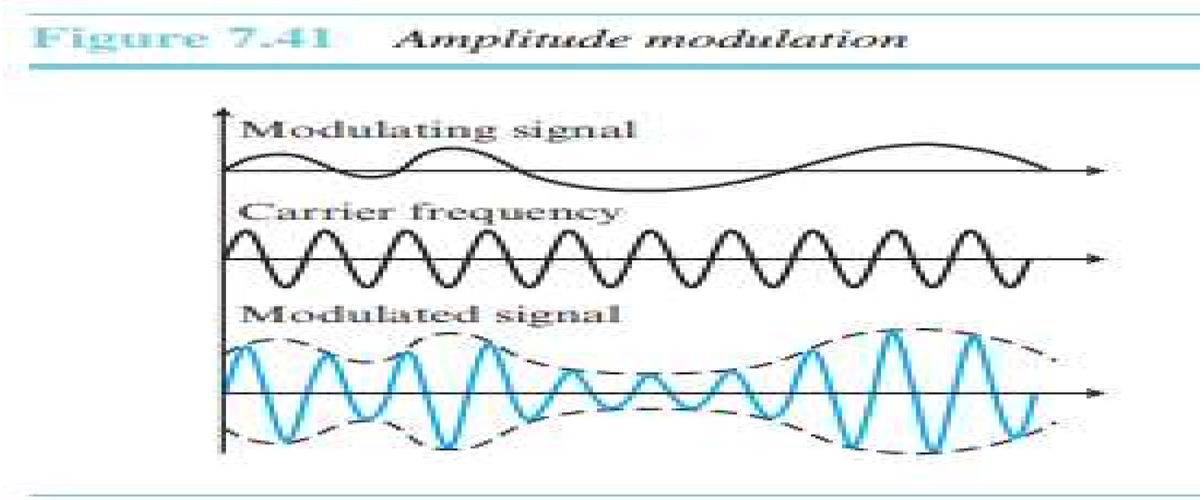
Analog-to-Analog Conversion

4. Analog-to-Analog Conversion

- Analog-to-analog conversion can be accomplished in three ways: amplitude modulation (AM), frequency modulation (FM), and phase modulation (PM).

Amplitude Modulation

- In AM transmission, the carrier signal is modulated so that its amplitude varies with the changing amplitudes of the modulating signal.



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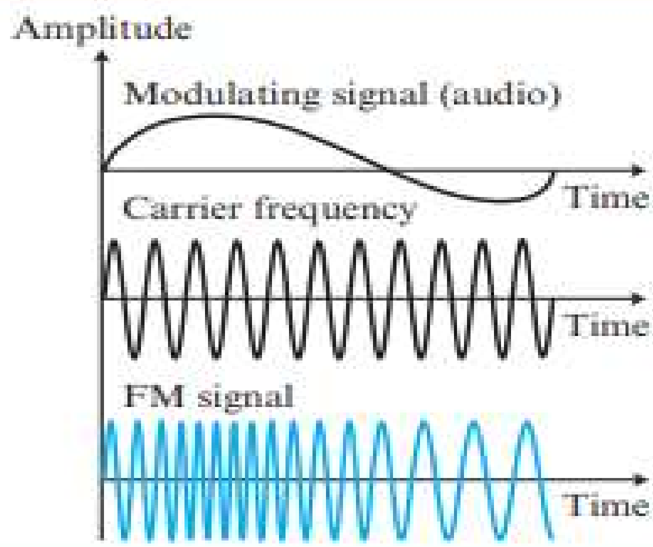
4. Analog-to-Analog Conversion

Frequency Modulation

- In FM transmission, the frequency of the carrier signal is modulated.

Figure 7.42 *Frequency modulation*



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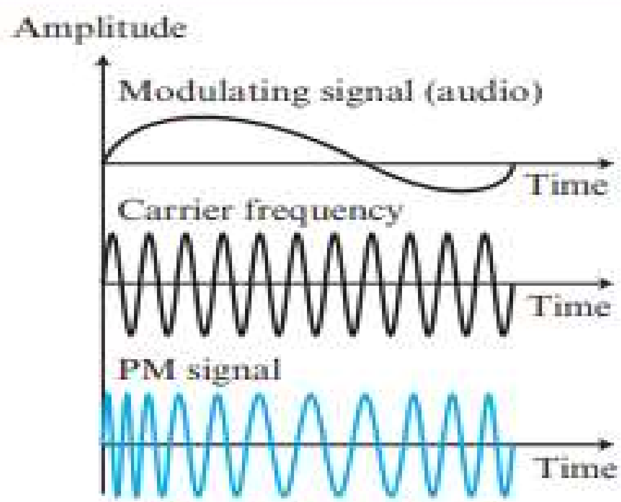
4. Analog-to-Analog Conversion

Phase Modulation

- In PM transmission, the phase of the carrier signal is modulated.

Figure 7.43 *Phase modulation*



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IEEE 802.3 standard for LAN
Ethernet

How the channel allocation protocols/ principles apply to real systems, in particular, in LANs ????

Ethernet

- IEEE has standardized a number of local area networks and metropolitan area networks under the name of IEEE 802.

- One of the most important one is 802.3 (for Ethernet)

  IEEE 802.3 standard is for a 1-persistent CSMA/CD LAN

- The terms "Ethernet" and "IEEE 802.3" are used interchangeably.

Ethernet Cabling

Name	Cable	Max. seg.	Nodes/seg.	Advantages
10Base5	Thick coax	500 m	100	Original cable; now obsolete
10Base2	Thin coax	185 m	30	No hub needed
10Base-T	Twisted pair	100 m	1024	Cheapest system
10Base-F	Fiber optics	2000 m	1024	Best between buildings

Figure 4.5. The most common kinds of Ethernet cabling

- **10Base5** cabling, popularly called **Thick Ethernet**
- **10Base2** is known as **Thin Ethernet**
- **10BaseT –** Twisted Pair. Different kind of wiring pattern, uses a **central hub**
- **10Base F –** Specially for Fiber**. E**xcellent noise immunity.

Ethernet Cabling

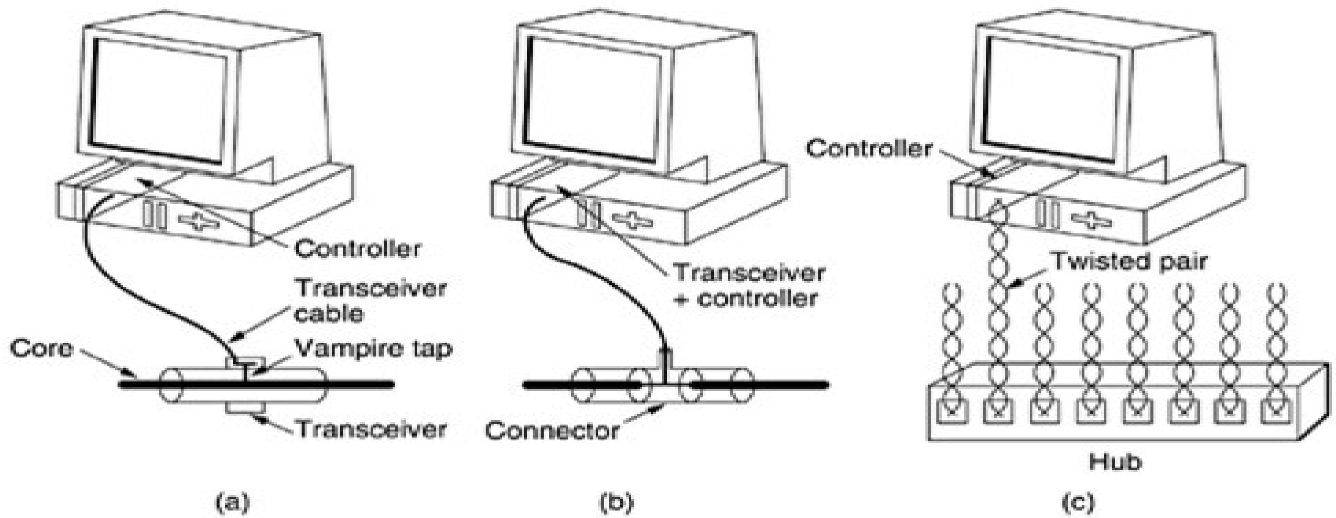


Figure 4.6. Three kinds of Ethernet cabling. (a) 10Base5. (b) 10Base2. (c) 10Base-T.

