CHRIST
(DEEMED TO BE UNIVERSITY)
BANGALORE . INDIA

MCA331 – COMPUTER NETWORKS

Introduction COMPUTER NETWORKS

Dr. Nismon Rio

Objectives :

- Uses of Computer Networks,
- Internetworks;
- Network Software: Protocol hierarchies,
- Design issues for the layers,
- Connection Oriented and Connection less Services

Introduction :

- Data Communications are the transfer of data from one device to another via some form of transmission medium.
- A data communications system must transmit data to the correct destination in an accurate and timely manner.
- Data communications between remote parties can be achieved through a process called networking, involving the connection of computers, media, and networking devices.

- A NETWORK is a set of communication devices connected by media links.

- Protocols and standards are vital to the implementation of data communications and networking.

- Protocols refer to the rules; a standard is a protocol that has been adopted by vendors and manufacturers.

The effectiveness of a data communications system depends on four fundamental characteristics:

1. **Delivery:** The system must deliver data to the correct destination. Data must be received by the intended device or user and only by that device or user.

2. **Accuracy:** The system must deliver the data accurately. Data that have been altered in transmission and left uncorrected are unusable.

3. **Timeliness:** The system must deliver data in a timely manner. Data delivered late are useless.

4. **Jitter:** Jitter refers to the variation in the packet arrival time. It is the uneven delay in the delivery of audio or video packets.

Components of data communication

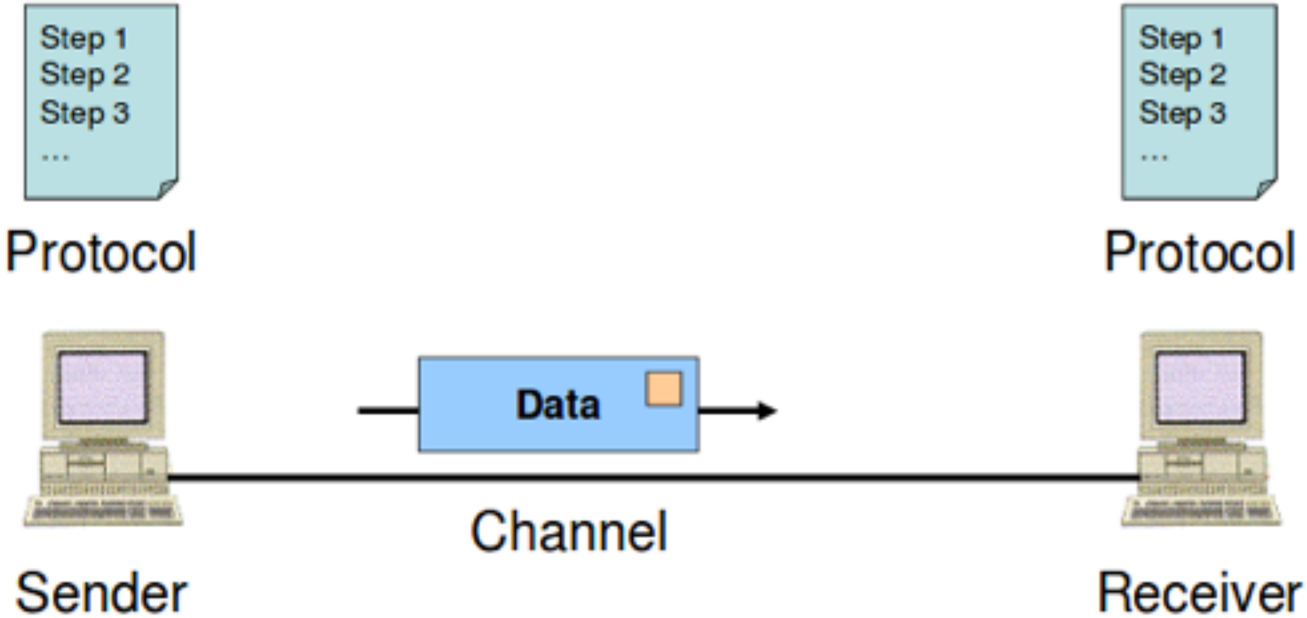


Figure 1 : Five components of data communication

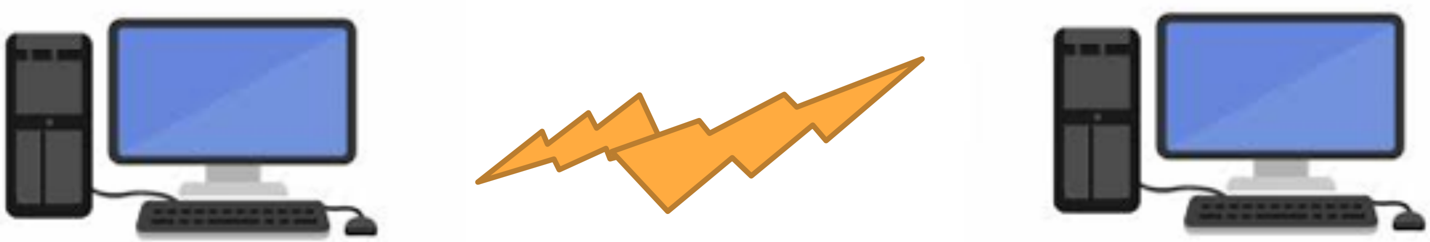
- **Message:** The message is the information (data) to be communicated.
- **Sender:** The sender is the device that sends the data message.
- **Receiver:** The receiver is the device that receives the message.
- **Transmission medium:** The transmission medium is the physical path by which a message travels from sender to receiver.
- **Protocol:** A protocol is a set of rules that govern data communications. It represents an agreement between the communicating devices.

Data Representation

- ✓ Text
- ✓ Numbers
- ✓ Images
- ✓ Audio
- ✓ Video

Scenario 1:

How to connect two computers (DESKTOP) ?



Computational Device 1
DESKTOP

OS : Windows 8.1

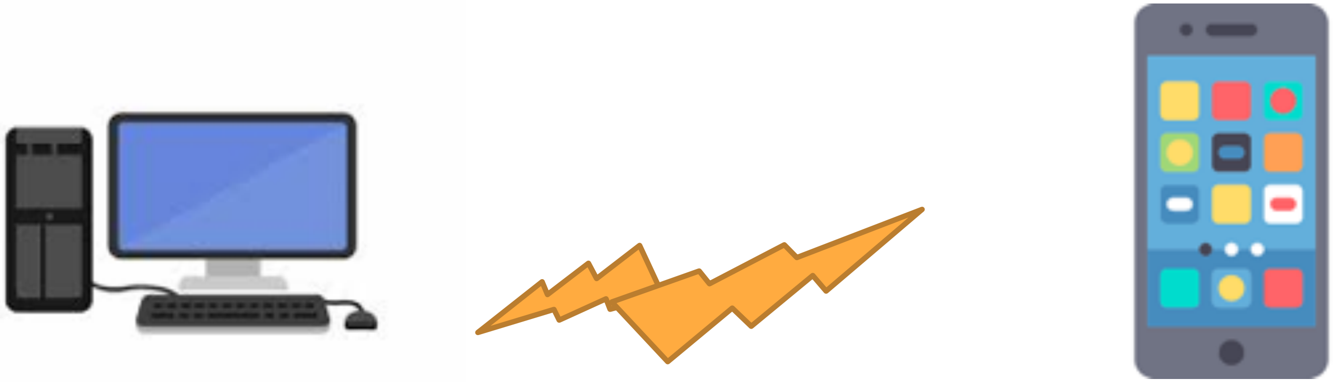
Computational Device 2
DESKTOP / LAPTOP

OS : Windows 10

NOTE : Unmute your MIC and Video – Discuss – One by One mode

Scenario 2:

How to connect two heterogeneous computational devices (PC and PHONE) ?



