Computer Networks CSE306

Lecture 0

Presented by: Dr. Amandeep Singh

Course details

- LTP – 3 0 0 [Three lectures & /week]

Text Book

DATA COMMUNICATION AND NETWORKING

By Behrouz Forouzan, Mcgraw Hill Education

Course Assessment Model

- **Marks break up***

Attendance	5
CA (Two best out of three tasks)	25
MTE	20
ETE	50
Total	**100**

POLL 1

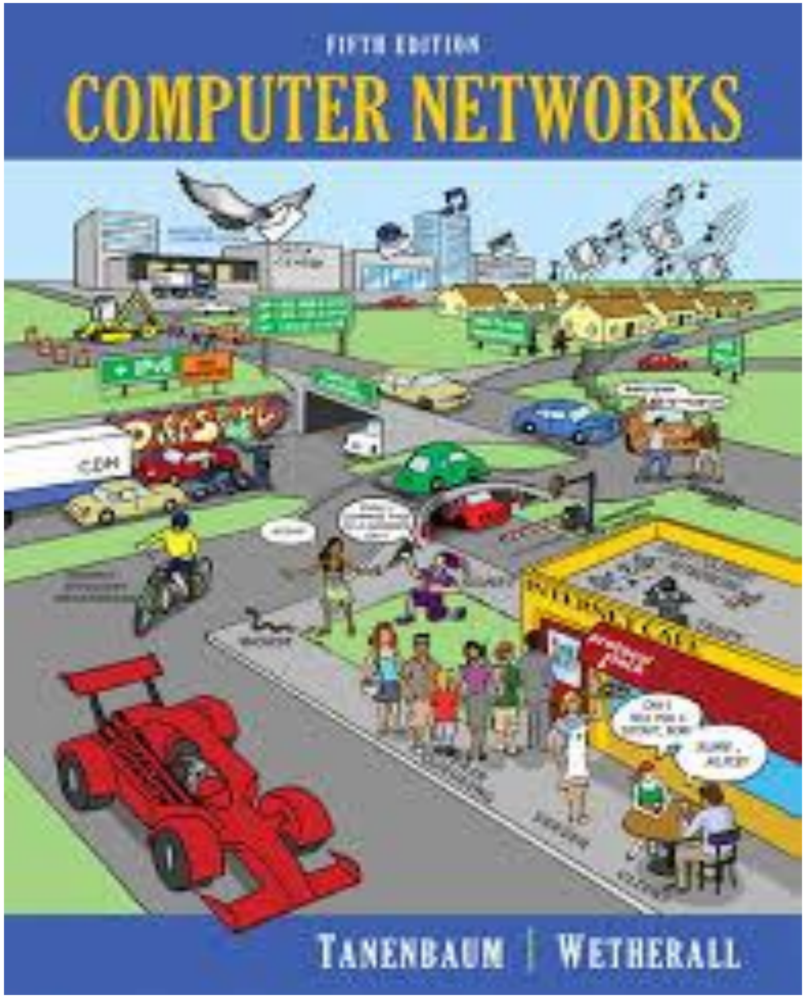
- The weightage of ETE component is

a) 20

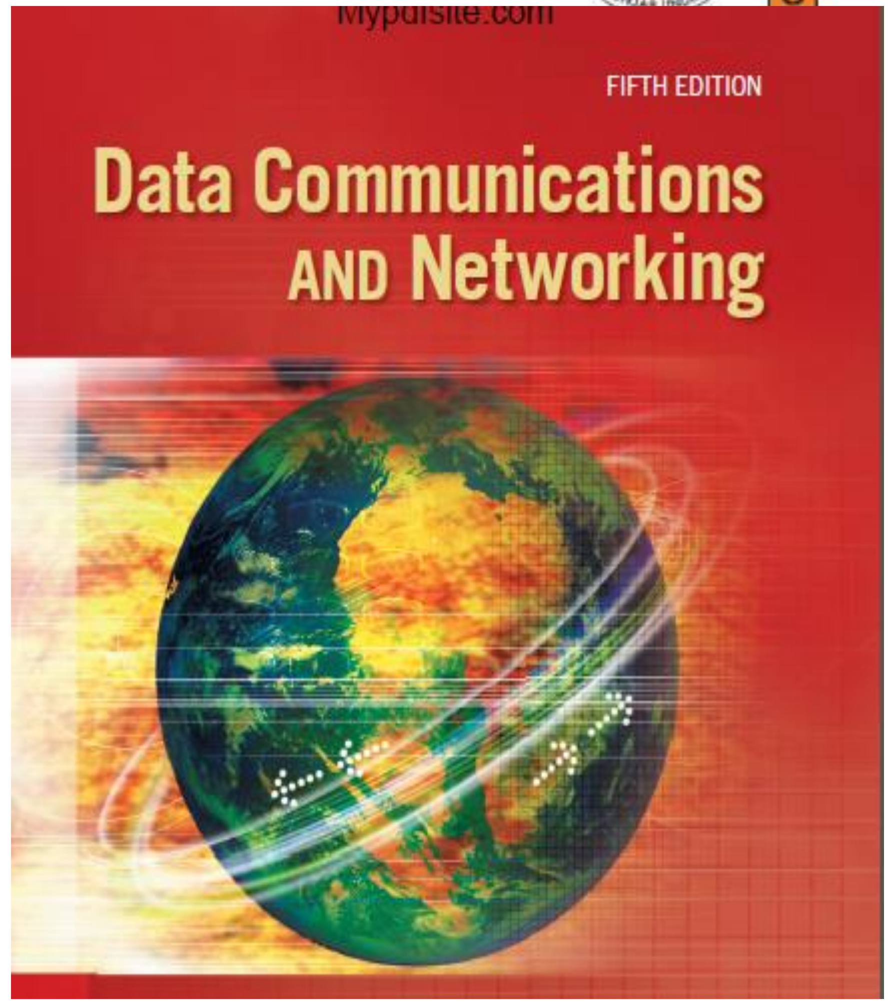
b) 50

c) 25

d) 30



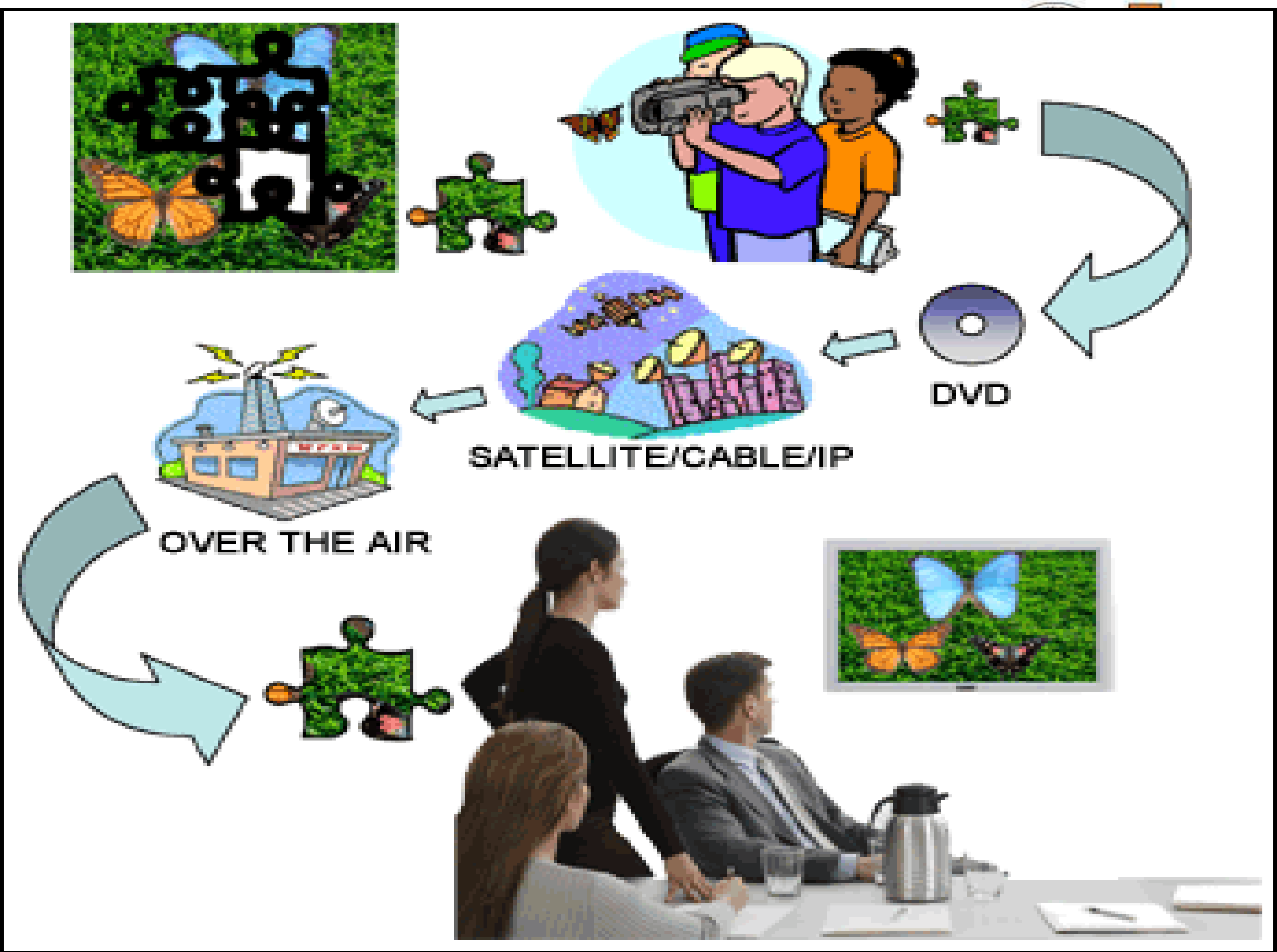
Reference Book 1
Ed 5



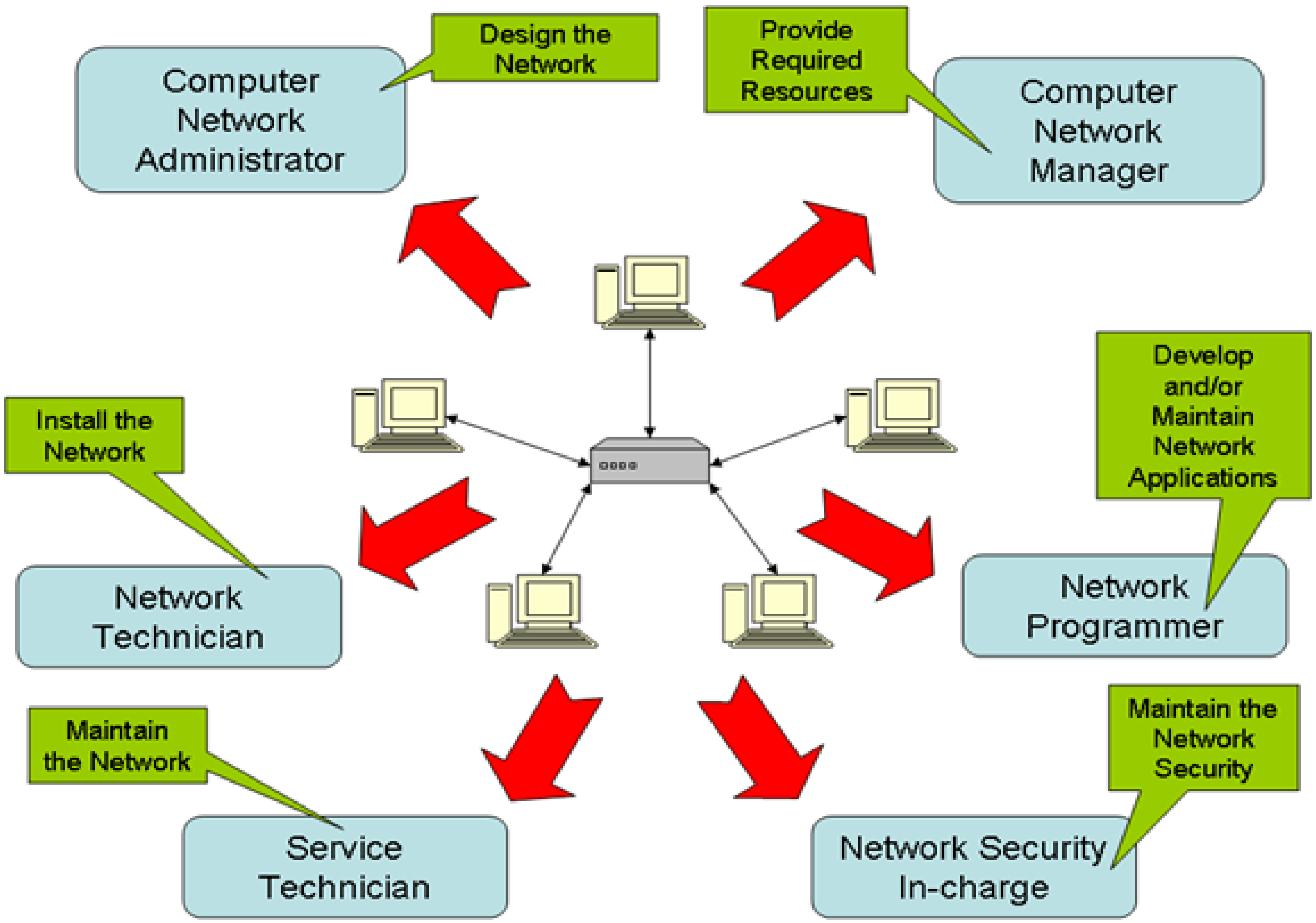
Text Book

OLD TIMES

NOW


DVD
SATELLITE/CABLE/IP
OVER THE AIR

Why Study ?



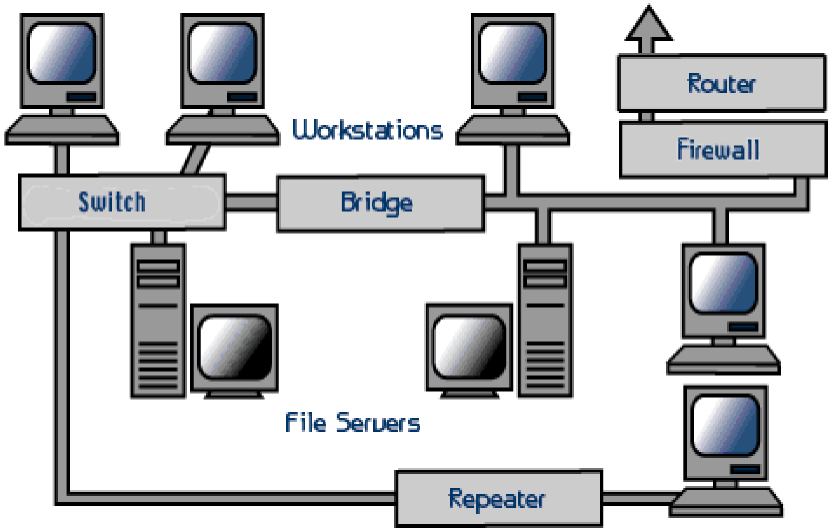
(Career Avenues in Computer Networking)

Objective of Computer Networks

- Networking has revolutionized the way in which we ***WORK***, ***CONNECT*** and ***COMMUNICATE*** to the world.

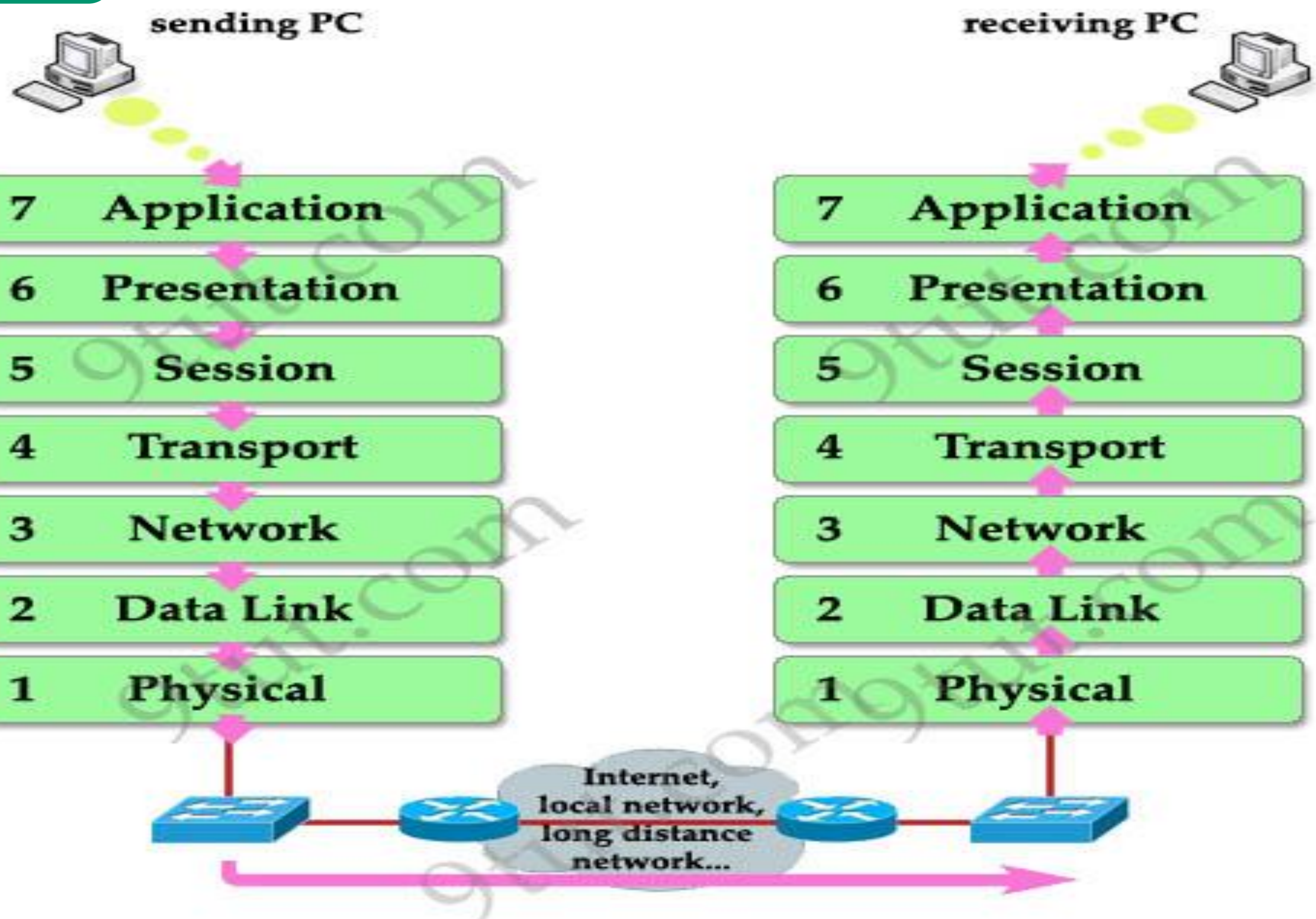
What Is Networking

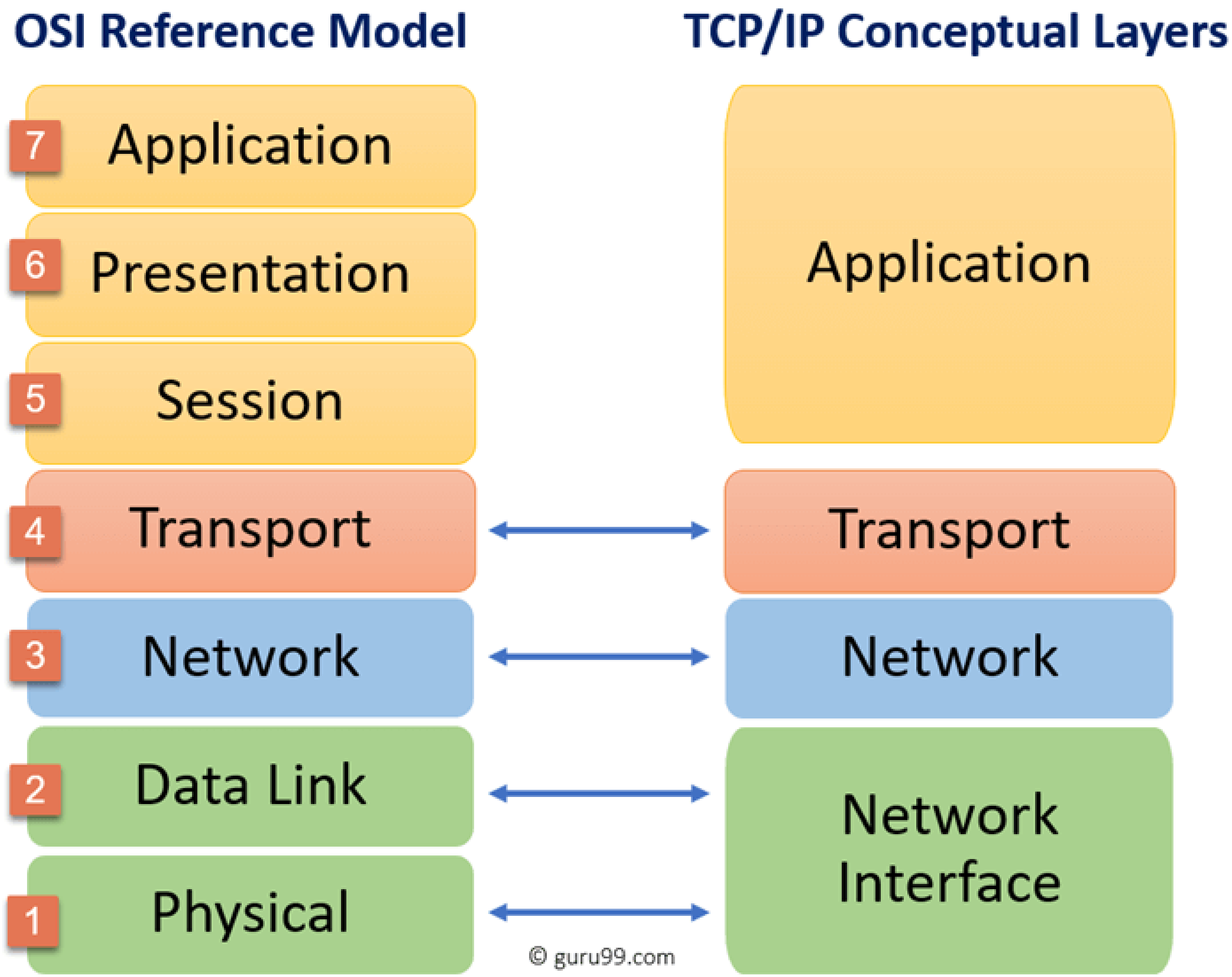
A computer **network** or data **network** is a telecommunications **network** that allows computers to exchange data.



OSI and TCP Model

Unit 1




OSI Reference Model
TCP/IP Conceptual Layers
7 Application
6 Presentation
5 Session
4 Transport
3 Network
2 Data Link
1 Physical
Application
Transport
Network
Network Interface
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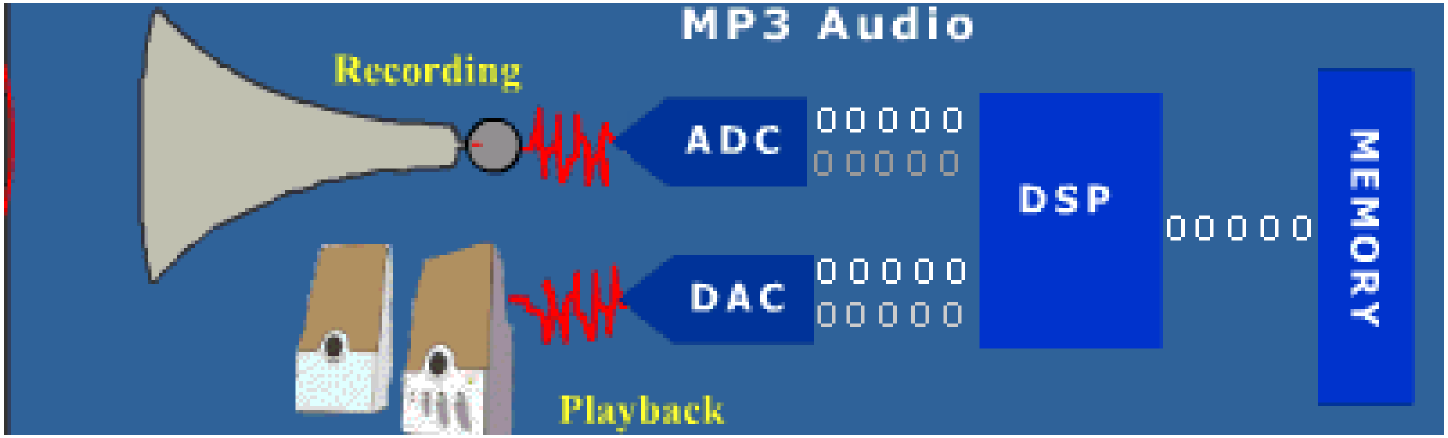
POLL 2

Which of the following layers is merged in TCP/IP protocol

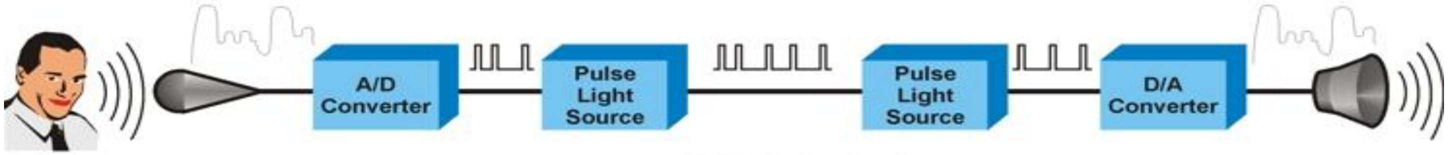
a) Session layer
b) Network layer
c) Transport layer
d) None of the above

PHYSICAL LAYER: Signal & Media

Unit 2



Analog Optical



Digital Optical

DATA LINK LAYER

Unit 3

Physical Addressing
Framing
Flow Control
Error Control

POLL 3

- Physical addressing takes place at

a) Physical layer

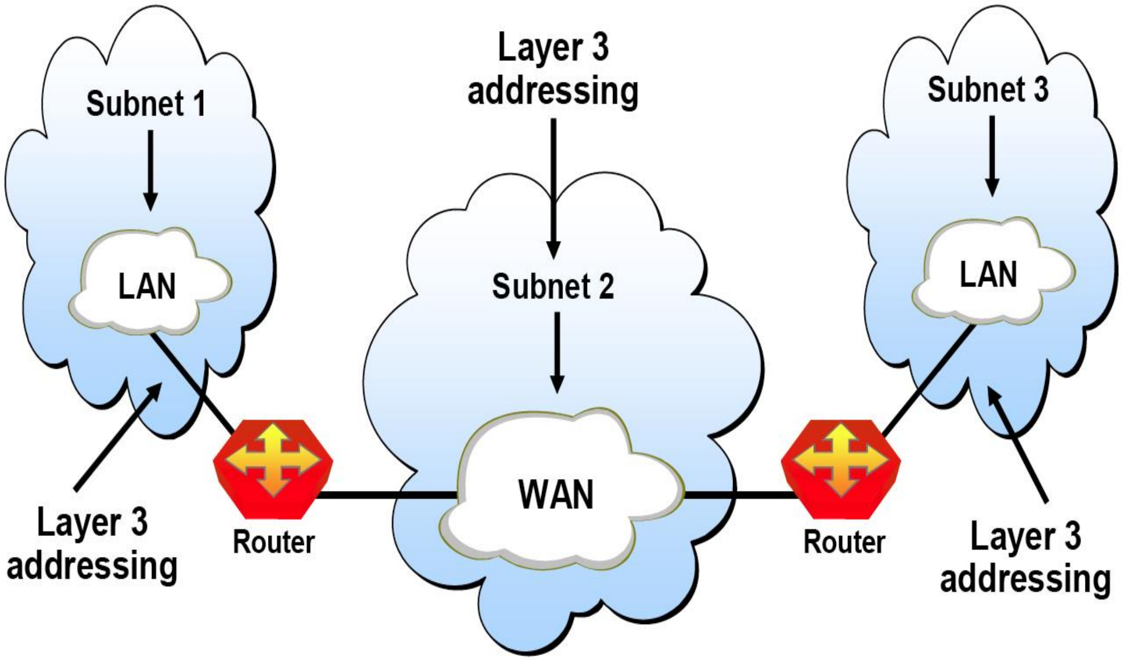
b) Data link layer

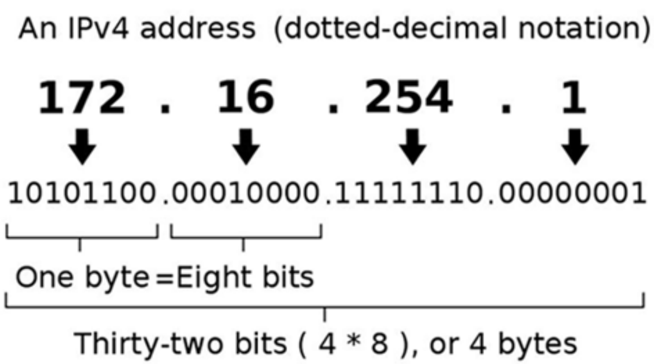
c) Network layer

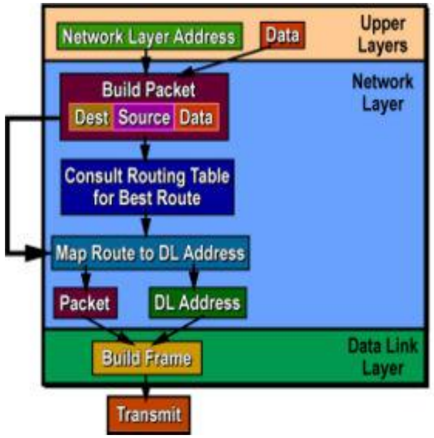
d) Session layer

NETWORK LAYER: IP Addressing

Unit 4







POLL 4

- PIv4 is a __________ bit addressing

a) 32

b) 16

c) 64

d) 128

Routing and Congestion Control

Unit 5

Routing Algorithms
Shortest Path
Metric
Congestion Control Algorithms

POLL 5

- Network Layer deals

a) Routing only

b) Routing & IP addressing

c) Congestion control

d) Both b & c

TRANSPORT LAYER

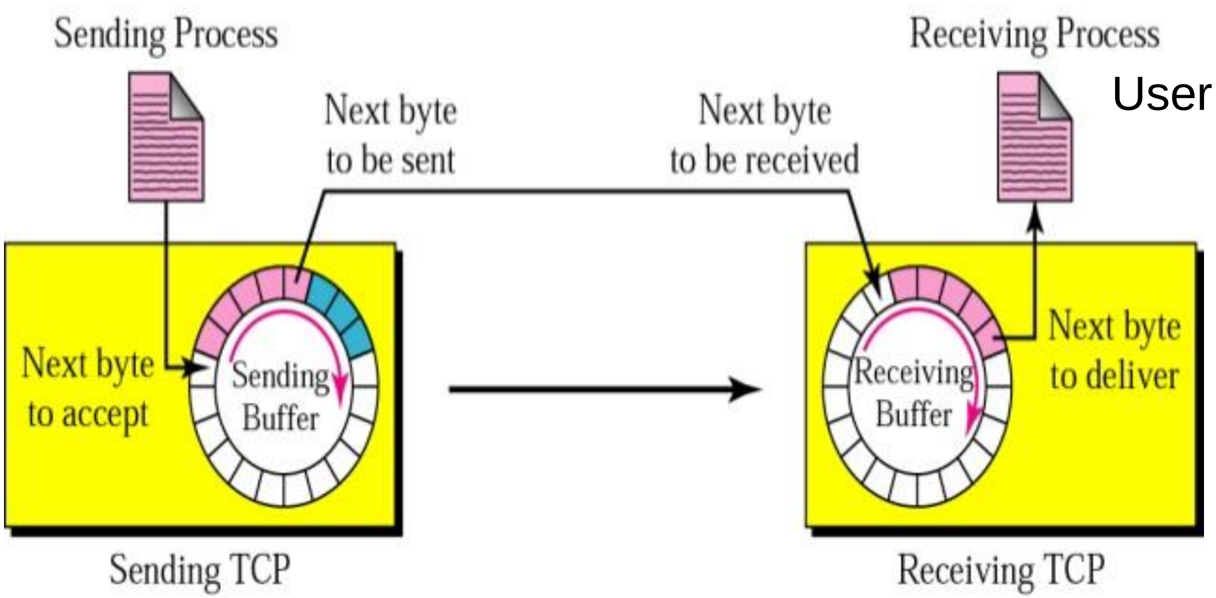
Unit 6

1. Reliable delivery of data
2. Ordering of delivery
3. Port addressing
4. Segmentation and reassembly
5. Connection control
6. Flow control and Error control
7. Main protocols are TCP and UDP

Transmission Control Protocol (TCP)

User Datagram Protocol (UDP)

Sending & Receiving Window



POLL 6

- Data reliability is a part of

a) Data link layer

b) Physical layer

c) Application layer

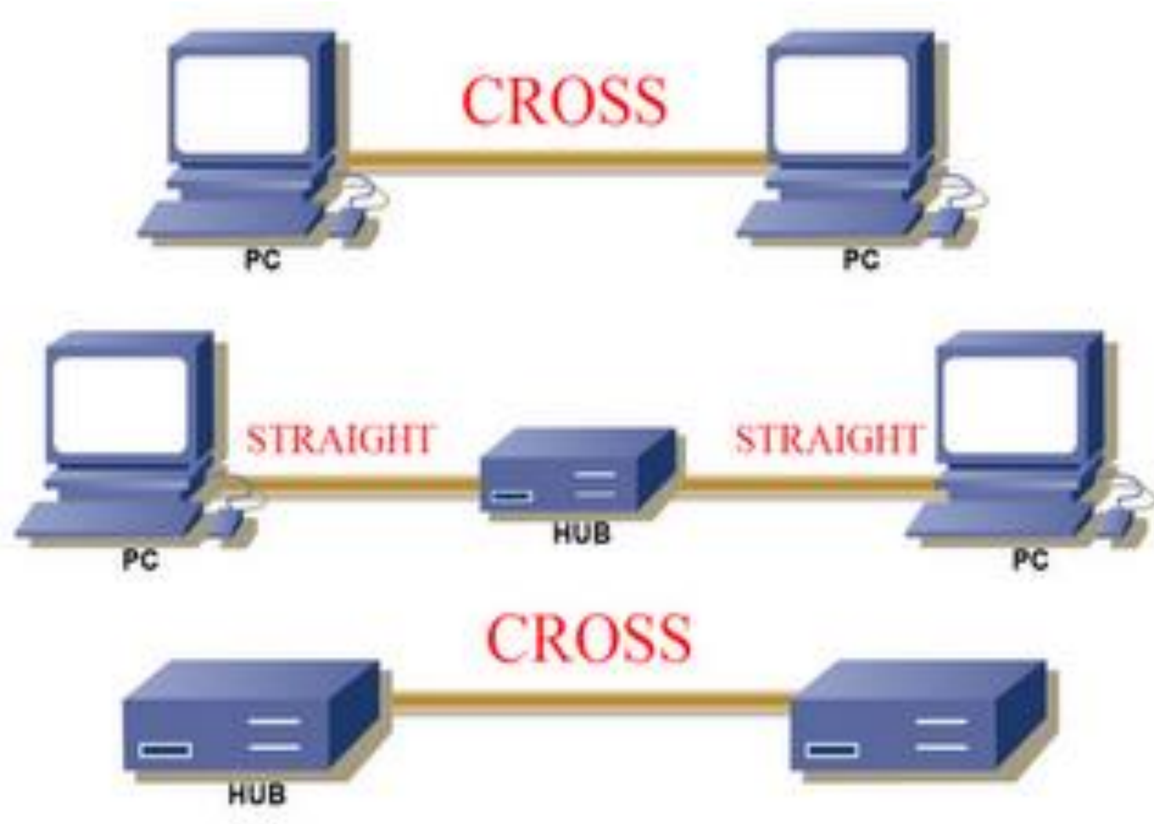
d) Transport layer

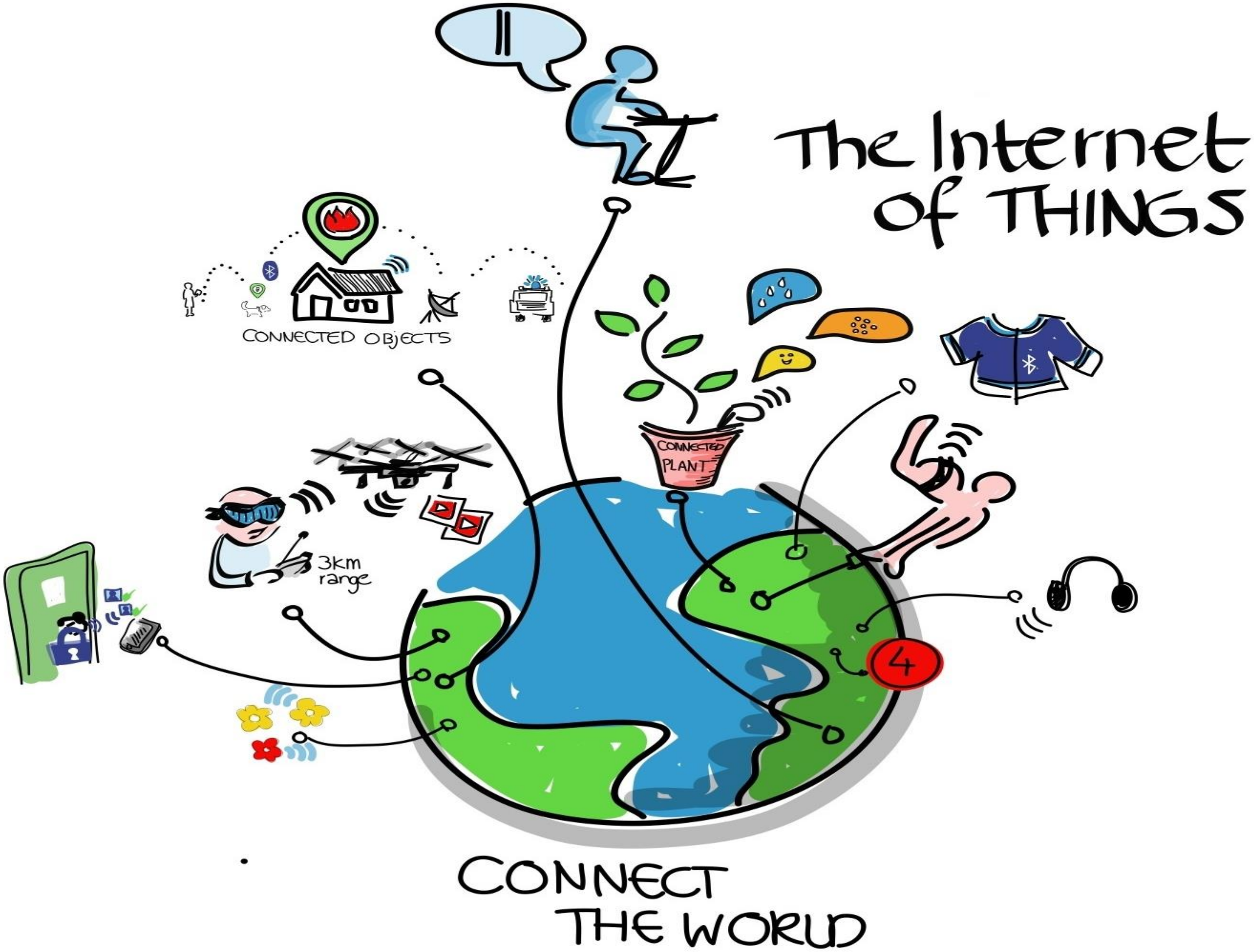
APPLICATION LAYER

Unit 6

Types of Devices

- Laptops
- PDAs
- Cell phones
- Pagers
- Sensors
- Hub
- Switch
- Router etc




The Internet of THINGS
CONNECTED OBJECTS
CONNECTED PLANT
3km range
CONNECT THE WORLD

FUTURE SCOPE

They receive live information from the road authority about the state of the roads including traffic jams, accidents and weather. The car transmits information to the road authority regarding speed, distance travelled, use of windscreen wipers, etc.

Challenges

- Bandwidth
- Security risks
- Wide variety terminals and devices with different capabilities
- Fit more functionality into single, smaller device
- QoS

Limitations to Computer Network

- Cyber Crime.
- Need Connectivity.
- Global Protocol acceptance. IPv4 and IPv6.
- Power Source for Mobile Devices.
- Size and Design.
- Cost.

Types of Network

- **Wired Networks**

- high bandwidth
- low bandwidth variability
- can listen on wire
- high power machines
- high resource machines
- low delay
- connected operation

-No Mobility.

- **Mobile Networks**

- low bandwidth
- high bandwidth variability
- hidden terminal problem
- low power machines
- low resource machines
- higher delay
- disconnected operation

Mobility.


Any questions?

Introduction

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DATA COMMUNICATIONS

- The term TELECOMMUNICATION means communication at a distance. The word DATA refers to whatever form is agreed upon by the parties creating and using the data. information presented in

- Data communications are the exchange of data between two devices via some form of transmission medium such as a wire cable or may be wireless.

Effectiveness of Data Communication

Four Fundamental Characteristics

- Delivery
- Accuracy
- Timeliness - -*real time*
- Jitter

POLL 1

Which of the following is NOT an example of fundamental characteristics of communication

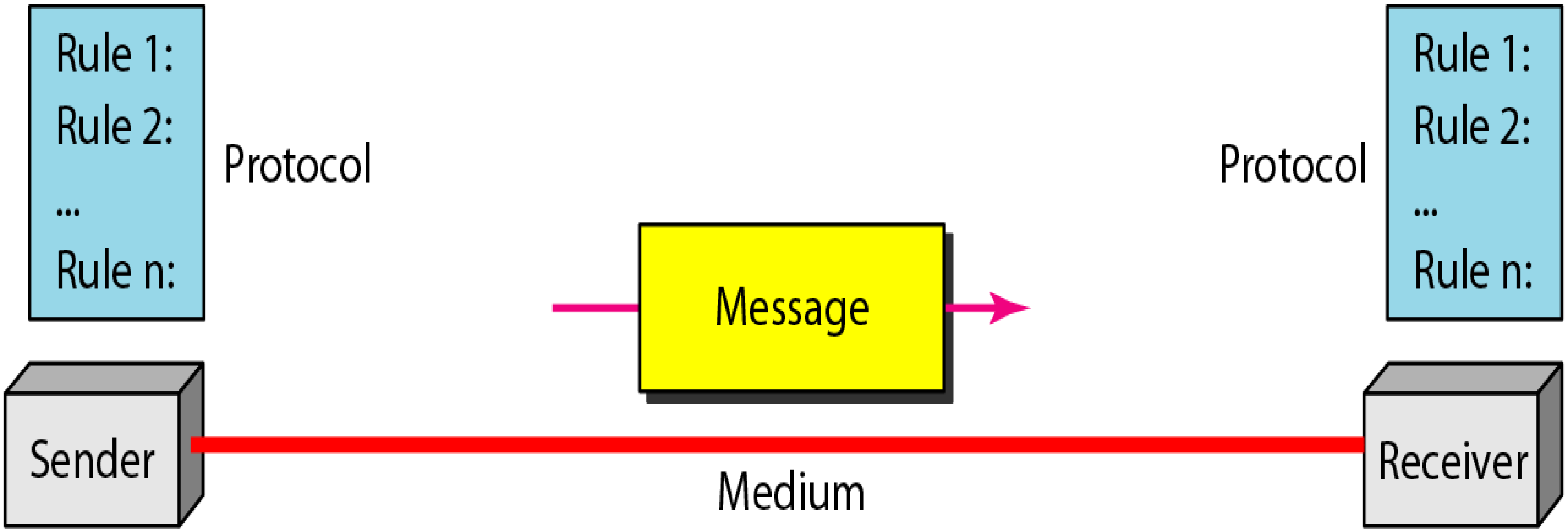
a) Accuracy

b) Delivery

c) Jitter

d) Compression

Components of a Data Communication System

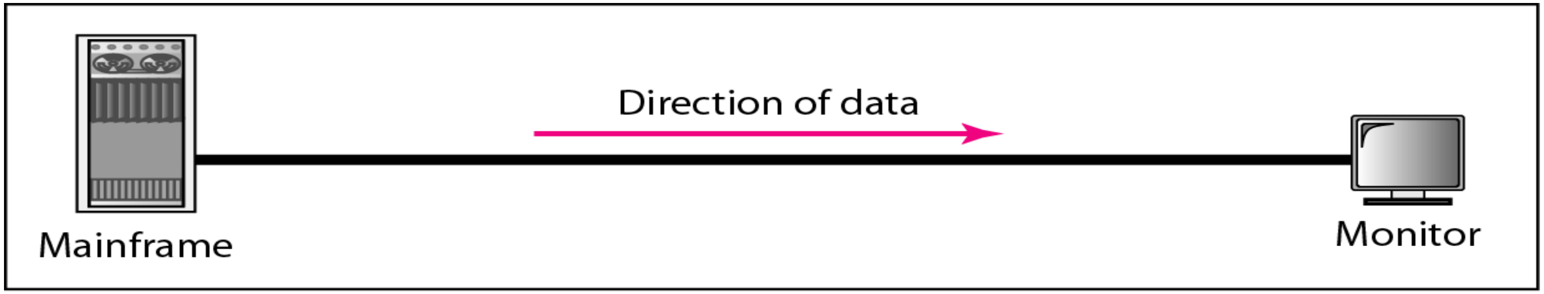


Continue…

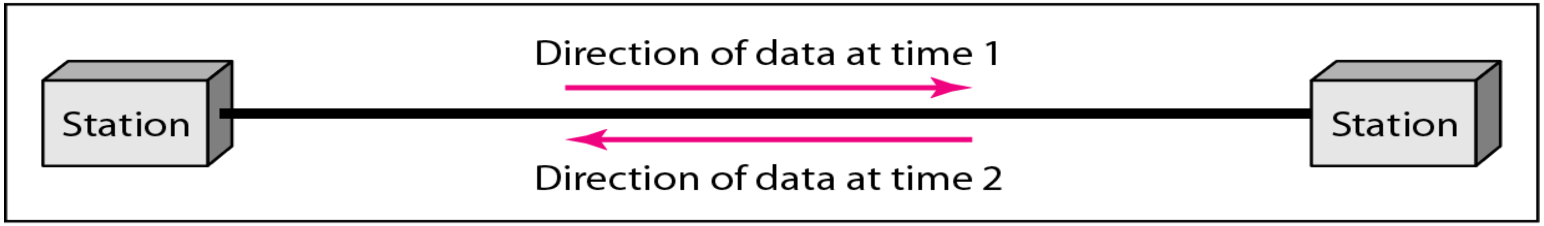
Five Components:

- Message- ***Text, Number, Image, Audio, Video***
- Sender
- Receiver
- Transmission Medium
- Protocol

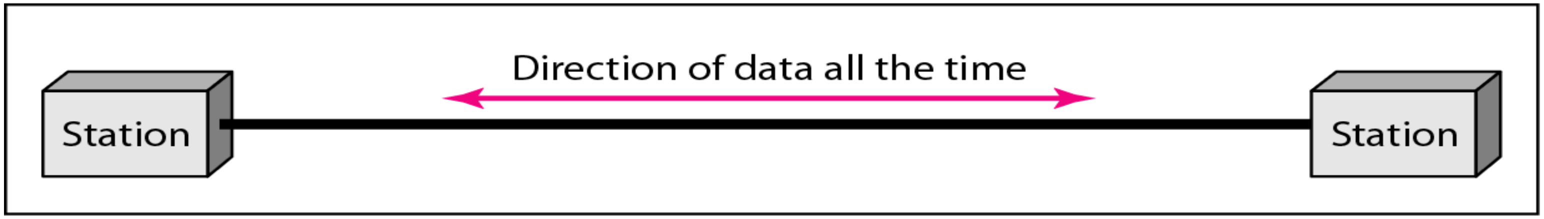
Data flow (Simplex, Half-duplex, and Full-duplex



a. Simplex



b. Half-duplex



c. Full-duplex

POLL 2

Bi-directional data communication possible only at two different time interval is associated with

a) Simplex

b) Half-Duplex

c) Duplex

d) None of the above

NETWORKS

- A network is a set of devices (often referred to as nodes) connected by communication links. A node can be a computer, printer, or any other device capable of sending and/or receiving data generated by other nodes on the network.

- A link can be a cable, air, optical fiber, or any medium which can transport a signal carrying information.

POLL 3

A node is a representation of

a) PC

b) Printer

c) Laptop

d) All of the above

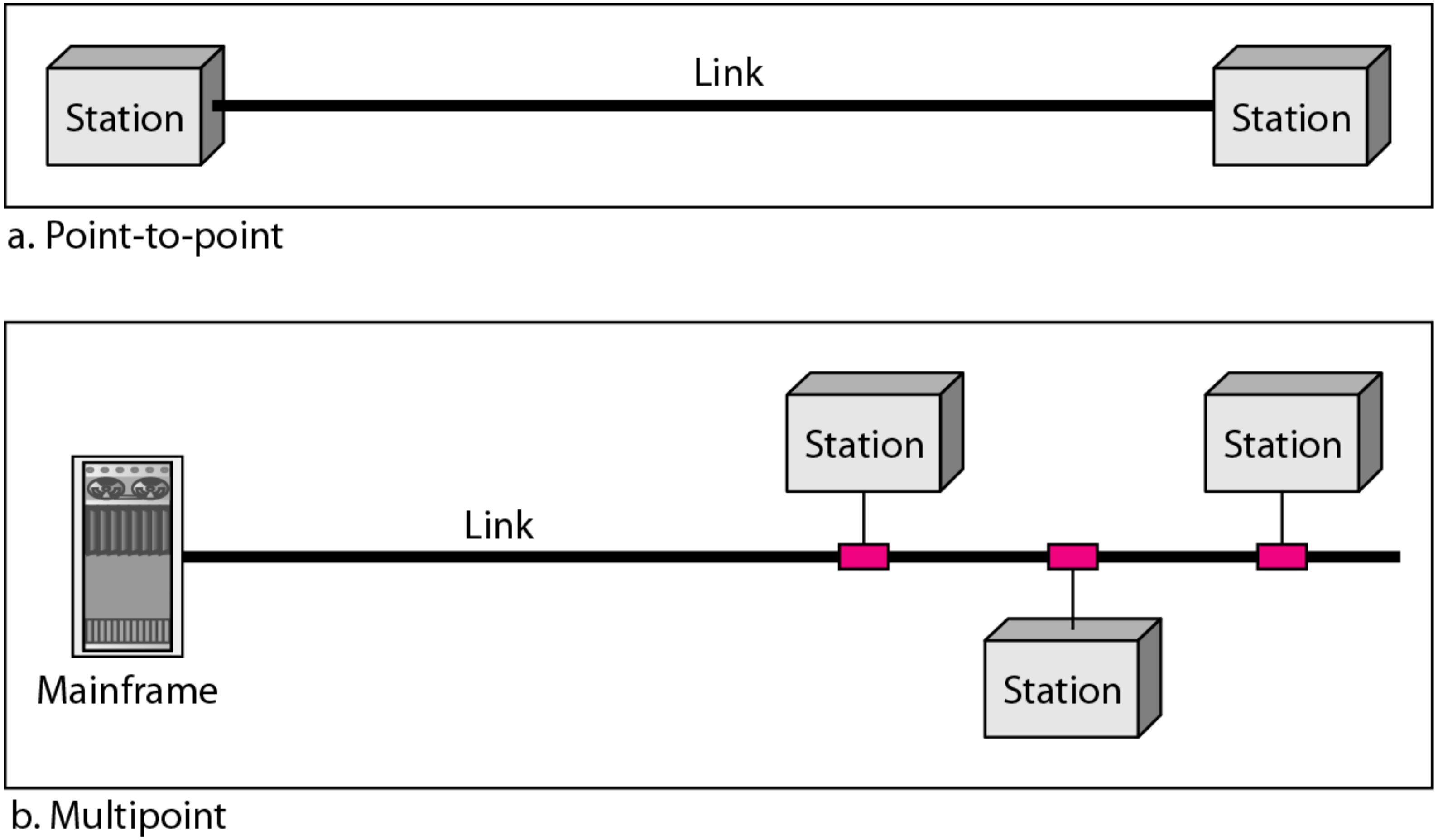
Network Criteria

- Performance
  - Depends on Network Elements- Transmit time, Response Time, Number of users, type of transmission medium, hardware, software.
  - Measured in terms of Delay and Throughput
- Reliability
  - Failure rate of network components.
  - Time to recover from a failure.
  - Measured in terms of availability/robustness
- Security
  - Data protection against corruption/loss of data due to:
    - Errors
    - Malicious users/ Unauthorized access.

Physical Structures

- Type of Connection
  - Point to Point - single transmitter and receiver
  - Multipoint - multiple recipients of single transmission
- Physical Topology
  - Connection of devices
  - Type of transmission - unicast, mulitcast, broadcast

Types of connections: point-to-point and multipoint



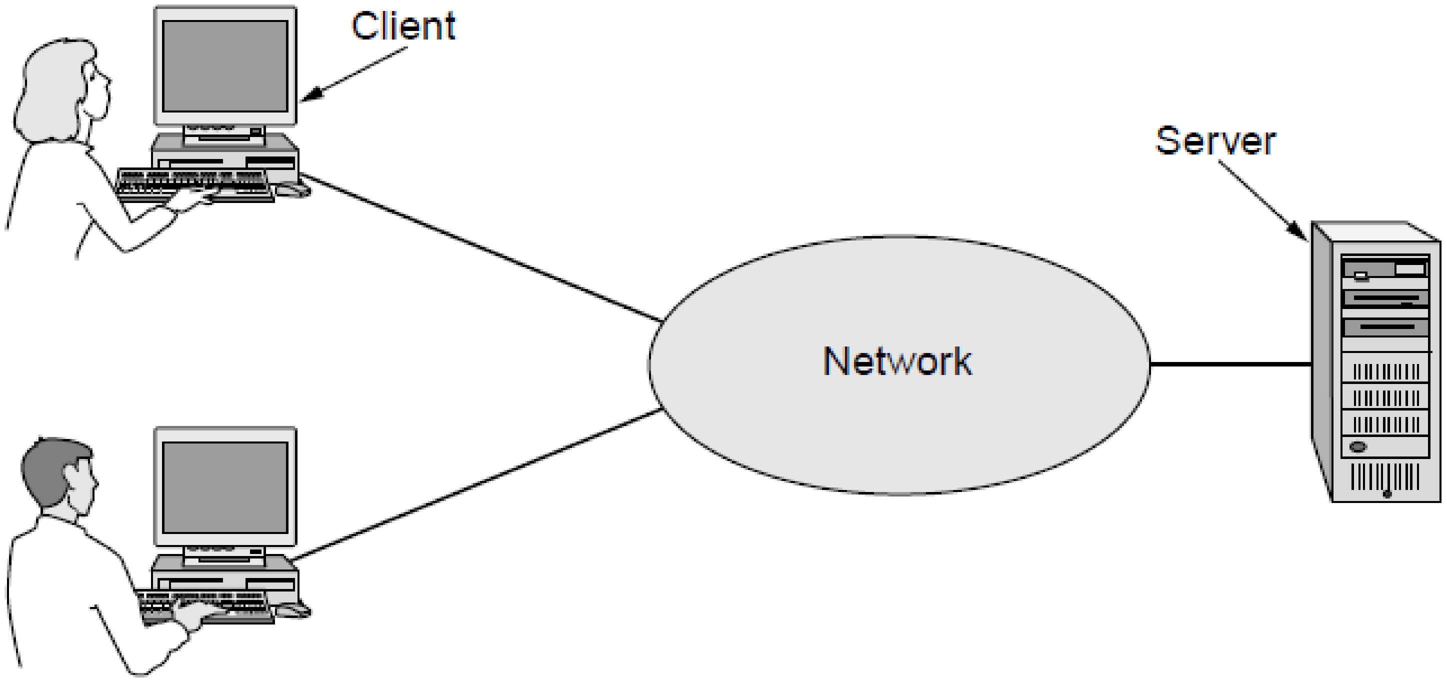
Uses of Computer Network

- Business Applications
- Home Applications
- Mobile Users
- Social Issues

Business Applications

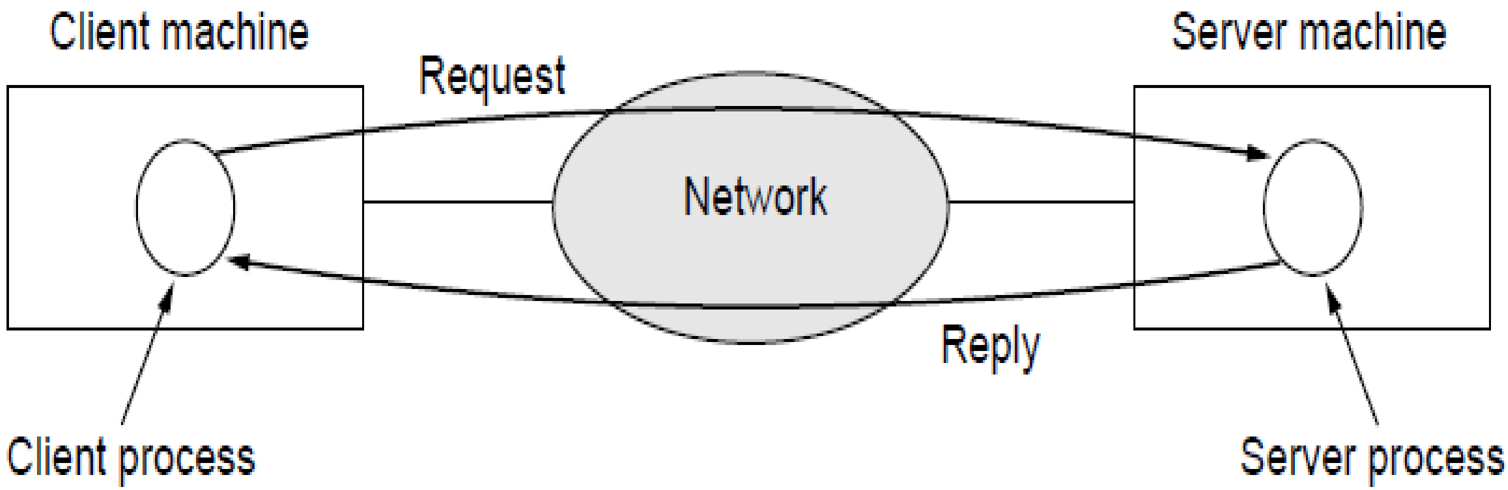
- Resource sharing such as printers and storage devices
- Exchange of information by means of e-Mails and FTP

Business Applications (1)



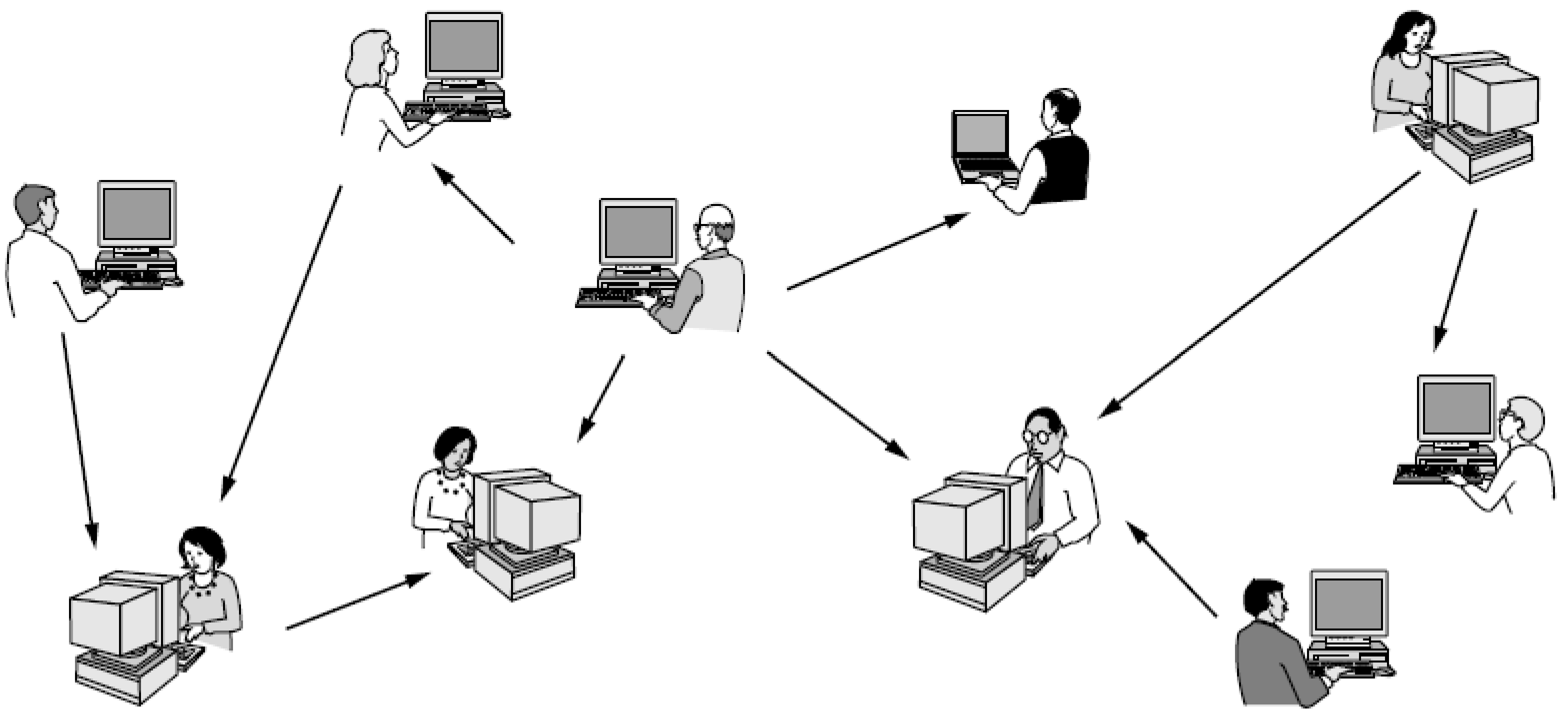
A network with two clients and one server

Business Applications (2)



The client-server model involves requests and replies

Home Applications (1)



In a peer-to-peer system there are no fixed clients and servers.

Home Applications (2)

Some forms of e-commerce

Tag	Full name	Example
B2C	Business-to-consumer	Ordering books online
B2B	Business-to-business	Car manufacturer ordering tires from supplier
G2C	Government-to-consumer	Government distributing tax forms electronically
C2C	Consumer-to-consumer	Auctioning second-hand products online
P2P	Peer-to-peer	Music sharing

Mobile Users

Combinations of wireless networks and mobile

Wireless	Mobile	Typical applications
No	No	Desktop computers in offices
No	Yes	A notebook computer used in a hotel room
Yes	No	Networks in unwired buildings
Yes	Yes	Store inventory with a handheld computer

Social Issues

- Network neutrality
- Digital Millennium Copyright Act
- Profiling users
- Phishing

PROTOCOLS

- A protocol is synonymous with rule. It consists of a set of rules that govern data communications. It determines what is communicated, how it is communicated and when it is communicated.
- The key elements of a protocol are
  – Syntax
  – Semantics
  – Timing

Elements of a Protocol

- Syntax
  - Structure or format of the data
  - Indicates how to read the bits - field delineation
- Semantics
  - Interprets the meaning of the bits
  - Knows which fields define what action
- Timing
  - When data should be sent and what
  - Speed at which data should be sent or speed at which it is being received.

POLL 4

The Key elements of a Protocol is/are

a) Syntax
b) Semantic
c) Timing
d) All of the above

Types of Network

- **Wired Networks**
- high bandwidth
- low bandwidth variability
- can listen on wire
- high power machines
- high resource machines
- low delay
- connected operation

-No Mobility.

- **Mobile Networks**
- low bandwidth
- high bandwidth variability
- hidden terminal problem
- low power machines
- low resource machines
- higher delay
- disconnected operation

Mobility.


Any questions?

Network Hardware

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Categories of Networks

- Personal area networks
- Local Area networks
- Metropolitan Area networks
- Wide Area networks
- Wireless Networks
- Home Networks
- Internetworks- The Internet

POLL 1

Which of the following is **NOT** an example of a Network

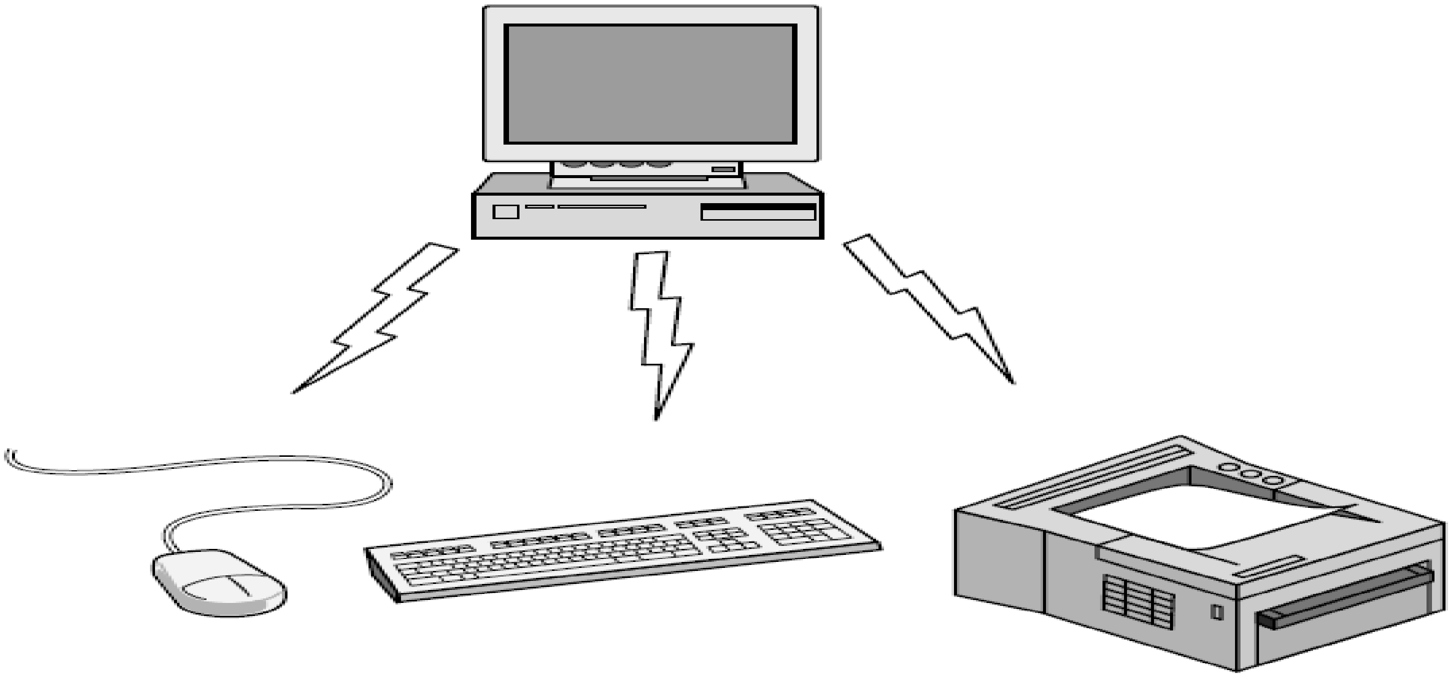
a) LAN

b) MAN

c) WAN

d) FAN

Personal Area Network

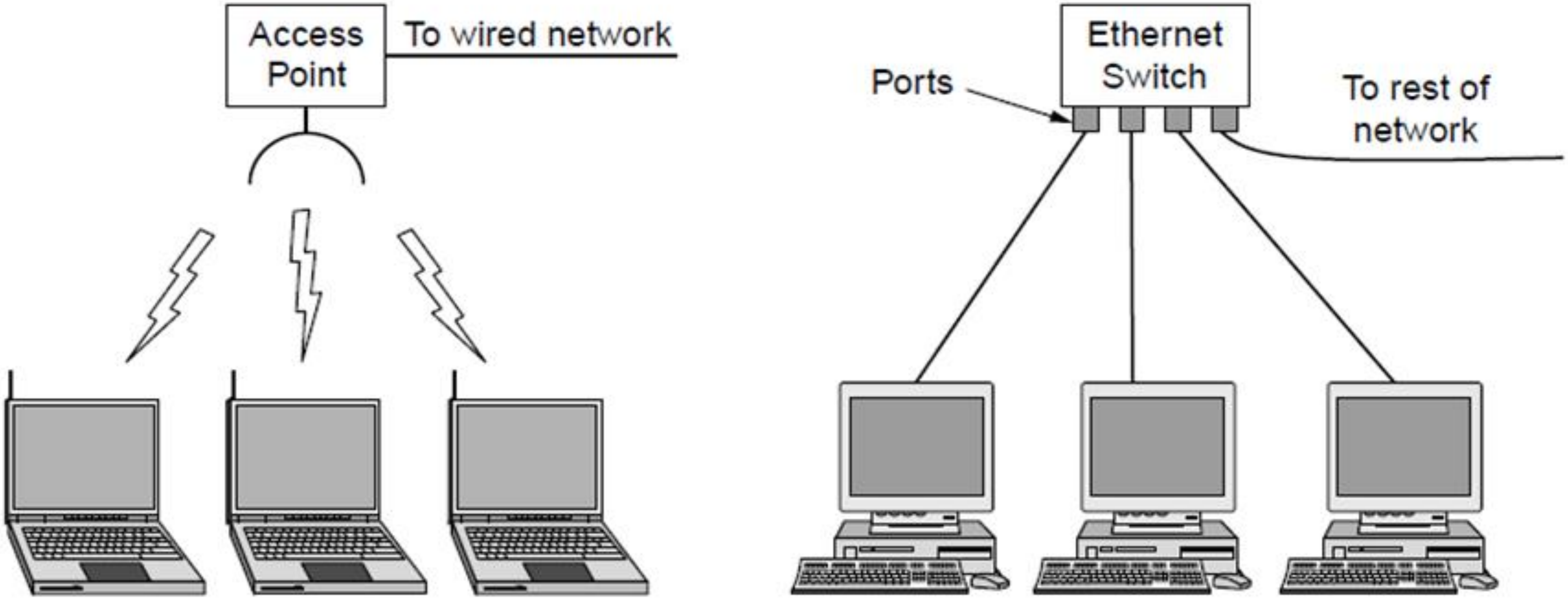


Bluetooth PAN configuration

Local Area Networks (LANs)

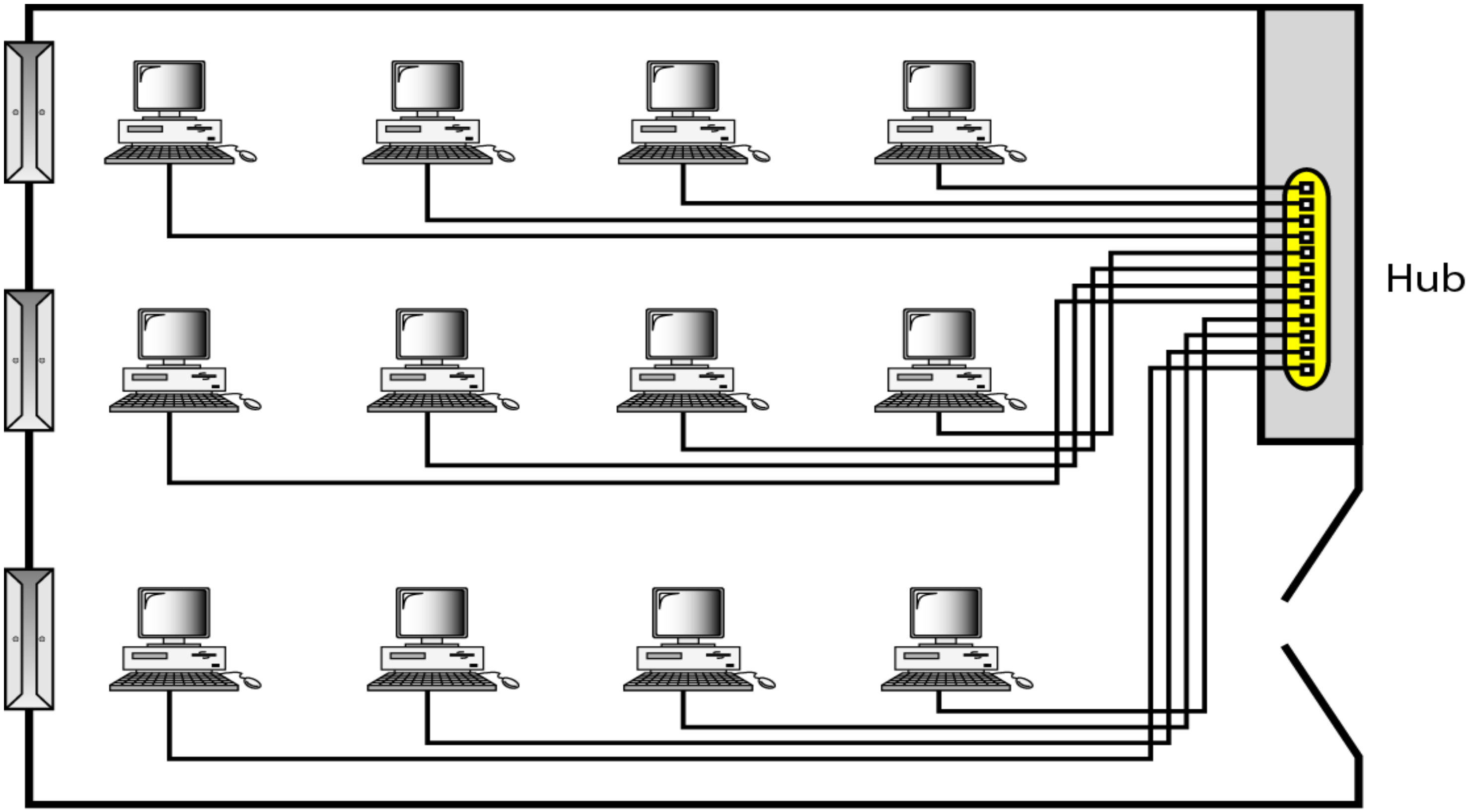
– Short distances

– Designed to provide local interconnectivity



Wireless and wired LANs. (a) 802.11. (b) Switched Ethernet.

Isolated LAN connecting 12 computers to a hub in a closet



POLL 2

- Hub is a

a) Broad-cast device

b) Uni-cast device

c) Multi-cast device

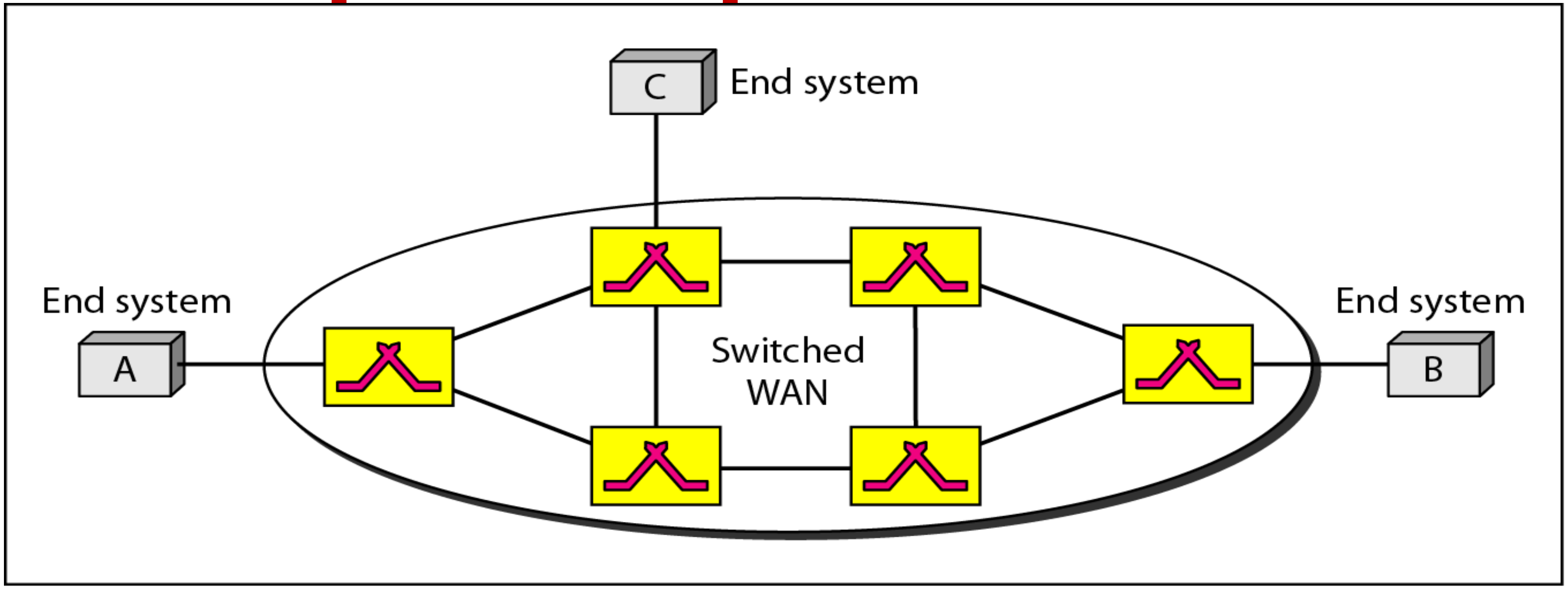
d) None of the above

Wide Area Networks (WANs)

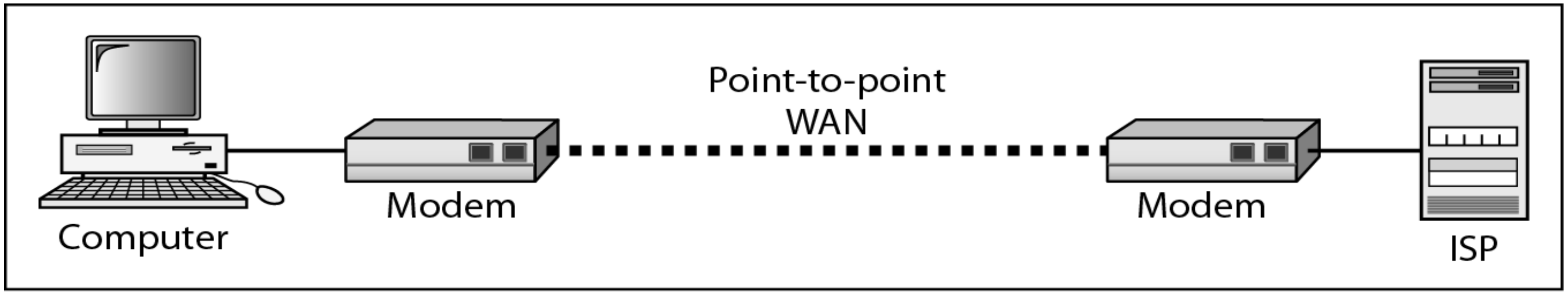
– Long distances

– Provide connectivity over large areas

WANs: a switched WAN and a point-to-point WAN



a. Switched WAN



b. Point-to-point WAN

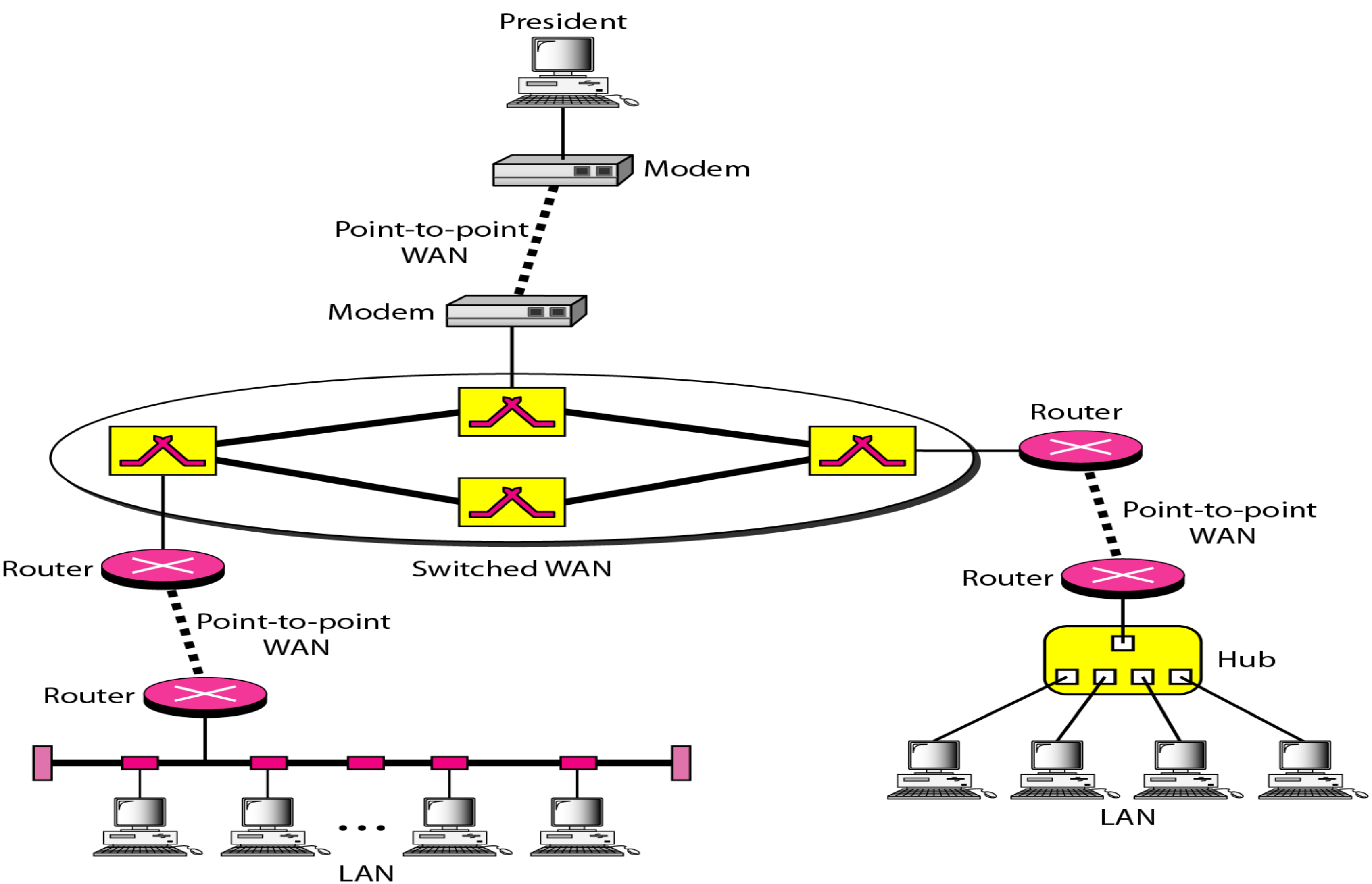
POLL 2

- Switch is a intelligent device

a) True

b) False

A heterogeneous network made of four WANs and two LAN



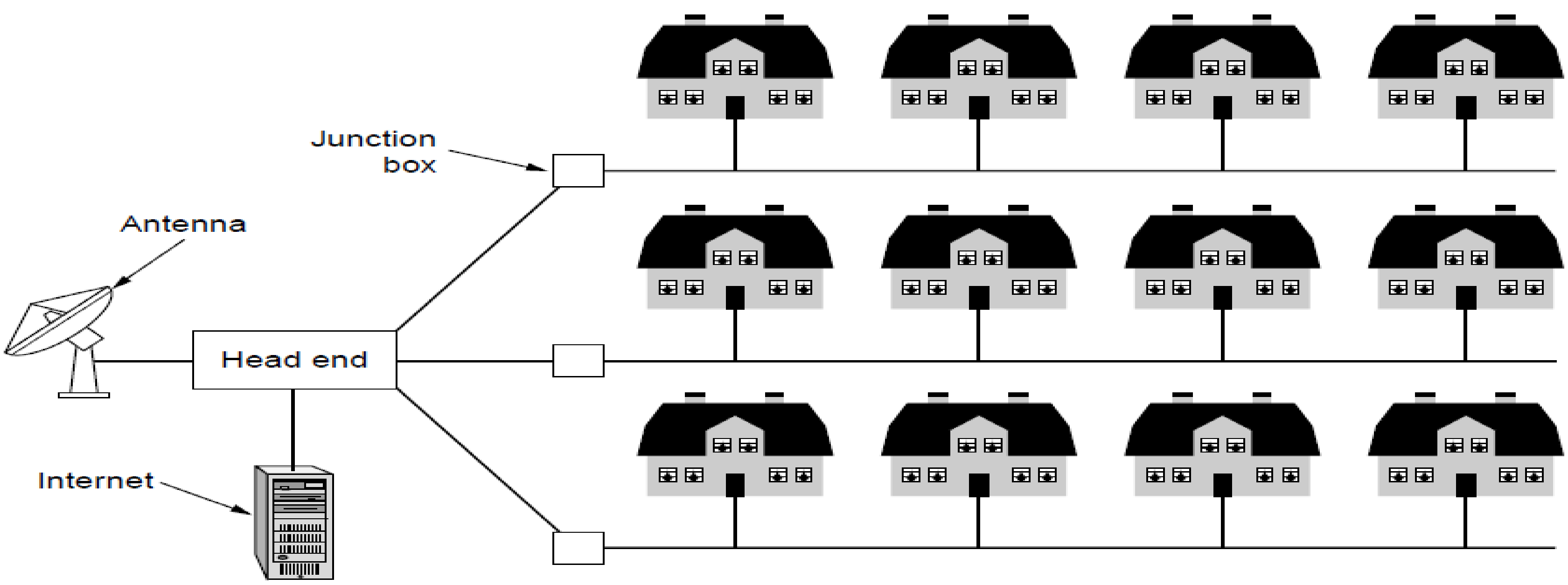
POLL 3

A heterogenous network may include

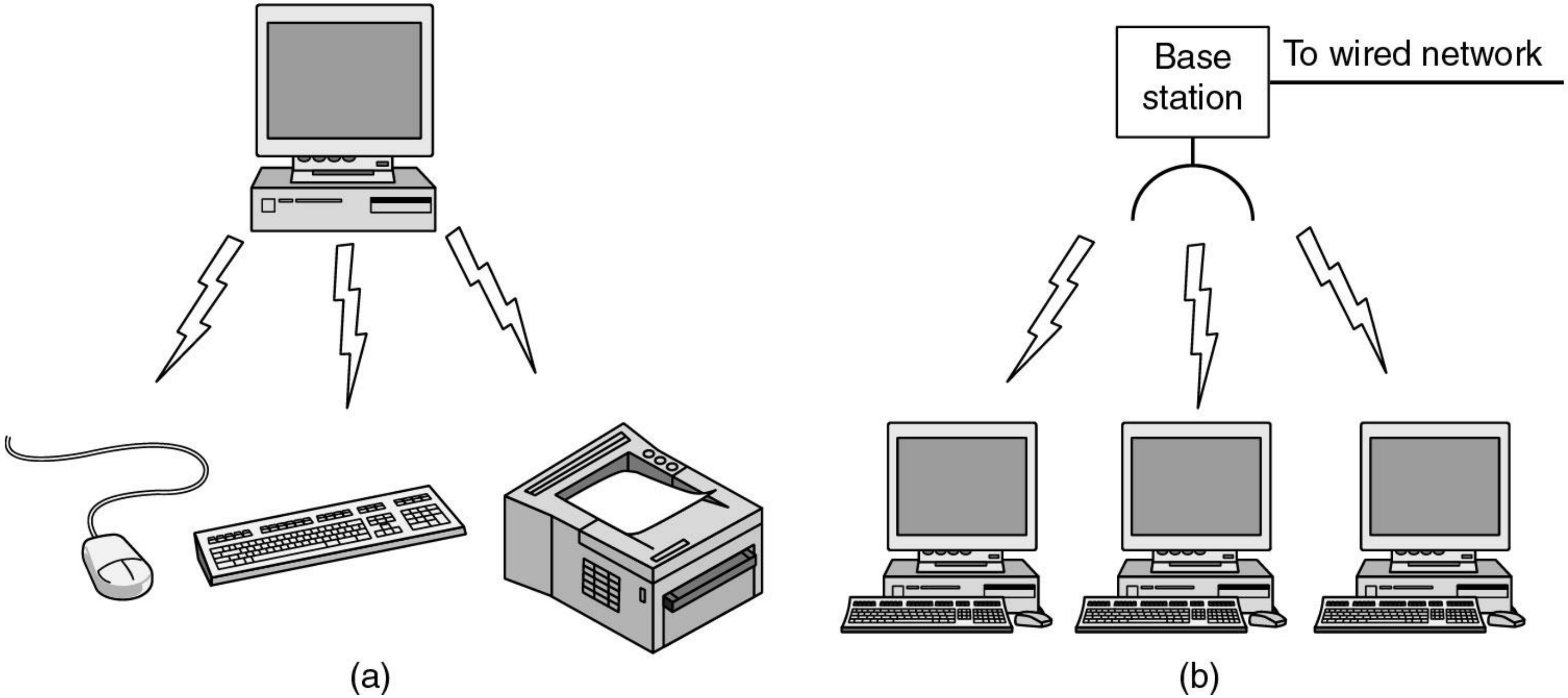
a) Hub only
b) Hub and Switch only
c) Switch and Router only
d) Hub, Switch and Router

Metropolitan Area Networks (MANs)

- Provide connectivity over areas such as a city, a campus
- A metropolitan area network based on cable TV or telephone cable using DSL

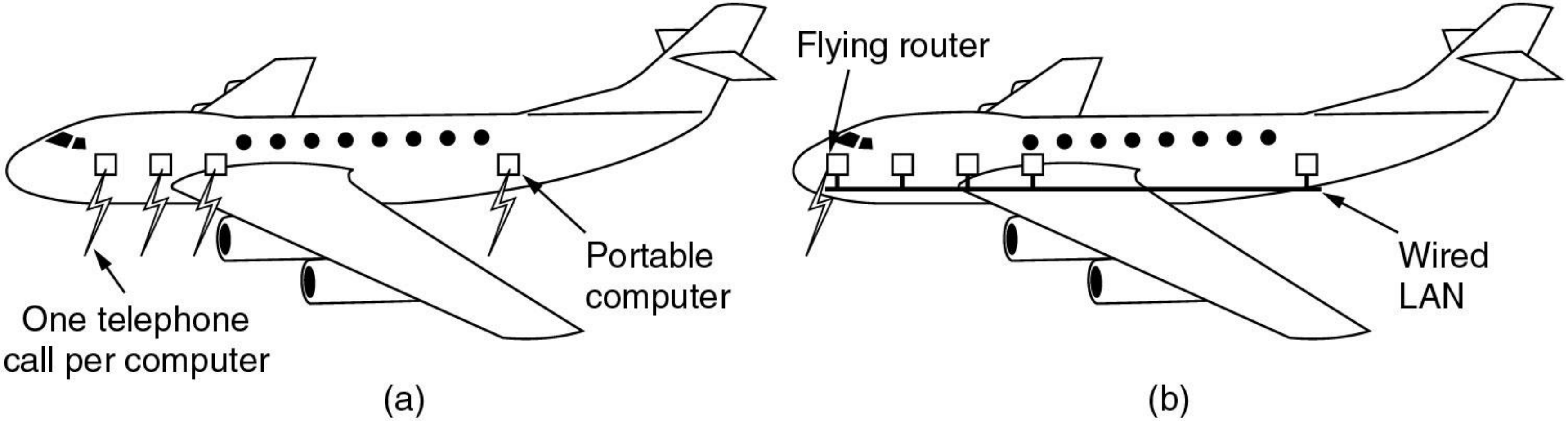


Wireless Networks



- (a) Bluetooth configuration
- (b) Wireless LAN

Wireless Networks



- (a) Individual mobile computers
- (b) A flying LAN

Home Network Categories

- Computers (desktop PC, PDA, shared peripherals
- Entertainment (TV, DVD, VCR, camera, stereo, MP3)
- Telecomm (telephone, cell phone, intercom, fax)
- Appliances (microwave, fridge, clock, furnace, airco)
- Telemetry (utility meter, burglar alarm, babycam).