- **10Base5** – Vampire Taps are used
- **10Base2** uses BNC T-junction connector
- **10BaseT -** connected electrically to **central hub**

ETHERNET **Cable topologies**

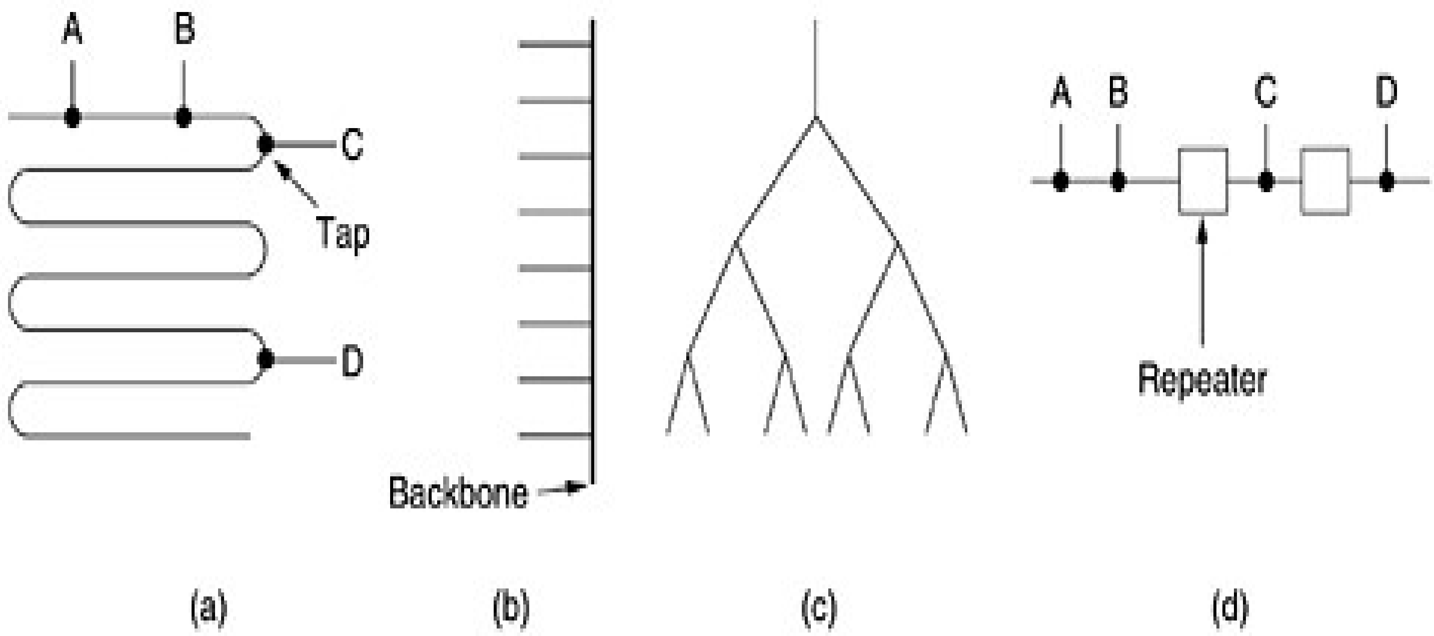
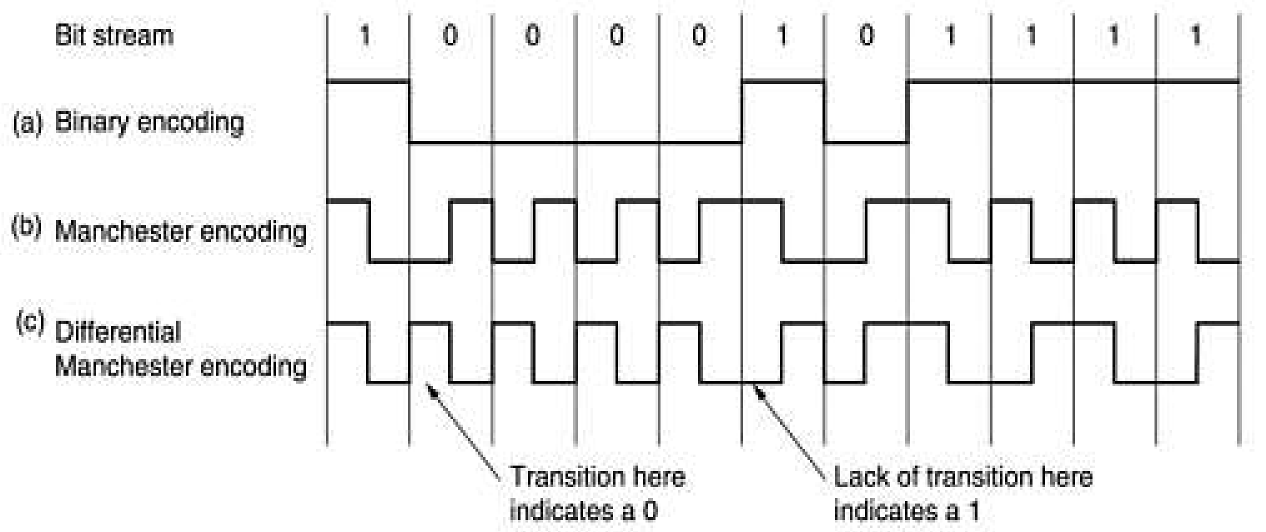


Figure 4.7. Cable topologies. (a) Linear. (b) Spine. (c) Tree. (d) Segmented.

Encoding Schemes

(a) Binary encoding. (b) Manchester encoding. (c) Differential Manchester encoding



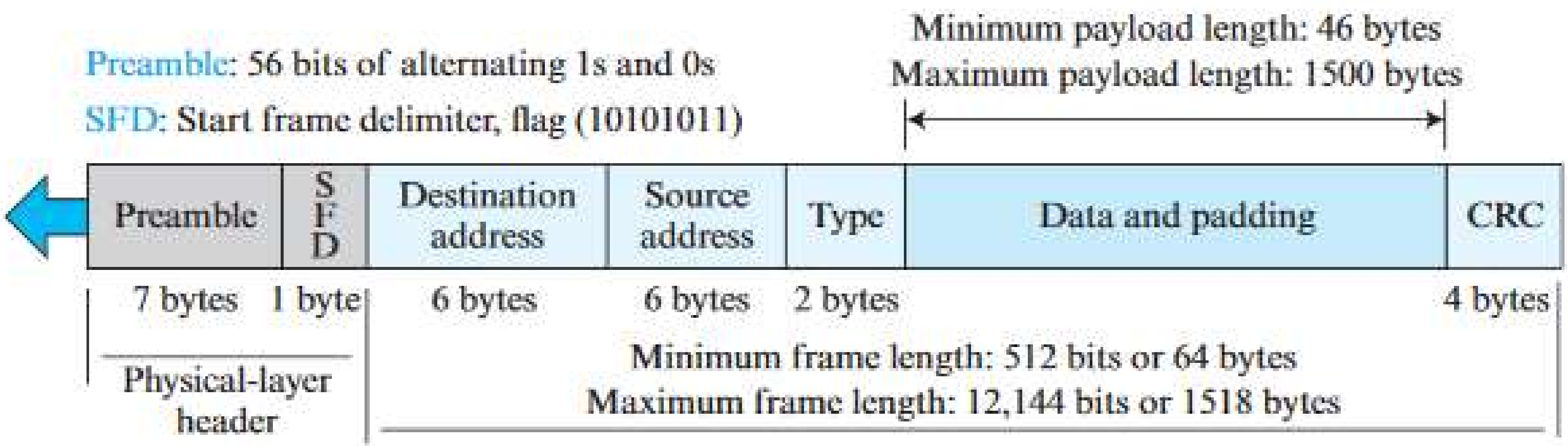
- Both Schemes : Transition at Middle
- Manchester: Binary 1 – High to Low and Binary 0 – Low to High
- Differential Manchester: Bit1 bit - Absence of a transition at the start of the interval and Bit 0- Presence of transition at beginning.