Computational Device 1
DESKTOP

OS : Windows 8.1

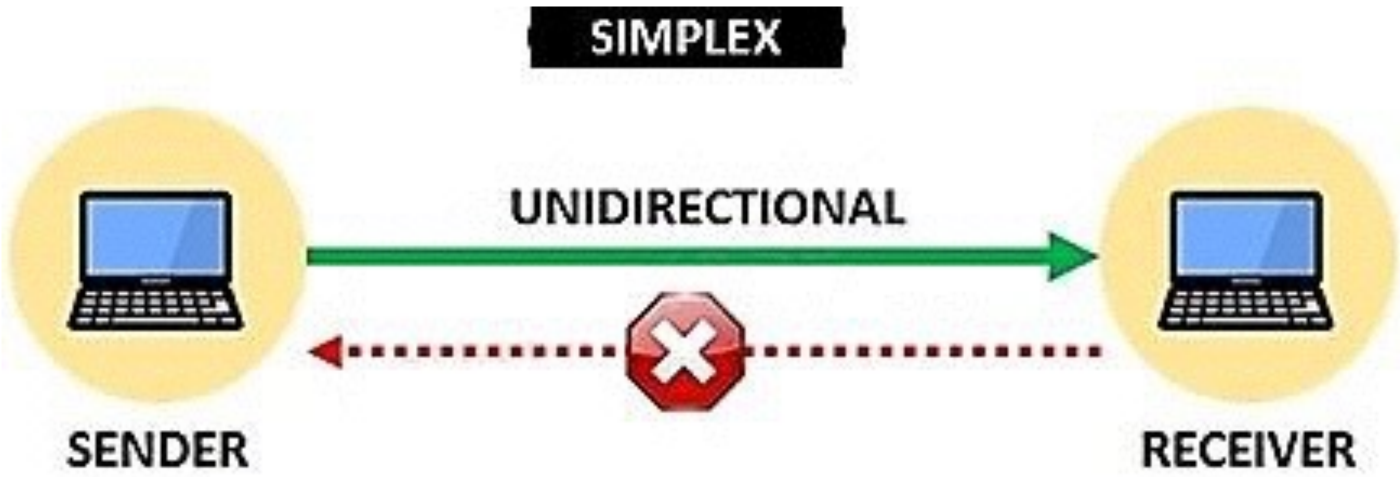
Computational Device 2
SMARTPHONE

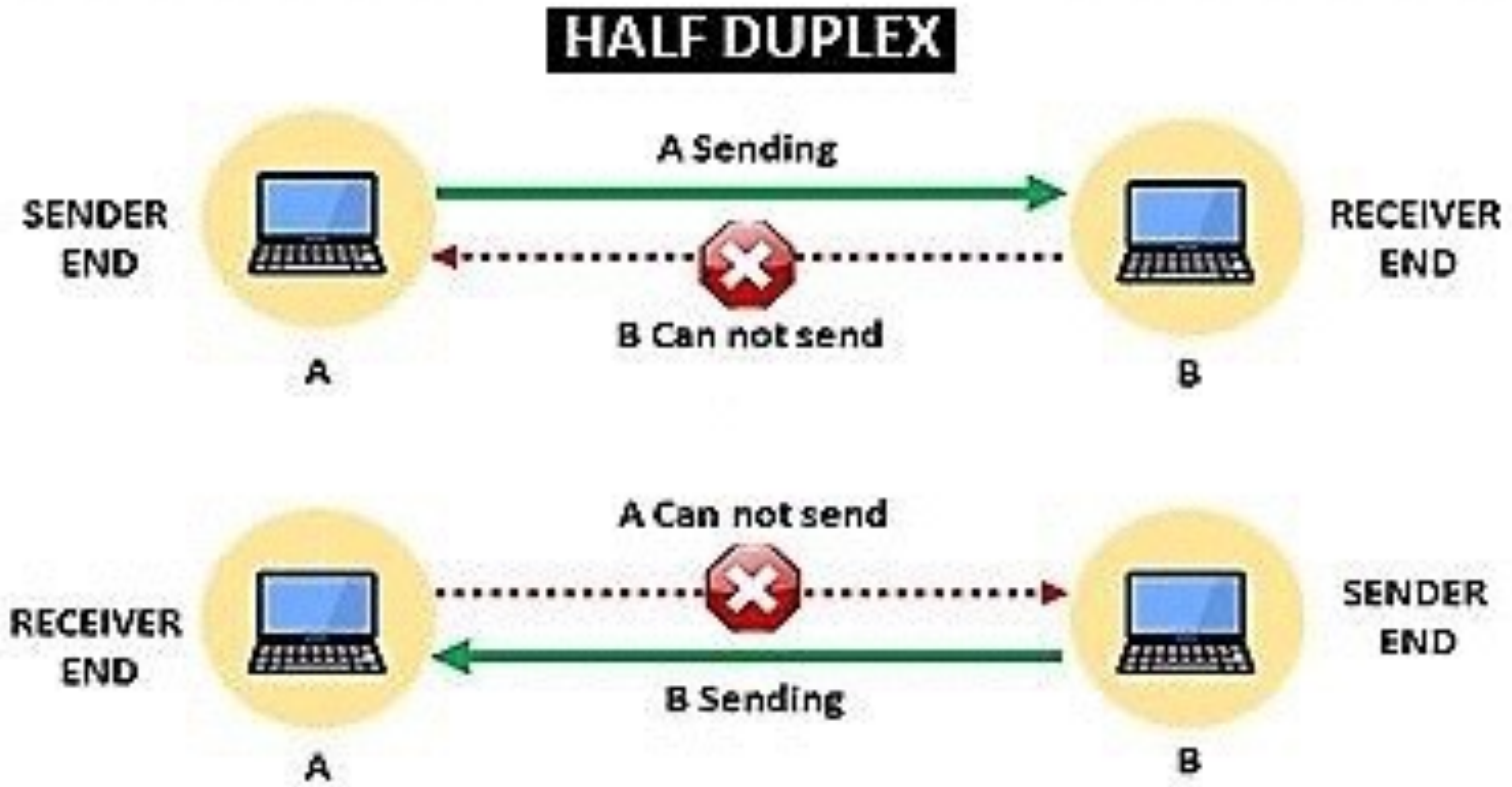
OS : Android

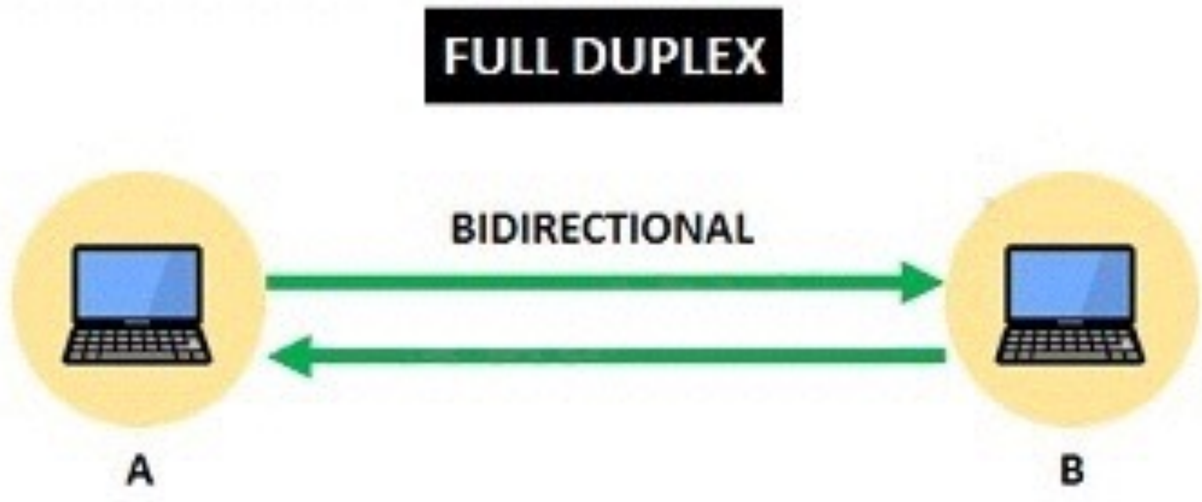
NOTE : Unmute your MIC and Video – Discuss – One by One mode

Data Flow

Communication between two devices can be simplex, half-duplex, or full-duplex (WAY OF COMMUNICATION)




HALF DUPLEX
A Sending
SENDER END
RECEIVER END
B Can not send
A
B
A Can not send
SENDER END
RECEIVER END
B Sending
A
B


FULL DUPLEX
BIDIRECTIONAL
A
B

BASIS	SIMPLEX	HALF-DUPLEX	FULL-DUPLEX
Type of Communication	Unidirectional	Bidirectional (one at a time)	Bidirectional (simultaneously)
Exchange of Data	Sender can only send data (can't receive back)	Sender can send as well receive data (but one at a time)	Sender can send and receive data (both simultaneously)
Performance	Least	Better	Best
Advantage	It uses the entire capacity of the channel to send data in one direction. So it is used when maximum bandwidth is required during the transmission.	It is used to conserve bandwidth as only a single communicati on channel is needed, which is shared alternately between the two directions.	It is used when communication in both directions is required all the time without any delays.

COMPUTER NETWORK

A computer network is a digital telecommunications network for sharing resources between nodes, which are computing devices that use a common telecommunications technology.

Computer networks support many applications and services, such as access to the World Wide Web, digital video, digital audio, shared use of application and storage servers, printers, and fax machines, and use of email and instant messaging applications.

Computer Network

? Are they Same

Internet

NOTE : Unmute your MIC and Video – Discuss – One by One mode

Network Criteria

A network must be able to meet a certain number of criteria. The most important of these are performance, reliability, and security.

Performance

Performance can be measured in many ways, including transit time and response time.

Transit time is the amount of time required for a message to travel from one device to another.

Response time is the elapsed time between an inquiry and a response.

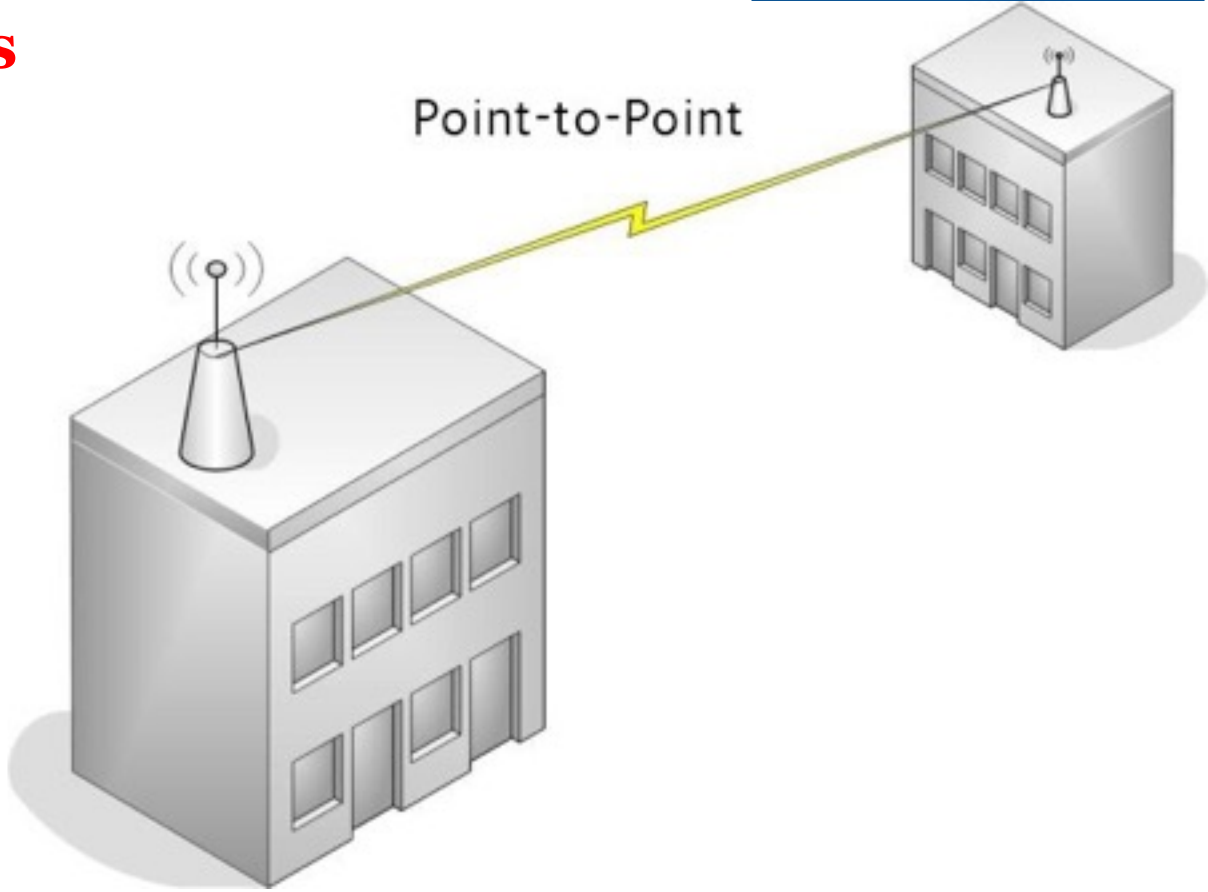
Reliability

In addition to accuracy of delivery, network reliability is measured by the frequency of failure, the time it takes a link to recover from a failure, and the network's robustness in a catastrophe.

Security

Network security issues include protecting data from unauthorized access, protecting data from damage and development, and implementing policies and procedures for recovery from breaches and data losses.

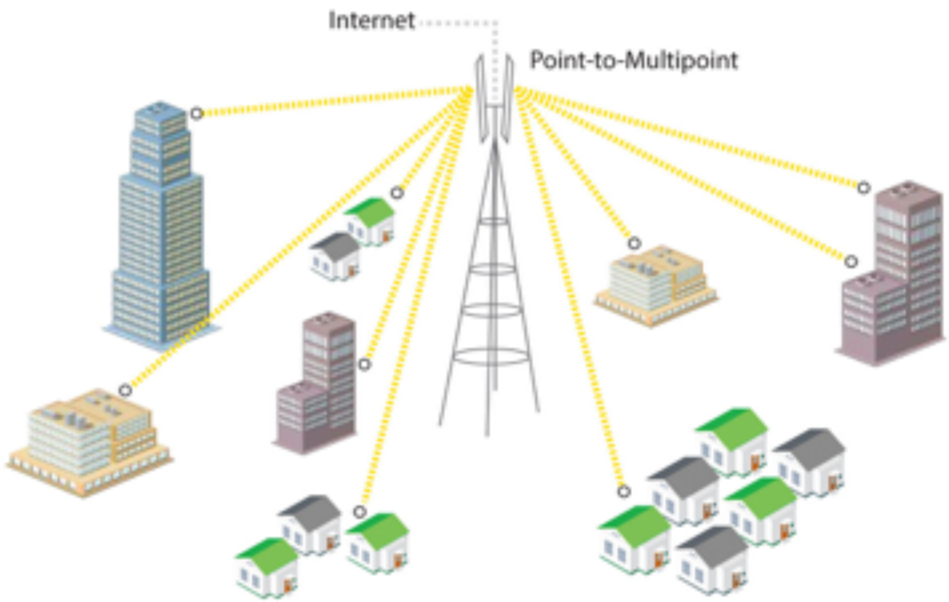
Physical Structures



Point-to-Point

A point-to-point connection provides a dedicated link between two devices. The entire capacity of the link is reserved for transmission between those two devices. When we change television channels by infrared remote control, we are establishing a point-to-point connection between the remote control and the television's control system.

Physical Structures



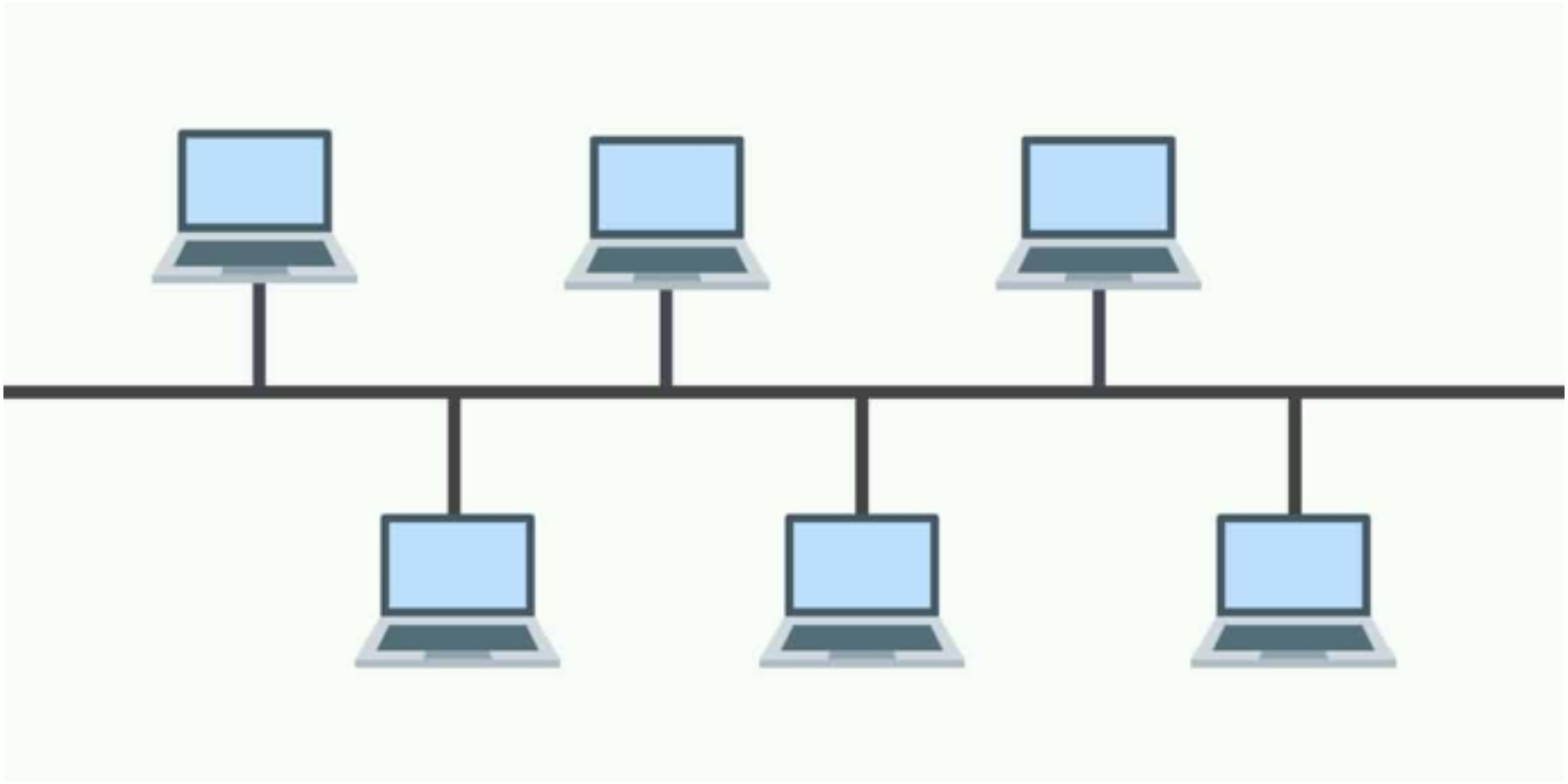
Multipoint

A multipoint (also called multidrop) connection is one in which more than two specific devices share a single link. In a multipoint environment, the capacity of the channel is shared, either spatially or temporally. If several devices can use the link simultaneously, it is a spatially shared connection. If users must take turns, it is a timeshared connection.