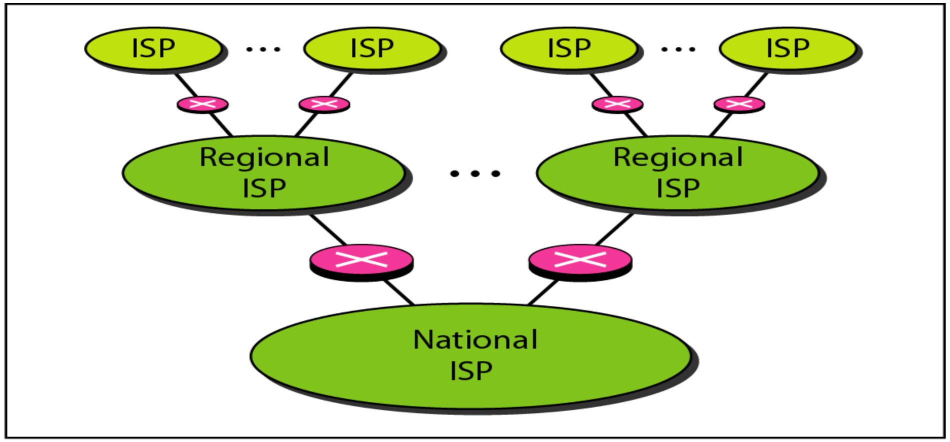
THE INTERNET

- Inter connection of two or more networks become an internet.

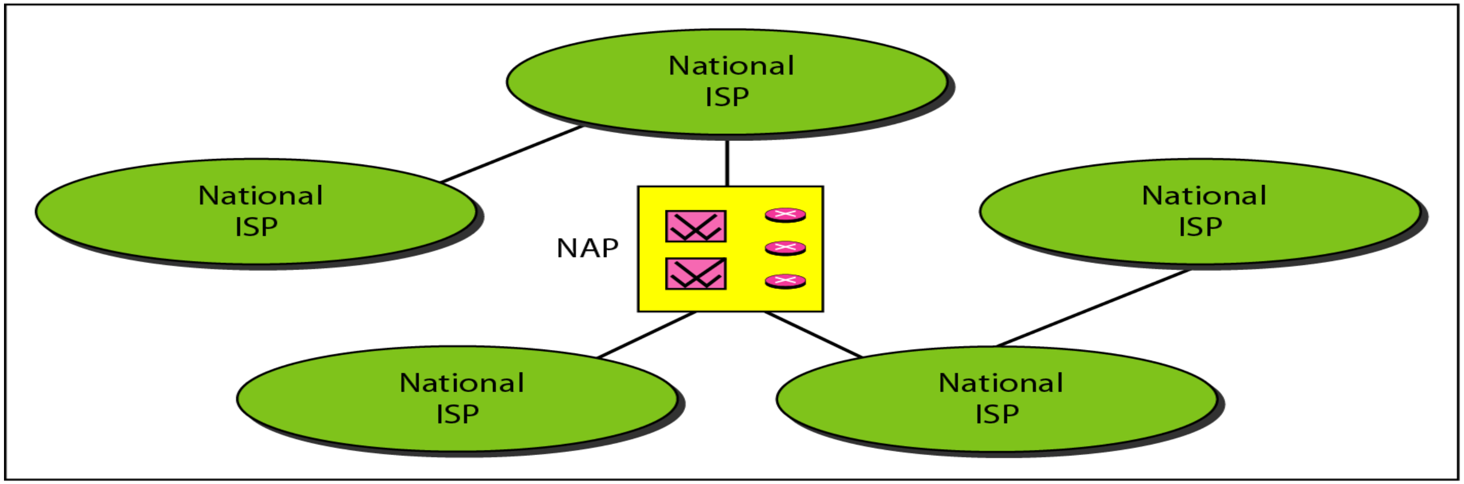
- The Internet has revolutionized many aspects of our daily lives. It has affected the way we do business as well as the way we spend our leisure time.

- The Internet is a communication system that has brought a wealth of information to our fingertips and organized it for our use.

Hierarchical organization of the Internet



a. Structure of a national ISP



b. Interconnection of national ISPs

Broadcast Networks

- Classification of interconnected processors by scale.

Interprocessor distance	Processors located in same	Example
1 m	Square meter	Personal area network
10 m	Room	
100 m	Building	Local area network
1 km	Campus	
10 km	City	Metropolitan area network
100 km	Country	Wide area network
1000 km	Continent	
10,000 km	Planet	The Internet

Network Topologies

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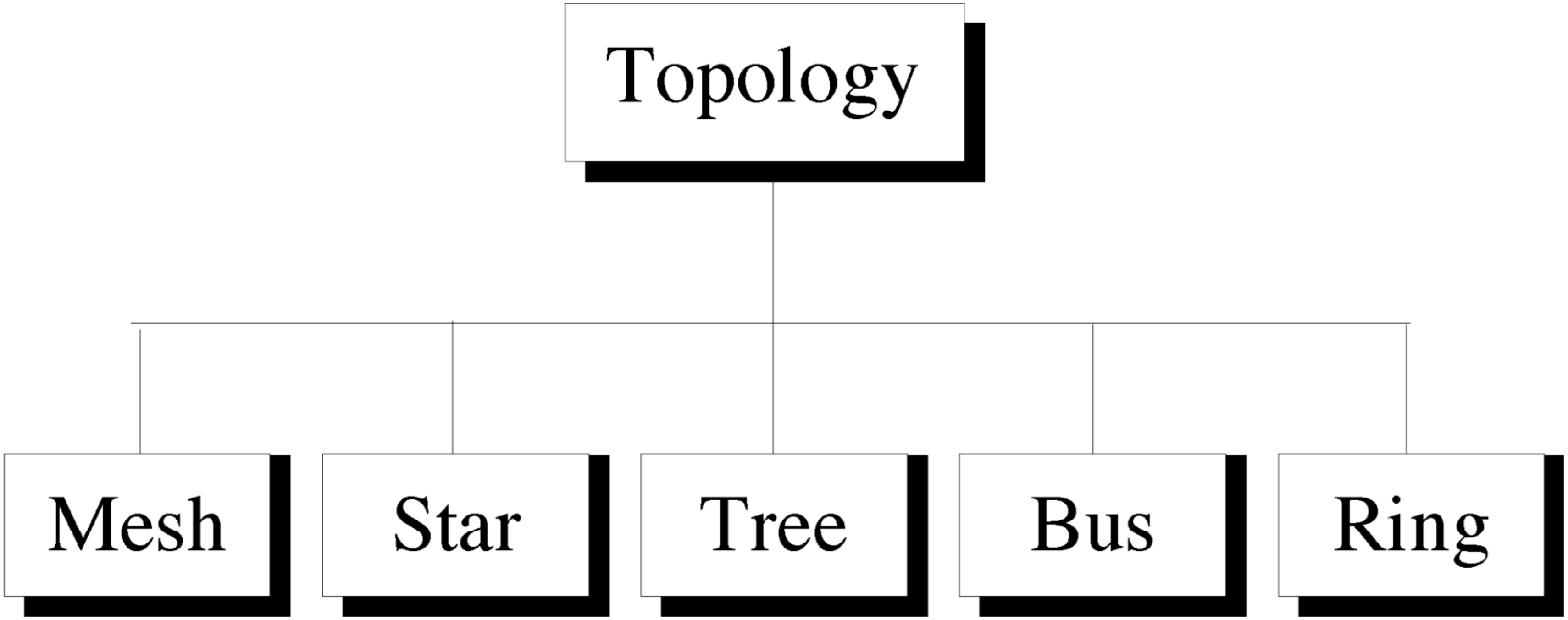
Network Topology

- The topology of a network defines how the nodes of a network are connected.
- The shape of the cabling layout used to link devices is called the **physical topology** of the network.
- The **logical topology**, in contrast, is the way that the signals act on the network media, or the way that the data passes through the network from one device to the next without regard to the physical interconnection of the devices.

Categories of Physical Topology



POLL 1

- Which of the following is NOT is a example of the topologies

a) Mesh

b) Bus

c) Truck

d) Star

Mesh Topology

- Here every device has a point to point link to every other device.
- Node 1 node must be connected with n-1 nodes.
- A fully connected mesh can have $n(n-1)/2$ physical channels to link n devices.
- It must have n-1 I/O ports.

POLL 2

If there are 5 devices, then how many channels are required in a mesh topology

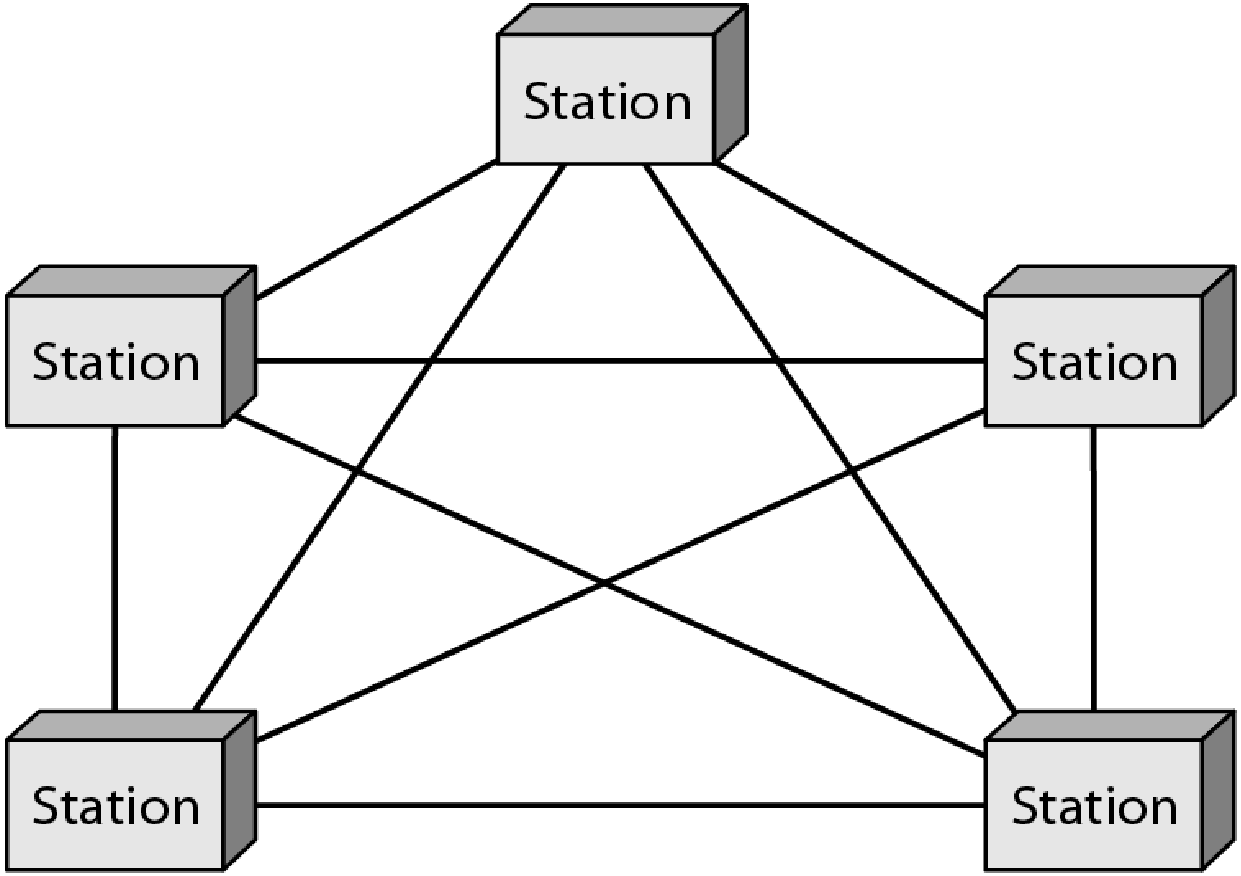
a) 10

b) 15

c) 20

d) 25

A fully connected mesh topology (five devices)



Advantages of Mesh

1. They use dedicated links so each link can only carry its own data load. So traffic problem can be avoided.
2. It is robust. If any one link get damaged it cannot affect others.
3. It gives privacy and security.(Message travels along a dedicated link)
4. Fault identification and fault isolation are easy.

Disadvantages of Mesh

1. The amount of cabling and the number of I/O ports required are very large. Since every device is connected to each devices through dedicated links.
2. The sheer bulk of wiring is larger then the available space.
3. Hardware required to connected each device is highly expensive.

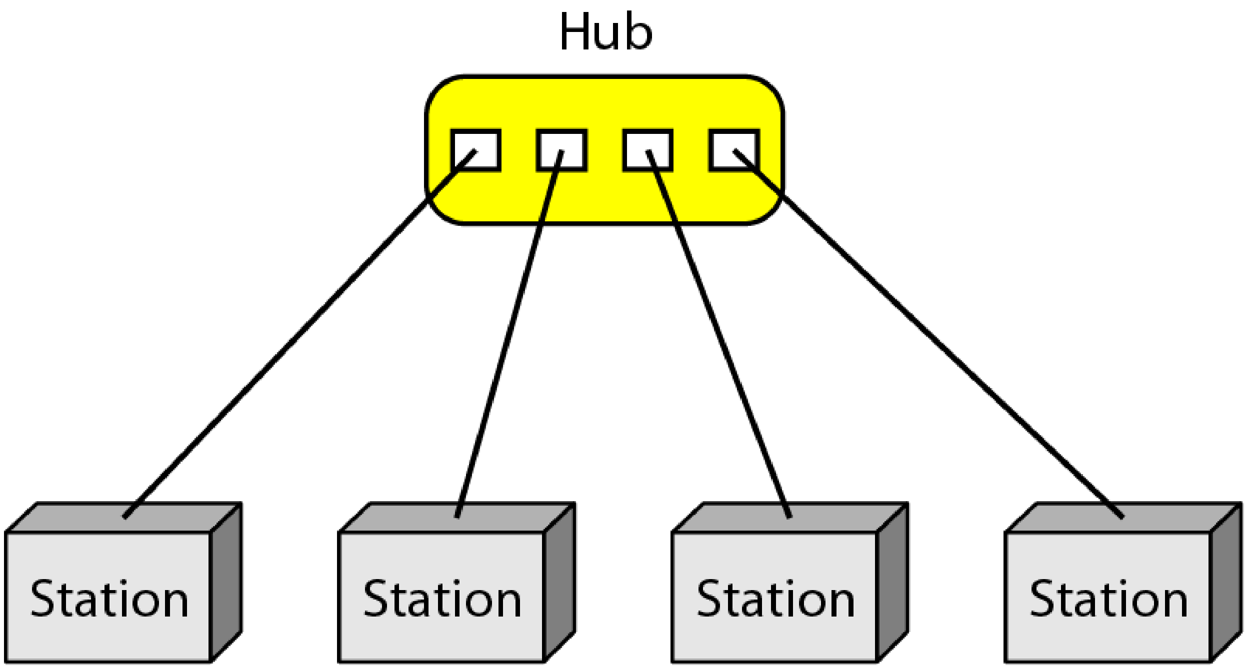
Applications of Mesh

1. Telephone Regional office.
2. WAN.(Wide Area Network).

Star Topology

- Here each device has a dedicated point-to-point link to the central controller called “Hub”(Act as a Exchange).
- There is no direct traffic between devices.
- The transmission are occurred only through the central “hub”.
- When device 1 wants to send data to device 2; First sends the data to hub. Which then relays the data to the other connected device.

Star Topology



Advantages of Star Topology

1. Less expensive then mesh since each device is connected only to the hub.
2. Installation and configuration are easy.
3. Less cabling is need then mesh.
4. Robustness.(if one link fails, only that links is affected. All other links remain active)
5. Easy to fault identification & to remove parts.
6. No distruptions to the network then connecting(or) removing devices.

Disadvantages of Star Topology

1. Even it requires less cabling then mesh when compared with other topologies it still large.(Ring or bus).

2. Dependency(whole n/w dependent on one single point(hub). When it goes down. The whole system is dead.

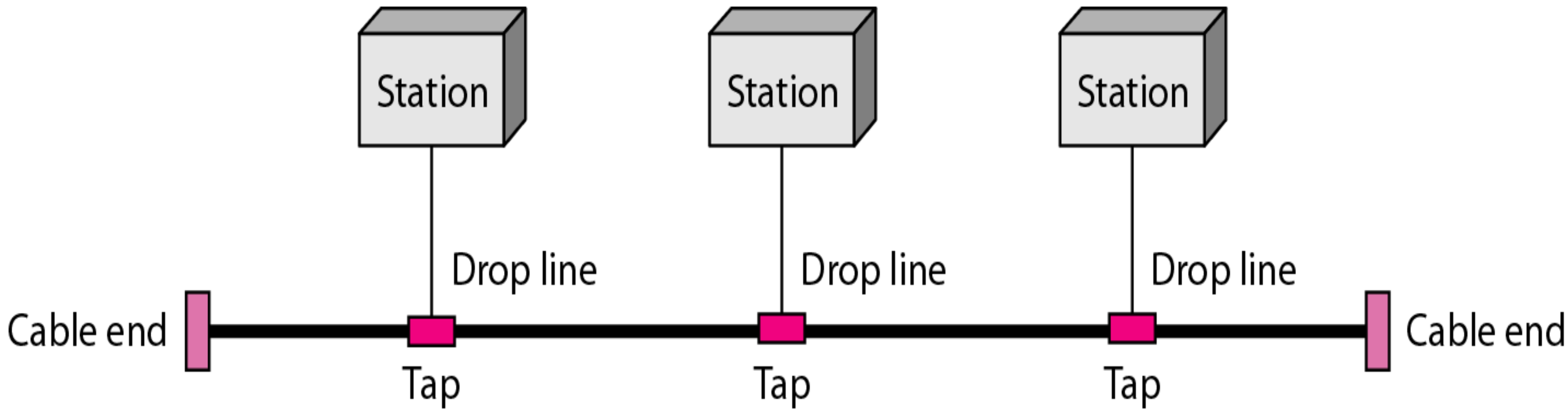
Applications of Star Topology

- Star topology used in Local Area Networks(LANs).
- High speed LAN often used STAR.

Bus Topology

- A bus topology is multipoint.
- Here one long cable act as a backbone to link all the devices are connected to the backbone by drop lines and taps.
- Drop line- is the connection b/w the devices and the cable.
- Tap- is the splitter that cut the main link.
- This allows only one device to transmit at a time.

Bus Topology



- When a device sends a message, it is broadcast down on the cable in both directions. Terminators at the end of the cable prevent the signal from reflecting back to the sender.

- All devices on the cable constantly monitor for messages meant to them. When a device detects a message meant for it, it reads the message from the cable and the other devices will ignore it.

- Since all devices are sharing the same cable, some form of control is needed to make sure which device will transmit when, otherwise there will be a collision.

Advantages of Bus Topology

1. Ease of installation.
2. Less cabling.
3. less expensive.

Disadvantages of Bus Topology

1. Difficult reconfiguration and fault isolation.
2. Difficult to add new devices.
3. Signal reflection at top can degradation in quality.
4. If any fault in backbone can stops all transmission.

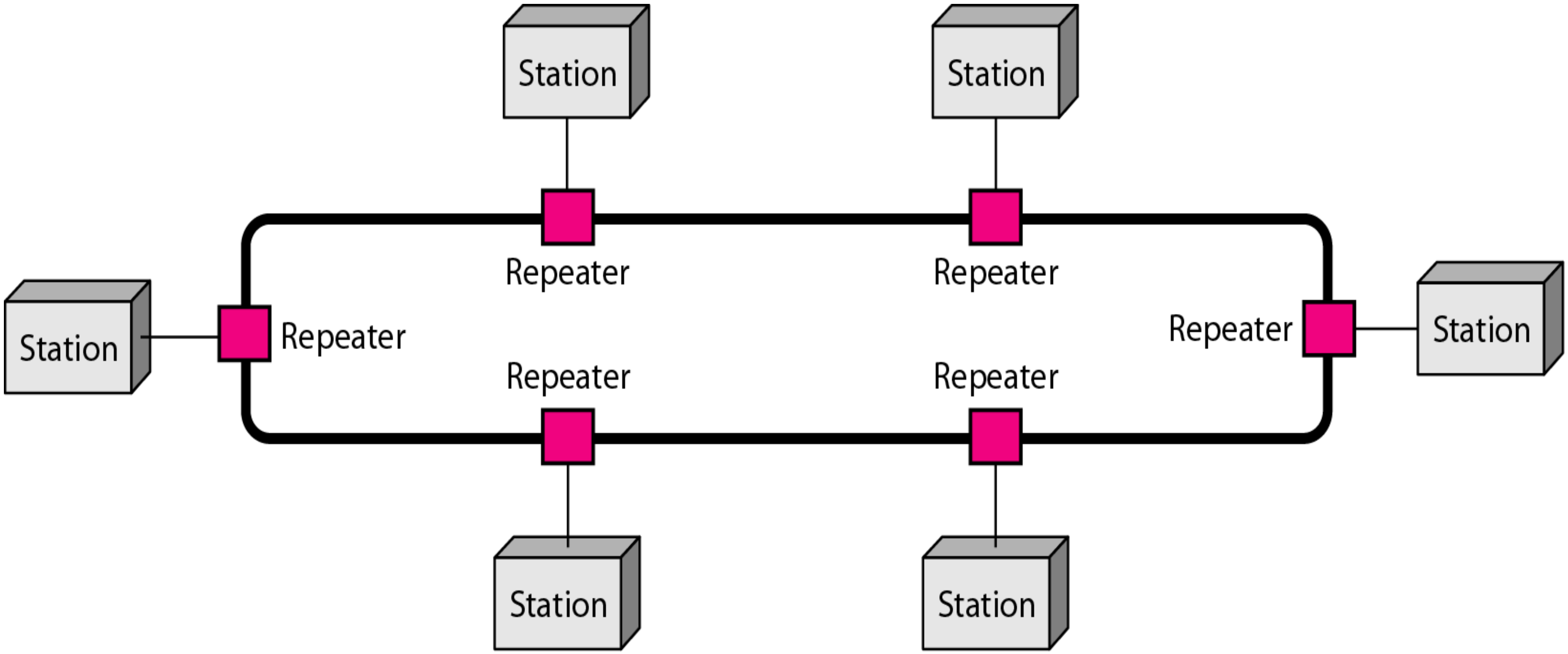
Applications of Bus Topology

- Most computer motherboard.

Ring Topology

- Here each device has a dedicated connection with two devices on either side.
- The signal is passed in one direction from device to device until it reaches the destination and each device have repeater.
- When one device received signals instead of intended another device, its repeater then regenerates the data and passes them along.
- To add or delete a device requires changing only two connections.

Ring Topology



Ring Topology

Advantages:

1. Easy to install.
2. Easy to reconfigure.
3. Fault identification is easy.

Disadvantages:

1. Unidirectional traffic.
2. Break in a single ring can break entire network.

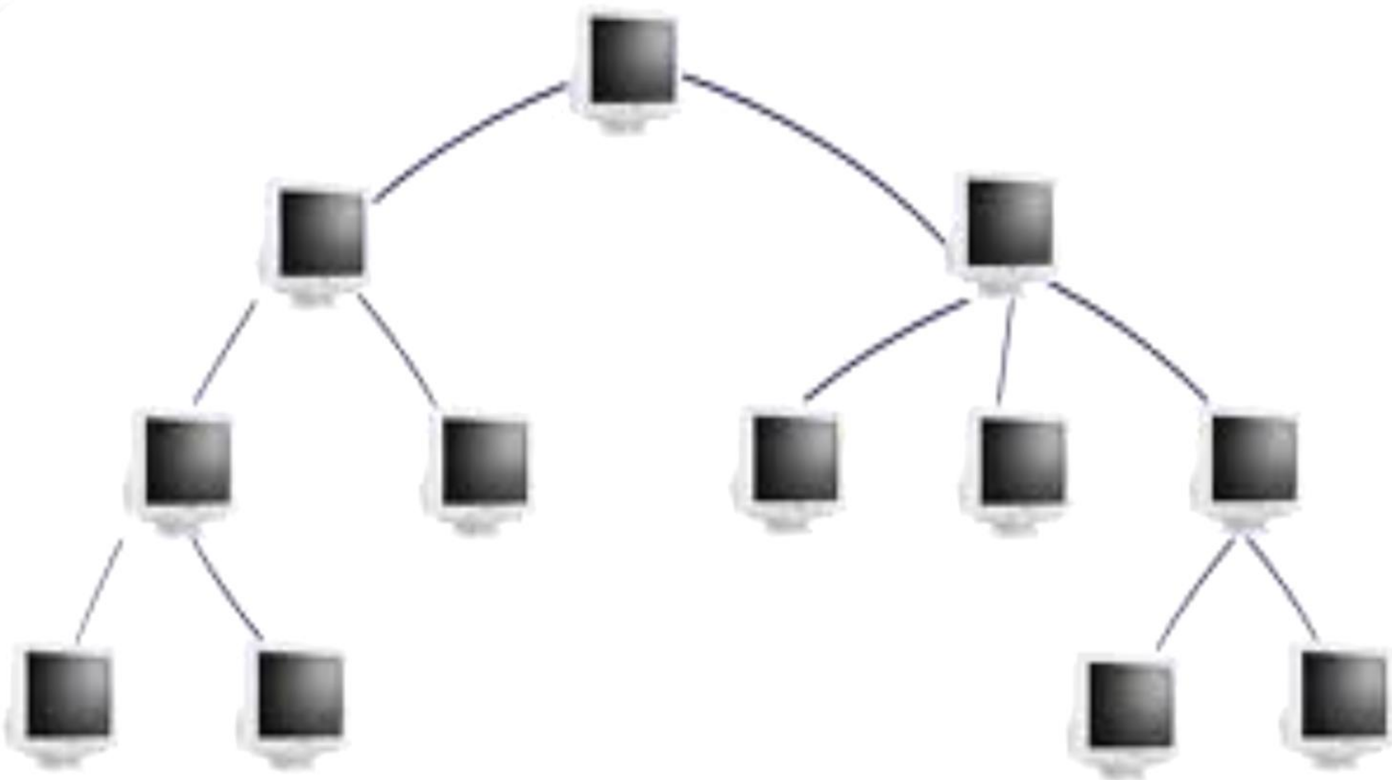
Ring Topology

Applications:

- Ring topologies are found in some office buildings or school campuses.
- Today high speed LANs made this topology less popular.

Tree Topology

- Alternatively referred to as a star bus topology.
- Tree topology is one of the most common network setups that is similar to a bus topology and a star topology.
- A tree topology connects multiple star networks to other star networks. Below is a visual example of a simple computer setup on a network using the star topology.



Digram - Tree Topology

POLL 3

- Which of the following topology is the most expensive in terms of installation

a) Star

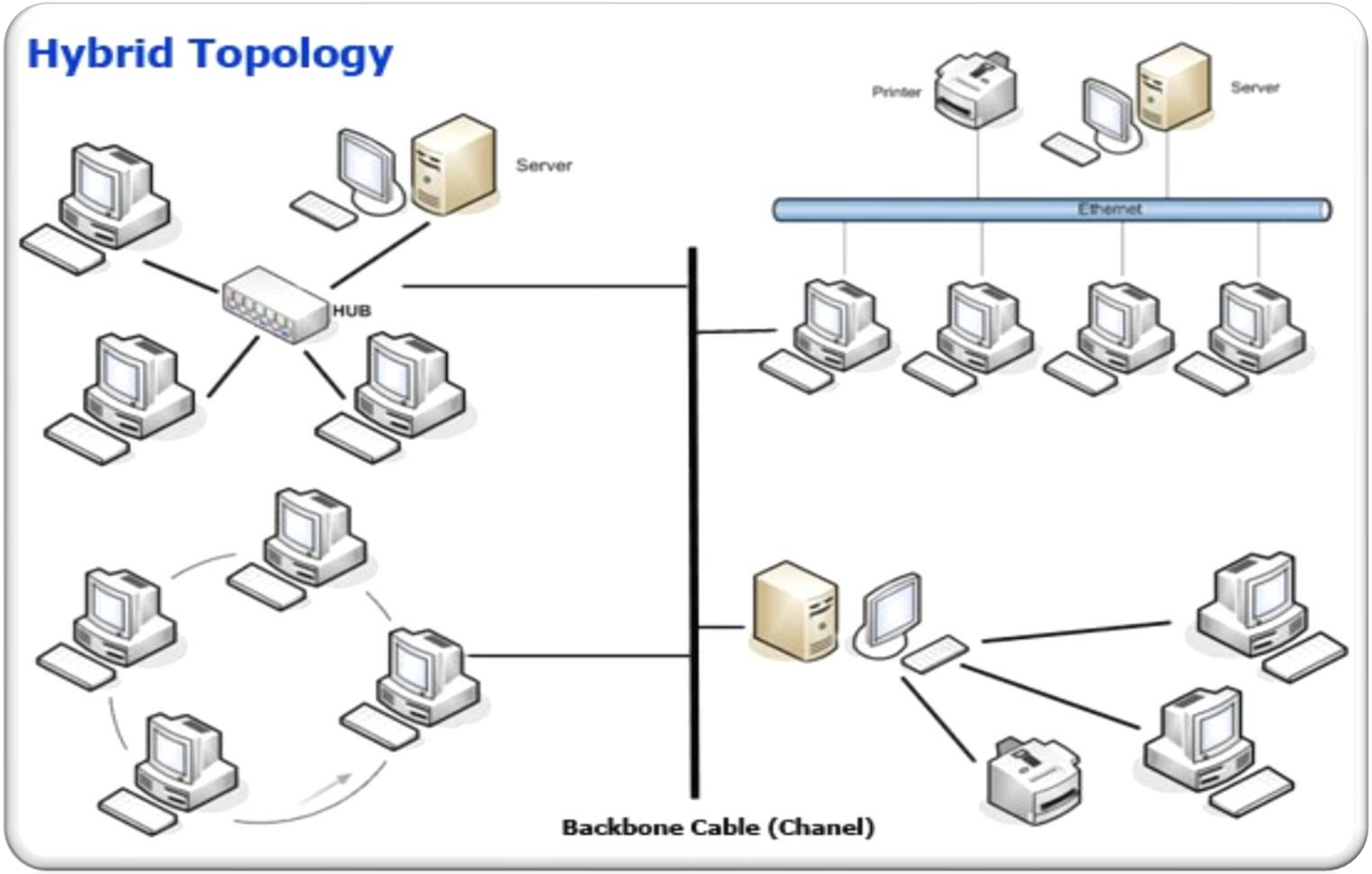
b) Bus

c) Mesh

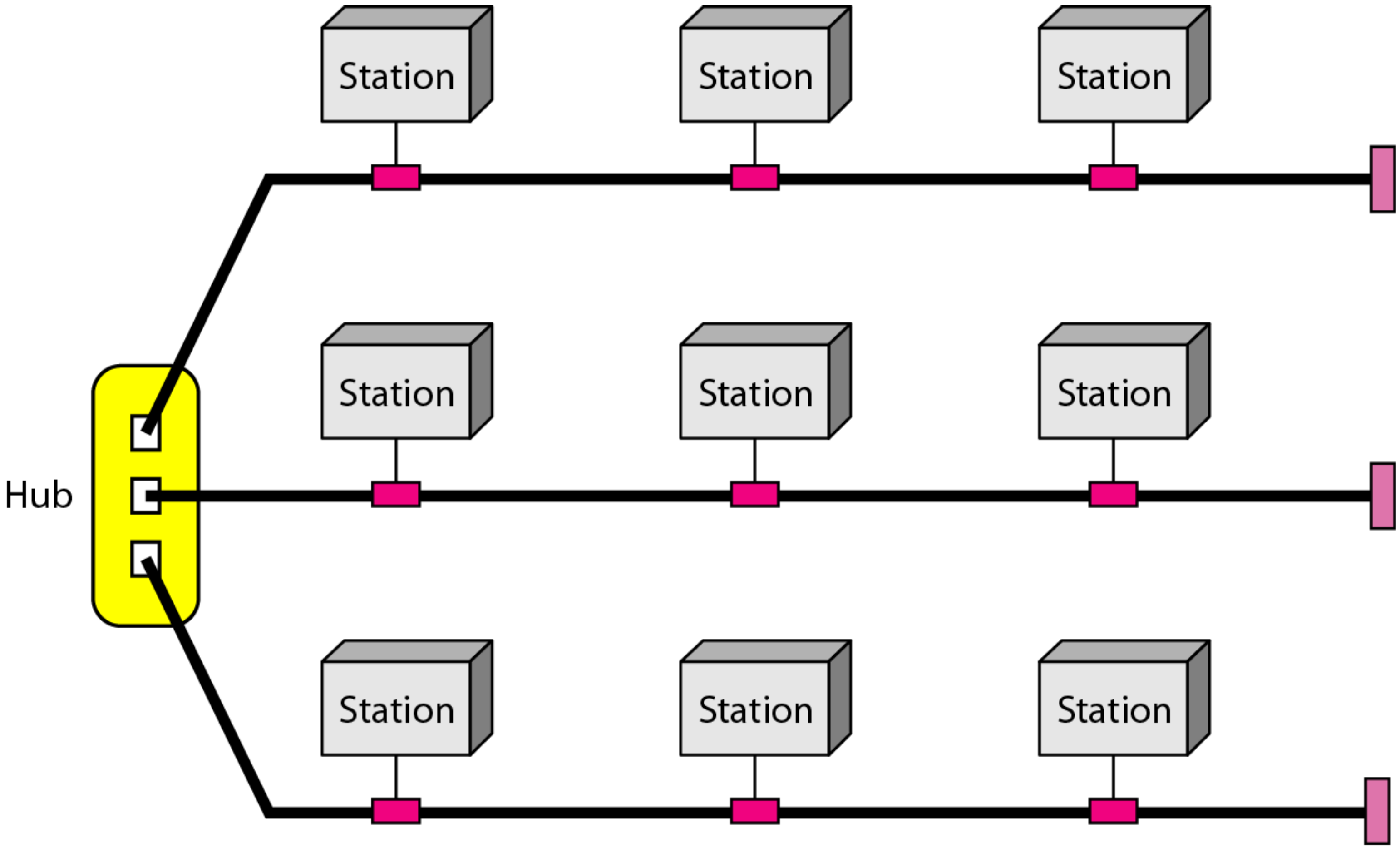
d) Hub

Hybrid Topology

- A network which contain all type of physical structure and connected under a single backbone channel.


Hybrid Topology
Server
HUB
Printer
Server
Ethernet
Backbone Cable (Chanel)

Hybrid Topology



Considerations for Choosing Network Topology

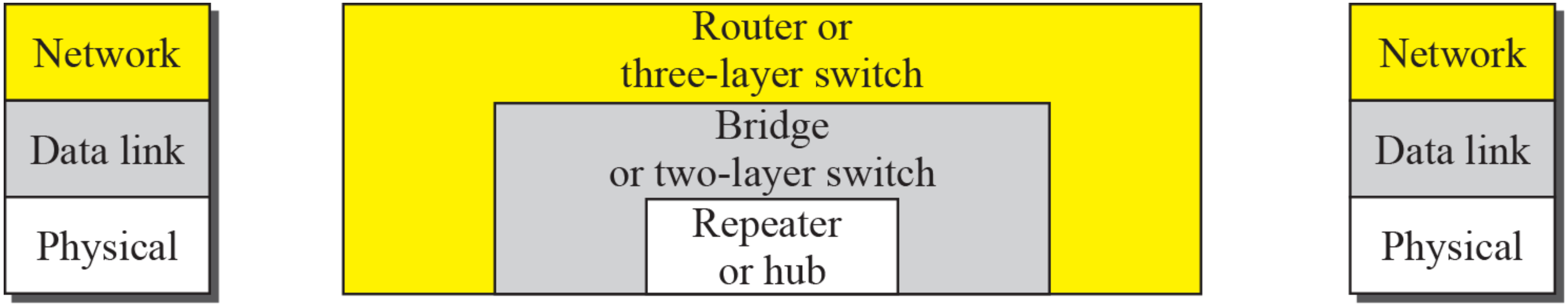
- Money-Bus n/w may be the least expensive way to install a n/w.
- Length-of cable needed- the linear bus n/w uses shorter lengths of cable.
- Future growth-with star topology, expending a n/w is easily done by adding another devices.
- Cable type-most common used cable in commercial organization is twisted pair. Which is often used with star topologies.

- Full **mesh topology** is theoretically the best since every device is connected to every other device.(thus maximizing speed and security. however, it quite expensive to install)
- Next best would be **tree topology** , which is basically a connection of star.

Backbone Networks: Serial Backbone

- Daisy chain: linked series of devices
  - Hubs and switches often connected in daisy chain to extend a network
- Hubs, gateways, routers, switches, and bridges can form part of backbone
- Extent to which hubs can be connected is limited

Connecting devices



- Router is also Known as

a) Three Layer Switch

b) Two Layer Switch

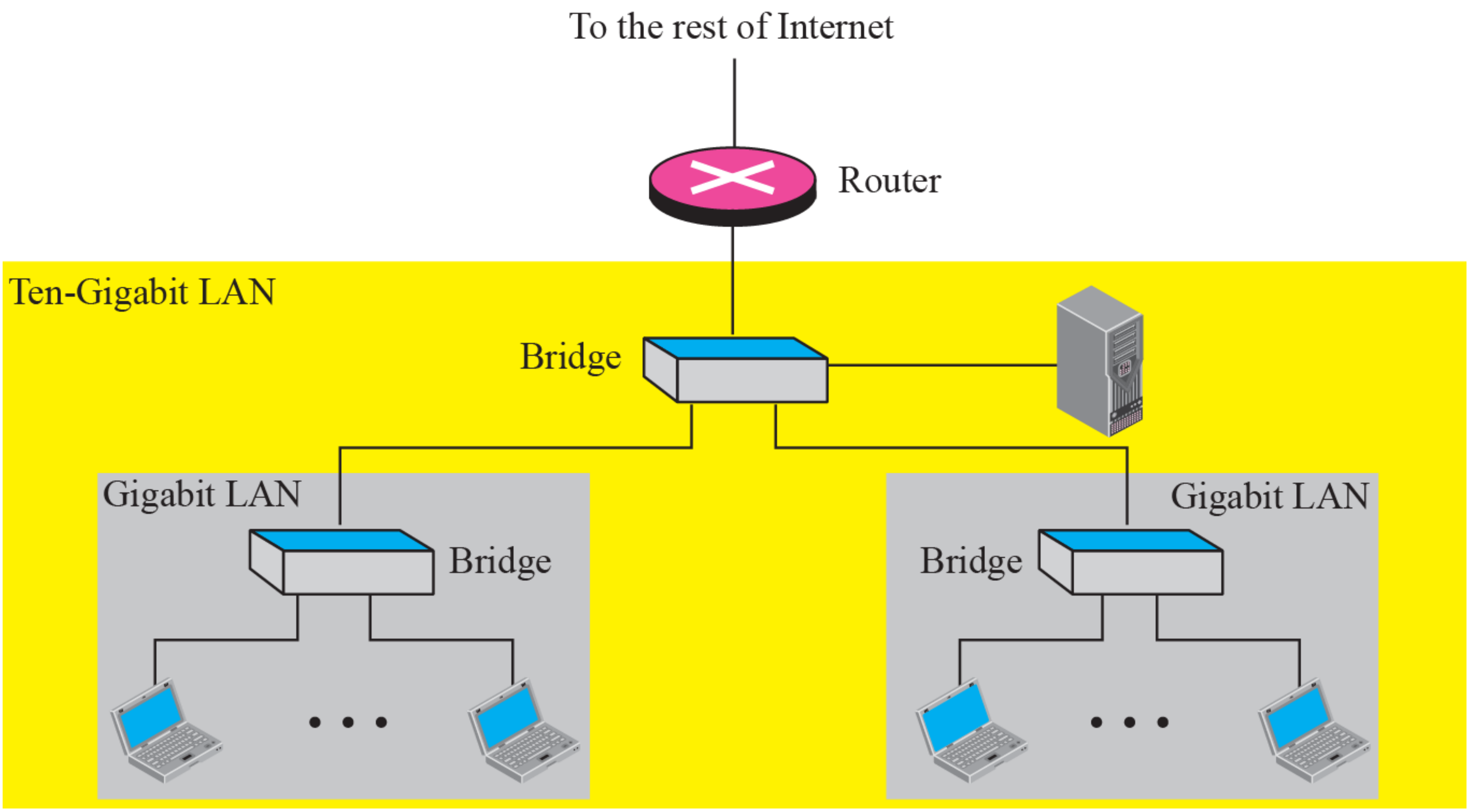
Repeater or hub

A repeater forwards every bit; it has no filtering capability.

A router is a three-layer (physical, data link, and network) device.

A repeater or a bridge connects segments of a LAN. A router connects independent LANs or WANs to create an internetwork (internet).

Routing example



Hub

- Broadcast
- More collision
- Connect same networking device

Switch

- Switch is intelligent device
- Learning the address
- Forwarding
- Work on mac address

Router

- Connect different networks
- Routing

Network Software Architecture and its Layers and Protocols

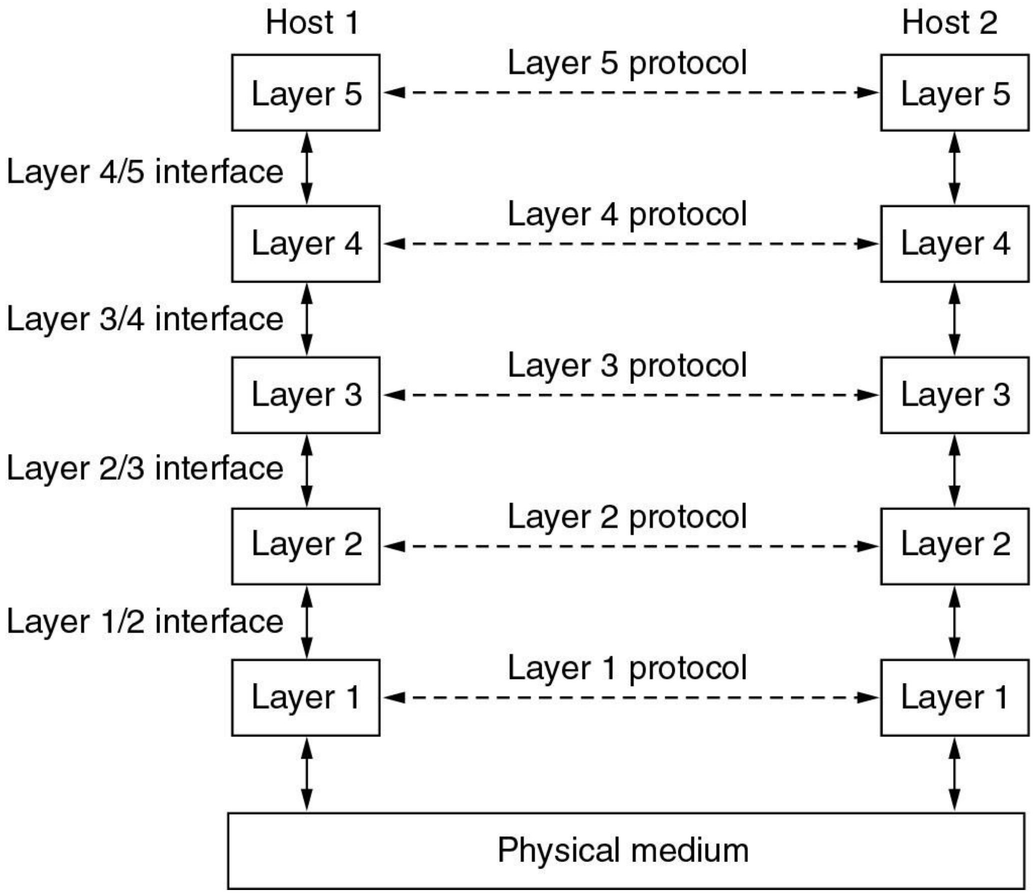
CSE306

Presented by: Dr. Amandeep Singh

Network Software

- Protocol Hierarchies
- Design Issues for the Layers
- Connection-Oriented and Connectionless Services
- Service Primitives
- The Relationship of Services to Protocols

Network Software
Protocol Hierarchies



- Layers, protocols, and interfaces- **Network Architecture**

POLL 1

- Network Architecture includes which of the following

a) Layers

b) Protocols

c) Interfaces

d) All of the above

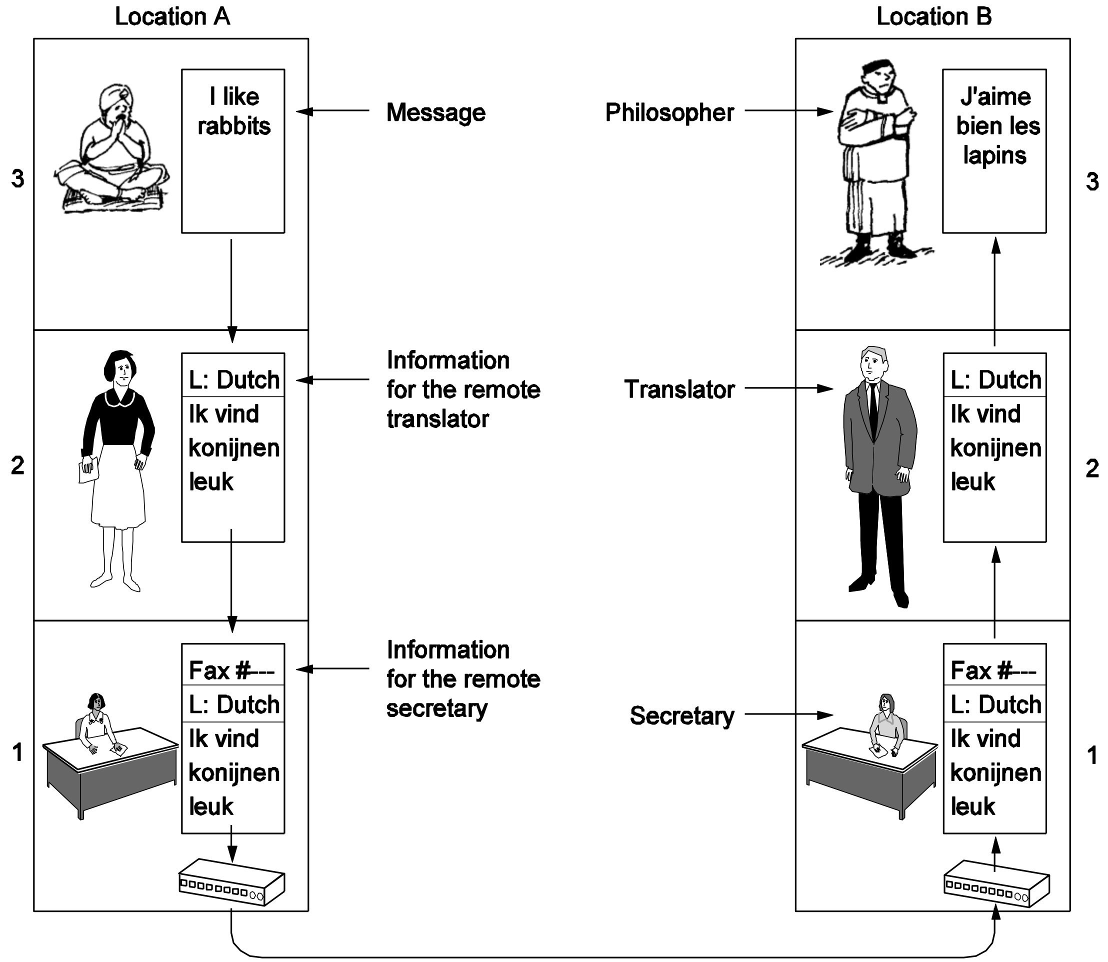
- A **protocol** is an agreement between the communicating parties on how communication is to proceed.

- The entities comprising the corresponding layers on different machines are called **peers.** The peers may be software processes, hardware devices, or even human beings. In other words, it is the peers that communicate by using the protocol to talk to each other.

- A list of the protocols used by a certain system, one protocol per layer, is called a **protocol stack.**

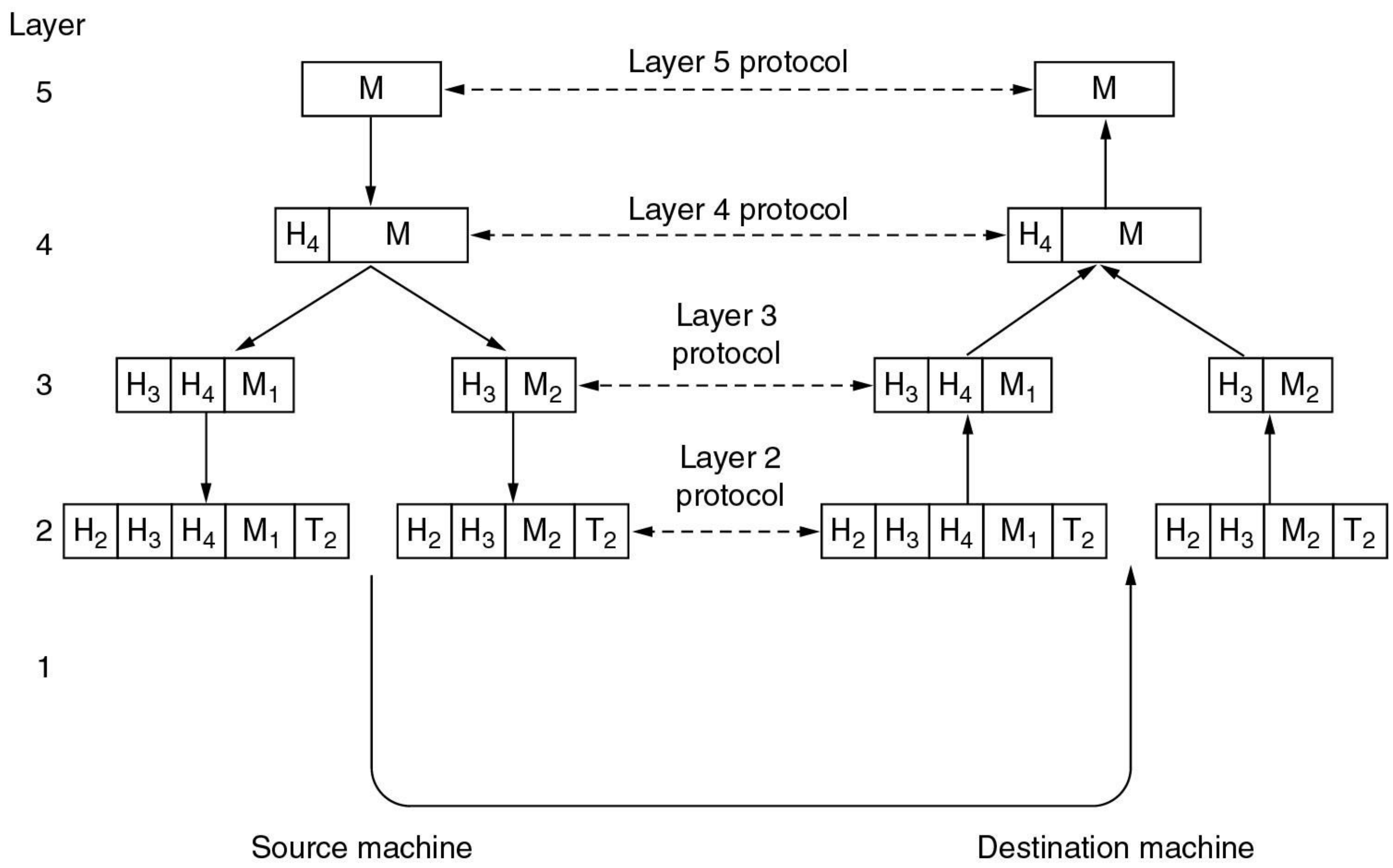
Protocol Hierarchies (2)

- The philosopher-translator-secretary architecture.



Protocol Hierarchies (3)

- Example information flow supporting virtual communication in layer 5.



Design Issues for the Layers

- Addressing or naming
- Error Control
- Flow Control---*Congestion*
- Statistical Multiplexing
- Routing
- Scalable
- Quality of Service (QoS)---*real time*
- Reliability
- Security

Connection-Oriented and Connectionless Services

- A **circuit is another name for a connection with associated resources,** such as a fixed bandwidth.
- This dates from the telephone network in which a circuit was a path over copper wire that carried a phone conversation.
- In contrast to connection-oriented service, **connectionless service is modeled** after the postal system.
- Each message (letter) carries the full destination address, and each one is routed through the intermediate nodes inside the system independent of all the subsequent messages.
- **Store or forward switching**
- **Cut through switching**

- Each kind of service can further be characterized by its reliability. Some services are reliable in the sense that they never lose data.

- Usually, a reliable service is implemented by having the receiver acknowledge the receipt of each message so the sender is sure that it arrived.

- Reliable connection-oriented service has two minor variations: **message sequences and byte streams.**

- The acknowledgement process introduces overhead and delays, which are often worth it but are sometimes undesirable.

- One such application is digitized voice traffic for voice over IP.

- Unreliable (meaning *not acknowledged*) connectionless service is often called **datagram service.**

POLL 2

- A connection-less service needs acknowledgement

a) True

b) False

Connection-Oriented and Connectionless Services

- Six different types of service.

	Service	Example
Connection-oriented	Reliable message stream	Sequence of pages
	Reliable byte stream	Remote login
	Unreliable connection	Digitized voice
Connection-less	Unreliable datagram	Electronic junk mail
	Acknowledged datagram	Registered mail
	Request-reply	Database query

POLL 3

Voice- over internet is an example of which service(in layers):

a. Connection-less service

b. Connection –oriented Service

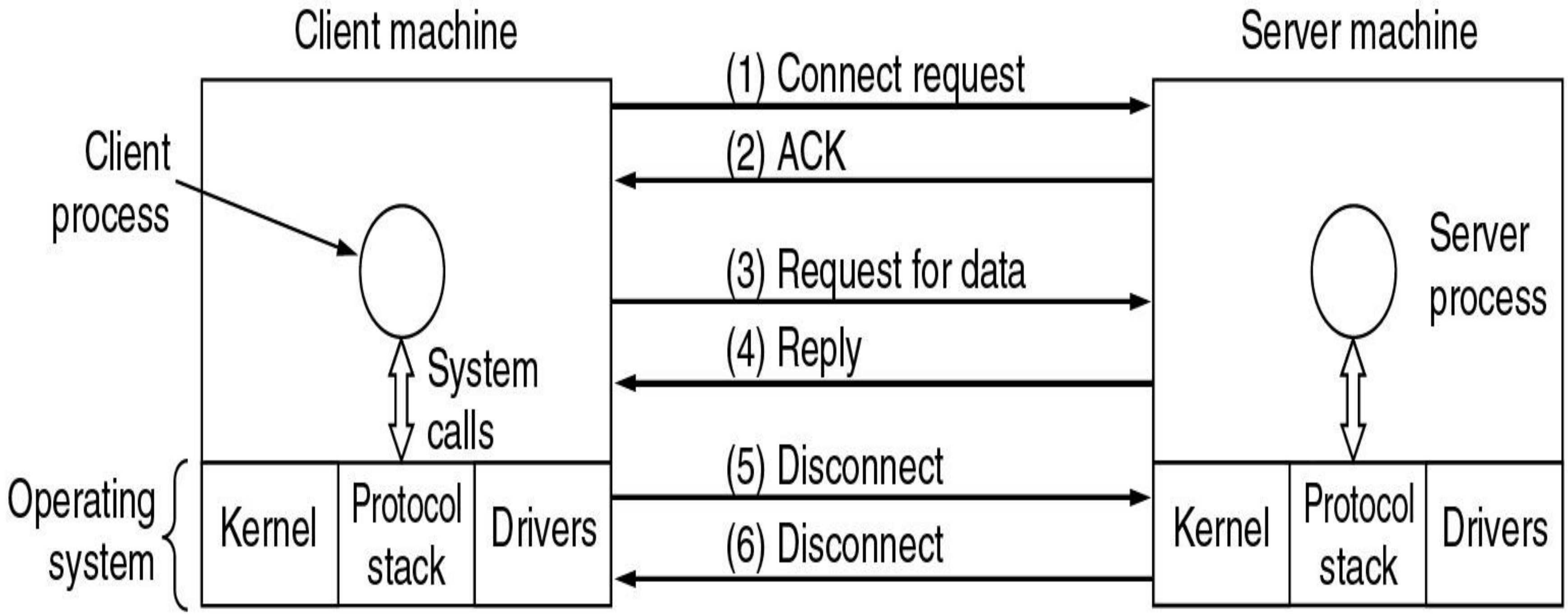
c. Both a and b

Service Primitives

Primitive	Meaning
LISTEN	Block waiting for an incoming connection
CONNECT	Establish a connection with a waiting peer
RECEIVE	Block waiting for an incoming message
SEND	Send a message to the peer
DISCONNECT	Terminate a connection

- Five service primitives for implementing a simple connection-oriented service.

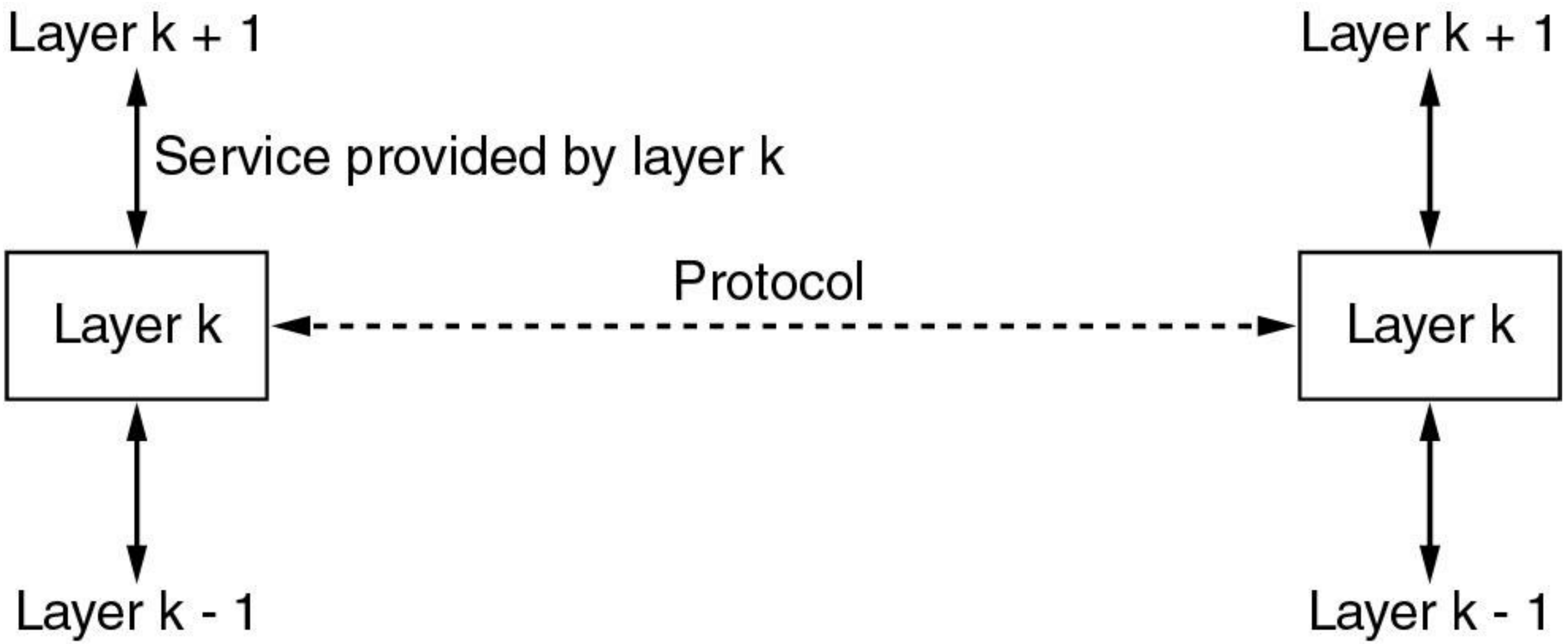
Service Primitives (2)



- Packets sent in a simple client-server interaction on a connection-oriented network.

Services to Protocols Relationship

- The relationship between a service and a protocol.



OSI
Model
and
TCP/IP protocol suite)

CSE306
Presented by: Dr. Amandeep Singh

THE OSI MODEL

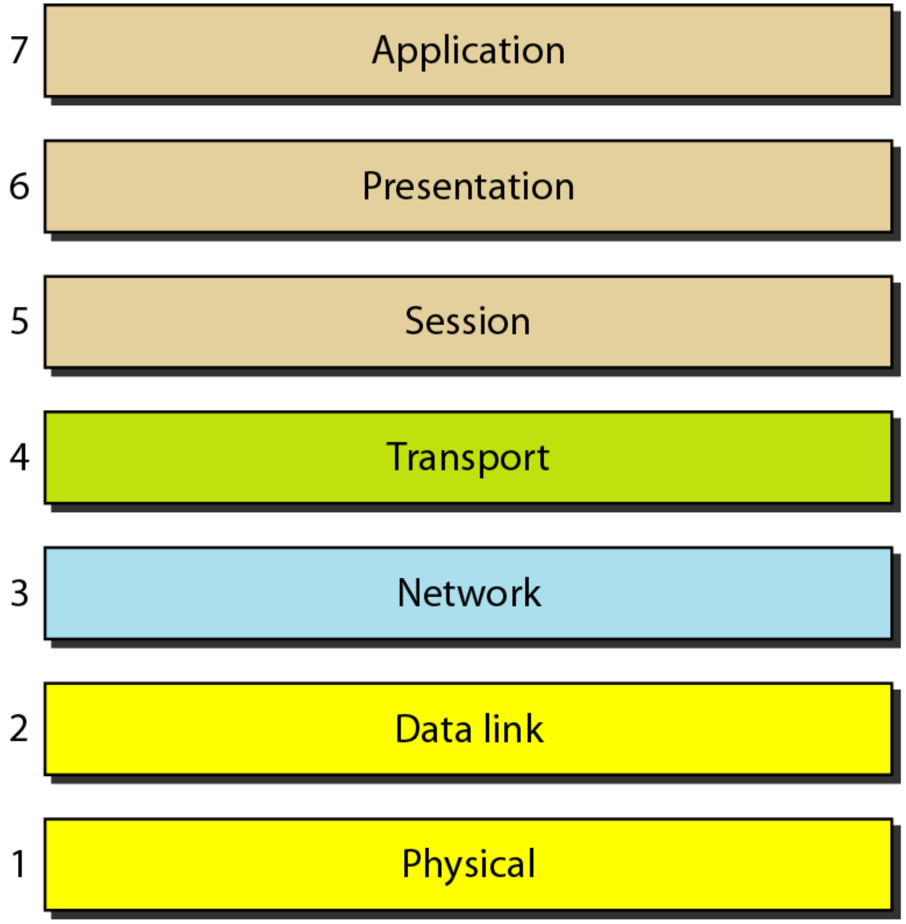
Established in 1947, the International Standards Organization (ISO) is a multinational body dedicated to worldwide agreement on international standards. An ISO standard that covers all aspects of network communications is the Open Systems Interconnection (OSI) model. It was first introduced in the late 1970s.

<u>Topics discussed in this section:</u>

Layered Architecture
Peer-to-Peer Processes
Encapsulation

ISO is the organization.
OSI is the model.

Seven layers of the OSI model



POLL 1

- Which of the following is not an immediate layer to the network layer

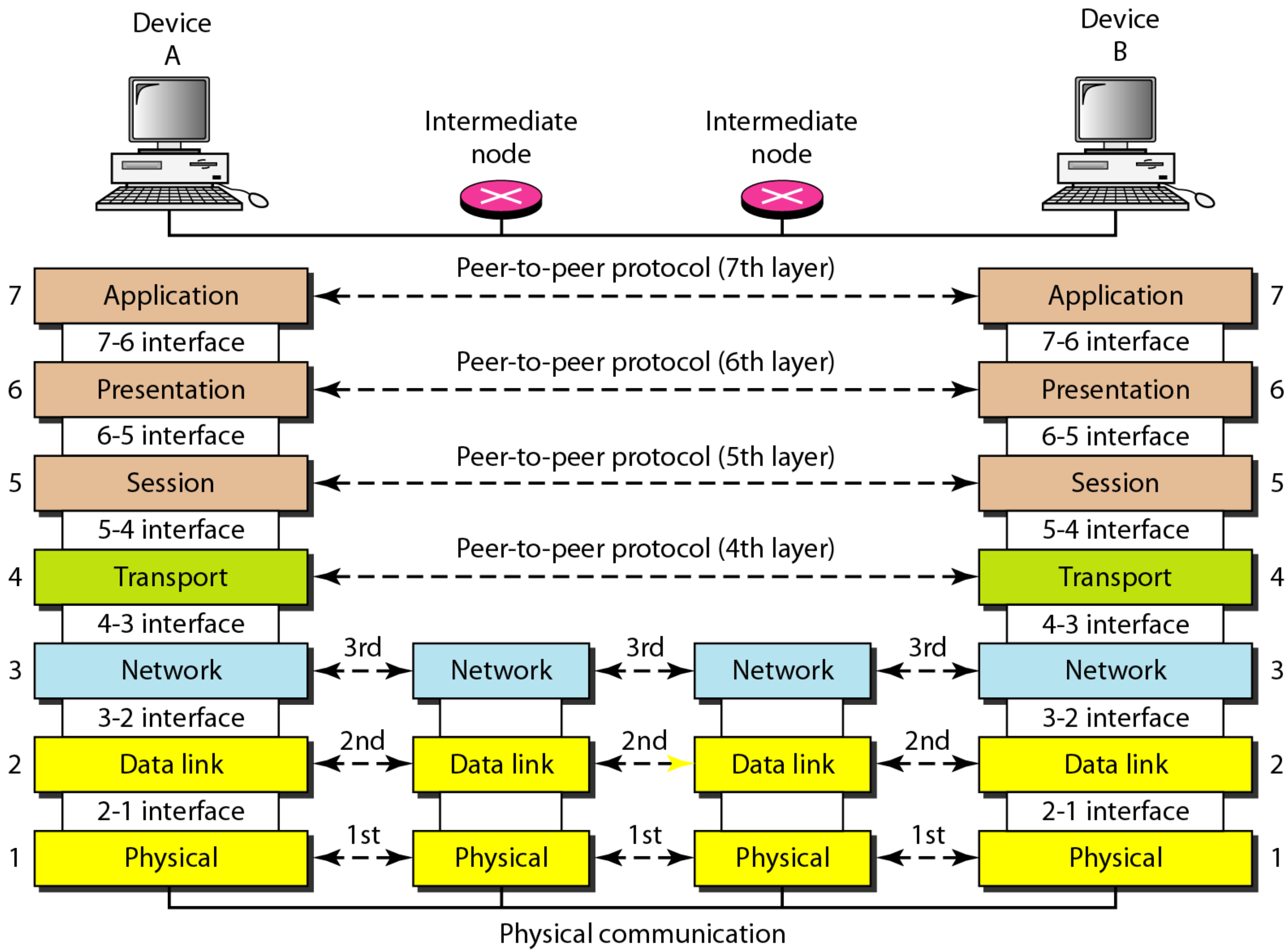
a) Transport Layer

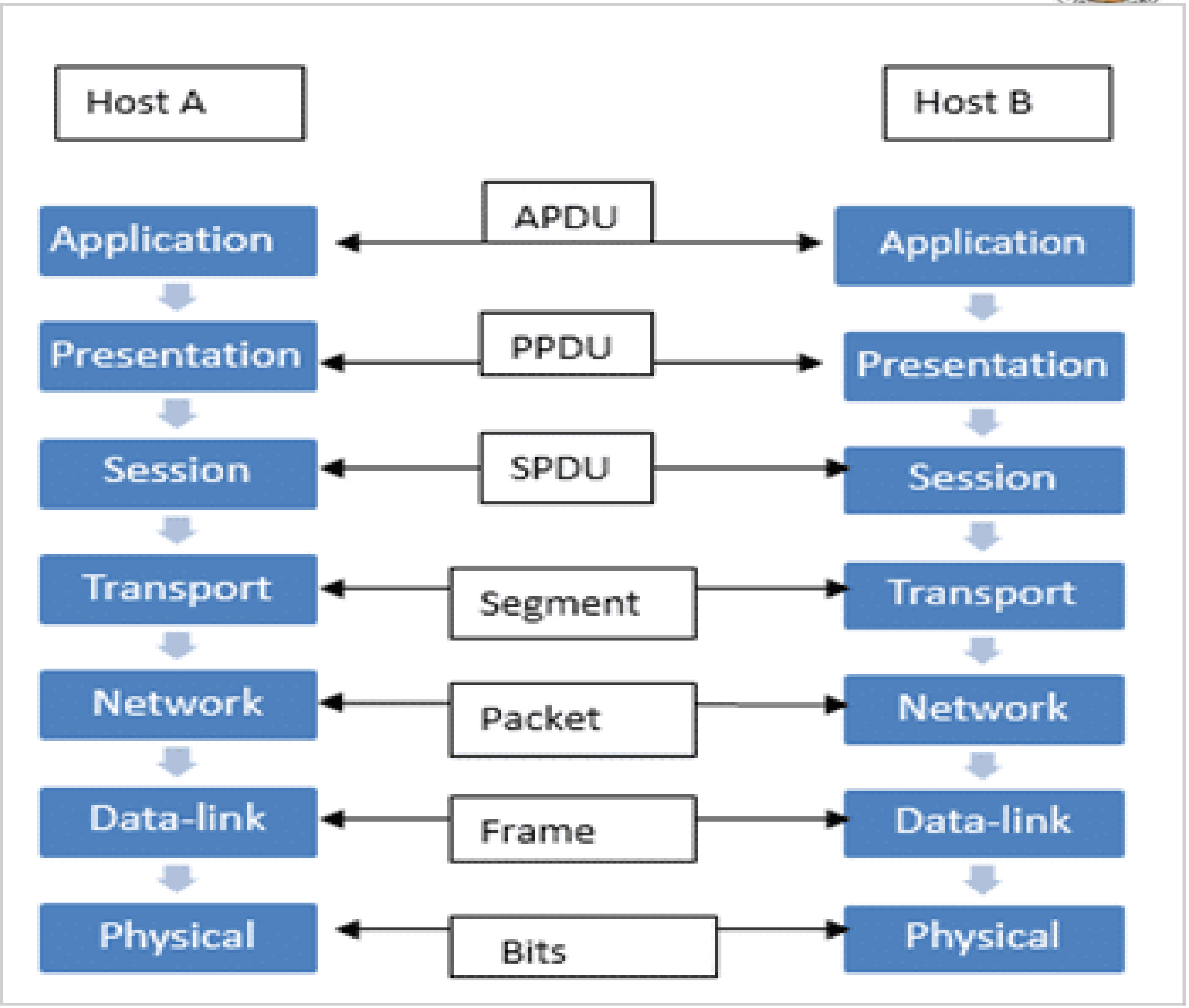
b) Data Link Layer

c) Both

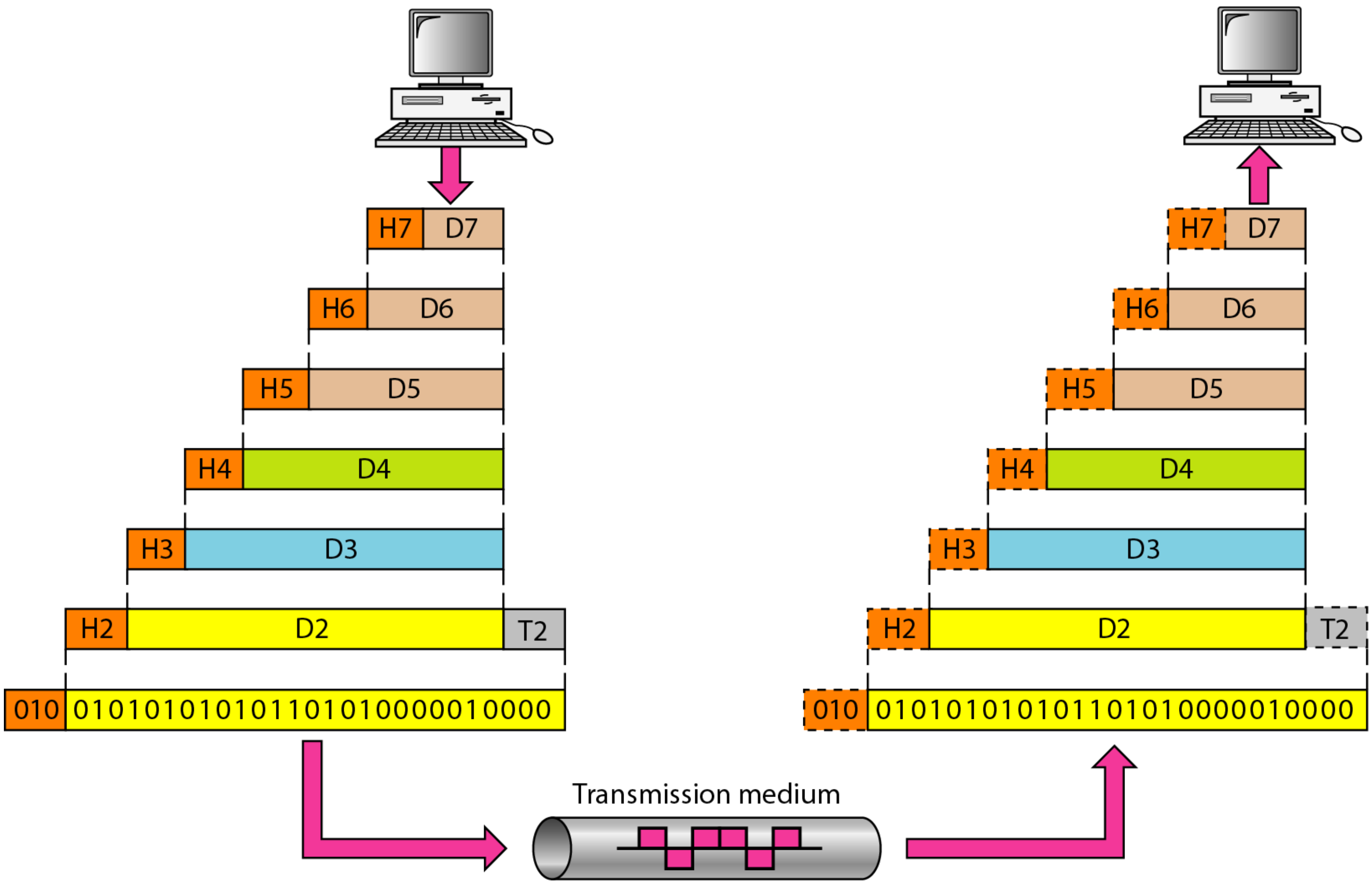
d) None

The interaction between layers in the OSI model




Host A
Host B
Application
APDU
Application
Presentation
PPDU
Presentation
Session
SPDU
Session
Transport
Segment
Transport
Network
Packet
Network
Data-link
Frame
Data-link
Physical
Bits
Physical

An exchange using the OSI model



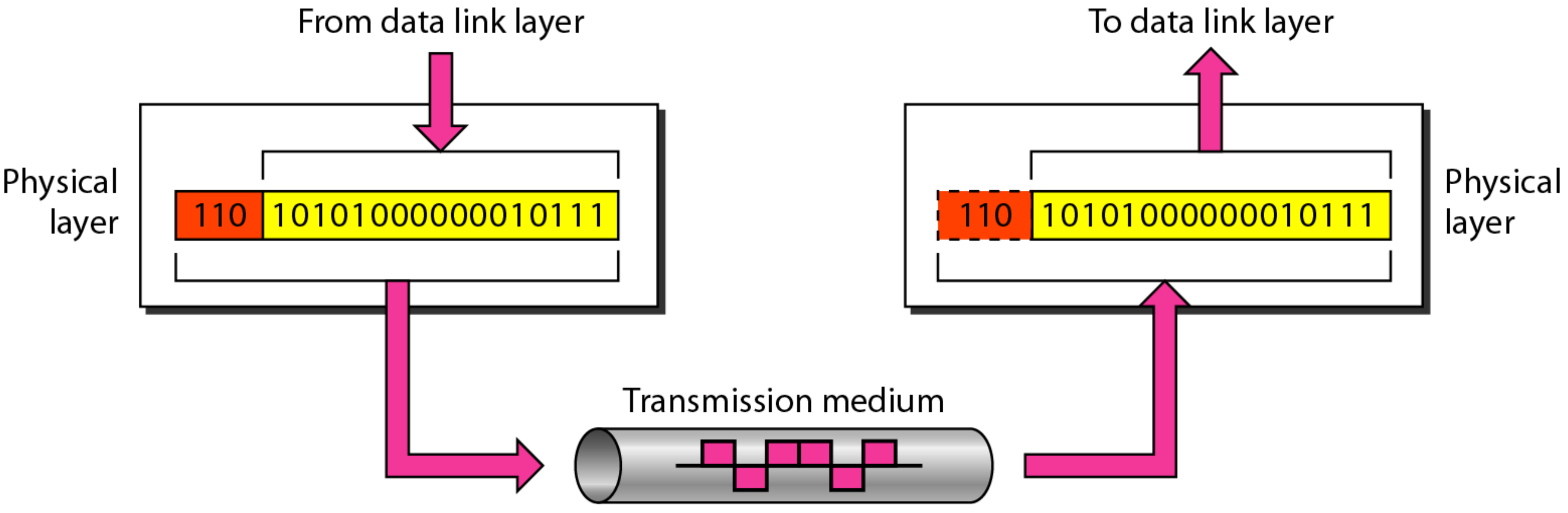
LAYERS IN THE OSI MODEL

In this section we briefly describe the functions of each layer in the OSI model.

Topics discussed in this section:

Physical Layer
Data Link Layer
Network Layer
Transport Layer
Session Layer
Presentation Layer
Application Layer

Physical layer

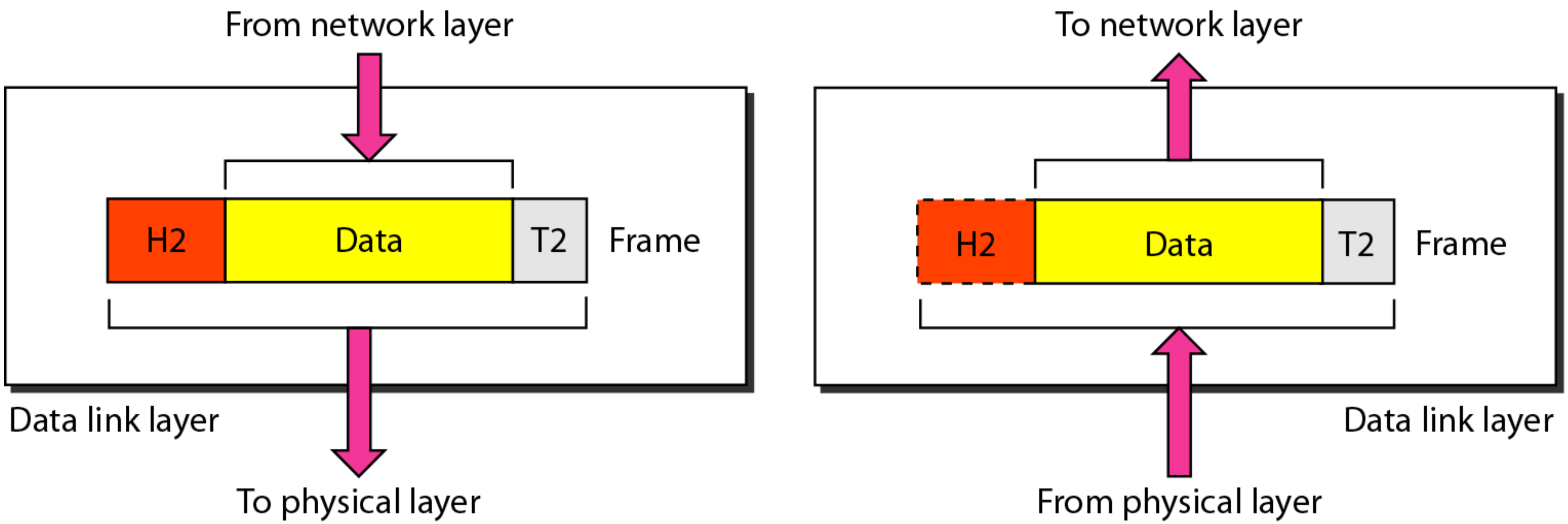


The physical layer is responsible for movements of individual bits from one hop (node) to the next.

Physical layer

- Type of transmission media
- Representation of bits
- Data rate
- Synchronization of bits
- Line Configuration
- Topology
- Transmission mode

Data link layer



The data link layer is responsible for moving frames from one hop (node) to the next.

Data link layer

- Framing
- Physical addressing
- Flow control
- Error control
- Access control

POLL 2

- Hop to Hop Communication takes place at

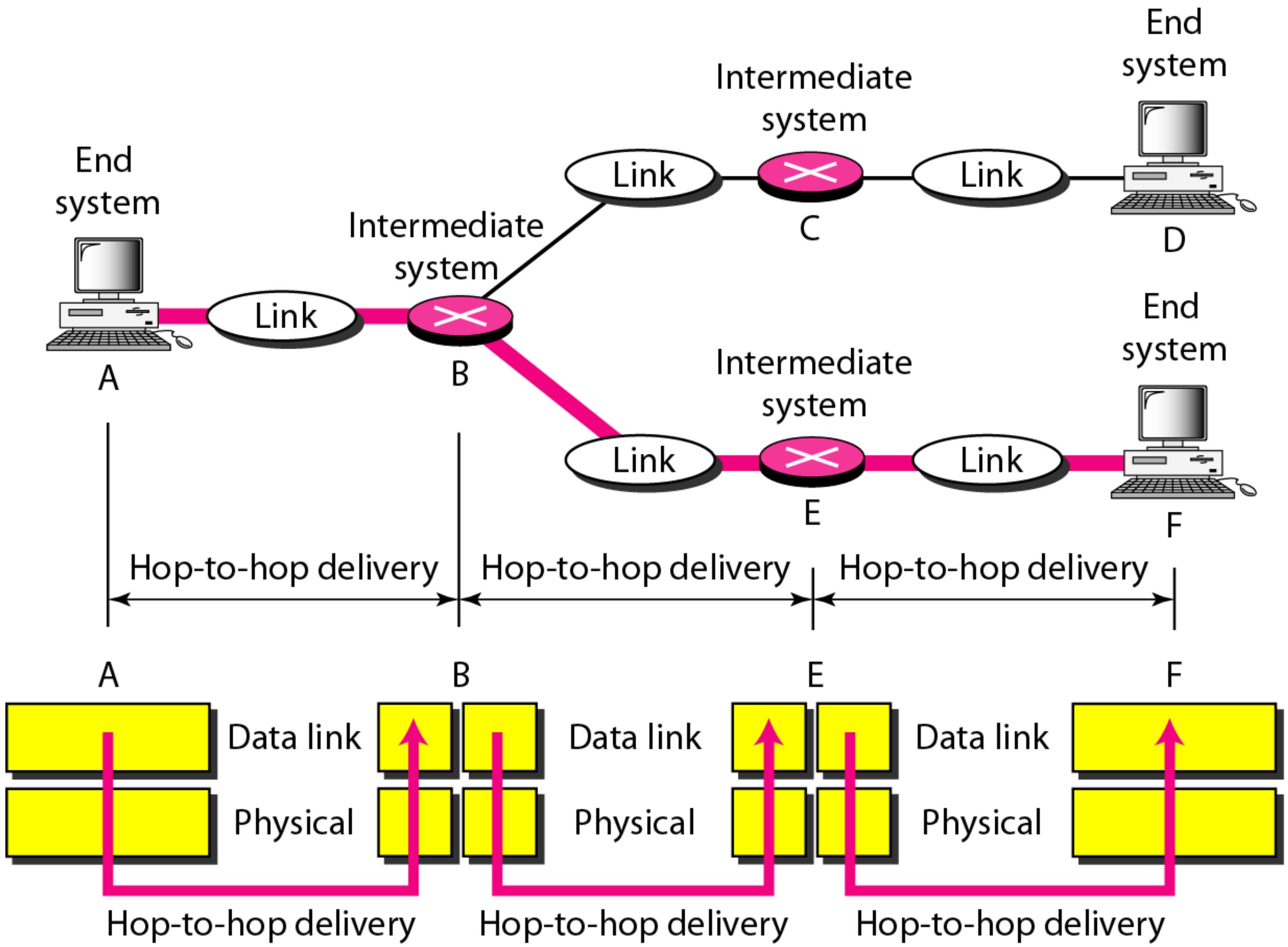
a) Physical Layer

b) Data link Layer

c) Network Layer

d) Transport Layer

Hop-to-hop delivery



POLL 3

- Data Link Layer Communicates with

a) Physical Layer only

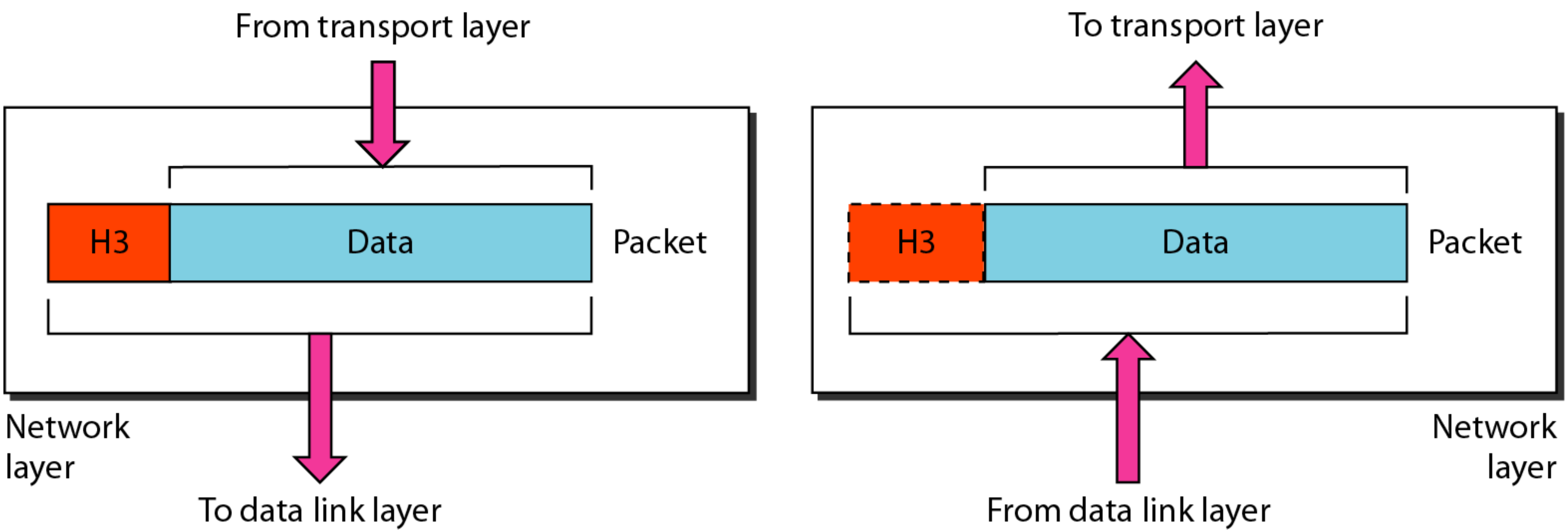
b) Network Layer only

c) Transport Layer only

d) Only a and b

e) a b and c

Network layer

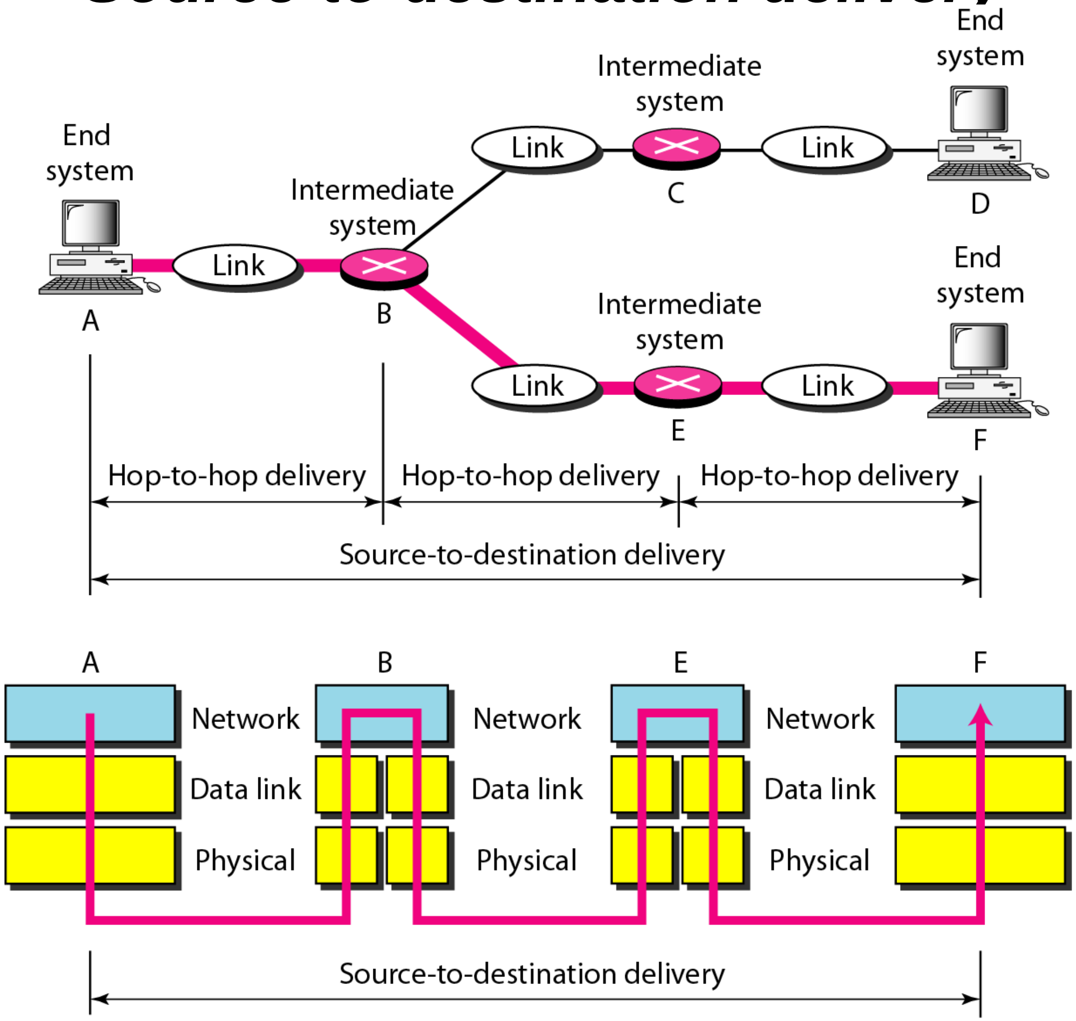


The network layer is responsible for the delivery of individual packets from the source host to the destination host.