802.3 Frame Format

Frame Format

The Ethernet frame contains seven fields, as shown in Figure 5.55.

Figure 5.55 *Ethernet frame*



802.3 Frame Format

- Preamble.
  - The first field of the 802.3 frame
    - contains 7 bytes (56 bits) of alternating 0 s and 1 s
    - The pattern provides only an alert and a timing pulse.
      - alerts the receiving system to the coming frame
      - and enables it to synchronize its input timing.
    - The preamble is actually added at the physical layer and is not (formally) part of the frame.
- Start frame delimiter (SFD).
  - The second field (1 byte: 10101011) signals the beginning of the frame.
  - The SFD warns the station or stations that this is the last chance for synchronization.
  - The last 2 bits is 11 and alerts the receiver that the next field is the destination address.

- Destination address (DA).
  - The DA field is 6 bytes and contains the physical address of the destination station.
- Source address (SA).
  - The SA field is also 6 bytes and contains the physical address of the sender of the packet.
- Length or type.
  - This field is defined as a type field or length field.
  - The original Ethernet used this field as the type field to define the uppe layer protocol using the MAC frame.
  - The IEEE standard used it as the length field to define the number of bytes in the data field.
  - Both uses are common today.

- Data.
  - This field carries data encapsulated from the upper-layer protocols.
  - It is a minimum of 46 and a maximum of 1500 bytes.
- CRC.
  - The last field contains error detection information, in this case a CRC-32

Frame Length

- Ethernet has imposed restrictions on both the minimum and maximum lengths of a frame,
- as shown in Figure 13.5.
- The minimum length restriction is required for the correct operation of CSMA/CD
  - An Ethernet frame needs to have a minimum length of 512 bits or 64 bytes.
  - Part of this length is the header and the trailer.
  - If we count 18 bytes of header and trailer
    - 6 bytes of source address,
    - 6 bytes of destination address,
    - 2 bytes of length or type,
    - 4 bytes of CRC),
  - then the minimum length of data from the upper layer is 64 - 18 = 46 bytes.
  - If the upper-layer packet is less than 46 bytes, padding is added to make up the difference.

Frame Length

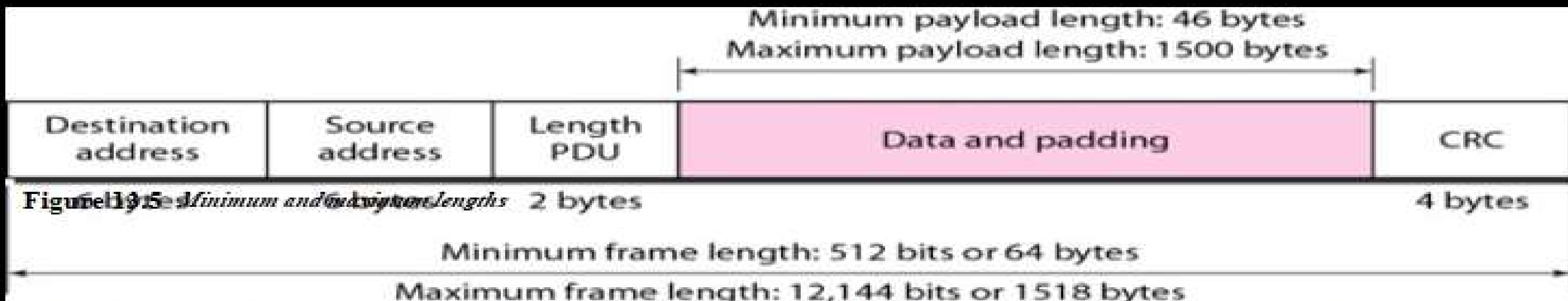


Figure 13.5 Minimum and maximum lengths

- The standard defines the maximum length of a framewithout) preamble and SFD (field as 1518.bytes
  - If we subtract the 18 bytes of header and ,trailer the maximum lengthof the payload is 1500.bytes
  - The maximum length restriction has two historical.reasons
  - ,First memory was very expensive when Ethernet was:designed
    - a maximum length restriction helped to reduce the size of the.buffer
  - ,Second the maximum length restrictionprevents
    - one station from monopolizing the shared,medium
    - blocking other stations that have data to.send

Minimum frame length: 64 bytes	**Minimum data length: 46 bytes**
Maximum frame length: 1518 bytes	**Maximum data length: 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 6-byte physical address.
- As shown in Figure 13.6, the Ethernet address is 6 bytes
- (48 bits), normally written in hexadecimal notation, with a colon between the bytes.

Figure 13.6 *Example of an Ethernet address in hexadecimal notation*

06 : 01 : 02 : 01 : 2C : 4B

6 bytes = 12 hex digits = 48 bits

Addressing

- Unicast, Multicast, and Broadcast Addresses
- A source address is always a unicast address
  - the frame comes from only one station.
  - The destination address, can be unicast, multicast, or broadcast.
  - Figure 13.7 shows how to distinguish a unicast address from a multicast address.
  - If the least significant bit of the first byte in a destination address is
    - 0, the address is unicast;
    - otherwise, it is multicast.

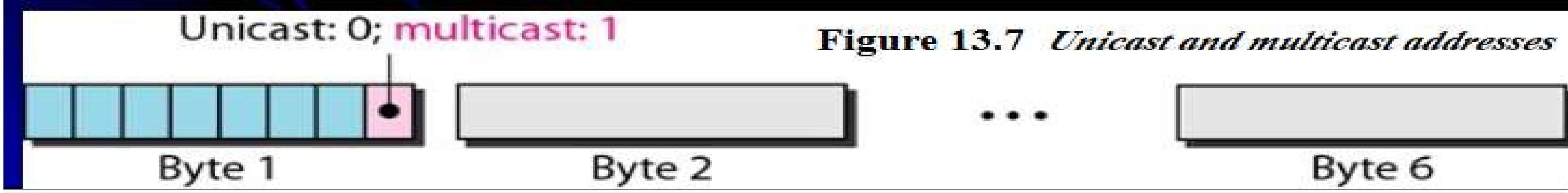


Figure 13.7 *Unicast and multicast addresses*

Addressing

- A unicast destination address defines only one recipient; the relationship between the sender and the receiver is one-to-one.
- A multicast destination address defines a group of addresses; the relationship between the sender and the receivers is one-to-many.
- The broadcast address is a special case of the multicast address; the recipients are all the stations on the LAN. A broadcast destination address is forty-eight 1s.