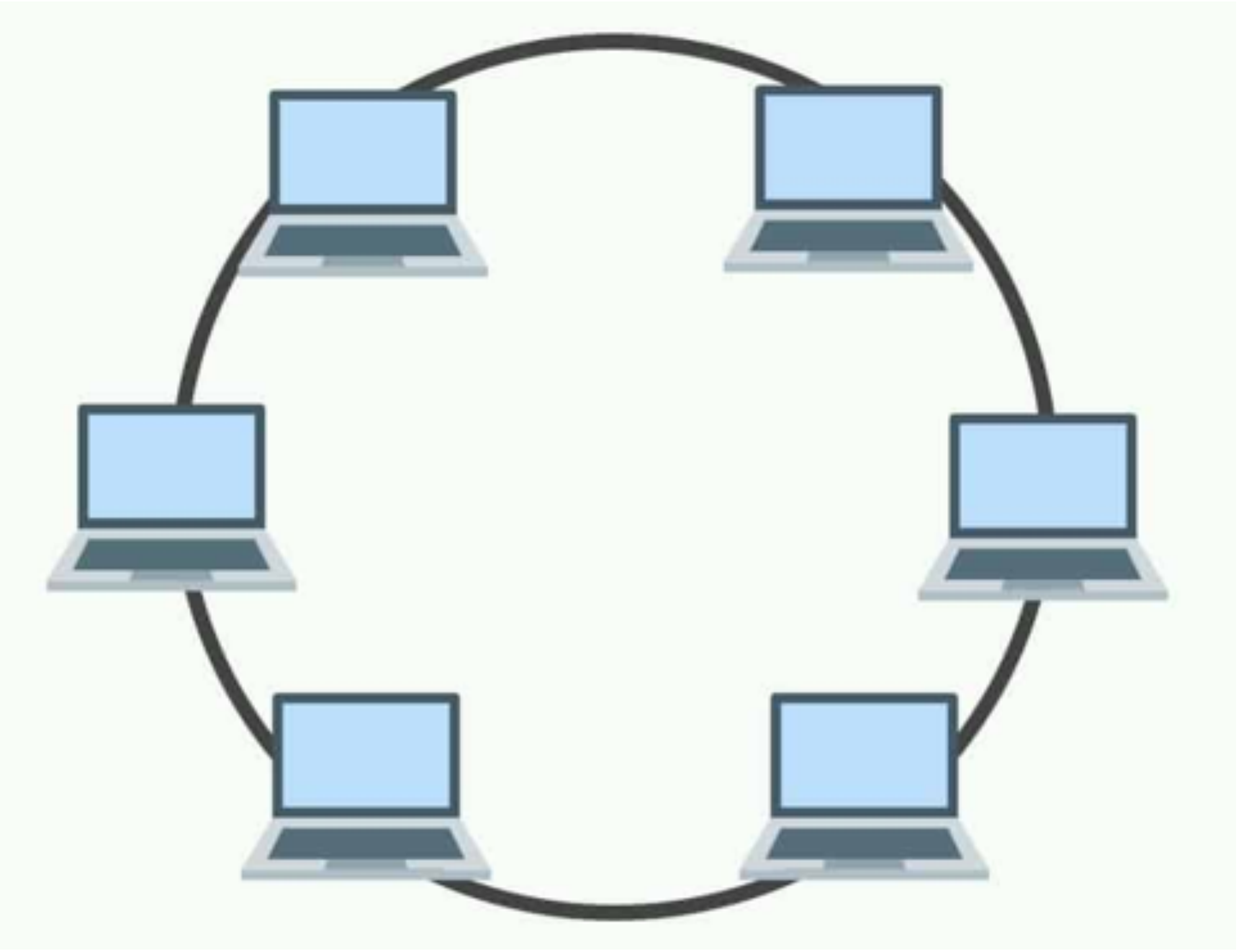
Physical Topology

- The term physical topology refers to the way in which a network is laid out physically.
- Two or more devices connect to a link; two or more links form a topology.
- The topology of a network is the geometric representation of the relationship of all the links and linking devices
- (usually called nodes) to one another.
- There are four basic topologies possible: mesh, star, bus, and ring.