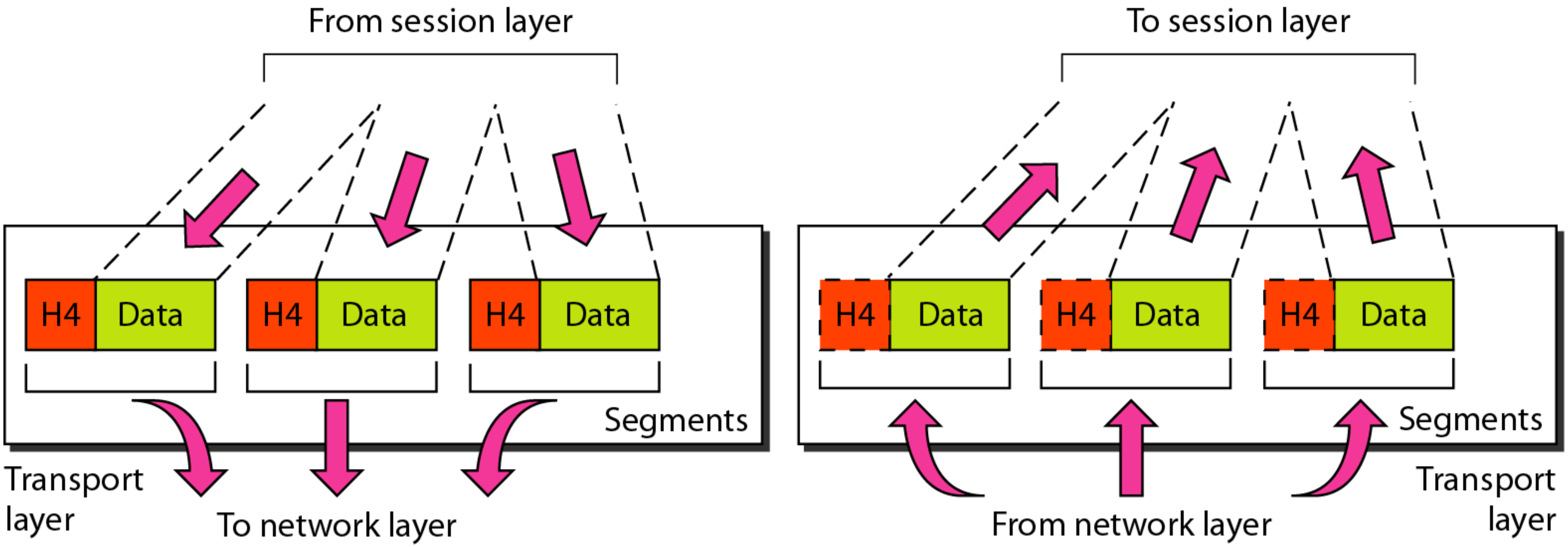
Network layer

- Logical addressing
- Routing

Source-to-destination delivery



Transport layer

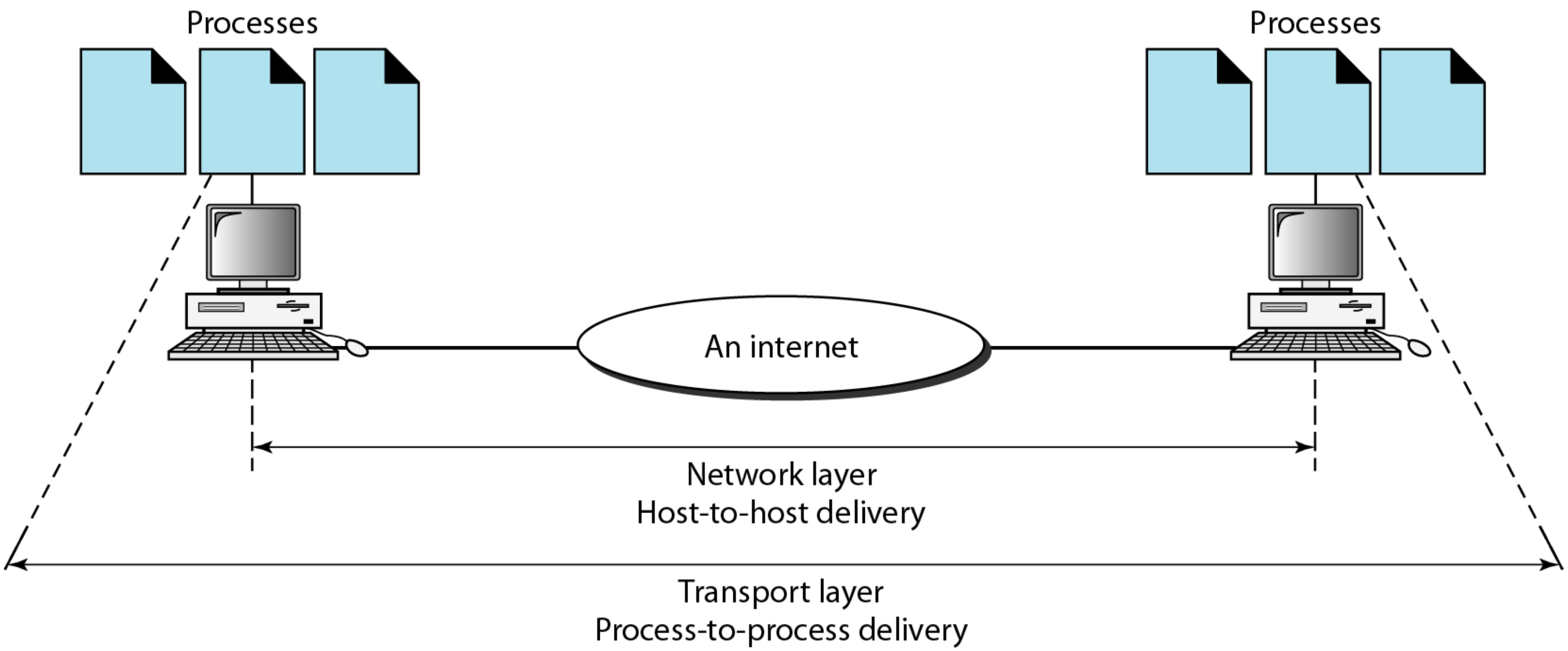


The transport layer is responsible for the delivery of a message from one process to another.

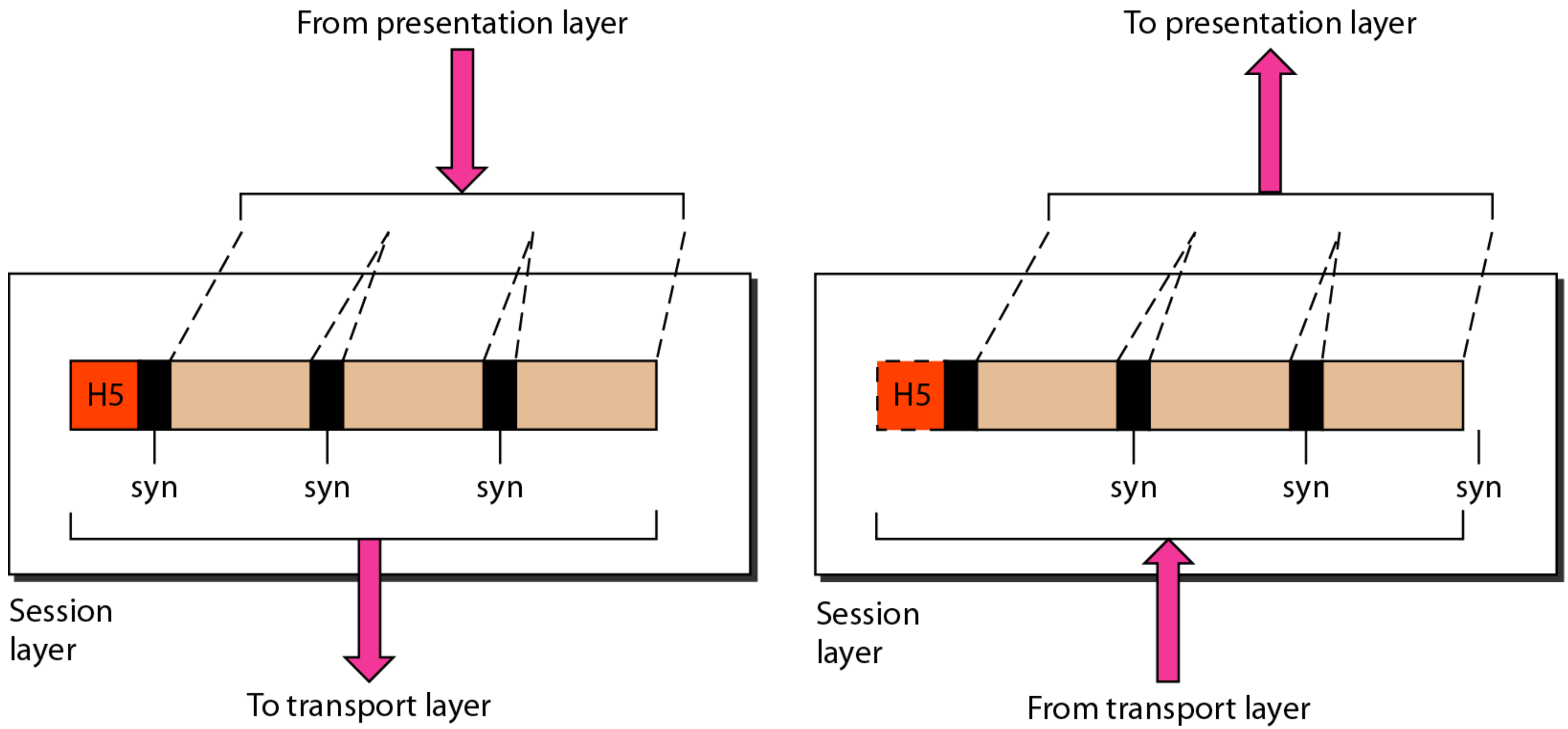
Transport layer

- Service-point addressing
- Segmentation and reassembly
- Connection control
- Flow control
- Error control

Reliable process-to-process delivery of a message



Session layer

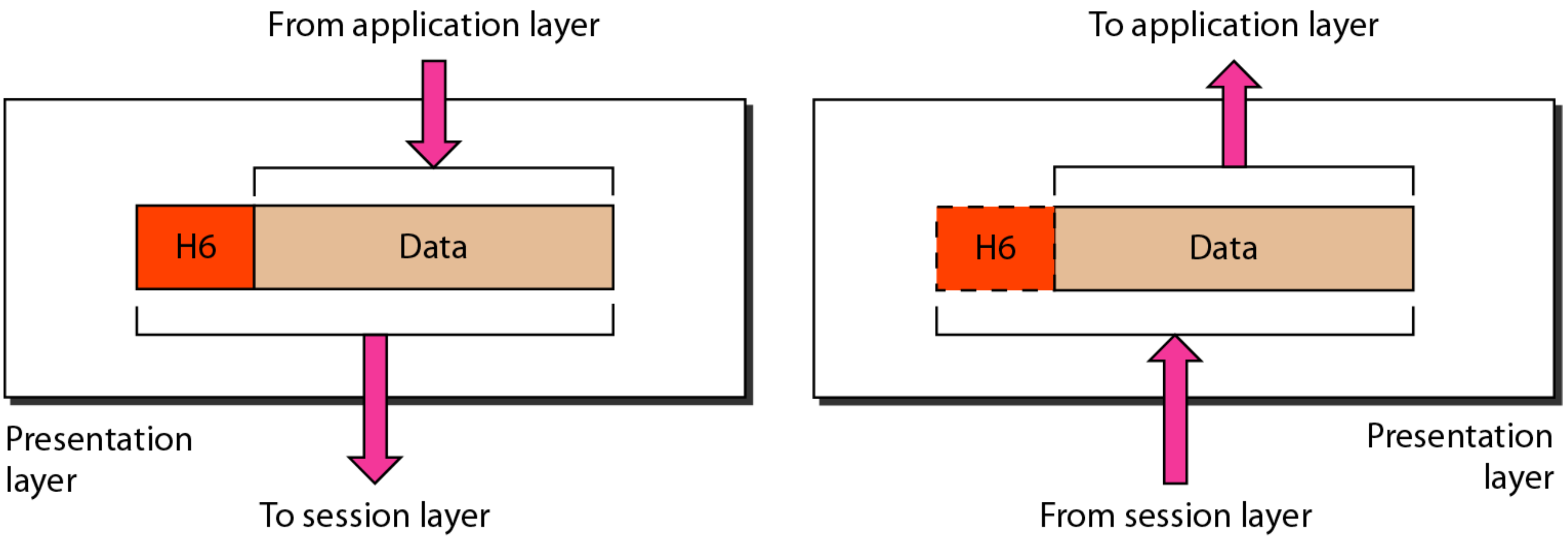


The session layer is responsible for dialog control and synchronization.

Session layer

- Dialog control (turn to transmit)
- Synchronization (introducing check point)

Presentation layer

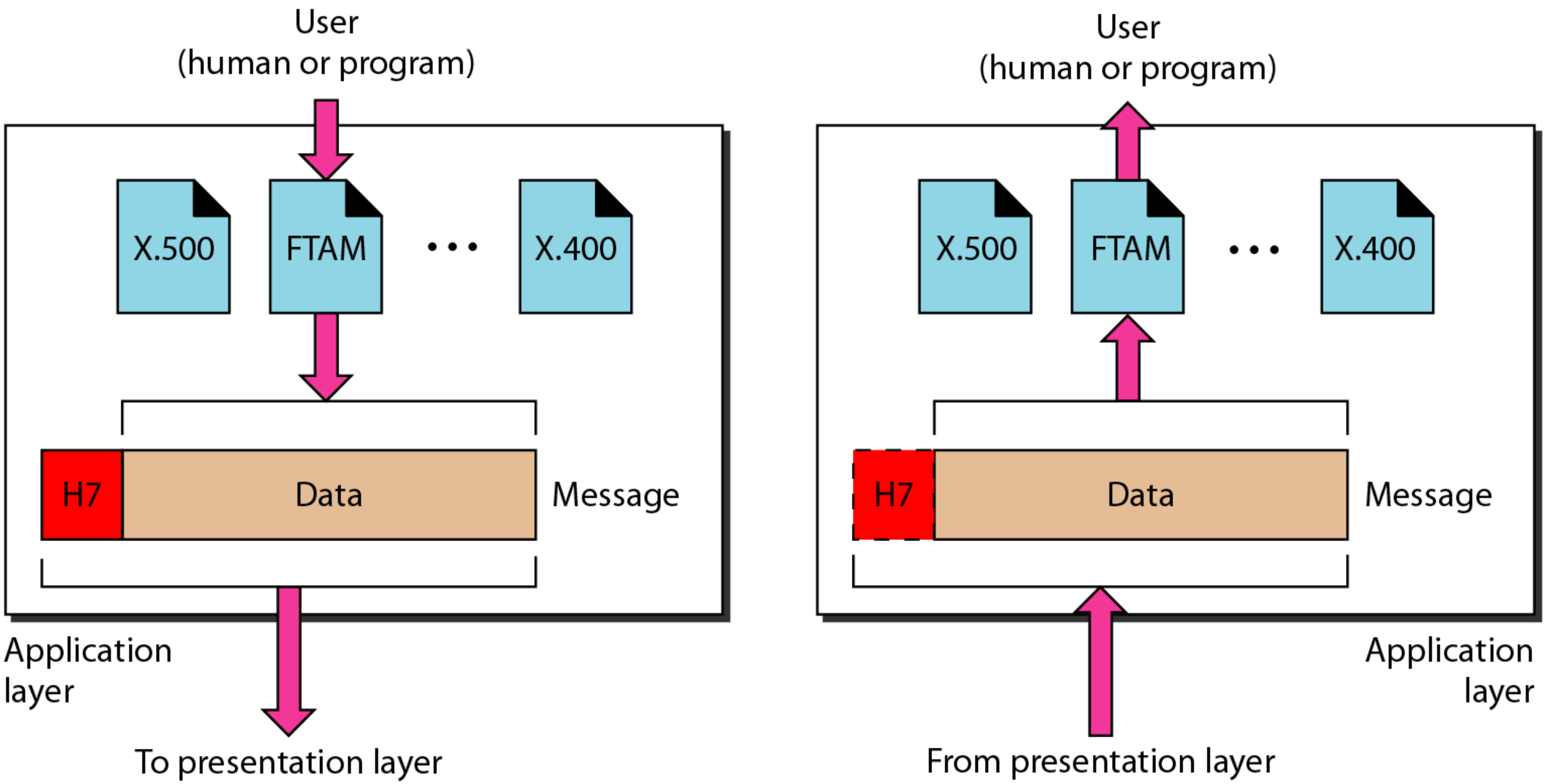


The presentation layer is responsible for translation, compression, and encryption.

Presentation layer

- Translation
- Encryption
- Compression

Application layer

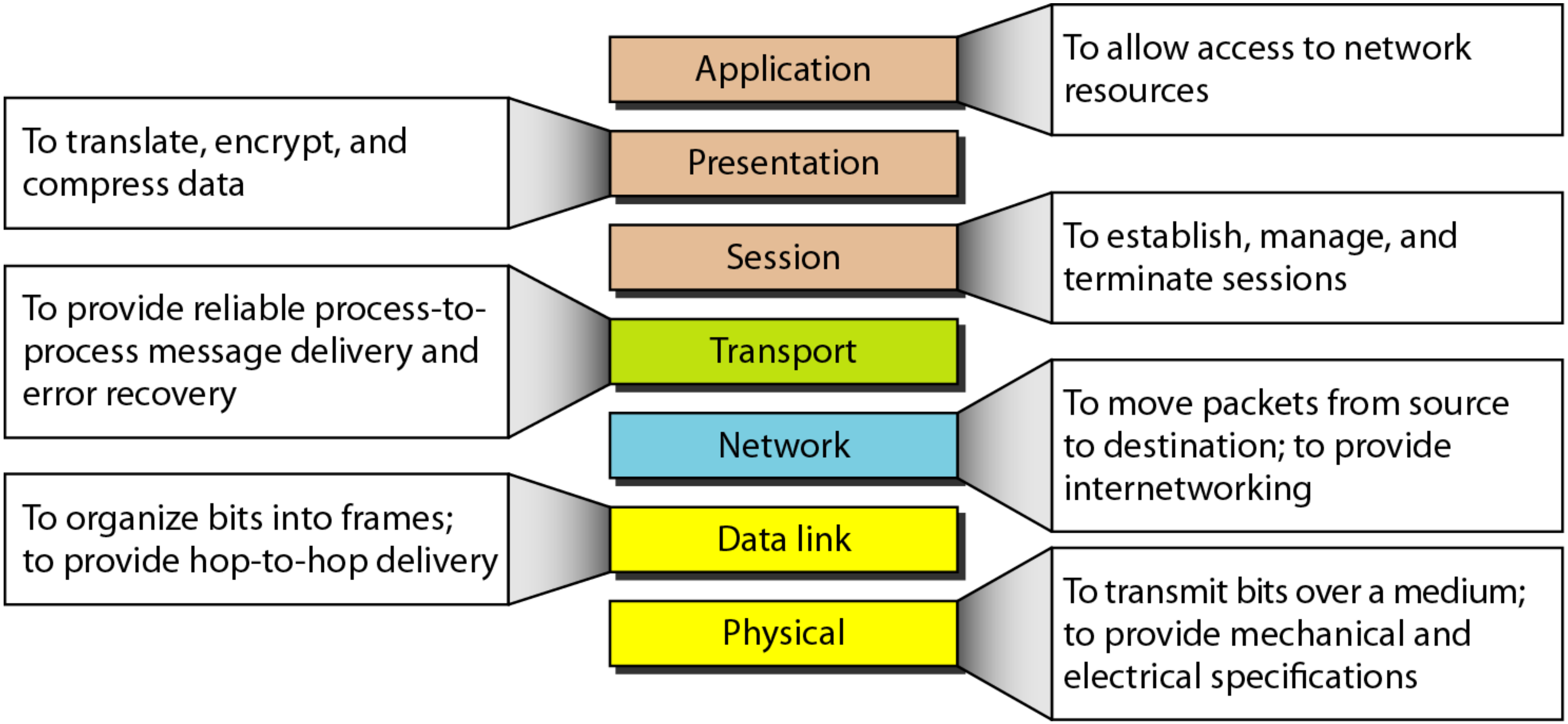


The application layer is responsible for providing services to the user.

Application layer

- Network Virtual Terminal
- File transfer, access, and management.
- Mail services
- Directory Services

Summary of layers



TCP/IP PROTOCOL SUITE

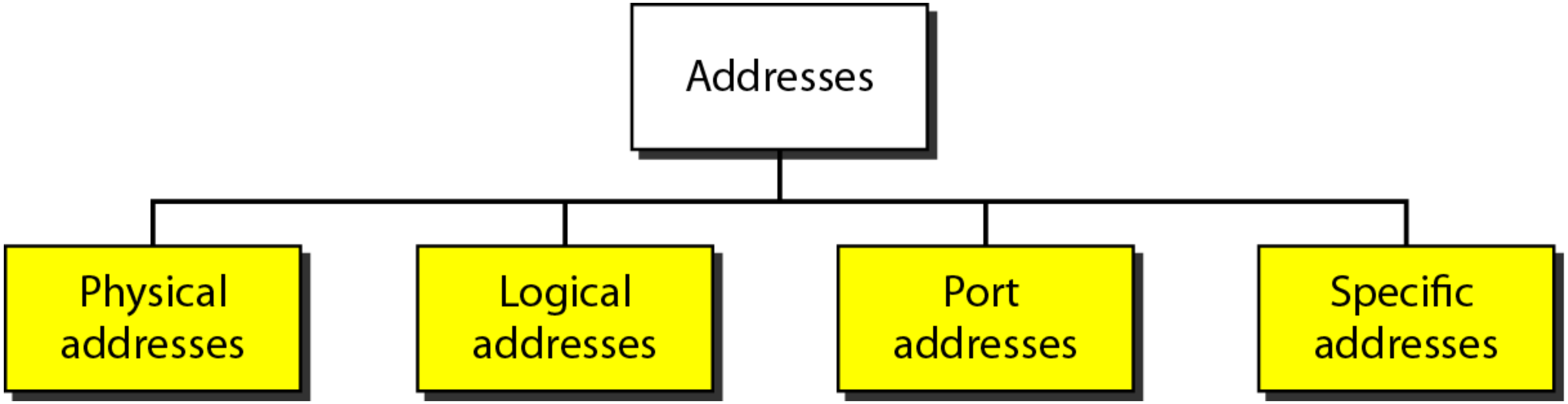
The layers in the TCP/IP protocol suite do not exactly match those in the OSI model. The original TCP/IP protocol suite was defined as having four layers: host-to-network, internet, transport, and application. However, when TCP/IP is compared to OSI, we can say that the TCP/IP protocol suite is made of five layers: physical, data link, network, transport, and application.

ADDRESSING

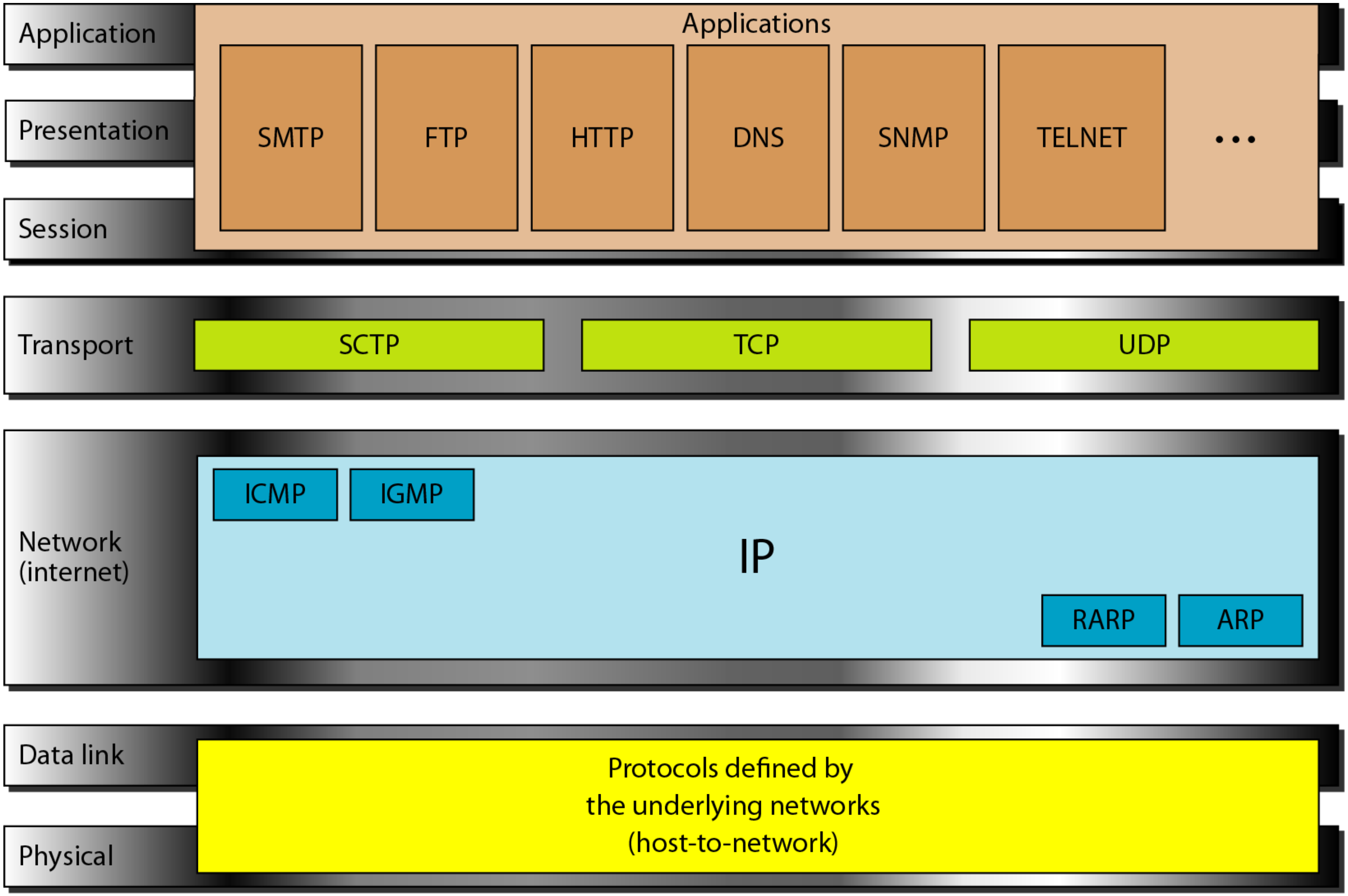
Four levels of addresses are used in an internet employing the TCP/IP protocols: physical, logical, port, and specific.

Physical Addresses
Logical Addresses
Port Addresses
Specific Addresses

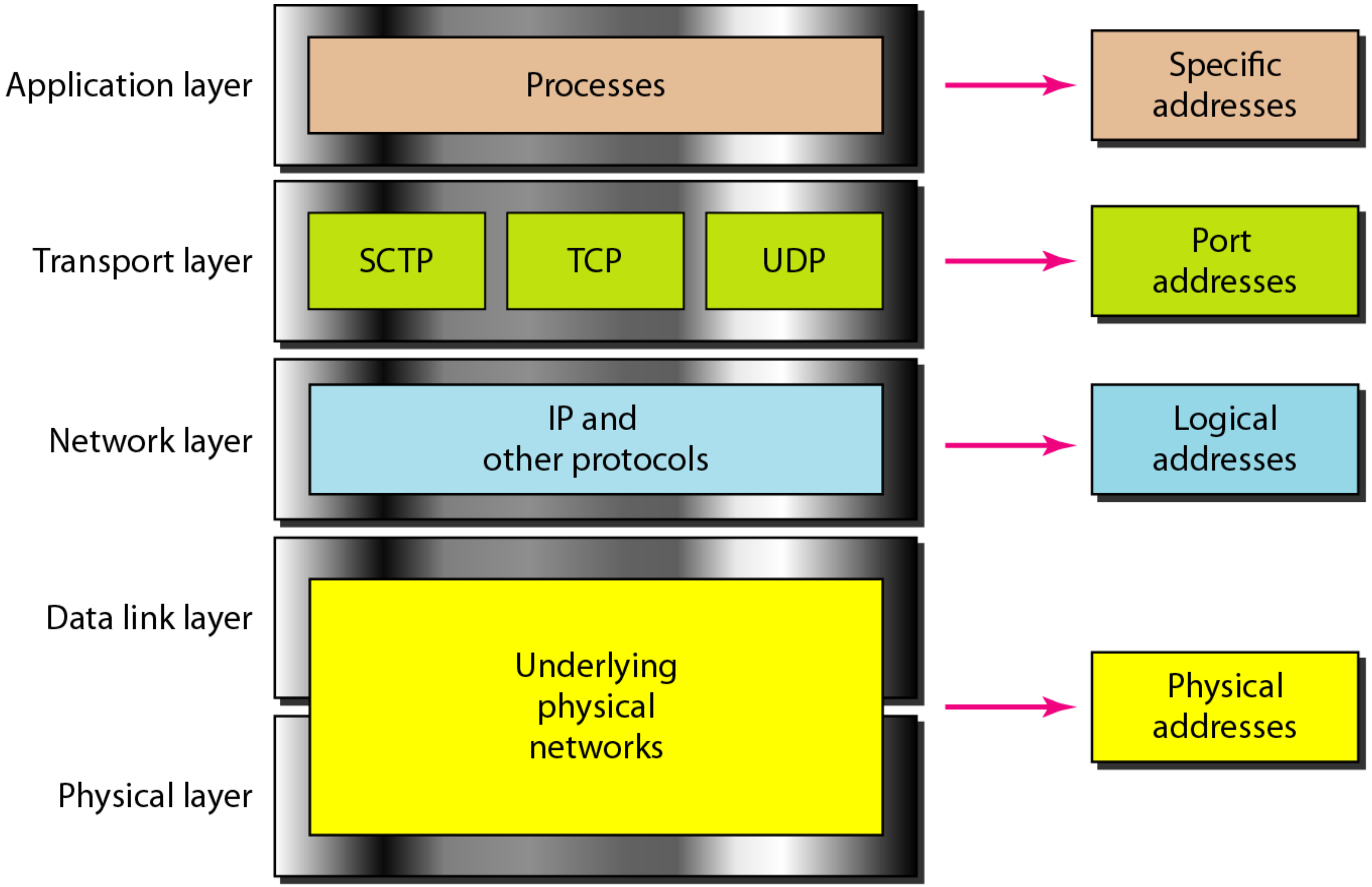
Addresses in TCP/IP



TCP/IP and OSI model



Relationship of layers and addresses in TCP/IP



Comparison of the OSI and TCP/IP Reference Models

- Functionality of the layers is roughly similar

Concepts central to OSI model

- Services : The service definition tells what the layer does, not how entities above it access it . It defines the layer's semantics.
- Interfaces : tells the processes above it how to access it. It specifies what the parameters are and what results to expect
- Protocols: the layer's own business.

Comparison of the OSI and TCP/IP Reference Models

- OSI reference model was devised before the corresponding protocols were invented. This ordering means that the model was not biased toward one particular set of protocols
- In TCP/IP, the protocols came first, and the model was really just a description of the existing protocols
- Number of layers: the OSI model has seven layers and the TCP/IP has four layers.
- The TCP/IP model has only one mode in the network layer (connectionless) but supports both modes in the transport layer.

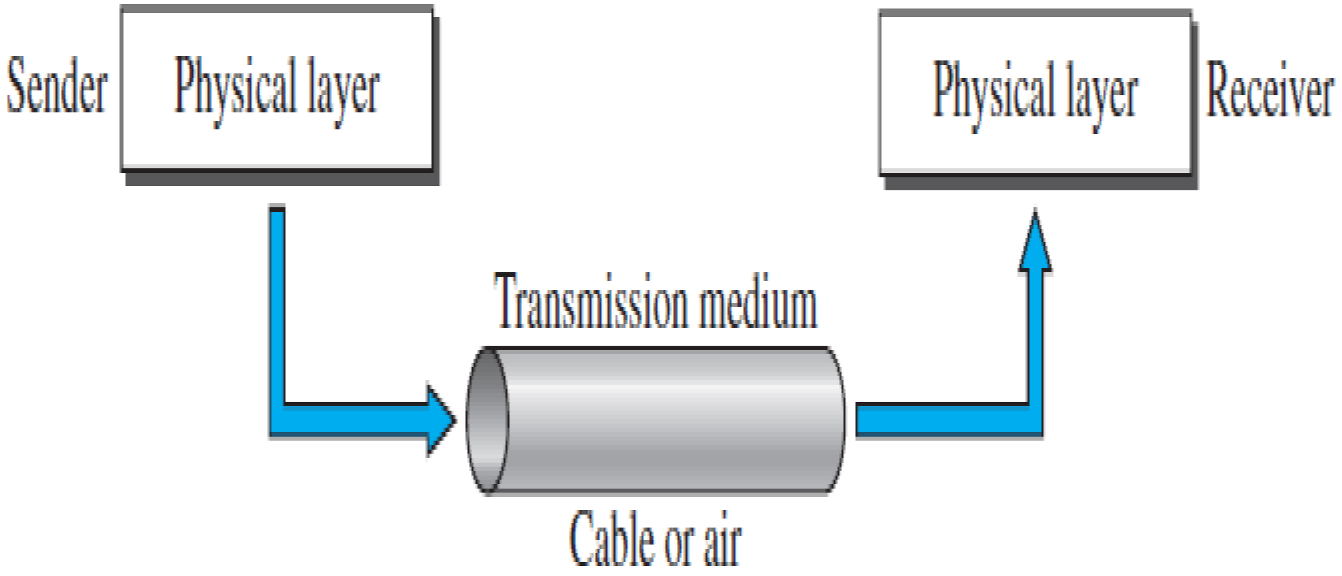
Transmission Media Guided

CSE306

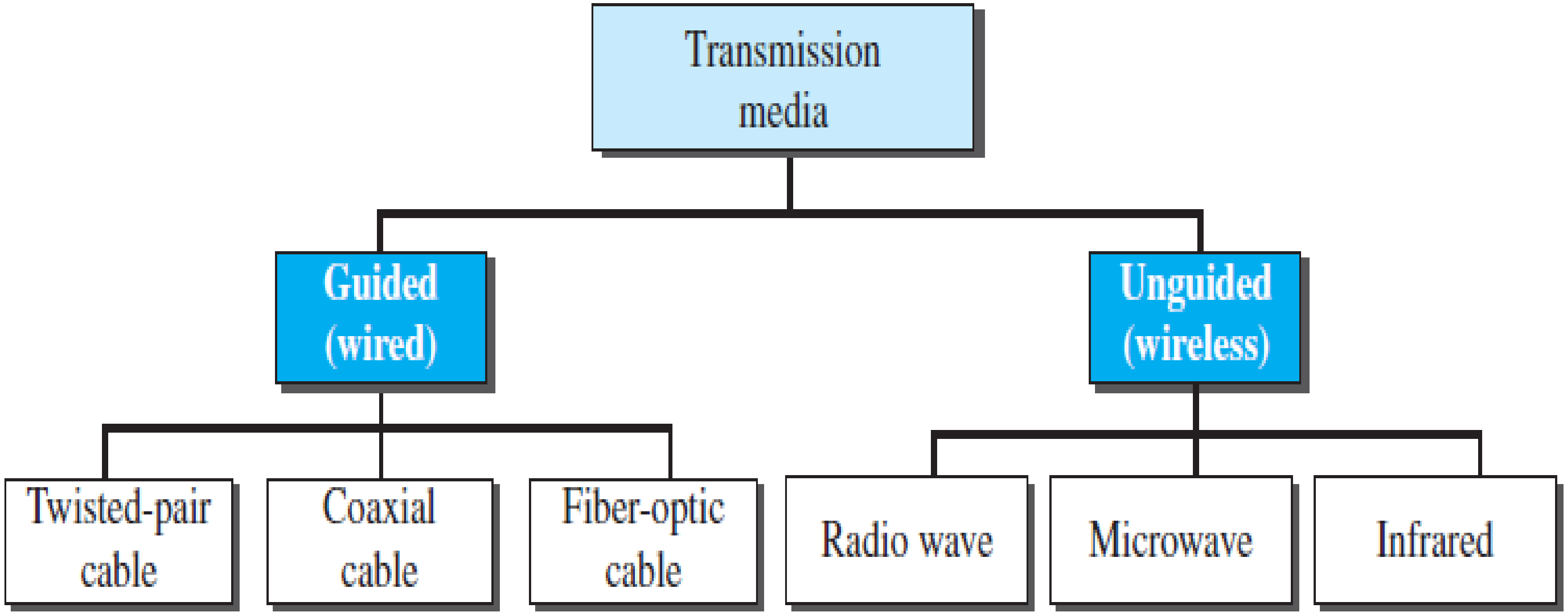
Presented by: Dr. Amandeep Singh

- A transmission **medium** can be broadly defined as anything that can carry information from a source to a destination.

- For example, the transmission medium for two people having a dinner conversation is the air.


Sender
Physical layer
Physical layer
Receiver
Transmission medium
Cable or air

Classes of transmission media



POLL 1

- Which of the following is **NOT** an example of transmission Media

a) Twisted-Pair Cable
b) Coaxial Cable
c) Microwave
d) None of the above

Guided media, which are those that provide a conduit from one device to another.

Unguided media transport electromagnetic waves without using a physical conductor.

POLL 2

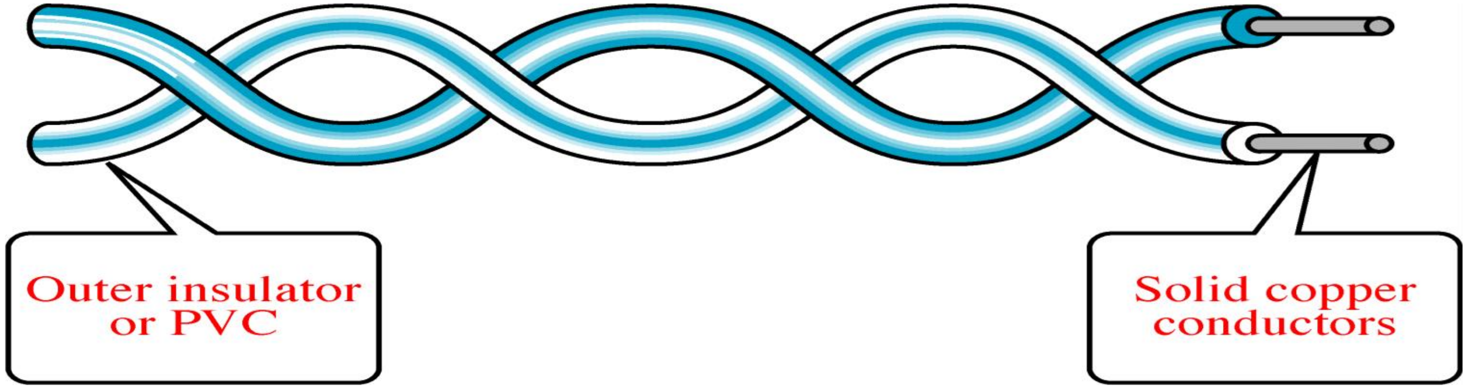
- Is Vacuum a type of transmission media

a) Yes

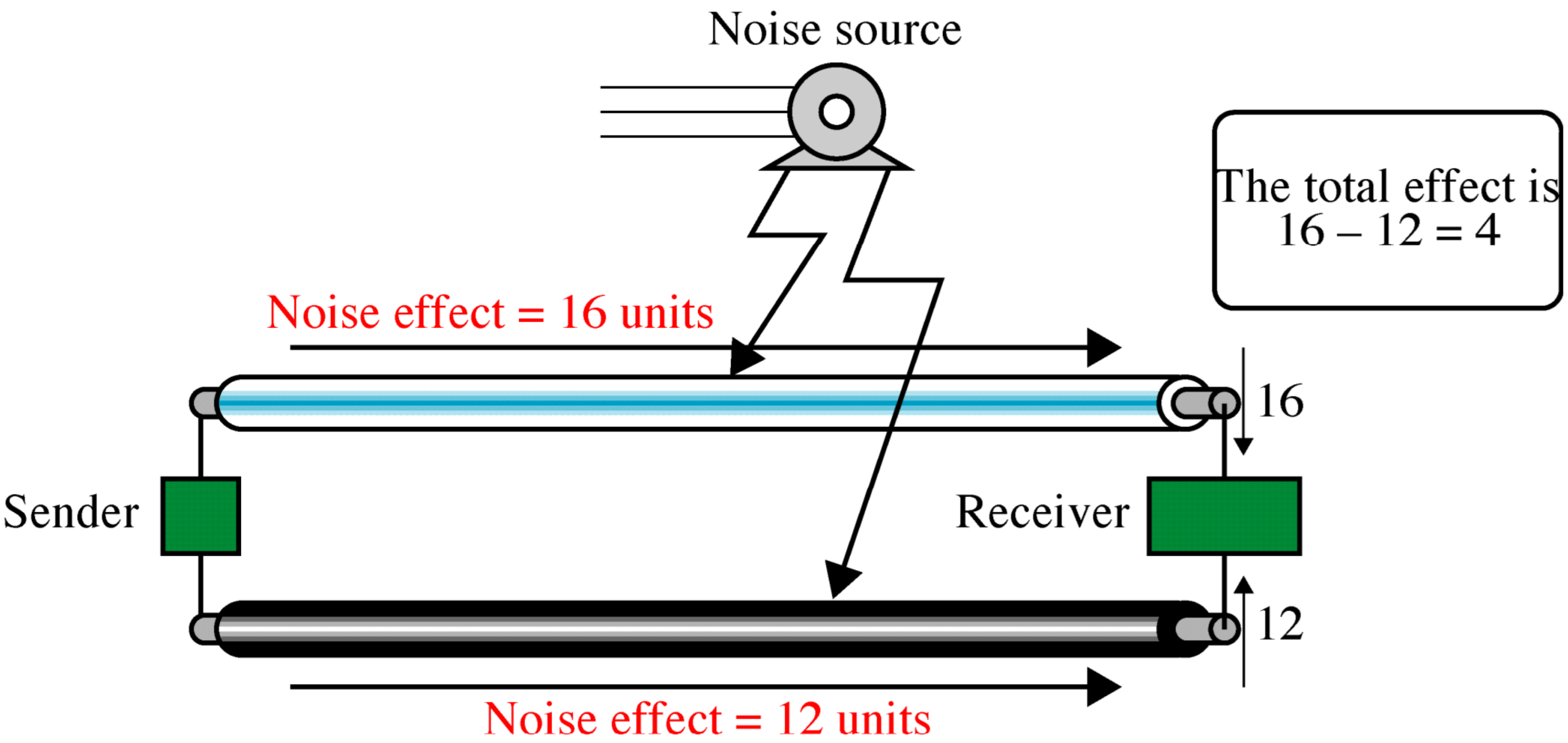
b) No

Twisted-Pair Cable

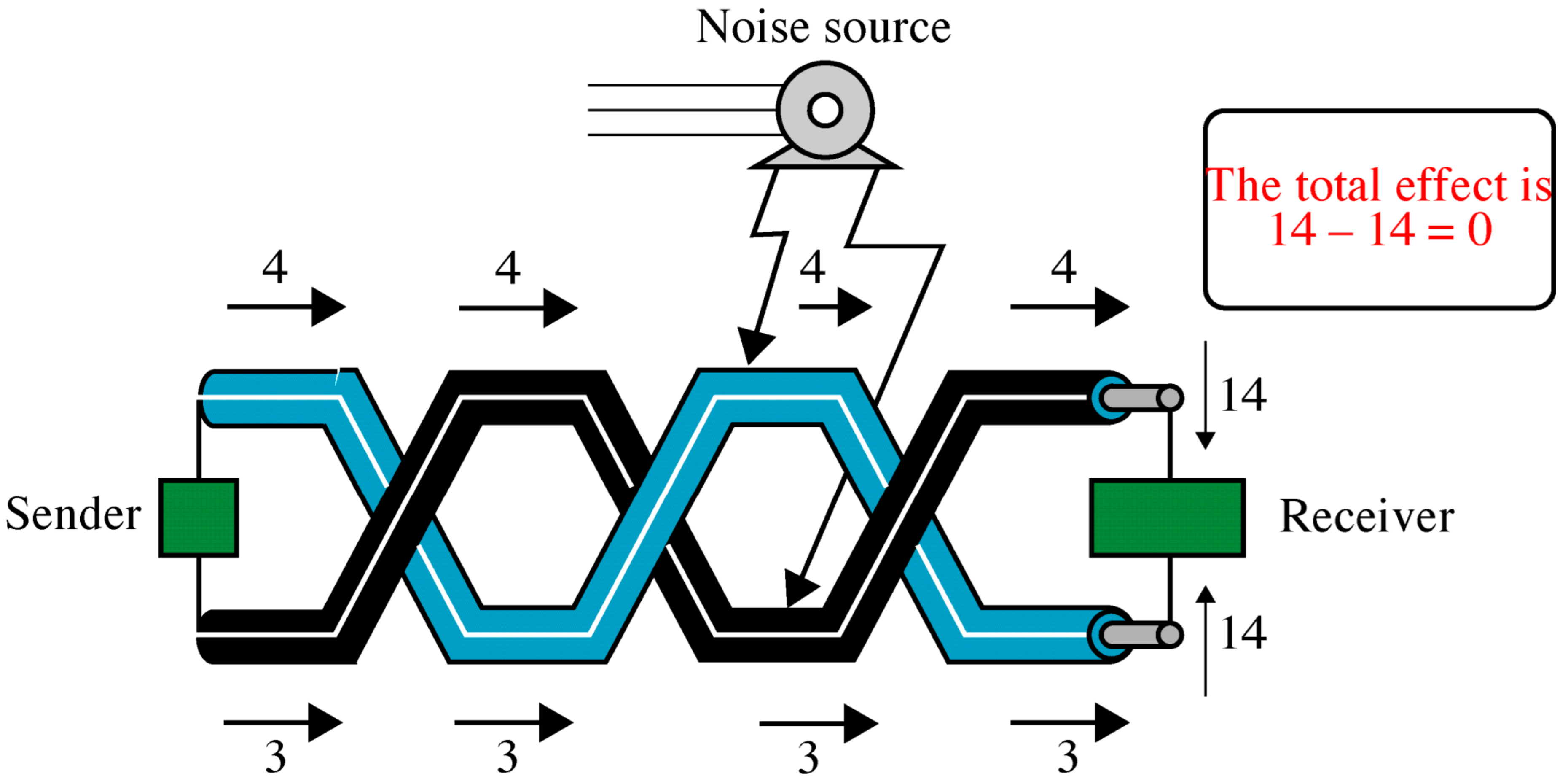
Twisted Pair and Coax use metallic(Copper) conductors that accept and transport the signals in the form of Electrical Current.



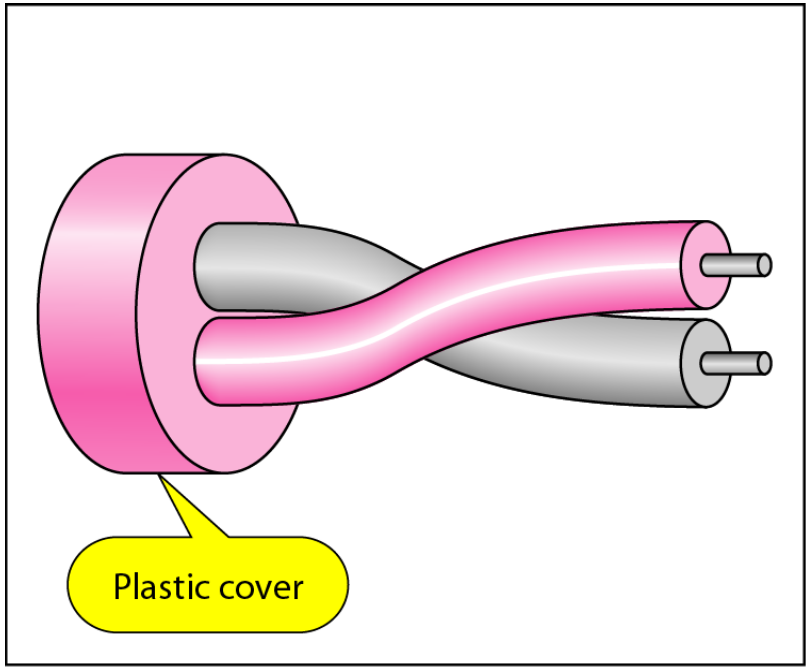
Effect of Noise on Parallel Lines



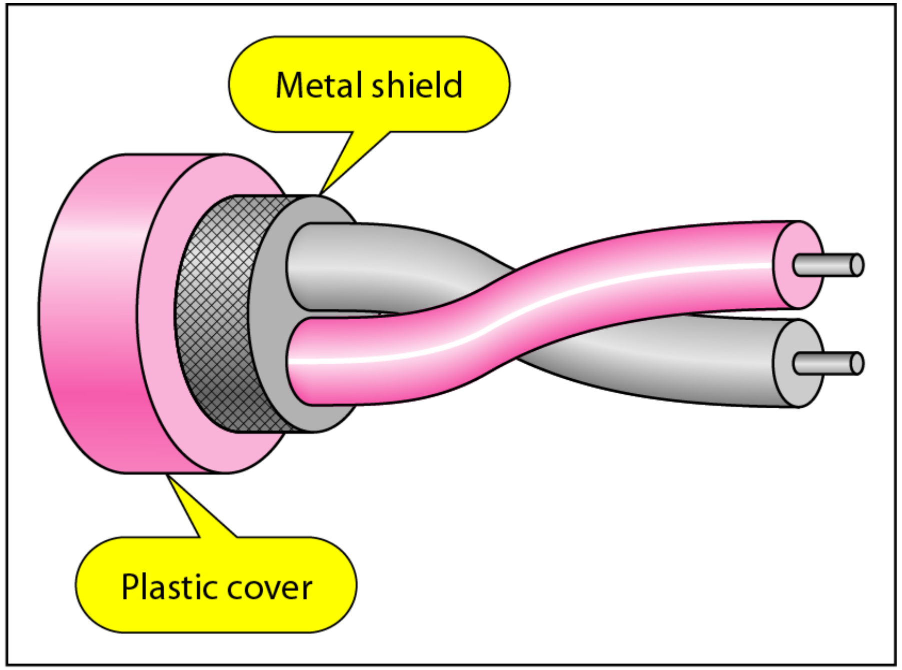
Noise on Twisted-Pair Lines



UTP and STP cables



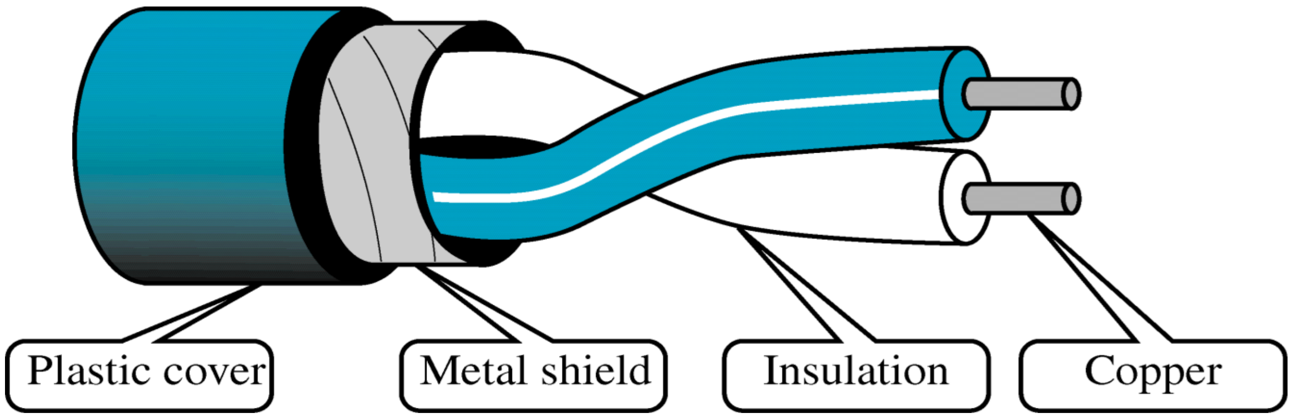
a. UTP



b. STP

Shielded Twisted-Pair Cable

- Metal casing prevents the penetration of electromagnetic noise.
- Eliminate the phenomenon , called CROSSTALK



Type	No of Pairs	Transmission Rate	Implementation
Category 1	1	Voice Grade	• used in telephone industry • not suitable for long distance data transmission(used only for short distance)
Category 2	2	4 Mbps	• used for both data and voice transmission
Category 3	4	10 Mbps	• required 3 twist per foot • used for 10 base networks. • used for voice • communication
Category 4	4	16 Mbps	• required 3 twist per foot • used in IBM token ring networks
Category 5	4	100 Mbps	• used in Ethernet and 100 Base-X networks
Category 6	4	100 Mbps and higher	• used in Ethernet and 1000 Base-X networks

Advantages :

1. Cheaper
2. Less susceptible to electrical interference caused by nearby equipment or wires.
3. In turn are less likely to cause interference themselves.
4. Because it is electrically "cleaner", STP wire can carry data at a faster speed.

Disadvantages :

1. STP wire is that it is physically larger and more expensive than twisted pair wire.

Unshielded Twisted-Pair Cable

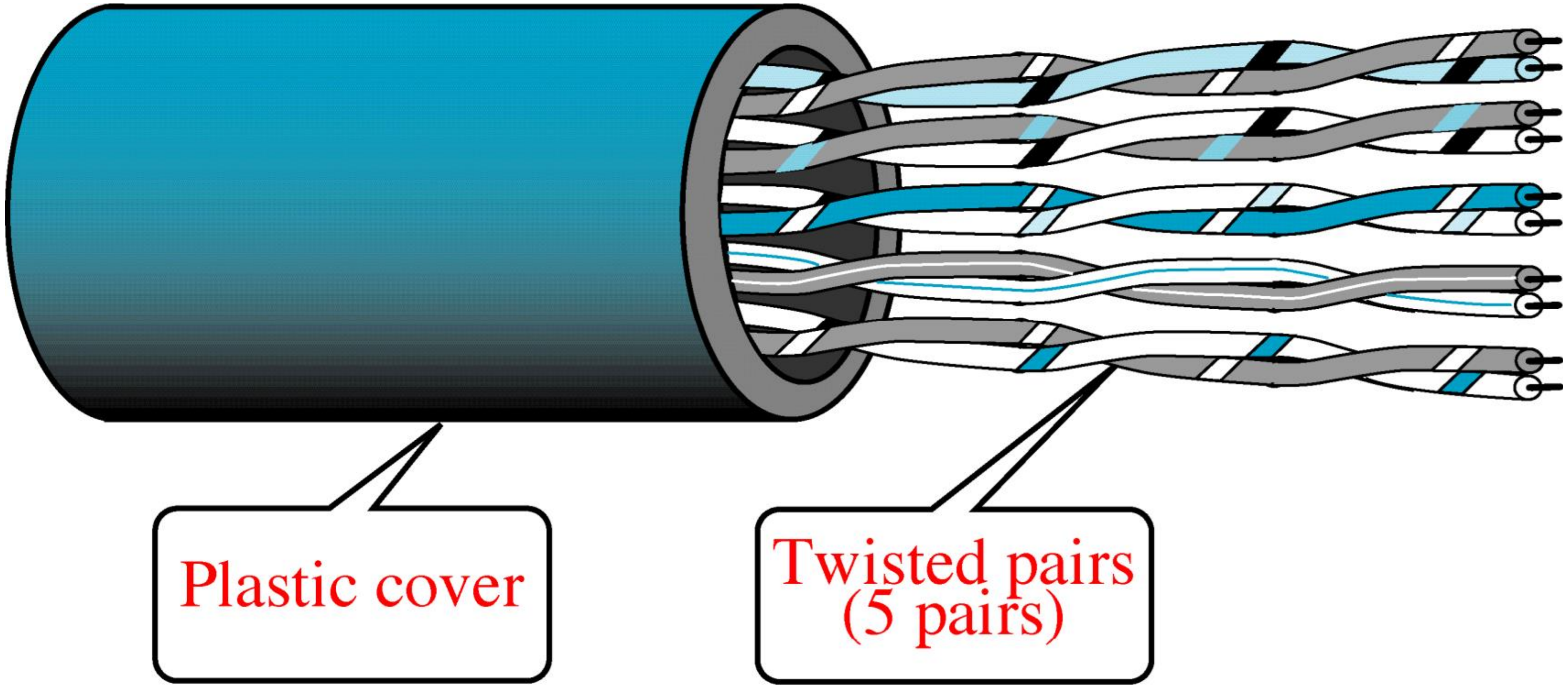
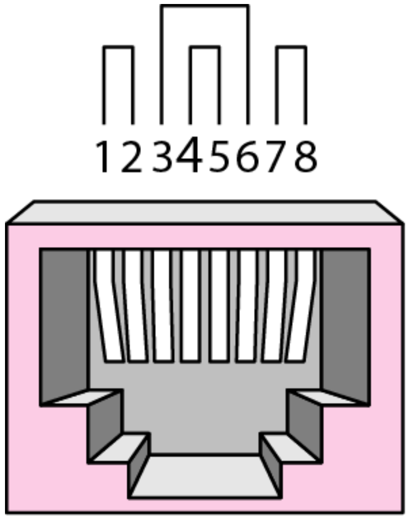
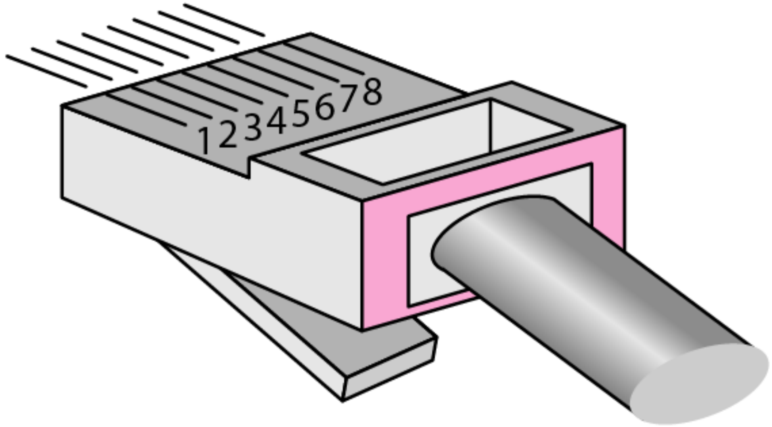


Table 7.1 *Categories of unshielded twisted-pair cables*

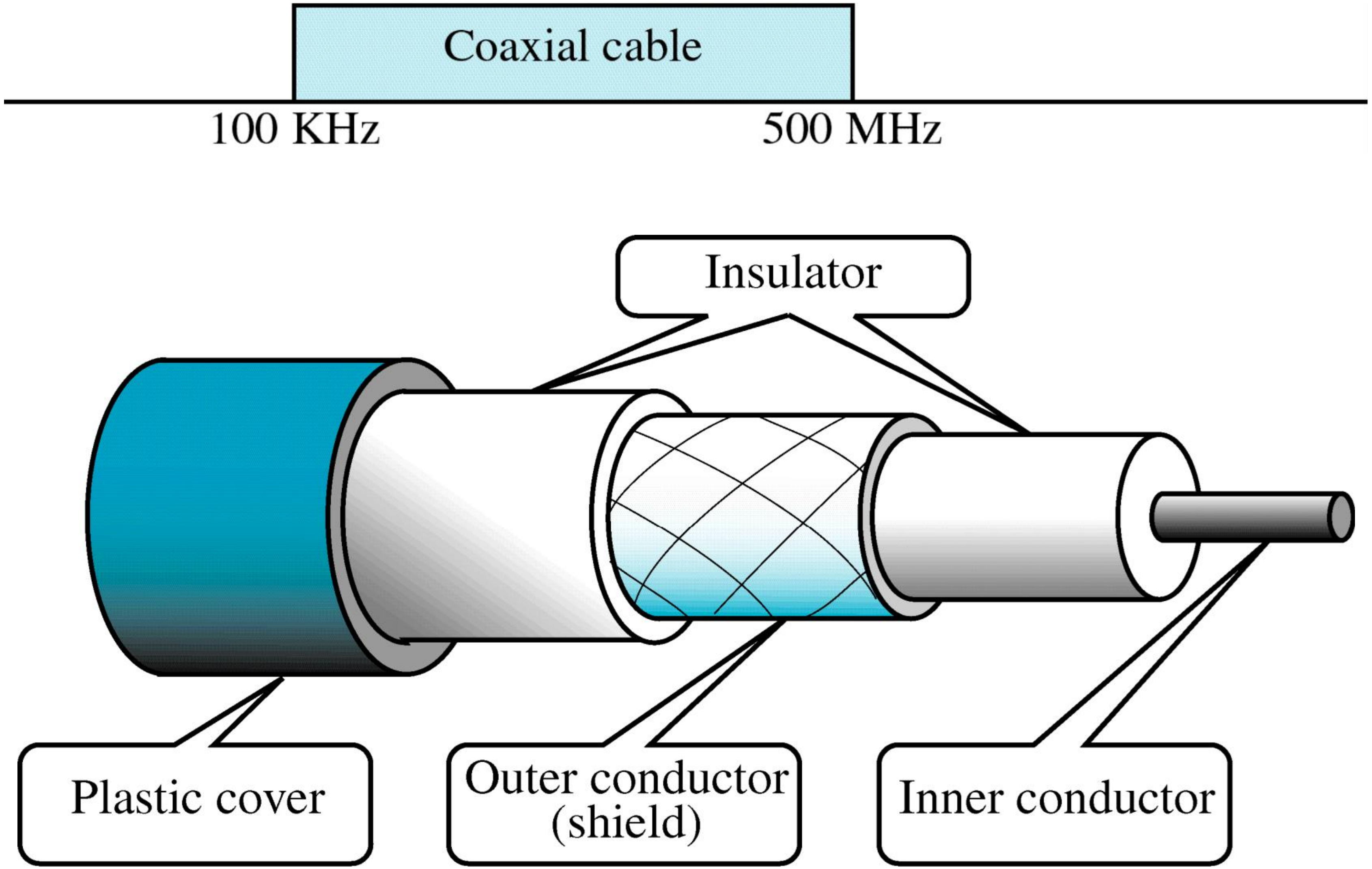
Category	*Specification*	*Data Rate (Mbps)*	*Use*
1	Unshielded twisted-pair used in telephone	< 0.1	Telephone
2	Unshielded twisted-pair originally used in T-lines	2	T-1 lines
3	Improved CAT 2 used in LANs	10	LANs
4	Improved CAT 3 used in Token Ring networks	20	LANs
5	Cable wire is normally 24 AWG with a jacket and outside sheath	100	LANs
5E	An extension to category 5 that includes extra features to minimize the crosstalk and electromagnetic interference	125	LANs
6	A new category with matched components coming from the same manufacturer. The cable must be tested at a 200-Mbps data rate.	200	LANs
7	Sometimes called SSTP (shielded screen twisted-pair). Each pair is individually wrapped in a helical metallic foil followed by a metallic foil shield in addition to the outside sheath. The shield decreases the effect of crosstalk and increases the data rate.	600	LANs

UTP Connector





Coaxial Cable



Two kinds of coaxial cable

- ✓ 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.
  - ✓ Cable TV operators began to provide Internet access over cable, which has made 75-ohm cable more important for data communication.

- High bandwidth
- Excellent noise immunity.
- The bandwidth possible depends on the cable quality and length.
- Used within the telephone system, cable television and MAN
- For long-distance lines, but have now replaced by fiber optics on long distance routes.

Categories of coaxial cables

Category	*Impedance*	*Use*
RG-59	75 Ω	Cable TV
RG-58	50 Ω	Thin Ethernet
RG-11	50 Ω	Thick Ethernet

RG-59 (***RADIO GUIDE***) used for low-power video and RF signal
RG-58 (***RADIO GUIDE***) used for low-power video and RF signal
RG-11 (***RADIO GUIDE)***Wide Broadband with considerable signal transmission distance

Optical Fiber Cable

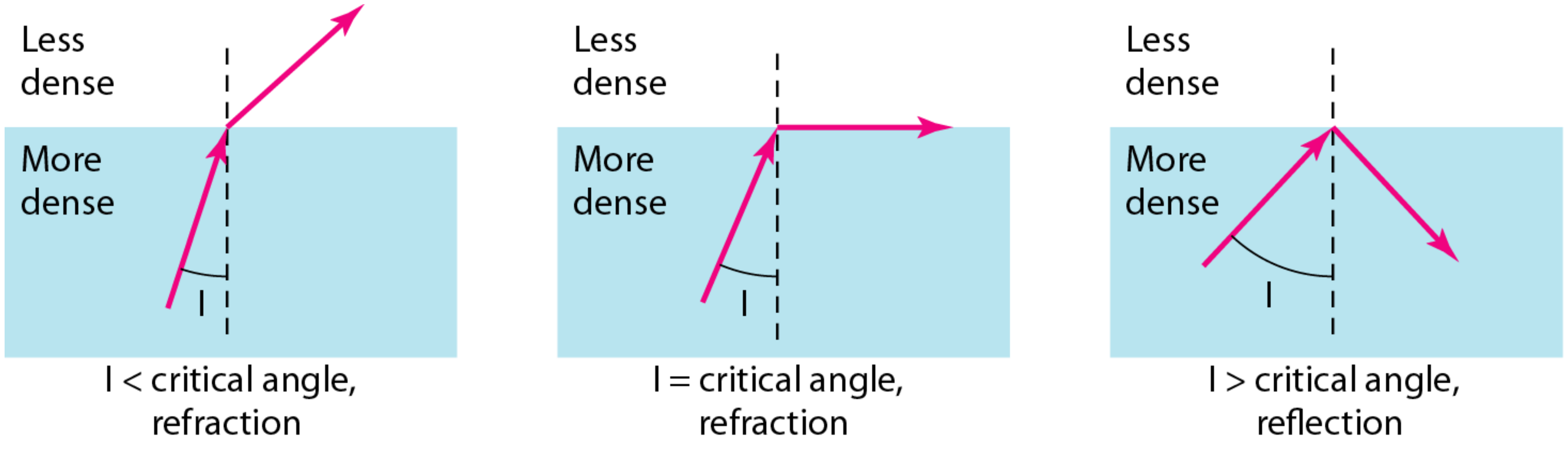
Optical Fiber is a **glass or plastic** cable that accept and transport the signals in the form of Light.

Advantages:

- Noise Resistance
- Less Signal Attenuation
- Higher BW

Disadvantages:

- Cost
- Installation/Maintenance
- Fragility(Broken Wire)


Less dense
More dense
I
I < critical angle, refraction
Less dense
More dense
I
I = critical angle, refraction
Less dense
More dense
I
I > critical angle, reflection

POLL 3

- For Total internal reflection to take place

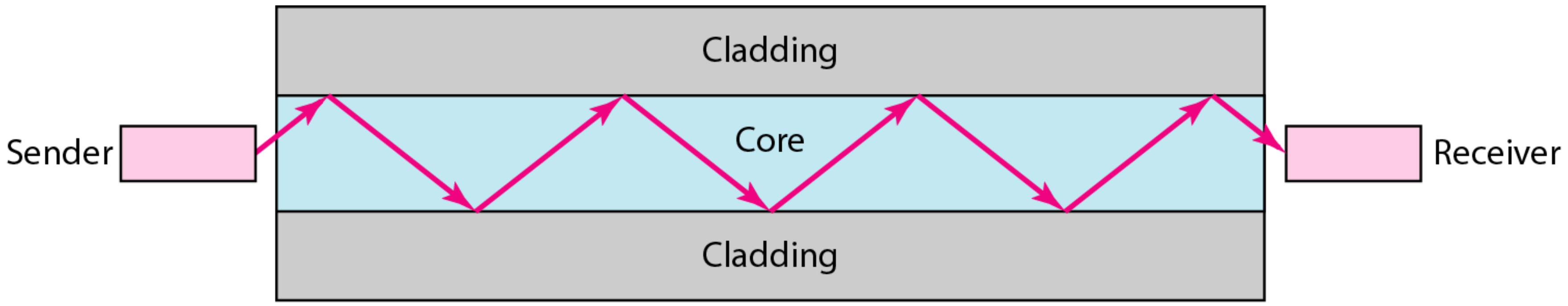
a) Incidence angle > critical angle

b) Incidence angle < critical angle

c) Incidence angle = critical angle

d) Independent of Incidence angle and critical angle

Optical fiber



POLL-4

- Light transmission takes place at

a) Cladding

b) Core

Transmission Media
Unguided
Impairments

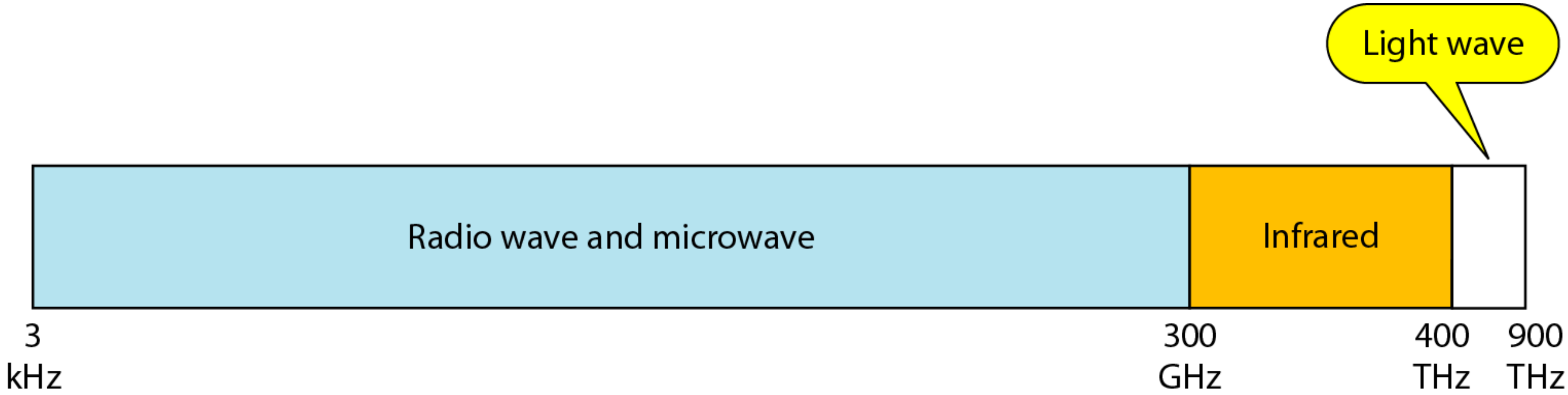
CSE306

Presented by: Dr. Amandeep Singh

UNGUIDED MEDIA: WIRELESS

Unguided media transport electromagnetic waves without using a physical conductor. This type of communication is often referred to as wireless communication.

Electromagnetic spectrum for wireless communication



Bands

Band	*Range*	*Propagation*	*Application*
VLF (very low frequency)	3–30 kHz	Ground	Long-range radio navigation
LF (low frequency)	30–300 kHz	Ground	Radio beacons and navigational locators
MF (middle frequency)	300 kHz–3 MHz	Sky	AM radio
HF (high frequency)	3–30 MHz	Sky	Citizens band (CB), ship/aircraft communication
VHF (very high frequency)	30–300 MHz	Sky and line-of-sight	VHF TV, FM radio
UHF (ultrahigh frequency)	300 MHz–3 GHz	Line-of-sight	UHF TV, cellular phones, paging, satellite
SHF (superhigh frequency)	3–30 GHz	Line-of-sight	Satellite communication
EHF (extremely high frequency)	30–300 GHz	Line-of-sight	Radar, satellite

POLL 1

- Which of the following band is associated with Cellular phones and Pagers

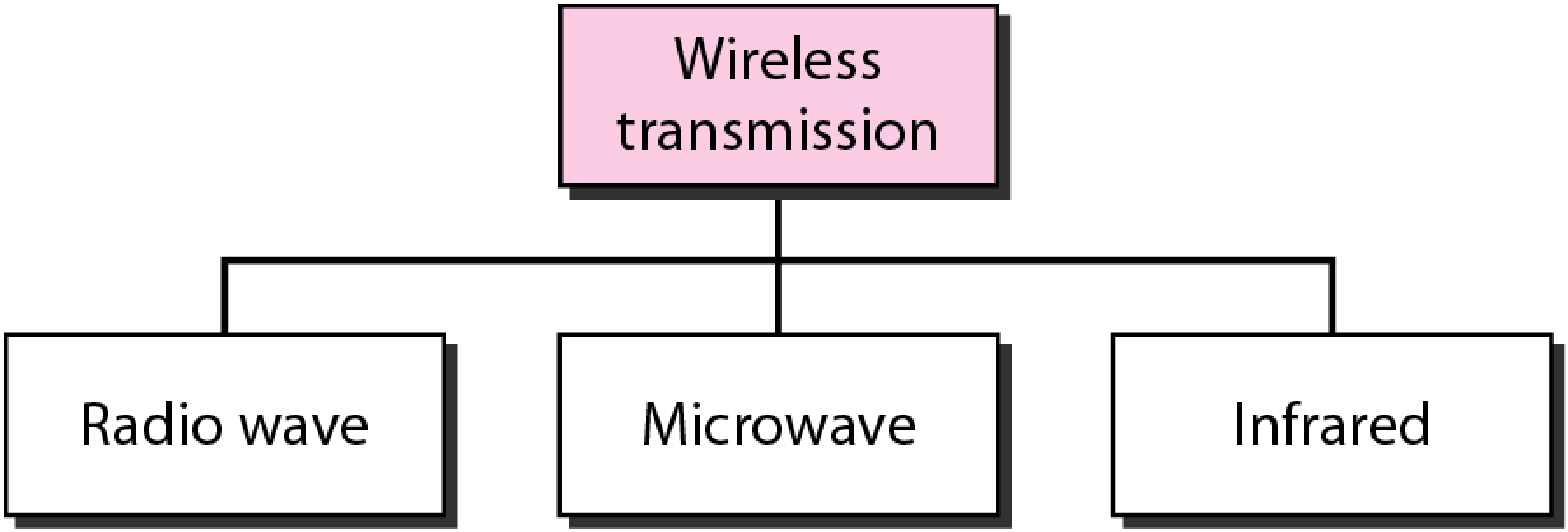
a) UHF

b) VHF

c) SHF

d) EHF

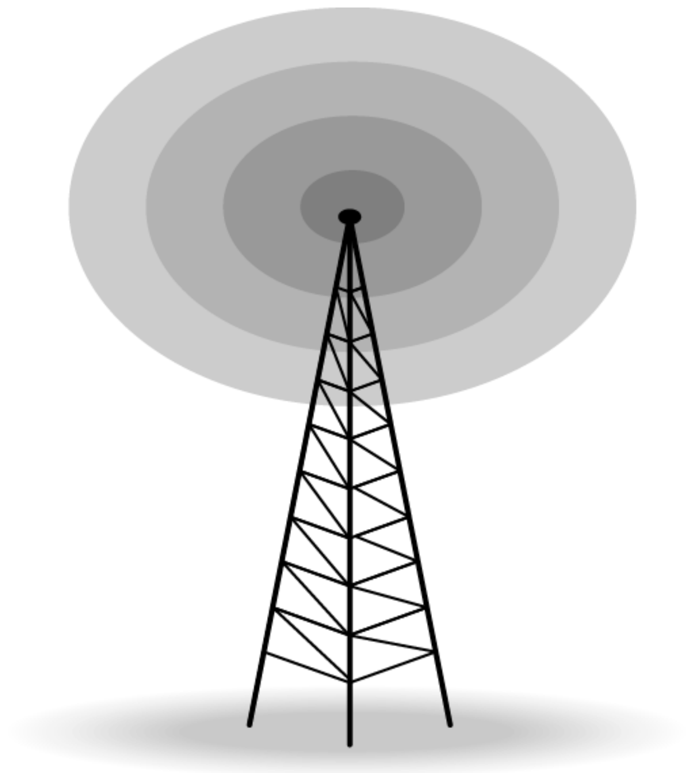
Wireless transmission waves



Note

Radio waves are used for multicast communications, such as radio and television.
They can penetrate through walls.
Use Omni directional antennas

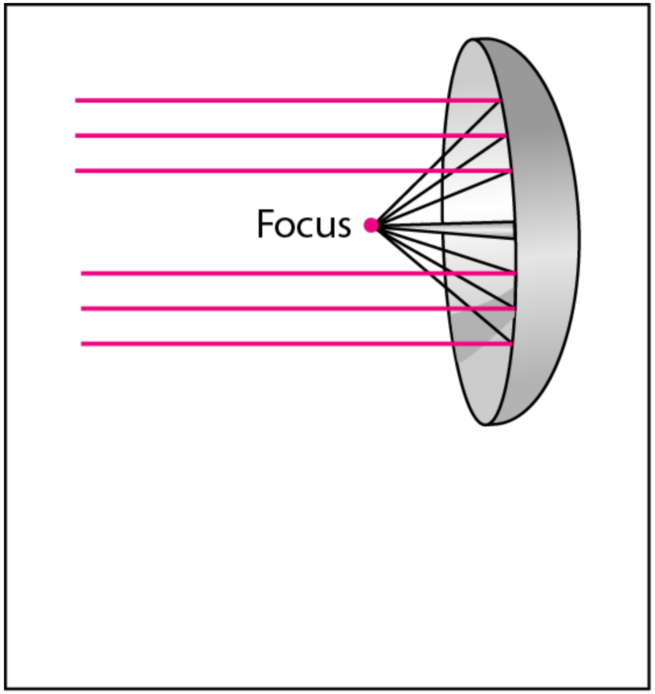
Omnidirectional antenna



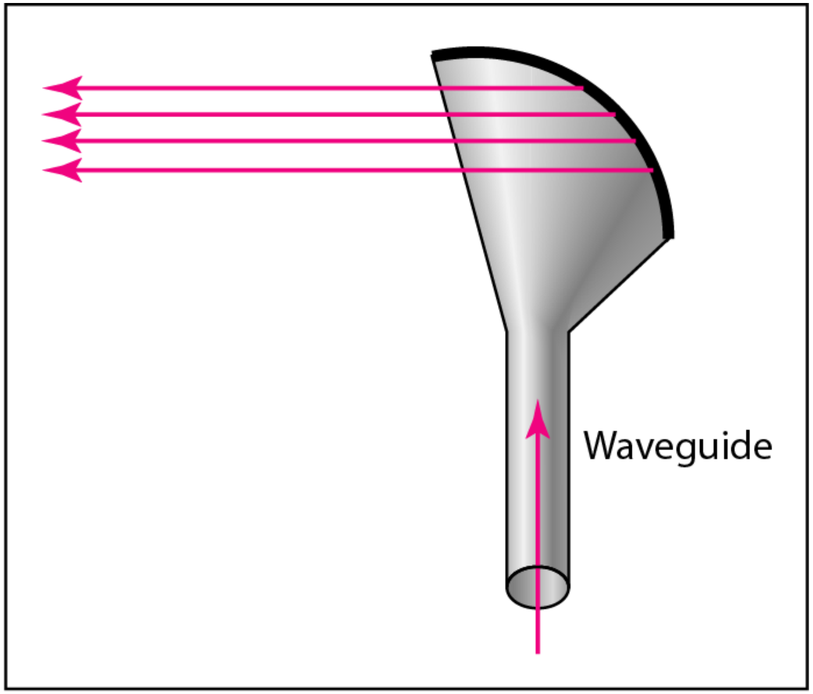
Note

Microwaves are used for unicast communication such as cellular telephones and wireless LANs.
Higher frequency ranges cannot penetrate walls.
Use directional antennas - point to point line of sight communications.

Unidirectional antennas



a. Dish antenna



b. Horn antenna

Note

Infrared signals can be used for short-range communication in a closed area using line-of-sight propagation.

POLL 2

- Which of the following is related to Unicast communication

a) Infrared Signals

b) Microwave Signals

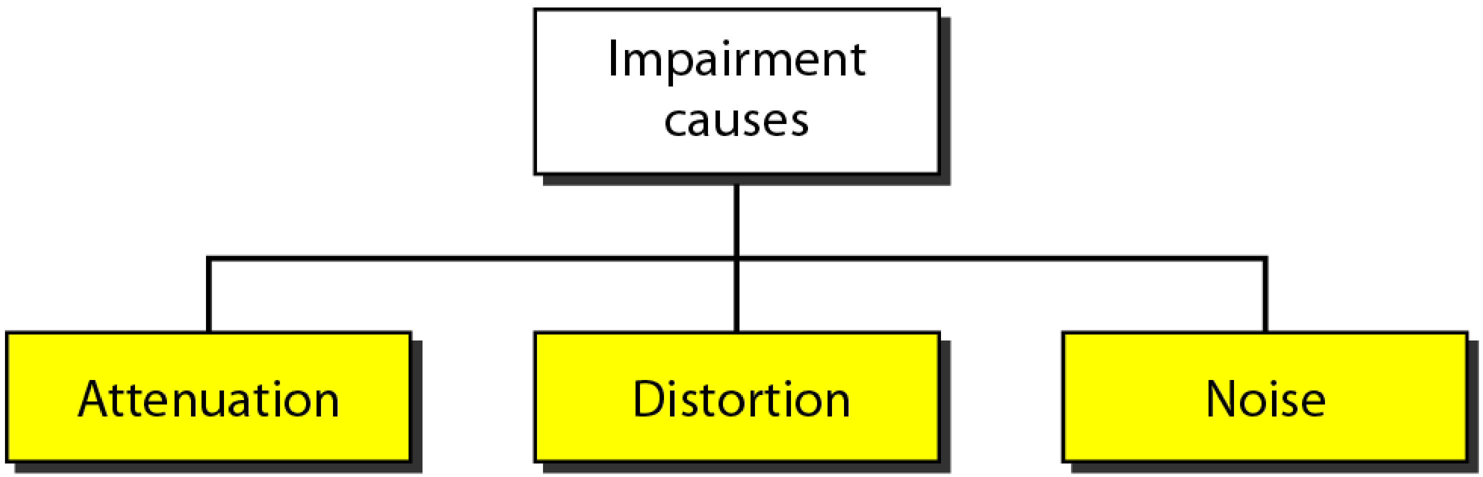
c) Radio Signals

d) None of the above

Transmission Impairment

- Signal transmit through medium that are not perfect.
- This imperfection cause signal impairment.
- What is sent is not received.

Causes of impairment



POLL 3

- Which of the following is **NOT** a type of impairment

a) Distortion

b) Attenuation

c) Noise

d) Amplification

Attenuation

- Means loss of energy => weaker signal
- When a signal travels through a medium it loses energy overcoming the resistance of the medium
- Amplifiers are used to compensate for this loss of energy by amplifying the signal.