Example 13.1

- Define the type of the following destination addresses:
  a. 4A:30:10:21:10:IA
  b. 47:20:1B:2E:08:EE
  c. FF:FF:FF:FF:FF:FF

Unicast, Multicast, and Broadcast Addresses

Solution

- we need to look at the second hexadecimal digit from the left.
  - If it is even, the address is unicast.
  - If it is odd, the address is multicast.
  - If all digits are F's, the address is broadcast.
- Therefore, we have the following:

  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 F's.
- The way the addresses are sent out on line is different from the way they are written in hexadecimal notation. The transmission is left-to-right, byte by byte; however, for each byte, the least significant bit is sent first and the most significant bit is sent last. This means that the bit that defines an address as unicast or multicast arrives first at the receiver.

Unicast, Multicast, and Broadcast Addresses

Example 13.2

- Show how the address 47:20:IB:2E:08:EE is sent out on line.

Solution

- 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:

11100010 00000100 11011000 01110100 00010000 01110111

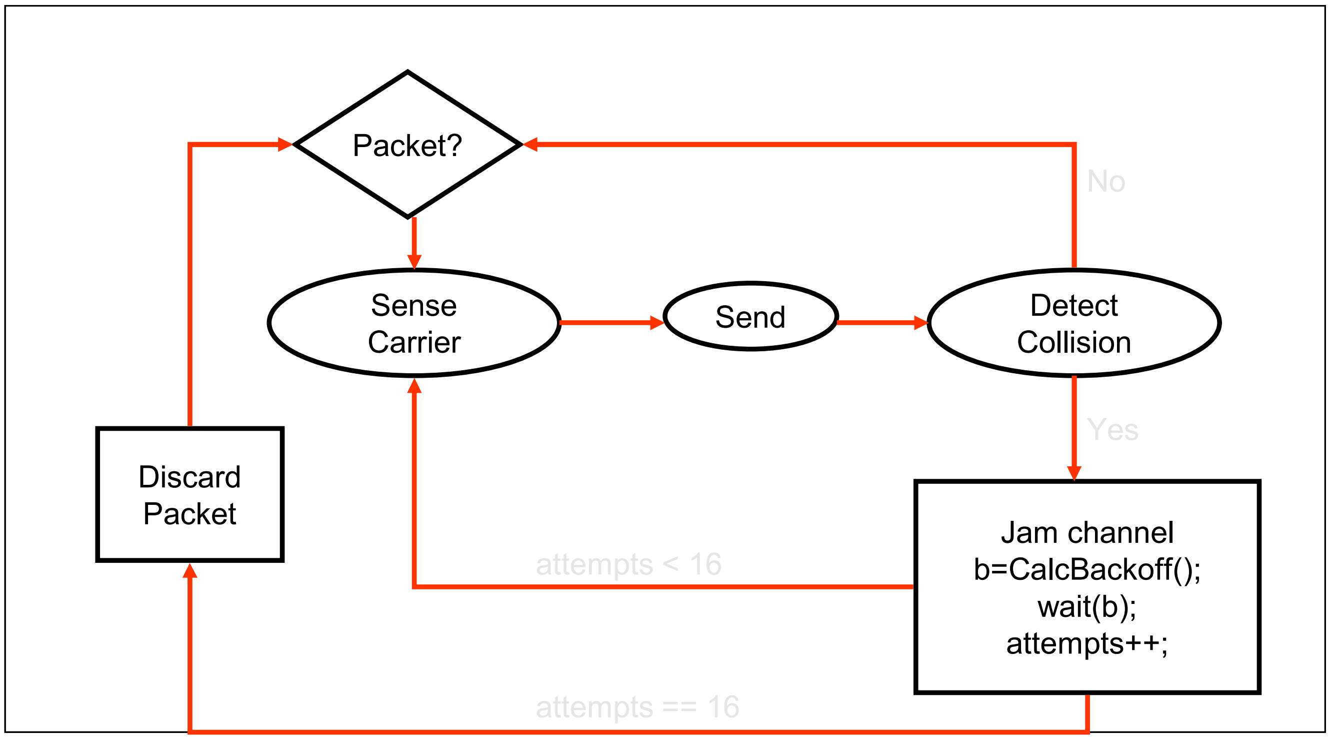
The least significant bit of the first byte defines the type of address.
If the bit is 0, the address is unicast; otherwise, it is multicast.

The broadcast destination address is a special case of the multicast address in which all bits are 1s.

The Binary Exponential Back-off Algorithm

- Randomization is done using this algorithm when a collision occurs.
- After the first collision, each station waits either 0 or 1 slot times before trying again.
- If two stations collide and each one picks the same random number, they will collide again.
- After the second collision, each one picks either 0, 1, 2, or 3 at random and waits that number of slot times.
- In general, after i collisions, a random number between 0 and $2^i - 1$ is chosen, and that number of slots is skipped.
- After 16 collisions, the controller reports failure back to the computer. Further recovery is up to higher layers

The Binary Exponential Back-off Algorithm - State Diagram



Fast Ethernet

- To pump up the speed, various industry groups proposed two new ring-based optical LANs.
  - FDDI (Fiber Distributed Data Interface)
  - Fibre Channel

BOTH ARE FAILURES!!!

Fast Ethernet, 802.3u

- Basic idea: keep all the old frame formats, interfaces, and procedural rules, but just reduce the bit time from 100 nsec to 10 nsec (increase speed).

Gigabit Ethernet

- Ratified by IEEE in 1998 under the name 802.3z.
- Gigabit Ethernet had to offer
  - unacknowledged datagram service with both unicast and multicast
  - use the same 48-bit addressing scheme already in use.
  - maintain the same frame format, including the minimum and maximum frame sizes.
- All configurations of gigabit Ethernet are point-to-point rather than multidrop as in the original 10 Mbps standard, now honoured as classic Ethernet.

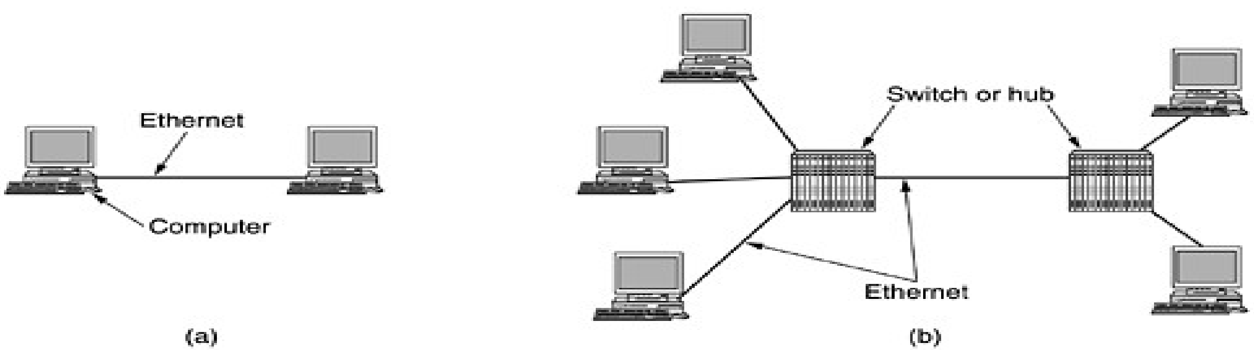


Figure 4.9. (a) A two-station Ethernet. (b) A multistation Ethernet

Gigabit Ethernet

- Two different modes of operation:
  - Full-duplex mode
  - Half-duplex mode.

- The "normal" mode is full-duplex mode, which allows traffic in both directions at the same time. Since no contention is possible, the CSMA/CD protocol is not used.

- Half-duplex is used when the computers are connected to a hub rather than a switch. In this mode, collisions are possible, so the standard CSMA/CD protocol is required.

Gigabit Ethernet

- The 802.3z committee considered a radius of 25 meters to be unacceptable and added two features to the standard to increase the radius.
- The first feature, called carrier extension, essentially tells the hardware to add its own padding after the normal frame to extend the frame to 512 bytes.
- The second feature, called frame bursting, allows a sender to transmit a concatenated sequence of multiple frames in a single transmission.