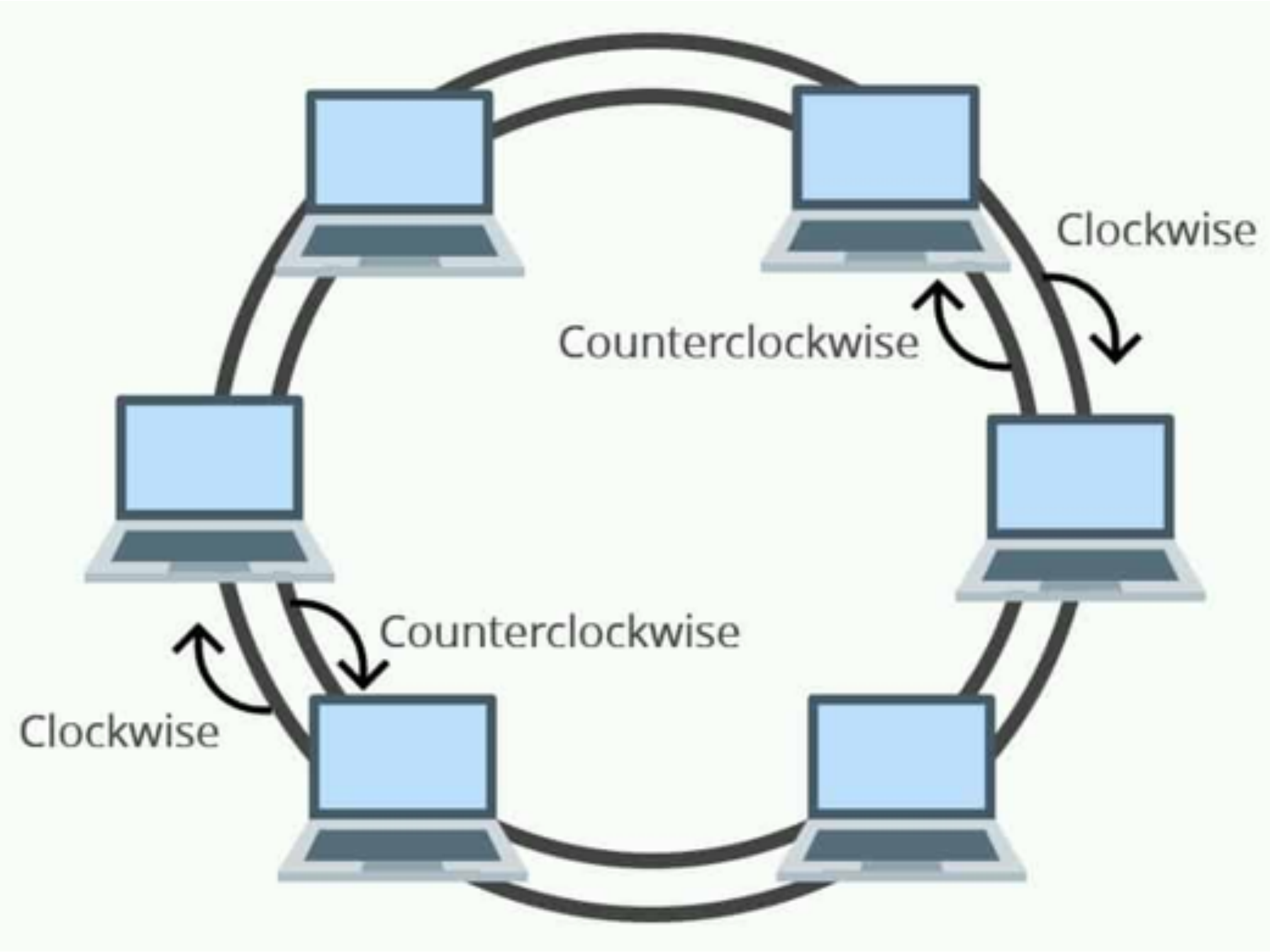
Bus Topology



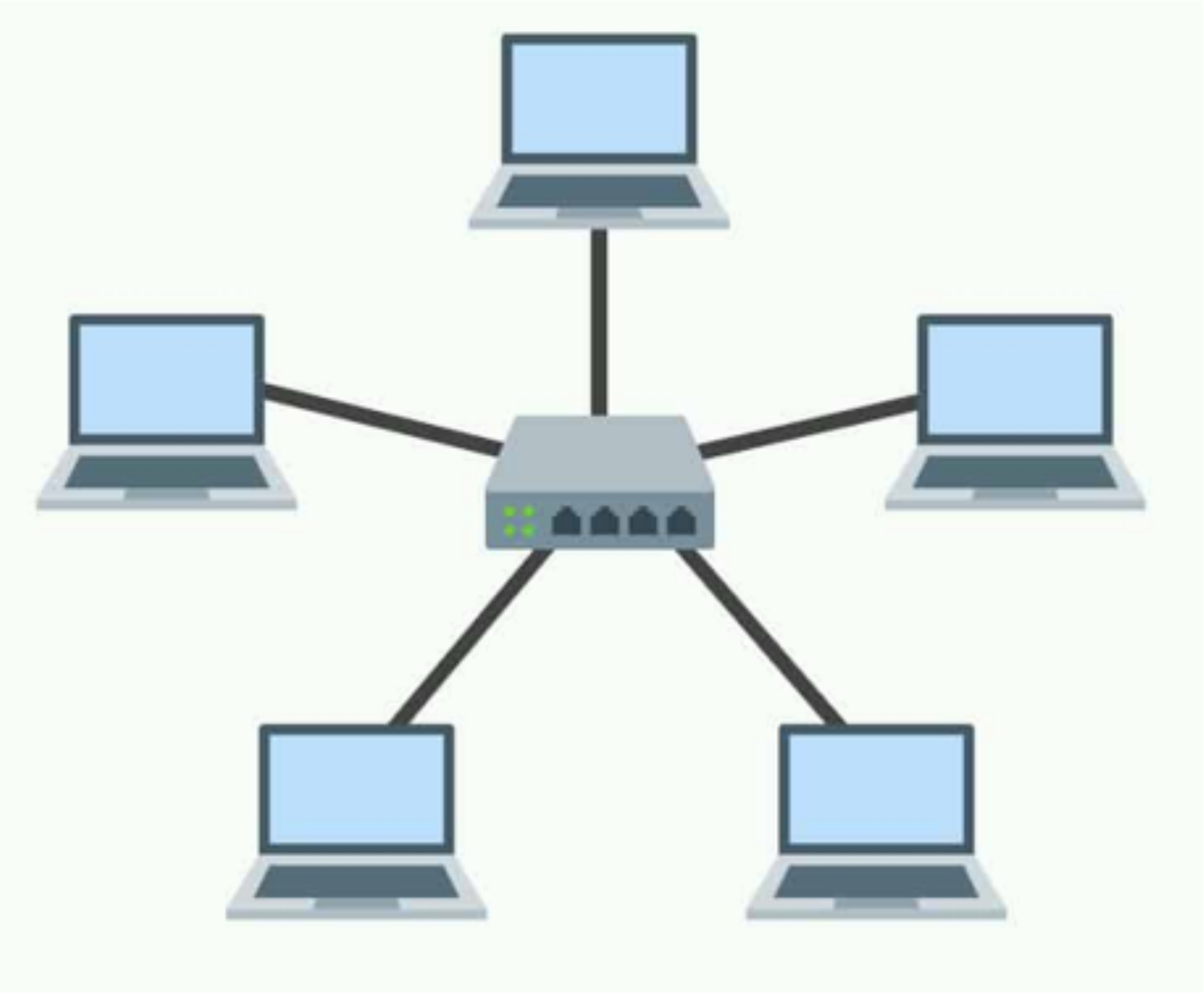
Ring Topology



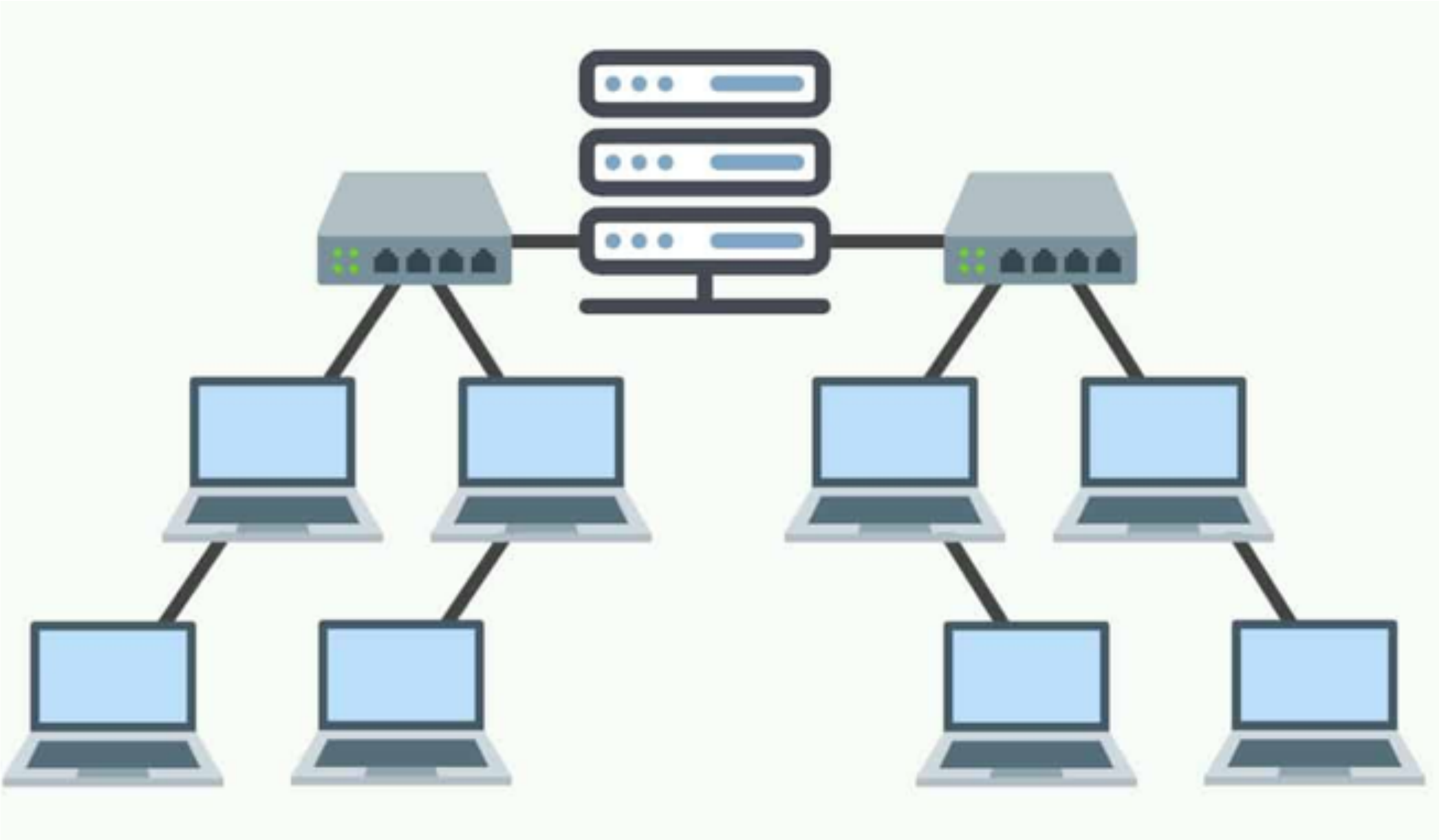
Dual Ring Topology



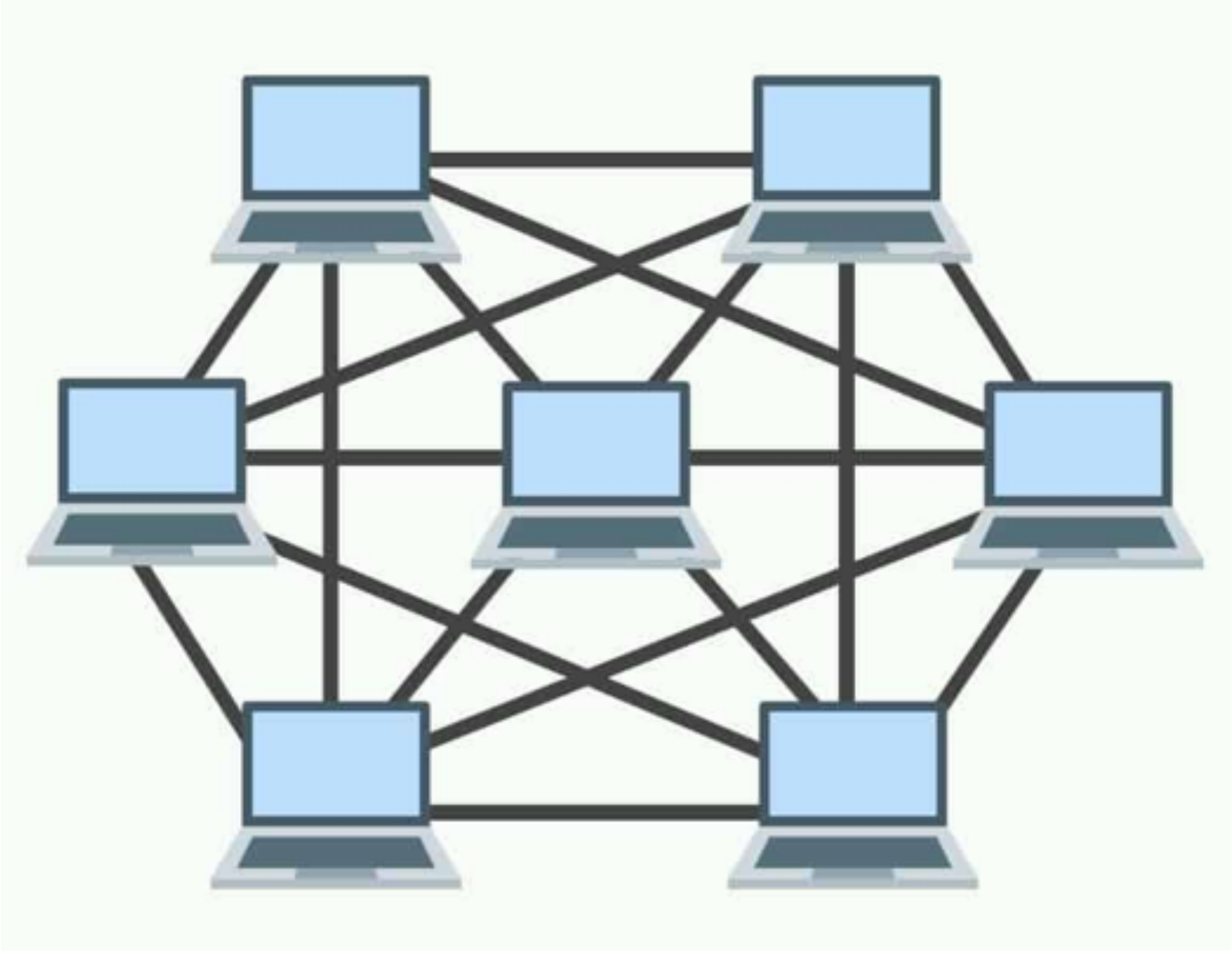
Star Topology



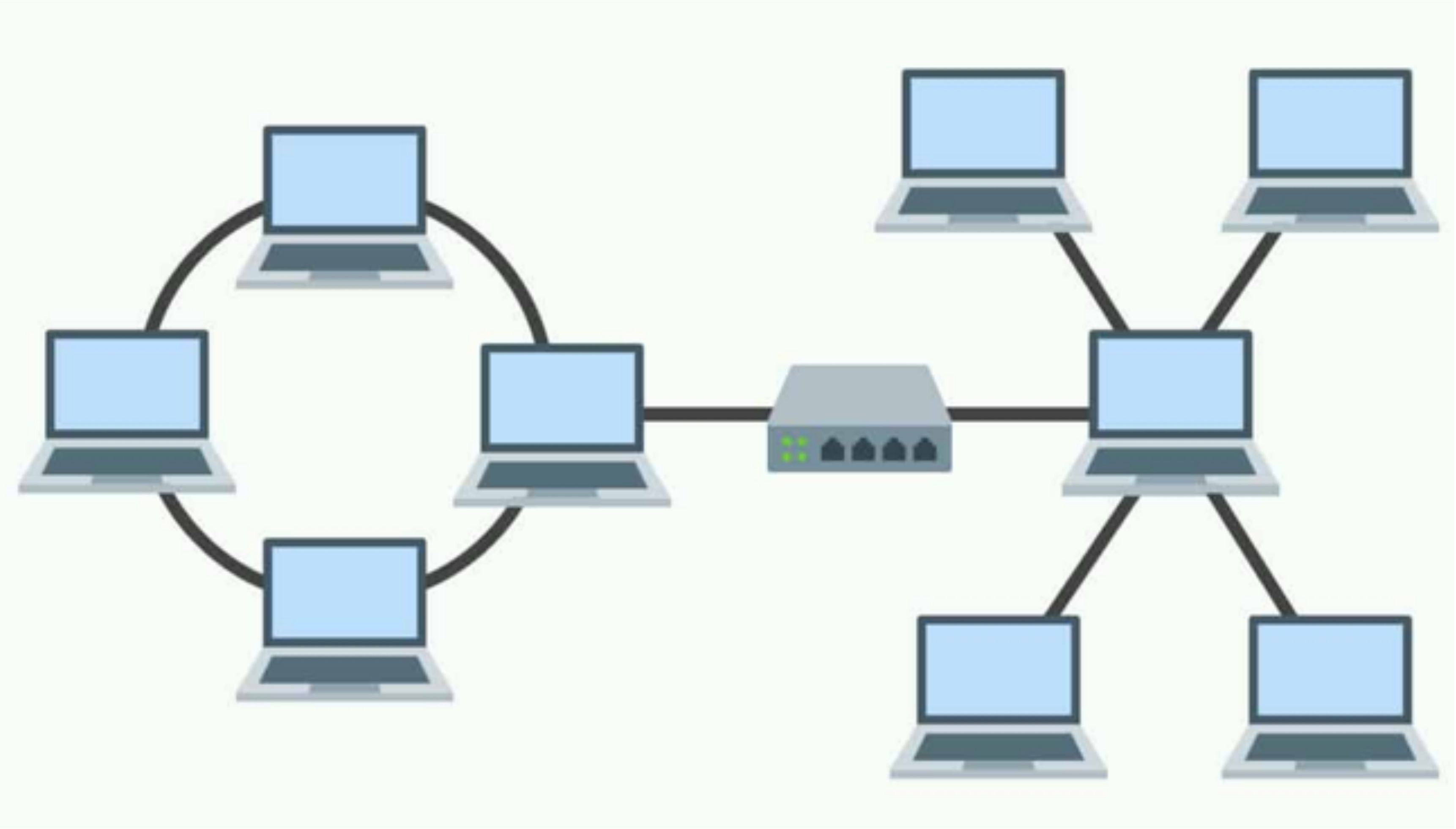
Tree Topology



Mesh Topology



Hybrid Topology



PROTOCOLS AND STANDARDS

For communication to occur, the entities must agree on a protocol.