Measurement of Attenuation

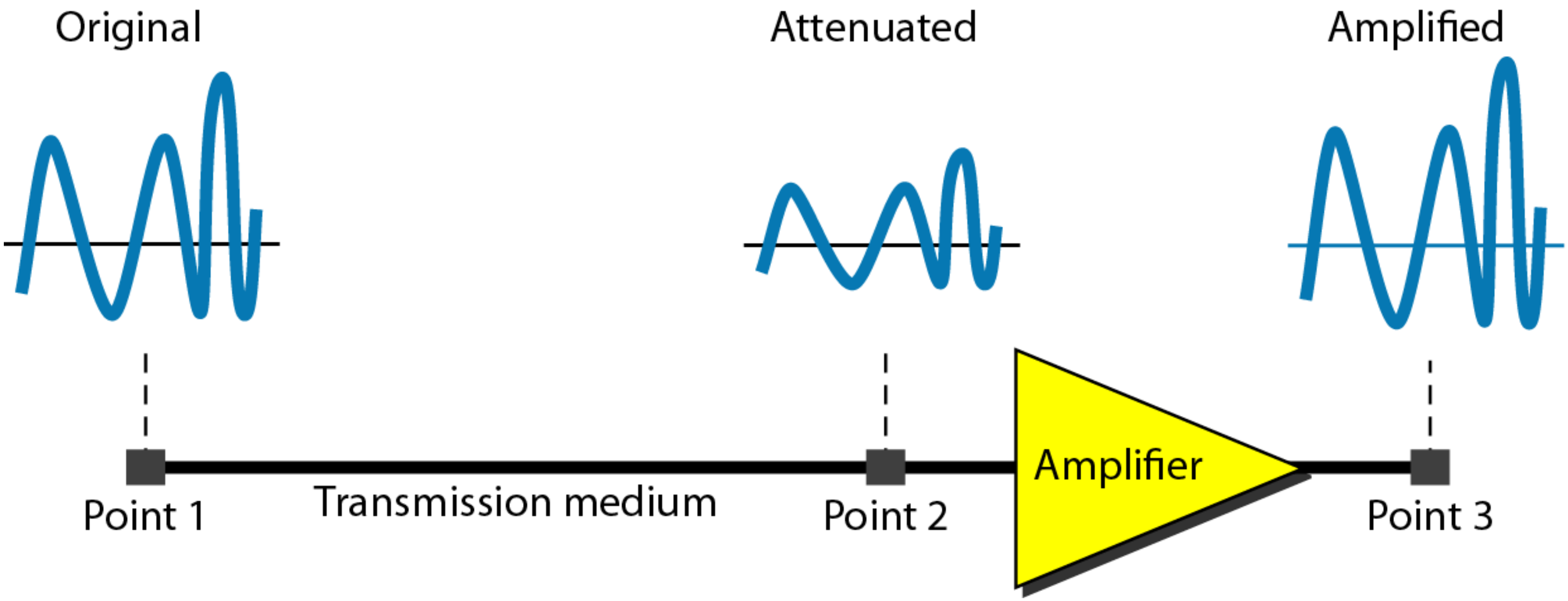
- To show the loss or gain of energy the unit "decibel" is used.

$$dB = 10\log_{10} P_2/P_1$$

P_1 - input signal

P_2 - output signal

Attenuation



Example

Suppose a signal travels through a transmission medium and its power is reduced to one-half. This means that P_2 is (1/2)P_1. In this case, the attenuation (loss of power) can be calculated as

$$10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{0.5 P_1}{P_1} = 10 \log_{10} 0.5 = 10(-0.3) = -3 \text{ dB}$$

A loss of 3 dB (–3 dB) is equivalent to losing one-half the power.

Question

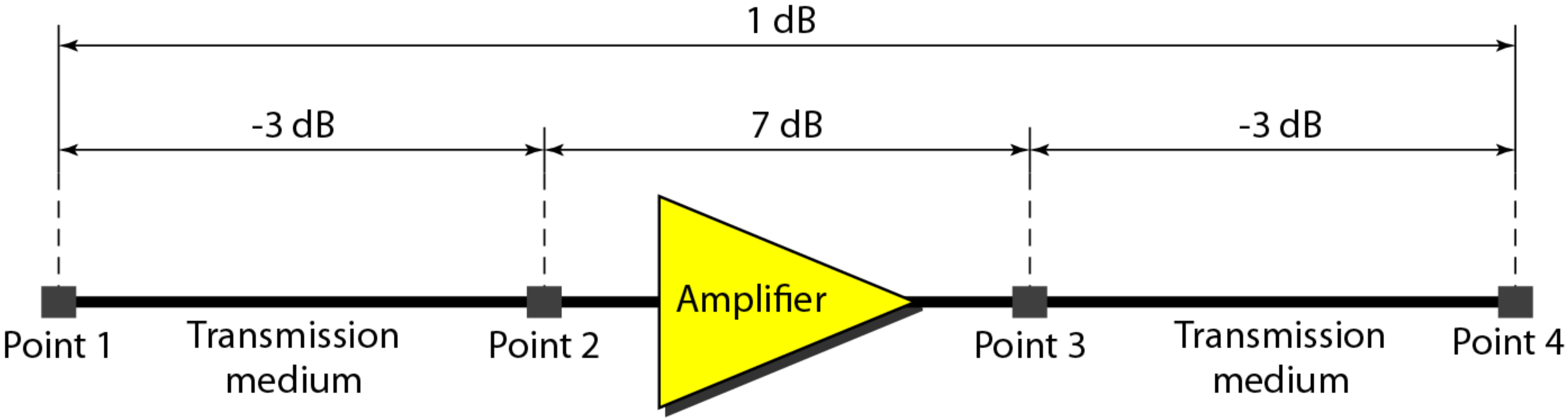
A signal travels through an amplifier, and its power is increased 10 times. This means that $P_2 = 10P_1$. In this case, the amplification (gain of power) will be

a) 11 dB
b) 12 dB
c) 20 dB
d) 10 dB

$$10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{10P_1}{P_1}$$

$$= 10 \log_{10} 10 = 10(1) = 10 \text{ dB}$$

Decibels for Example



Example

One reason that engineers use the decibel to measure the changes in the strength of a signal is that decibel numbers can be added (or subtracted) when we are measuring several points (cascading) instead of just two. In Figure 3.27 a signal travels from point 1 to point 4. In this case, the decibel value can be calculated as

$$\boxed{\mathrm{dB} = -3 + 7 - 3 = +1}$$

Example

Sometimes the decibel is used to measure signal power in milliwatts. In this case, it is referred to as dB_m and is calculated as $dB_m = 10 \log10 P_m$, where P_m is the power in milliwatts. Calculate the power of a signal with $dB_m = -30$.

Solution

We can calculate the power in the signal as

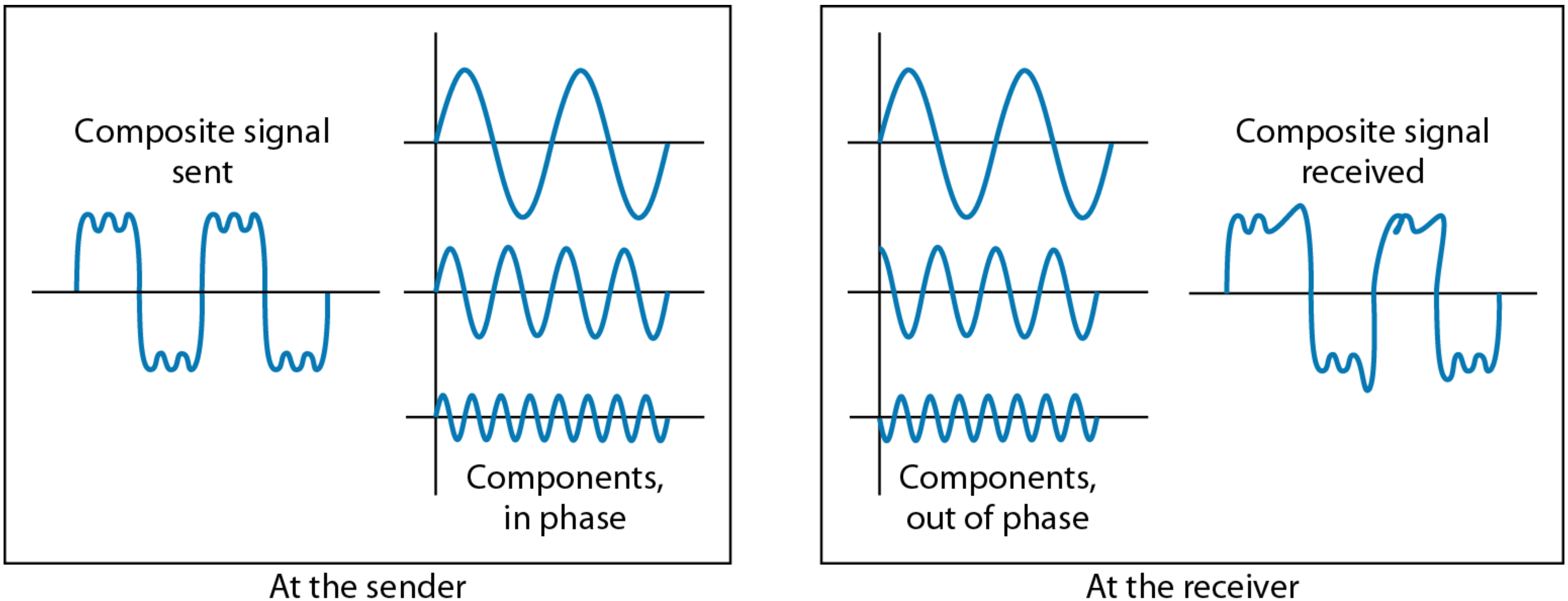
$$\mathrm{dB_m} = 10 \log_{10} P_m = -30$$

$$\log_{10} P_m = -3 \qquad P_m = 10^{-3}\ \mathrm{mW}$$

Distortion

- Means that the signal changes its form or shape
- Distortion occurs in composite signals
- Each frequency component has its own propagation speed traveling through a medium.
- The different components therefore arrive with different delays at the receiver.
- That means that the signals have different phases at the receiver than they did at the source.

Distortion

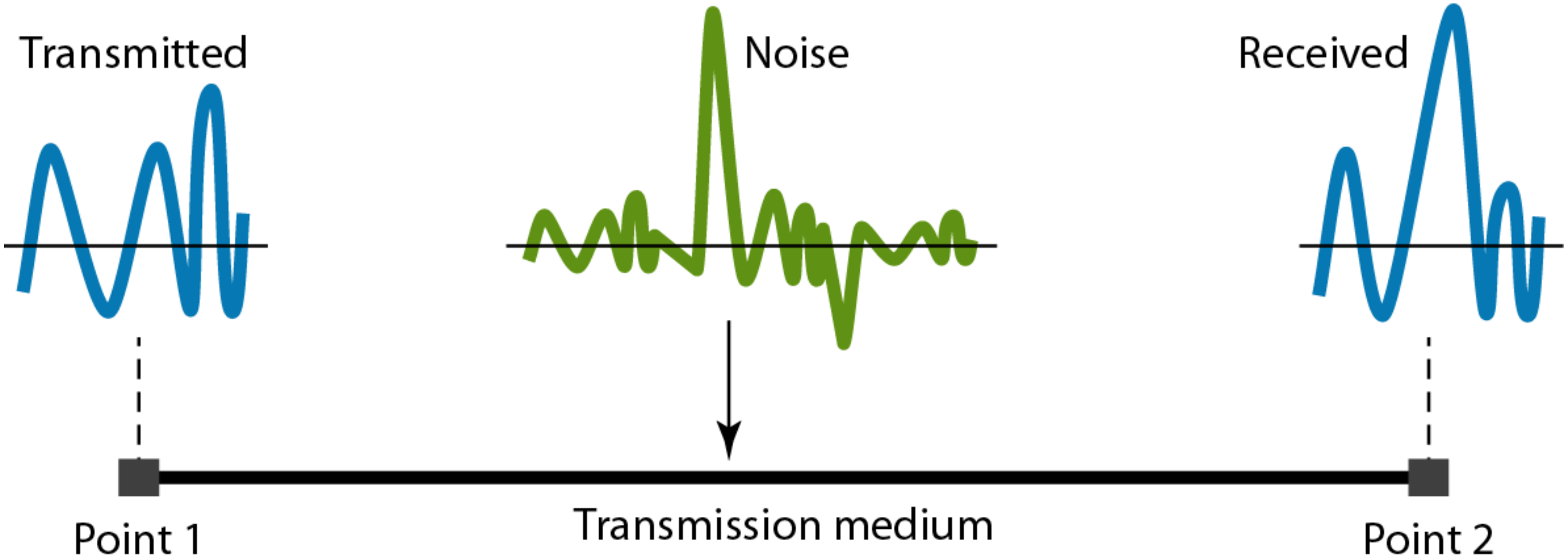


Composite signal sent
Components, in phase
At the sender
Components, out of phase
Composite signal received
At the receiver

Noise

- There are different types of noise
  - Thermal - random noise of electrons in the wire creates an extra signal
  - Crosstalk - same as above but between two wires.
  - Impulse - Spikes that result from power lines, lightening, etc.
  - Induced

Noise



Transmitted
Noise
Received
Point 1
Transmission medium
Point 2

Signal to Noise Ratio (SNR)

- To measure the quality of a system the SNR is often used. It indicates the strength of the signal wrt the noise power in the system.
- It is the ratio between two powers.
- It is usually given in dB and referred to as SNR_{dB}.

Example

The power of a signal is 10 mW and the power of the noise is 1 μW; what are the values of SNR and SNR_{dB}?

Solution

The values of SNR and SNR_{dB} can be calculated as follows:

$$SNR = \frac{10{,}000\ \mu W}{1\ mW} = 10{,}000$$

$$SNR_{dB} = 10 \log_{10} 10{,}000 = 10 \log_{10} 10^4 = 40$$

Example

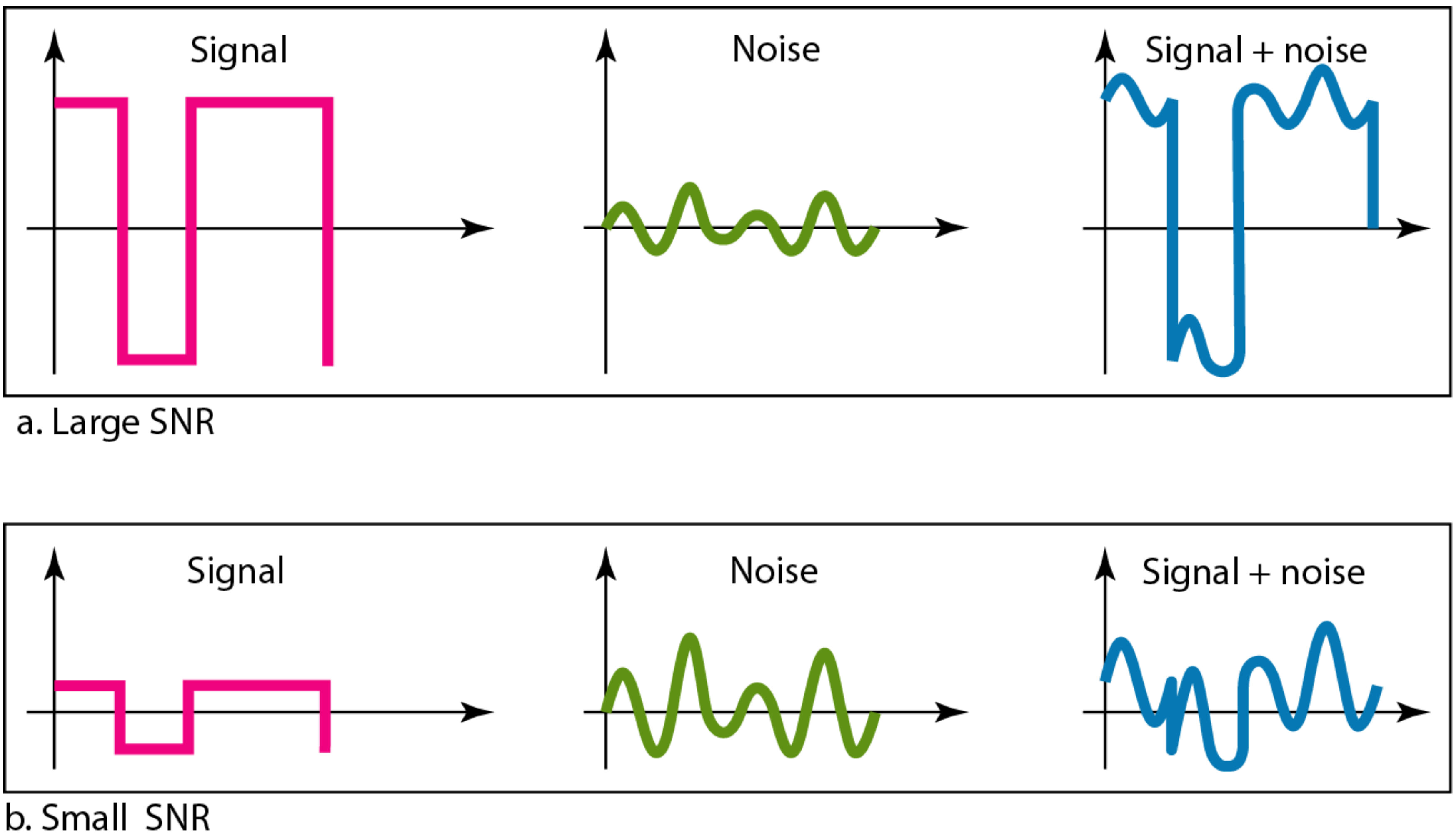
The values of SNR and SNR_{dB} for a noiseless channel are

$$SNR = \frac{\text{signal power}}{0} = \infty$$

$$SNR_{dB} = 10 \log_{10} \infty = \infty$$

We can never achieve this ratio in real life; it is an ideal.

Figure ***Two cases of SNR: a high SNR and a low SNR***



Transmission Media
DATA AND SIGNALS

CSE306

Presented by: Dr. Amandeep Singh

To be transmitted, data must be transformed to electromagnetic signals.

ANALOG AND DIGITAL

Data can be analog or digital. The term analog data refers to information that is continuous; digital data refers to information that has discrete states. Analog data take on continuous values. Digital data take on discrete values.

Analog and Digital Data
Analog and Digital Signals
Periodic and Nonperiodic Signals

POLL 1

- Data can be

a) Digital Only

b) Analog Only

c) Both A and B

d) None of the Above

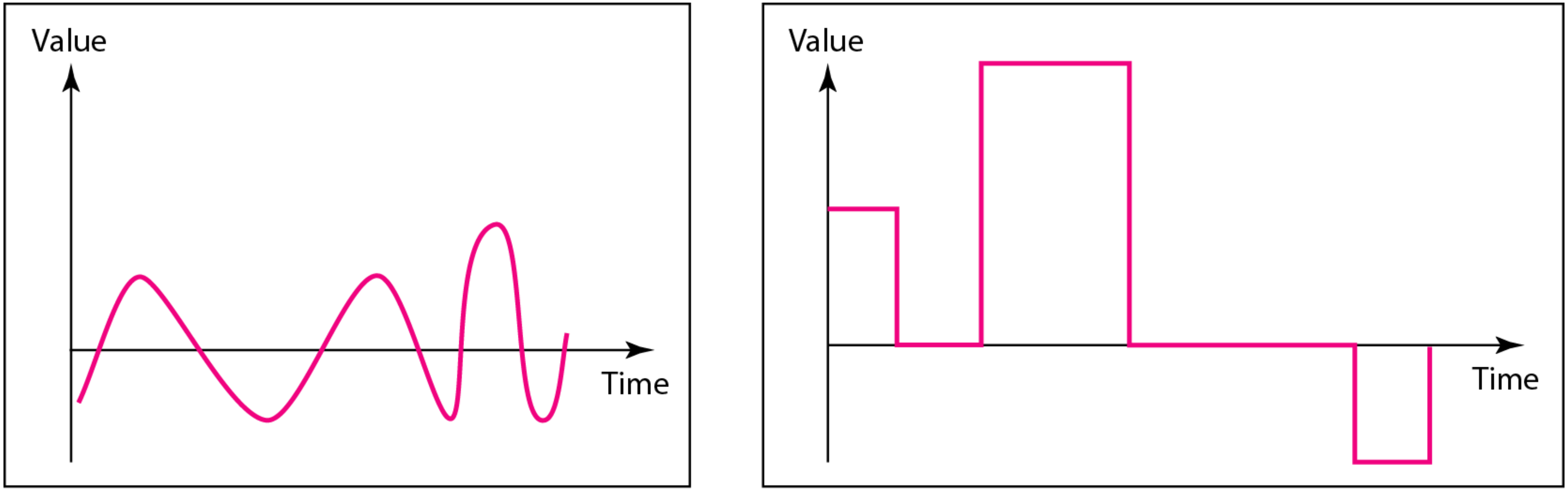
Note

Data can be analog or digital.
Analog data are continuous and take continuous values.
Digital data have discrete states and take discrete values.

Note

Signals can be analog or digital. Analog signals can have an infinite number of values in a range; digital signals can have only a limited number of values.

Comparison of analog and digital signals



a. Analog signal

b. Digital signal

Periodic and Non Periodic

- **A periodic signal** completes a pattern within a measurable time frame, called a period, and repeats that pattern over subsequent identical periods.

- The completion of one full pattern is called as a **cycle.**

- A **non-periodic signal** changes without exhibiting a pattern or a cycle.

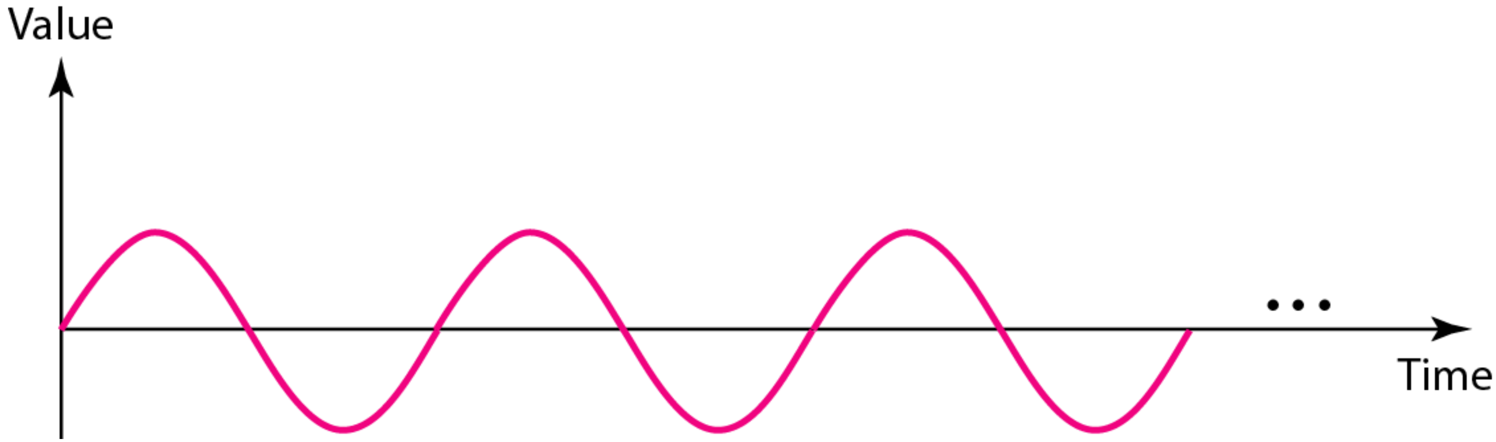
Note

In data communications, we commonly use periodic analog signals and nonperiodic digital signals.

PERIODIC ANALOG SIGNALS

Periodic analog signals can be classified as simple or composite.

Figure ***A sine wave***



A sine wave is represented by:

- Peak Amplitude
- Frequency
- Phase
- Wavelength

POLL 2

- Which of the following is//are representation of a wave

a) Amplitude

b) Frequency

c) Wavelength

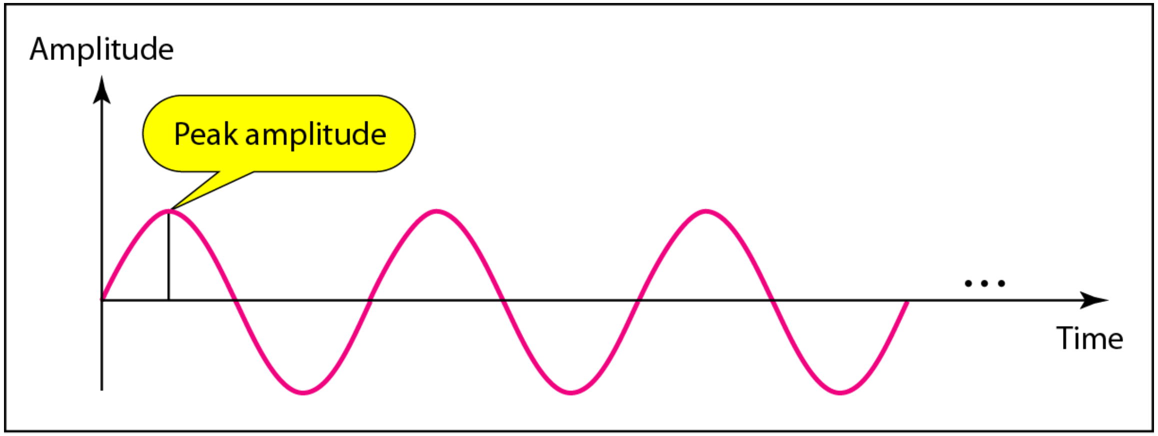
d) All of the above

Peak Amplitude

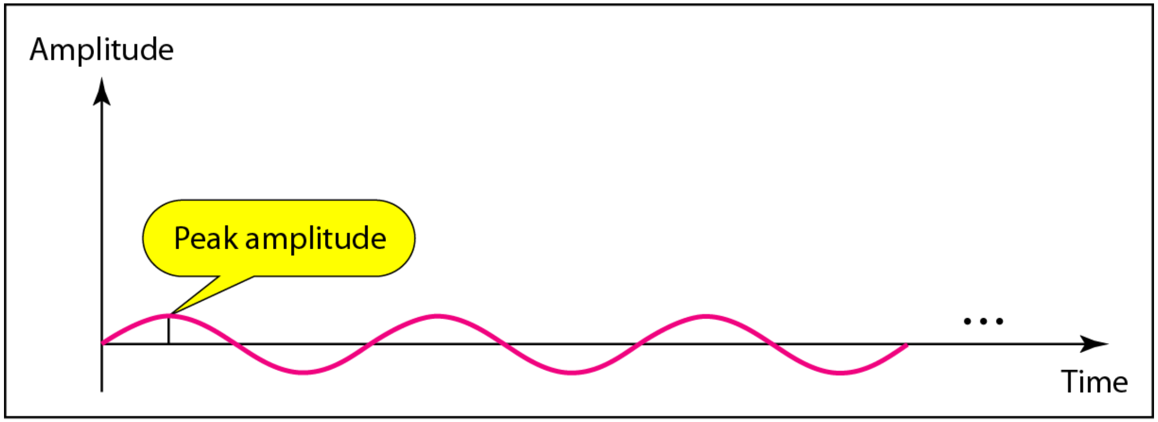
- The peak amplitude of a signal is the absolute value of its highest intensity, proportional to energy it carries.

- Measured in volts.

Two signals with the same phase and frequency, but different amplitudes



a. A signal with high peak amplitude



b. A signal with low peak amplitude

Period and Frequency

- Period refers to amount of time, in seconds, a signal takes to complete one cycle.
- Frequency refers to the number of periods in 1 second.
- Period is expressed in seconds and frequency is expressed in hertz (Hz)

Note

Frequency and period are the inverse of each other.

$$f = \frac{1}{T} \quad \text{and} \quad T = \frac{1}{f}$$

Note

Frequency is the rate of change with respect to time.

Change in a short span of time means high frequency.

Change over a long span of time means low frequency.

Note

If a signal does not change at all, its frequency is zero.
If a signal changes instantaneously, its frequency is infinite.

POLL 3

- If the signal doesn't changes then its frequency is

a) High

b) Low

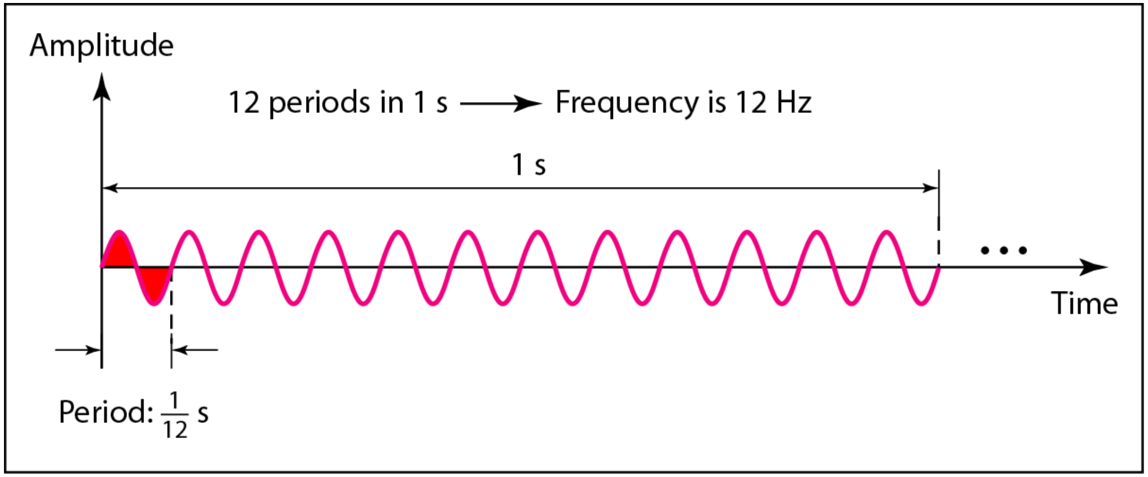
c) Zero

d) Can’t be determined

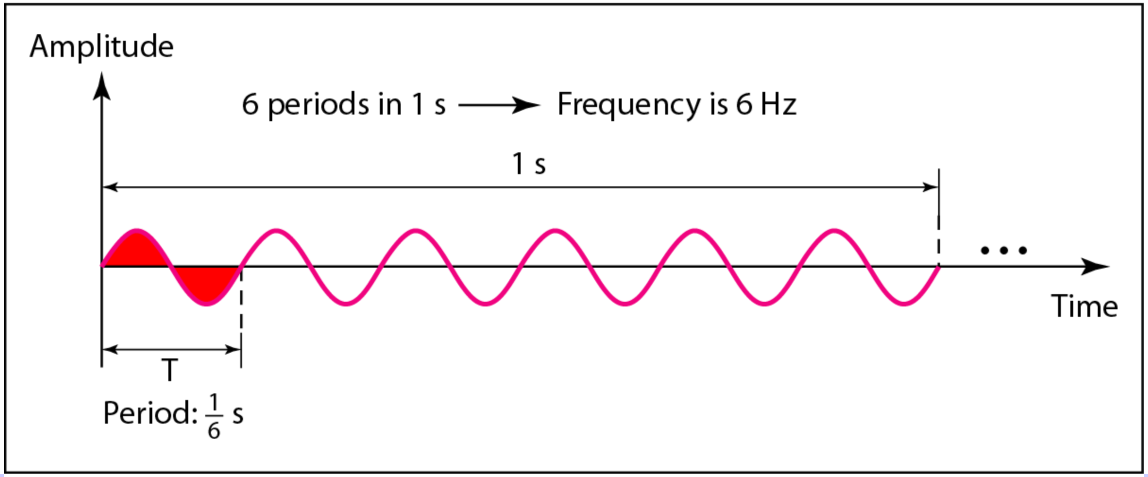
Table ***Units of period and frequency***

Unit	*Equivalent*	*Unit*	*Equivalent*
Seconds (s)	1 s	Hertz (Hz)	1 Hz
Milliseconds (ms)	10^{-3} s	Kilohertz (kHz)	10^{3} Hz
Microseconds (μs)	10^{-6} s	Megahertz (MHz)	10^{6} Hz
Nanoseconds (ns)	10^{-9} s	Gigahertz (GHz)	10^{9} Hz
Picoseconds (ps)	10^{-12} s	Terahertz (THz)	10^{12} Hz

Figure *Two signals with the same amplitude and phase, but different frequencies*



a. A signal with a frequency of 12 Hz



b. A signal with a frequency of 6 Hz

Example

The power we use at home has a frequency of 60 Hz. Determined the period of this sine wave?

$$T = \frac{1}{f} = \frac{1}{60} = 0.0166\ \text{s} = 0.0166 \times 10^{3}\ \text{ms} = 16.6\ \text{ms}$$

Example

Express a period of 100 ms in microseconds.

Example

The period of a signal is 100 ms. What is its frequency in kilohertz?

Solution

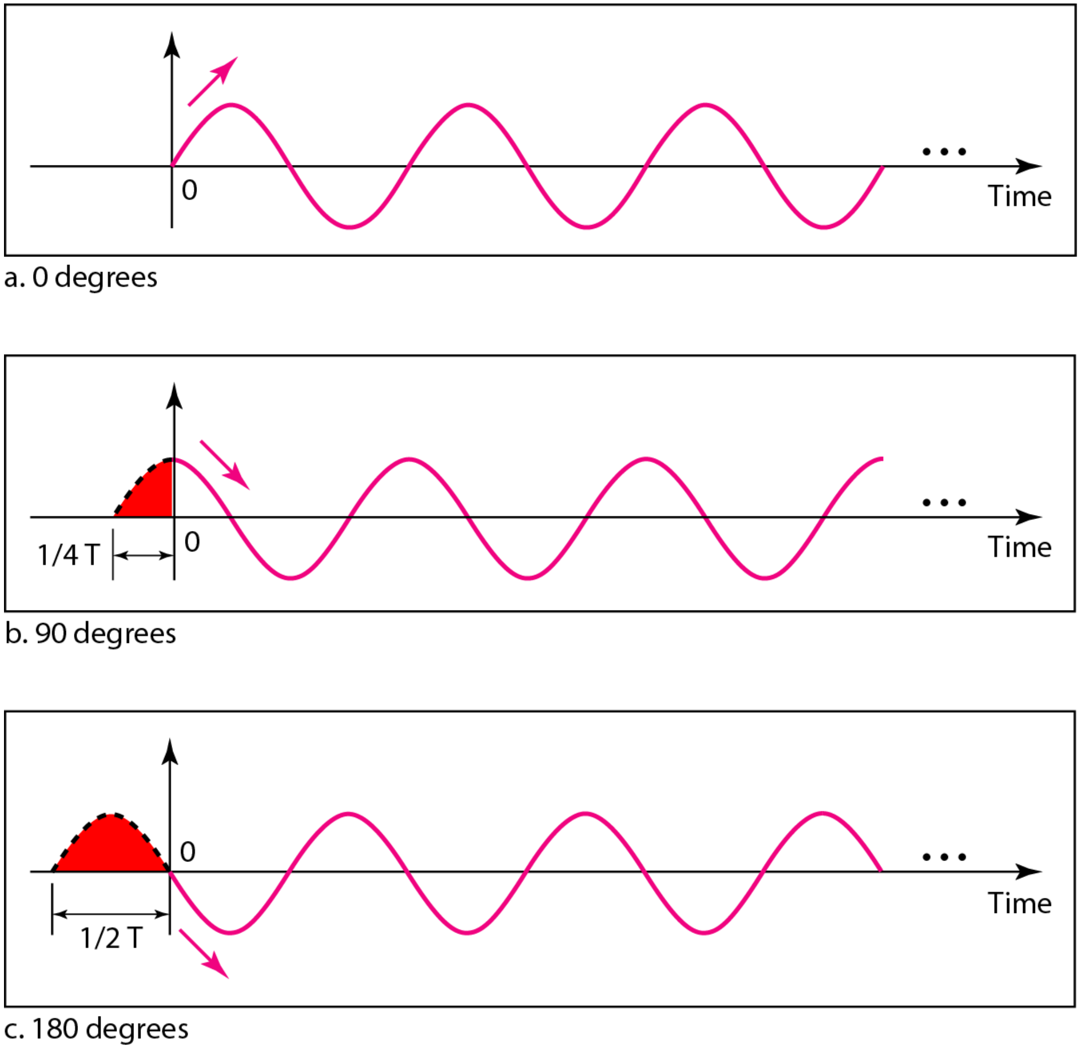
$$100 \text{ ms} = 100 \times 10^{-3} \text{ s} = 10^{-1} \text{ s}$$

$$f = \frac{1}{T} = \frac{1}{10^{-1}} \text{ Hz} = 10 \text{ Hz} = 10 \times 10^{-3} \text{ kHz} = 10^{-2} \text{ kHz}$$

Note

Phase describes the position of the waveform relative to time 0.

Figure *Three sine waves with the same amplitude and frequency, but different phases*

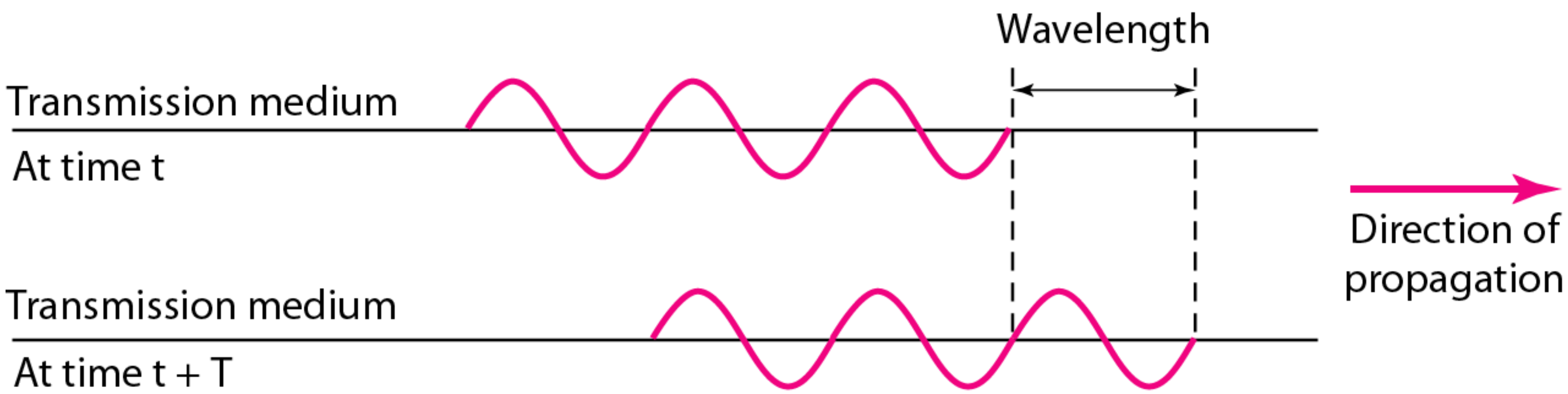


Example

A sine wave with value 1/6 cycle with respect to time 0. What is its phase in degrees and radians?

$$\frac{1}{6} \times 360 = 60^\circ = 60 \times \frac{2\pi}{360}\ \text{rad} = \frac{\pi}{3}\ \text{rad} = 1.046\ \text{rad}$$

Figure *Wavelength and period*



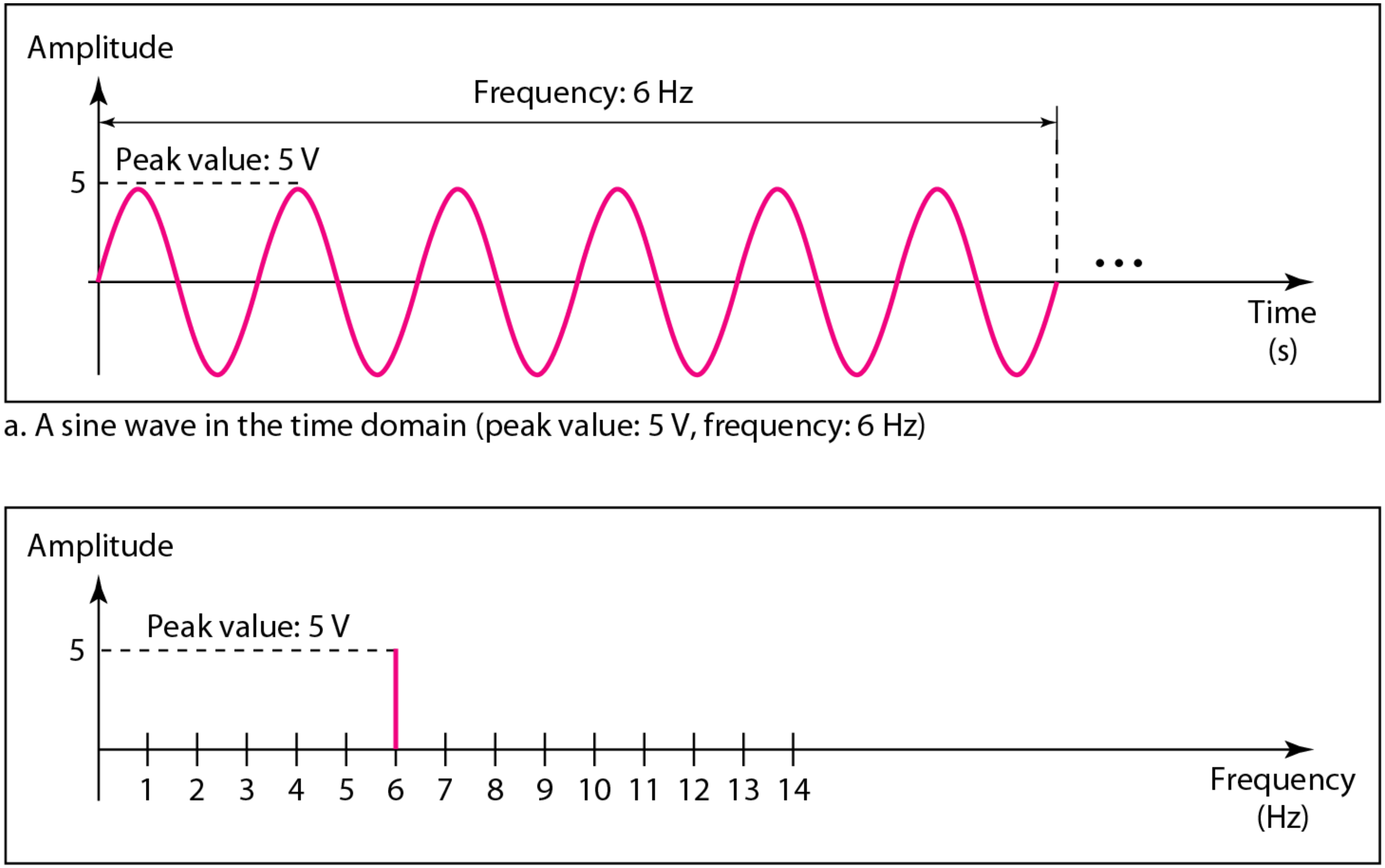
Wavelength

- Wavelength is the distance a signal can travel in one period.
- Wavelength= propagation speed* period

Or

- Wavelength= propagation speed/ frequency

Figure ***The time-domain and frequency-domain plots of a sine wave***



a. A sine wave in the time domain (peak value: 5 V, frequency: 6 Hz)

b. The same sine wave in the frequency domain (peak value: 5 V, frequency: 6 Hz)

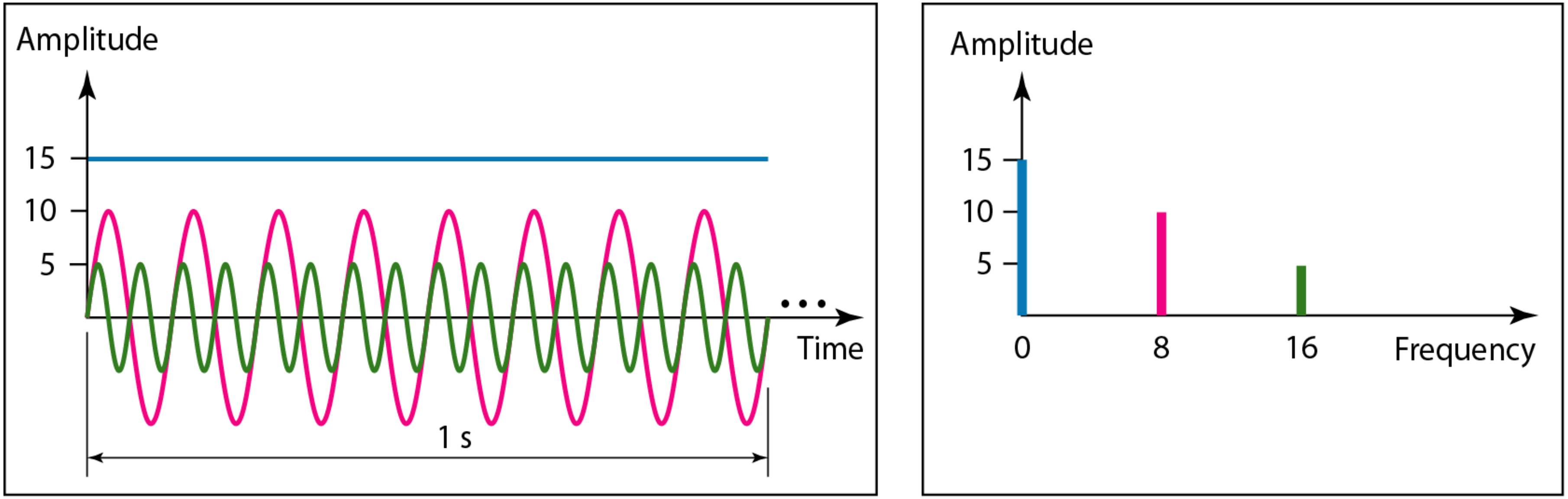
Note

A complete sine wave in the time domain can be represented by one single spike in the frequency domain.

Example

The frequency domain is more compact and useful when we are dealing with more than one sine wave.

Figure ***The time domain and frequency domain of three sine waves***



a. Time-domain representation of three sine waves with frequencies 0, 8, and 16

b. Frequency-domain representation of the same three signals

Note

A single-frequency sine wave is not useful in data communications; we need to send a composite signal, a signal made of many simple sine waves.

Note

According to Fourier analysis, any composite signal is a combination of simple sine waves with different frequencies, amplitudes, and phases.

Note

**If the composite signal is periodic, the decomposition gives a series of signals with discrete frequencies;
if the composite signal is nonperiodic, the decomposition gives a combination of sine waves with continuous frequencies.**

Example

Figure shows a periodic composite signal with frequency f. This type of signal is not typical of those found in data communications. We can consider it to be three alarm systems, each with a different frequency. The analysis of this signal can give us a good understanding of how to decompose signals.

Figure ***A composite periodic signal***

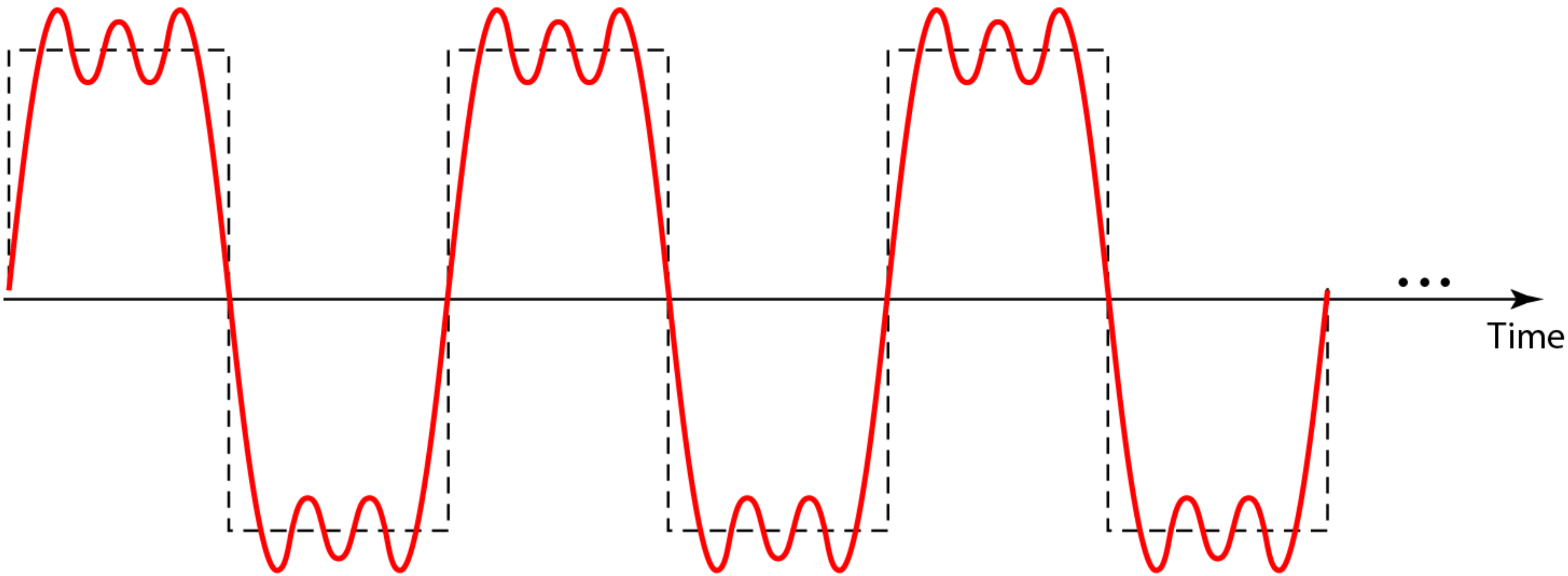
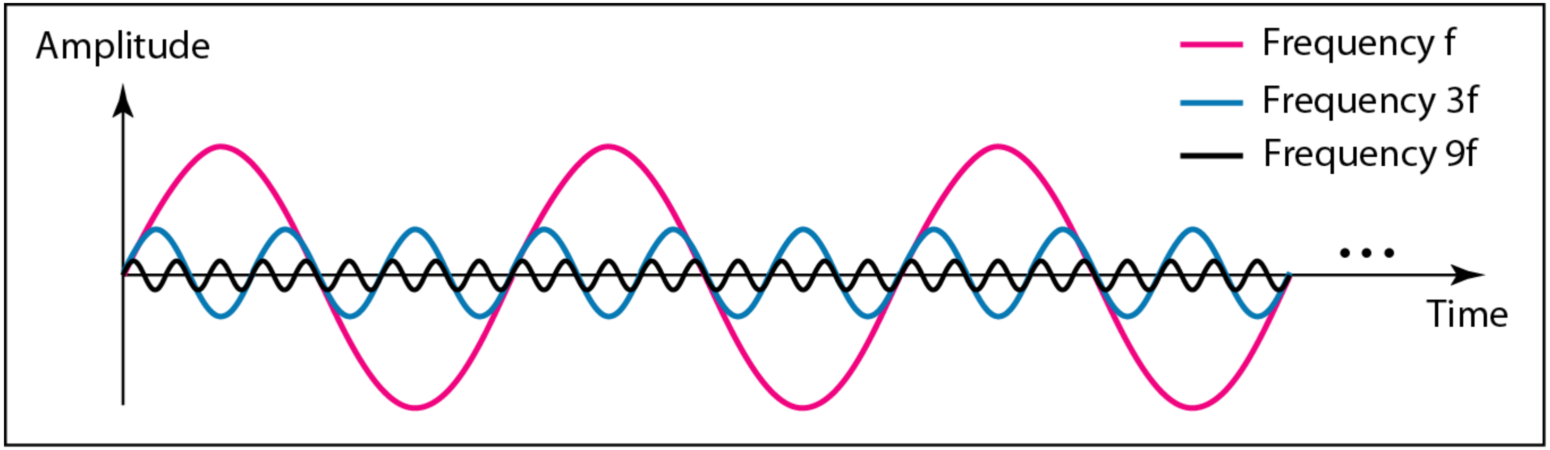
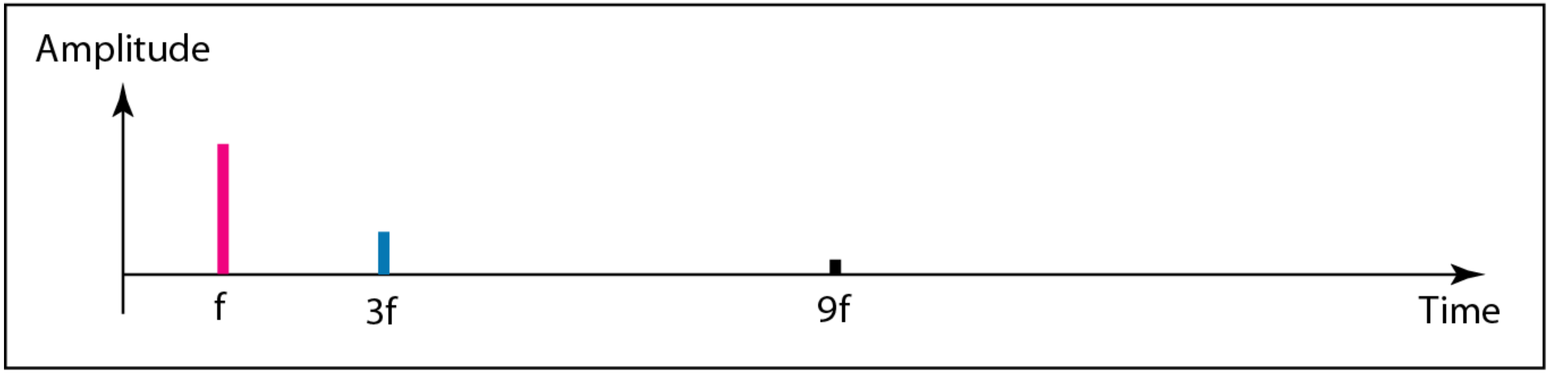


Figure ***Decomposition of a composite periodic signal in the time and frequency domains***



a. Time-domain decomposition of a composite signal

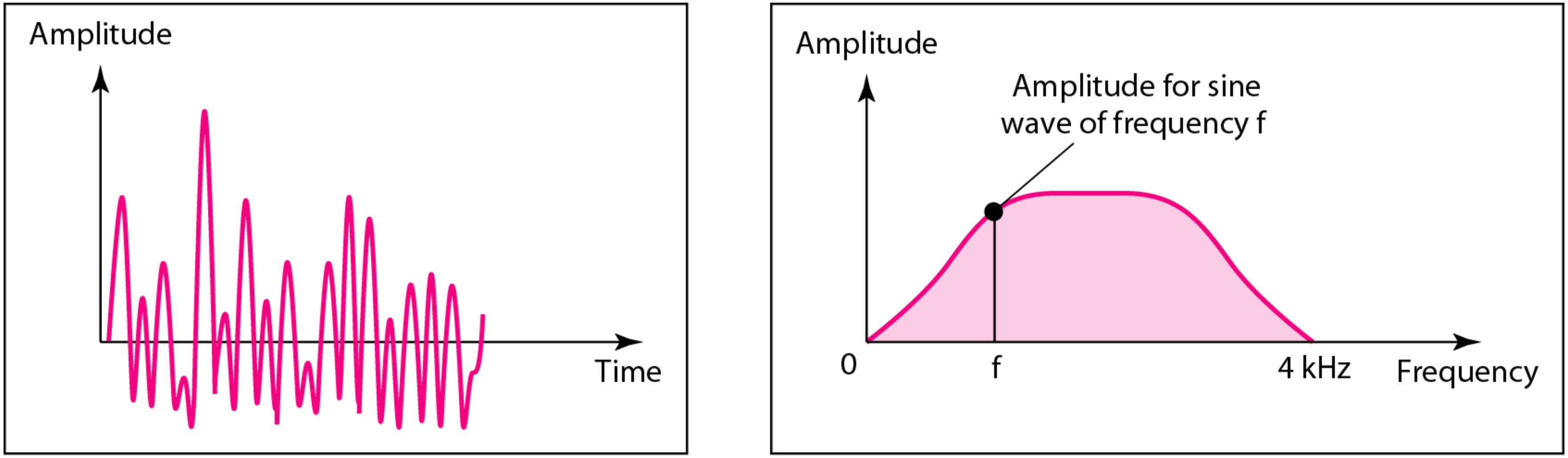


b. Frequency-domain decomposition of the composite signal

Example

Figure shows a nonperiodic composite signal. It can be the signal created by a microphone or a telephone set when a word or two is pronounced. In this case, the composite signal cannot be periodic, because that implies that we are repeating the same word or words with exactly the same tone.

Figure *The time and frequency domains of a nonperiodic signal*



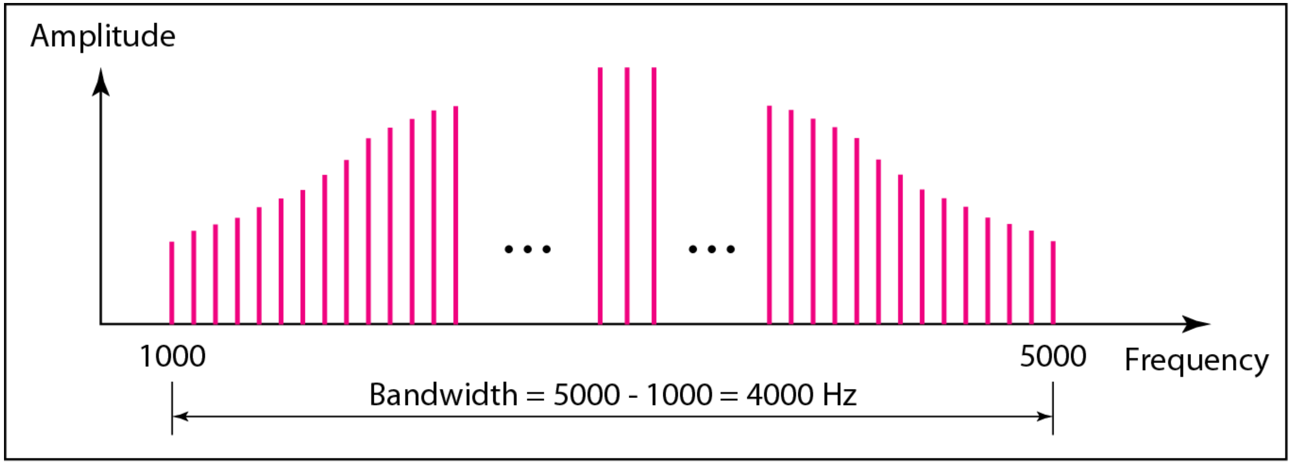
a. Time domain

b. Frequency domain

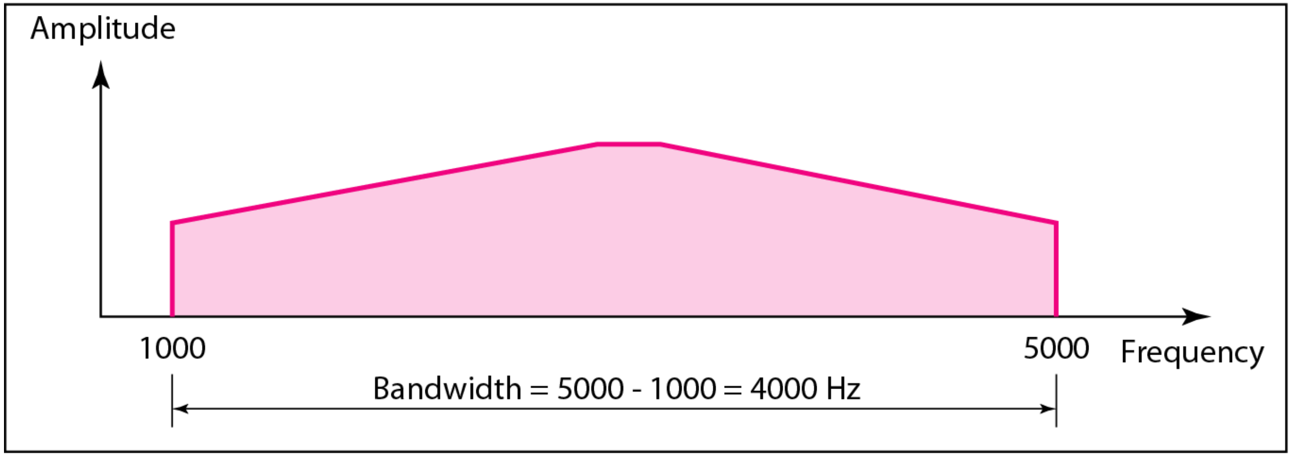
Note

The bandwidth of a composite signal is the difference between the highest and the lowest frequencies contained in that signal.

Figure *The bandwidth of periodic and nonperiodic composite signals*



a. Bandwidth of a periodic signal



b. Bandwidth of a nonperiodic signal

Example

If a periodic signal is decomposed into five sine waves with frequencies of 100, 300, 500, 700, and 900 Hz, what is its bandwidth? Draw the spectrum, assuming all components have a maximum amplitude of 10 V.

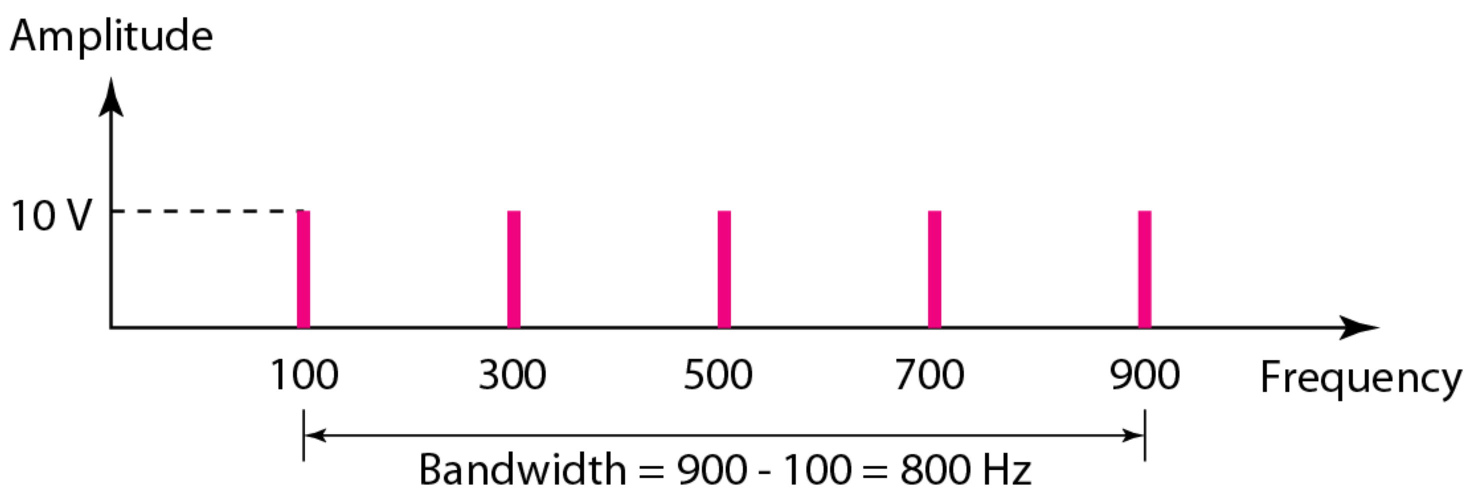
Solution

Let f_h be the highest frequency, f_l the lowest frequency, and B the bandwidth. Then

$$B = f_h - f_l = 900 - 100 = 800 \text{ Hz}$$

The spectrum has only five spikes, at 100, 300, 500, 700, and 900 Hz (see Figure 3.13).

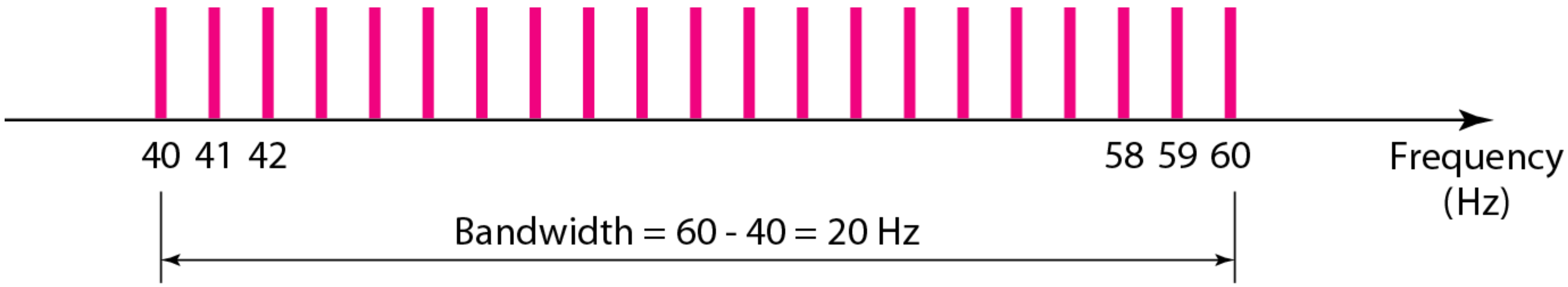
Figure ***The bandwidth for Example***



A periodic signal has a bandwidth of 20 Hz. The highest frequency is 60 Hz. What is the lowest frequency?

a) ***60 Hz***
b) ***20 HZ***
c) ***40 Hz***
d) ***80 Hz***

Draw the spectrum if the signal contains all frequencies of the same amplitude.



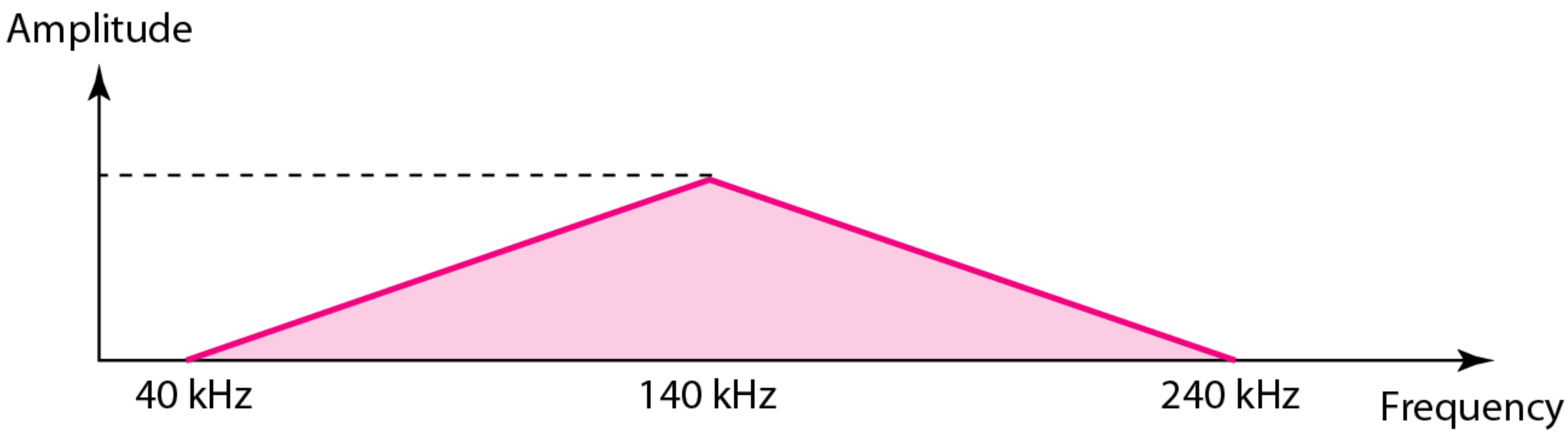
Example

A nonperiodic composite signal has a bandwidth of 200 kHz, with a middle frequency of 140 kHz and peak amplitude of 20 V. The two extreme frequencies have an amplitude of 0. Draw the frequency domain of the signal.

Solution

The lowest frequency must be at 40 kHz and the highest at 240 kHz. Figure shows the frequency domain and the bandwidth.

Figure *The bandwidth for Example*



DATA AND SIGNALS

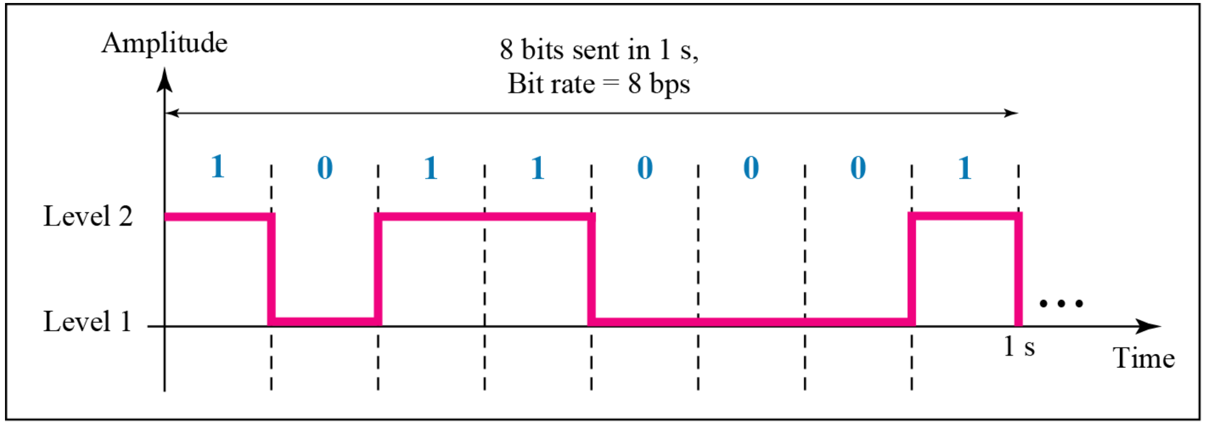
CSE306

Presented by: Dr. Amandeep Singh

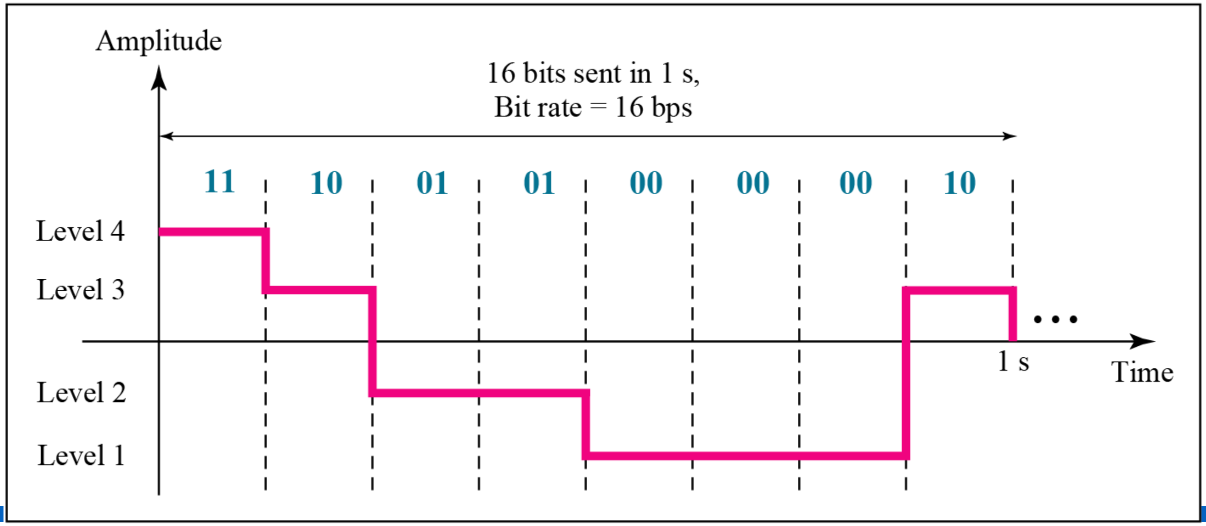
DIGITAL SIGNALS

In addition to being represented by an analog signal, information can also be represented by a digital signal. For example, a 1 can be encoded as a positive voltage and a 0 as zero voltage. A digital signal can have more than two levels. In this case, we can send more than 1 bit for each level.

Figure *Two digital signals: one with two signal levels and the other with four signal levels*



a. A digital signal with two levels



b. A digital signal with four levels

POLL 1

A digital Signal can be represented by

a) Two levels only
b) 4 levels only
c) Finite levels in the power of 2 only
d) Finite levels

Example

A digital signal has eight levels. How many bits are needed per level? We calculate the number of bits from the formula

$$\boxed{\text{Number of bits per level} = \log_2 8 = 3}$$

Each signal level is represented by 3 bits.

Example

A digital signal has nine levels. How many bits are needed per level? We calculate the number of bits by using the formula. Each signal level is represented by 3.17 bits. However, this answer is not realistic. The number of bits sent per level needs to be an integer as well as a power of 2. For this example, 4 bits can represent one level.

Bit Rate

- Most Digital Signals are non-periodic. Therefore, period and frequency are not appropriate characteristics.
- Bit rate is used.
- Bit rate is number of bits sent in 1s. Expressed in **bps.**

POLL 2

- A digital signal is represented in bps because

a) It is a non-periodic signal

b) It is a periodic signal

Example

Assume we need to download text documents at the rate of 100 pages per minute. What is the required bit rate of the channel?

Solution

A page is an average of 24 lines with 80 characters in each line. If we assume that one character requires 8 bits, the bit rate is

$$\boxed{100 \times 24 \times 80 \times 8 = 1{,}636{,}000 \text{ bps} = 1.636 \text{ Mbps}}$$

A digitized voice channel is made by digitizing a 4-kHz bandwidth analog voice signal. We need to sample the signal at twice the highest frequency (two samples per hertz). We assume that each sample requires 8 bits. What is the required bit rate?

a) 64 kbps
b) 12 kbps
c) 32 kbps

Example

A digitized voice channel is made by digitizing a 4-kHz bandwidth analog voice signal. We need to sample the signal at twice the highest frequency (two samples per hertz). We assume that each sample requires 8 bits. What is the required bit rate?

Solution

The bit rate can be calculated as

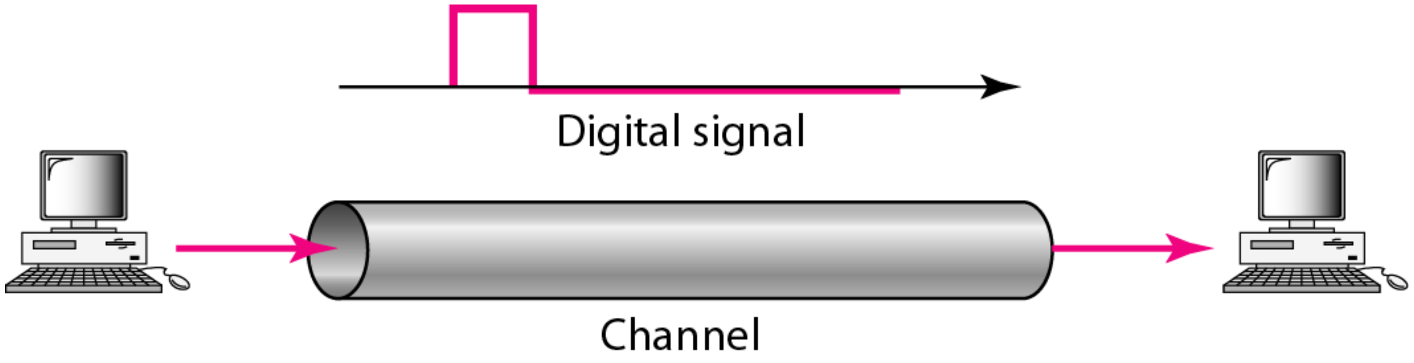
$$\boxed{2 \times 4000 \times 8 = 64{,}000 \text{ bps} = 64 \text{ kbps}}$$

Bit Length

- Bit length is distance one bit occupies on transmission medium.

- Bit length= propagation speed* bit duration

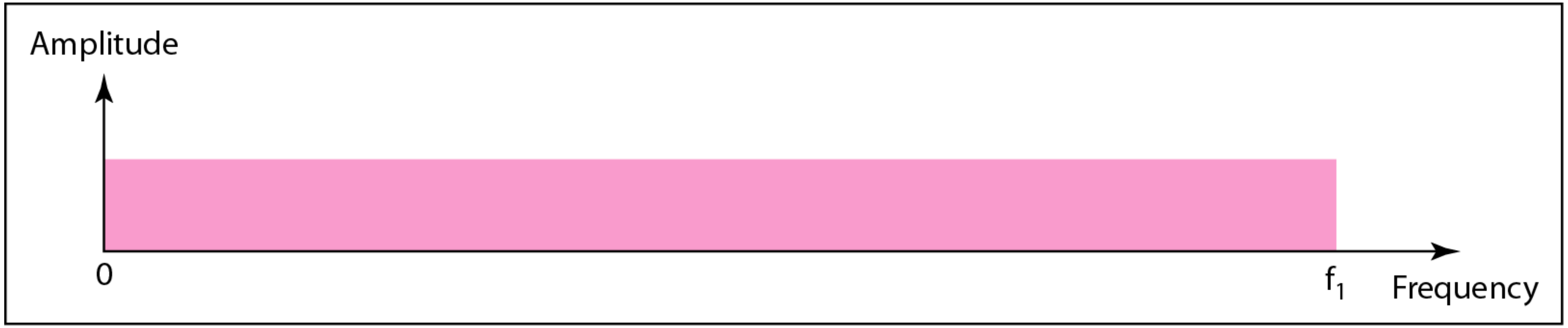
Figure *Baseband transmission*



Note

A digital signal is a composite analog signal with an infinite bandwidth.

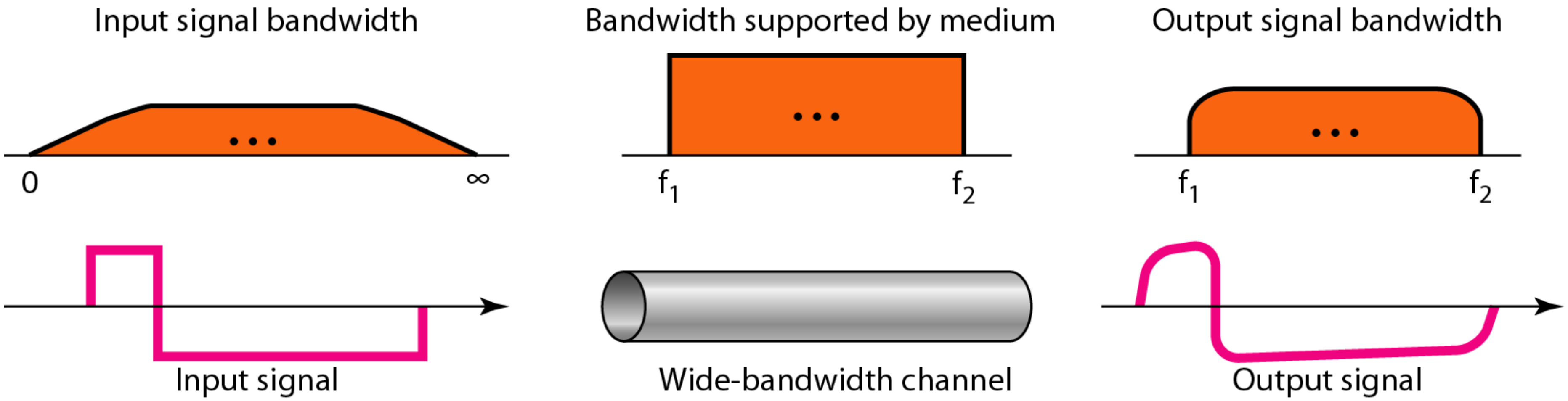
Figure *Bandwidths of two low-pass channels*



a. Low-pass channel, wide bandwidth

b. Low-pass channel, narrow bandwidth

Figure ***Baseband transmission using a dedicated medium***



Note

Baseband transmission of a digital signal that preserves the shape of the digital signal is possible only if we have a low-pass channel with an infinite or very wide bandwidth.

Note

In baseband transmission, the required bandwidth is proportional to the bit rate; if we need to send bits faster, we need more bandwidth. Bit rate is twice the bandwidth required.

Example

What is the required bandwidth of a low-pass channel if we need to send 1 Mbps by using baseband transmission?

Solution

The minimum bandwidth, is B = bit rate /2, or 500 kHz.

Example

We have a low-pass channel with bandwidth 100 kHz. What is the maximum bit rate of this channel?

a) ***100 kbps***
b) ***200 kbps***
c) ***400 kbps***

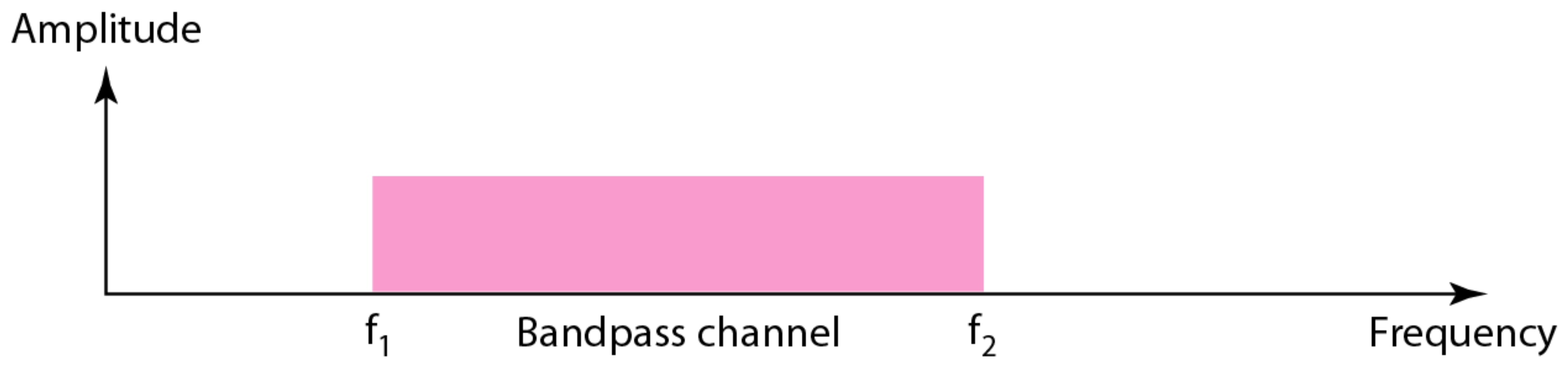
Example

We have a low-pass channel with bandwidth 100 kHz. What is the maximum bit rate of this channel?

Solution

The maximum bit rate can be achieved if we use the first harmonic. The bit rate is 2 times the available bandwidth, or 200 kbps.

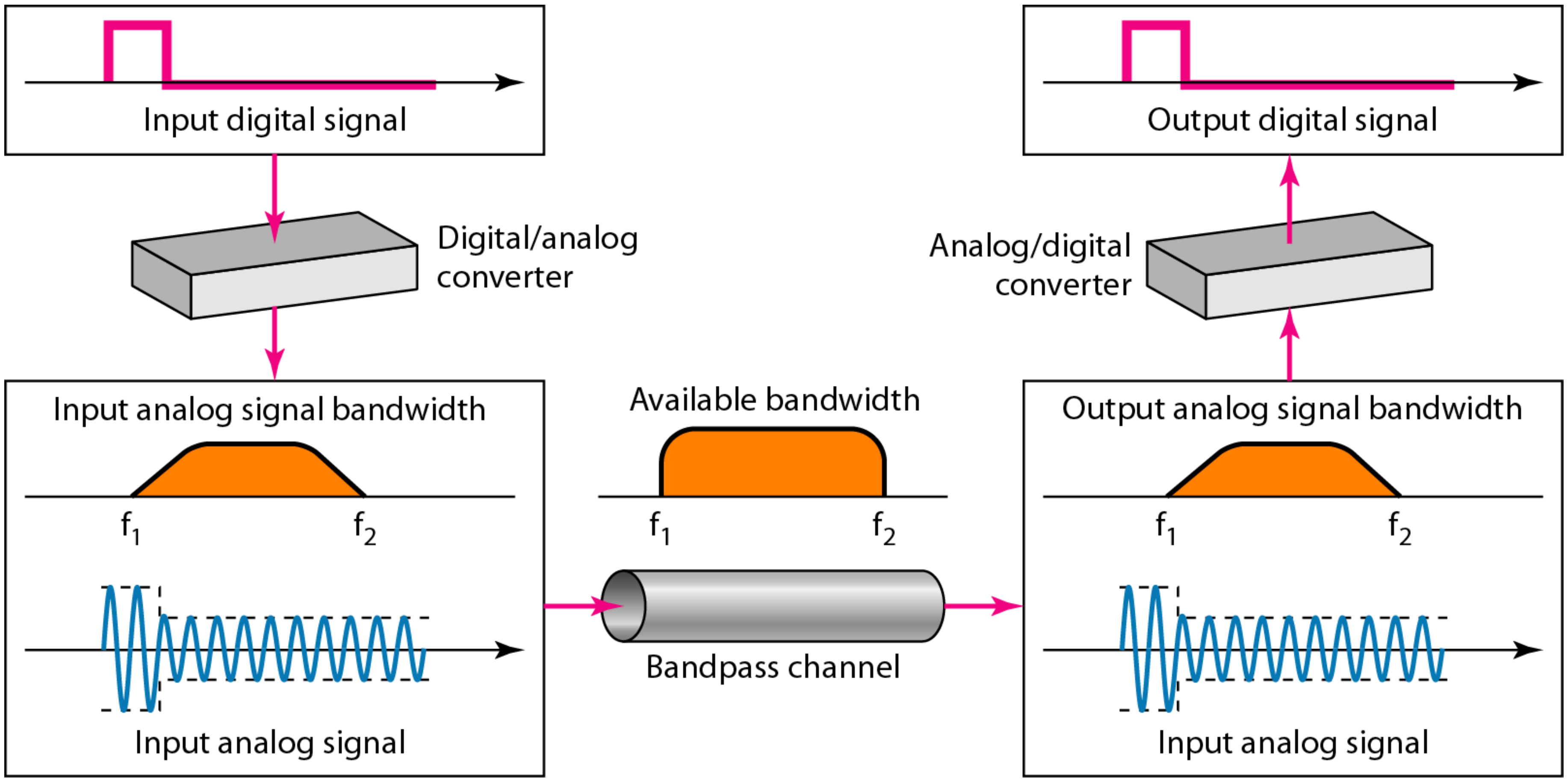
Broadband Transmission: ***Bandwidth of a bandpass channel***



Note

**If the available channel is a bandpass channel, we cannot send the digital signal directly to the channel;
we need to convert the digital signal to an analog signal before transmission.**

Figure *Modulation of a digital signal for transmission on a bandpass channel*



Example

An example of broadband transmission using modulation is the sending of computer data through a telephone subscriber line, the line connecting a resident to the central telephone office. These lines are designed to carry voice with a limited bandwidth. The channel is considered a bandpass channel. We convert the digital signal from the computer to an analog signal, and send the analog signal. We can install two converters to change the digital signal to analog and vice versa at the receiving end. The converter, in this case, is called a modem

DATA RATE LIMITS

A very important consideration in data communications is how fast we can send data, in bits per second, over a channel. Data rate depends on three factors:

1. The bandwidth available
2. The level of the signals we use
3. The quality of the channel (the level of noise)

Noiseless Channel: Nyquist Bit Rate

Noisy Channel: Shannon Capacity

Using Both Limits

Note

Increasing the levels of a signal may reduce the reliability of the system.

Noiseless Channel: Nyquist Bit Rate

$$\text{Bit Rate} = 2 * \text{bandwidth} * \log_2 L$$

Example

Consider a noiseless channel with a bandwidth of 3000 Hz transmitting a signal with two signal levels. The maximum bit rate can be calculated as

$$\boxed{\text{BitRate} = 2 \times 3000 \times \log_2 2 = 6000 \text{ bps}}$$

Example

Consider the same noiseless channel transmitting a signal with four signal levels (for each level, we send 2 bits). The maximum bit rate will be

A) 6000 bps
B) 4000 bps
C) 12000 bps

Example

Consider the same noiseless channel transmitting a signal with four signal levels (for each level, we send 2 bits). The maximum bit rate can be calculated as

$$\text{BitRate} = 2 \times 3000 \times \log_2 4 = 12{,}000 \text{ bps}$$

Example

We need to send 265 kbps over a noiseless channel with a bandwidth of 20 kHz. How many signal levels do we need?

Solution

We can use the Nyquist formula as shown:

$$265{,}000 = 2 \times 20{,}000 \times \log_2 L$$

$$\log_2 L = 6.625 \qquad L = 2^{6.625} = 98.7 \text{ levels}$$

Since this result is not a power of 2, we need to either increase the number of levels or reduce the bit rate. If we have 128 levels, the bit rate is 280 kbps. If we have 64 levels, the bit rate is 240 kbps.

Noisy Channel : Shannon Capacity

- Capacity= Bandwidth * $\log_2(1+SNR)$

Example

Consider an extremely noisy channel in which the value of the signal-to-noise ratio is almost zero. In other words, the noise is so strong that the signal is faint. For this channel the capacity C is calculated as

$$\boxed{C = B \log_2 (1 + \text{SNR}) = B \log_2 (1 + 0) = B \log_2 1 = B \times 0 = 0}$$

This means that the capacity of this channel is zero regardless of the bandwidth. In other words, we cannot receive any data through this channel.

Example

We can calculate the theoretical highest bit rate of a regular telephone line. A telephone line normally has a bandwidth of 3000. The signal-to-noise ratio is usually 3162. For this channel the capacity is calculated as

$$C = B \log_2 (1 + \text{SNR}) = 3000 \log_2 (1 + 3162) = 3000 \log_2 3163$$
$$= 3000 \times 11.62 = 34{,}860 \text{ bps}$$

This means that the highest bit rate for a telephone line is 34.860 kbps. If we want to send data faster than this, we can either increase the bandwidth of the line or improve the signal-to-noise ratio.