Name	Cable	Max. segment	Advantages
1000Base-SX	Fiber optics	550 m	Multimode fiber (50, 62.5 microns)
1000Base-LX	Fiber optics	5000 m	Single (10 µ) or multimode (50, 62.5 µ)
1000Base-CX	2 Pairs of STP	25 m	Shielded twisted pair
1000Base-T	4 Pairs of UTP	100 m	Standard category 5 UTP

Figure 4.10. Gigabit Ethernet cabling

Bridging and Switching

- Bridging and switching occur at the link layer, which controls data flow, handles transmission errors, provides physical (as opposed to logical) addressing, and manages access to the physical medium.
- Bridges and switches are not complicated devices. They analyze incoming frames, make forwarding decisions based on information contained in the frames, and forward the frames toward the destination.
- Bridges are capable of filtering frames based on any Layer 2 fields. For example, a bridge can be programmed to reject (not forward) all frames sourced from a particular network.

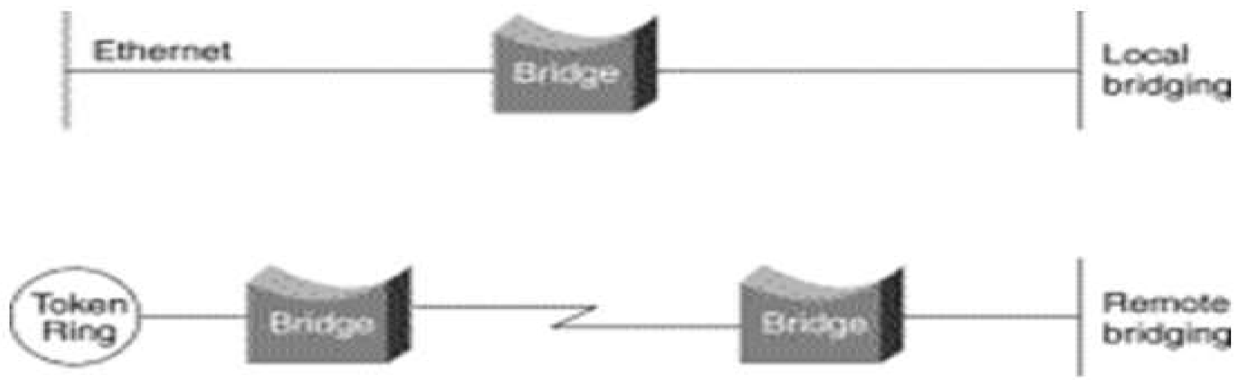
Bridging and Switching

- Bridges are generally used to segment a LAN into a couple of smaller segments. Switches are generally used to segment a large LAN into many smaller segments.
- Bridges generally have only a few ports for LAN connectivity, whereas switches generally have many.
- Switches can also be used to connect LANs with different media—for example, a 10-Mbps Ethernet LAN and a 100-Mbps Ethernet LAN can be connected using a switch.
- Some switches support cut-through switching, which reduces latency and delays in the network, while bridges support only store-and-forward traffic switching.
- Finally, switches reduce collisions on network segments because they provide dedicated bandwidth to each network segment.

Types of Bridges

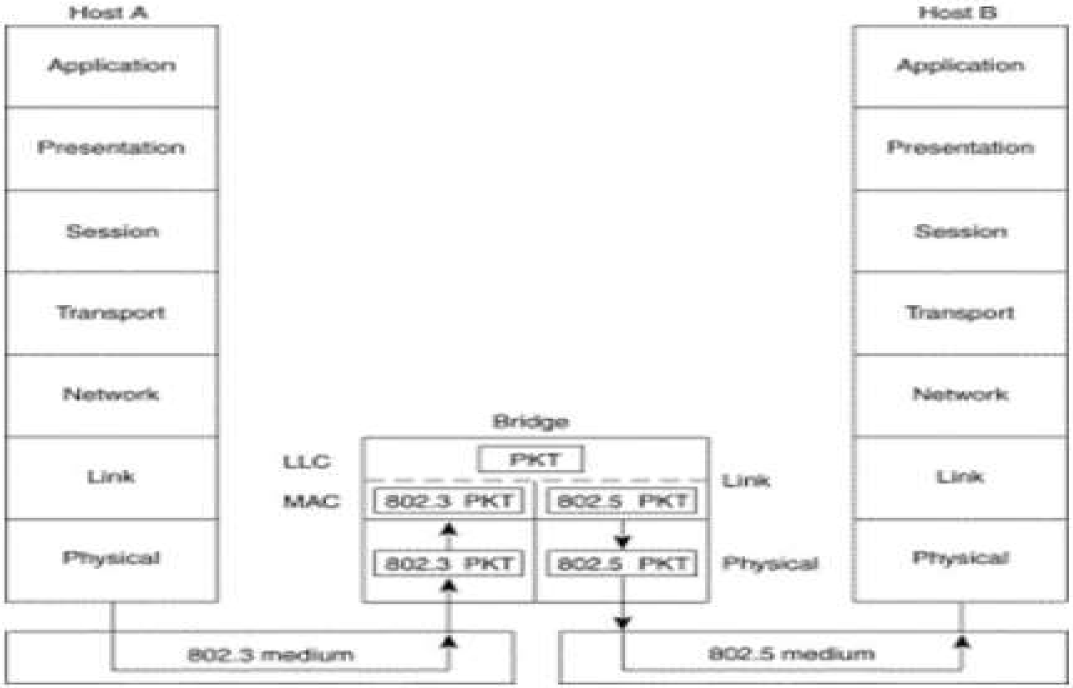
- *Local bridges* provide a direct connection between multiple LAN segments in the same area.
- *Remote bridges* connect multiple LAN segments in different areas, usually over telecommunications lines

Types of Bridges



.ocal and Remote Bridges Connect LAN Segments in Specific Areas

Bridges



switching

- Some bridges are *MAC-layer bridges*, which bridge between homogeneous networks (for example, IEEE 802.3 and IEEE 802.3),
- other bridges can translate between different link layer protocols (for example, IEEE 802.3 and IEEE 802.5).

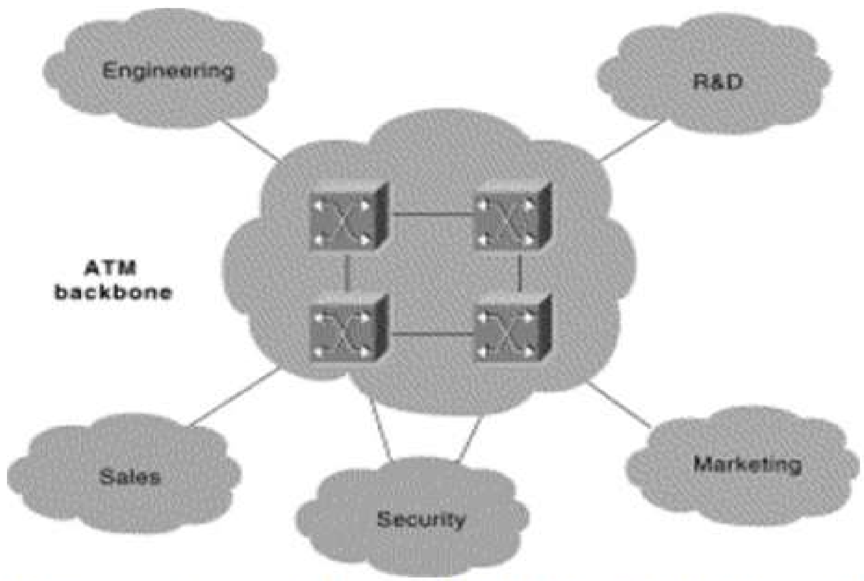
Types of Switches

- Switches can use different forwarding techniques—two of these are store-and-forward switching and cut-through switching.
- In *store-and-forward switching*, an entire frame must be received before it is forwarded.
- *Cut-through switching* allows the switch to begin forwarding the frame when enough of the frame is received to make a forwarding decision. This reduces the latency through the switch.
- Store-and-forward switching gives the switch the opportunity to evaluate the frame for errors before forwarding it.
- Cut-through switching does not offer this advantage, so the switch might forward frames containing errors.