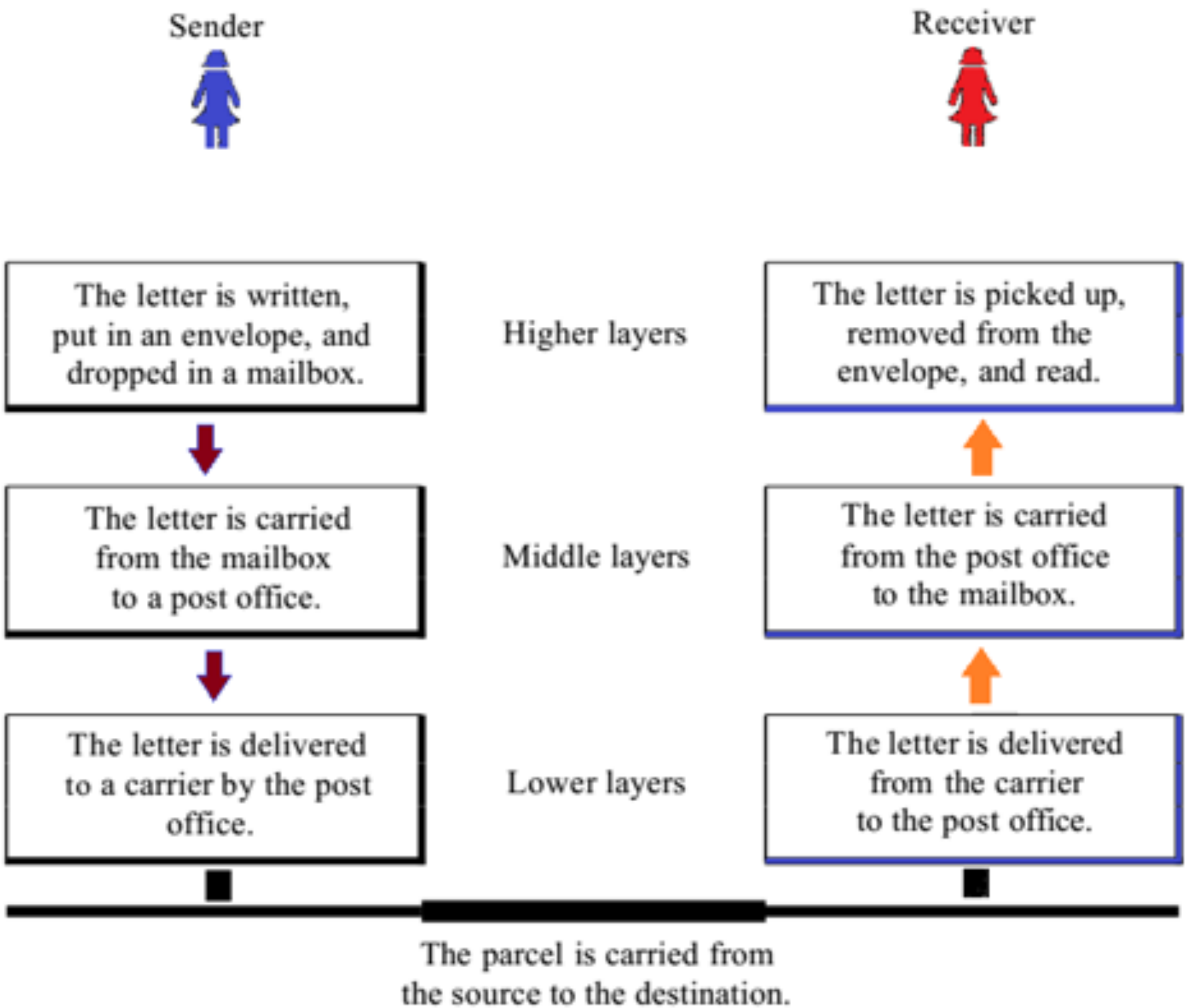
- A protocol is a set of rules that govern data communications. A protocol defines what is communicated, how it is communicated, and when it is communicated. The key elements of a protocol are syntax, semantics, and timing.
- Standards provide guidelines to manufacturers, vendors, government agencies, and other service providers to ensure the kind of interconnectivity necessary in today's marketplace and in international communications.

Standards Organizations

1. International Organization for Standardization (**ISO**)
2. International Telecommunication Union-Telecommunication Standards Sector (**ITU-T**)
3. American National Standards Institute (**ANSI**)
4. Institute of Electrical and Electronics Engineers (**IEEE**)
5. Electronic Industries Association (**EIA**)
6. **CISCO** – (Kind of private)

7. Regulatory Agency : Federal Communications Commission (FCC)

LAYERED TASKS



ISO - Open Systems Interconnection model (OSI model)

- A conceptual model that characterizes and standardizes the communication functions of a telecommunication or computing system

- Its goal is the interoperability of diverse communication systems with standard communication protocols.

- The model partitions a communication system into abstraction layers.

ISO OSI Reference Model
Layer architecture :

Layer 7: Application Layer

Layer 6: Presentation Layer

Layer 5: Session Layer

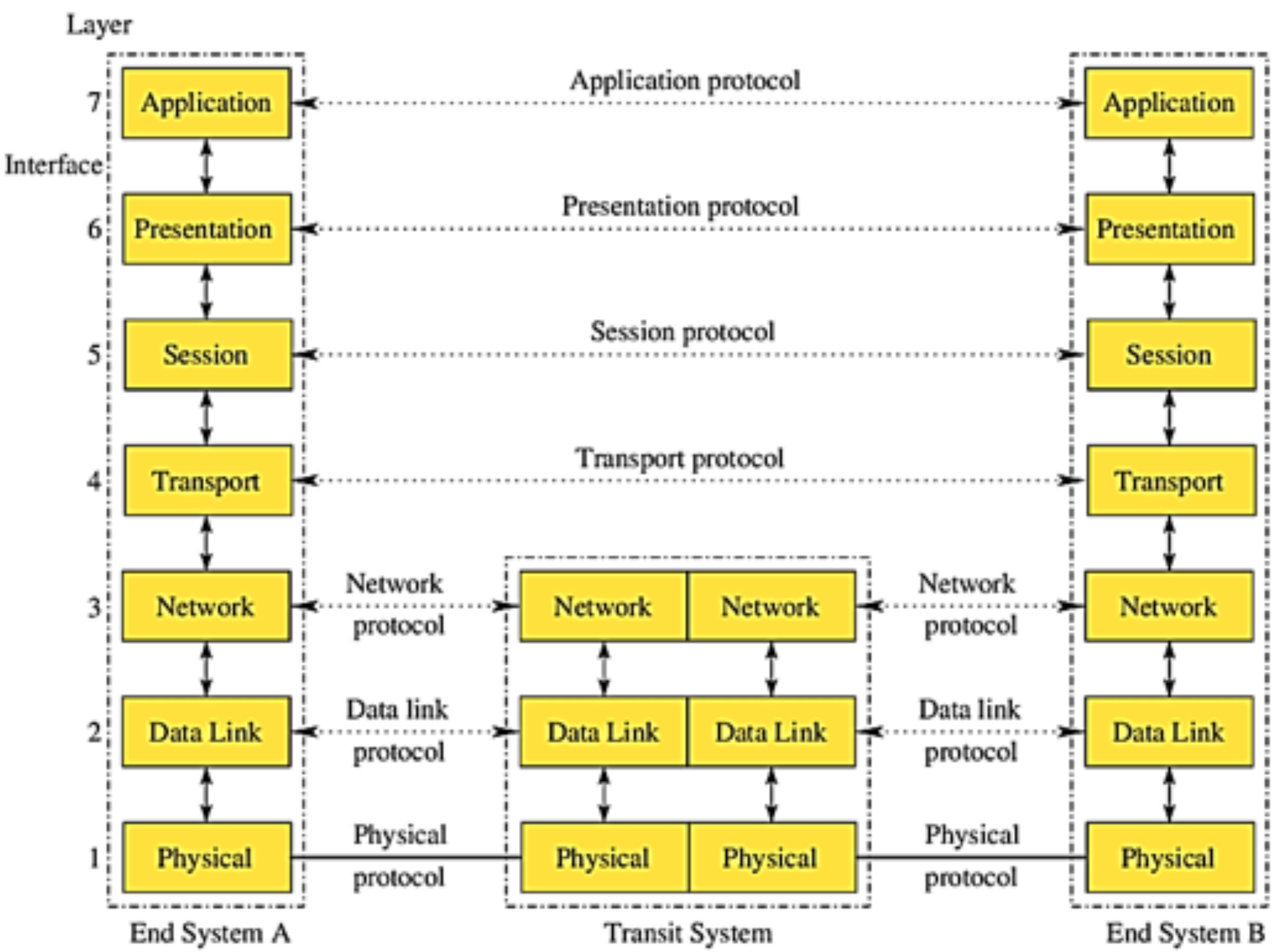
Layer 4: Transport Layer

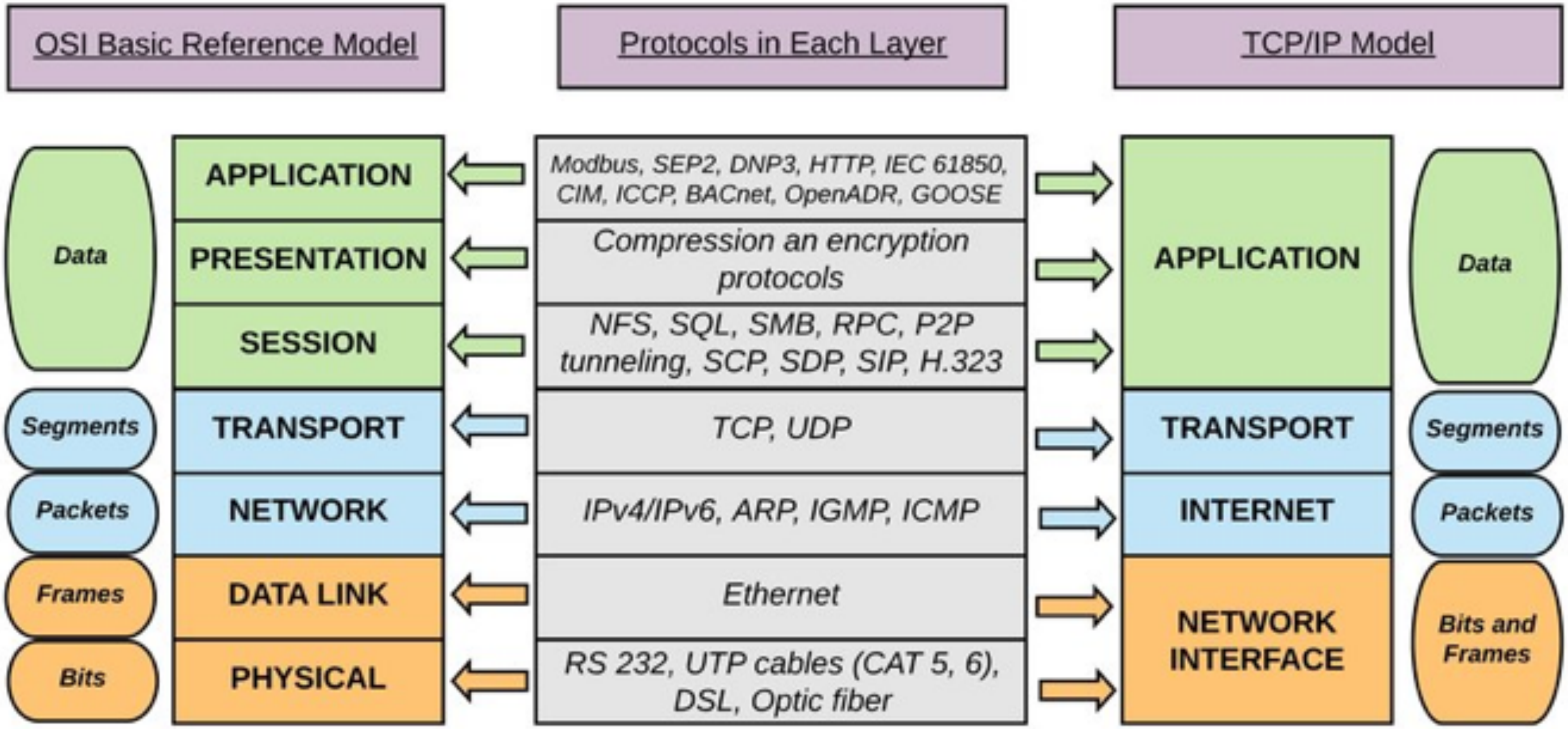
Layer 3: Network Layer

Layer 2: Data Link Layer

Layer 1: Physical Layer

ISO OSI Reference Model




OSI Basic Reference Model
Protocols in Each Layer
TCP/IP Model
Data
APPLICATION
Modbus, SEP2, DNP3, HTTP, IEC 61850, CIM, ICCP, BACnet, OpenADR, GOOSE
PRESENTATION
Compression an encryption protocols
SESSION
NFS, SQL, SMB, RPC, P2P tunneling, SCP, SDP, SIP, H.323
APPLICATION
Data
Segments
TRANSPORT
TCP, UDP
TRANSPORT
Segments
Packets
NETWORK
IPv4/IPv6, ARP, IGMP, ICMP
INTERNET
Packets
Frames
DATA LINK
Ethernet
Bits
PHYSICAL
RS 232, UTP cables (CAT 5, 6), DSL, Optic fiber
NETWORK INTERFACE
Bits and Frames

Physical Layer (Layer 1) :

The functions of the physical layer are :

Bit synchronization: The physical layer provides the synchronization of the bits by providing a clock.