Example

The signal-to-noise ratio is often given in decibels. Assume that SNR_{dB} = 36 and the channel bandwidth is 2 MHz. The theoretical channel capacity can be calculated as

$$SNR_{dB} = 10 \log_{10} SNR \rightarrow SNR = 10^{SNR_{dB}/10} \rightarrow SNR = 10^{3.6} = 3981$$

$$C = B \log_2 (1 + SNR) = 2 \times 10^6 \times \log_2 3982 = 24 \text{ Mbps}$$

Analog Transmission

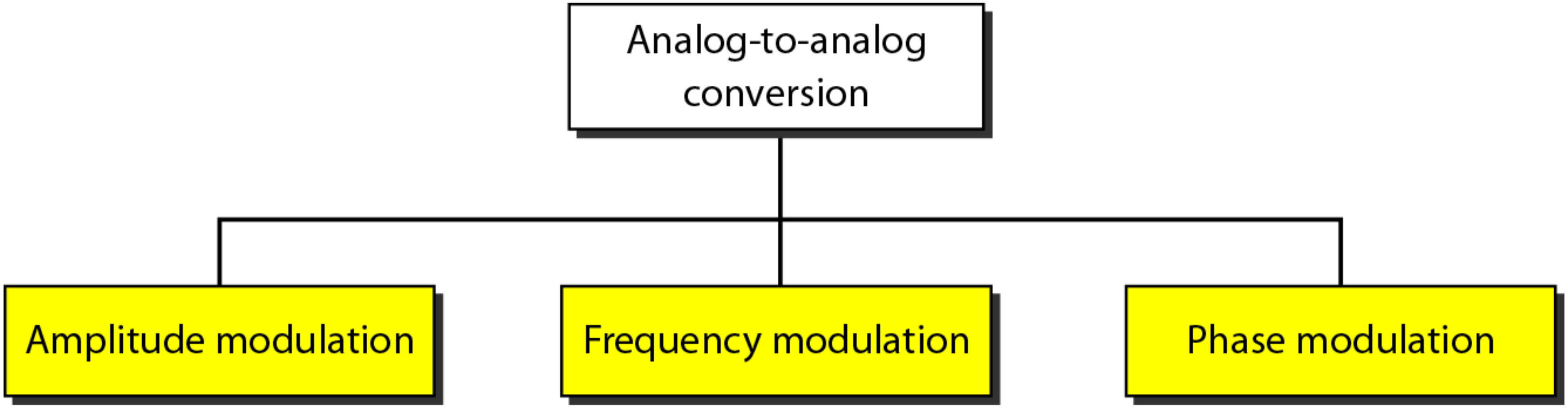
ANALOG AND ANALOG

Analog-to-analog conversion is the representation of analog information by an analog signal. One may ask why we need to modulate an analog signal; it is already analog. Modulation is needed if the medium is bandpass in nature or if only a bandpass channel is available to us.

Topics discussed in this section:

- **Amplitude Modulation**
- **Frequency Modulation**
- **Phase Modulation**

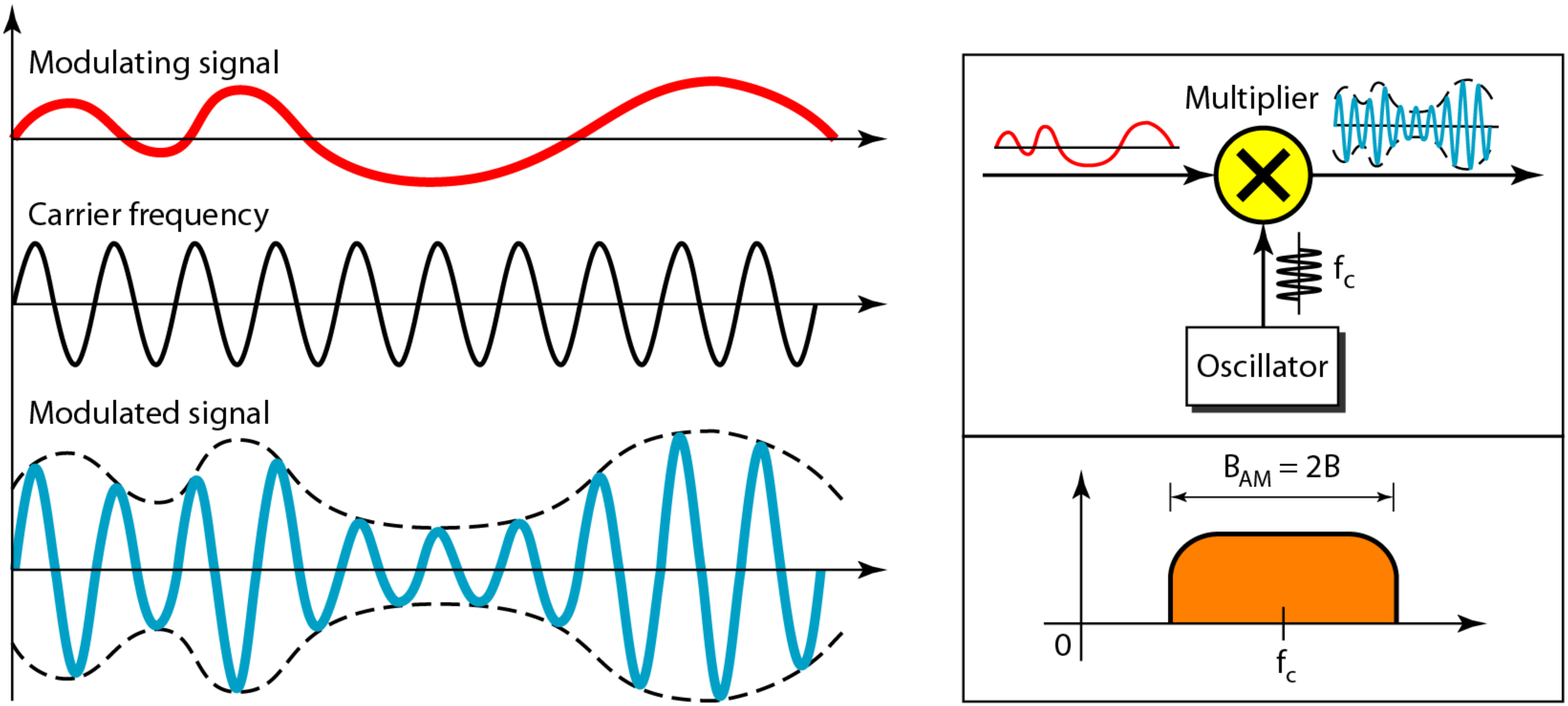
Types of analog-to-analog modulation



Amplitude Modulation

- A carrier signal is modulated only in amplitude value
- The modulating signal is the envelope of the carrier
- The required bandwidth is 2B, where B is the bandwidth of the modulating signal

Amplitude modulation



Note

The total bandwidth required for AM can be determined from the bandwidth of the audio signal: $B_{AM} = 2B$.

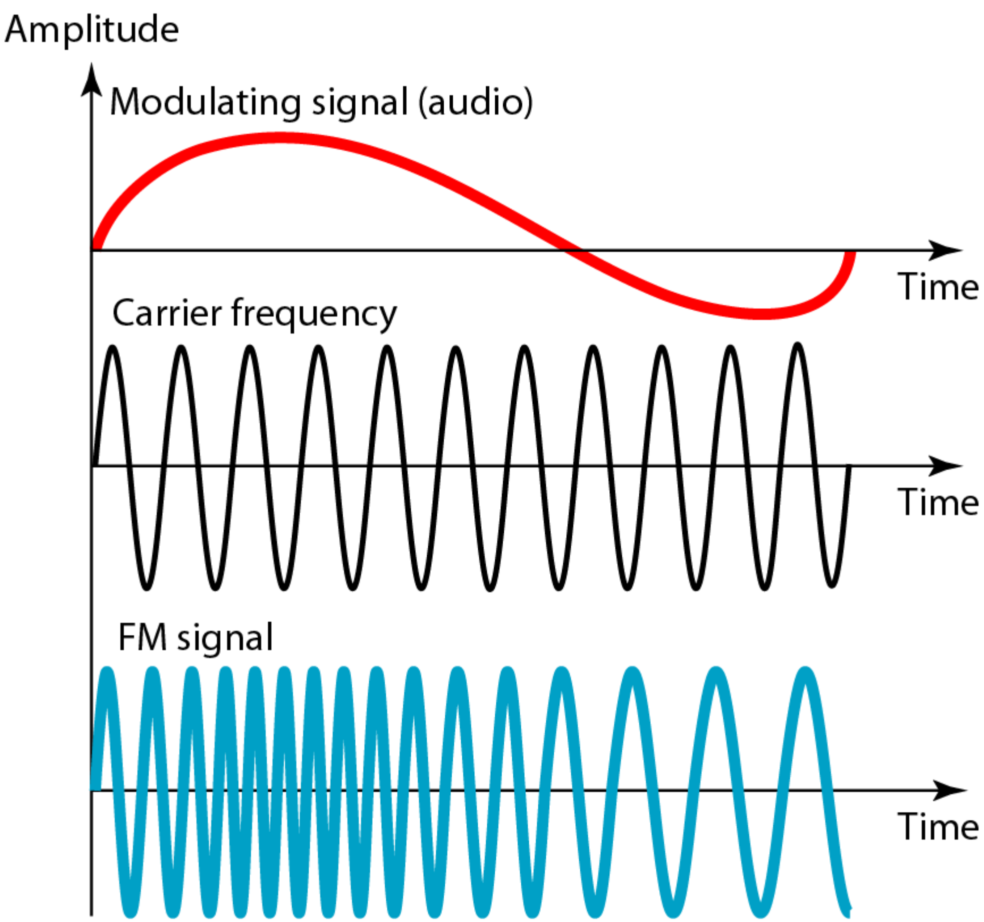
Frequency Modulation

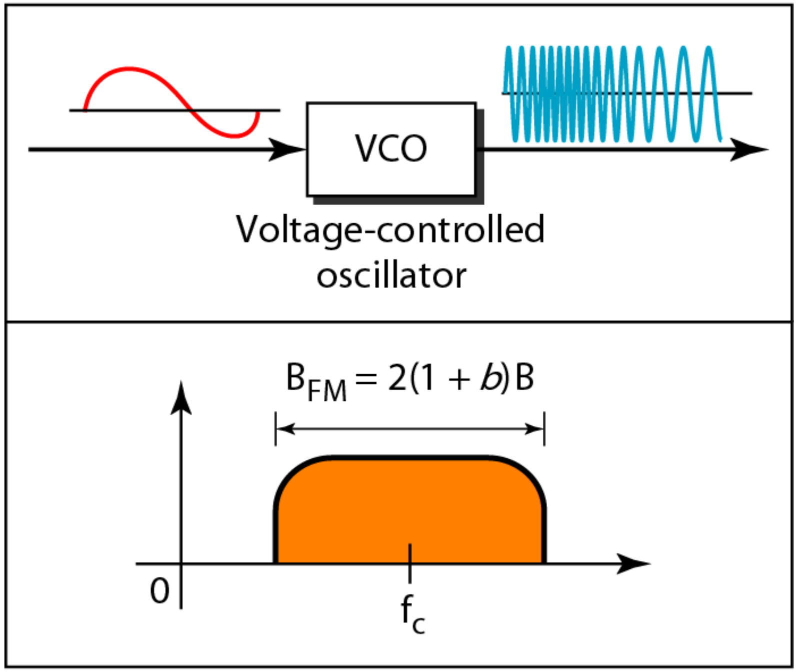
- The modulating signal changes the freq. f_c of the carrier signal
- The bandwidth for FM is high
- It is approx. 10x the signal frequency

Note

The total bandwidth required for FM can be determined from the bandwidth of the audio signal: $B_{FM} = 2(1 + \beta)B$. Where β is usually 4.

Frequency modulation

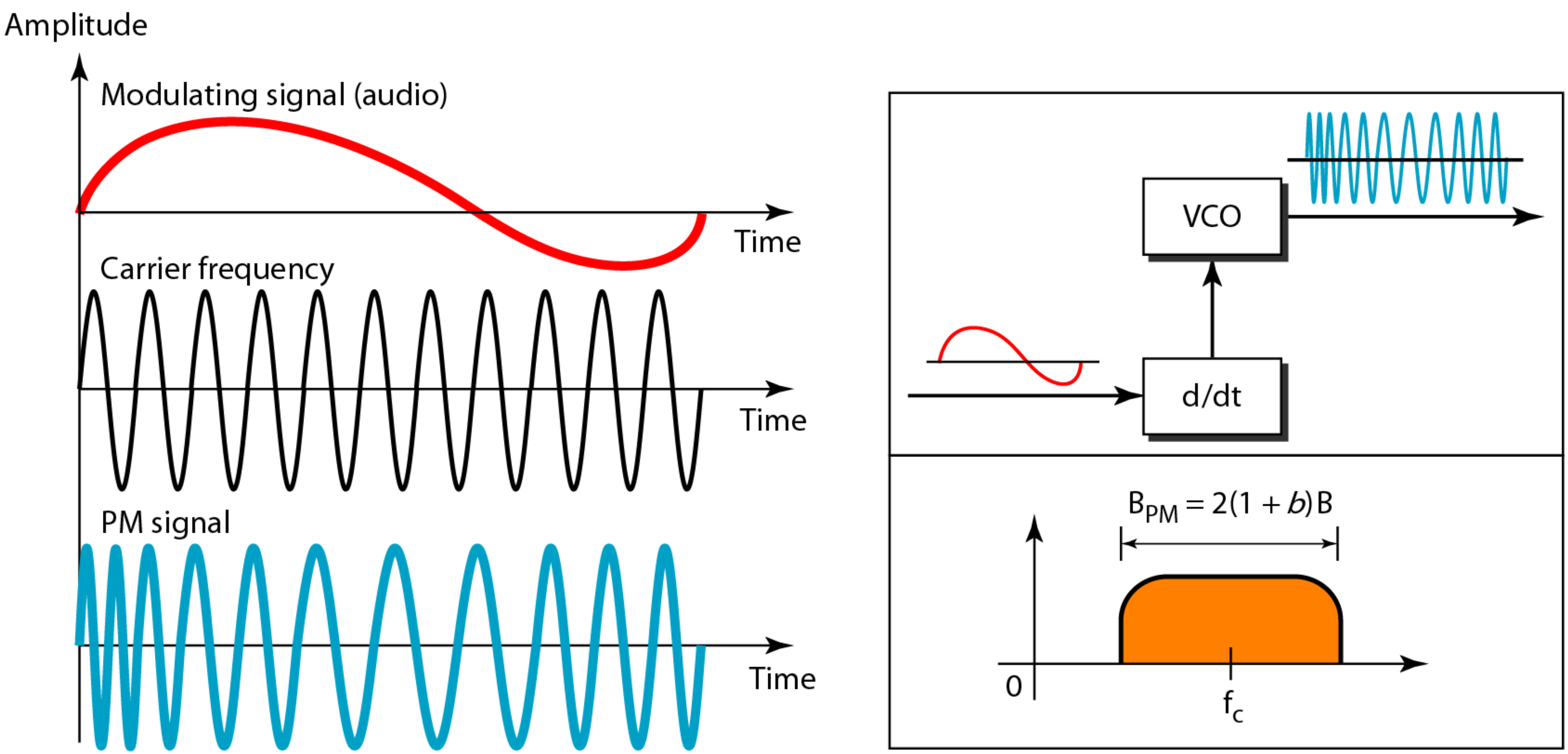




Phase Modulation (PM)

- The modulating signal only changes the phase of the carrier signal.
- The phase change manifests itself as a frequency change but the instantaneous frequency change is proportional to the derivative of the amplitude.
- The bandwidth is higher than for AM.

Phase modulation



Note

The total bandwidth required for PM can be determined from the bandwidth and maximum amplitude of the modulating signal:

$$B_{PM} = 2(1 + \beta)B.$$

Where $\beta = 2$ most often.

POLL 1

- Which of the following has the maximum Bandwidth

a) AM

b) FM

c) PM

d) None

POLL 2

- PM can be achieved using

a) VCO only

b) Derivative + VCO

c) Multiplier

d) None

Analog Transmission

DIGITAL-TO-ANALOG CONVERSION

Digital-to-analog conversion is the process of changing one of the characteristics of an analog signal based on the information in digital data.

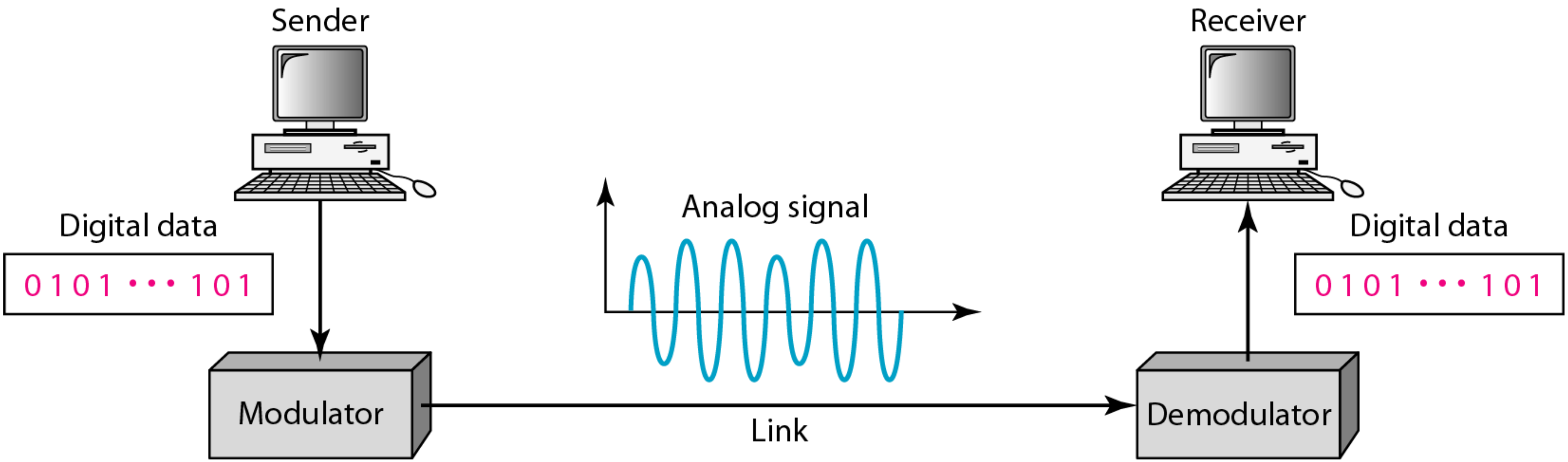
Topics discussed in this section:

- **Aspects of Digital-to-Analog Conversion**
- **Amplitude Shift Keying**
- **Frequency Shift Keying**
- **Phase Shift Keying**
- **Quadrature Amplitude Modulation**

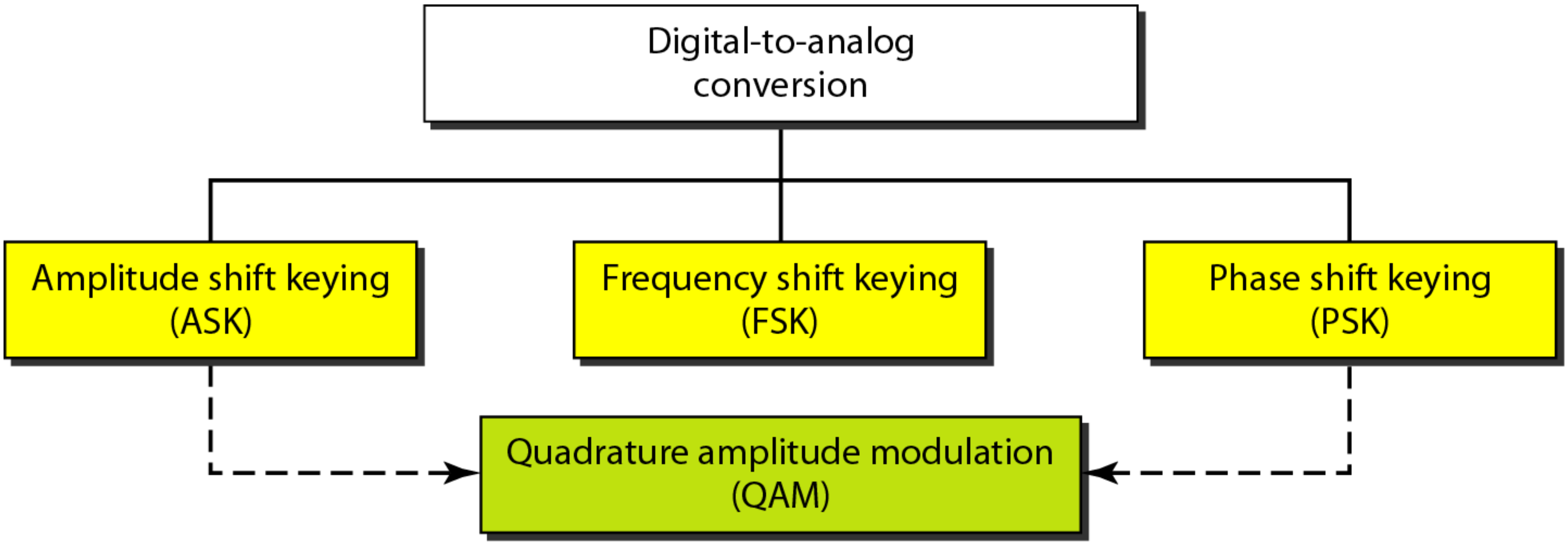
Digital to Analog Conversion

- Digital data needs to be carried on an analog signal.
- A carrier signal (frequency f_c) performs the function of transporting the digital data in an analog waveform.
- The analog carrier signal is manipulated to uniquely identify the digital data being carried.

Digital-to-analog conversion



Types of digital-to-analog conversion



POLL 3

- QAM is a combination of

a) ASK + PSK

b) ASK + FSK

c) PSK + FSK

d) none

Note

Bit rate, N, is the number of bits per second (bps). Baud rate is the number of signal elements per second (bauds).

In the analog transmission of digital data, the signal or baud rate is less than or equal to the bit rate.

S=Nx1/r bauds

Where r is the number of data bits per signal element.

Solution

An analog signal carries 4 bits per signal element. If 1000 signal elements are sent per second, find the bit rate.

Solution

In this case, r = 4, S = 1000, and N is unknown. We can find the value of N from

$$S = N \times \frac{1}{r} \qquad \text{or} \qquad N = S \times r = 1000 \times 4 = 4000 \text{ bps}$$

An analog signal has a bit rate of 8000 bps and a baud rate of 1000 baud. How many data elements are carried by each signal element? How many signal elements do we need?

Example

An analog signal has a bit rate of 8000 bps and a baud rate of 1000 baud. How many data elements are carried by each signal element? How many signal elements do we need?

Solution

In this example, S = 1000, N = 8000, and r and L are unknown. We find first the value of r and then the value of L.

$$S = N \times \frac{1}{r} \rightarrow r = \frac{N}{S} = \frac{8000}{1000} = 8 \text{ bits/baud}$$

$$r = \log_2 L \rightarrow L = 2^r = 2^8 = 256$$

Amplitude Shift Keying (ASK)

- ASK is implemented by changing the amplitude of a carrier signal to reflect amplitude levels in the digital signal.
- For example: a digital “1” could not affect the signal, whereas a digital “0” would, by making it zero.
- The line encoding will determine the values of the analog waveform to reflect the digital data being carried.

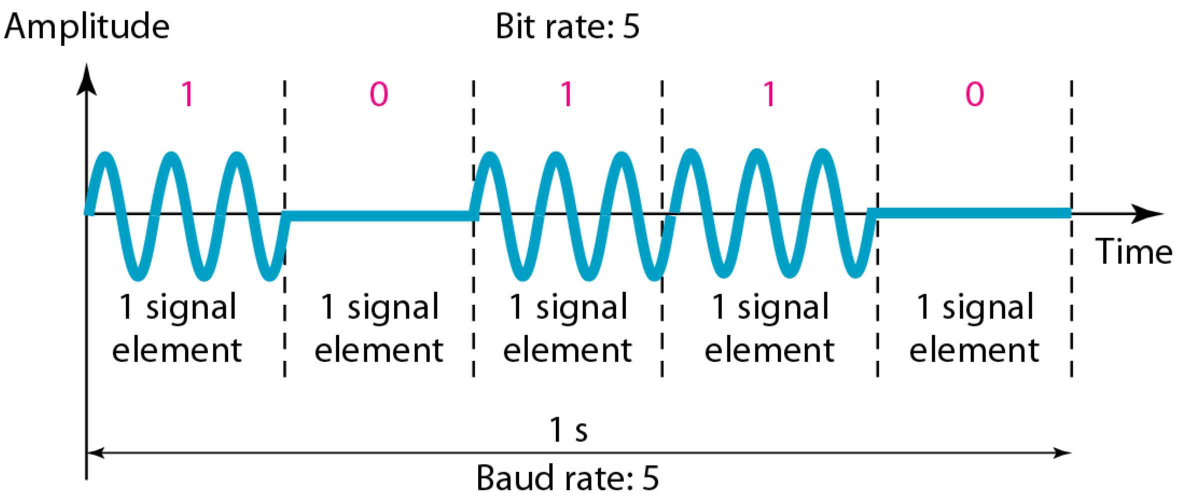
Bandwidth of ASK

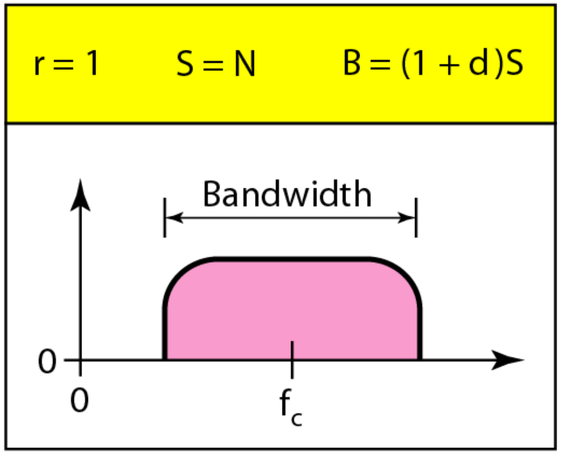
- The bandwidth B of ASK is proportional to the signal rate S.

$$B = (1+d)S$$

- "d" is due to modulation and filtering, lies between 0 and 1.

Binary amplitude shift keying

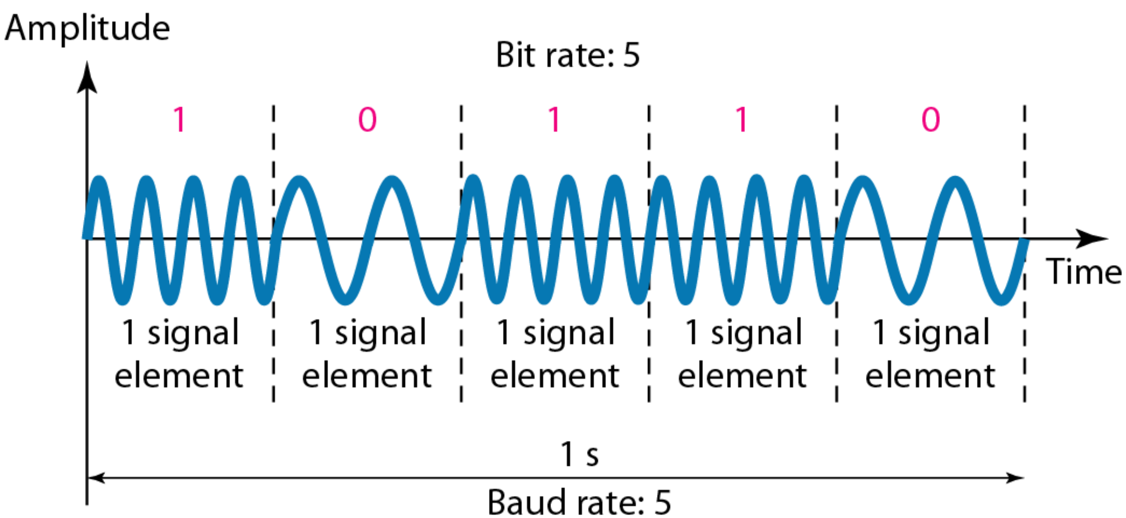


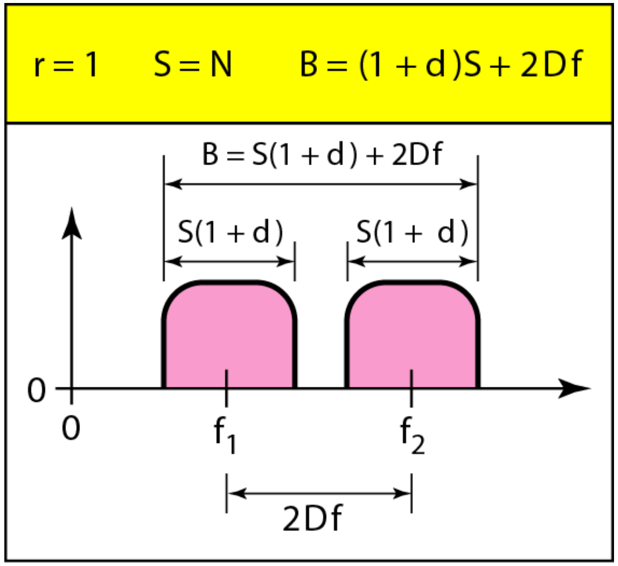


Frequency Shift Keying

- The digital data stream changes the frequency of the carrier signal, f_c.
- For example, a "1" could be represented by $f_1=f_c+\Delta f$, and a "0" could be represented by $f_2=f_c-\Delta f$.

Binary frequency shift keying





Bandwidth of FSK

- If the difference between the two frequencies (f_1 and f_2) is $2\Delta f$, then the required BW B will be:

$$B = (1+d)xS + 2\Delta f$$

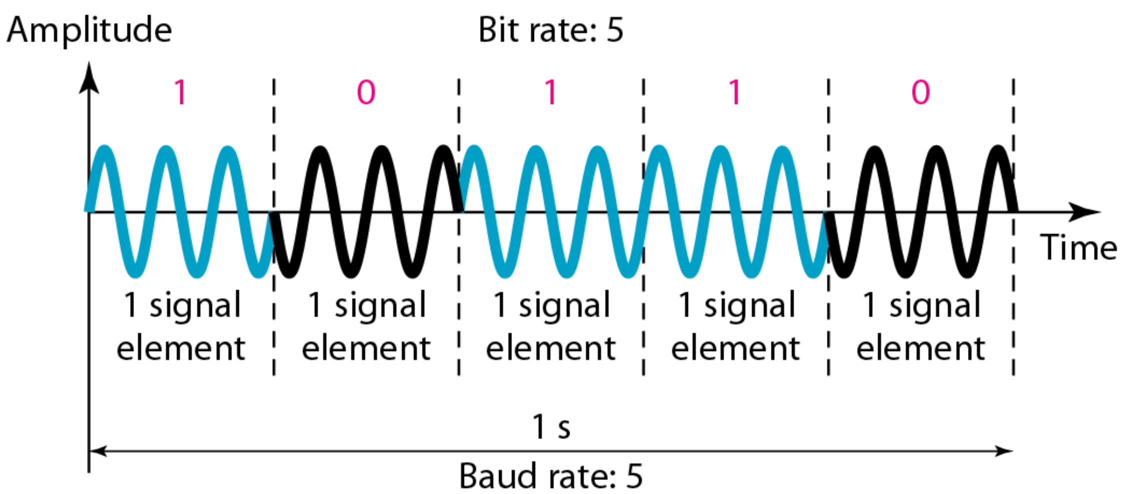
Phase Shift Keying

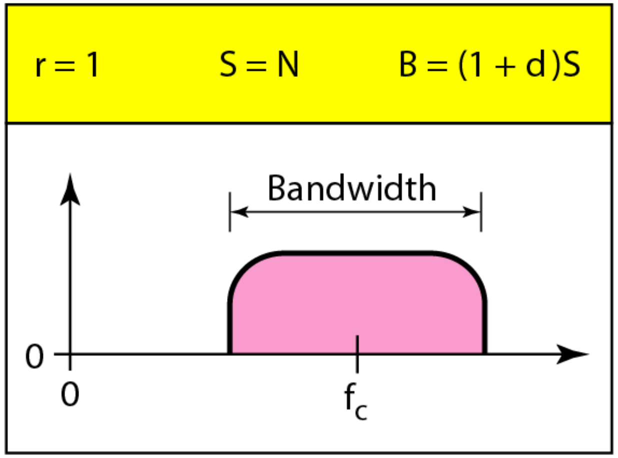
- We vary the phase shift of the carrier signal to represent digital data.
- The bandwidth requirement, B is:

  $$B = (1+d) \times S$$

- PSK is much more robust than ASK as it is not that vulnerable to noise, which changes amplitude of the signal.

Binary phase shift keying





POLL 4

BW of binary FSK is

a) S(1+d)

b) S(1+d) + 2Df

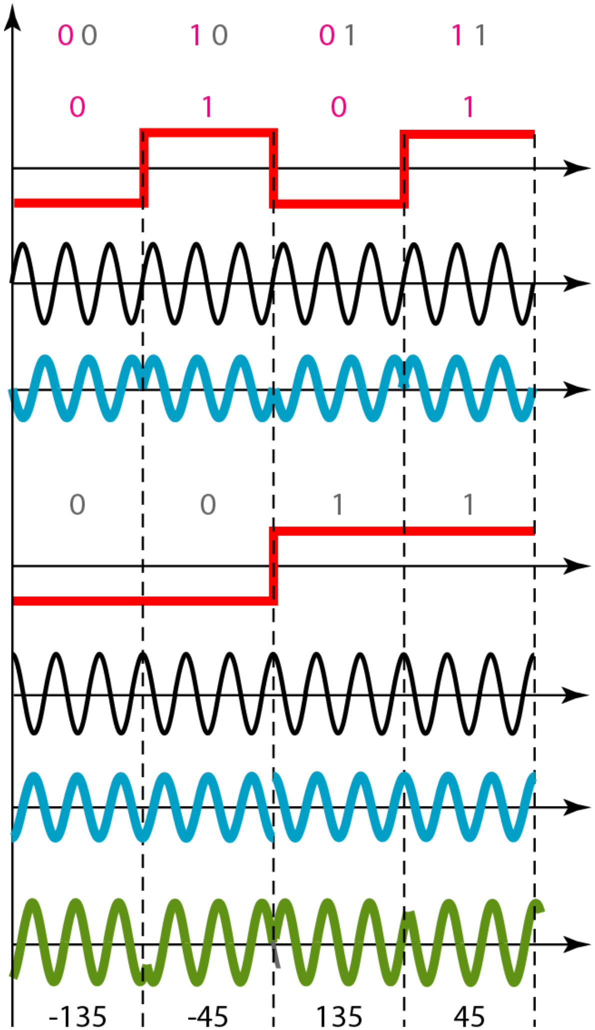
c) S(1-d)

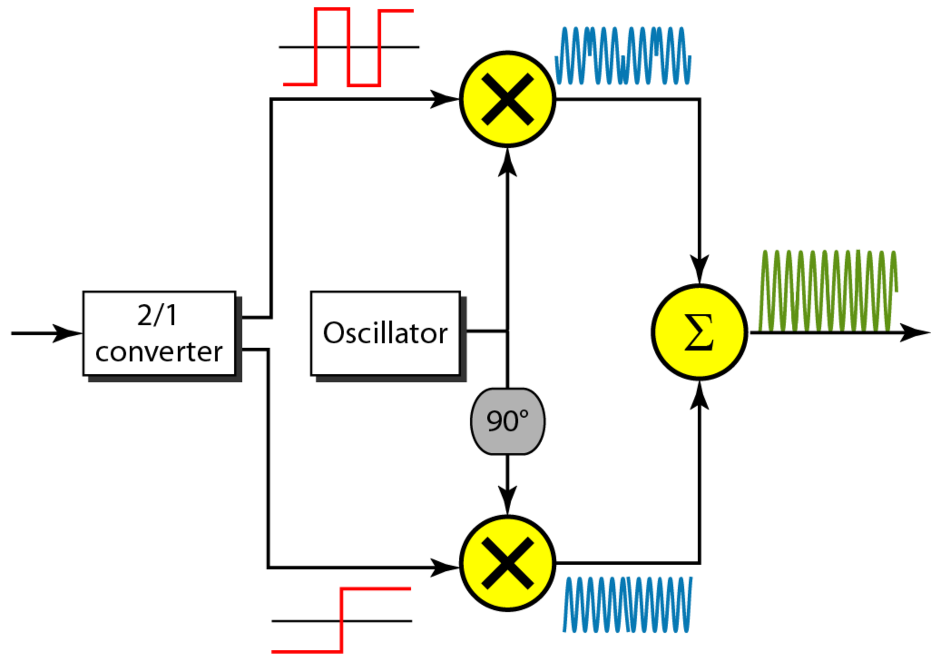
d) S(1+d) – 2Df

Quadrature PSK

- To increase the bit rate, we can code 2 or more bits onto one signal element.
- In QPSK, we parallelize the bit stream so that every two incoming bits are split up and PSK a carrier frequency. One carrier frequency is phase shifted 90^o from the other - in quadrature.
- The two PSKed signals are then added to produce one of 4 signal elements. L = 4 here.

QPSK and its implementation





Note

Quadrature amplitude modulation is a combination of ASK and PSK.

Digital Transmission

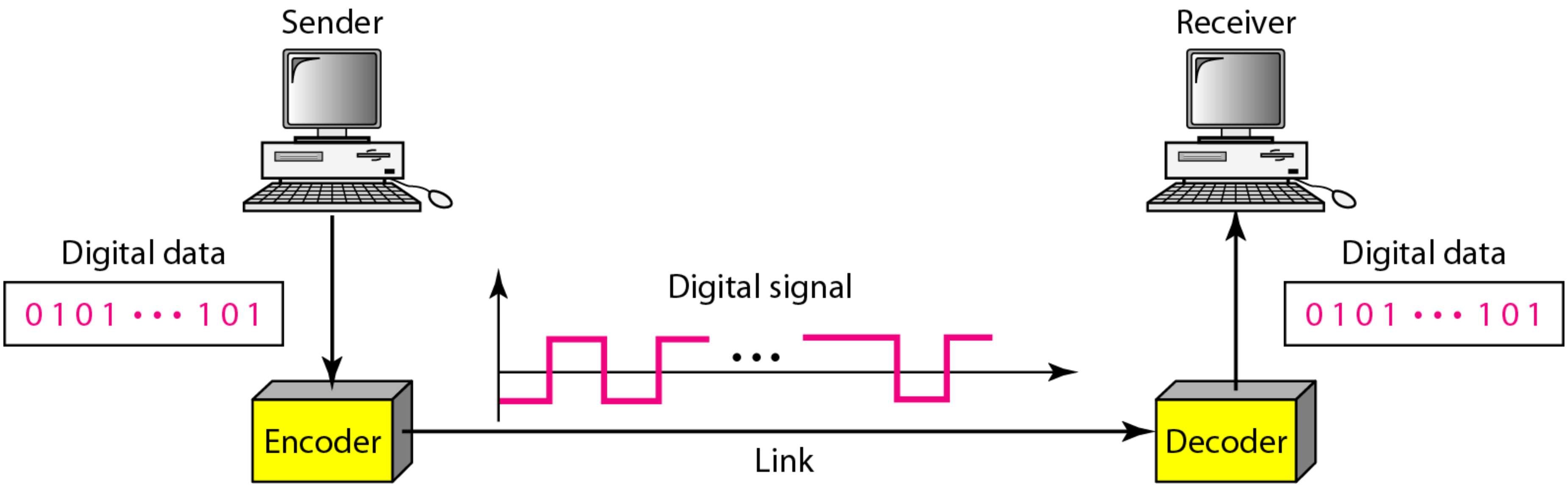
DIGITAL-TO-DIGITAL CONVERSION

In this section, we see how we can represent digital data by using digital signals. The conversion involves three techniques: line coding, block coding, and scrambling. Line coding is always needed; block coding and scrambling may or may not be needed.

Line Coding

- Converting a string of 1’s and 0’s (digital data) into a sequence of signals that denote the 1’s and 0’s.
- For example a high voltage level (+V) could represent a “1” and a low voltage level (0 or -V) could represent a “0”.

Line coding and decoding



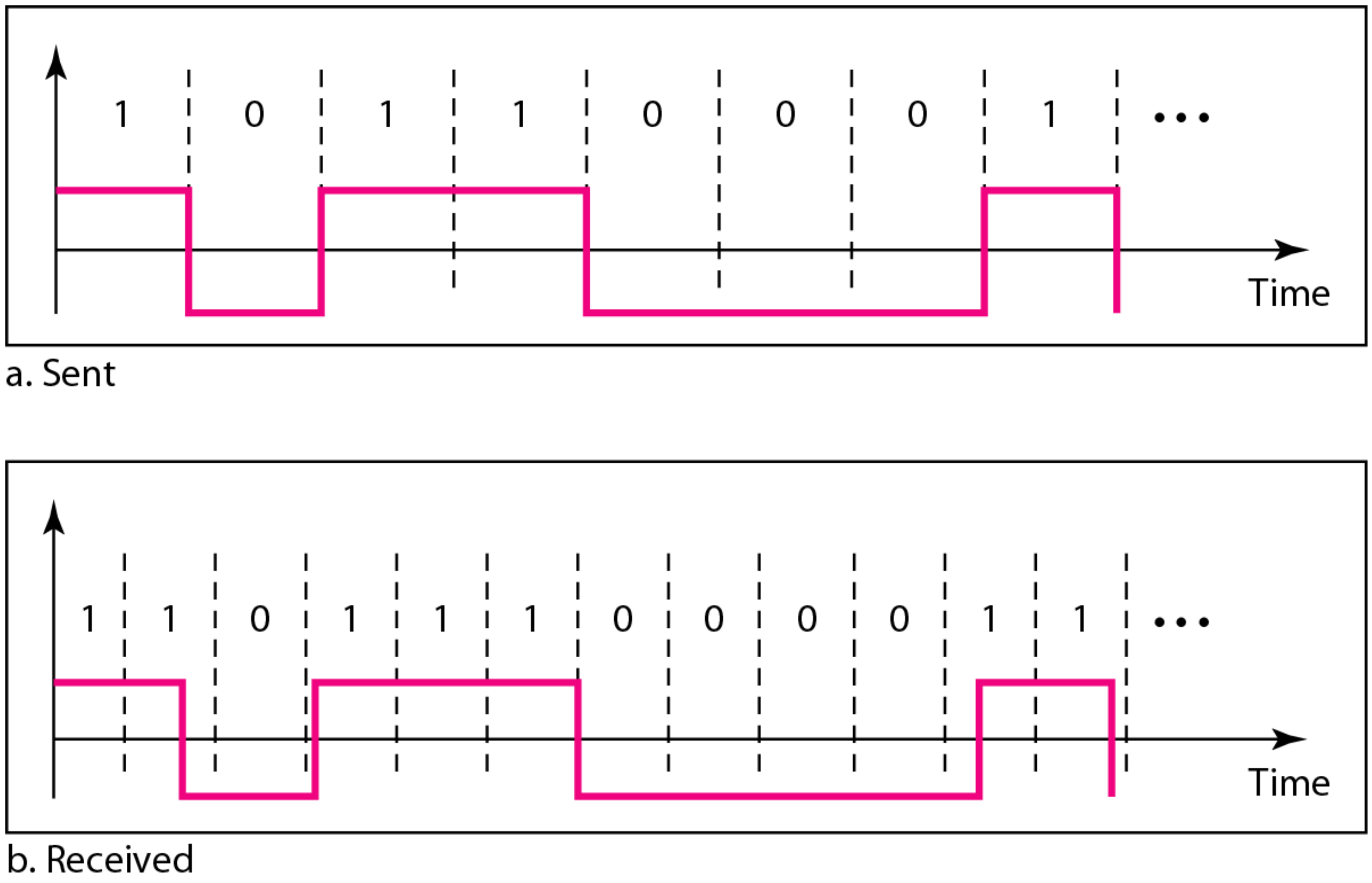
Line encoding C/Cs

- DC components - when the voltage level remains constant for long periods of time, there is an increase in the low frequencies of the signal. Most channels are bandpass and may not support the low frequencies.
- This will require the removal of the dc component of a transmitted signal.

Line encoding C/Cs

- Self synchronization - the clocks at the sender and the receiver must have the same bit interval.
- If the receiver clock is faster or slower it will misinterpret the incoming bit stream.

Figure ***Effect of lack of synchronization***



Example

In a digital transmission, the receiver clock is 0.1 percent faster than the sender clock. How many extra bits per second does the receiver receive if the data rate is 1 kbps? How many if the data rate is 1 Mbps?

Solution

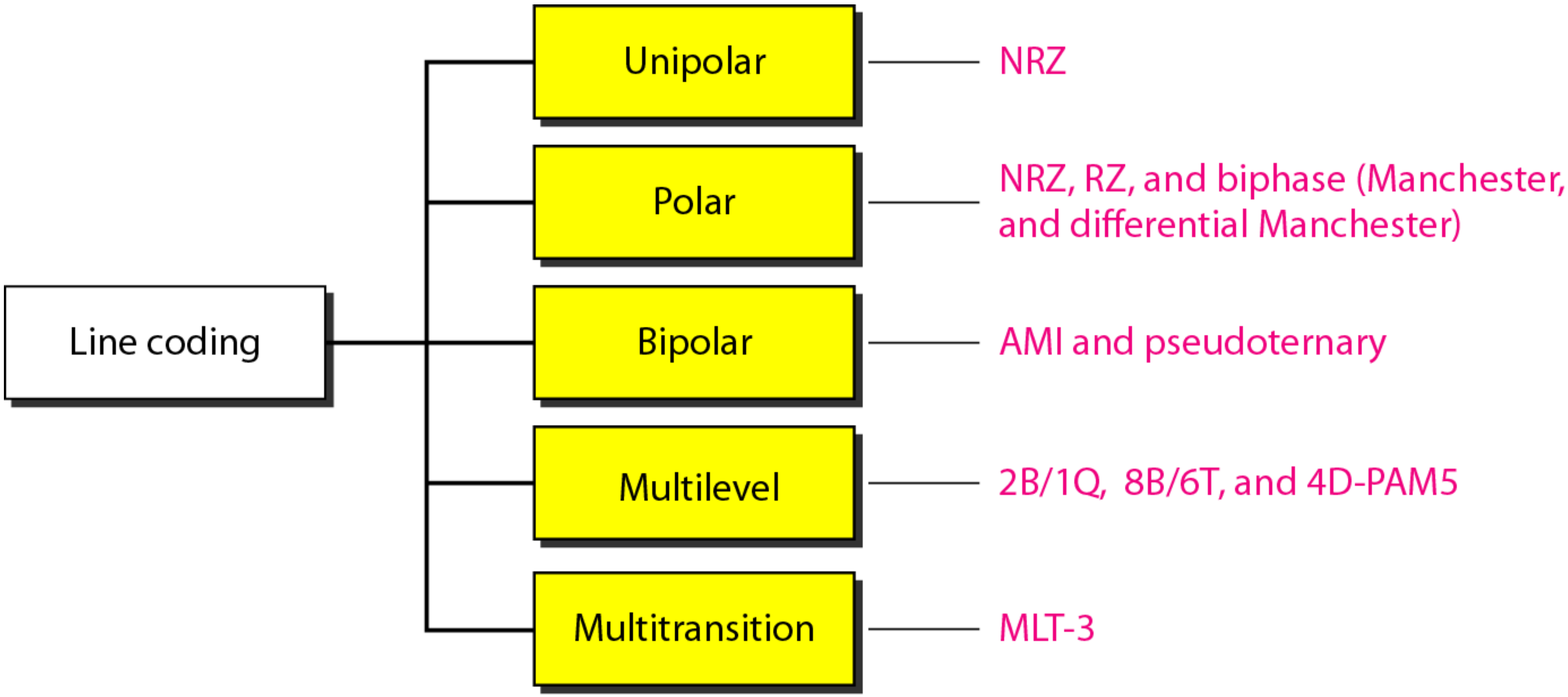
At 1 kbps, the receiver receives 1001 bps instead of 1000 bps.

1000 bits sent	1001 bits received	1 extra bps

At 1 Mbps, the receiver receives 1,001,000 bps instead of 1,000,000 bps.

1,000,000 bits sent	1,001,000 bits received	1000 extra bps

Figure ***Line coding schemes***



POLL 5

Which of the following is NOT a type of Line Coding

a) Unipolar

b) Bipolar

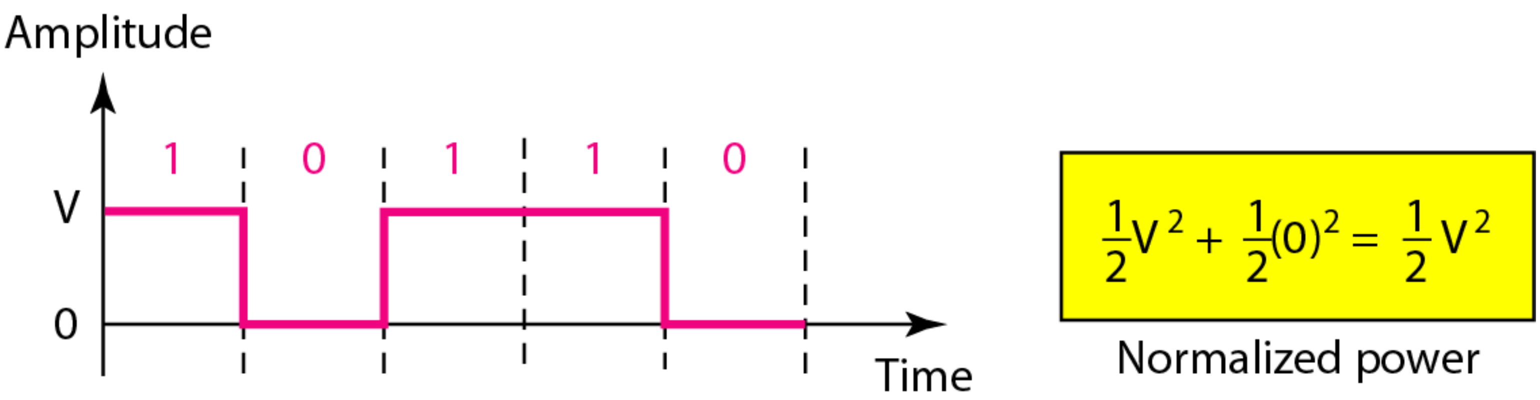
c) Polar

d) Multipolar

Unipolar

- All signal levels are on one side of the time axis - either above or below
- NRZ - Non Return to Zero scheme is an example of this code. The signal level does not return to zero during a symbol transmission.
- Scheme is prone to DC components. It has no synchronization or any error detection. It is simple but costly in power consumption.

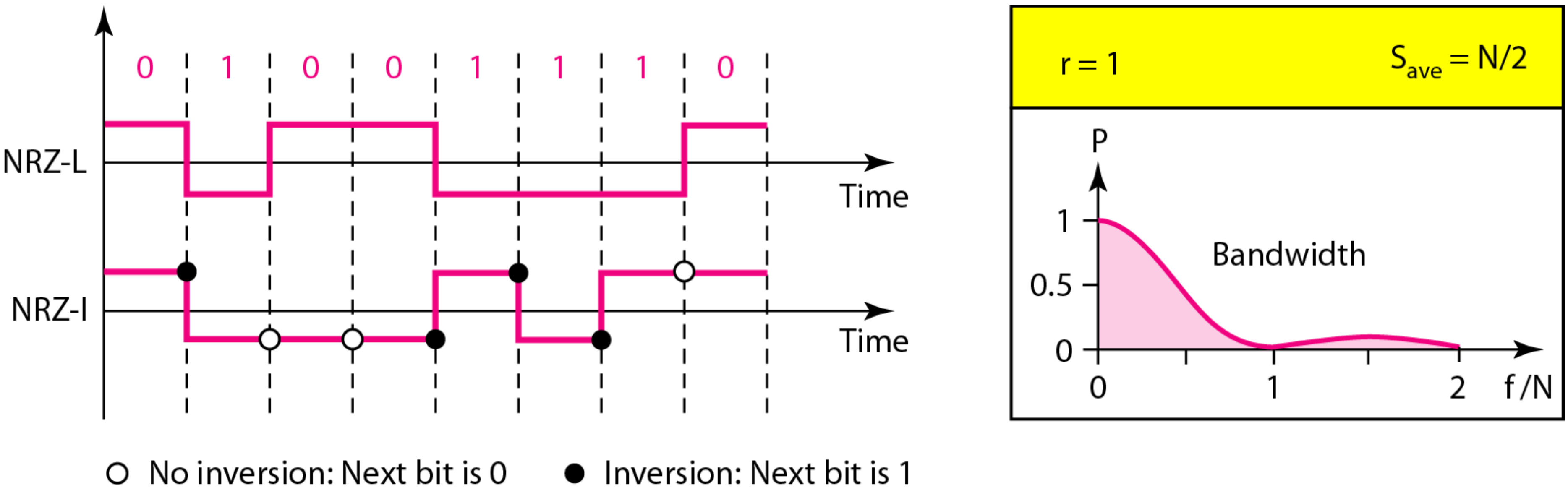
Figure *Unipolar NRZ scheme*



Polar - NRZ

- The voltages are on both sides of the time axis.
- Polar NRZ scheme can be implemented with two voltages. E.g. +V for 1 and -V for 0.
- There are two versions:
  - NZR - Level (NRZ-L) - positive voltage for one symbol and negative for the other
  - NRZ - Inversion (NRZ-I) - the change or lack of change in polarity determines the value of a symbol. E.g. a “1” symbol inverts the polarity a “0” does not.

Figure *Polar NRZ-L and NRZ-I schemes*



Note

In NRZ-L the level of the voltage determines the value of the bit.
In NRZ-I the inversion or the lack of inversion determines the value of the bit.

Note

NRZ-L and NRZ-I both have an average signal rate of N/2 Bd.

Note

NRZ-L and NRZ-I both have a DC component problem, it is worse for NRZ-L. Both have no self synchronization &no error detection. Both are relatively simple to implement.

POLL 6

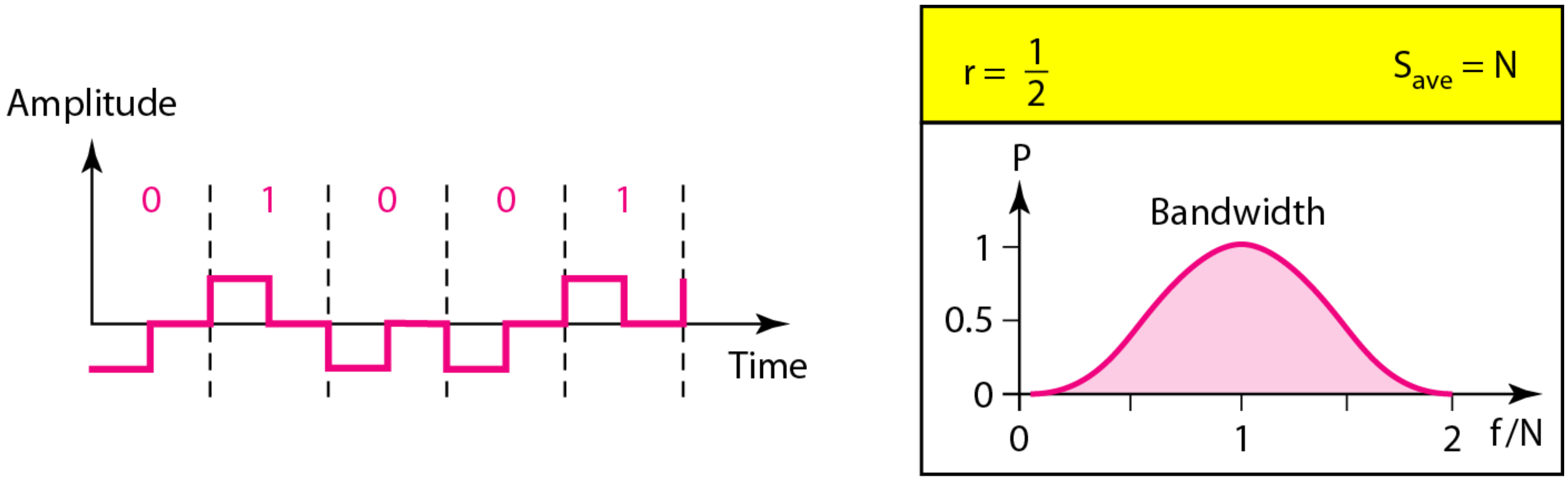
NRZ-L and NRZ-I both have

a) DC component problem
b) AC component Problem
c) Self Synchronization
d) Error Detection

Polar - RZ

- The Return to Zero (RZ) scheme uses three voltage values. +, 0, -.
- Each symbol has a transition in the middle. Either from high to zero or from low to zero.
- This scheme has more signal transitions (two per symbol) and therefore requires a wider bandwidth.
- No DC components or baseline wandering.
- Self synchronization - transition indicates symbol value.
- More complex as it uses three voltage level. It has no error detection capability.

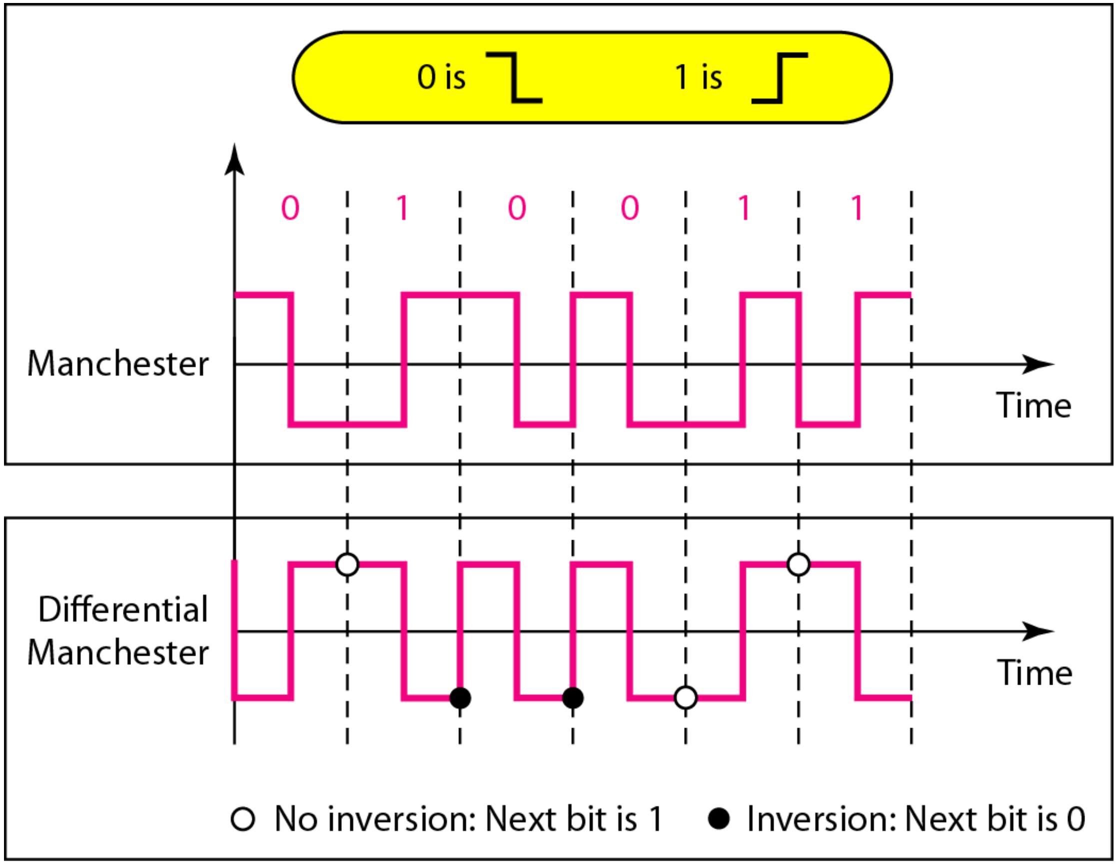
Figure *Polar RZ scheme*

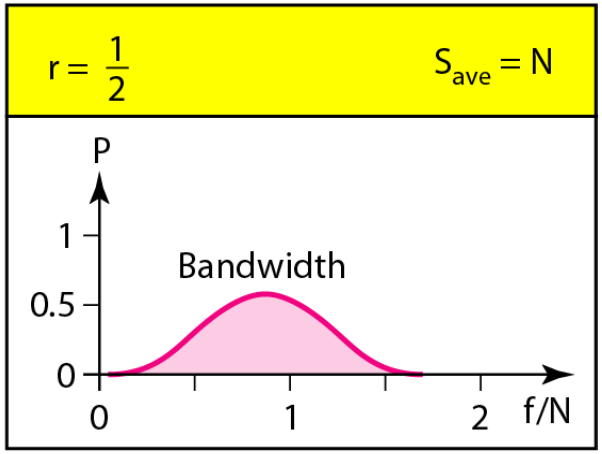


Polar - Biphase: Manchester and Differential Manchester

- Manchester coding consists of combining the NRZ-L and RZ schemes.
  - Every symbol has a level transition in the middle: from high to low or low to high. Uses only two voltage levels.
- Differential Manchester coding consists of combining the NRZ-I and RZ schemes.
  - Every symbol has a level transition in the middle. But the level at the beginning of the symbol is determined by the symbol value. One symbol causes a level change the other does not.

Figure ***Polar biphase: Manchester and differential Manchester schemes***





Note

In Manchester and differential Manchester encoding, the transition at the middle of the bit is used for synchronization.

Note

The minimum bandwidth of Manchester and differential Manchester is 2 times that of NRZ. The is no DC component. None of these codes has error detection.

Digital Transmission

ANALOG-TO-DIGITAL CONVERSION

A digital signal is superior to an analog signal because it is more robust to noise and can easily be recovered, corrected and amplified. For this reason, the tendency today is to change an analog signal to digital data. In this section we describe two techniques, pulse code modulation and delta modulation.

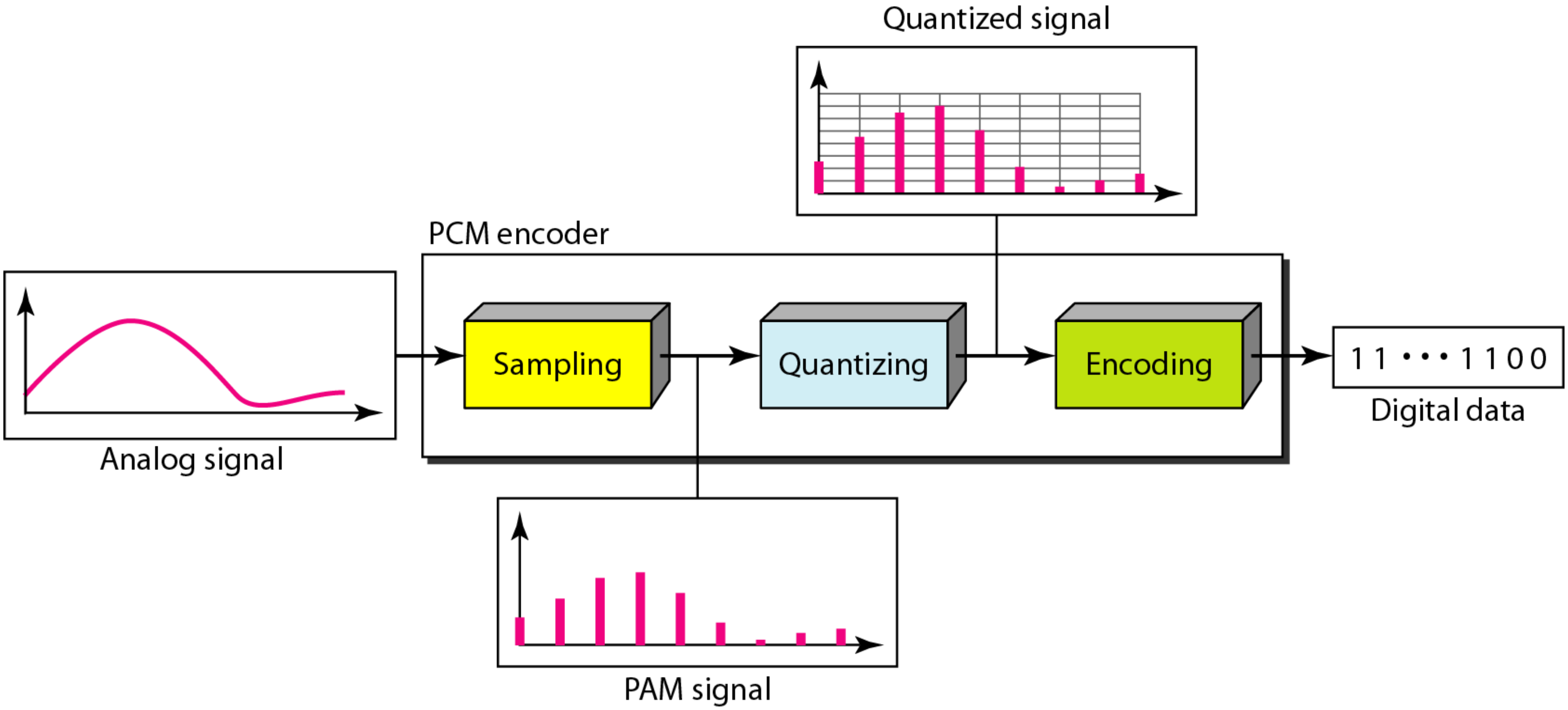
Topics discussed in this section:

- **Pulse Code Modulation (PCM)**

PCM

- PCM consists of three steps to digitize an analog signal:
  1. Sampling
  2. Quantization
  3. Binary encoding
- Before we sample, we have to filter the signal to limit the maximum frequency of the signal as it affects the sampling rate.
- Filtering should ensure that we do not distort the signal, ie remove high frequency components that affect the signal shape.

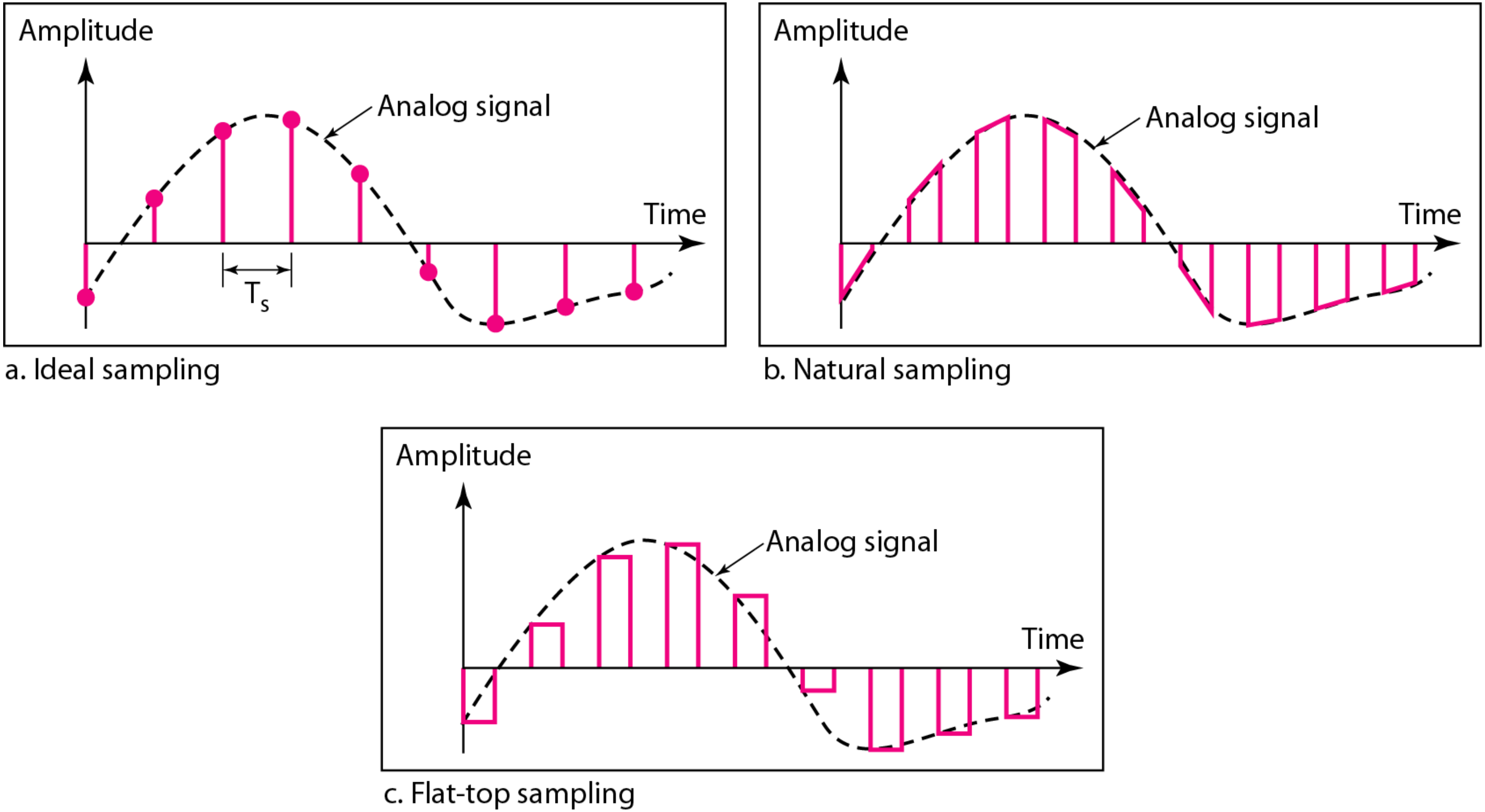
Figure *Components of PCM encoder*



Sampling

- Analog signal is sampled every T_S secs.
- T_s is referred to as the sampling interval.
- $f_s = 1/T_s$ is called the sampling rate or sampling frequency.
- There are 3 sampling methods:
  - Ideal - an impulse at each sampling instant
  - Natural - a pulse of short width with varying amplitude
  - Flattop - sample and hold, like natural but with single amplitude value
- The process is referred to as pulse amplitude modulation PAM and the outcome is a signal with analog (non integer) values

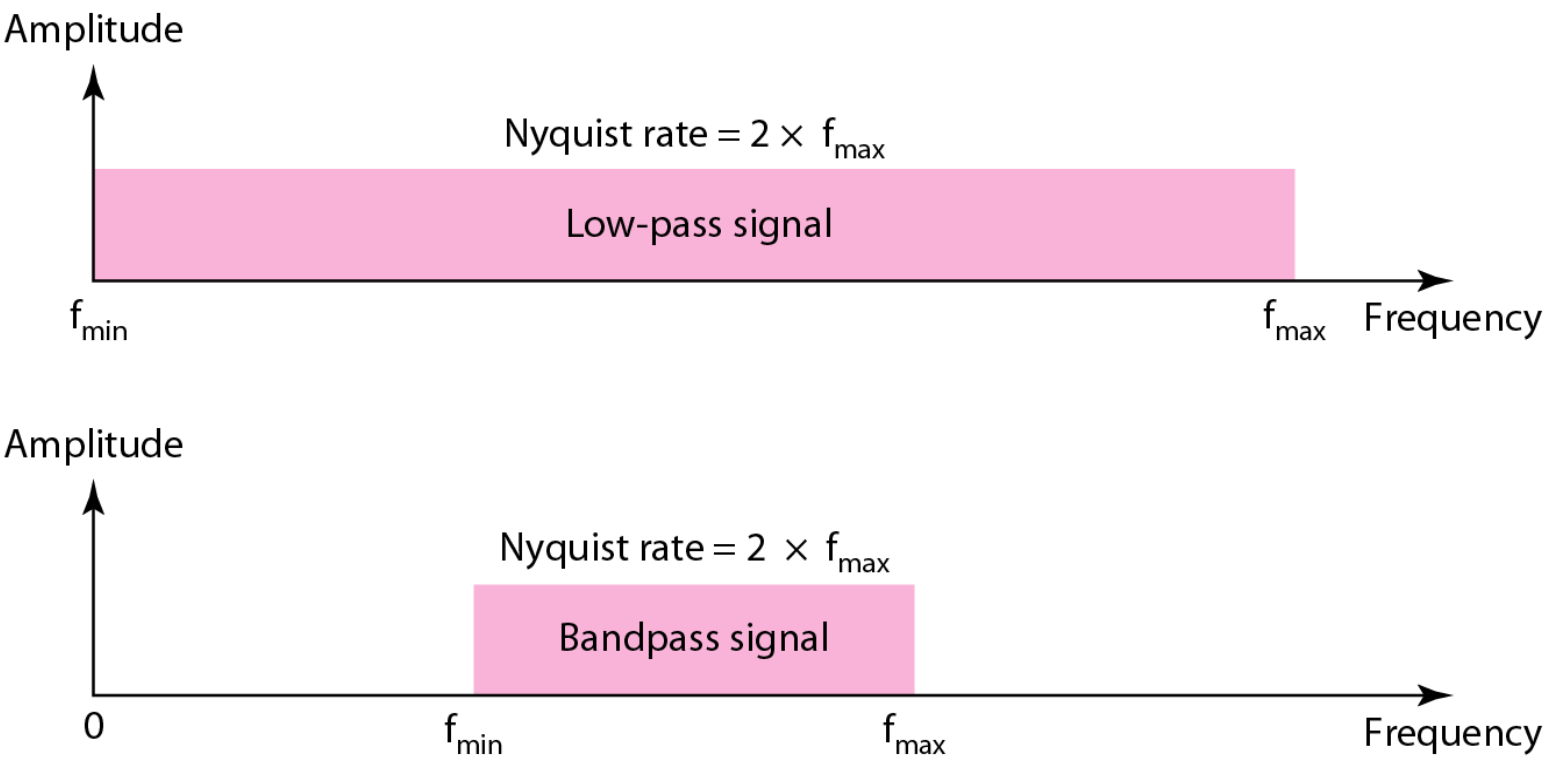
Figure *Three different sampling methods for PCM*



Note

According to the Nyquist theorem, the sampling rate must be at least 2 times the highest frequency contained in the signal.

Figure ***Nyquist sampling rate for low-pass and bandpass signals***



Quantization

- Sampling results in a series of pulses of varying amplitude values ranging between two limits: a min and a max.
- The amplitude values are infinite between the two limits.
- We need to map the *infinite* amplitude values onto a finite set of known values.
- This is achieved by dividing the distance between min and max into L zones, each of height Δ.

$$\Delta = (\text{max} - \text{min})/L$$

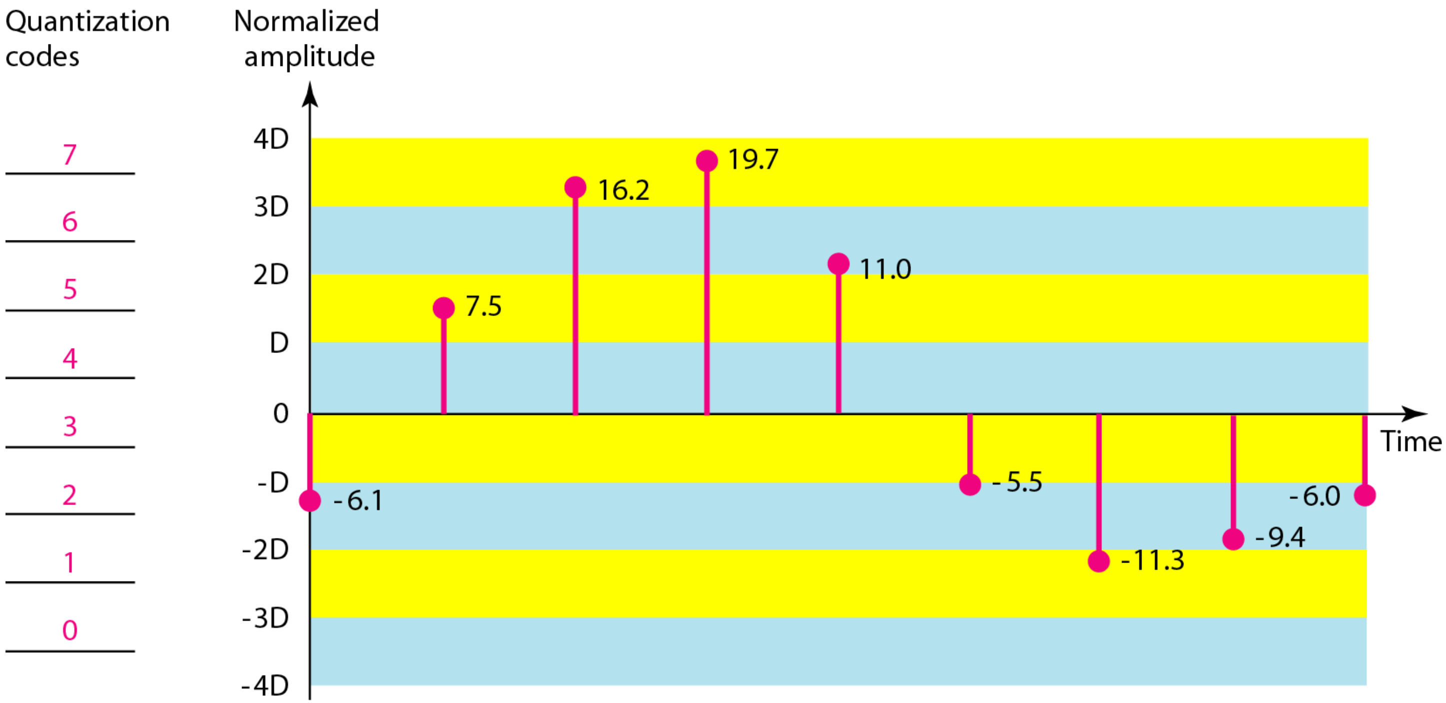
Quantization Levels

- The midpoint of each zone is assigned a value from 0 to L-1 (resulting in L values)
- Each sample falling in a zone is then approximated to the value of the midpoint.

Quantization Zones

- Assume we have a voltage signal with amplitutes V_{min}=-20V and V_{max}=+20V.
- We want to use L=8 quantization levels.
- Zone width Δ = (20 - -20)/8 = 5
- The 8 zones are: -20 to -15, -15 to -10, -10 to -5, -5 to 0, 0 to +5, +5 to +10, +10 to +15, +15 to +20
- The midpoints are: -17.5, -12.5, -7.5, -2.5, 2.5, 7.5, 12.5, 17.5

Figure *Quantization and encoding of a sampled signal*



Normalized PAM values	-1.22	1.50	3.24	3.94	2.20	-1.10	-2.26	-1.88	-1.20
Normalized quantized values	-1.50	1.50	3.50	3.50	2.50	-1.50	-2.50	-1.50	-1.50
Normalized error	-0.38	0	+0.26	-0.44	+0.30	-0.40	-0.24	+0.38	-0.30
Quantization code	2	5	7	7	6	2	1	2	2
Encoded words	010	101	111	111	110	010	001	010	010

Analog Transmission

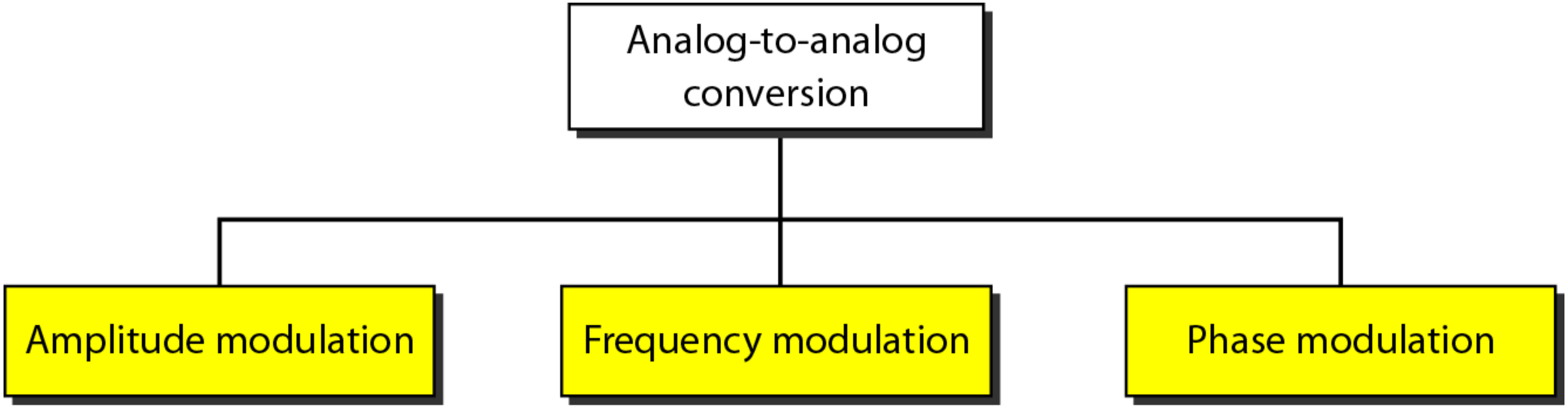
ANALOG AND ANALOG

Analog-to-analog conversion is the representation of analog information by an analog signal. One may ask why we need to modulate an analog signal; it is already analog. Modulation is needed if the medium is bandpass in nature or if only a bandpass channel is available to us.

Topics discussed in this section:

- **Amplitude Modulation**
- **Frequency Modulation**
- **Phase Modulation**

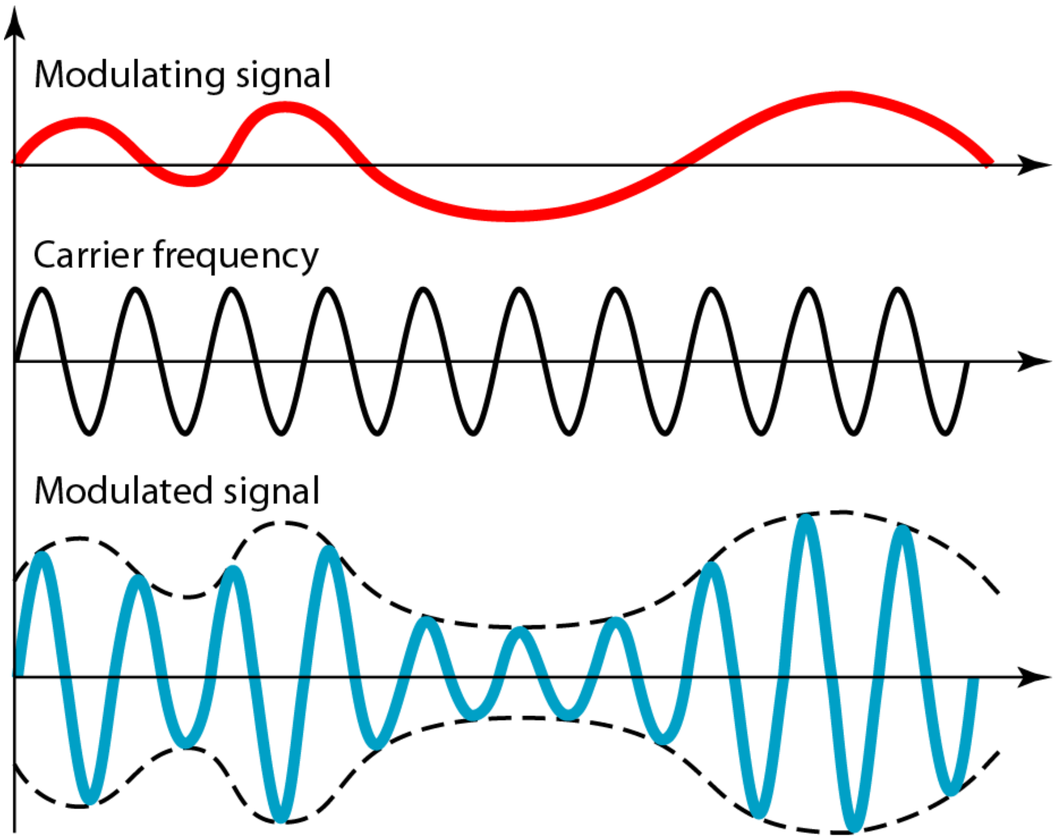
Types of analog-to-analog modulation

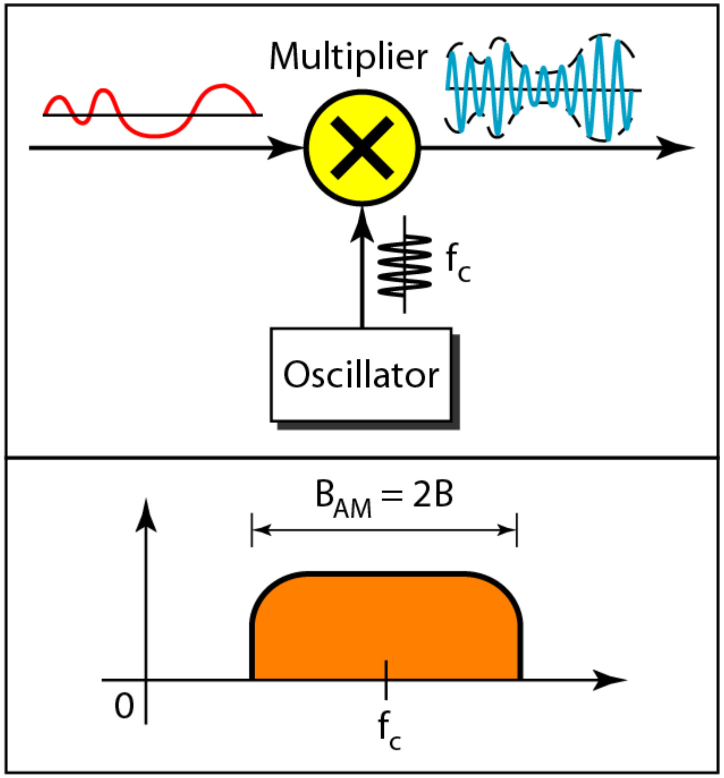


Amplitude Modulation

- A carrier signal is modulated only in amplitude value
- The modulating signal is the envelope of the carrier
- The required bandwidth is 2B, where B is the bandwidth of the modulating signal

Amplitude modulation





Note

The total bandwidth required for AM can be determined from the bandwidth of the audio signal: $B_{AM} = 2B$.

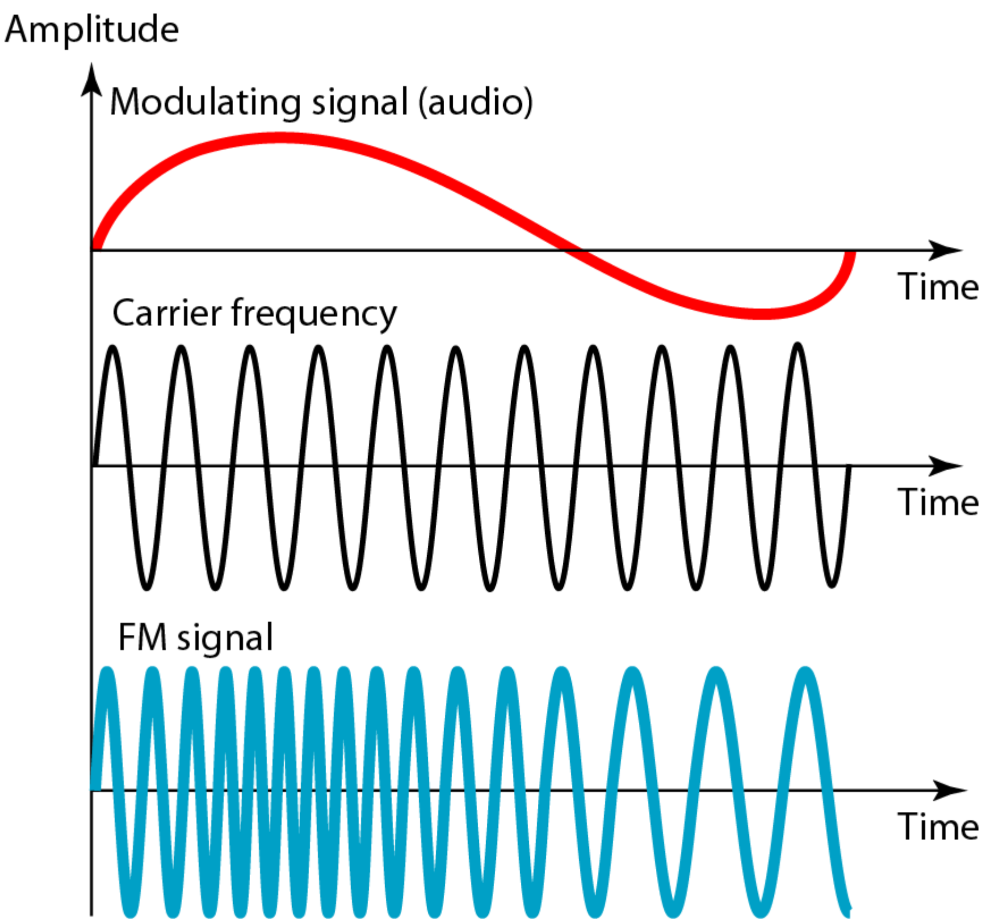
Frequency Modulation

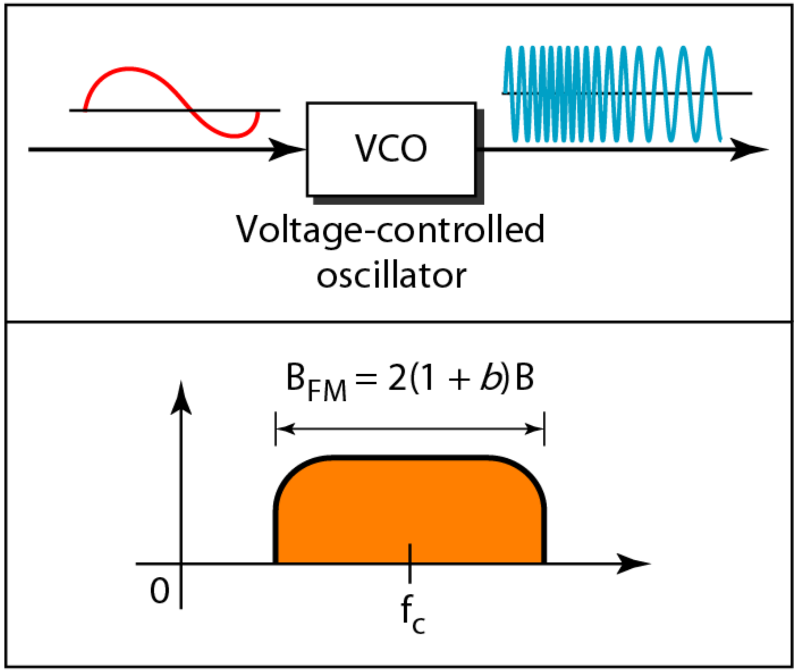
- The modulating signal changes the freq. f_c of the carrier signal
- The bandwidth for FM is high
- It is approx. 10x the signal frequency

Note

The total bandwidth required for FM can be determined from the bandwidth of the audio signal: $B_{FM} = 2(1 + \beta)B$. Where β is usually 4.