ATM Switch

- *Asynchronous Transfer Mode (ATM) switches* provide high-speed switching and scalable bandwidths in the workgroup, the enterprise network backbone, and the wide area.
- ATM switches support voice, video, and data applications, and are designed to switch fixed-size information units called cells

ATM Switch



Multi-LAN Networks Can Use an ATM-Based Backbone When Switching Cells

LAN Switch

- *LAN switches* are used to interconnect multiple LAN segments.
- LAN switching provides dedicated, collision-free communication between network devices, with support for multiple simultaneous conversations.
- LAN switches are designed to switch data frames at high speeds.

TRANSMISSION MEDIA

Transmission Media

- The purpose of the physical layer is to transport a raw bit stream from one machine to another.

- Each one has its own position in terms of bandwidth, delay, cost, and ease of installation and maintenance.

- Media are roughly grouped into guided media, such as copper wire and fiber optics, and unguided media, such as radio and lasers through the air.

Guided Transmission Media

1. Magnetic Media
2. Twisted Pair
3. Coaxial Cable
4. Fiber Optics

1. Magnetic Media

- Magnetic tape or removable media (e.g., recordable DVDs), physically transport the tape or disks to the destination machine, and read them back in again.
- More cost effective, especially for applications in which high bandwidth or cost per bit transported is the key factor.
- Never underestimate the bandwidth of a station wagon full of tapes hurtling down the highway.

2. Twisted Pair

- Bandwidth characteristics of magnetic tape are excellent, the delay characteristics are poor.
- Transmission time is measured in minutes or hours, not milliseconds.
- One of the oldest and still most common transmission media is twisted pair.
- A twisted pair consists of two insulated copper wires, typically about 1 mm thick.
- Twisting is done because two parallel wires constitute a fine antenna. When the wires are twisted, the waves from different twists cancel out, so the wire radiates less effectively.
- Most common application of the twisted pair is the telephone system.

Twisted Pair

- Twisted pairs can run several kilometers without amplification, but for longer distances, repeaters are needed.
- Twisted pairs can be used for transmitting either analog or digital signals.
- The bandwidth depends on the thickness of the wire and the distance travelled, but several megabits/sec can be achieved for a few kilometres in many cases.
- Due to their adequate performance and low cost, twisted pairs are widely used and are likely to remain so for years to come.

Figure 1.15. (a) Category 3 UTP. (b) Category 5 UTP.

3. Coaxial Cable

- Another common transmission medium is the coaxial cable (known to be as just ''coax'' and pronounced ''co-ax'').

- It has better shielding than twisted pairs, so it can span longer distances at higher speeds.

- Two kinds of coaxial cable are widely used.
  - One kind, 50-ohm cable, is commonly used when it is intended for digital transmission from the start.
  - The other kind, 75-ohm cable, is commonly used for analog transmission and cable television but is becoming more important with the advent of Internet over cable.

Coaxial Cable

- A coaxial cable consists of a stiff copper wire as the core, surrounded by an insulating material.
- The insulator is encased by a cylindrical conductor, often as a closely-woven braided mesh.
- The outer conductor is covered in a protective plastic sheath.
- The construction and shielding of the coaxial cable give it a good combination of high bandwidth and excellent noise immunity.

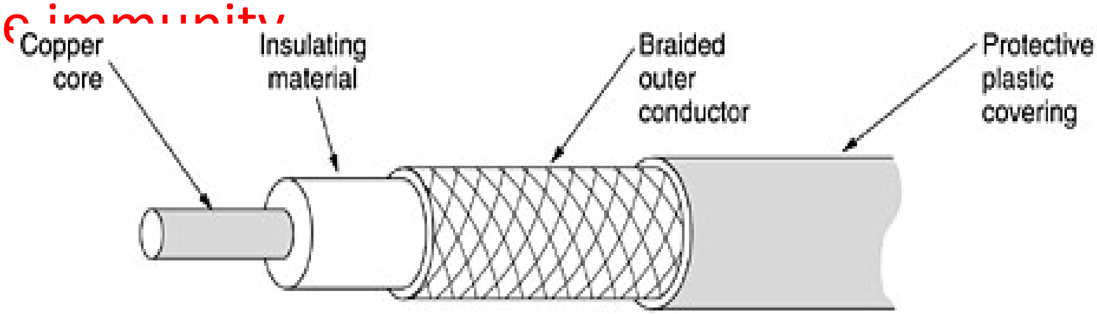


Figure 1.16. A coaxial cable.

Coaxial Cable

- The bandwidth possible depends on the cable quality, length, and signal-to-noise ratio of the data signal.
- Modern cables have a bandwidth of close to 1 GHz.
- Coaxial cables used to be widely used within the telephone system for long-distance lines but have now largely been replaced by fiber optics on long-haul routes.
- Coax is still widely used for cable television and metropolitan area networks.

4. Fiber Optics

- An optical transmission system has three key components: the light source, the transmission medium, and the detector.
- A pulse of light indicates a 1 bit and the absence of light indicates a 0 bit. Two kinds of light sources are used to do the signalling, Light Emitting Diodes and semiconductor lasers.
- The transmission medium is an ultra-thin fiber of glass.
- The detector generates an electrical pulse when light falls on it.
- By attaching a light source to one end of an optical fiber and a detector to the other, we have a unidirectional data transmission system that accepts an electrical signal, converts and transmits it by light pulses, and then reconverts the output to an electrical signal at the receiving end.

Fiber Optics

- The amount of refraction depends on the properties of the two media (in particular, their indices of refraction).
- Angles of incidence above a certain critical value, the light is refracted back into the silica; none of it escapes into the air.
- A light ray incident at or above the critical angle is trapped inside the fiber and can propagate for many kilometers with virtually no loss.

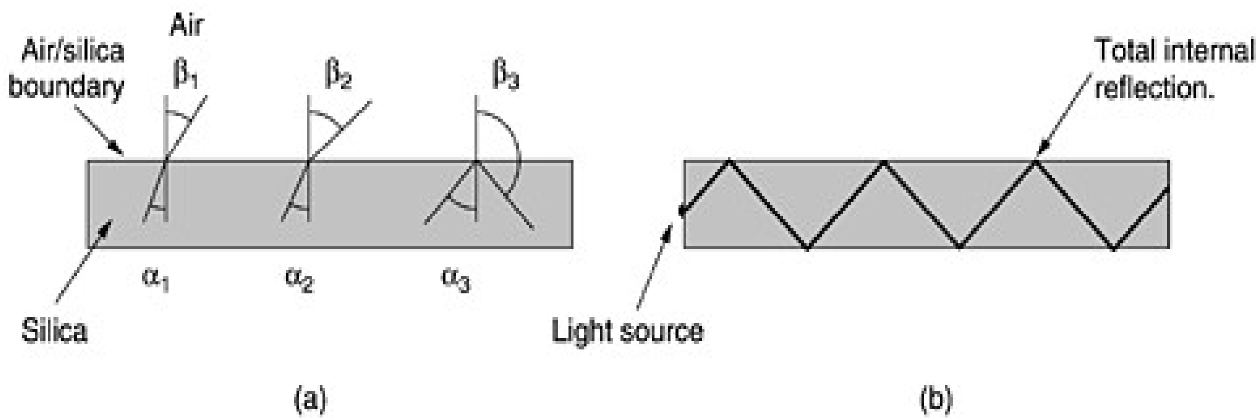


Figure 1.17. (a) Three examples of a light ray from inside a silica fiber impinging on the air/silica boundary at different angles. (b) Light trapped by total internal reflection.