Bit rate control: The number of bits sent per second.

Physical topologies: Physical layer specifies the way in which the different, devices/nodes are arranged in a network i.e. bus, star or mesh topology.

Transmission mode: Physical layer also defines the way in which the data flows between the two connected devices. The various transmission modes possible are: Simplex, half-duplex and full-duplex.

Data Link Layer (DLL) (Layer 2) :

Data Link Layer is divided into two sub layers :

Logical Link Control (LLC)
Media Access Control (MAC)

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

Network Layer (Layer 3) :

The functions of the Network layer are :

Routing: The network layer protocols determine which route is suitable from source to destination.

Logical Addressing: In order to identify each device on internetwork uniquely, network layer defines an addressing scheme.

Transport Layer (Layer 4) :

The functions of the transport layer are :

- Segmentation and Reassembly
- Service Point Addressing

The services provided by the transport layer :

- Connection Oriented Service
- Connection less service

Session Layer (Layer 5) :

The functions of the session layer are :

- **Session establishment, maintenance and termination:** The layer allows the two processes to establish, use and terminate a connection.
- **Synchronization :** This layer allows a process to add checkpoints which are considered as synchronization points into the data.
- **Dialog Controller :** The session layer allows two systems to start communication with each other in half-duplex or full-duplex.

Presentation Layer (Layer 6) :

The functions of the presentation layer are :

- **Translation :** For example, ASCII to EBCDIC.
- **Encryption/ Decryption :** Data encryption translates the data into another form or code.
- **Compression:** Reduces the number of bits that need to be transmitted on the network.

Application Layer (Layer 7) :

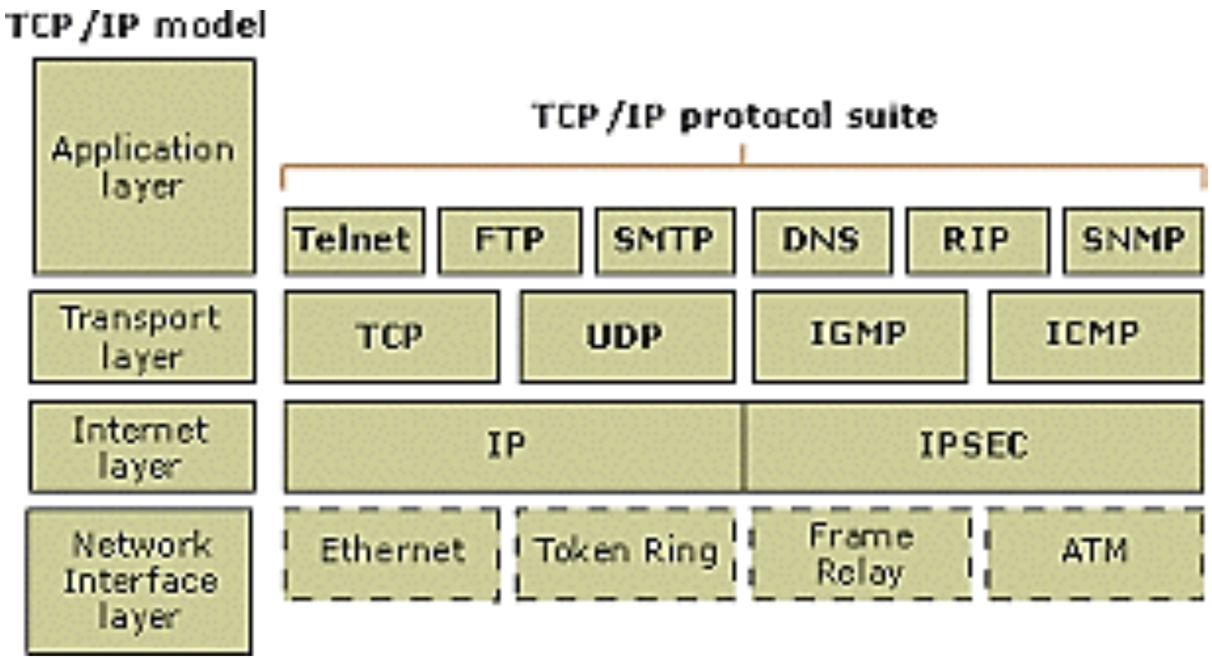
The functions of the Application layer are :

- Network Virtual Terminal
- FTAM-File transfer access and management
- Mail Services
- Directory Services

TCP / IP Reference Model

- TCP/IP Reference Model is a four-layered suite of communication protocols.
- It was developed by the DoD (Department of Defence) in the 1960s.
- It is named after the two main protocols that are used in the model, namely, TCP and IP.
- TCP stands for Transmission Control Protocol and IP stands for Internet Protocol.

TCP / IP Reference Model



Data and Signals

- One of the major functions of the physical layer is to move data in the form of electromagnetic signals across a transmission medium.
- Generally, the data usable to a person or application are not in a form that can be transmitted over a network.

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; Analog data are continuous and take continuous values.
- Analog signals can have an infinite number of values in a range;

- **Digital data** refers to information that has discrete states. Digital data have discrete states and take discrete values.
- Digital signals can have only a limited number of values.

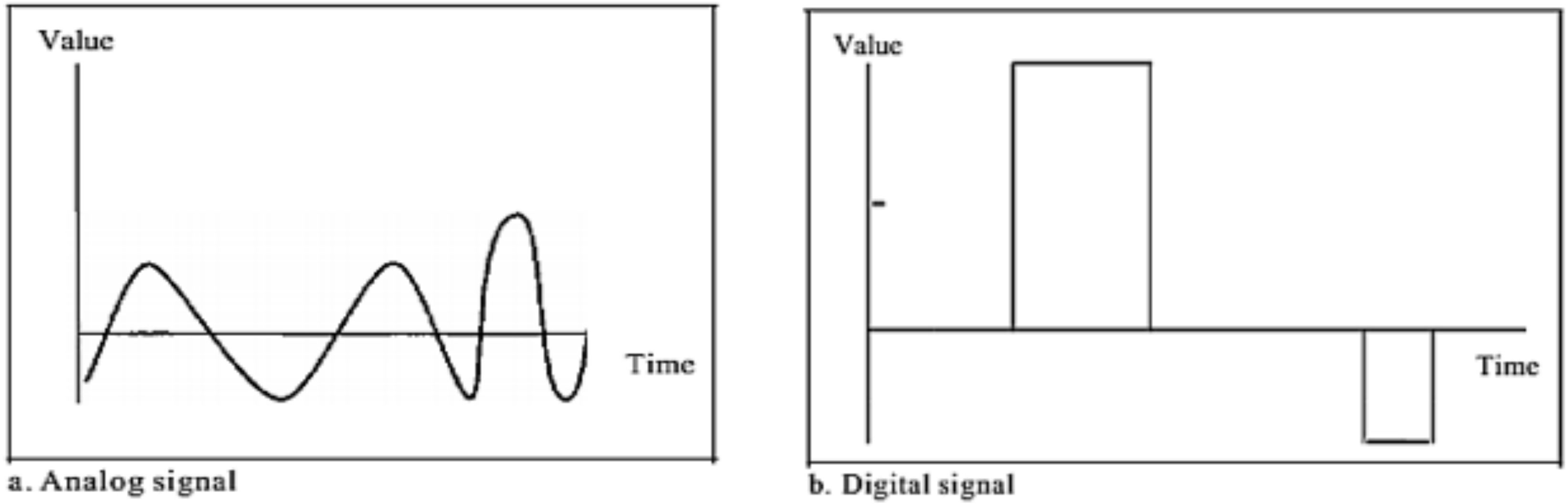


Figure : Comparison of analog and digital signals

Periodic and Nonperiodic Signals

Both analog and digital signals can take one of two forms: periodic or nonperiodic

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

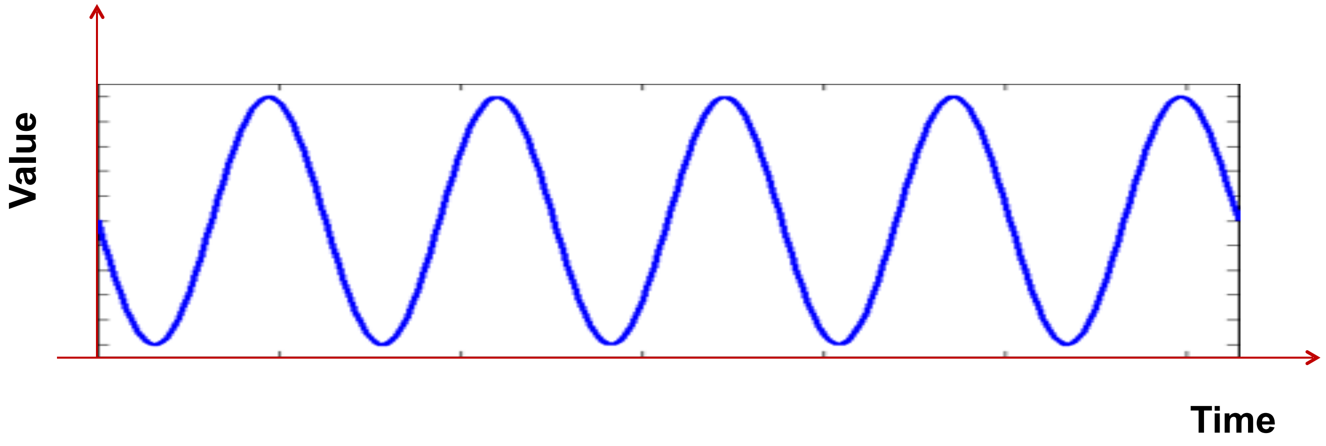
Periodic analog signals can be classified as

Simple :- a sine wave , cannot be decomposed into simpler signals.

Composite :- Composed of multiple sine waves.

Simple Signals

- The sine wave is the most fundamental form of a periodic analog signal.
- A sine wave can be represented by three parameters: the peak amplitude, the frequency, and the phase.
- These three parameters fully describe a sine wave.



Composite Signals

- 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.

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

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.