Frequency modulation

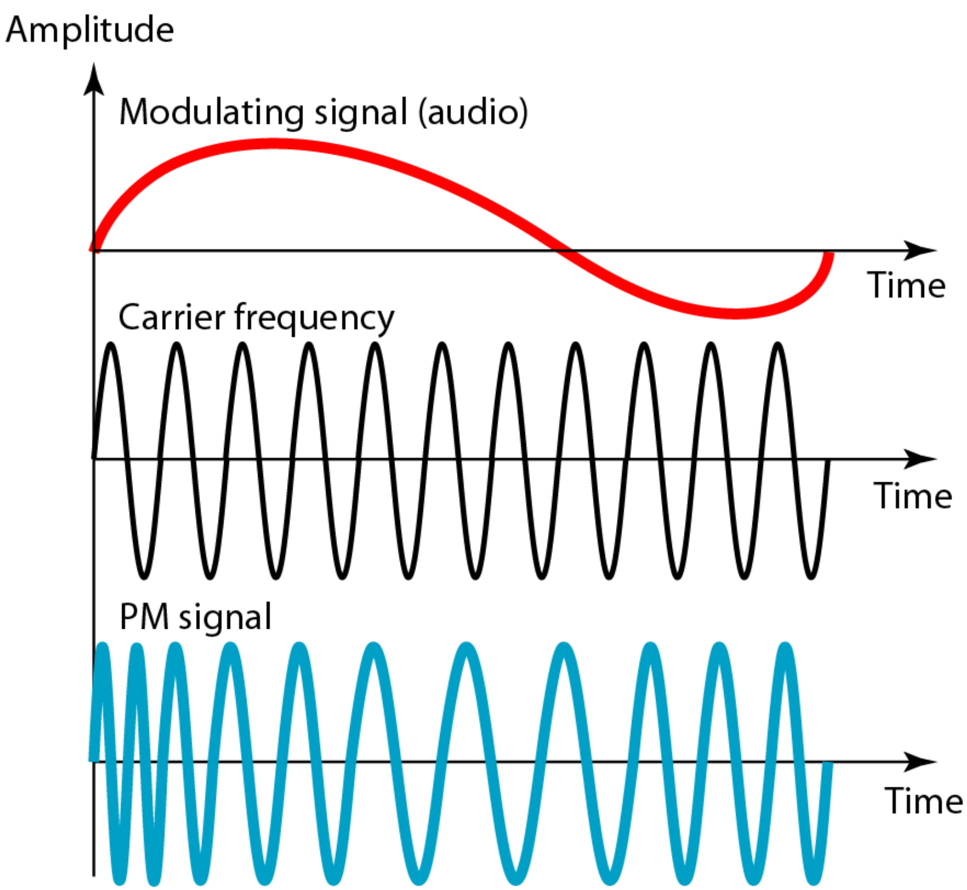


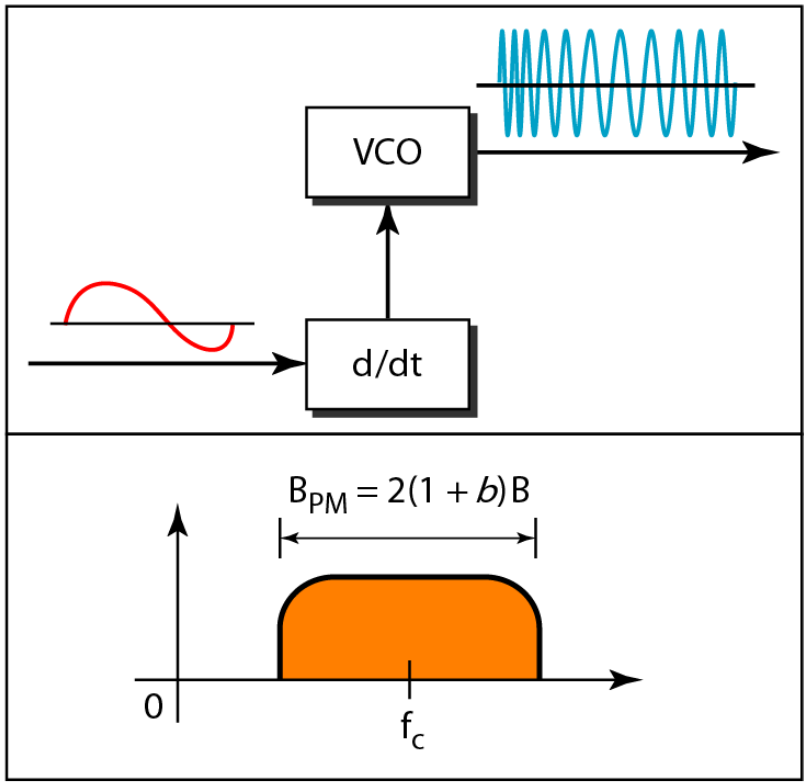


Phase Modulation (PM)

- The modulating signal only changes the phase of the carrier signal.
- The phase change manifests itself as a frequency change but the instantaneous frequency change is proportional to the derivative of the amplitude.
- The bandwidth is higher than for AM.

Phase modulation





Note

The total bandwidth required for PM can be determined from the bandwidth and maximum amplitude of the modulating signal:

$$B_{PM} = 2(1 + \beta)B.$$

Where $\beta = 2$ most often.

POLL 1

- Which of the following has the maximum Bandwidth

a) AM

b) FM

c) PM

d) None

POLL 2

- PM can be achieved using

a) VCO only

b) Derivative + VCO

c) Multiplier

d) None

Analog Transmission

DIGITAL-TO-ANALOG CONVERSION

Digital-to-analog conversion is the process of changing one of the characteristics of an analog signal based on the information in digital data.

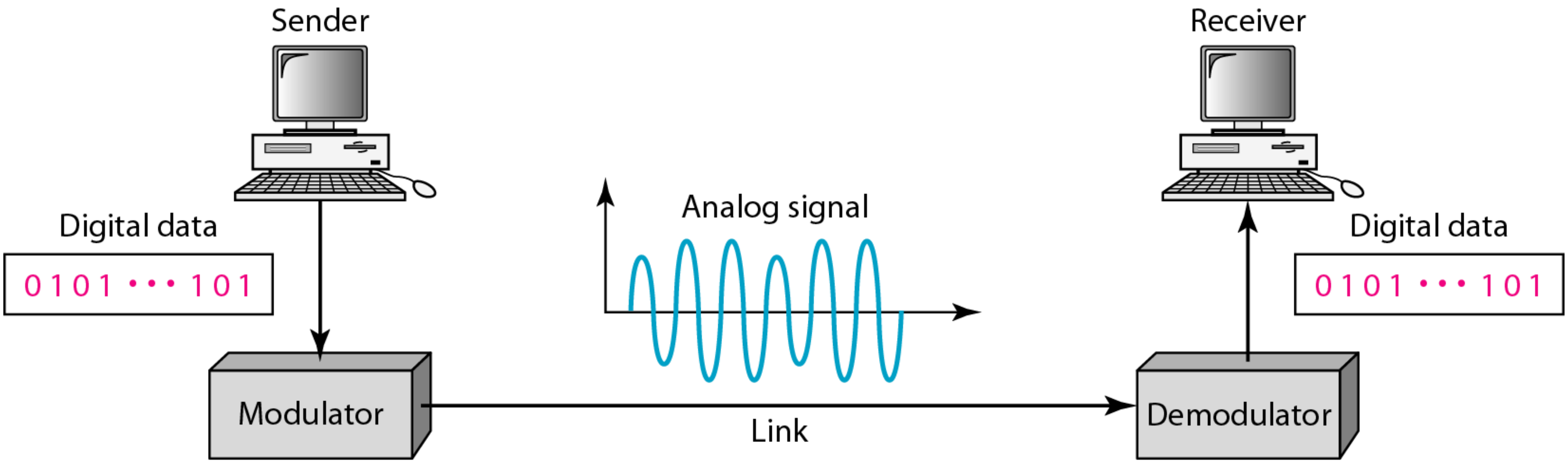
Topics discussed in this section:

- **Aspects of Digital-to-Analog Conversion**
- **Amplitude Shift Keying**
- **Frequency Shift Keying**
- **Phase Shift Keying**
- **Quadrature Amplitude Modulation**

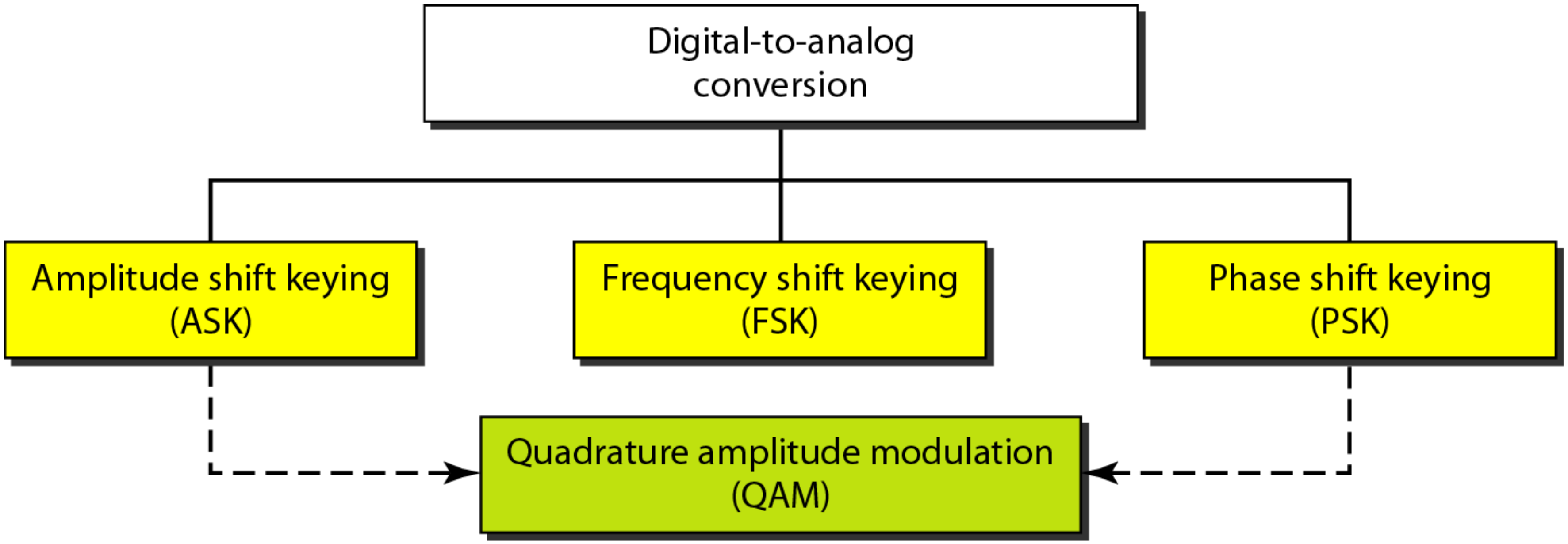
Digital to Analog Conversion

- Digital data needs to be carried on an analog signal.
- A carrier signal (frequency f_c) performs the function of transporting the digital data in an analog waveform.
- The analog carrier signal is manipulated to uniquely identify the digital data being carried.

Digital-to-analog conversion



Types of digital-to-analog conversion



POLL 3

- QAM is a combination of

a) ASK + PSK

b) ASK + FSK

c) PSK + FSK

d) none

Note

Bit rate, N, is the number of bits per second (bps). Baud rate is the number of signal elements per second (bauds).

In the analog transmission of digital data, the signal or baud rate is less than or equal to the bit rate.

S=Nx1/r bauds

Where r is the number of data bits per signal element.

Solution

An analog signal carries 4 bits per signal element. If 1000 signal elements are sent per second, find the bit rate.

Solution

In this case, r = 4, S = 1000, and N is unknown. We can find the value of N from

$$S = N \times \frac{1}{r} \qquad \text{or} \qquad N = S \times r = 1000 \times 4 = 4000 \text{ bps}$$

An analog signal has a bit rate of 8000 bps and a baud rate of 1000 baud. How many data elements are carried by each signal element? How many signal elements do we need?

Example

An analog signal has a bit rate of 8000 bps and a baud rate of 1000 baud. How many data elements are carried by each signal element? How many signal elements do we need?

Solution

In this example, S = 1000, N = 8000, and r and L are unknown. We find first the value of r and then the value of L.

$$S = N \times \frac{1}{r} \rightarrow r = \frac{N}{S} = \frac{8000}{1000} = 8 \text{ bits/baud}$$

$$r = \log_2 L \rightarrow L = 2^r = 2^8 = 256$$

Amplitude Shift Keying (ASK)

- ASK is implemented by changing the amplitude of a carrier signal to reflect amplitude levels in the digital signal.
- For example: a digital “1” could not affect the signal, whereas a digital “0” would, by making it zero.
- The line encoding will determine the values of the analog waveform to reflect the digital data being carried.

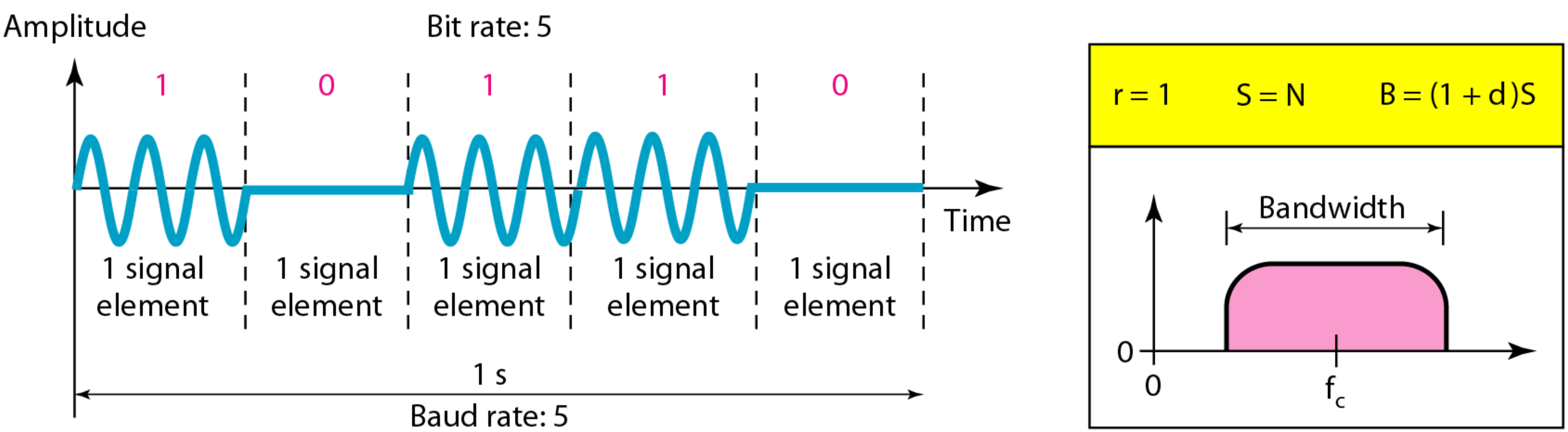
Bandwidth of ASK

- The bandwidth B of ASK is proportional to the signal rate S.

$$B = (1+d)S$$

- "d" is due to modulation and filtering, lies between 0 and 1.

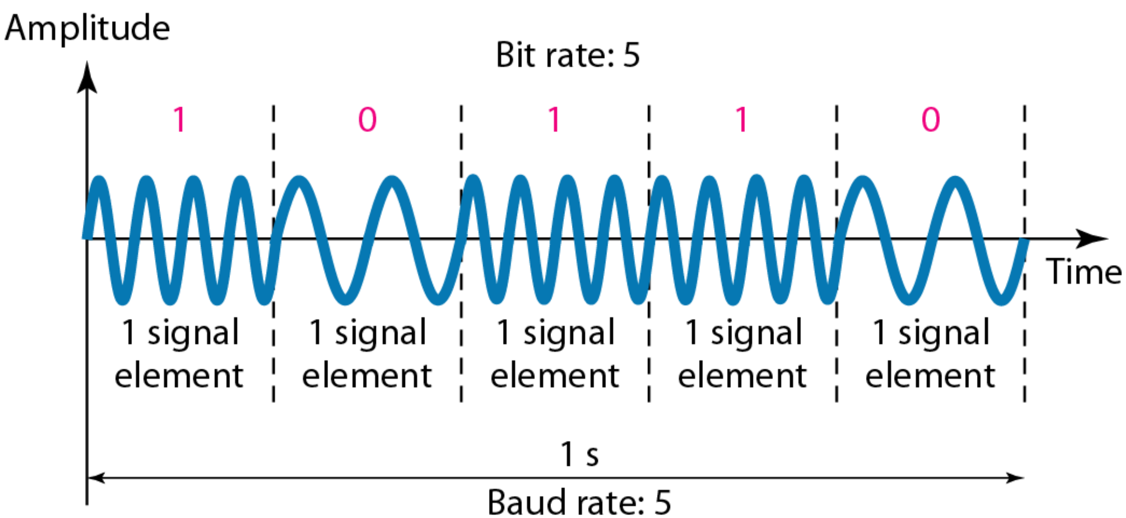
Binary amplitude shift keying

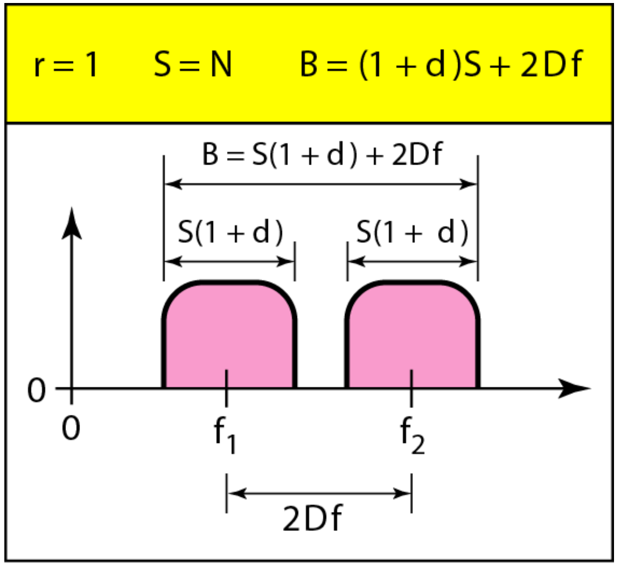


Frequency Shift Keying

- The digital data stream changes the frequency of the carrier signal, f_c.
- For example, a “1” could be represented by $f_1=f_c+\Delta f$, and a “0” could be represented by $f_2=f_c-\Delta f$.

Binary frequency shift keying





Bandwidth of FSK

- If the difference between the two frequencies (f_1 and f_2) is $2\Delta f$, then the required BW B will be:

$$B = (1+d)xS + 2\Delta f$$

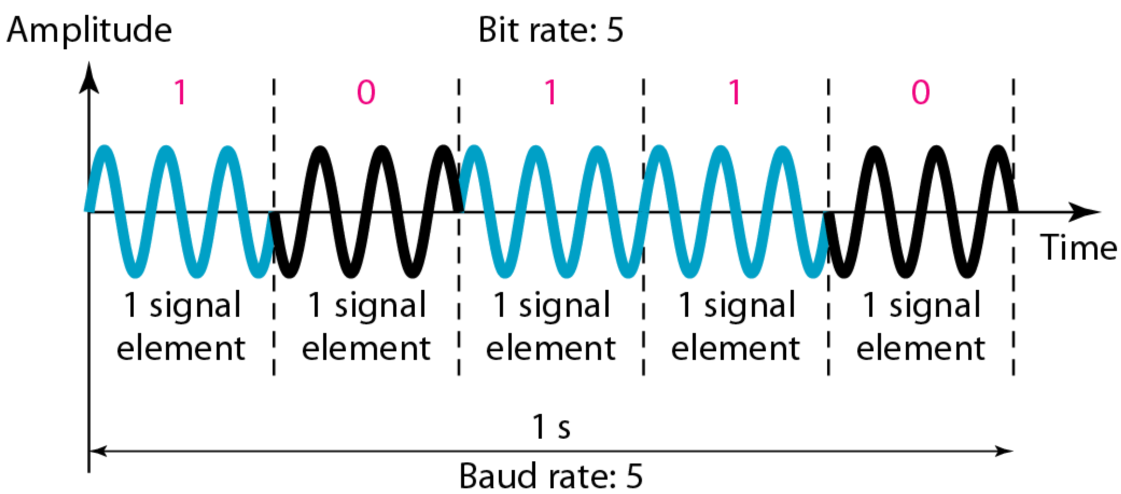
Phase Shift Keying

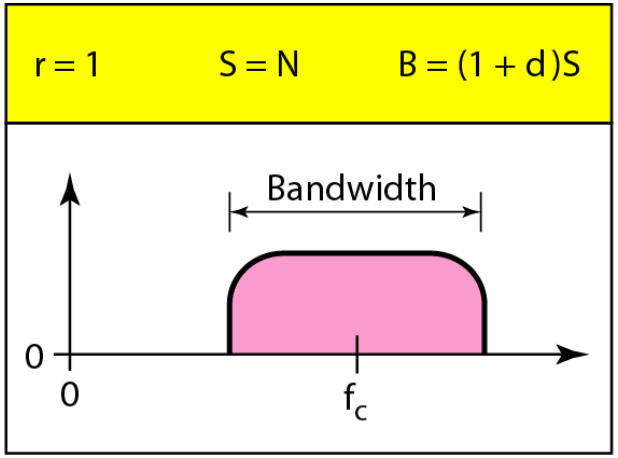
- We vary the phase shift of the carrier signal to represent digital data.
- The bandwidth requirement, B is:

  $$B = (1+d)xS$$

- PSK is much more robust than ASK as it is not that vulnerable to noise, which changes amplitude of the signal.

Binary phase shift keying





POLL 4

BW of binary FSK is

a) S(1+d)

b) S(1+d) + 2Df

c) S(1-d)

d) S(1+d) – 2Df

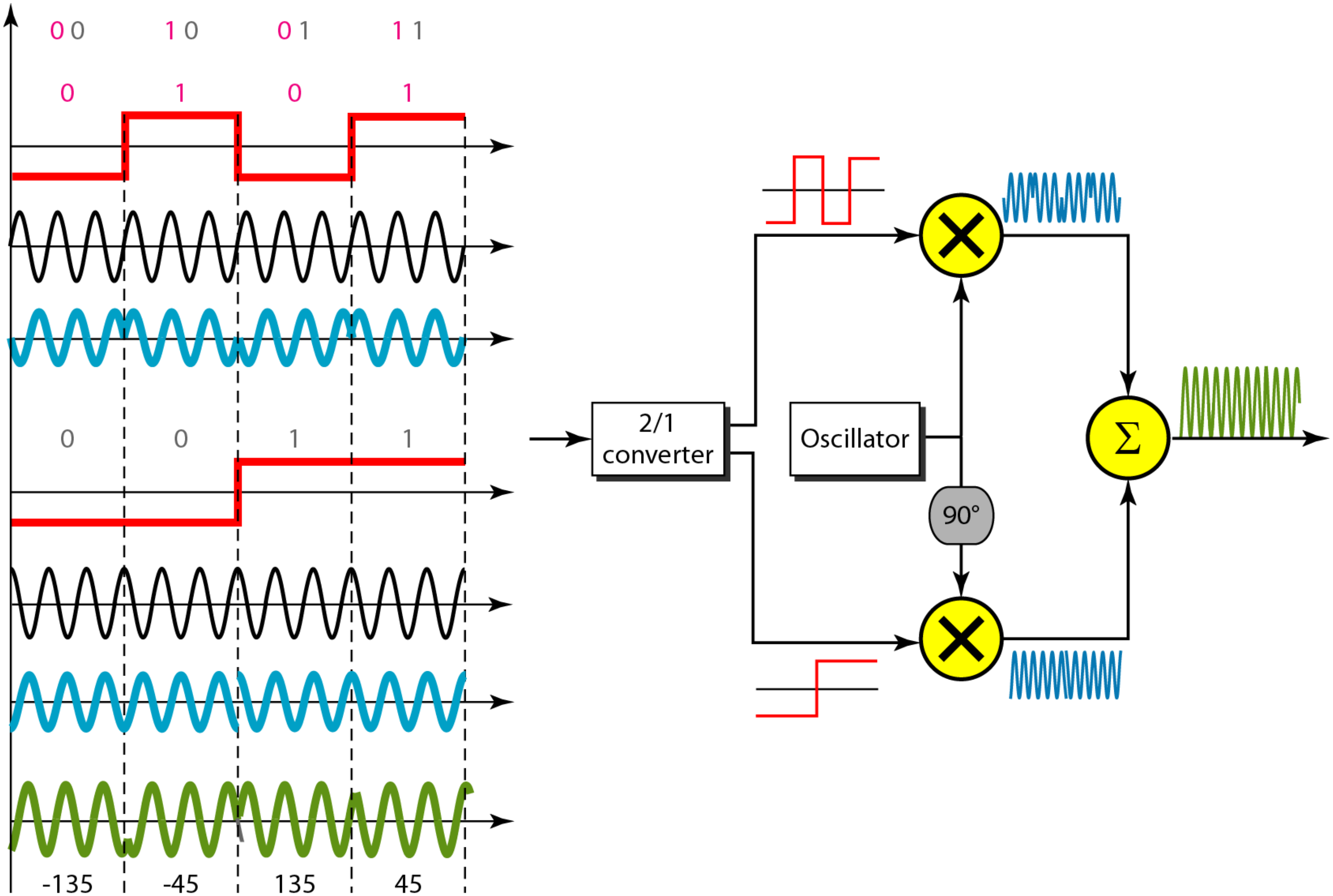
Quadrature PSK

- To increase the bit rate, we can code 2 or more bits onto one signal element.

- In QPSK, we parallelize the bit stream so that every two incoming bits are split up and PSK a carrier frequency. One carrier frequency is phase shifted 90^{o} from the other - in quadrature.

- The two PSKed signals are then added to produce one of 4 signal elements. L = 4 here.

QPSK and its implementation



Note

Quadrature amplitude modulation is a combination of ASK and PSK.

Digital Transmission

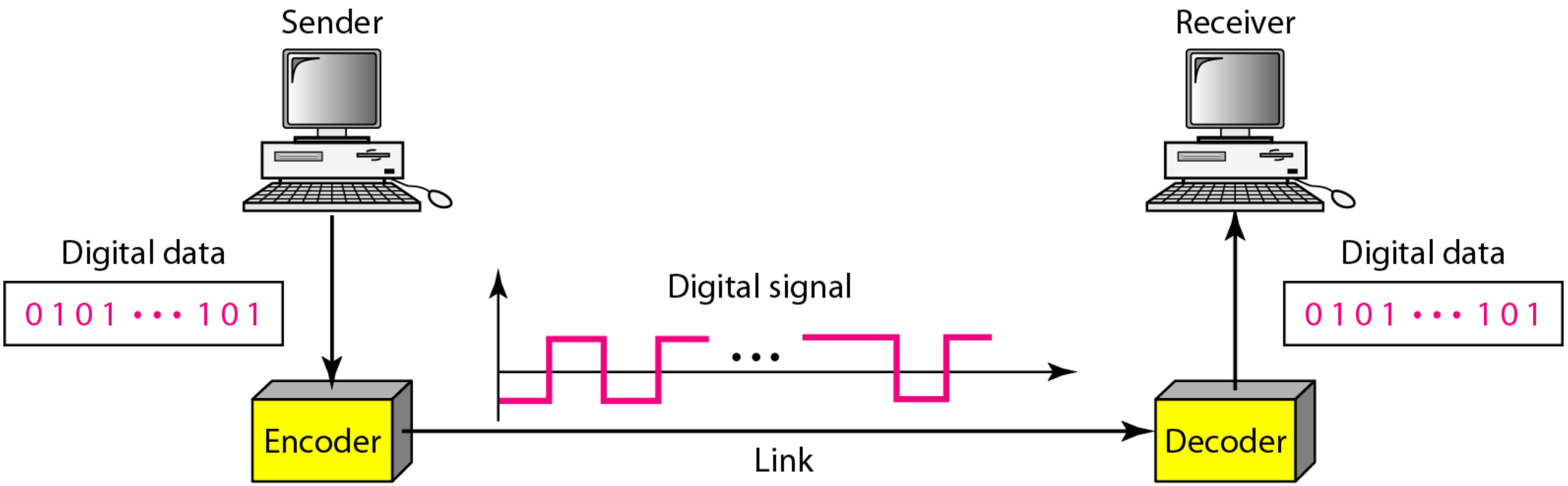
DIGITAL-TO-DIGITAL CONVERSION

In this section, we see how we can represent digital data by using digital signals. The conversion involves three techniques: line coding, block coding, and scrambling. Line coding is always needed; block coding and scrambling may or may not be needed.

Line Coding

- Converting a string of 1’s and 0’s (digital data) into a sequence of signals that denote the 1’s and 0’s.
- For example a high voltage level (+V) could represent a “1” and a low voltage level (0 or -V) could represent a “0”.

Line coding and decoding



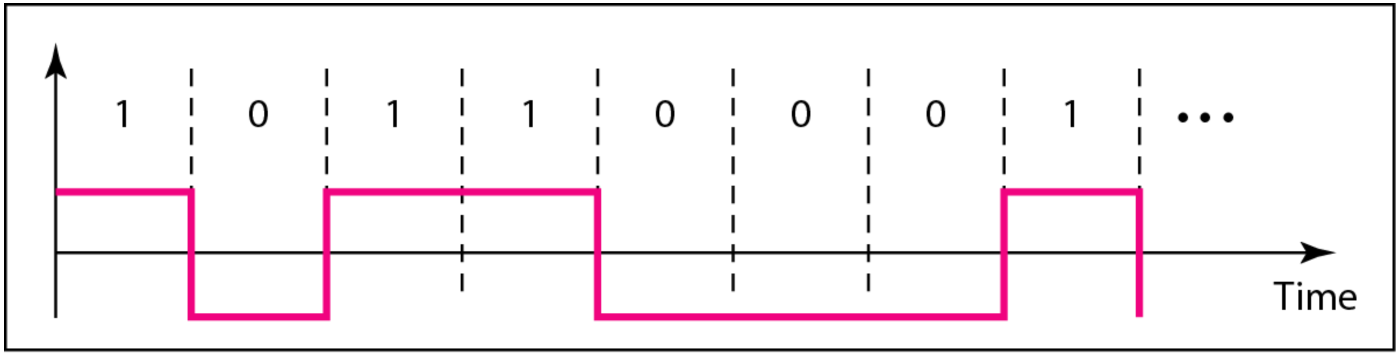
Line encoding C/Cs

- DC components - when the voltage level remains constant for long periods of time, there is an increase in the low frequencies of the signal. Most channels are bandpass and may not support the low frequencies.
- This will require the removal of the dc component of a transmitted signal.

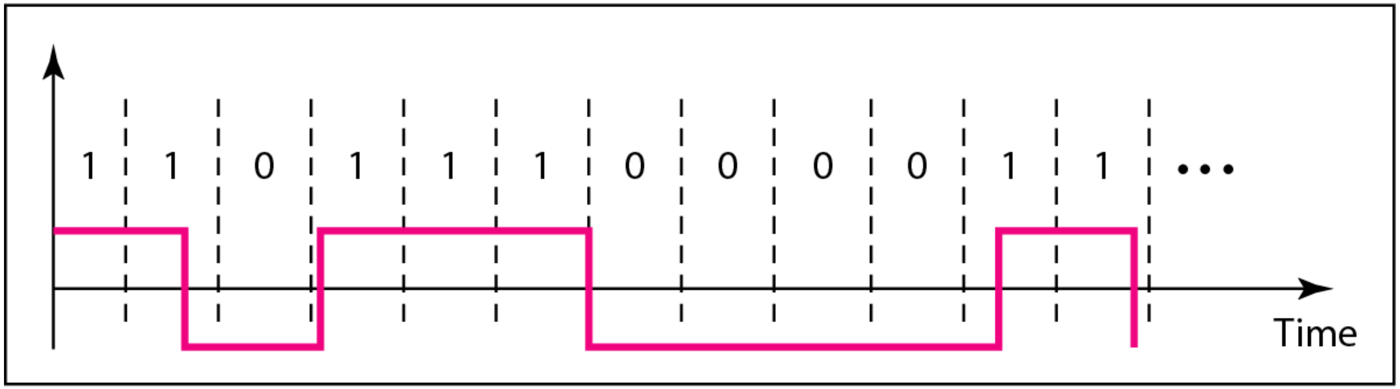
Line encoding C/Cs

- Self synchronization - the clocks at the sender and the receiver must have the same bit interval.
- If the receiver clock is faster or slower it will misinterpret the incoming bit stream.

Figure *Effect of lack of synchronization*



a. Sent



b. Received

Example

In a digital transmission, the receiver clock is 0.1 percent faster than the sender clock. How many extra bits per second does the receiver receive if the data rate is 1 kbps? How many if the data rate is 1 Mbps?

Solution

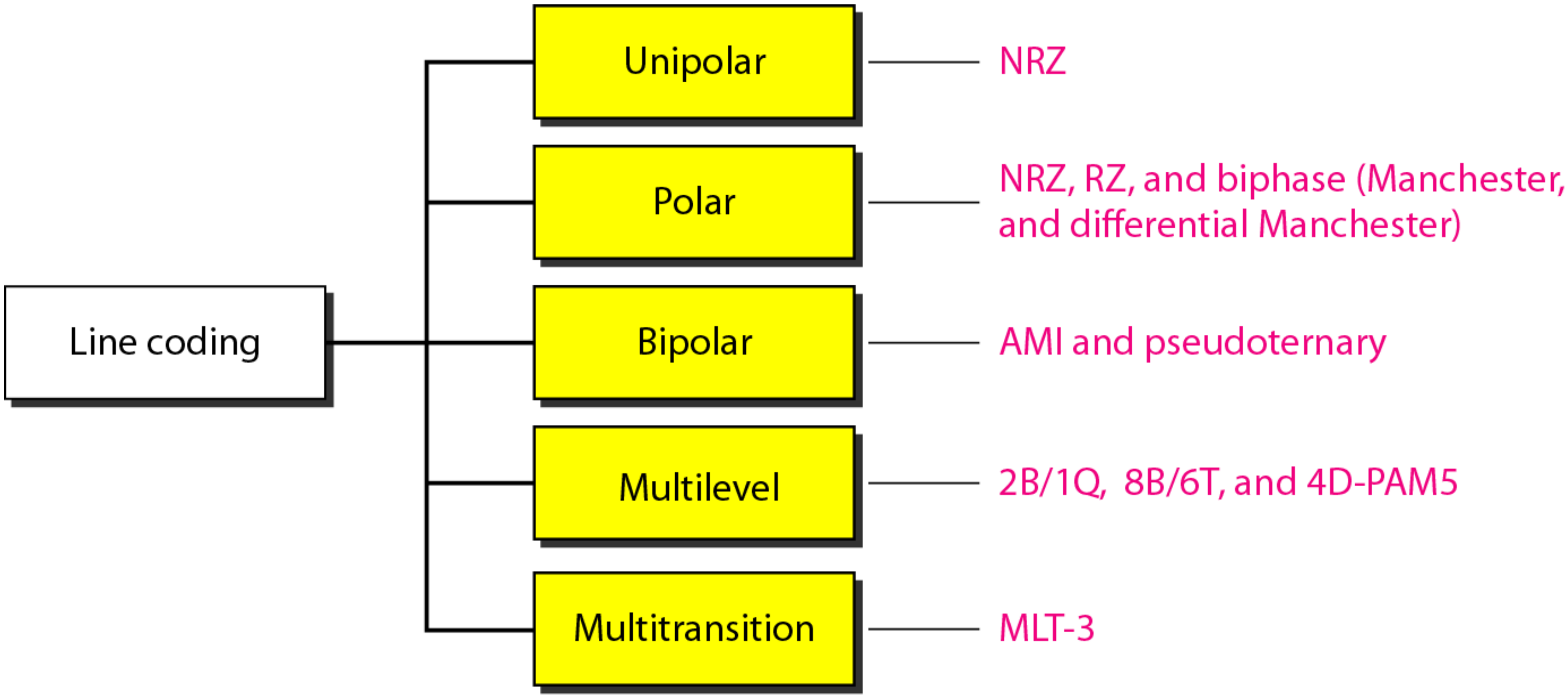
At 1 kbps, the receiver receives 1001 bps instead of 1000 bps.

1000 bits sent	1001 bits received	1 extra bps

At 1 Mbps, the receiver receives 1,001,000 bps instead of 1,000,000 bps.

1,000,000 bits sent	1,001,000 bits received	1000 extra bps

Figure *Line coding schemes*



POLL 5

Which of the following is NOT a type of Line Coding

a) Unipolar

b) Bipolar

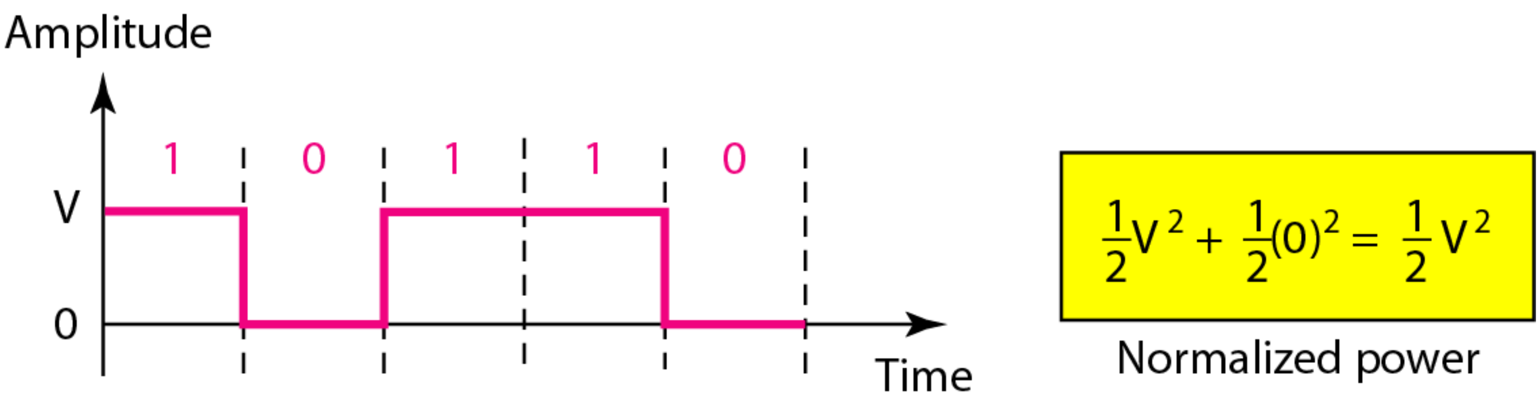
c) Polar

d) Multipolar

Unipolar

- All signal levels are on one side of the time axis - either above or below
- NRZ - Non Return to Zero scheme is an example of this code. The signal level does not return to zero during a symbol transmission.
- Scheme is prone to DC components. It has no synchronization or any error detection. It is simple but costly in power consumption.

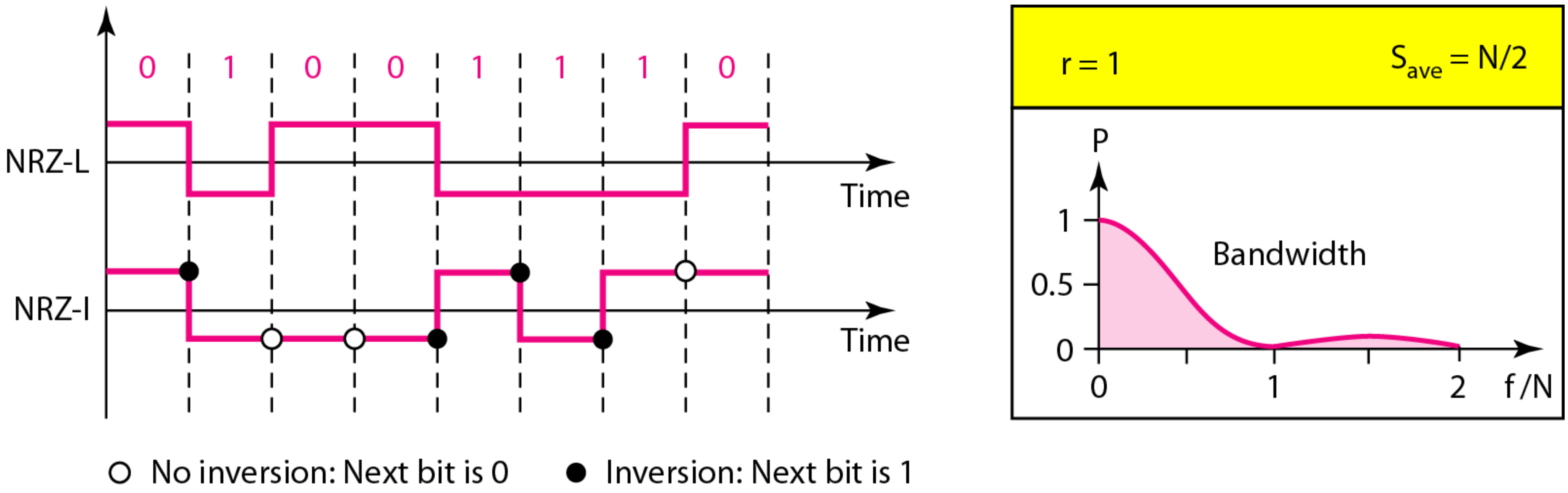
Figure *Unipolar NRZ scheme*



Polar - NRZ

- The voltages are on both sides of the time axis.
- Polar NRZ scheme can be implemented with two voltages. E.g. +V for 1 and -V for 0.
- There are two versions:
  - NZR - Level (NRZ-L) - positive voltage for one symbol and negative for the other
  - NRZ - Inversion (NRZ-I) - the change or lack of change in polarity determines the value of a symbol. E.g. a “1” symbol inverts the polarity a “0” does not.

Figure *Polar NRZ-L and NRZ-I schemes*



Note

In NRZ-L the level of the voltage determines the value of the bit.
In NRZ-I the inversion or the lack of inversion determines the value of the bit.

Note

NRZ-L and NRZ-I both have an average signal rate of N/2 Bd.

Note

NRZ-L and NRZ-I both have a DC component problem, it is worse for NRZ-L. Both have no self synchronization &no error detection. Both are relatively simple to implement.

POLL 6

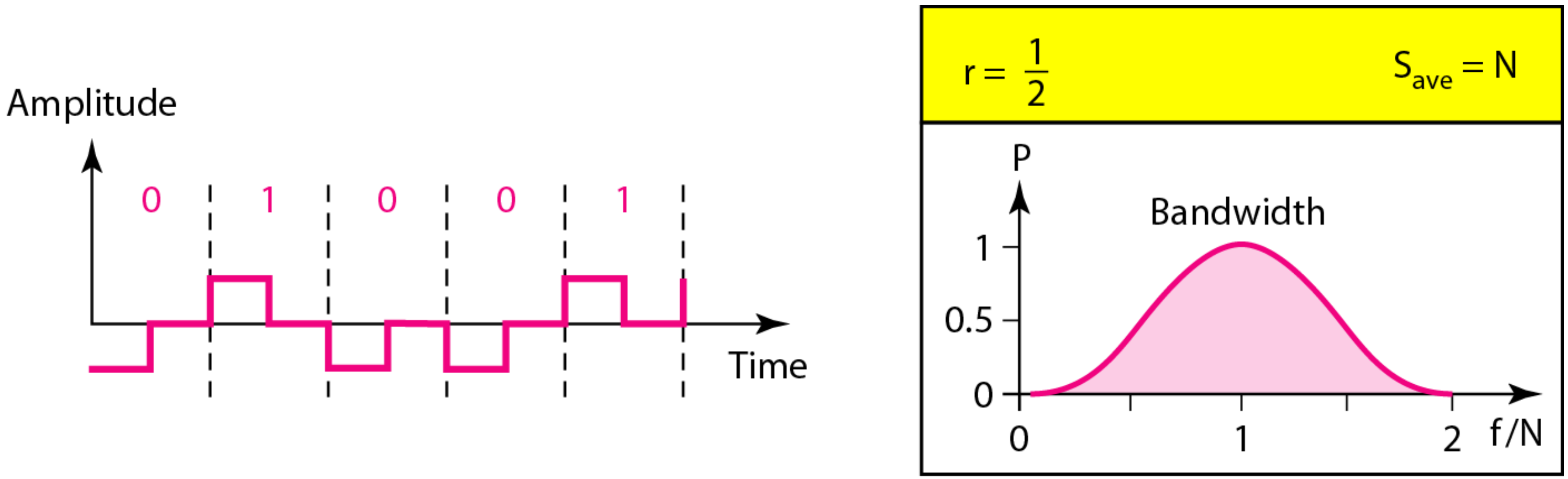
NRZ-L and NRZ-I both have

a) DC component problem
b) AC component Problem
c) Self Synchronization
d) Error Detection

Polar - RZ

- The Return to Zero (RZ) scheme uses three voltage values. +, 0, -.
- Each symbol has a transition in the middle. Either from high to zero or from low to zero.
- This scheme has more signal transitions (two per symbol) and therefore requires a wider bandwidth.
- No DC components or baseline wandering.
- Self synchronization - transition indicates symbol value.
- More complex as it uses three voltage level. It has no error detection capability.

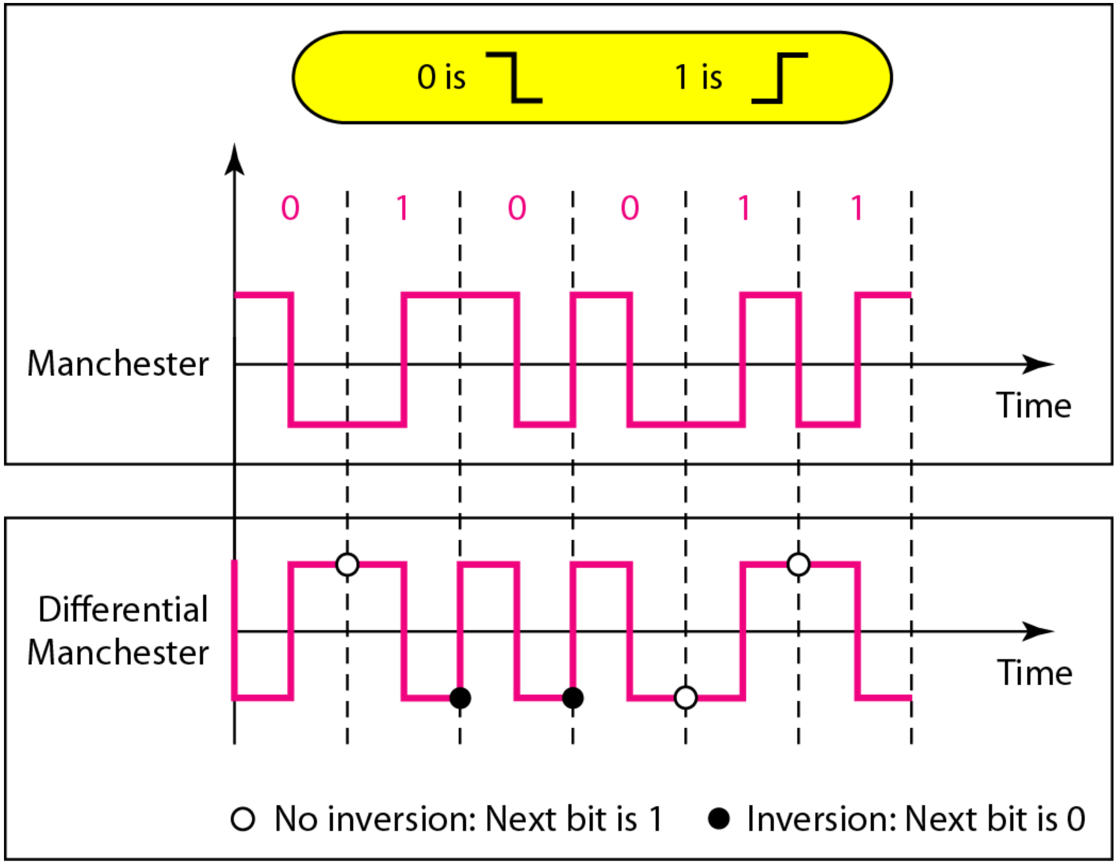
Figure ***Polar RZ scheme***

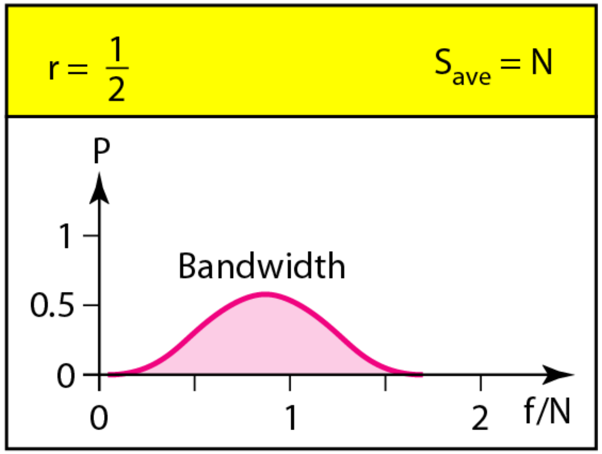


Polar - Biphase: Manchester and Differential Manchester

- Manchester coding consists of combining the NRZ-L and RZ schemes.
  - Every symbol has a level transition in the middle: from high to low or low to high. Uses only two voltage levels.
- Differential Manchester coding consists of combining the NRZ-I and RZ schemes.
  - Every symbol has a level transition in the middle. But the level at the beginning of the symbol is determined by the symbol value. One symbol causes a level change the other does not.

Figure ***Polar biphase: Manchester and differential Manchester schemes***





Note

In Manchester and differential Manchester encoding, the transition at the middle of the bit is used for synchronization.

Note

The minimum bandwidth of Manchester and differential Manchester is 2 times that of NRZ. The is no DC component. None of these codes has error detection.

Digital Transmission

ANALOG-TO-DIGITAL CONVERSION

A digital signal is superior to an analog signal because it is more robust to noise and can easily be recovered, corrected and amplified. For this reason, the tendency today is to change an analog signal to digital data. In this section we describe two techniques, pulse code modulation and delta modulation.

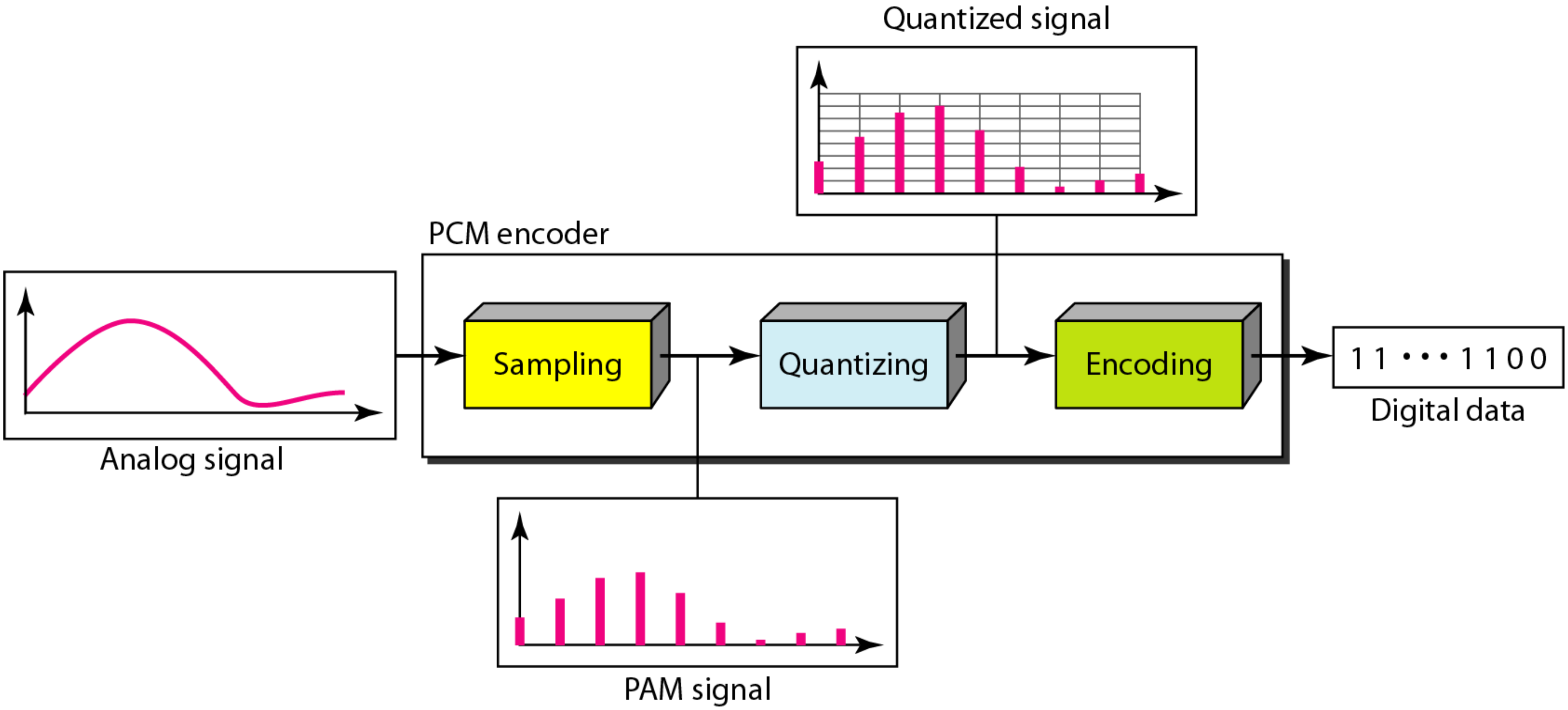
Topics discussed in this section:

- **Pulse Code Modulation (PCM)**

PCM

- PCM consists of three steps to digitize an analog signal:
  1. Sampling
  2. Quantization
  3. Binary encoding
- Before we sample, we have to filter the signal to limit the maximum frequency of the signal as it affects the sampling rate.
- Filtering should ensure that we do not distort the signal, ie remove high frequency components that affect the signal shape.

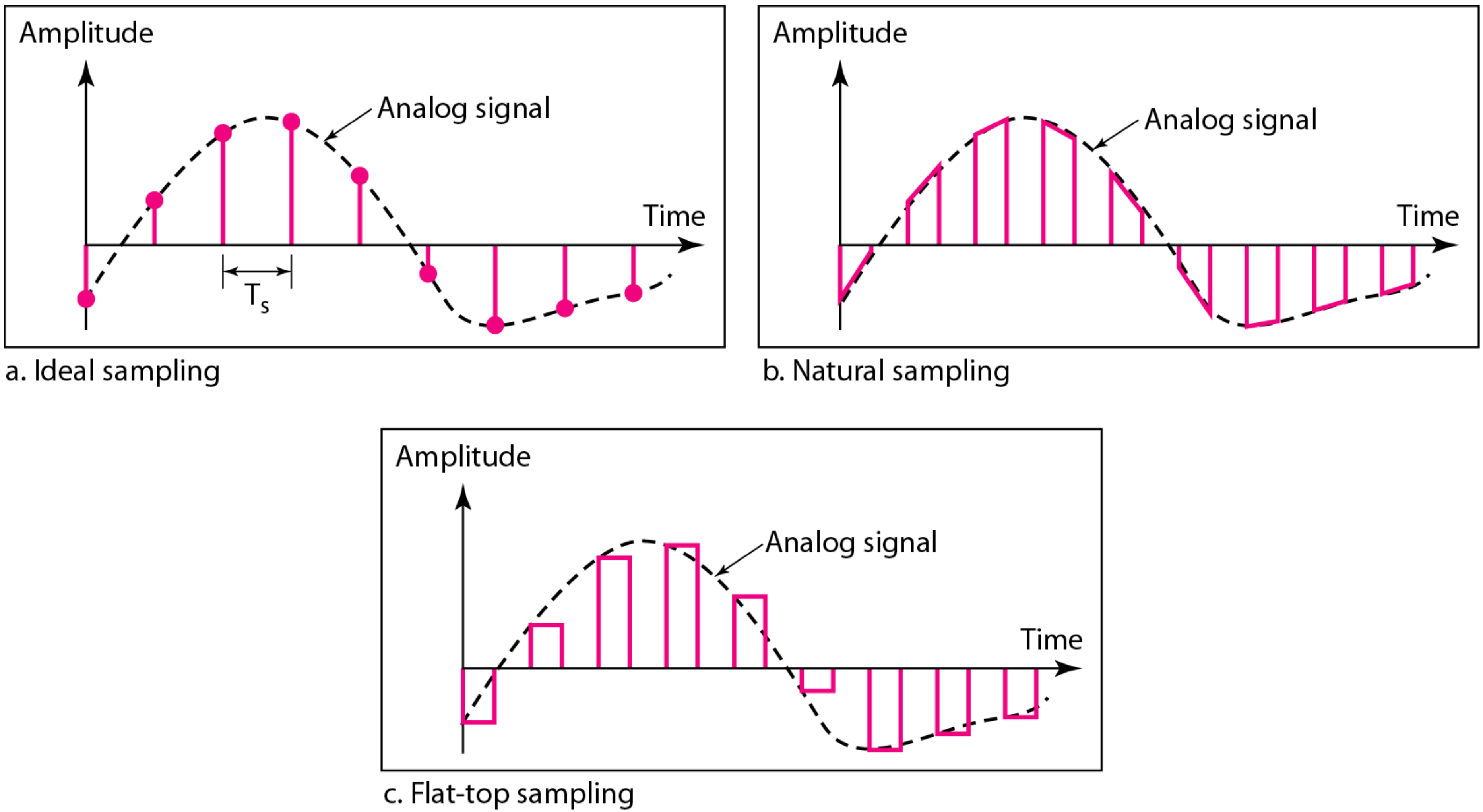
Figure *Components of PCM encoder*



Sampling

- Analog signal is sampled every T_S secs.
- T_s is referred to as the sampling interval.
- $f_s = 1/T_s$ is called the sampling rate or sampling frequency.
- There are 3 sampling methods:
  - Ideal - an impulse at each sampling instant
  - Natural - a pulse of short width with varying amplitude
  - Flattop - sample and hold, like natural but with single amplitude value
- The process is referred to as pulse amplitude modulation PAM and the outcome is a signal with analog (non integer) values

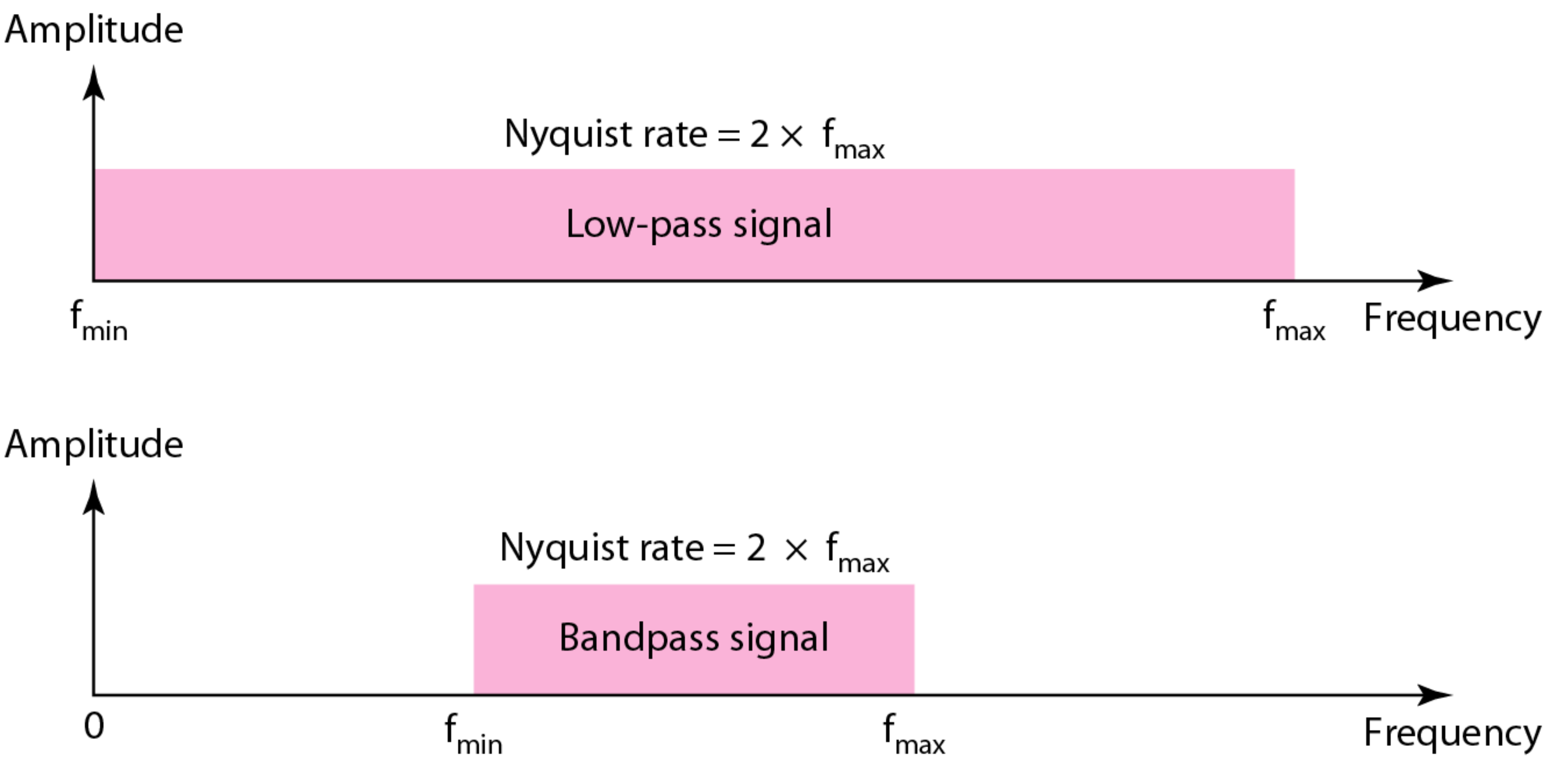
Figure *Three different sampling methods for PCM*



Note

According to the Nyquist theorem, the sampling rate must be at least 2 times the highest frequency contained in the signal.

Figure ***Nyquist sampling rate for low-pass and bandpass signals***



Quantization

- Sampling results in a series of pulses of varying amplitude values ranging between two limits: a min and a max.
- The amplitude values are infinite between the two limits.
- We need to map the *infinite* amplitude values onto a finite set of known values.
- This is achieved by dividing the distance between min and max into L zones, each of height Δ.

$$\Delta = (\text{max} - \text{min})/L$$

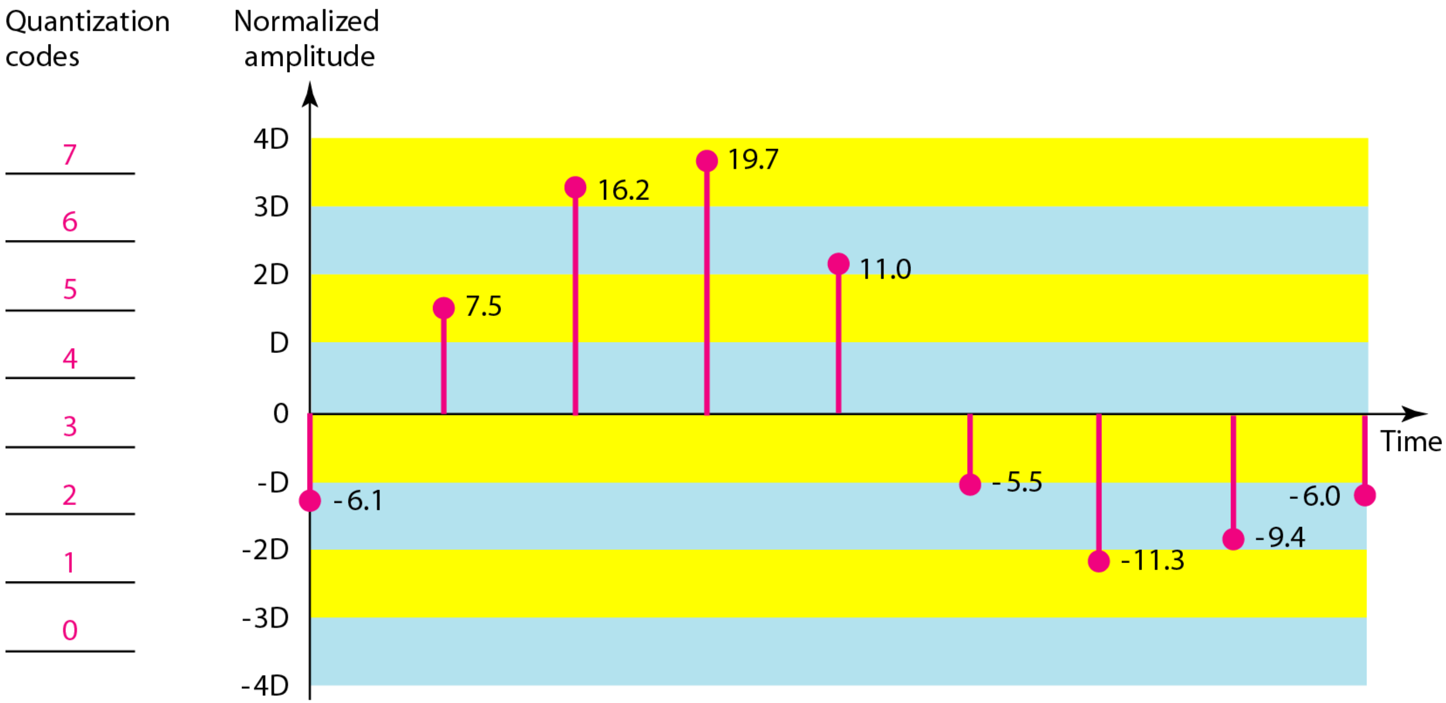
Quantization Levels

- The midpoint of each zone is assigned a value from 0 to L-1 (resulting in L values)
- Each sample falling in a zone is then approximated to the value of the midpoint.

Quantization Zones

- Assume we have a voltage signal with amplitutes V_{min}=-20V and V_{max}=+20V.
- We want to use L=8 quantization levels.
- Zone width Δ = (20 - -20)/8 = 5
- The 8 zones are: -20 to -15, -15 to -10, -10 to -5, -5 to 0, 0 to +5, +5 to +10, +10 to +15, +15 to +20
- The midpoints are: -17.5, -12.5, -7.5, -2.5, 2.5, 7.5, 12.5, 17.5

Figure *Quantization and encoding of a sampled signal*



Normalized PAM values	-1.22	1.50	3.24	3.94	2.20	-1.10	-2.26	-1.88	-1.20
Normalized quantized values	-1.50	1.50	3.50	3.50	2.50	-1.50	-2.50	-1.50	-1.50
Normalized error	-0.38	0	+0.26	-0.44	+0.30	-0.40	-0.24	+0.38	-0.30
Quantization code	2	5	7	7	6	2	1	2	2
Encoded words	010	101	111	111	110	010	001	010	010

DATA LINK CONTROL

Presented by: Dr. Amandeep Singh

Data Link Layer Design Issues

- Services Provided to the Network Layer
- Framing
- Error Control
- Flow Control

POLL 1

Which of the service is NOT provided by the DLL

a) Framing

b) Error Control

c) Flow Control

d) None of the above

FRAMING

The data link layer needs to pack bits into frames, so that each frame is distinguishable from another. Our postal system practices a type of framing. The simple act of inserting a letter into an envelope separates one piece of information from another; the envelope serves as the delimiter.

Topics discussed in this section:

Fixed-Size Framing
Variable-Size Framing

Types of Framing

- Fixed Size Framing
- Variable Size Framing--- Character oriented protocols and Bit oriented Protocols.

Figure *A frame in a character-oriented protocol*

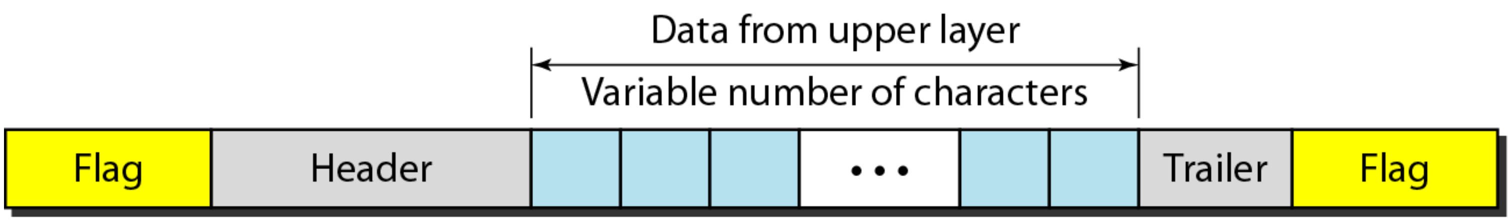
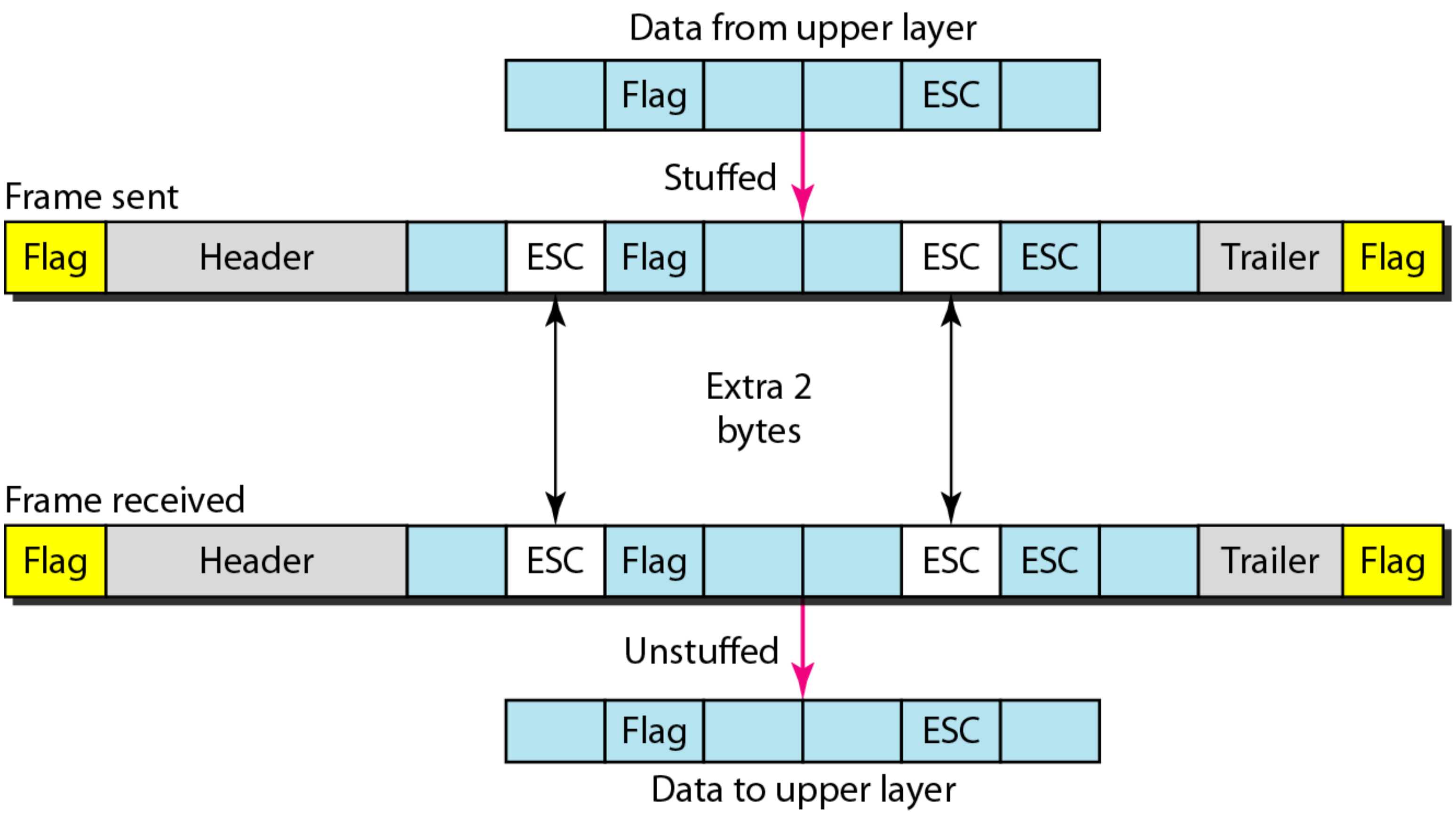


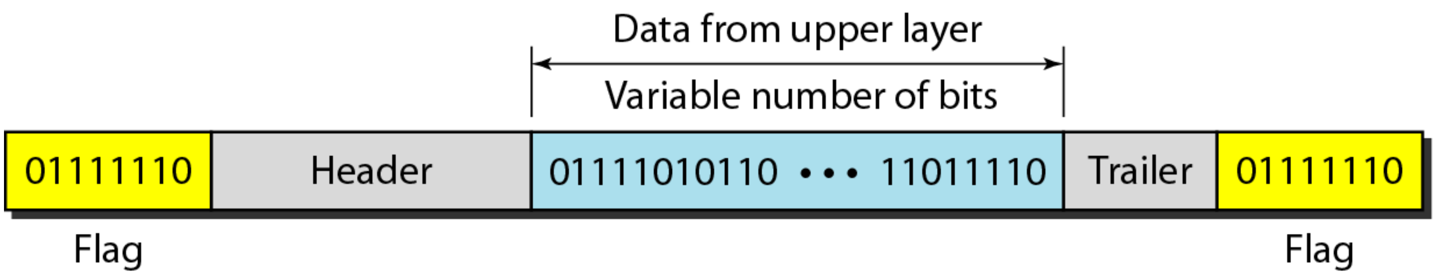
Figure *Byte stuffing and unstuffing*



Note

Byte stuffing is the process of adding 1 extra byte whenever there is a flag or escape character in the text.

Figure ***A frame in a bit-oriented protocol***



Note

Bit stuffing is the process of adding one extra 0 whenever five consecutive 1s follow a 0 in the data, so that the receiver does not mistake the pattern 0111110 for a flag.

POLL 2

The process of adding one extra 0 whenever five consecutive 1s follow a 0 in the data

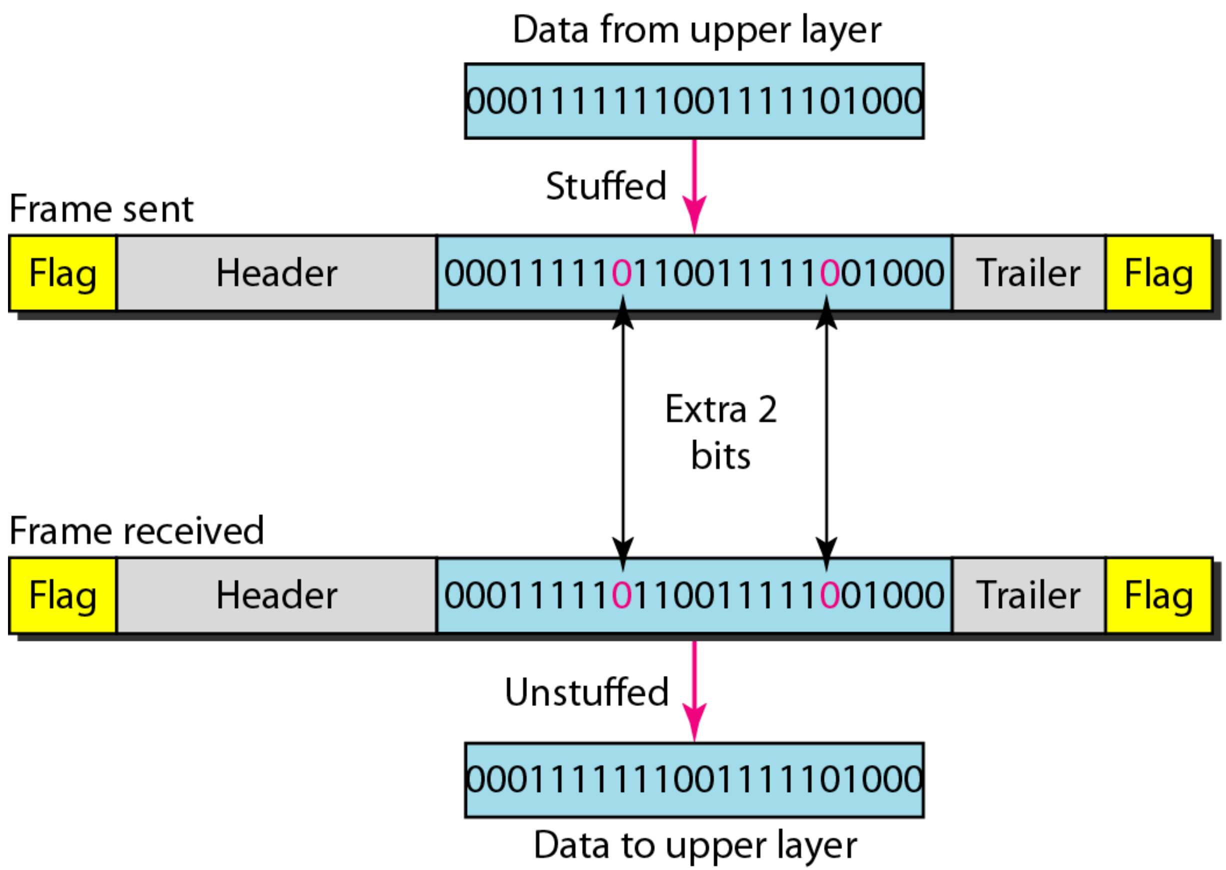
a) Bit Stuffing

b) Byte Stuffing

c) Nibble Stuffing

d) None of the above

Figure *Bit stuffing and unstuffing*



FLOW AND ERROR CONTROL

The most important responsibilities of the data link layer are flow control and error control. Collectively, these functions are known as data link control.

Topics discussed in this section:

Flow Control
Error Control

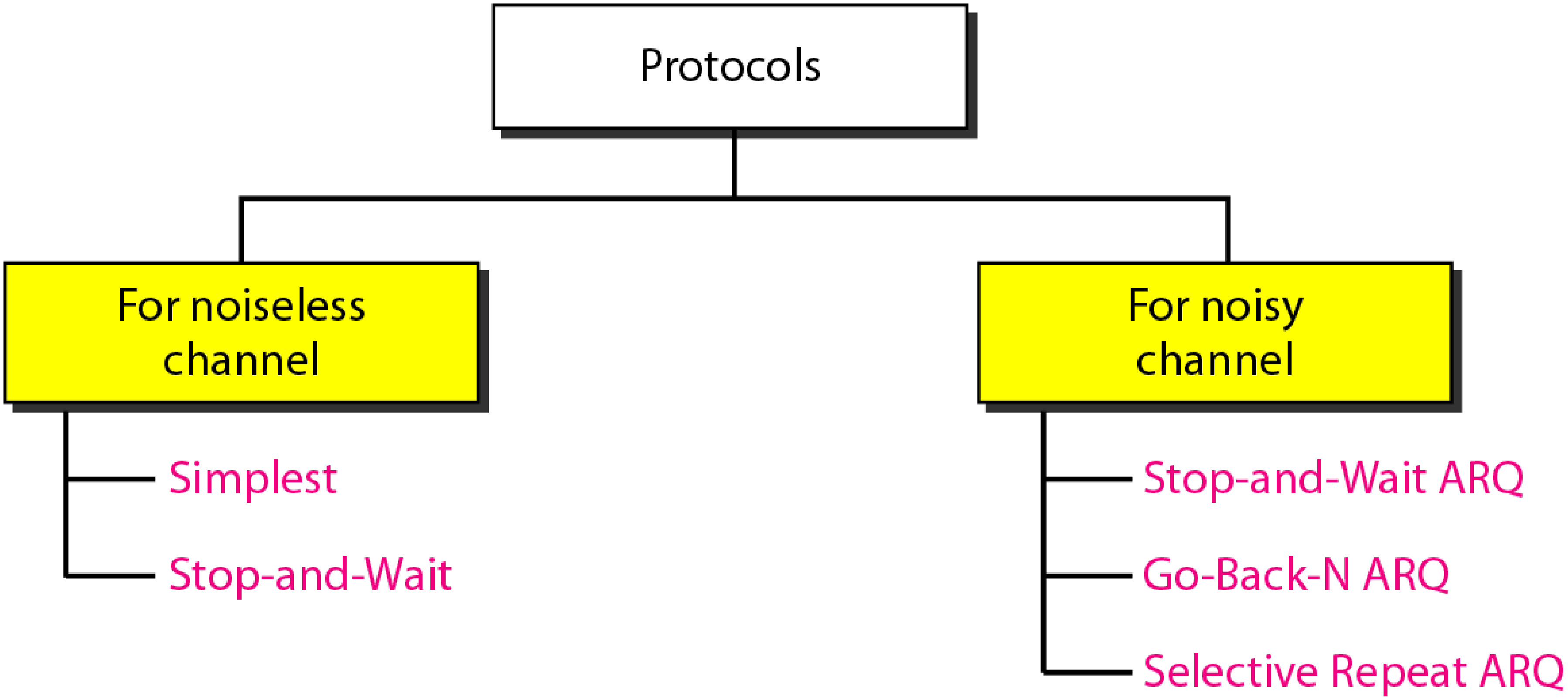
Note

Flow control refers to a set of procedures used to restrict the amount of data that the sender can send before waiting for acknowledgment.

Note

Error control in the data link layer is based on automatic repeat request, which is the retransmission of data.

Figure ***Taxonomy of protocols discussed in this chapter***



POLL 3

- Stop and Wait is a Protocol for

a) Noisy Channel

b) Noiseless Channel

c) Any of the above

d) None of the above

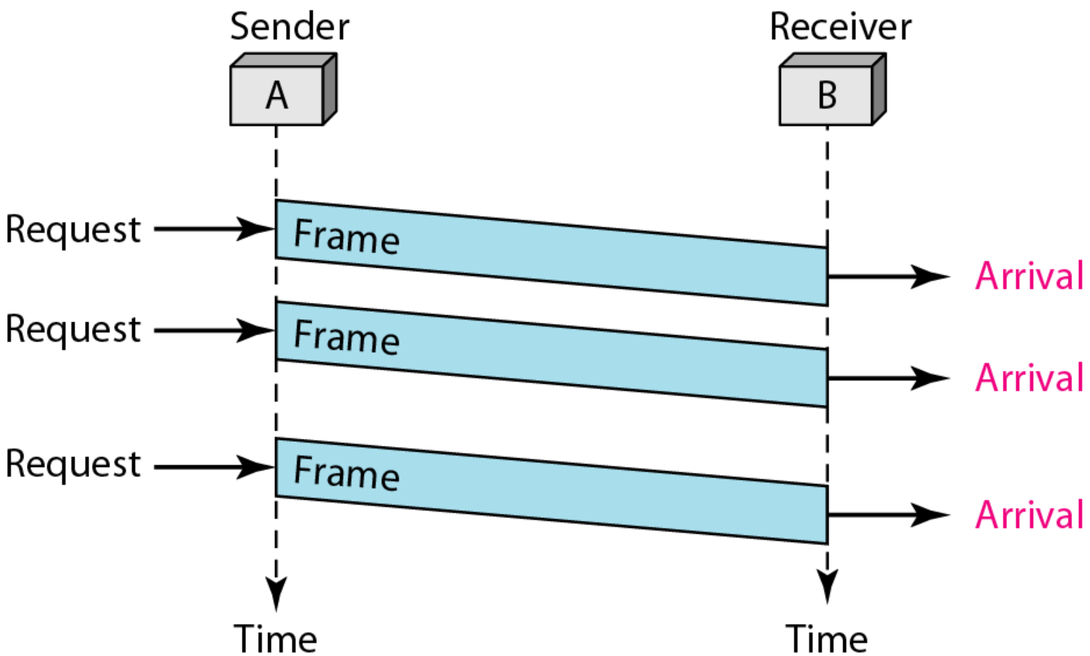
NOISELESS CHANNELS

Let us first assume we have an ideal channel in which no frames are lost, duplicated, or corrupted. We introduce two protocols for this type of channel.

Topics discussed in this section:

Simplest Protocol
Stop-and-Wait Protocol

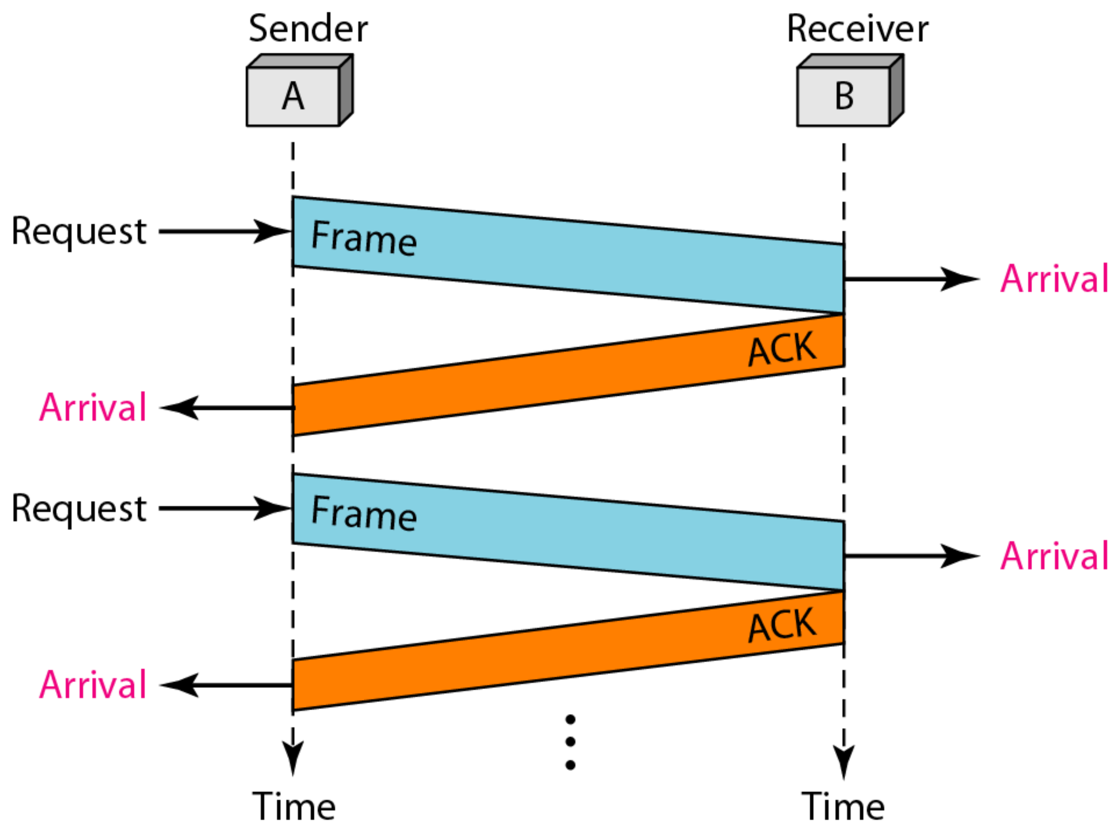
Figure *Flow diagram for Example*



Stop-and-Wait Protocol

- Sender sends one frame, stops until it gets confirmation from receiver.

Figure ***Flow diagram for Example***



NOISY CHANNELS

Although the Stop-and-Wait Protocol gives us an idea of how to add flow control to its predecessor, noiseless channels are nonexistent. We discuss three protocols in this section that use error control.

Topics discussed in this section:

Stop-and-Wait Automatic Repeat Request
Go-Back-N Automatic Repeat Request
Selective Repeat Automatic Repeat Request

Note

Error correction in Stop-and-Wait ARQ is done by keeping a copy of the sent frame and retransmitting of the frame when the timer expires.