Fiber Optics

- Any light ray incident on the boundary above the critical angle will be reflected internally, many different rays will be bouncing around at different angles. Each ray is said to have a different mode, so a fiber having this property is called a multimode fiber.

- If the fiber's diameter is reduced to a few wavelengths of light, the fiber acts like a wave guide, and the light can propagate only in a straight line, without bouncing, yielding a single-mode fiber.

- Single-mode fibers are more expensive but are widely used for longer distances.

- Currently available single-mode fibers can transmit data at 50 Gbps for 100 km without amplification.

Fiber Cables

- Fiber optic cables are similar to coax, except without the braid.
- In multimode fibers, the core is typically 50 microns in diameter, about the thickness of a human hair. In single-mode fibers, the core is 8 to 10 microns.
- The core is surrounded by a glass cladding with a lower index of refraction than the core, to keep all the light in the core.
- A thin plastic jacket to protect the cladding. Fibers are typically grouped in bundles, protected by an outer sheath. Figure 1.18 (b) shows a sheath with three fibers.

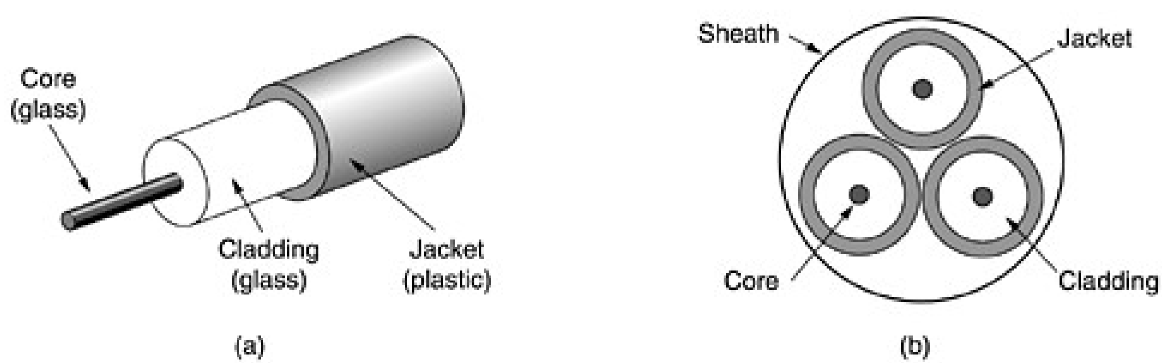


Figure 1.18. (a) Side view of a single fiber. (b) End view of a sheath with three fibers.

Fiber Optic Networks

- Fiber optics can be used for LANs as well as for long-haul transmission.
- The interface at each computer passes the light pulse stream through to the next link and also serves as a T junction to allow the computer to send and accept messages.

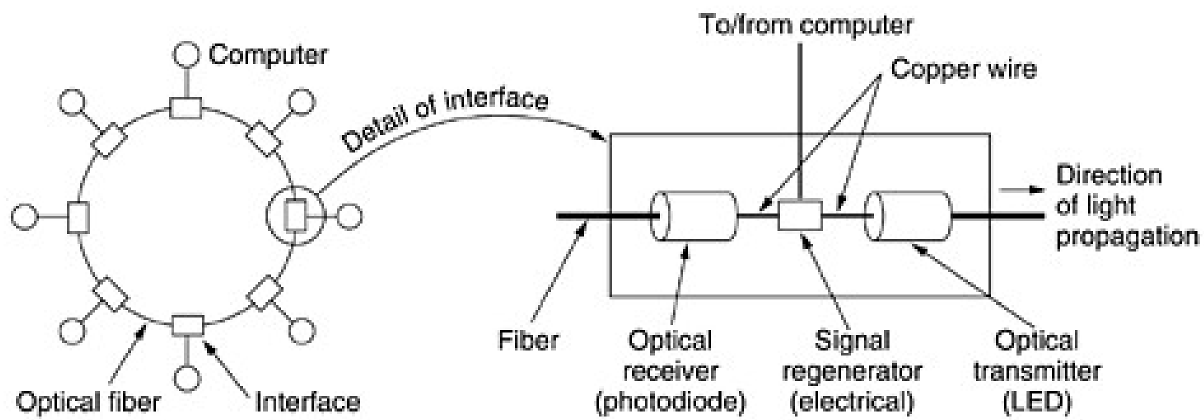


Figure 1.19. A fiber optic ring with active repeaters.

Fiber Optic Networks

- Passive star combines all the incoming signals and transmits the merged result on all lines.

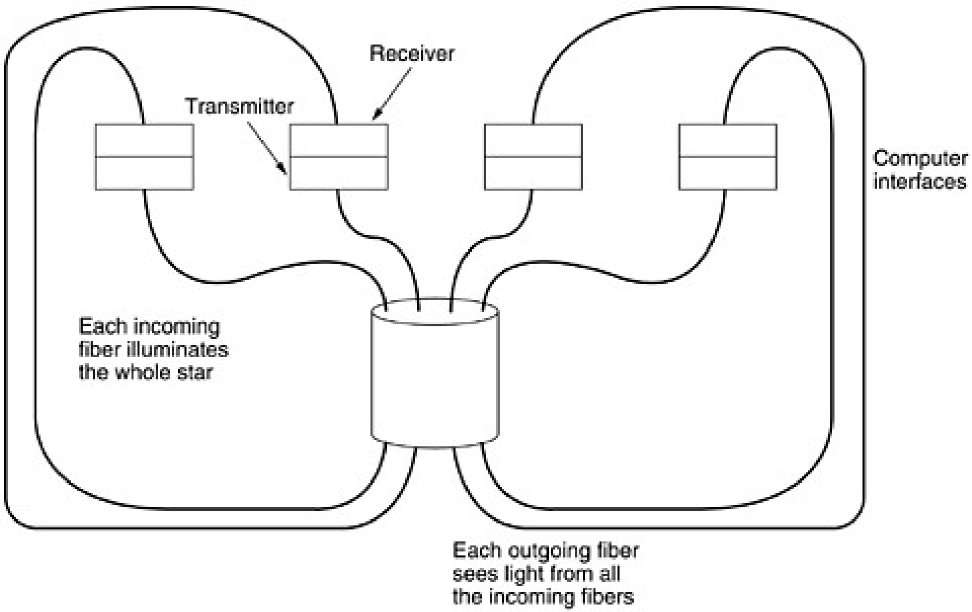


Figure 1.20. A passive star connection in a fiber optics network

Comparison of Fiber Optics and Copper Wire

- Fiber can handle much higher bandwidths than copper (use in high-end networks).
- Due to the low attenuation, repeaters are needed only about every 50 km on long lines, versus about every 5 km for copper, a substantial cost saving.
- Fiber is not being affected by power surges, electromagnetic interference, or power failures.
- Nor is it affected by corrosive chemicals in the air, making it ideal for harsh factory environments.
- Telephone companies like fiber for a different reason: it is thin and lightweight.

Comparison of Fiber Optics and Copper Wire

- For new routes, fiber wins hands down due to its much lower installation cost.
- Fibers do not leak light and are quite difficult to tap. These properties gives fiber excellent security against potential wiretappers.
- Fiber is a less familiar technology requiring skills not all engineers have, and fibers can be damaged easily by being bent too much.
- Since optical transmission is inherently unidirectional, two-way communication requires either two fibers or two frequency bands on one fiber.
- Fiber interfaces cost more than electrical interfaces.