Decomposition of composite periodic signal

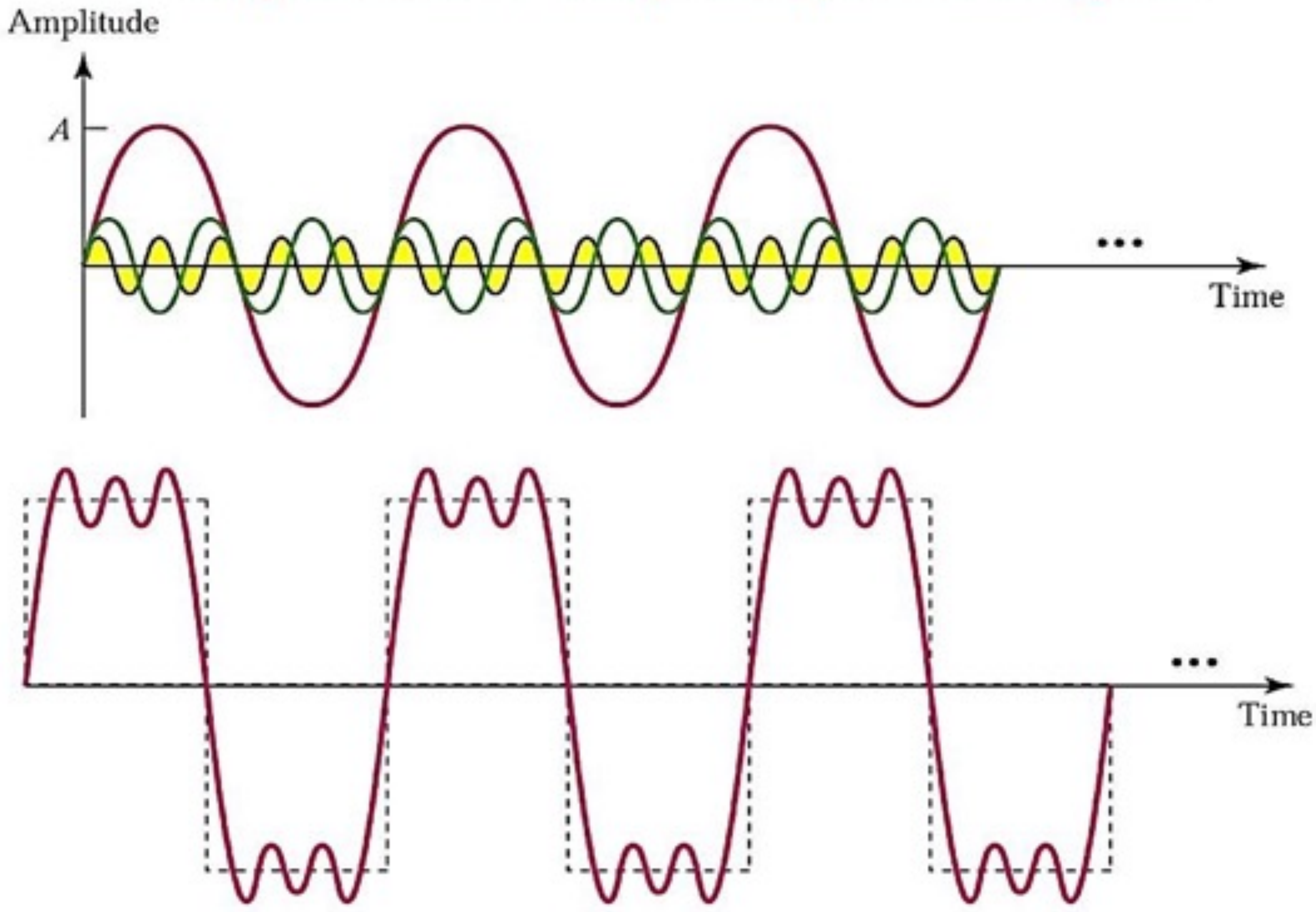


Figure : A composite periodic signal

Peak Amplitude

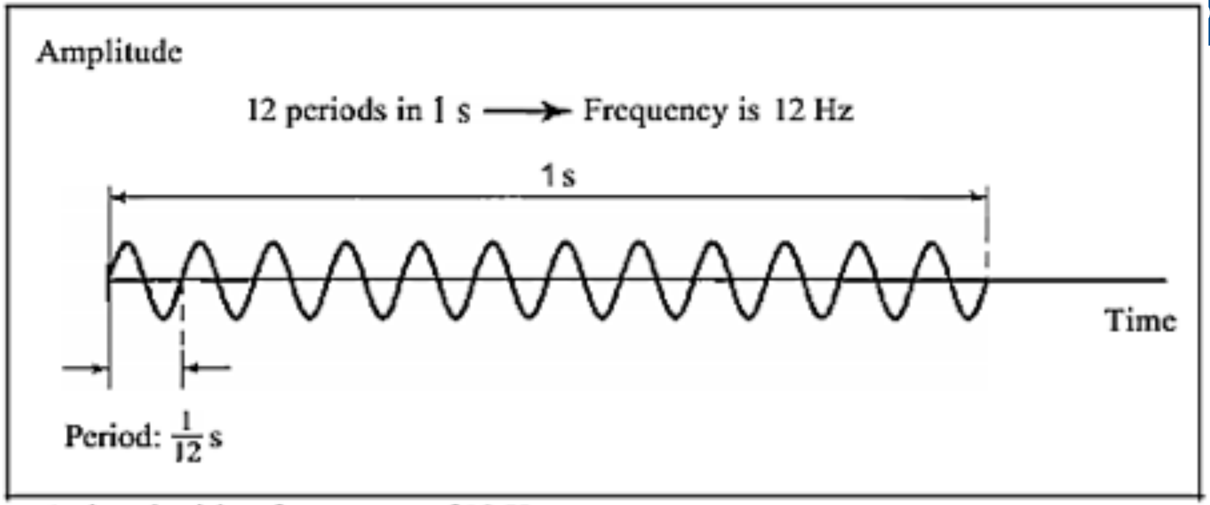
The peak amplitude of a signal is the absolute value of its highest intensity, proportional to the energy it carries.

Period and Frequency

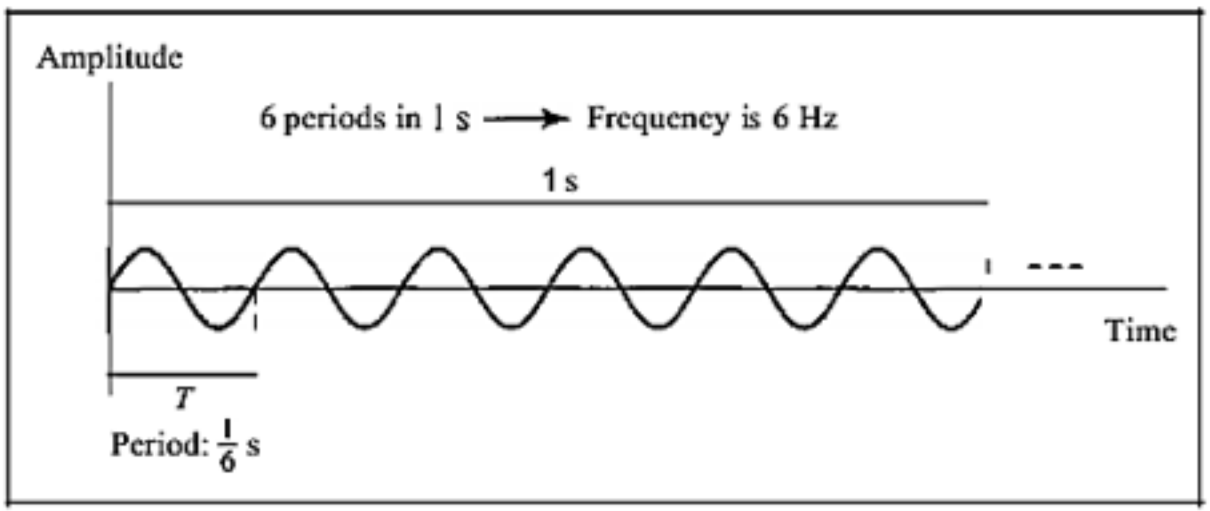
Period refers to the amount of time, in seconds, a signal needs to complete 1 cycle. Frequency refers to the number of periods in 1s.

Phase

The term phase describes the position of the waveform relative to time O.



a. A signal with a frequency of 12 Hz



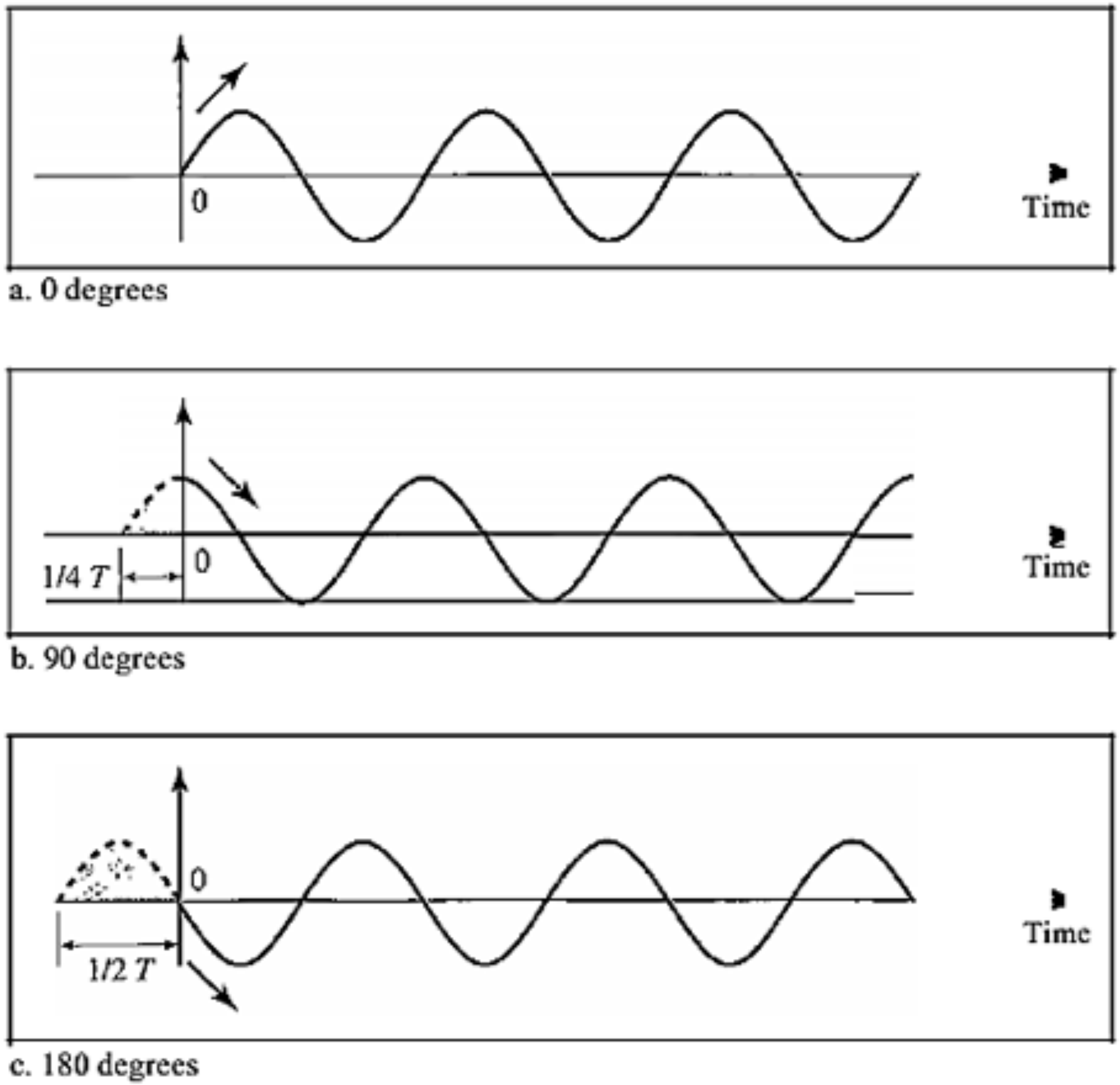
b. A signal with a frequency of 6 Hz

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

Table : Generic 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

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.



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

Wavelength

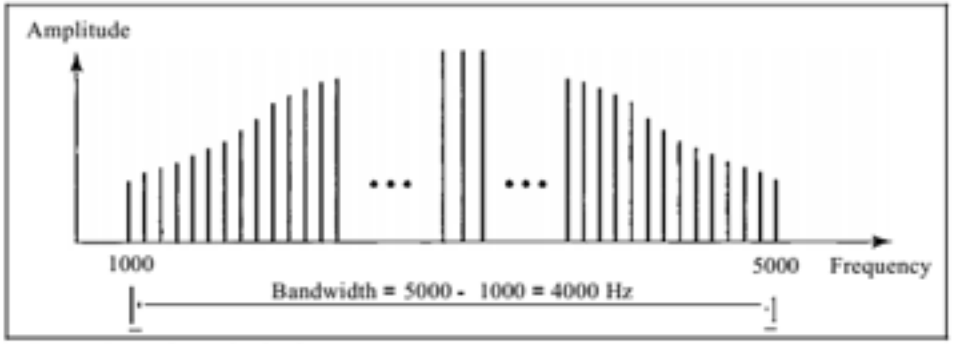
Wavelength is another characteristic of a signal traveling through a transmission medium.

Wavelength binds the period or the frequency of a simple sine wave to the propagation speed of the medium

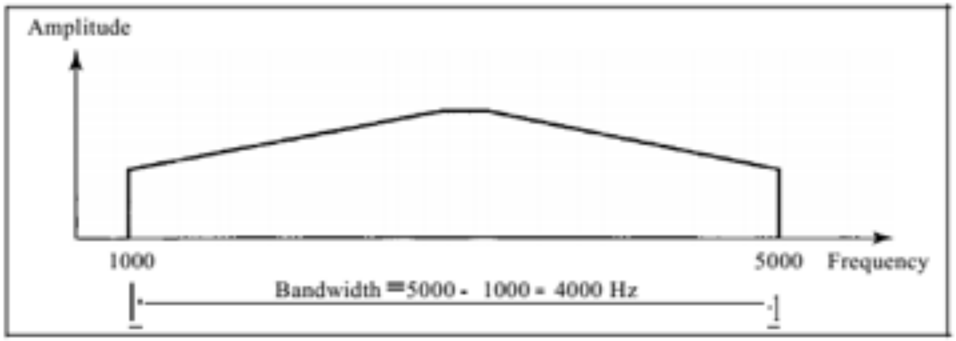
While the frequency of a signal is independent of the medium, the wavelength depends on both the frequency and the medium. Wavelength is a property of any type of signal.