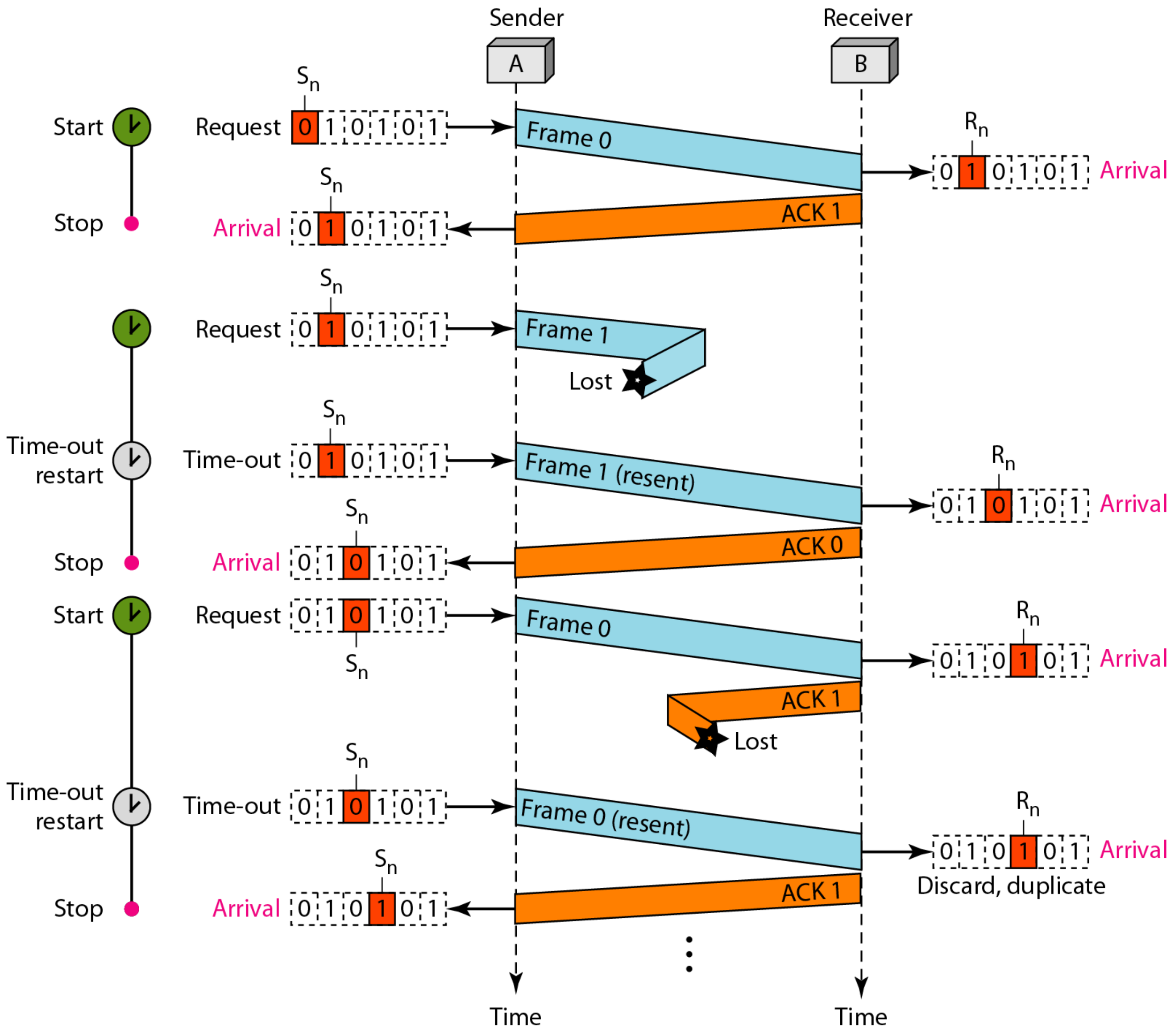
Note

In Stop-and-Wait ARQ, we use sequence numbers to number the frames. The sequence numbers are based on modulo-2 arithmetic.

Note

In Stop-and-Wait ARQ, the acknowledgment number always announces in modulo-2 arithmetic the sequence number of the next frame expected.

Figure *Flow diagram* Stop-and-Wait Automatic Repeat Request



Disadvantage *Stop-and-Wait ARQ Protocol*

- Inefficient---if channel is thick and long
- Thick means high bandwidth
- Long means roundtrip delay
- Product of both is bandwidth delay.
- Bandwidth delay is number of bits we can send while waiting for news from receiver.

Pipelining

- Task begins before end of first task.
- ***Stop-and-Wait ARQ does not use pipelining but other two techniques do.***

- ***This improves efficiency.***

Go-Back-N Protocol

- This sends multiple frames before receiving acknowledgment from receiver.

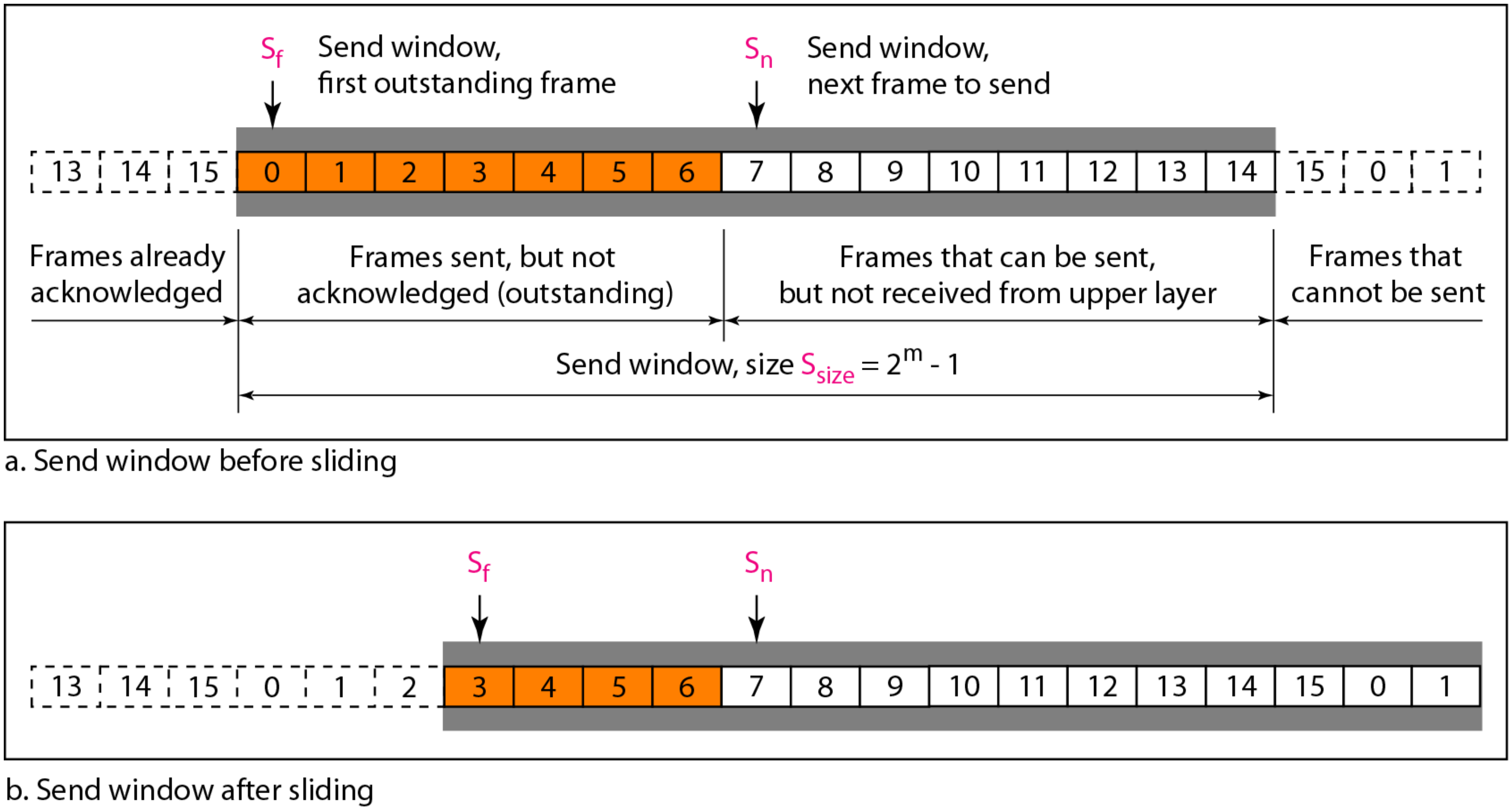
Note

In the Go-Back-N Protocol, the sequence numbers are modulo 2^m, where m is the size of the sequence number field in bits.

Sliding Window

- Defines the range of sequence numbers that is concern of sender and receiver.
- The range which is concern of sender is called sender sliding window.
- The range which is concern of receiver is called receiver sliding window.

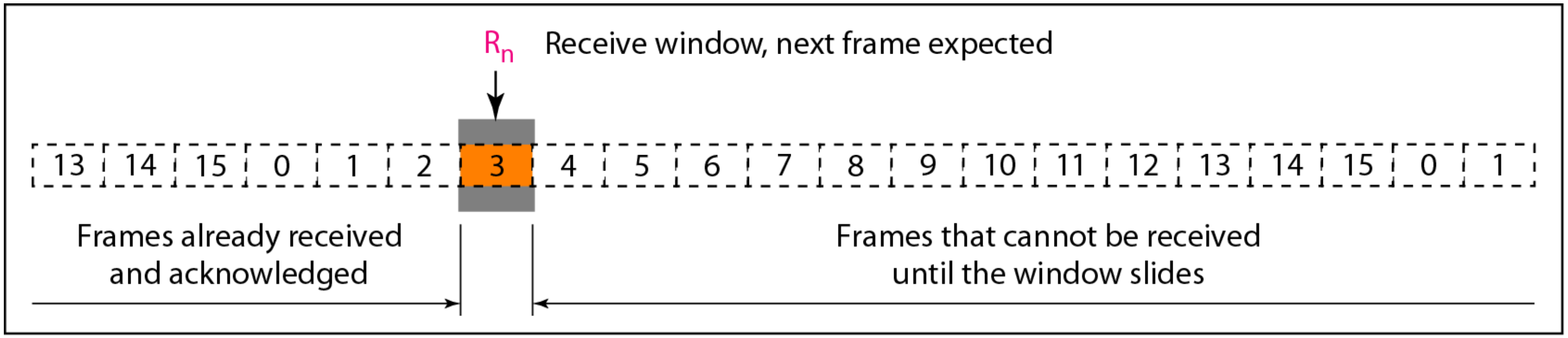
Figure *Send window for Go-Back-N ARQ*



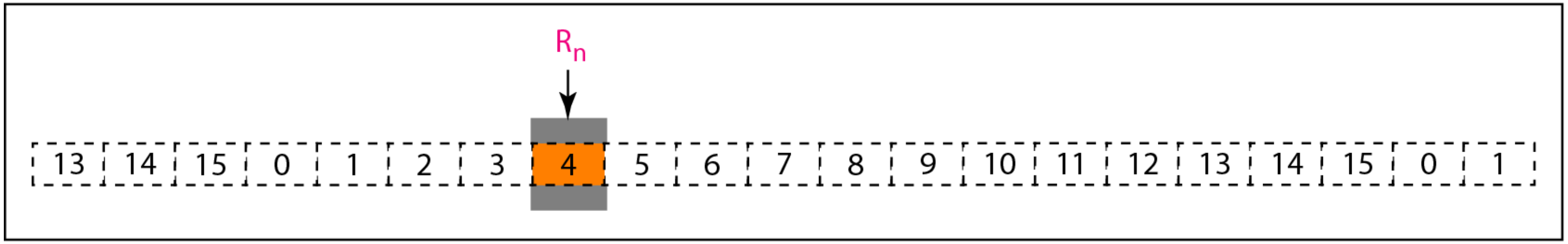
Note

The send window is an abstract concept defining an imaginary box of size $2^m - 1$ with three variables: Sf, Sn, and S_{size}.

Figure *Receive window for Go-Back-N ARQ*



a. Receive window



b. Window after sliding

Figure *Flow diagram*

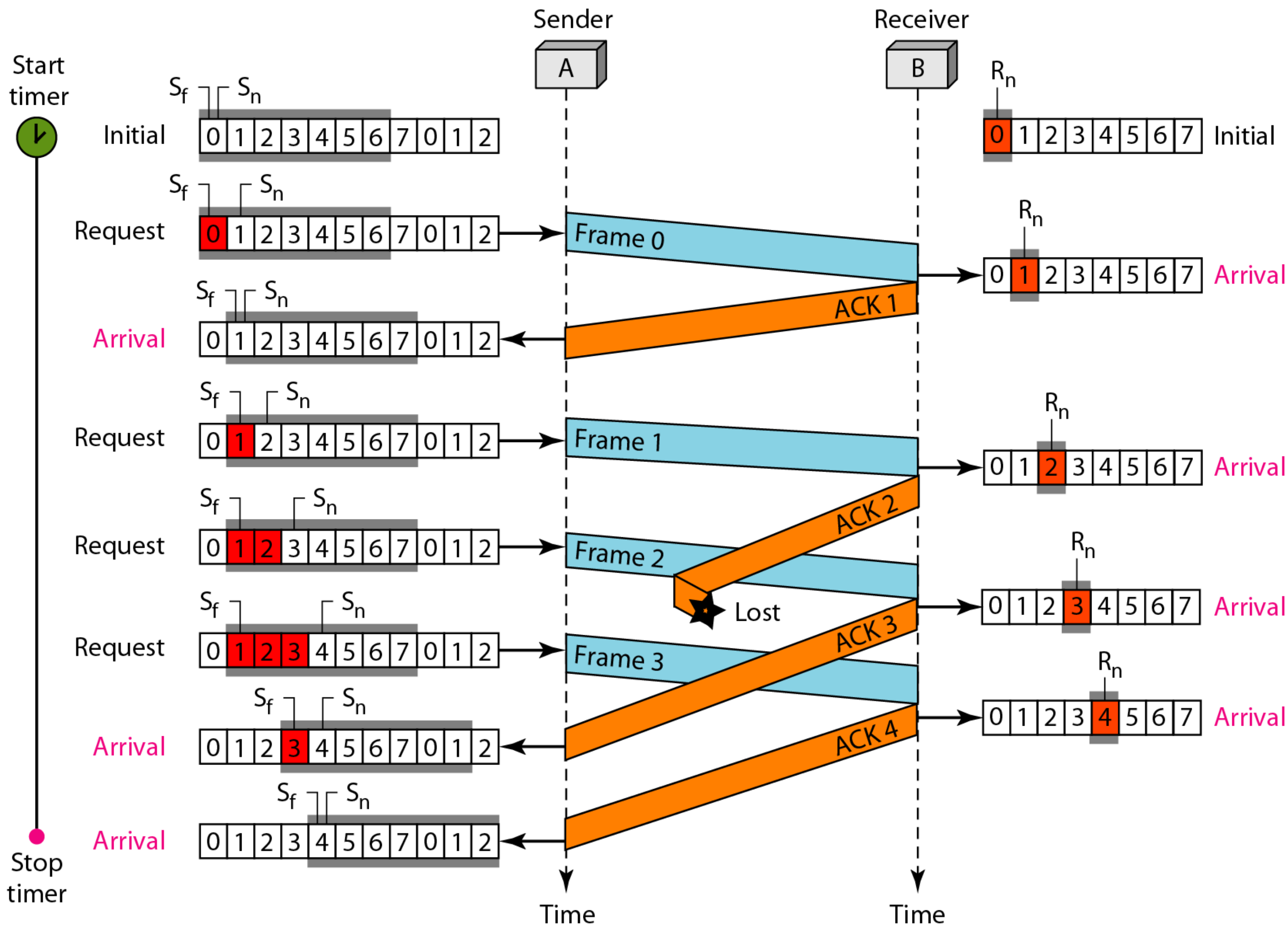
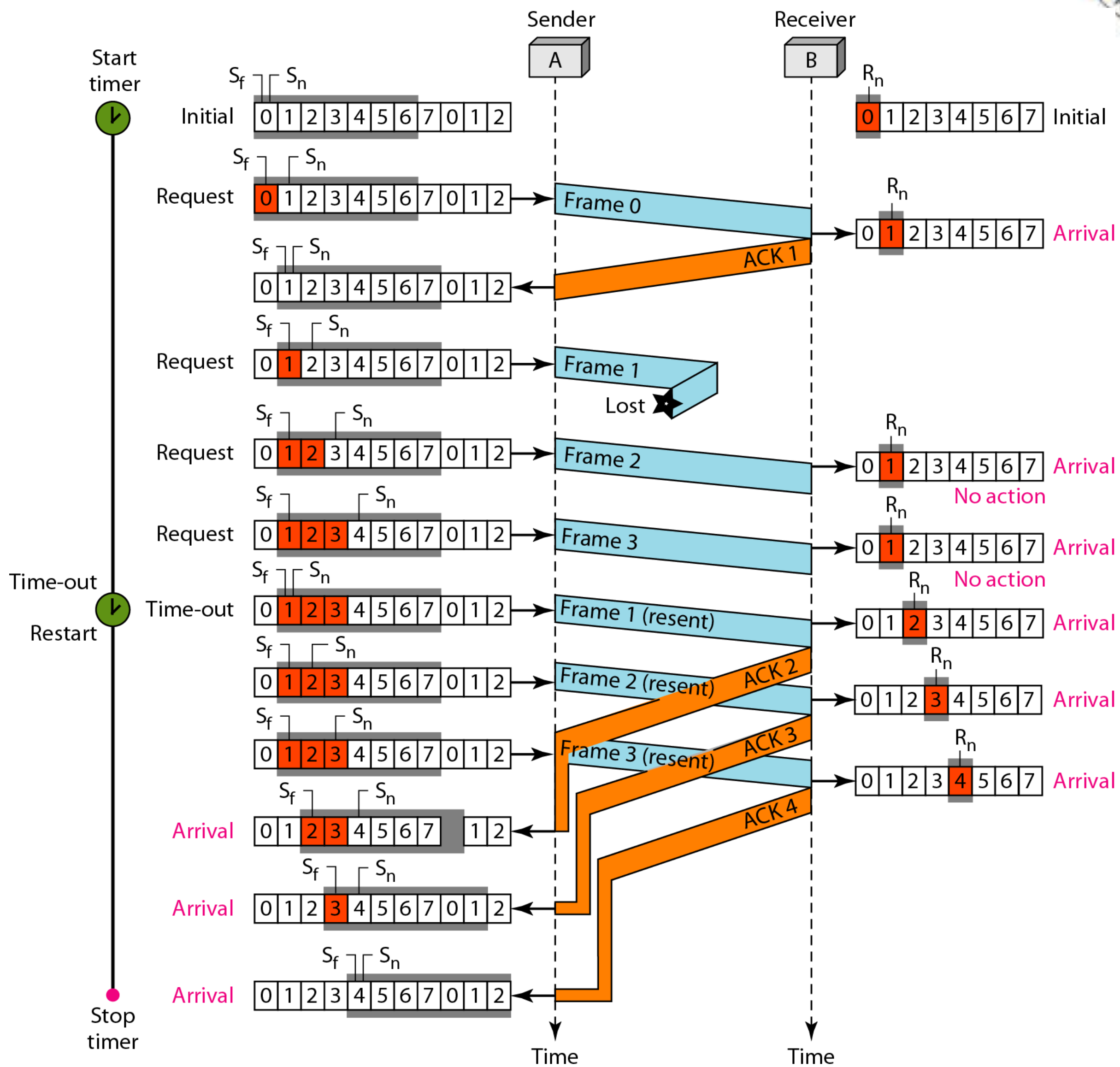


Figure *Flow diagram*



Note

Stop-and-Wait ARQ is a special case of Go-Back-N ARQ in which the size of the send window is 1.

Figure ***Send window for Selective Repeat ARQ***

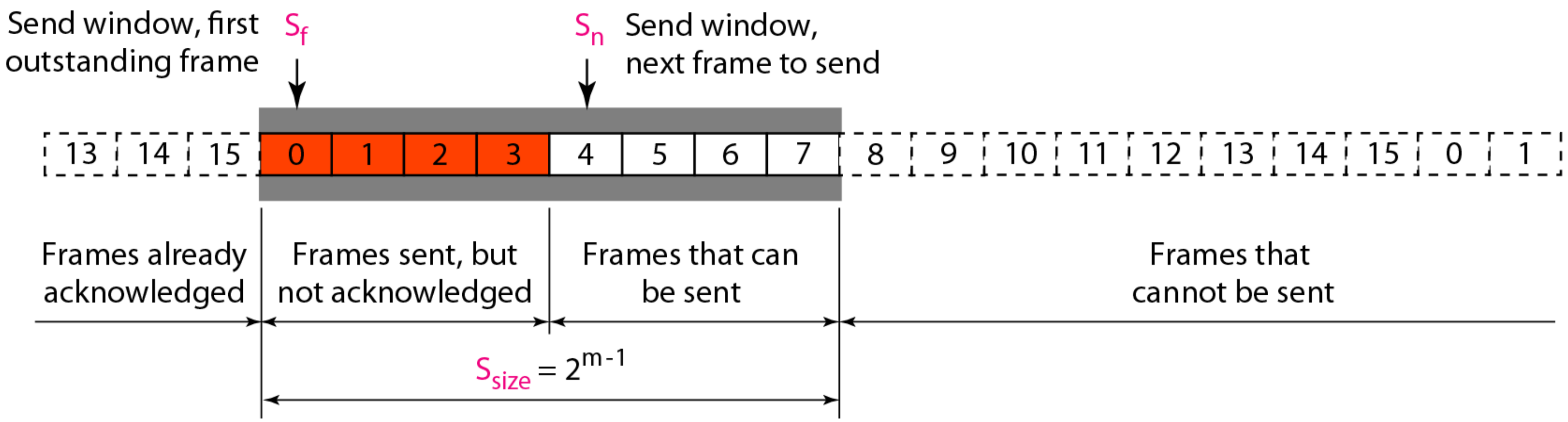
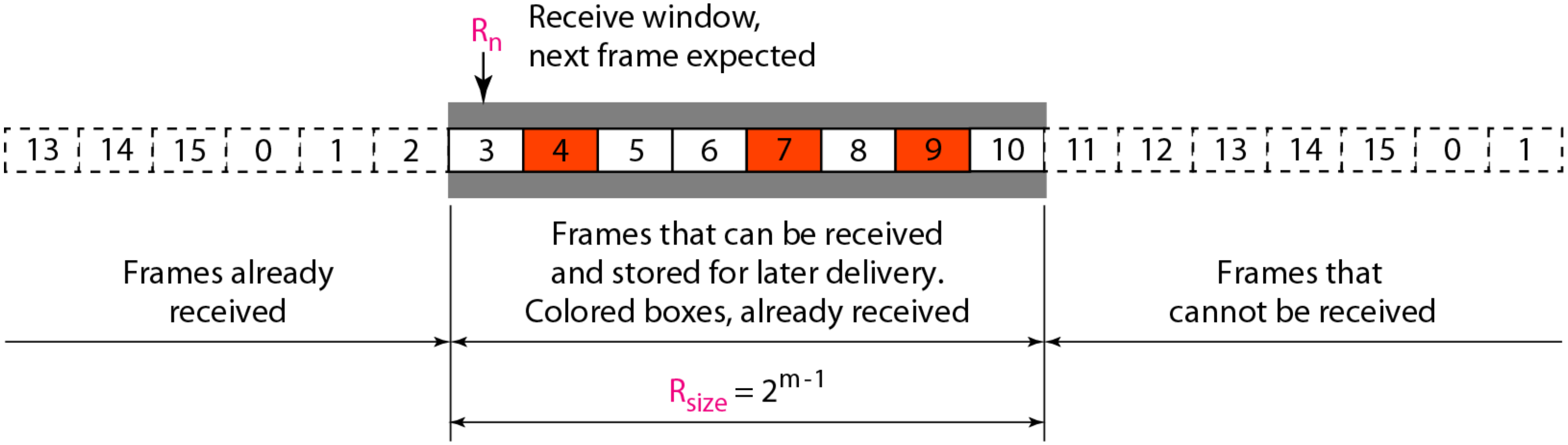


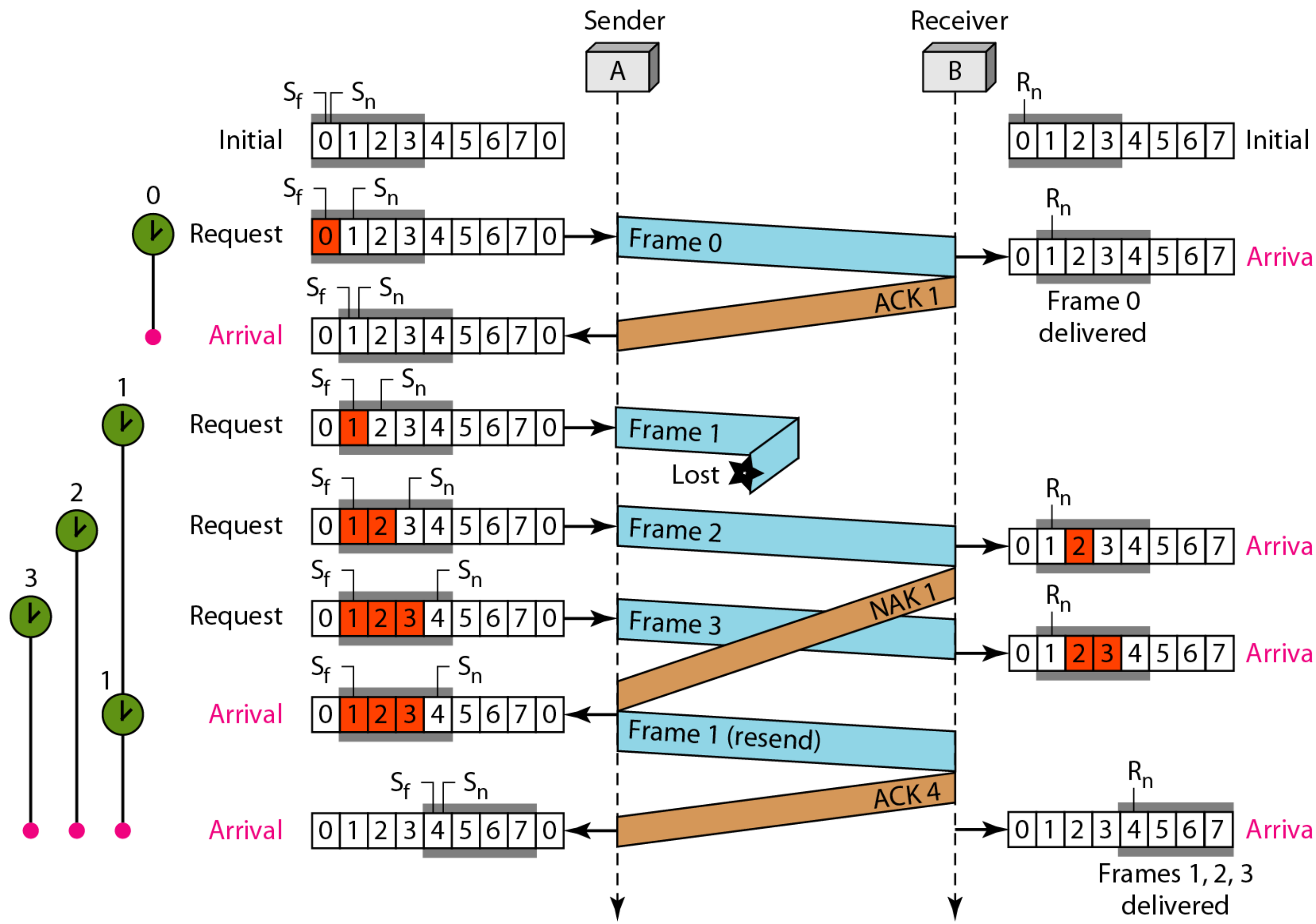
Figure *Receive window for Selective Repeat ARQ*



Note

In Selective Repeat ARQ, the size of the sender and receiver window must be at most one-half of 2^m.

Figure *Flow diagram Selective Repeat ARQ*



https://www2.tkn.tu-berlin.de/teaching/rn/animations/gbn_sr/

RECAP UNIT 2

Presented by: Dr. Amandeep Singh

Multiplexing

Note

Bandwidth utilization is the wise use of available bandwidth to achieve specific goals.

Efficiency can be achieved by multiplexing; i.e., sharing of the bandwidth between multiple users.

POLL 1

Multiplexing means

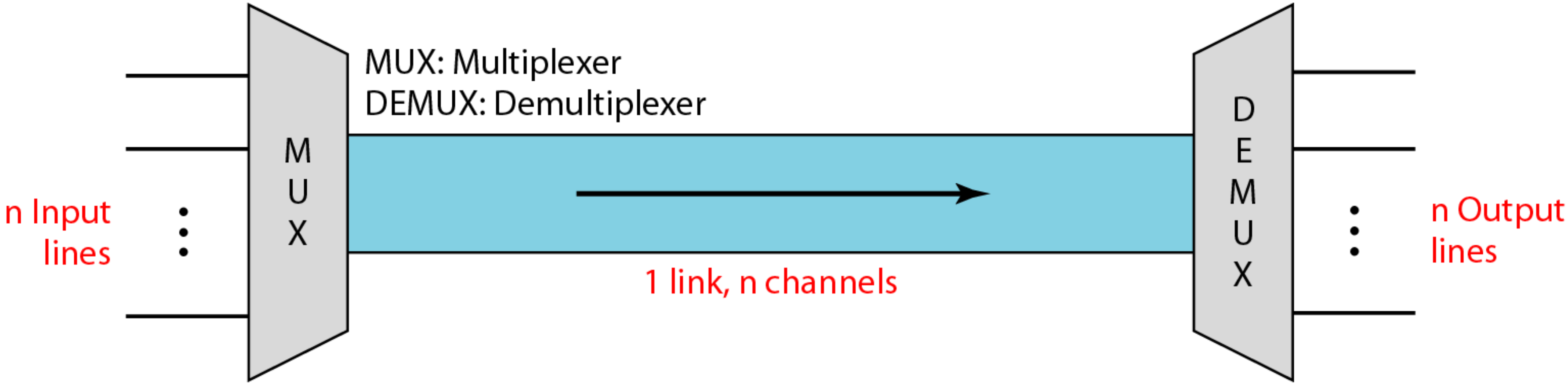
a) Sharing Bandwidth between two users

b) Sharing Bandwidth between multiple users

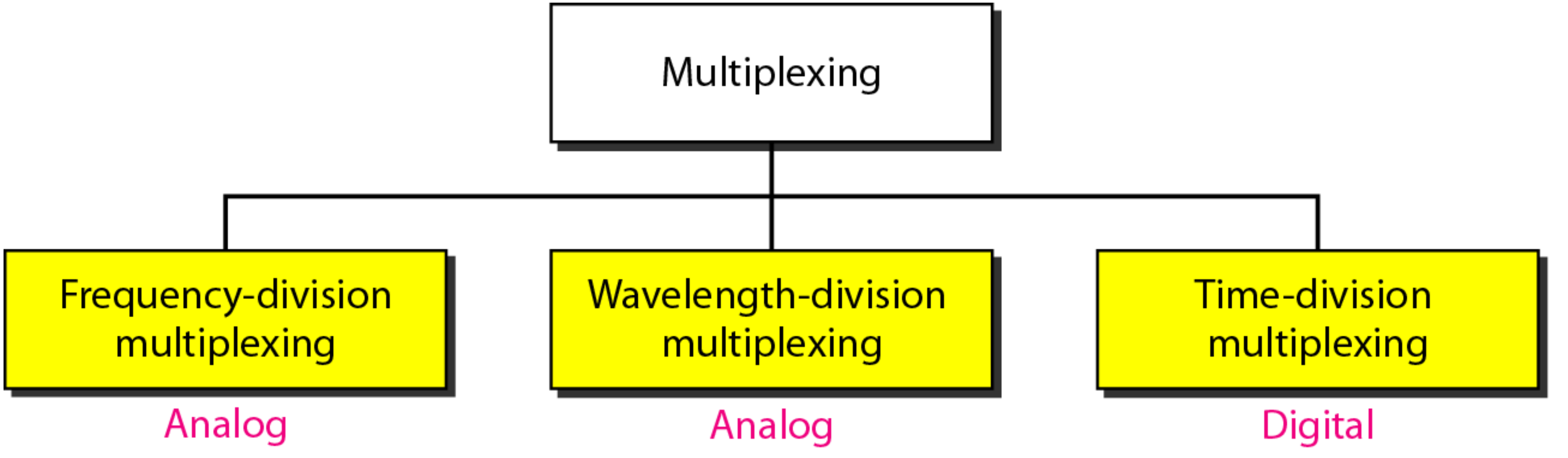
MULTIPLEXING

Whenever the bandwidth of a medium linking two devices is greater than the bandwidth needs of the devices, the link can be shared. Multiplexing is the set of techniques that allows the (simultaneous) transmission of multiple signals across a single data link. As data and telecommunications use increases, so does traffic.

Dividing a link into channels



Categories of multiplexing

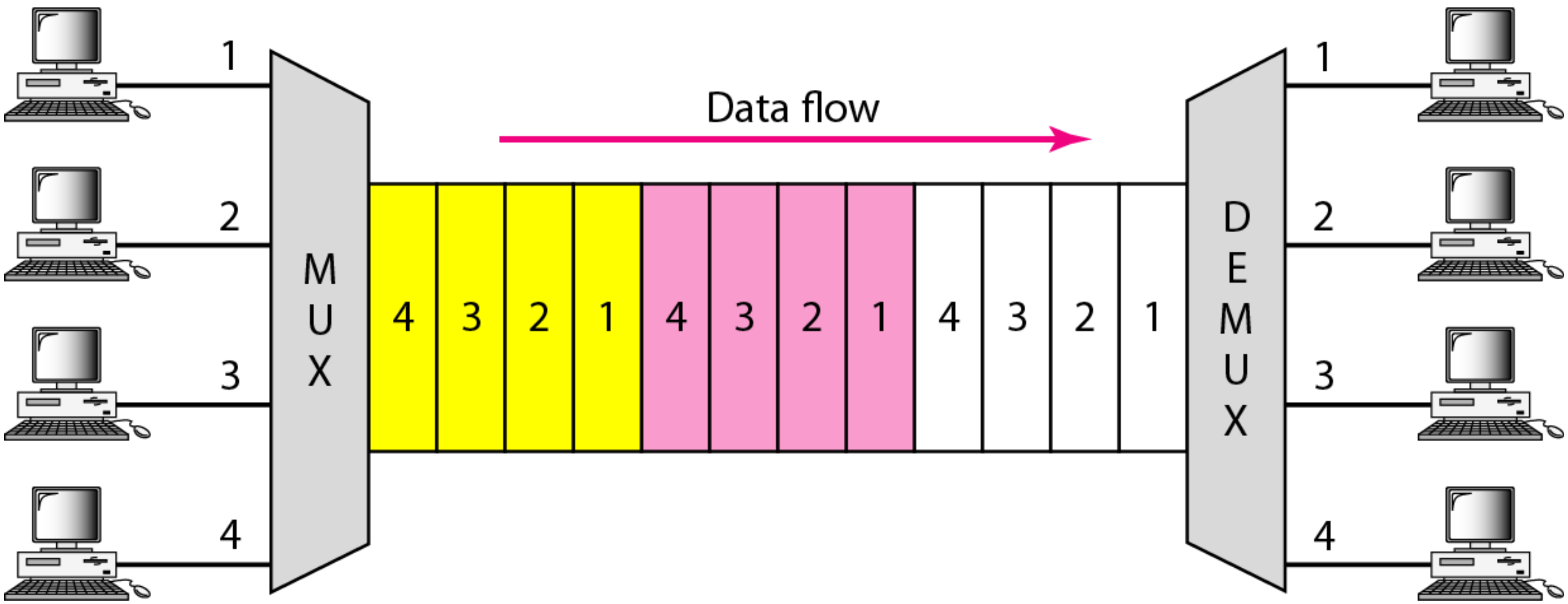


Frequency-division multiplexing (FDM)

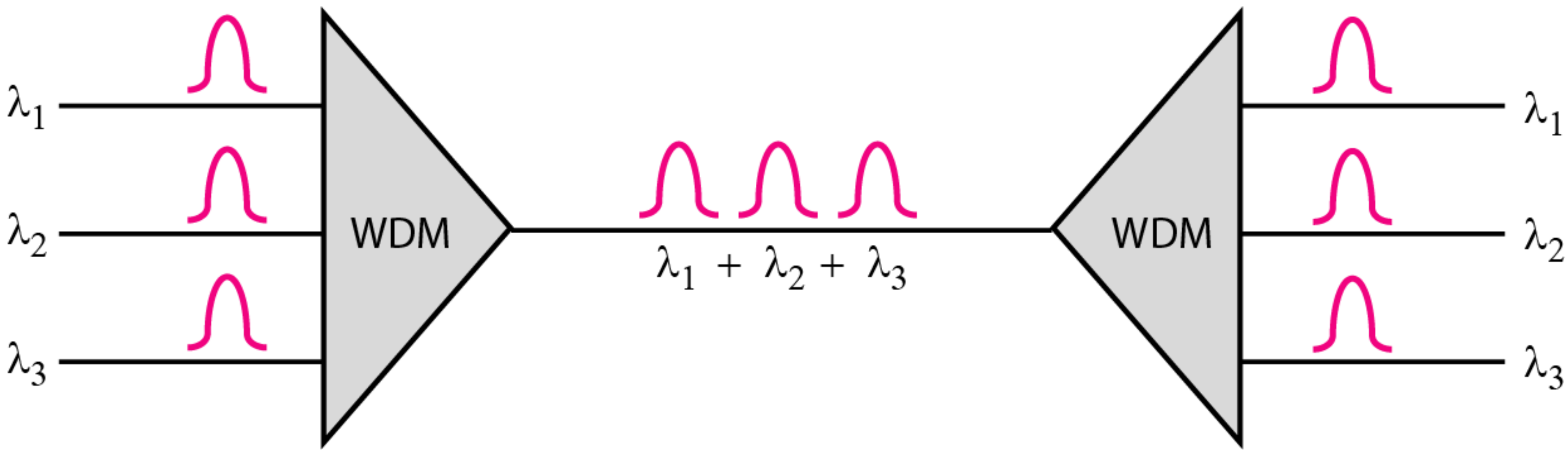
Note

FDM is an analog multiplexing technique that combines analog signals.
It uses the concept of modulation

Time Division Multiplexing (*TDM*)



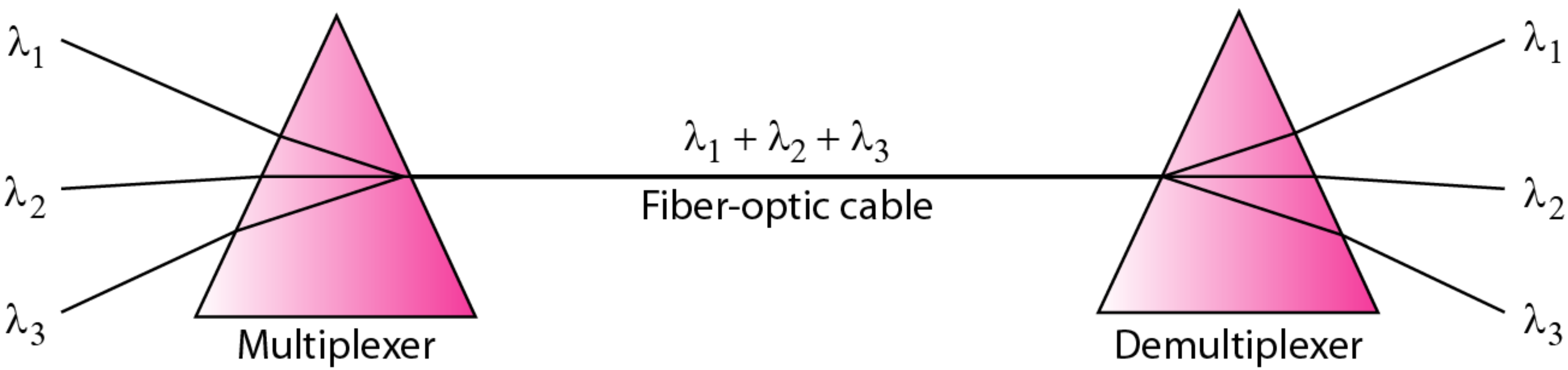
Wavelength-division multiplexing (WDM)



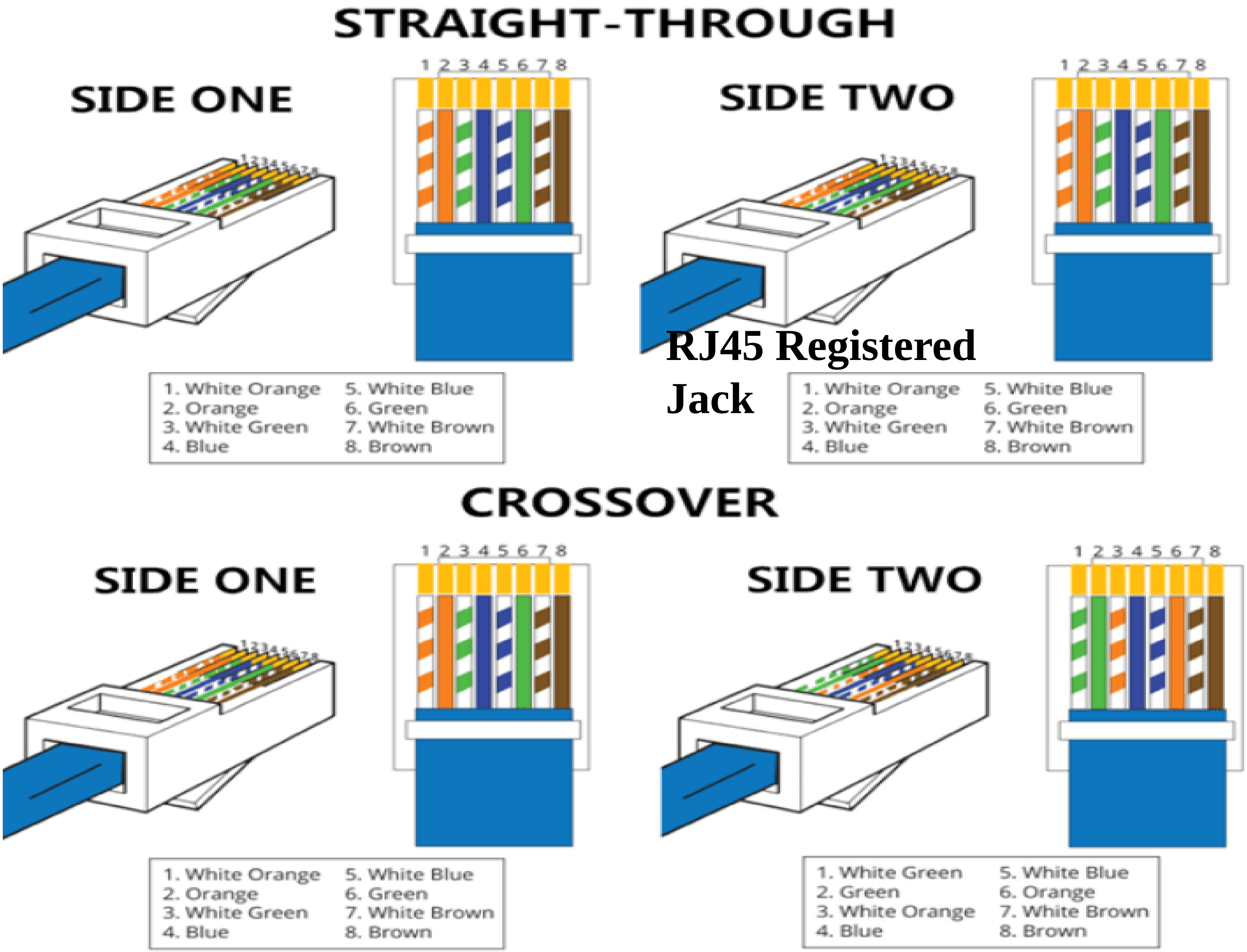
Note

WDM is an analog multiplexing technique to combine optical signals.

Prisms in wavelength-division multiplexing and demultiplexing



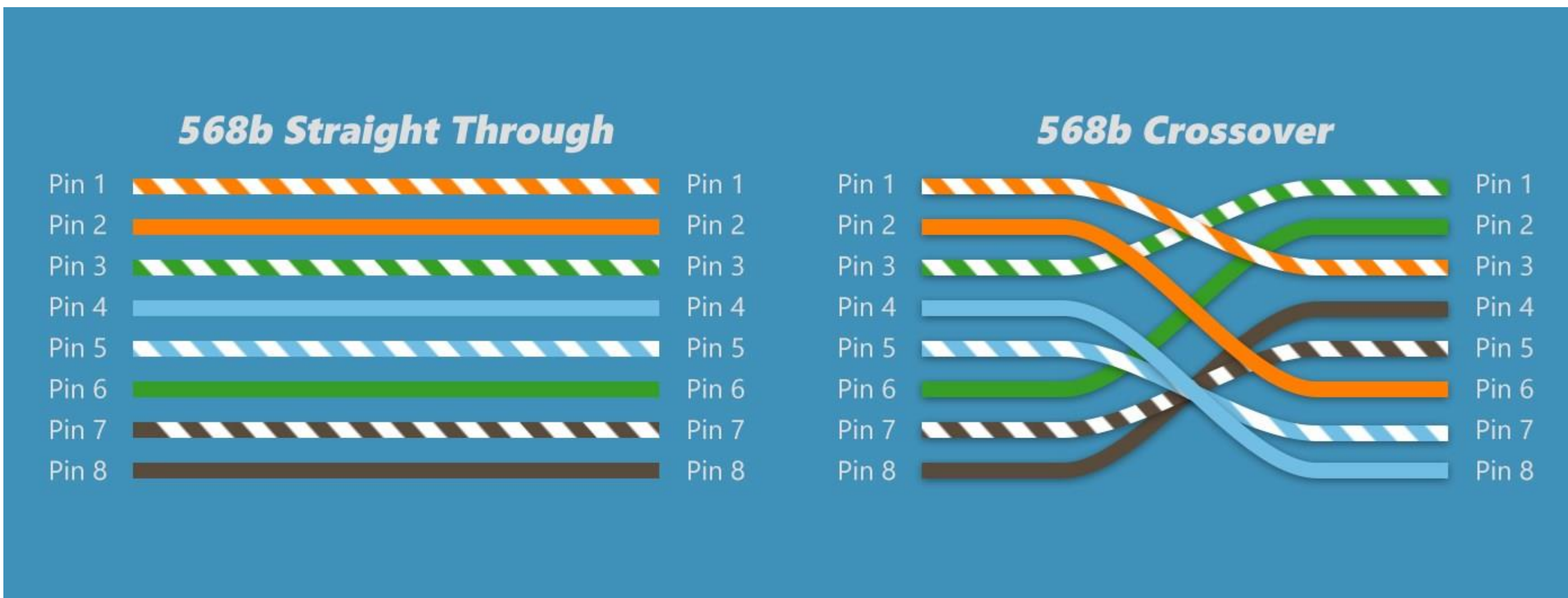
1
4



RJ45 Registered Jack

Uses of cable

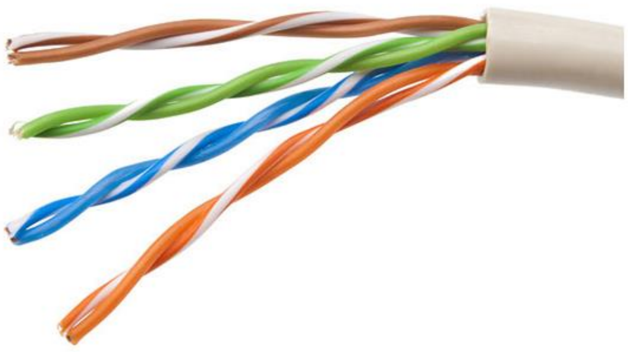
	HUB	SWITCH	ROUTER	PC
HUB	Crossover	Crossover	Straight	Straight
SWITCH	Crossover	Crossover	Straight	Straight
ROUTER	Straight	Straight	Crossover	Crossover
PC	Straight	Straight	Crossover	Crossover



Properties of UTP Cabling

UTP has four pairs of color-coded copper wires twisted together and encased in a flexible plastic sheath. No shielding is used. UTP relies on the following properties to limit crosstalk:

- Cancellation - Each wire in a pair of wires uses opposite polarity. One wire is negative, the other wire is positive. They are twisted together and the magnetic fields effectively cancel each other and outside EMI/RFI.
- Variation in twists per foot in each wire - Each wire is twisted a different amount, which helps prevent crosstalk amongst the wires in the cable.



POLL

Cables are twisted to overcome the problem of

a) Noise
b) Distortion
c) Attenuation
d) Cross-talk

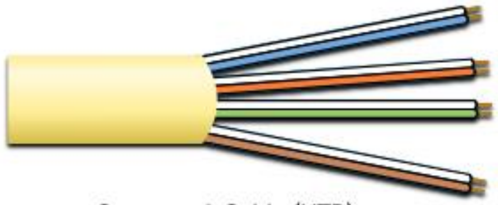
UTP Cabling Standards and Connectors

Standards for UTP are established by the TIA/EIA. TIA/EIA-568 standardizes elements like:

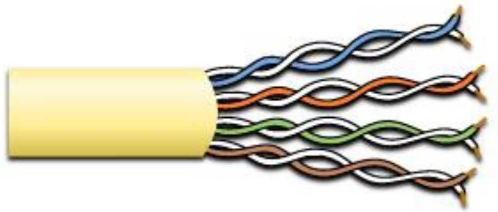
- Cable Types
- Cable Lengths
- Connectors
- Cable Termination
- Testing Methods

Electrical standards for copper cabling are established by the IEEE, which rates cable according to its performance. Examples include:

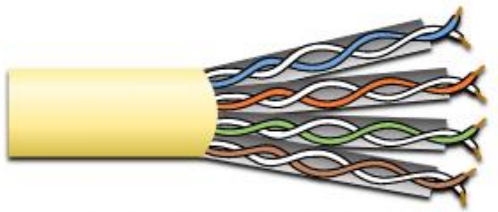
- Category 3
- Category 5 and 5e



Category 3 Cable (UTP)



Category 5 and 5e Cable (UTP)

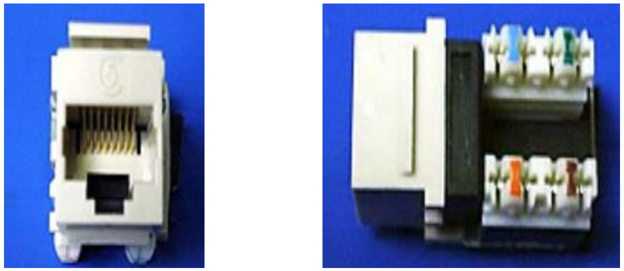


Category 6 Cable (UTP)

UTP Cabling Standards and Connectors (Cont.)

RJ-45 Connector

Poorly terminated UTP cable

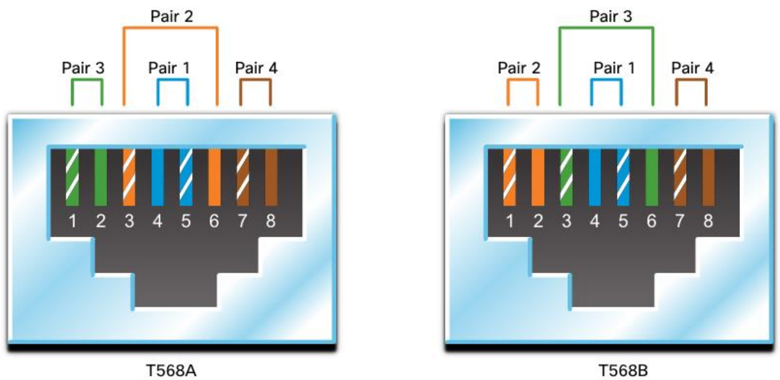


RJ-45 Socket

Properly terminated UTP cable

UTP Cabling

Straight-through and Crossover UTP Cables



Cable Type	Standard	Application
Ethernet Straight-through	Both ends T568A or T568B	Host to Network Device
Ethernet Crossover *	One end T568A, other end T568B	Host-to-Host, Switch-to-Switch, Router-to-Router
* Considered Legacy due to most NICs using Auto-MDIX to sense cable type and complete connection		
Rollover	Cisco Proprietary	Host serial port to Router or Switch Console Port, using an adapter

POLL

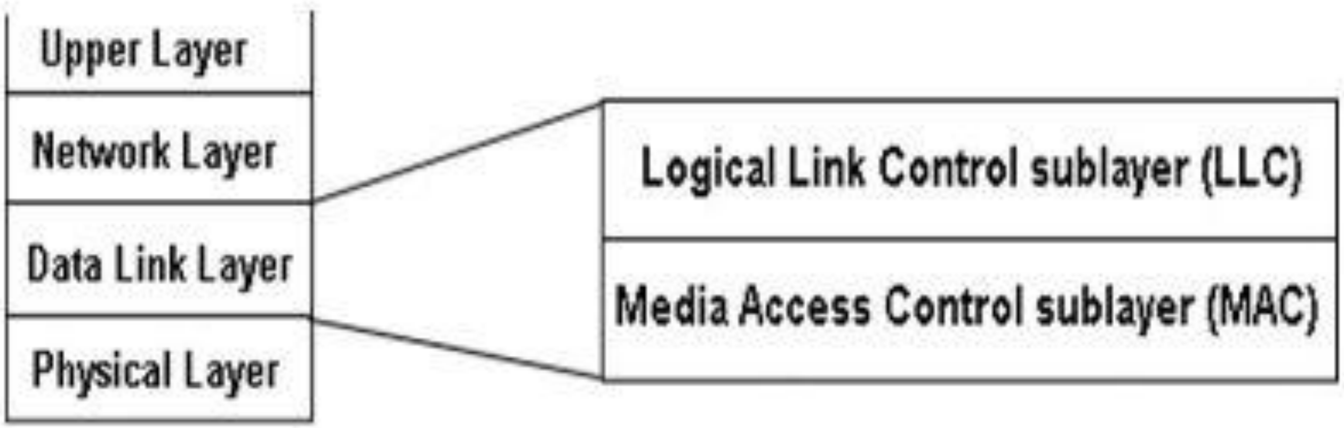
Router-Router can be connected using

a) Crossover cable
b) Straight through Cable
c) Any of the above
d) None of the above

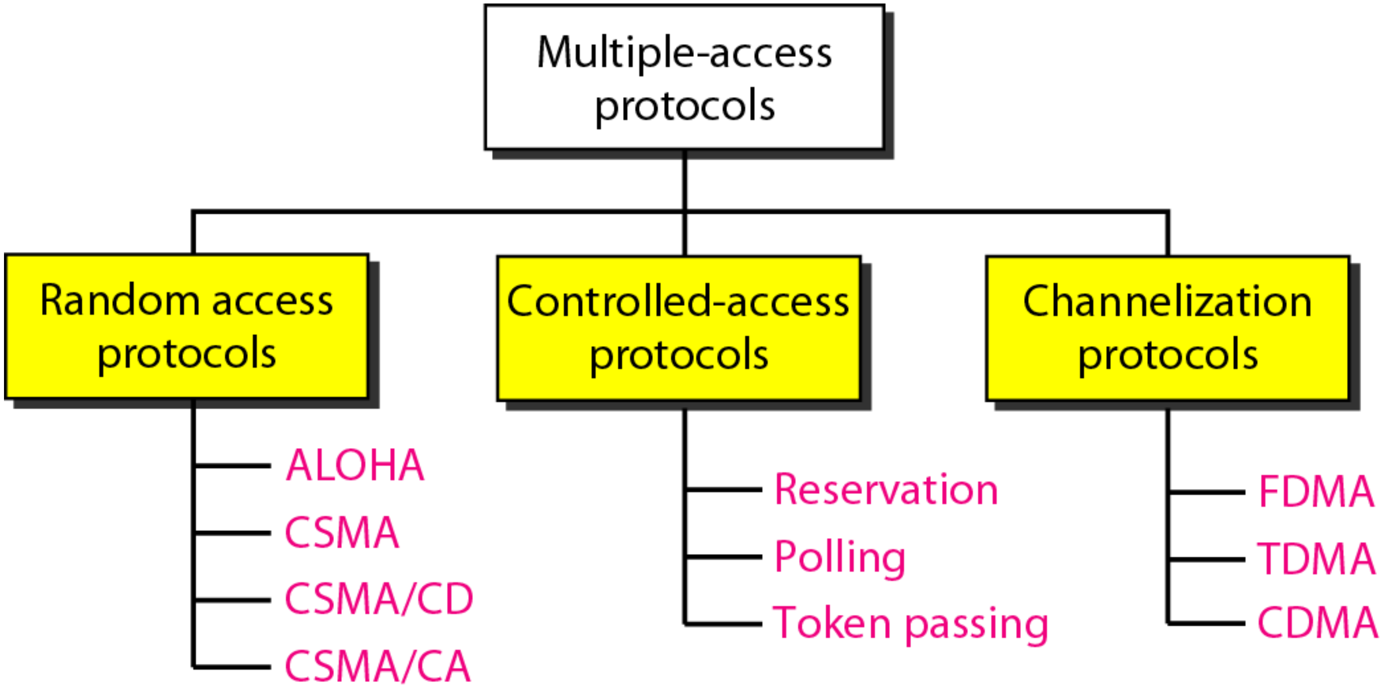
Multiple Access

Data Link Layer –Sub Layers

- DLL is divided into two Sub-Layers
  - **LLC Sub Layer**
  - **MAC Sub Layer**



Taxonomy of multiple-access protocols



POLL 1

- Which of the following is not a Random Access Method’

a) CSMA/CD

b) FDMA

c) CSMA/CA

d) Aloha

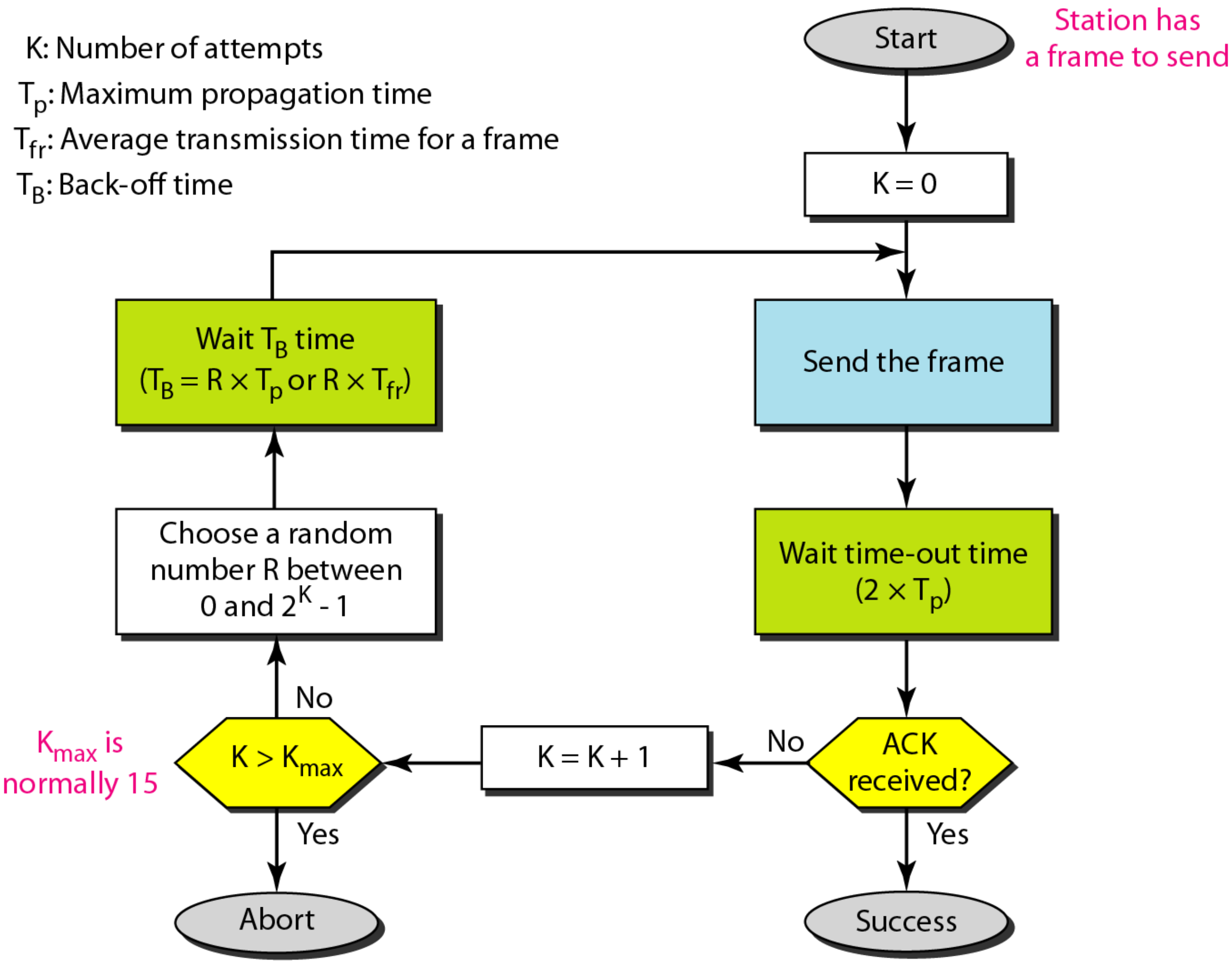
RANDOM ACCESS

In random access or contention methods, no station is superior to another station and none is assigned the control over another. No station permits, or does not permit, another station to send. At each instance, a station that has data to send uses a procedure defined by the protocol to make a decision on whether or not to send.

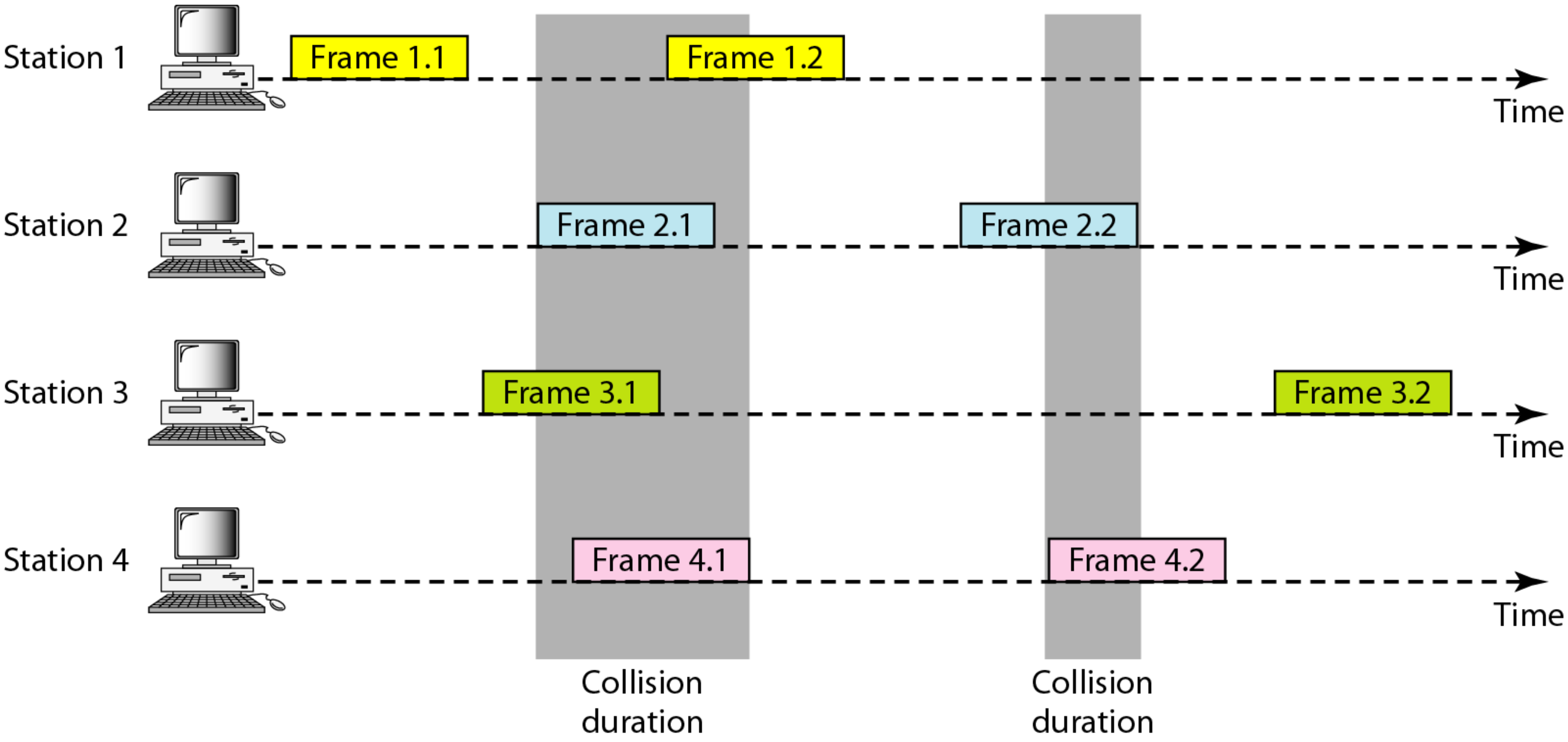
Topics discussed in this section:

ALOHA
Carrier Sense Multiple Access
Carrier Sense Multiple Access with Collision Detection
Carrier Sense Multiple Access with Collision Avoidance

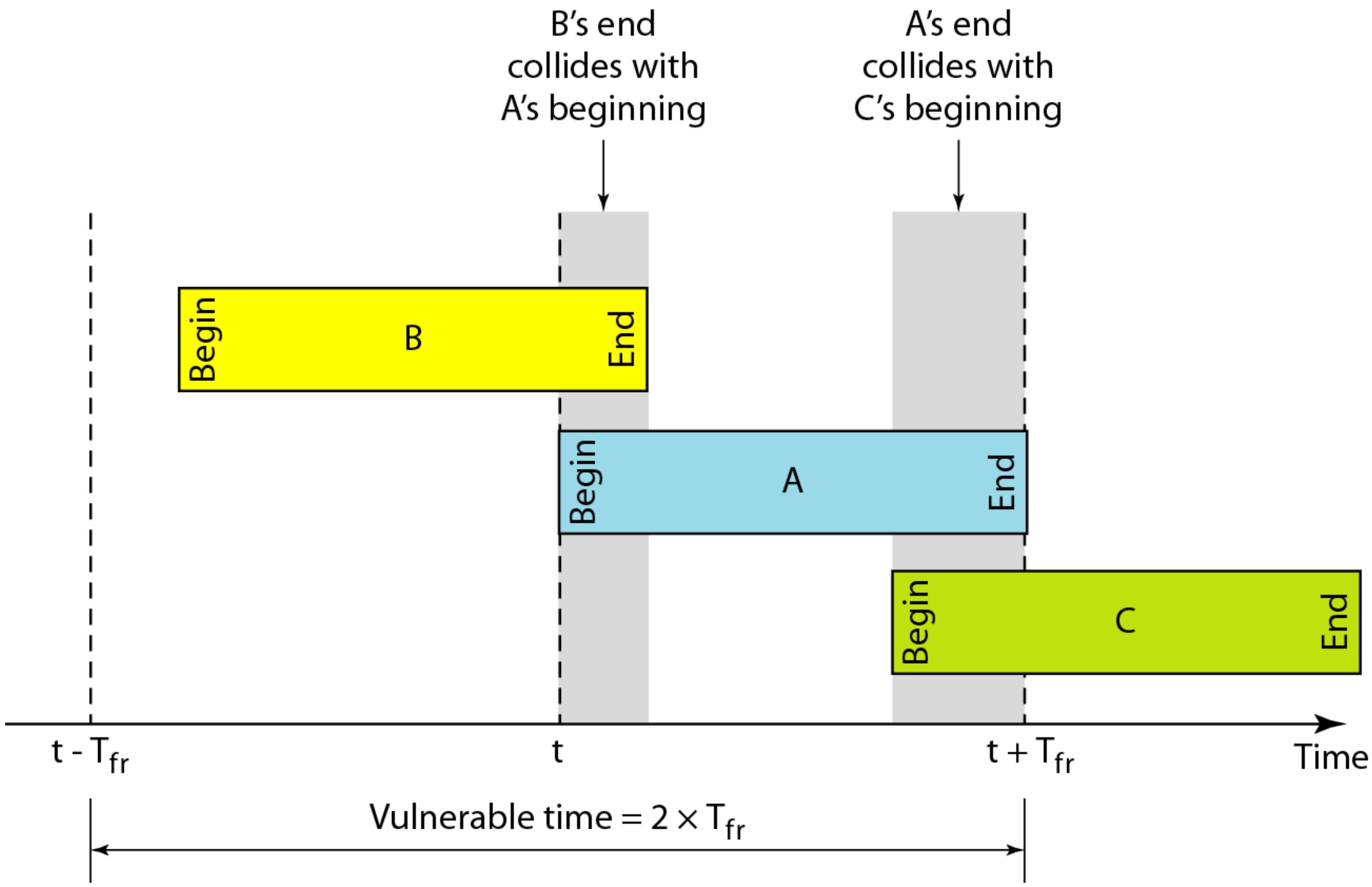
Procedure for pure ALOHA protocol



Frames in a pure ALOHA network



Vulnerable time for pure ALOHA protocol



Note

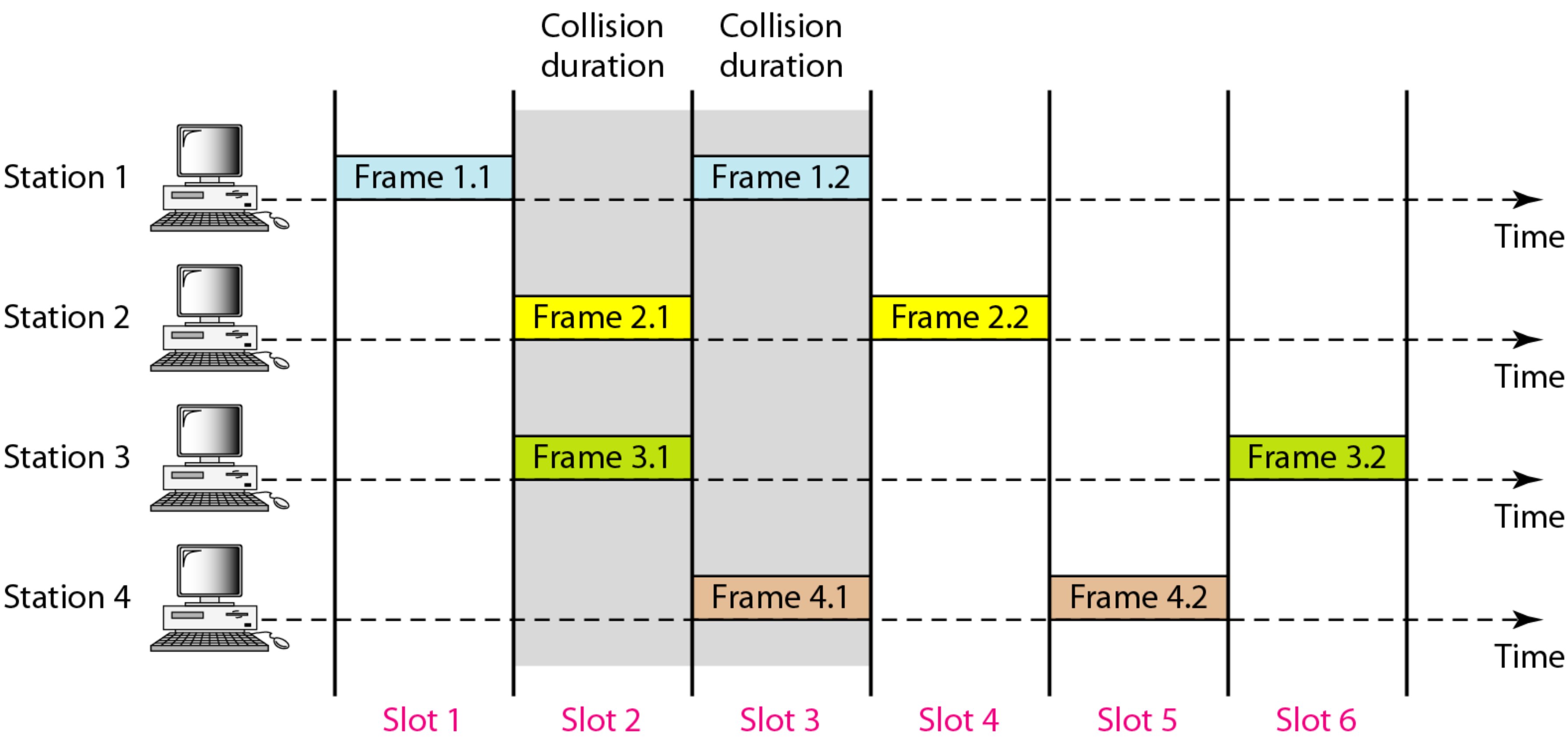
The throughput for pure ALOHA is

$$S = G \times e^{-2G}.$$

The maximum throughput

S_{max} = 0.184 when G= (1/2).

Frames in a slotted ALOHA network



Note

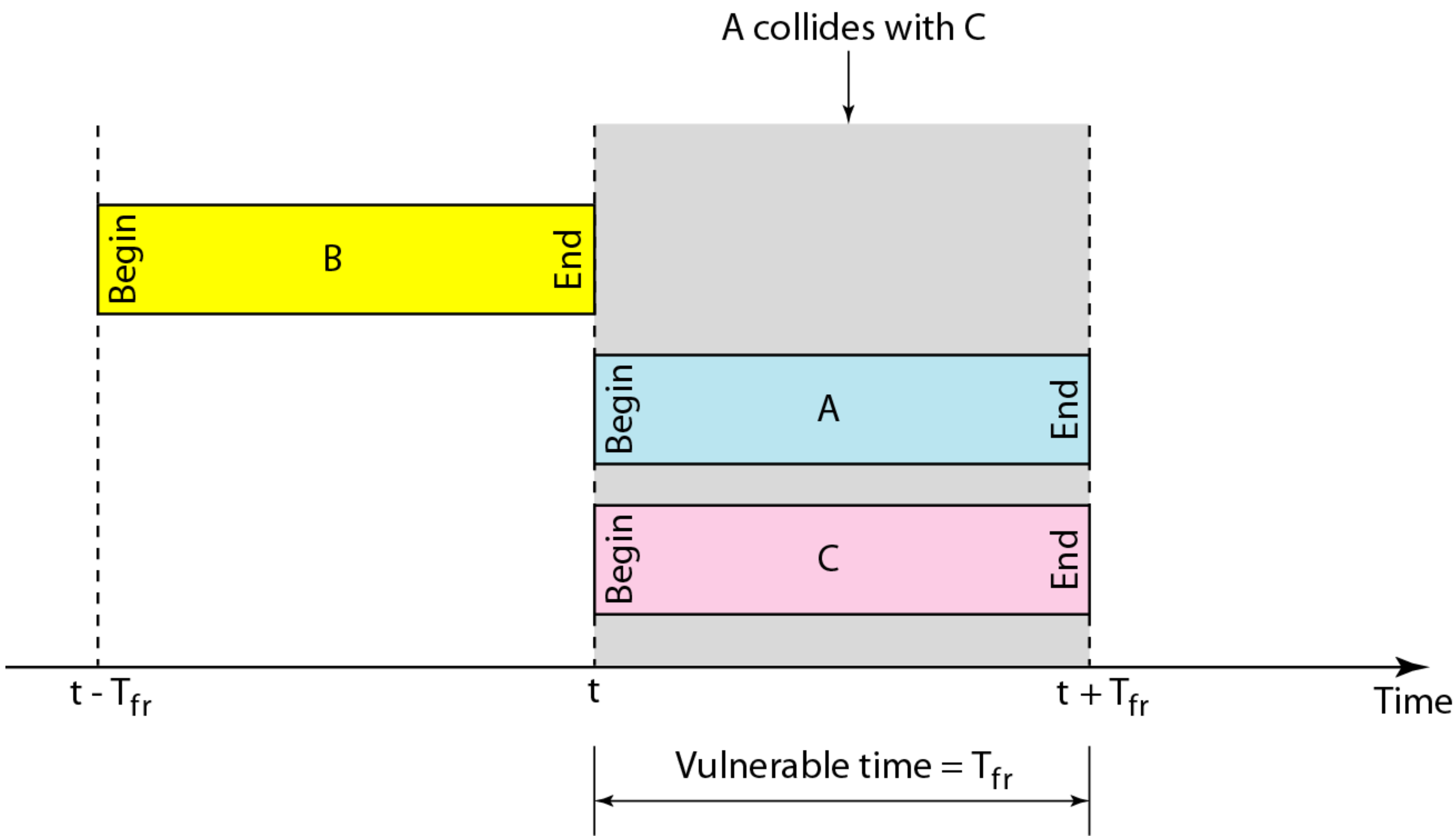
The throughput for slotted ALOHA is

$$S = G \times e^{-G} .$$

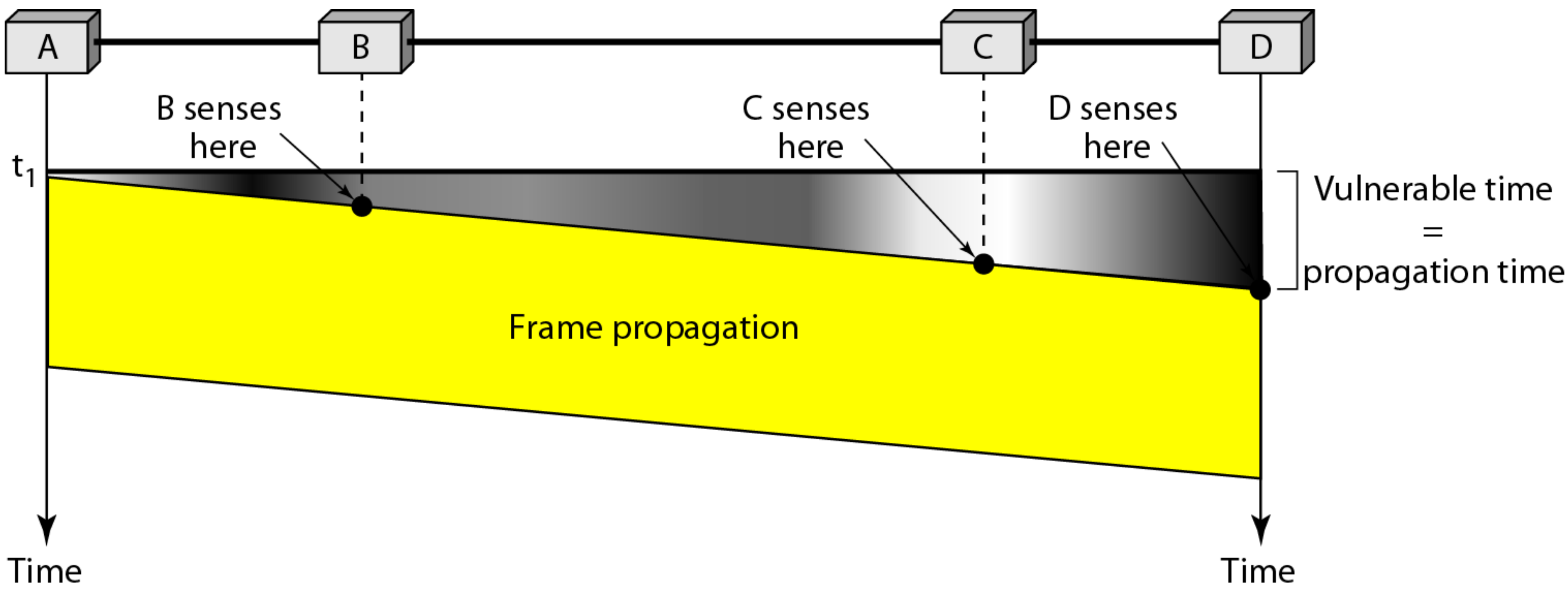
The maximum throughput

S_{max} = 0.368 when G = 1.