Wireless Transmission

- If running a fiber to a building is difficult due to the terrain (mountains, jungles, swamps, etc.), wireless may be better.

- Modern wireless digital communication began in the Hawaiian Islands, where large chunks of Pacific Ocean separated the users and the telephone system was inadequate.

- Different Types: The Electromagnetic Spectrum, Radio Transmission, Microwave Transmission, Infrared and Millimeter Waves, Lightwave Transmission

Radio Transmission

- Radio waves are easy to generate, can travel long distances, and can penetrate buildings easily, so they are widely used for communication, both indoors and outdoors.
- Radio waves also are omnidirectional, meaning that they travel in all directions from the source, so the transmitter and receiver do not have to be carefully aligned physically.

- The properties of radio waves are frequency dependent.
- At low frequencies, radio waves pass through obstacles well, but the power falls off sharply with distance from the source, roughly as $1/r^2$ in air.
- At high frequencies, radio waves tend to travel in straight lines and bounce off obstacles.

Radio Transmission

- They are also absorbed by rain.
- At all frequencies, radio waves are subject to interference from motors and other electrical equipment.
- Due to radio's ability to travel long distances, interference between users is a problem. Under certain atmospheric conditions, the signals can bounce several times.

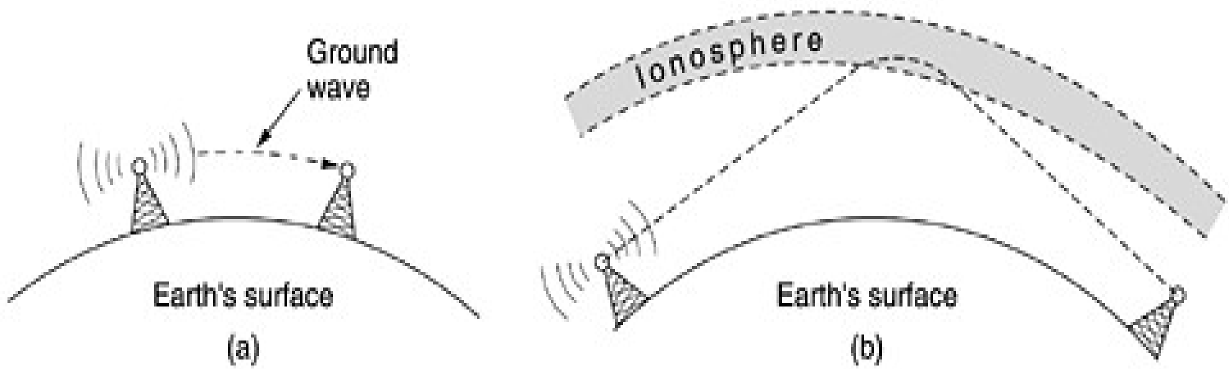


Figure 1.21. (a) In the VLF, LF, and MF bands, radio waves follow the curvature of the earth. (b) In the HF band, they bounce off the ionosphere.

Microwave Transmission

- Concentrating all the energy into a small beam by means of a parabolic antenna (like the familiar satellite TV dish) gives a much higher signal-to-noise ratio, but the transmitting and receiving antennas must be accurately aligned with each other.
- Before fiber optics, for decades these microwaves formed the heart of the long-distance telephone transmission system.
- MCI (stood for Microwave Communications, Inc.) built its entire system with microwave communications going from tower to tower tens of kilometres apart.
- Repeaters are needed periodically. The higher the towers are, the farther apart they can be. The distance between repeaters goes up very roughly with the square root of the tower height.

Microwave Transmission

- Microwaves do not pass through buildings well.
- In addition, even though the beam may be well focused at the transmitter, there is still some divergence in space.
- Some waves may be refracted off low-lying atmospheric layers and may take slightly longer to arrive than the direct waves.
- The delayed waves may arrive out of phase with the direct wave and thus cancel the signal. This effect is called multipath fading and is often a serious problem.
- Some operators keep 10 percent of their channels idle as spares to switch on when multipath fading wipes out some frequency band temporarily.
- It is weather and frequency dependent.

Microwave Transmission

- Bands up to 10 GHz are now in routine use, but at about 4 GHz a new problem sets in: absorption by water. These waves are only a few centimeters long and are absorbed by rain.
- Microwave communication is so widely used for long-distance telephone communication, mobile phones, television distribution, and other uses that a severe shortage of spectrum has developed.
- It has several significant advantages over fiber.
- No right of way is needed, and by buying a small plot of ground every 50 km and putting a microwave tower on it, one can bypass the telephone system and communicate directly.

Microwave Transmission

- Microwave is also relatively inexpensive.
- Putting up two simple towers (may be just big poles with four guy wires) and putting antennas on each one may be cheaper than burying 50 km of fiber through a congested urban area or up over a mountain.
- It may also be cheaper than leasing the telephone company's fiber, especially if the telephone company has not yet even fully paid for the copper it ripped out when it put in the fiber.

Communication Satellites

- A communication satellite can be thought of as a big microwave repeater in the sky.
- It contains several transponders, each of which listens to some portion of the spectrum, amplifies the incoming signal, and then rebroadcasts it at another frequency to avoid interference with the incoming signal.
- The downward beams can be broad, covering a substantial fraction of the earth's surface, or narrow, covering an area only hundreds of kilometers in diameter. This mode of operation is known as a bent pipe.
- According to Kepler's law, the orbital period of a satellite varies as the radius of the orbit to the 3/2 power.

Communication Satellites

- Another issue is the presence of the Van Allen belts, layers of highly charged particles trapped by the earth's magnetic field. Any satellite flying within them would be destroyed fairly quickly by the highly-energetic charged particles trapped there by the earth's magnetic field.
- These factors lead to three regions in which satellites can be placed safely.

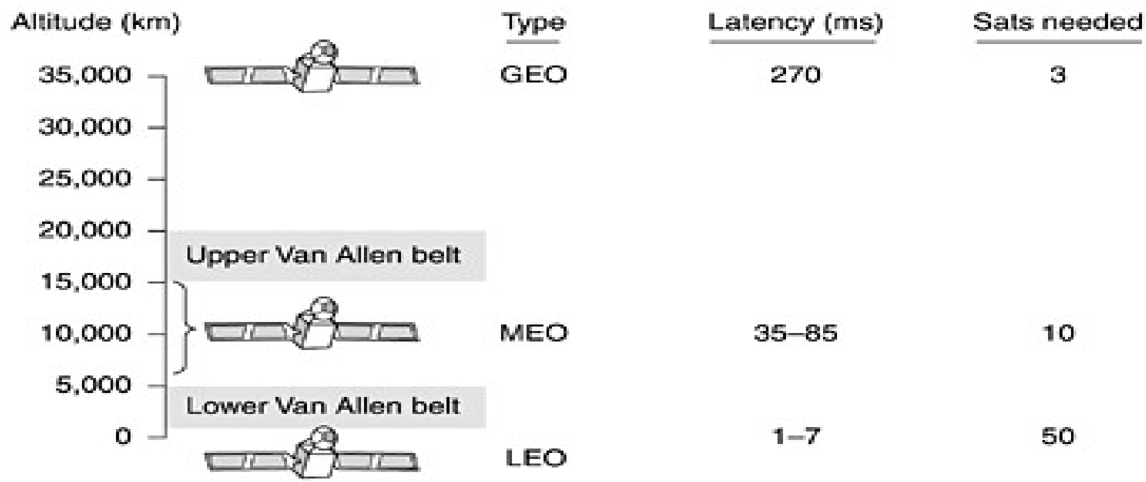


Figure 1.22. Communication satellites and some of their properties, including altitude above the earth, round-trip delay time, and number of satellites needed for global coverage.