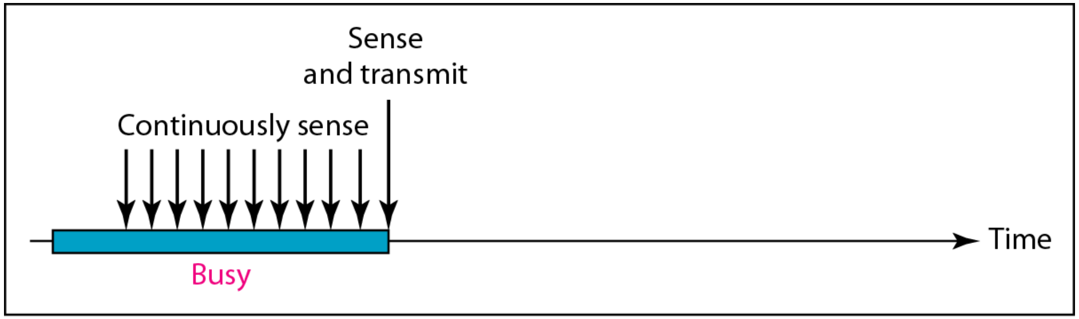
Vulnerable time for slotted ALOHA protocol



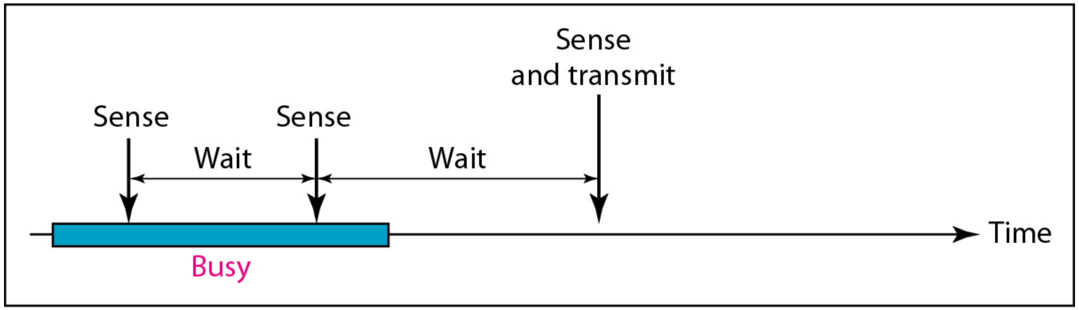
Vulnerable time in CSMA



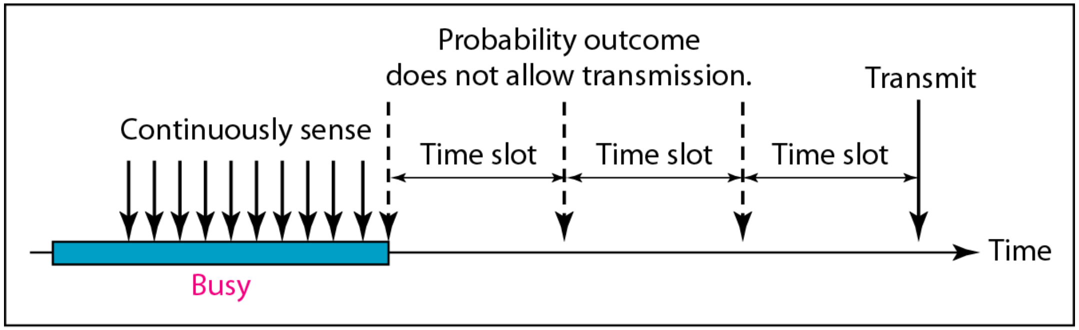
Behavior of three persistence methods



a. 1-persistent

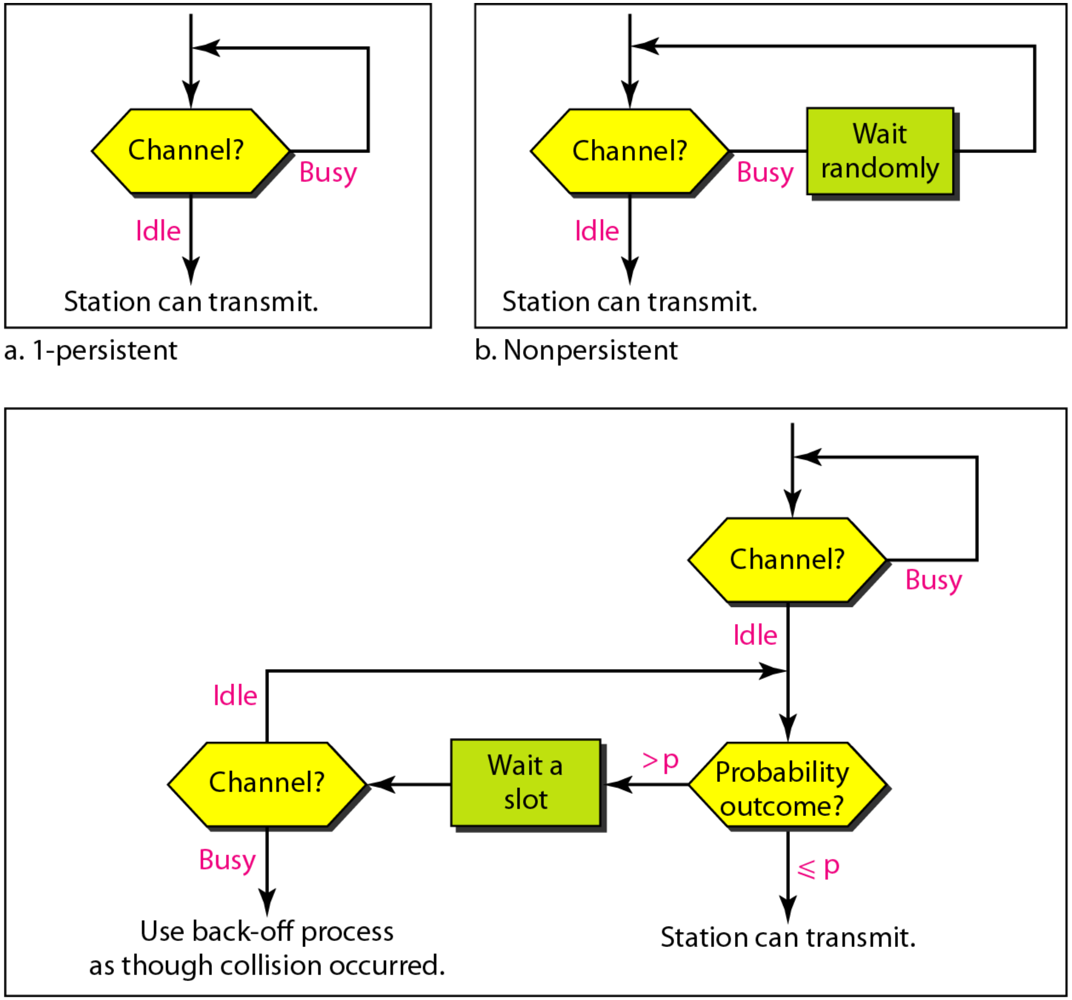


b. Nonpersistent



c. p-persistent

Flow diagram for three persistence methods

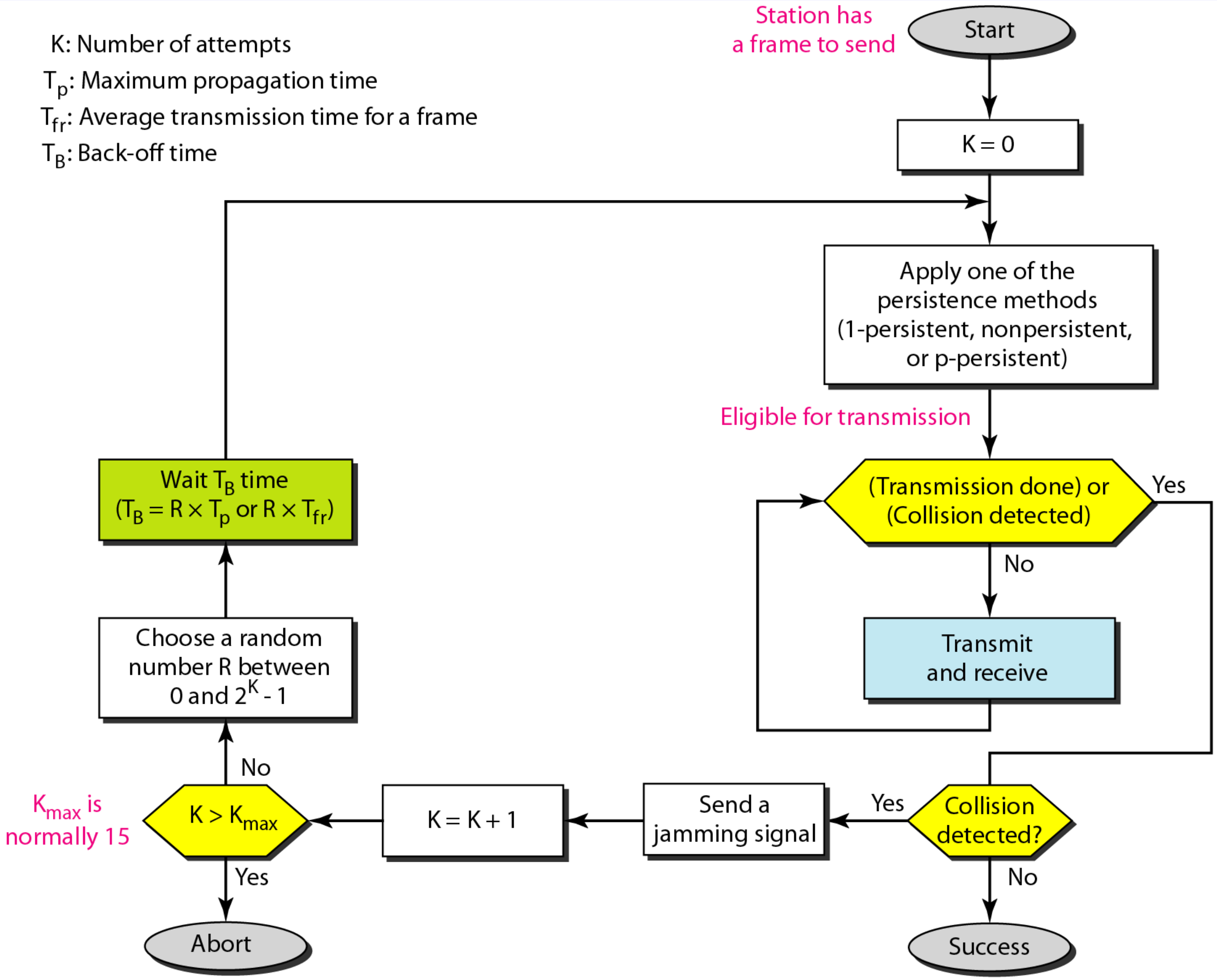


a. 1-persistent

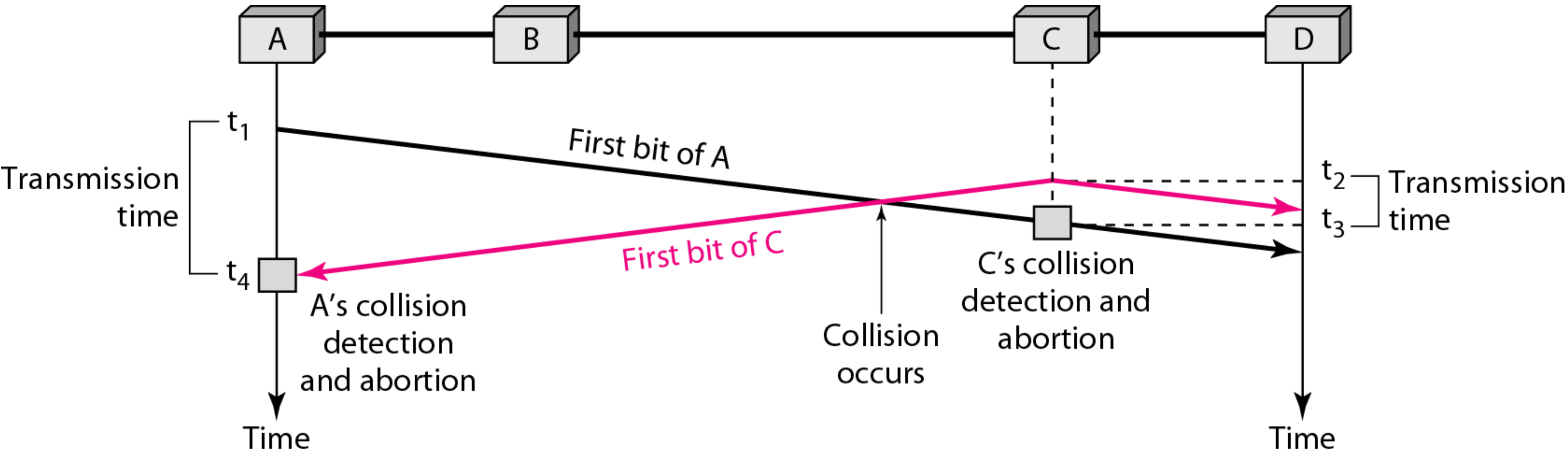
b. Nonpersistent

c. p-persistent

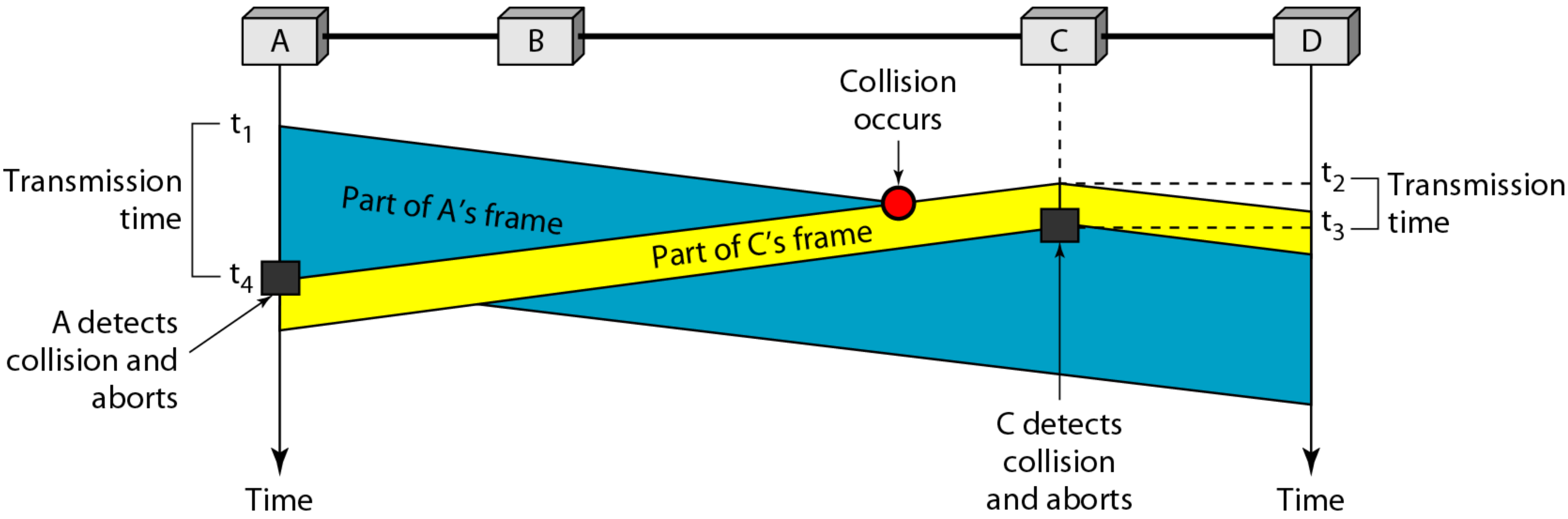
Flow diagram for the CSMA/CD



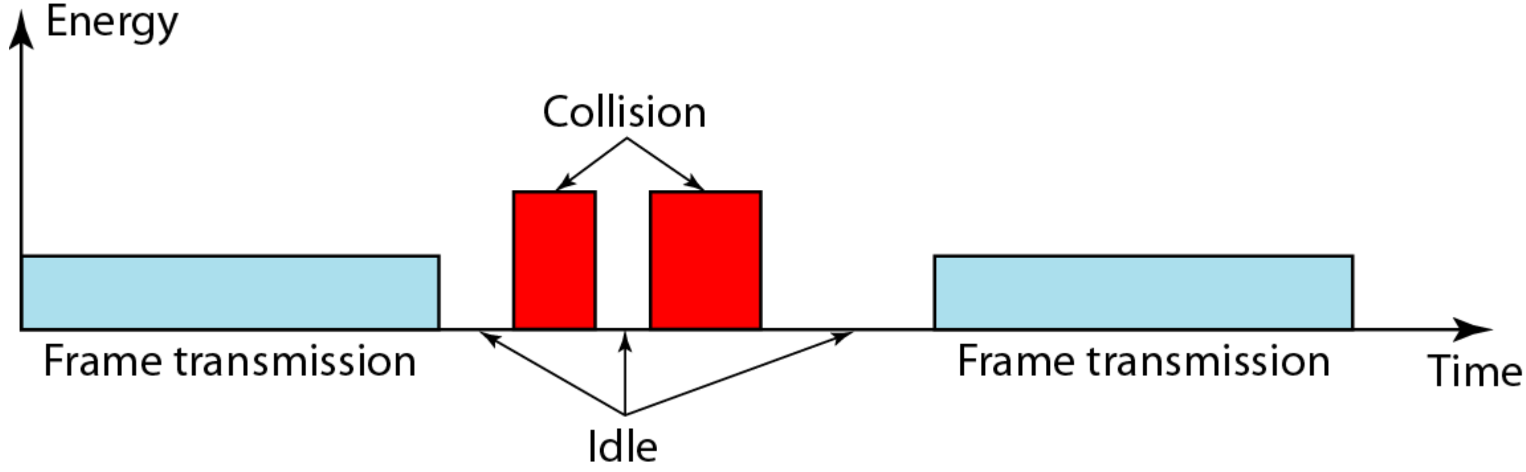
Collision of the first bit in CSMA/CD



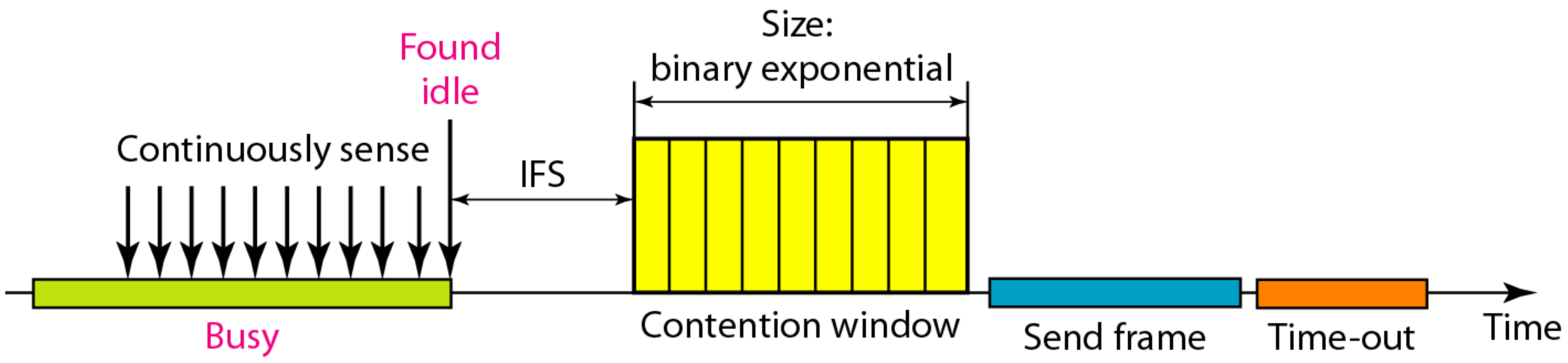
Collision and abortion in CSMA/CD



Energy level during transmission, idleness, or collision



Timing in CSMA/CA



InterFrame Space (IFS)

Note

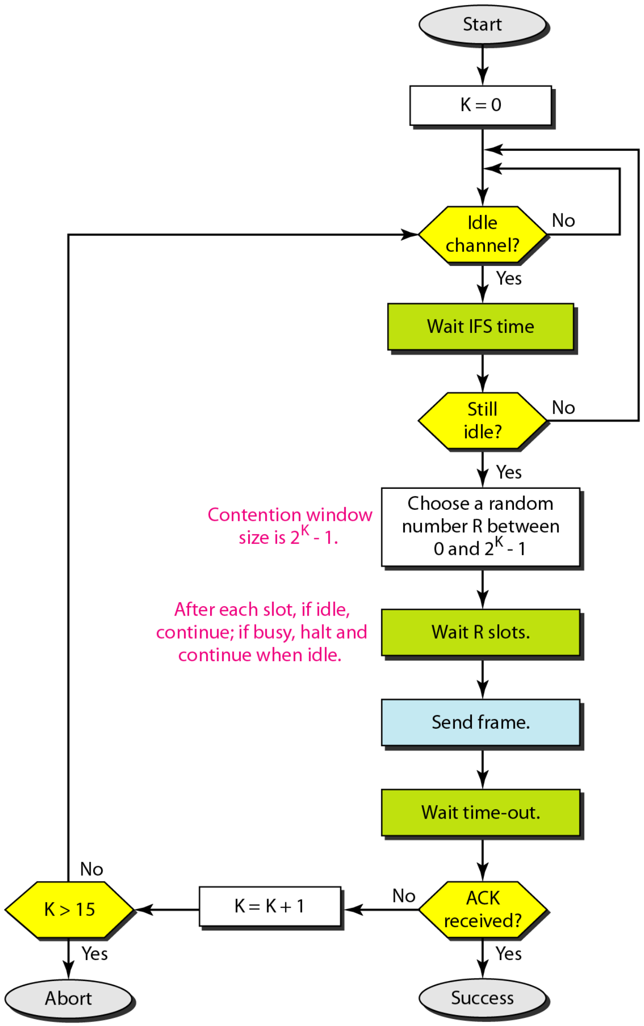
In CSMA/CA, the IFS can also be used to define the priority of a station or a frame.

InterFrame Space (IFS)

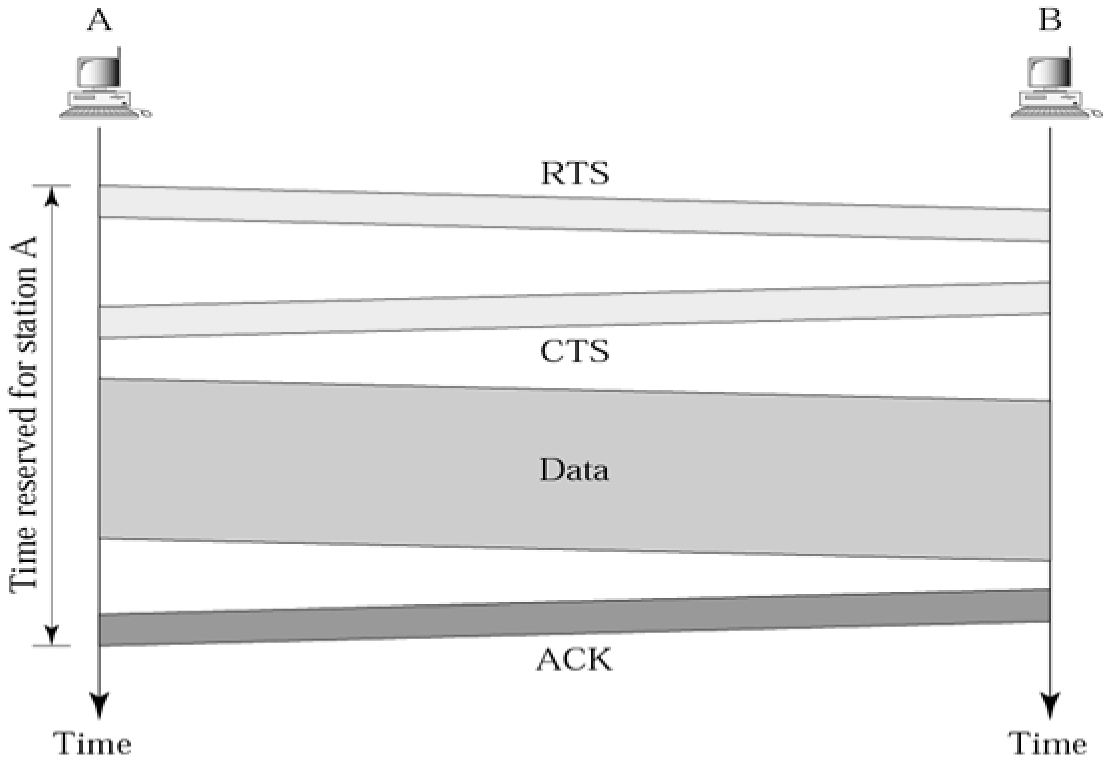
Note

In CSMA/CA, if the station finds the channel busy, it does not restart the timer of the contention window;
it stops the timer and restarts it when the channel becomes idle.

Flow diagram for CSMA/CA



Flow diagram for CSMA/CA



RTS = Request to Send

CTS = Clear to Send

ACK = Acknowledgement

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.

Topics discussed in this section:

Reservation
Polling
Token Passing

POLL 2

- Example of Controlled access is

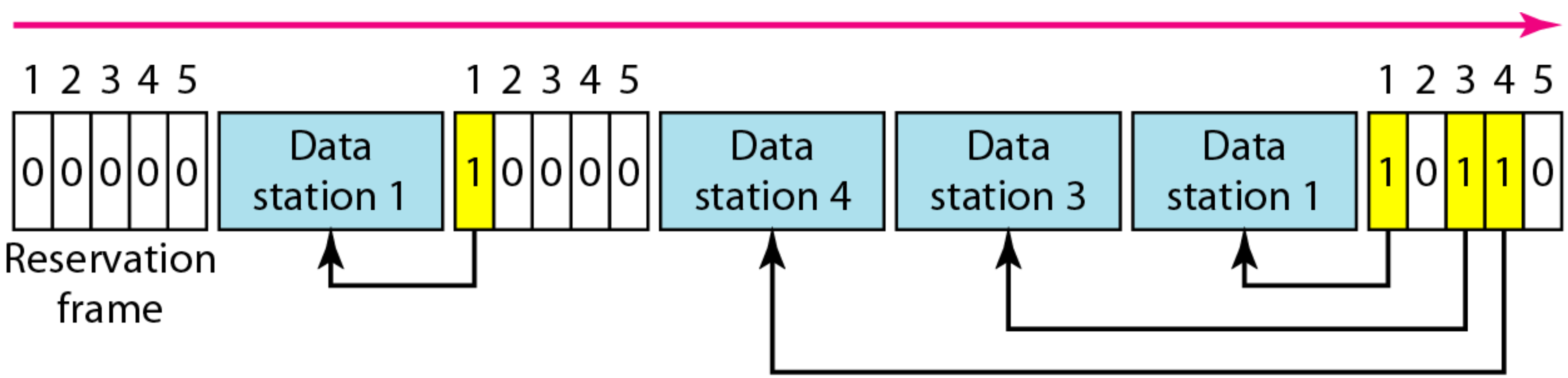
a) Reservation

b) Polling

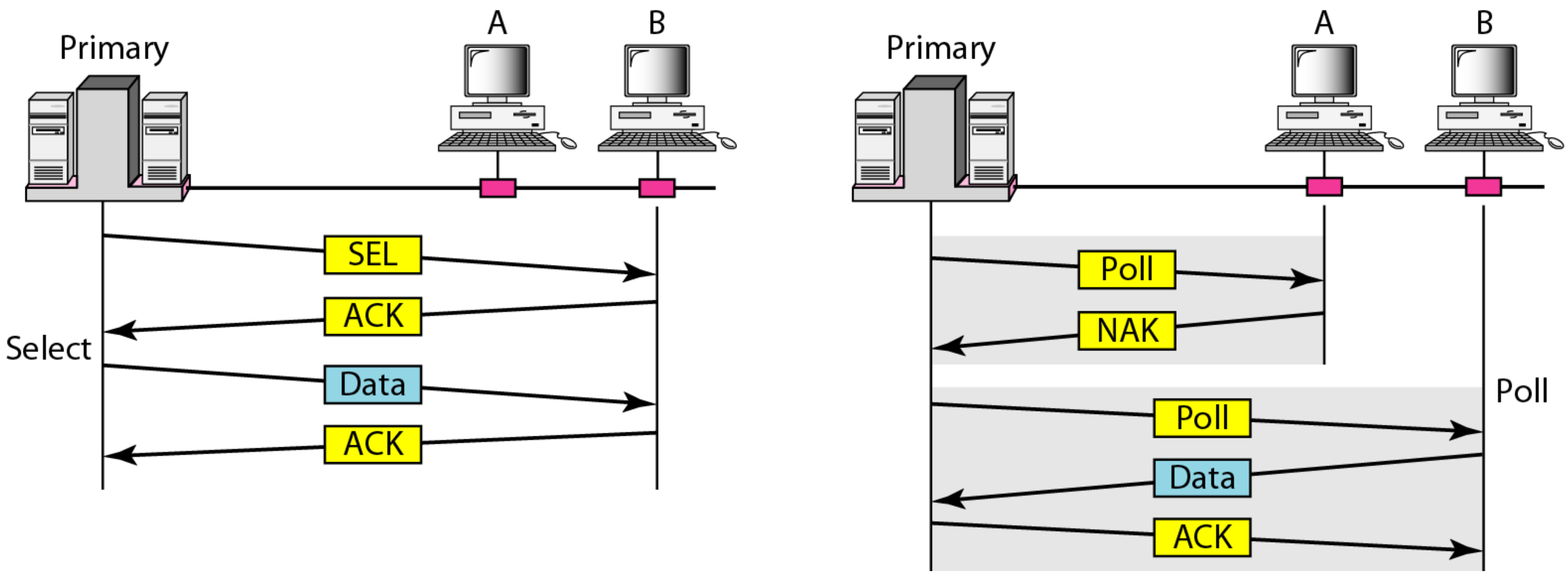
c) Token Passing

d) All of above

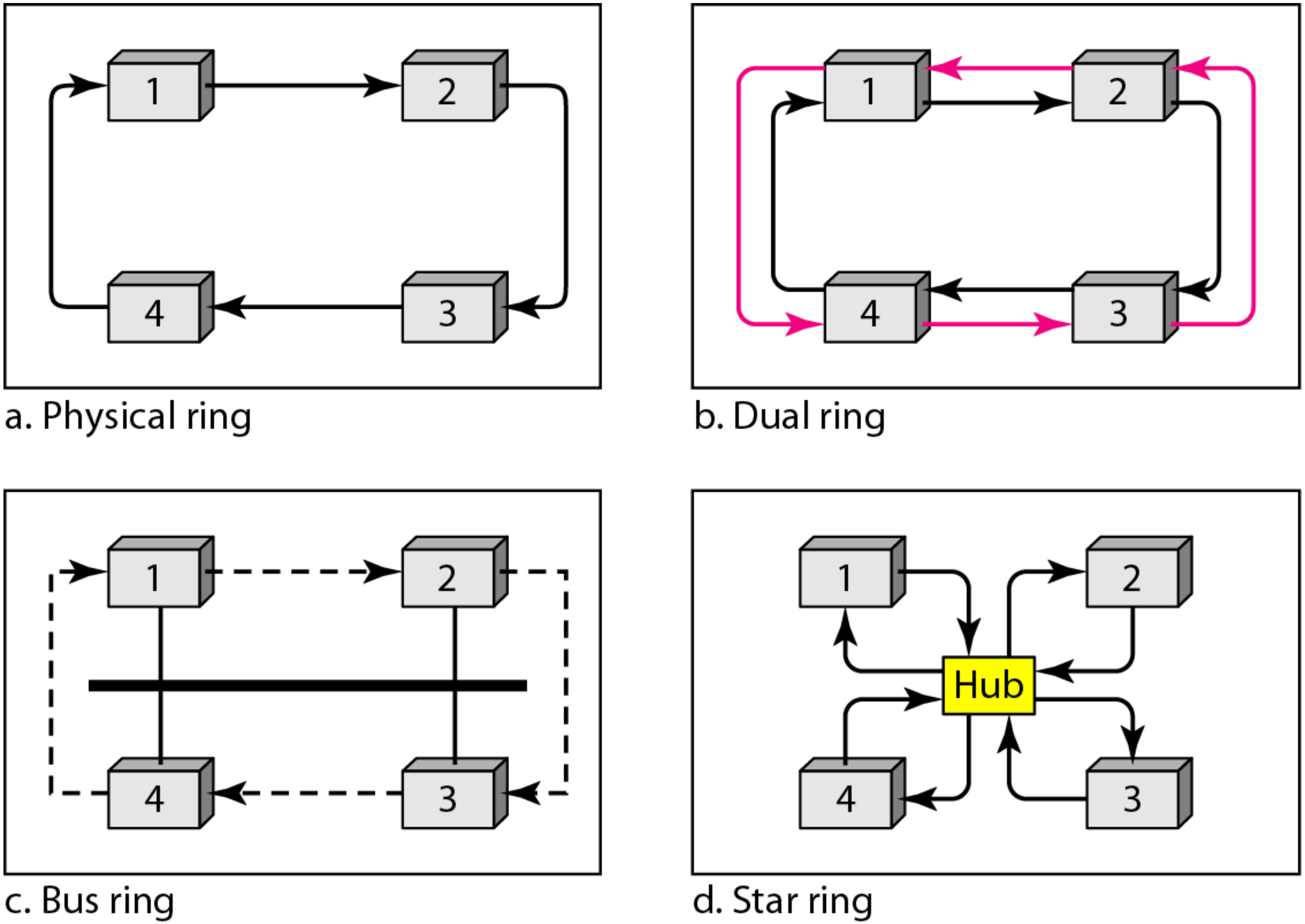
Reservation access method



Select and poll functions in polling access method



Logical ring and physical topology in token-passing access method

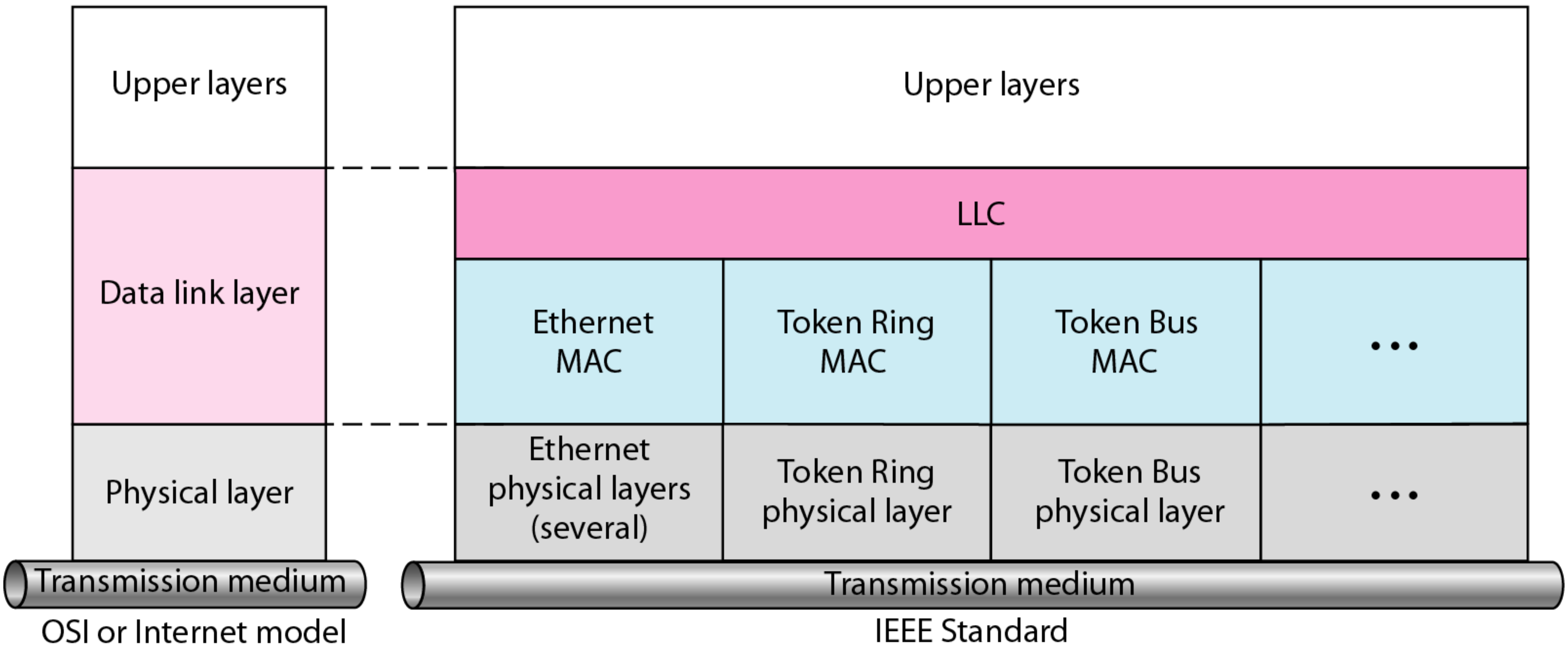


CSE 306

Presented by: Dr. Amandeep Singh

IEEE standard for LANs

LLC: Logical link control
MAC: Media access control



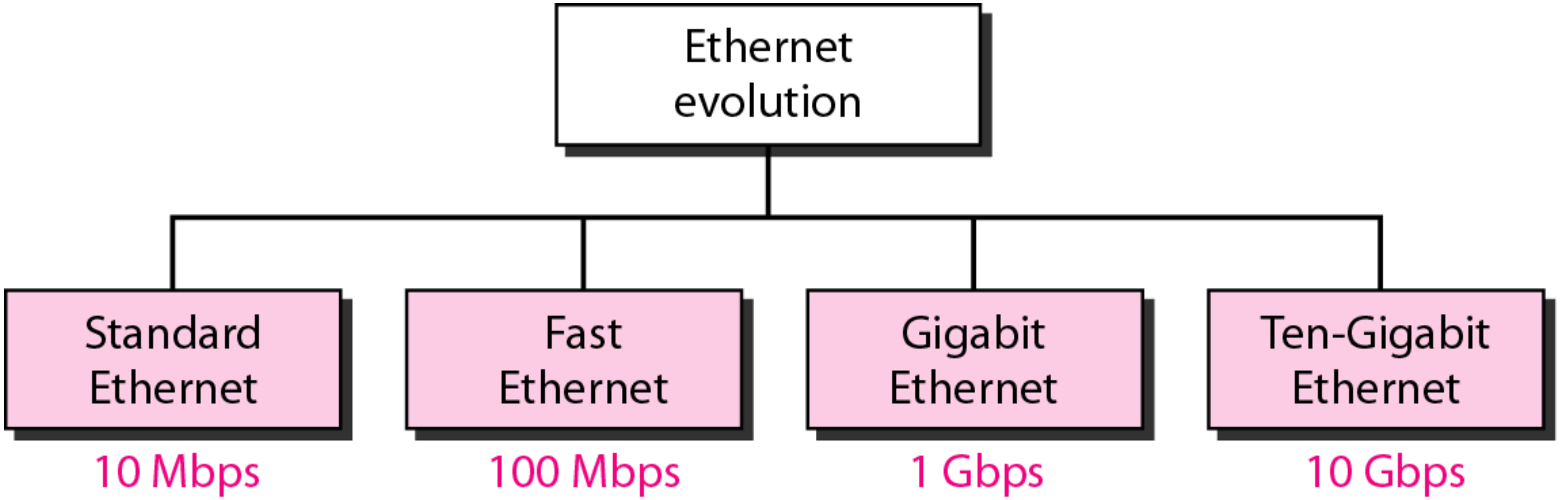
STANDARD ETHERNET

The original Ethernet was created in 1976 at Xerox's Palo Alto Research Center (PARC). Since then, it has gone through four generations. We briefly discuss the Standard (or traditional) Ethernet in this section.

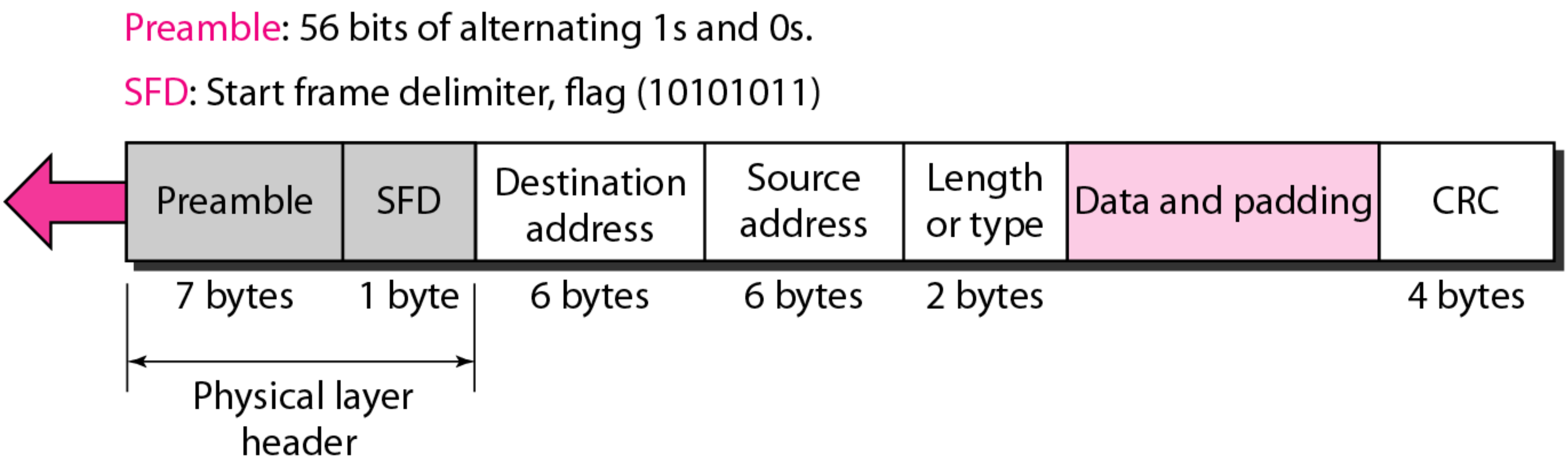
Topics discussed in this section:

MAC Sublayer
Physical Layer

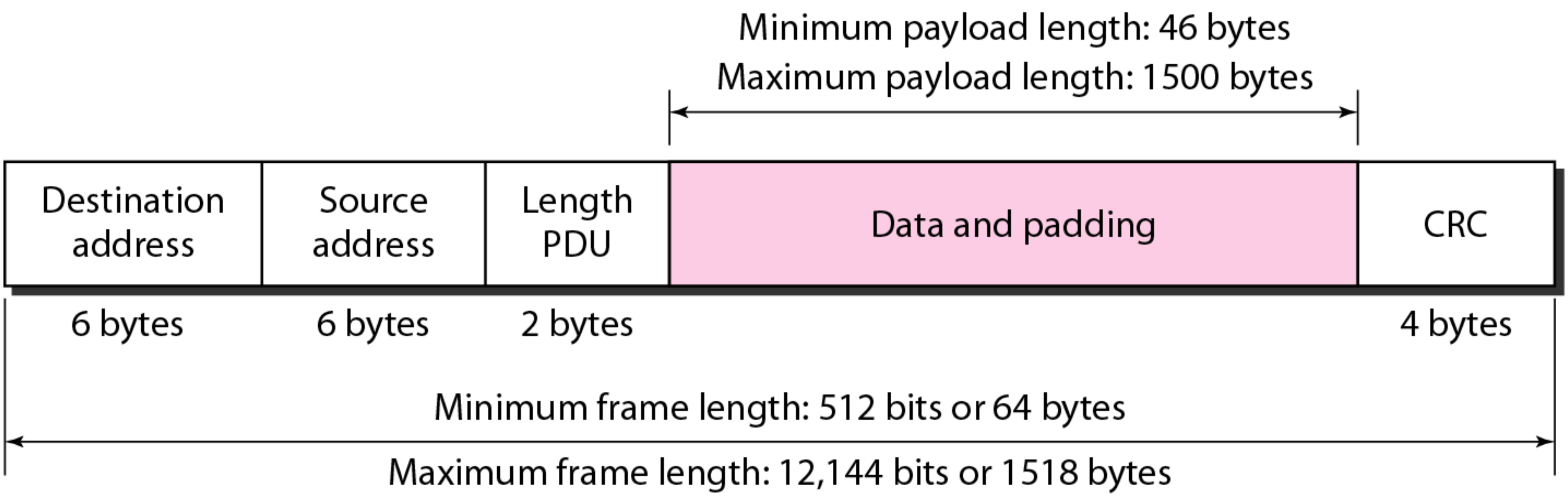
Ethernet evolution through four generations



802.3 MAC frame



Minimum and maximum lengths



Note

Frame length:

Minimum: 64 bytes (512 bits)

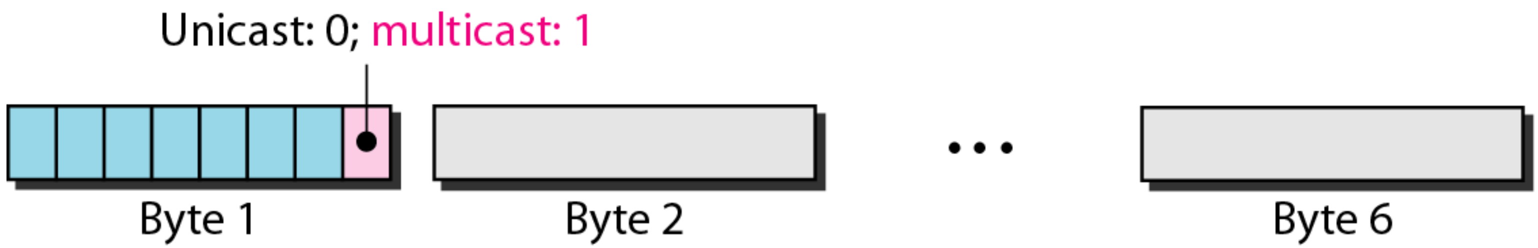
Maximum: 1518 bytes (12,144 bits)

Example of an Ethernet address in hexadecimal notation

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

6 bytes = 12 hex digits = 48 bits

Unicast and multicast addresses



Note

**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.**

Note

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

POLL 1

- In a MAC address, the address is broadcast if in the first byte

a) LSB is 1

b) MSB is 1

c) LSB is 0

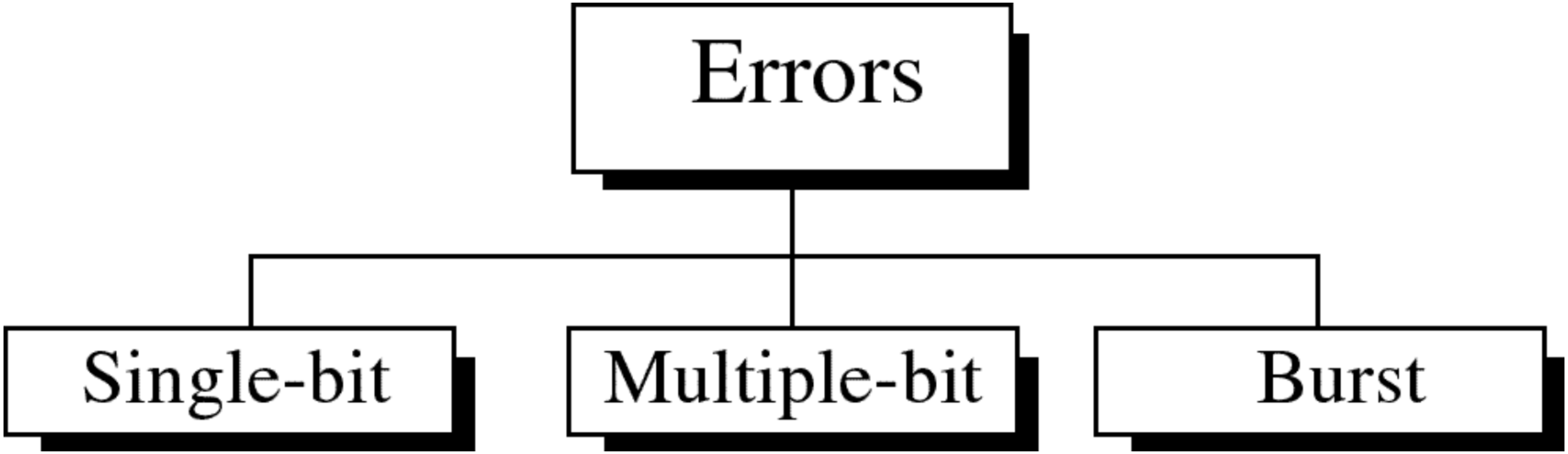
d) All bits are 1s

ERROR CONTROL

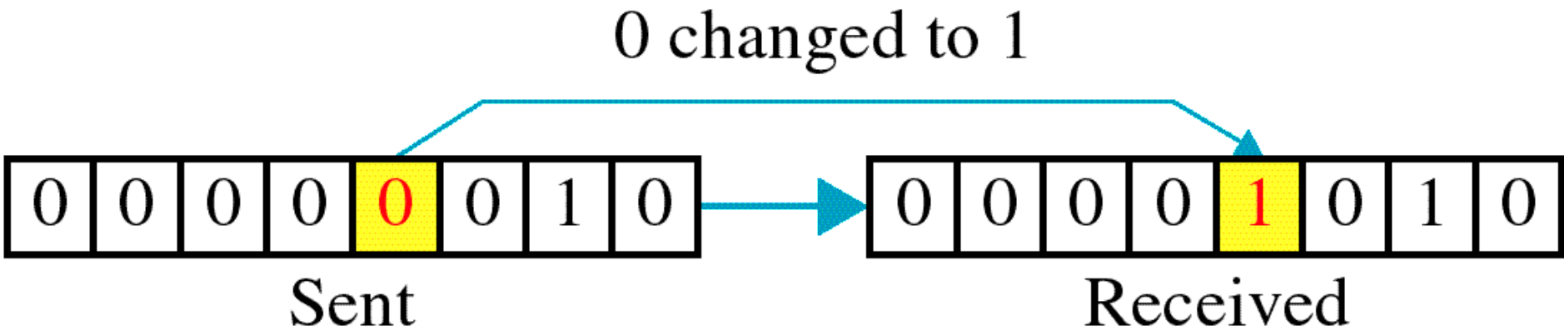
Basic concepts

- ★ Networks must be able to transfer data from one device to another with complete accuracy.
- ★ Data can be corrupted during transmission.
- ★ For reliable communication, errors must be detected and corrected.
- ★ **Error detection and correction** are implemented either at the **data link layer** or the **transport layer** of the OSI model.

Types of Errors

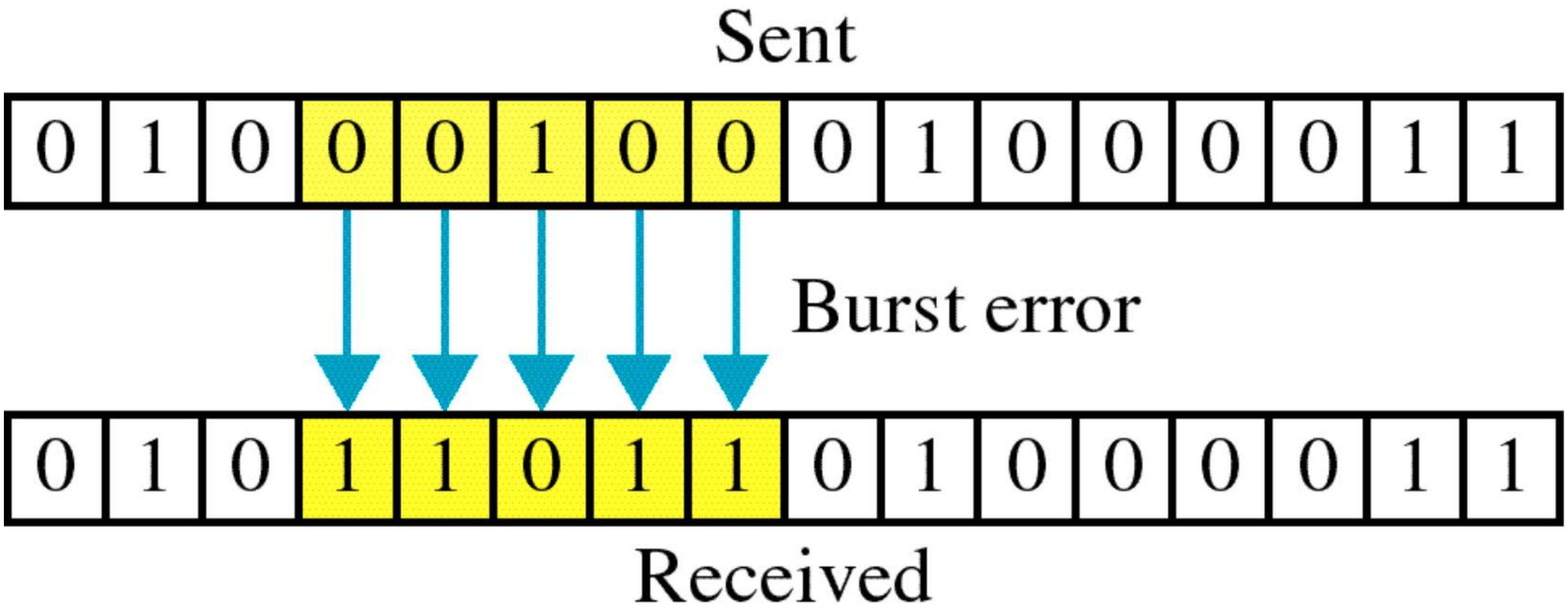


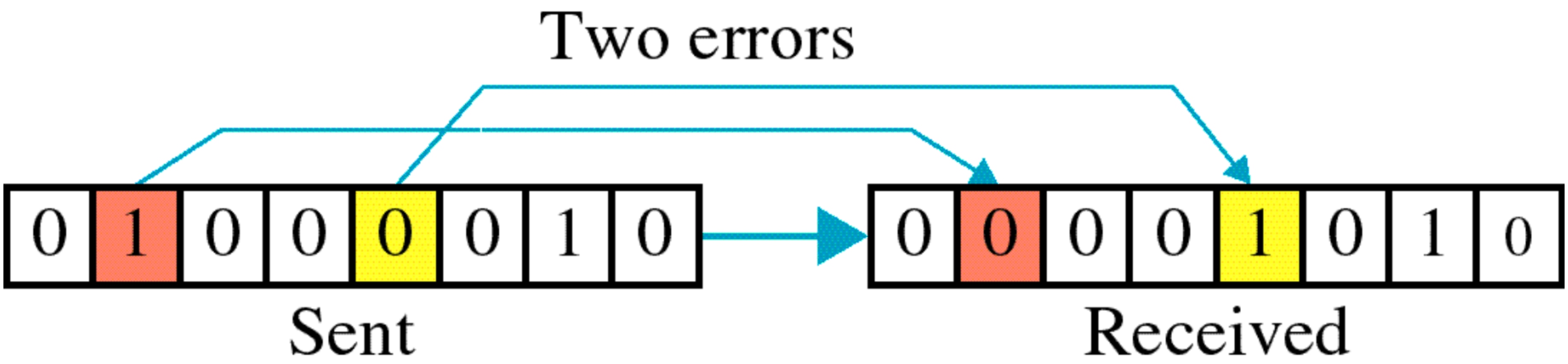
Single-bit error



Single bit errors are the **least likely** type of errors in serial data transmission because the noise must have a very short duration which is very rare. However this kind of errors can happen in parallel transmission.

Burst error


Sent
0 1 0 0 0 1 0 0 0 1 0 0 0 0 1 1
Burst error
0 1 0 1 1 0 1 1 0 1 0 0 0 0 1 1
Received


Two errors
0 1 0 0 0 0 1 0
Sent
0 0 0 0 1 0 1 0
Received

The term **burst error** means that two or more bits in the data unit have changed from 1 to 0 or from 0 to 1.

Burst errors does not necessarily **mean that the errors occur in consecutive bits**, the length of the burst is measured from the first corrupted bit to the last corrupted bit. Some bits in between may not have been corrupted.

- **Burst error is most likely to happen in serial transmission** since the duration of noise is normally longer than the duration of a bit.
- The number of bits affected depends on the data rate and duration of noise.

POLL 2

- Which is not an example of Error

a) Single bit

b) Double bit

c) Burst

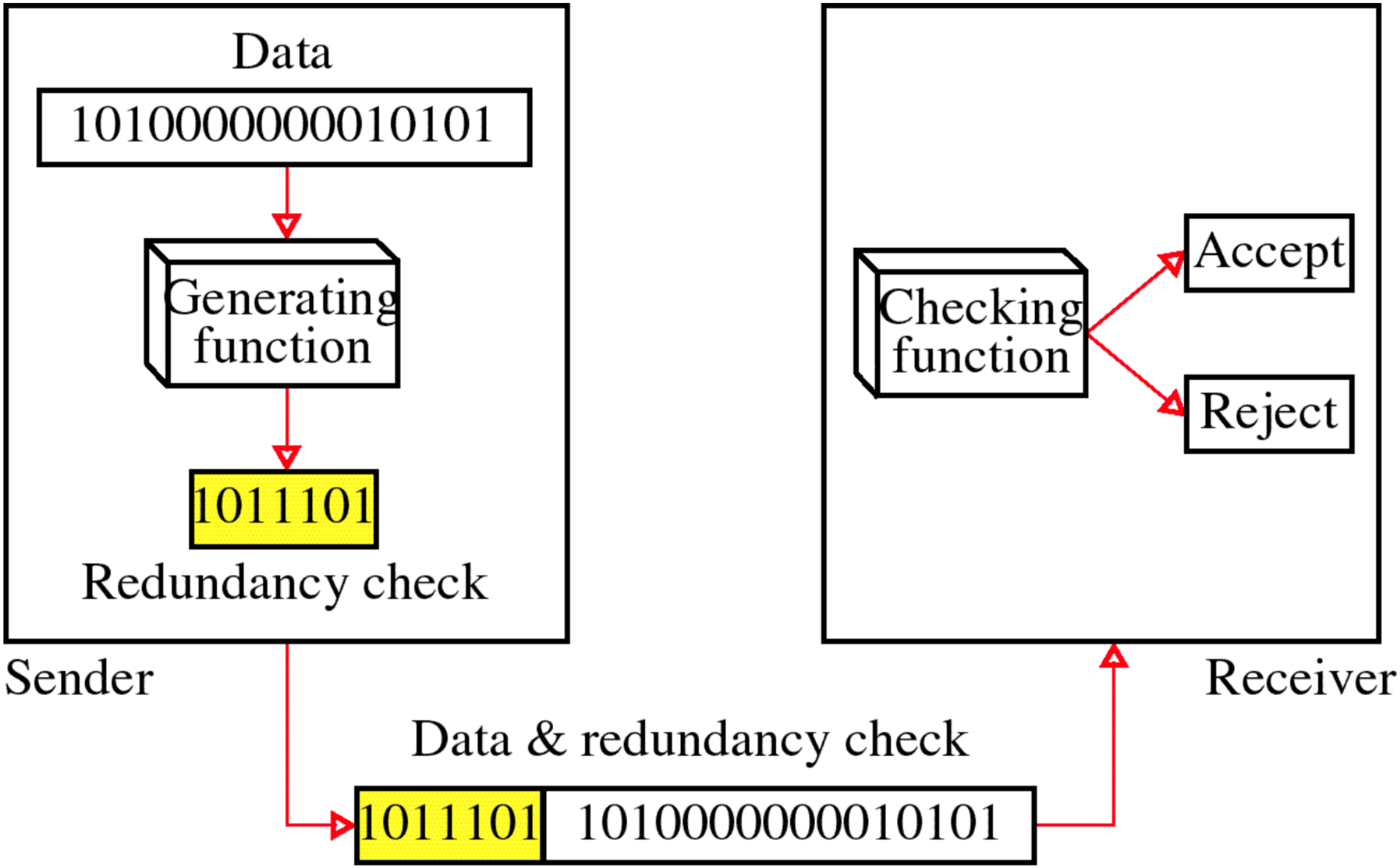
d) rust

Error detection

Error detection means to decide whether the received data is correct or not without having a copy of the original message.

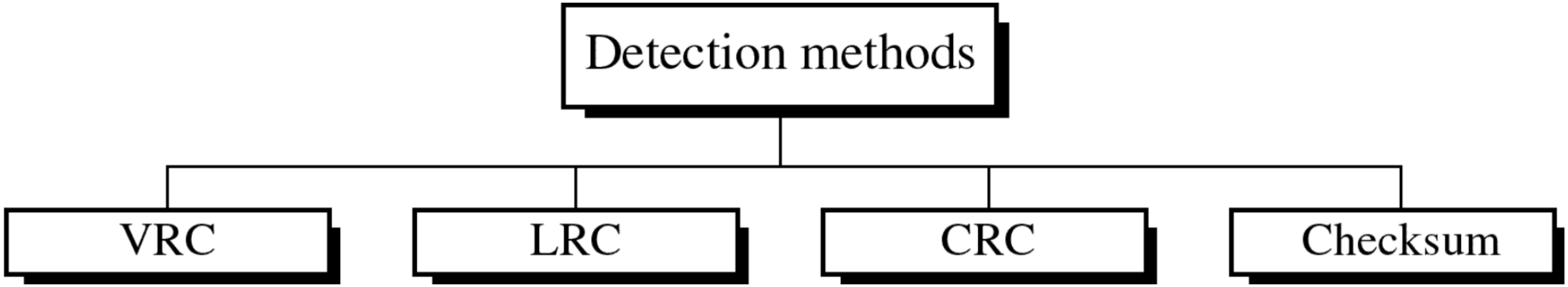
Error detection **uses the concept of redundancy**, **which means** adding extra bits for detecting errors at the destination.

Redundancy



Data
1010000000010101
Generating function
1011101
Redundancy check
Sender
Checking function
Accept
Reject
Receiver
Data & redundancy check
1011101
1010000000010101

Four types of redundancy checks are used in data communications



POLL 3

- Which of the following is not an example of redundancy check

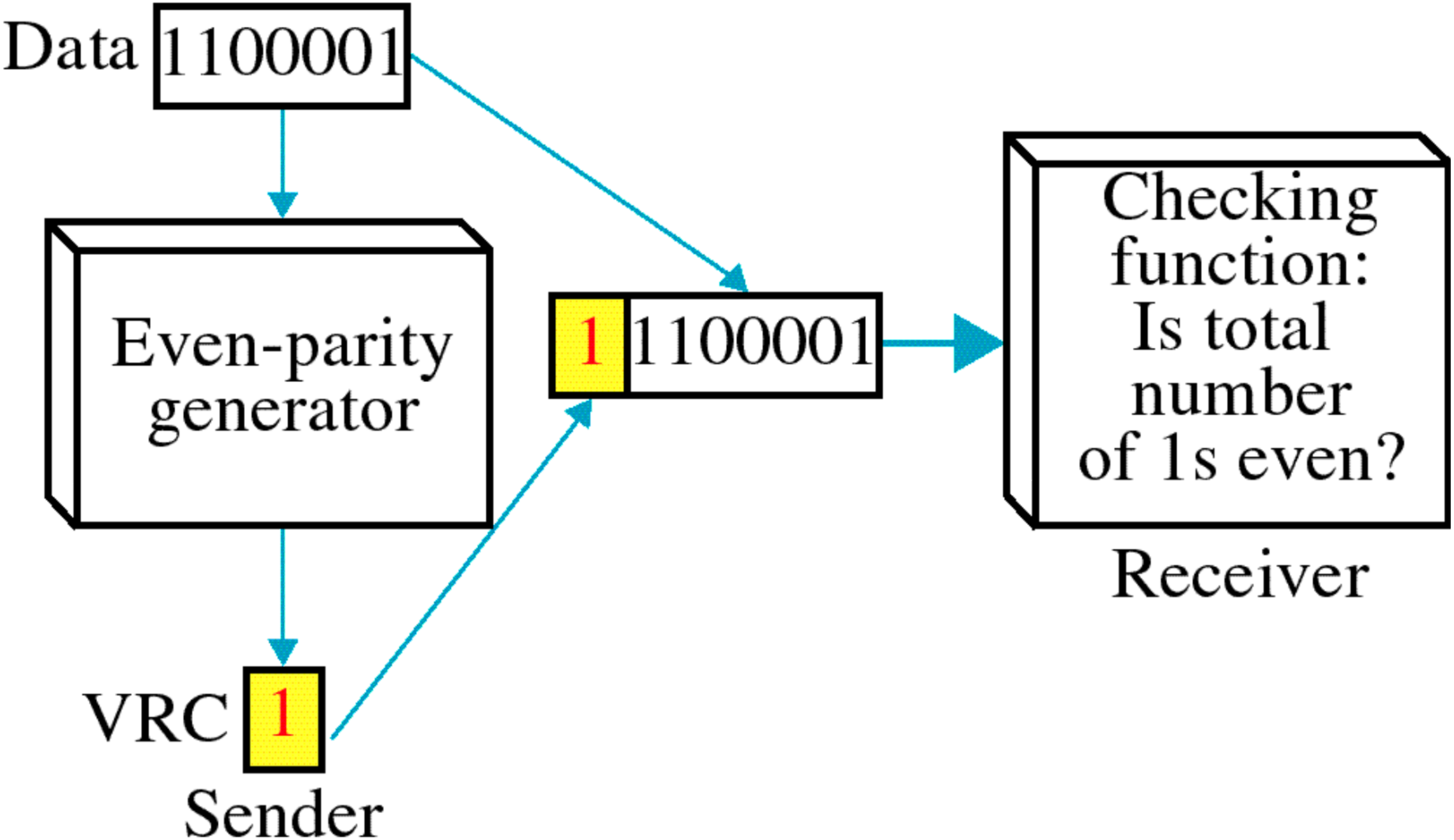
a) CRC

b) VRC

c) LRC

d) NRC

Vertical Redundancy Check VRC



Example

Suppose the sender wants to send the word *world*. In ASCII the five characters are coded as

1110111	**1101111**	**1110010**	**1101100**	**1100100**
w	o	r	l	d

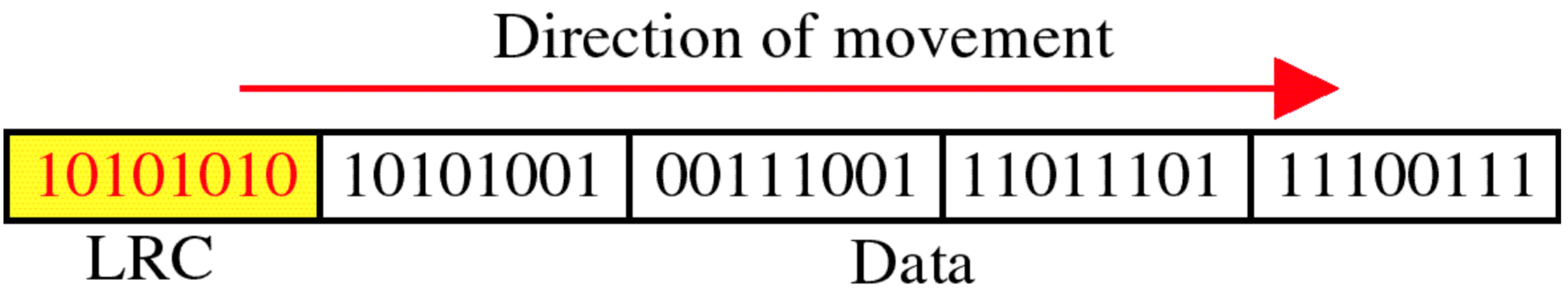
The following shows the actual bits sent

1110111<u>0</u> 1101111<u>0</u> 1110010<u>0</u> 1101100<u>0</u> 1100100<u>1</u>

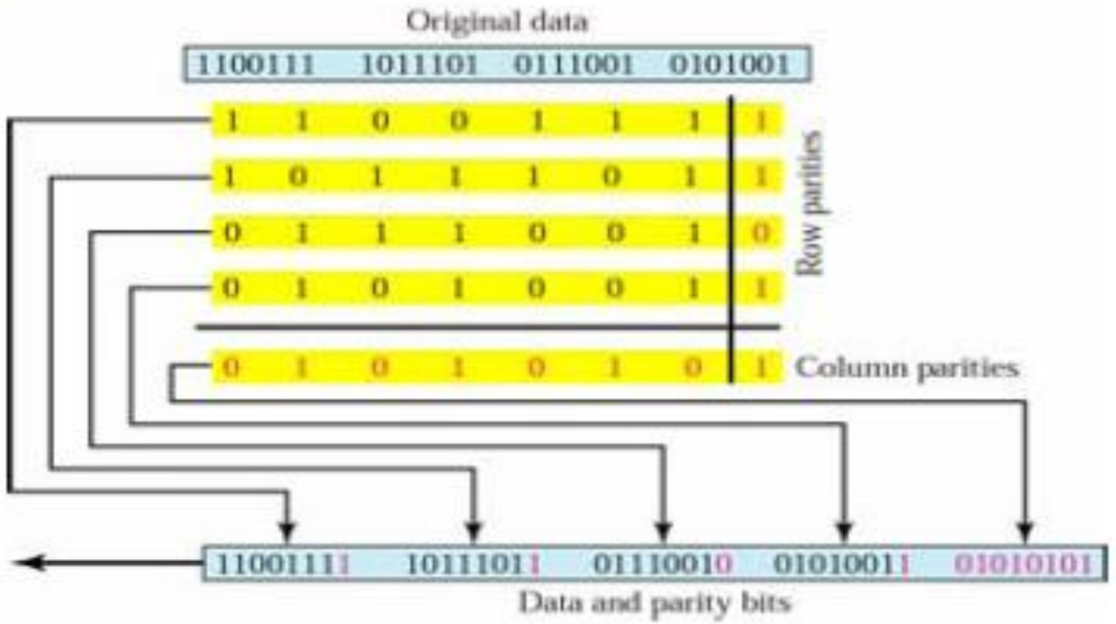
Performance

➔ It can detect burst errors only if the total number of errors is odd.

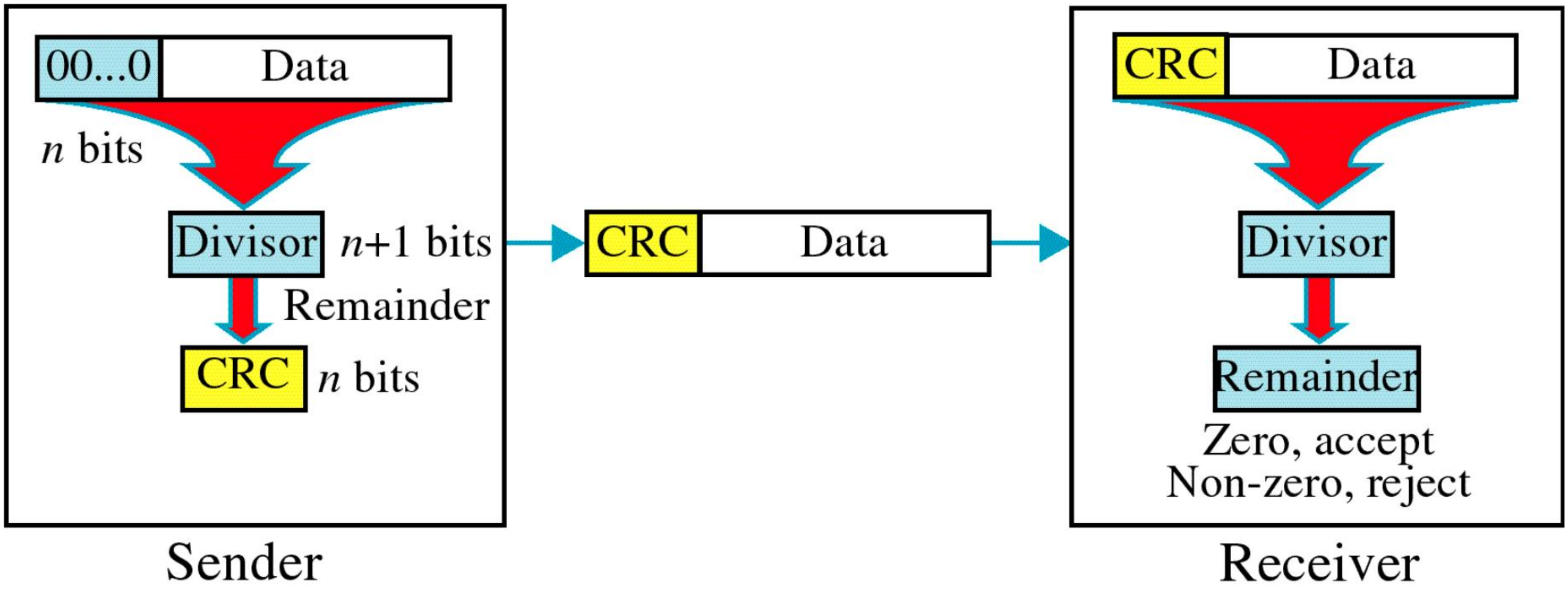
Longitudinal Redundancy Check LRC



Two-dimensional parity (LRC + VRC)



Cyclic Redundancy Check
CRC

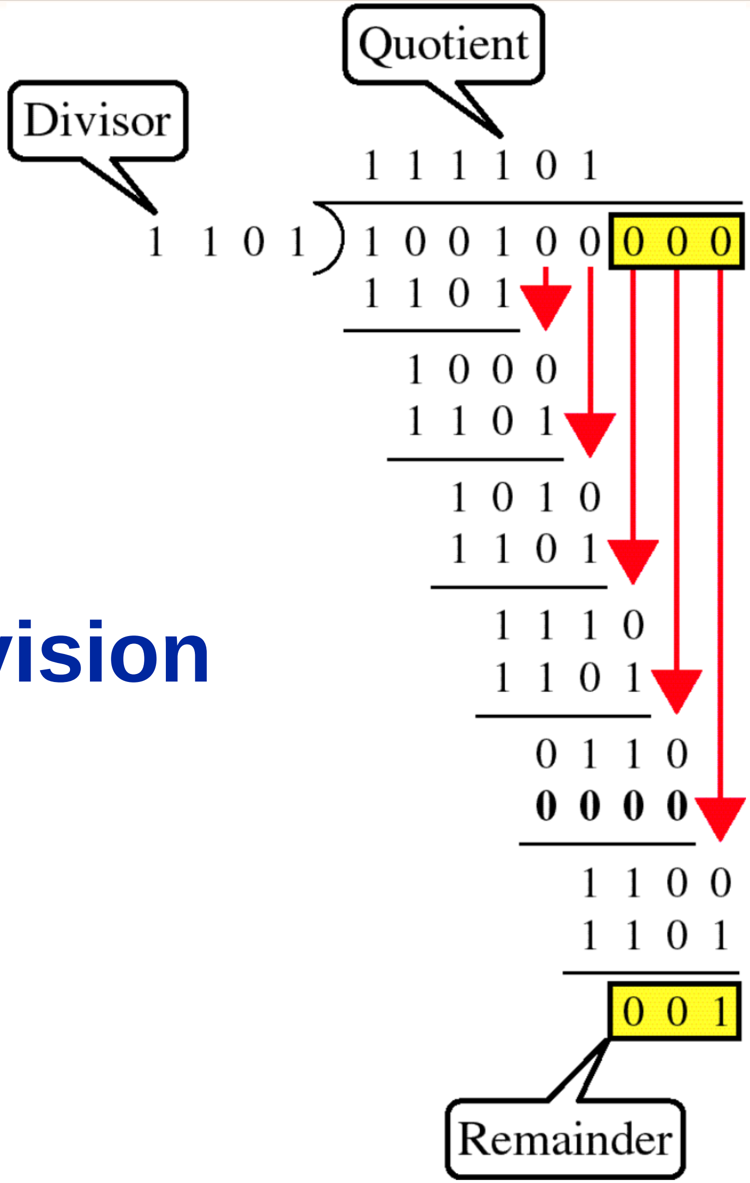


Cyclic Redundancy Check

- Given a k-bit frame or message, the transmitter generates an n-bit sequence, known as a *frame check sequence (FCS)*, so that the resulting frame, consisting of (k+n) bits, is exactly divisible by some predetermined number.

- The receiver then divides the incoming frame by the same number and, if there is no remainder, assumes that there was no error.

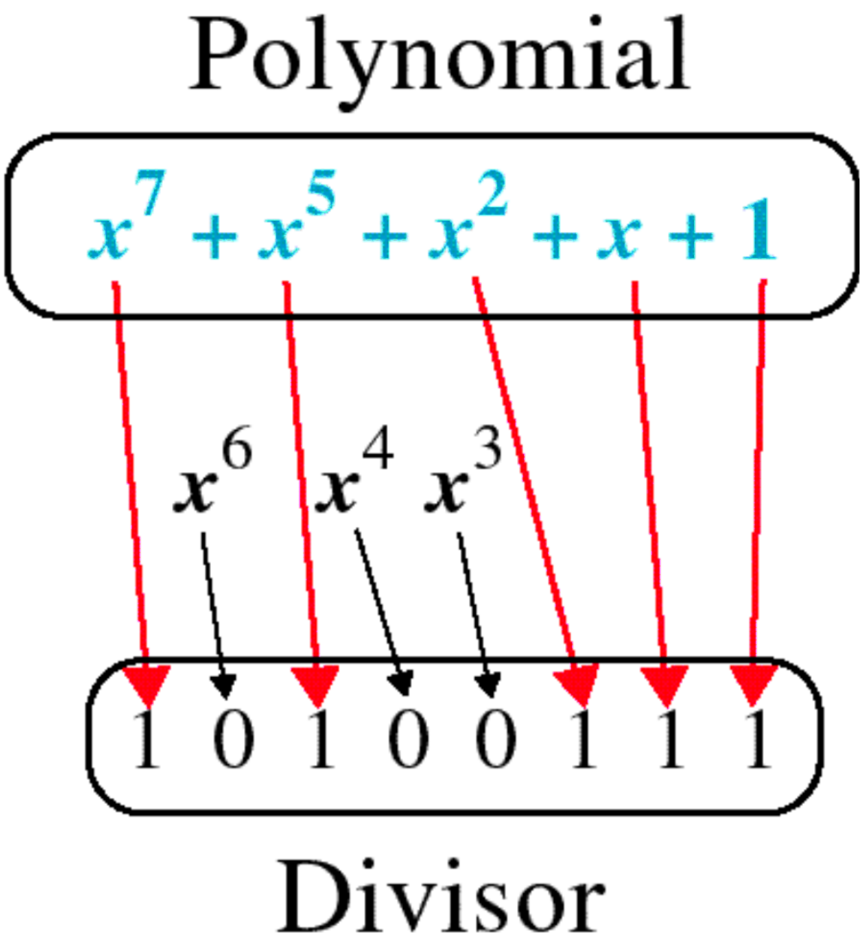
Binary Division



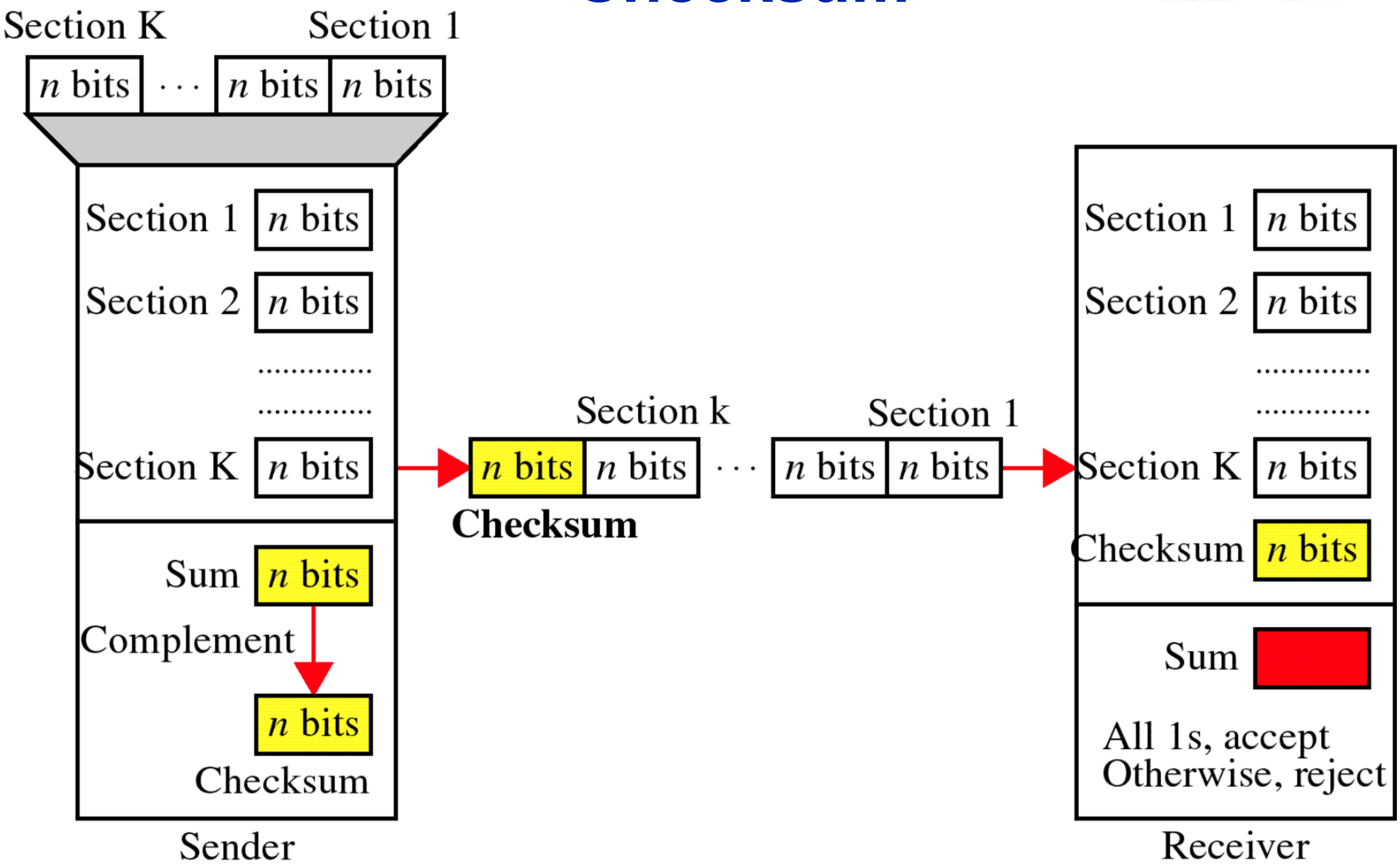
Polynomial

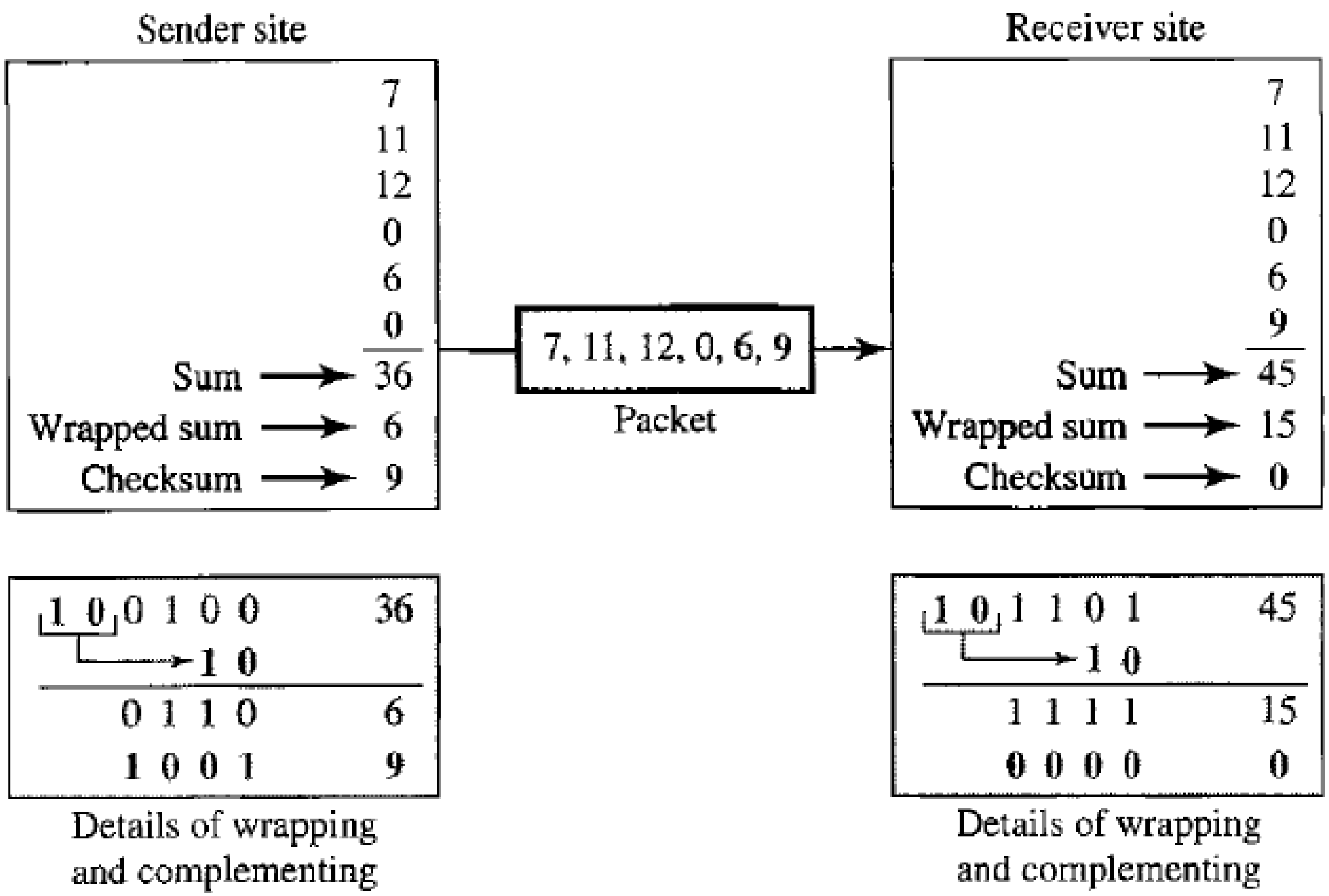
$$\boxed{x^7 + x^5 + x^2 + x + 1}$$

Polynomial and Divisor



Checksum


Section K
Section 1
n bits
n bits
n bits
Section 1
n bits
Section 2
n bits
Section K
n bits
Sum
n bits
Complement
n bits
Checksum
Sender
Section k
Section 1
n bits
n bits
n bits
n bits
Checksum
Section 1
n bits
Section 2
n bits
Section K
n bits
Checksum
n bits
Sum
All 1s, accept
Otherwise, reject
Receiver



Sender site
7
11
12
0
6
0
Sum → 36
Wrapped sum → 6
Checksum → 9
7, 11, 12, 0, 6, 9
Packet
Receiver site
7
11
12
0
6
9
Sum → 45
Wrapped sum → 15
Checksum → 0
1 0 0 1 0 0 36
1 0
0 1 1 0 6
1 0 0 1 9
Details of wrapping and complementing
1 0 1 1 0 1 45
1 0
1 1 1 1 15
0 0 0 0 0
Details of wrapping and complementing

Error Correction

It can be handled in two ways:

1) receiver can have the sender retransmit the entire data unit.

2) The receiver can use an error-correcting code, which automatically corrects certain errors.

Single-bit error correction

To correct an error, the receiver reverses the value of the altered bit. To do so, it must know which bit is in error.

Number of redundancy bits needed

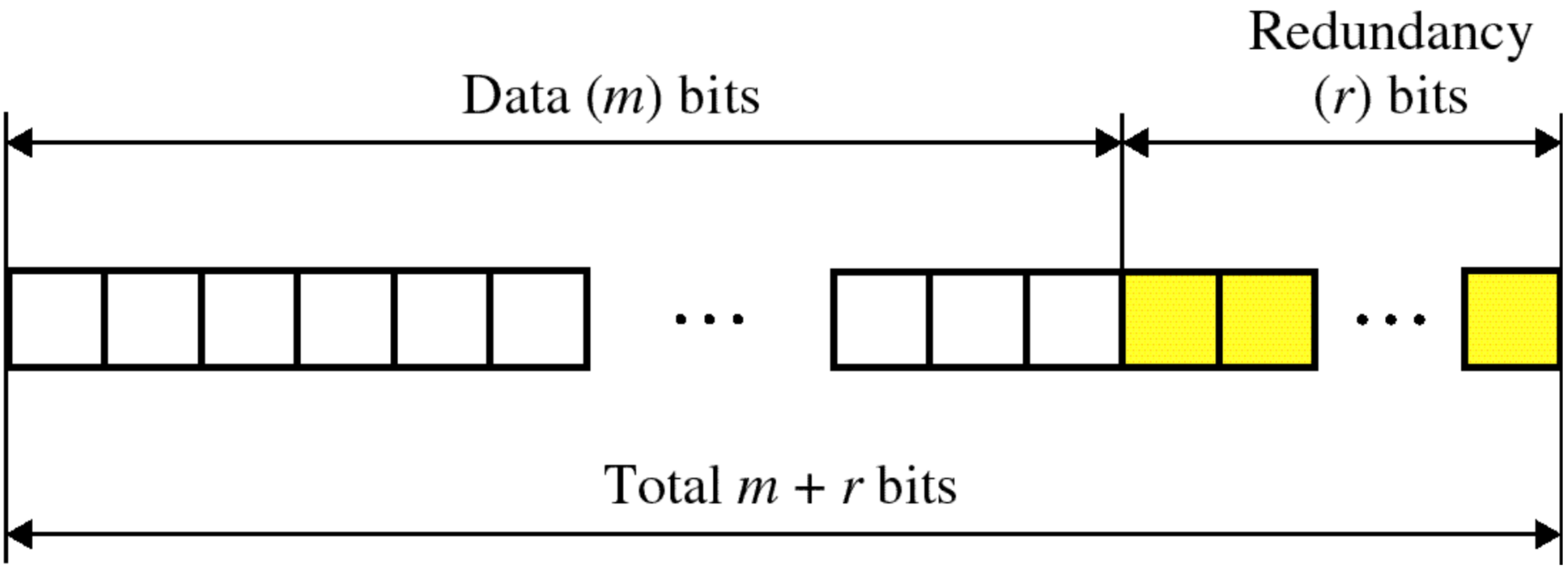
- Let data bits = *m*
- Redundancy bits = *r*

$\therefore$ Total message sent = $m+r$

The value of r must satisfy the following relation:

$$2^r \geq m+r+1$$

Error Correction



POLL 3

- Is Hamming code

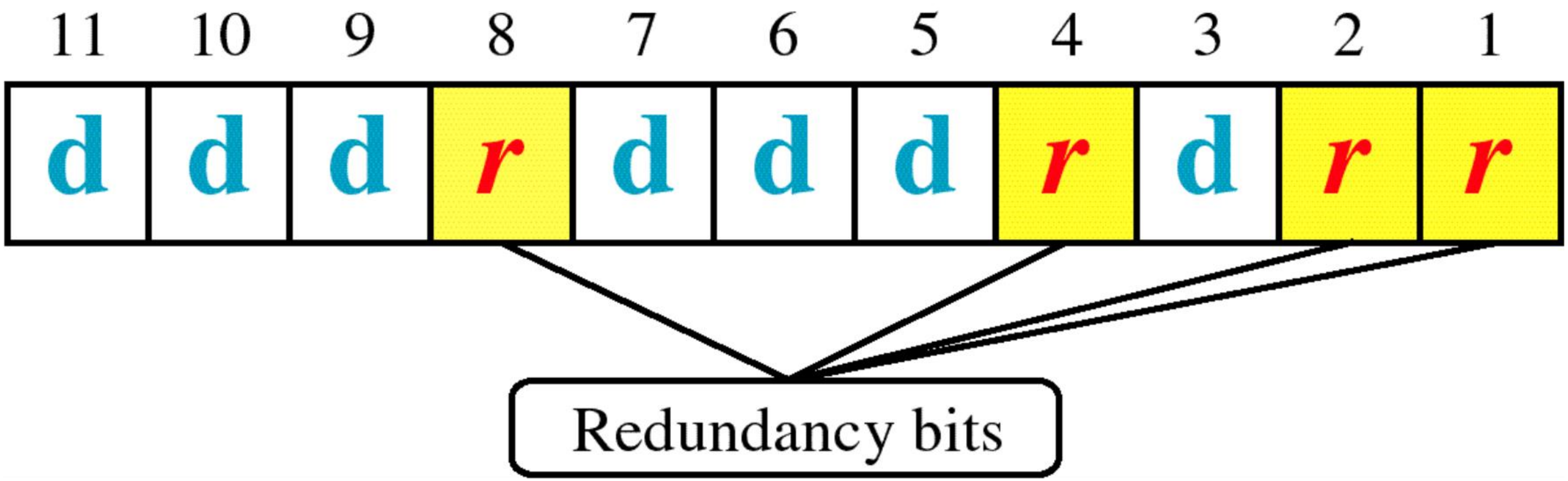
a) Error detection Only

b) Error Correction Only

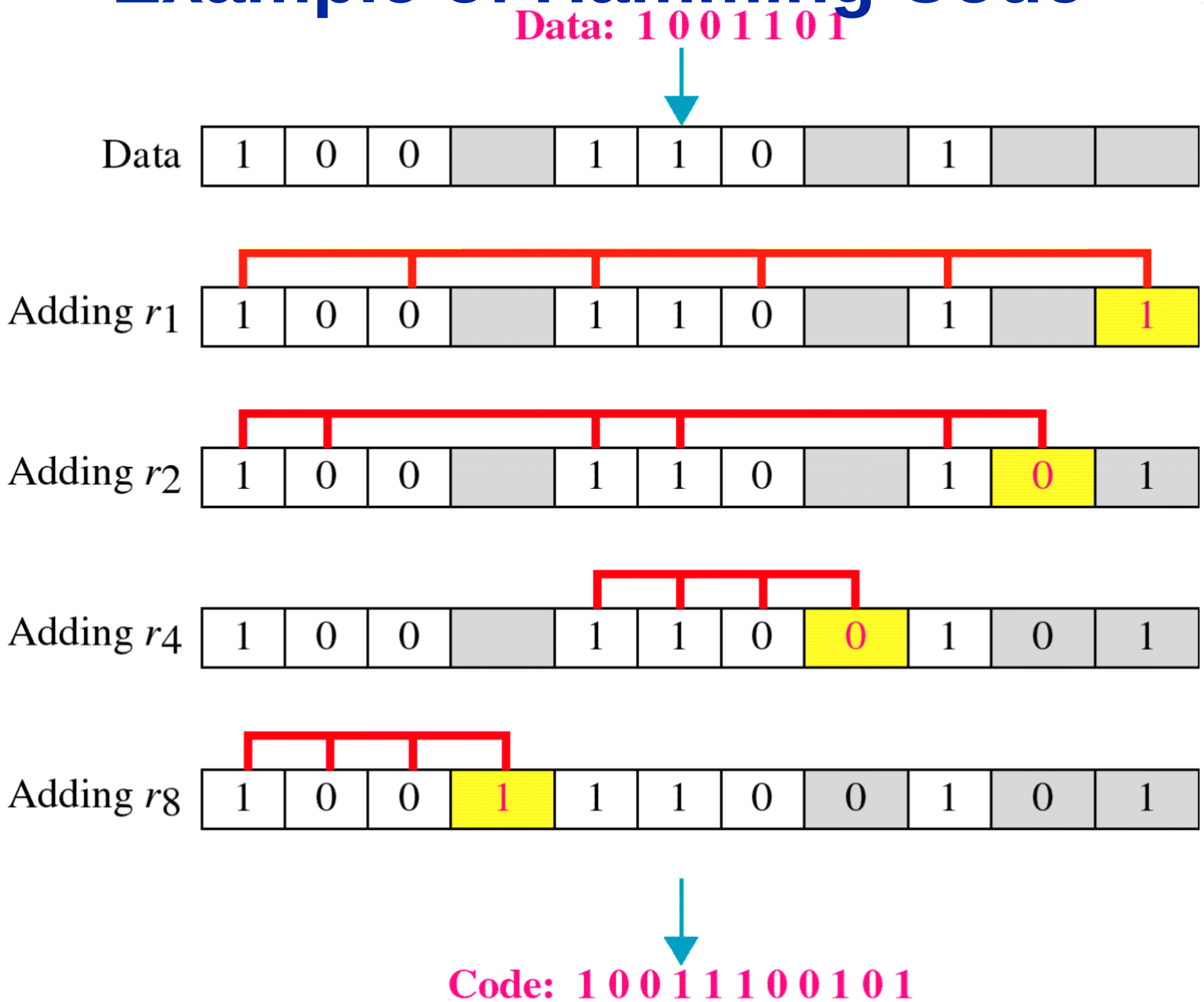
c) Both A and B

d) None of the above

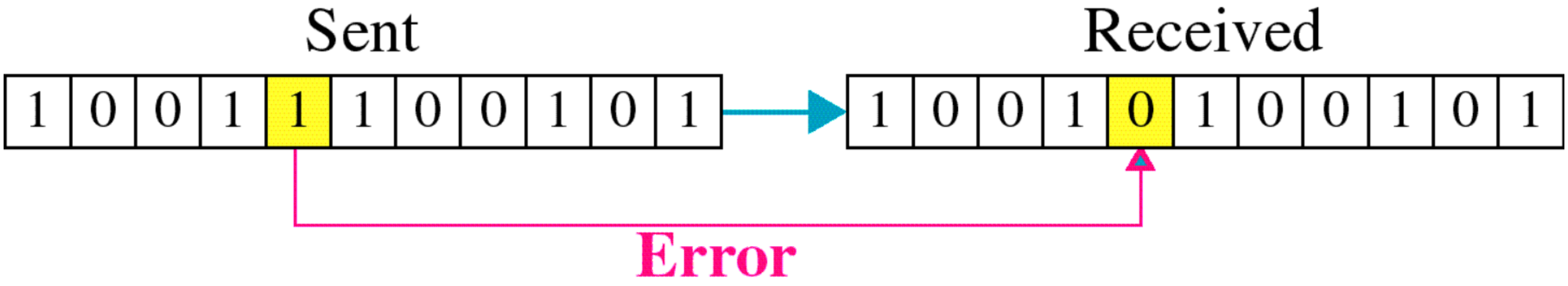
Hamming Code



Example of Hamming Code



Single-bit error



Error Detection