Bandwidth

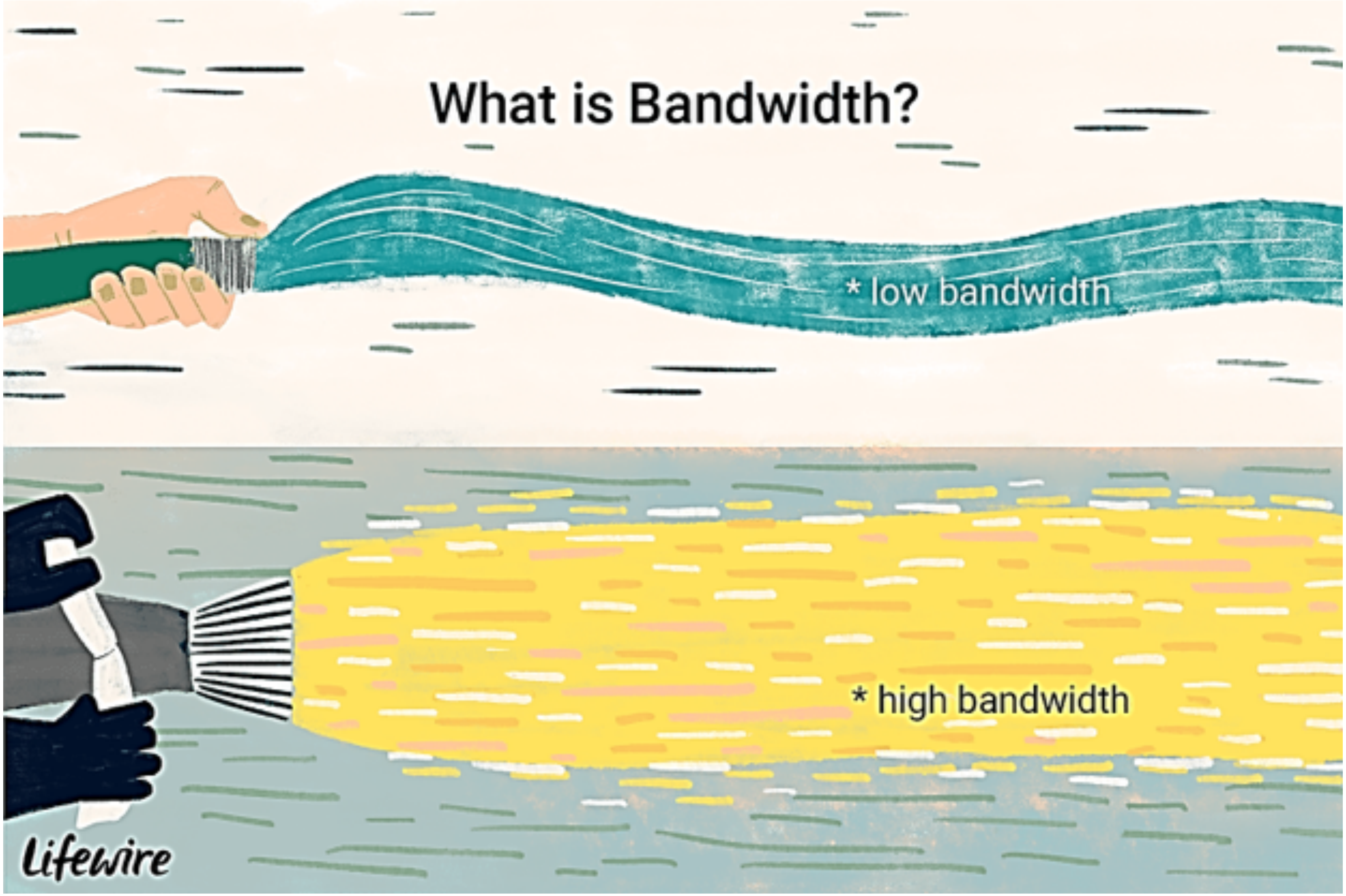
The range of frequencies contained in a composite signal is its bandwidth. The bandwidth is normally a difference between two numbers.



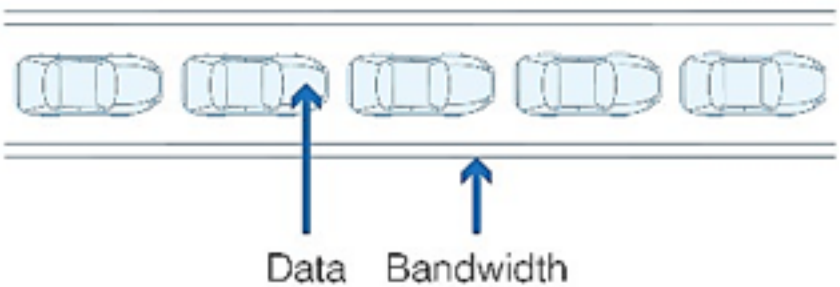
a. Bandwidth of a periodic signal

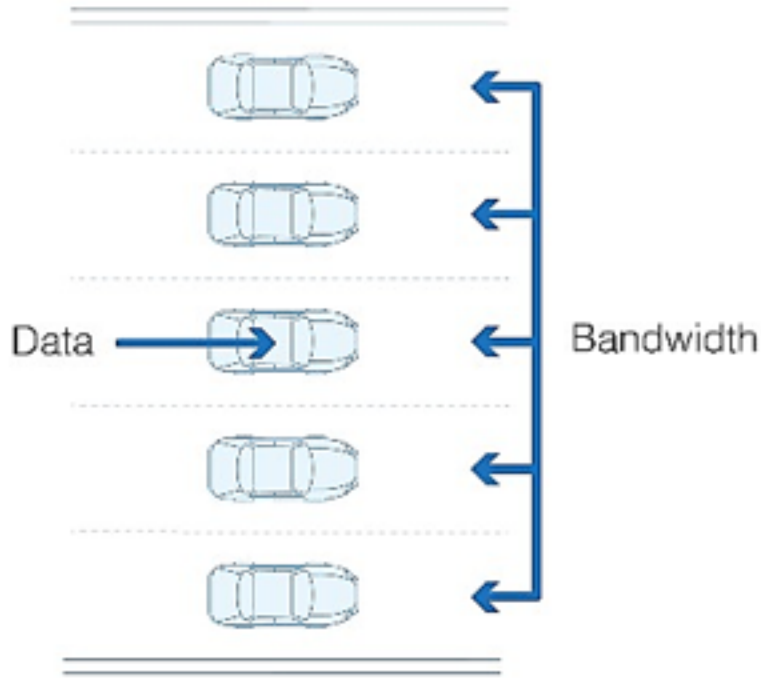


b. Bandwidth of a nonperiodic signal


What is Bandwidth?
* low bandwidth
* high bandwidth
Lifewire

Bandwidth Vs Throughput

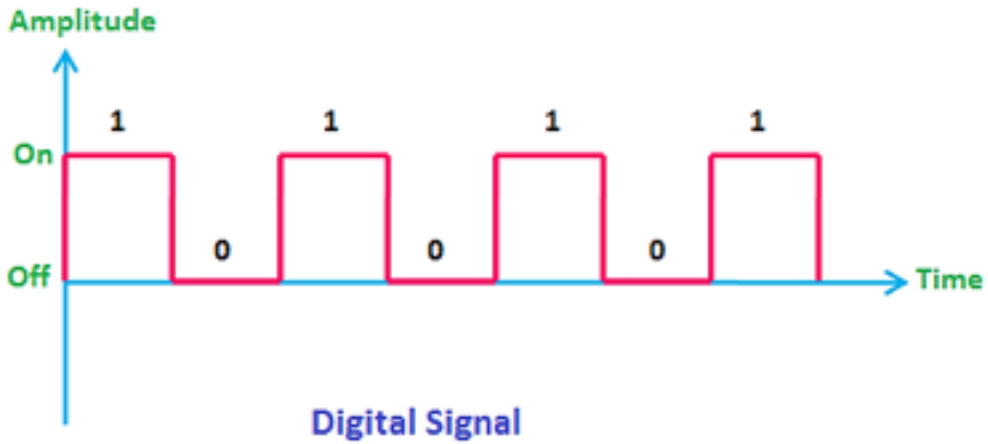




Throughput:
One data packet arrives within one second.

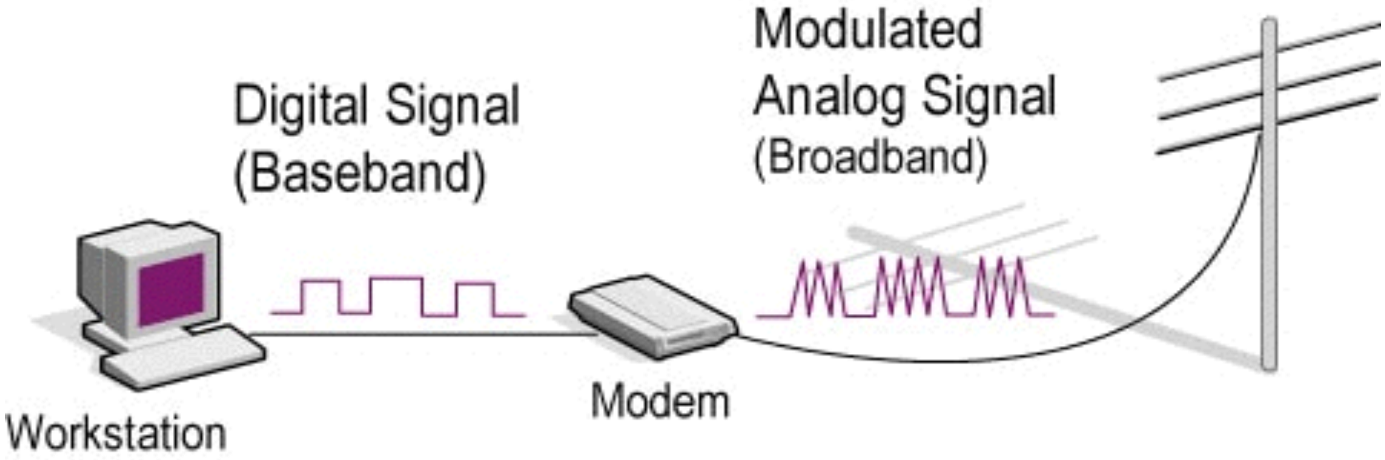
Throughput:
One data packet arrives within one second.

Special Case – Digital Signal transmission

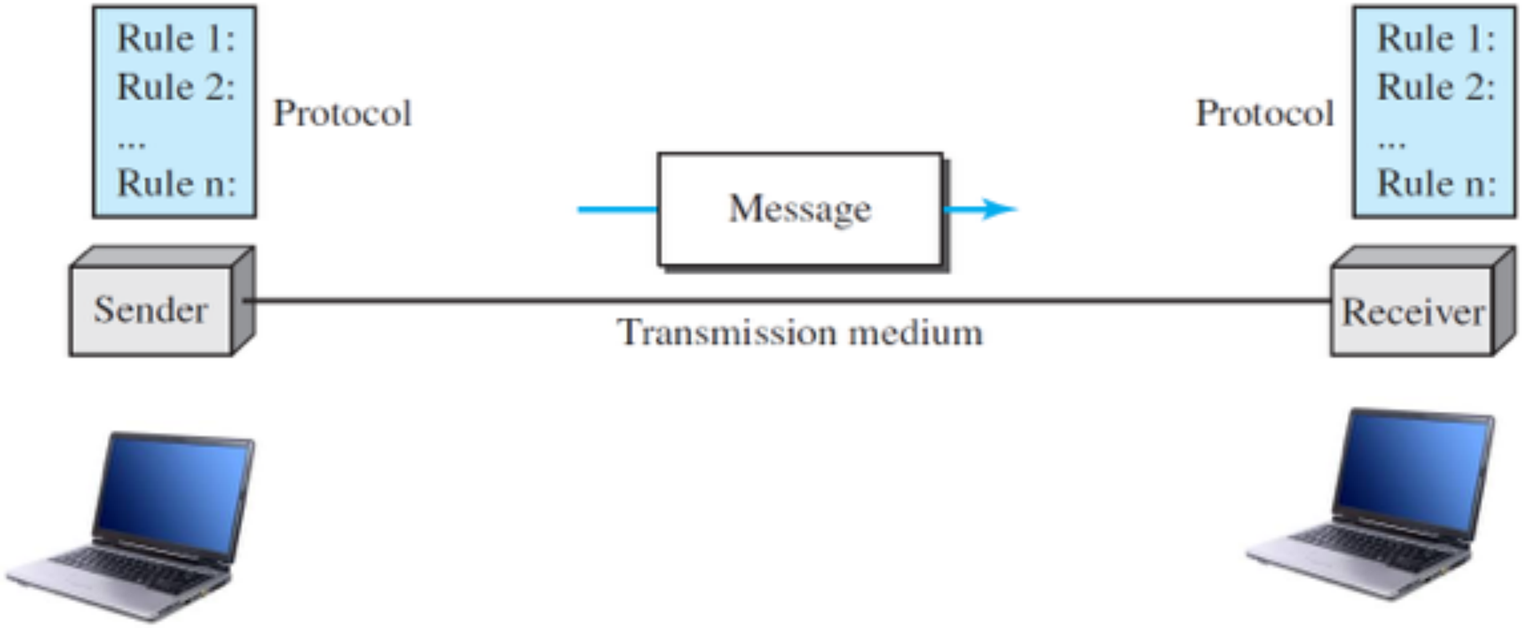


Bit Rate : Number of bits sent in 1s
Bit Length : Propagation speed x bit duration
Transmission of Digital Signals : Baseband Transmission

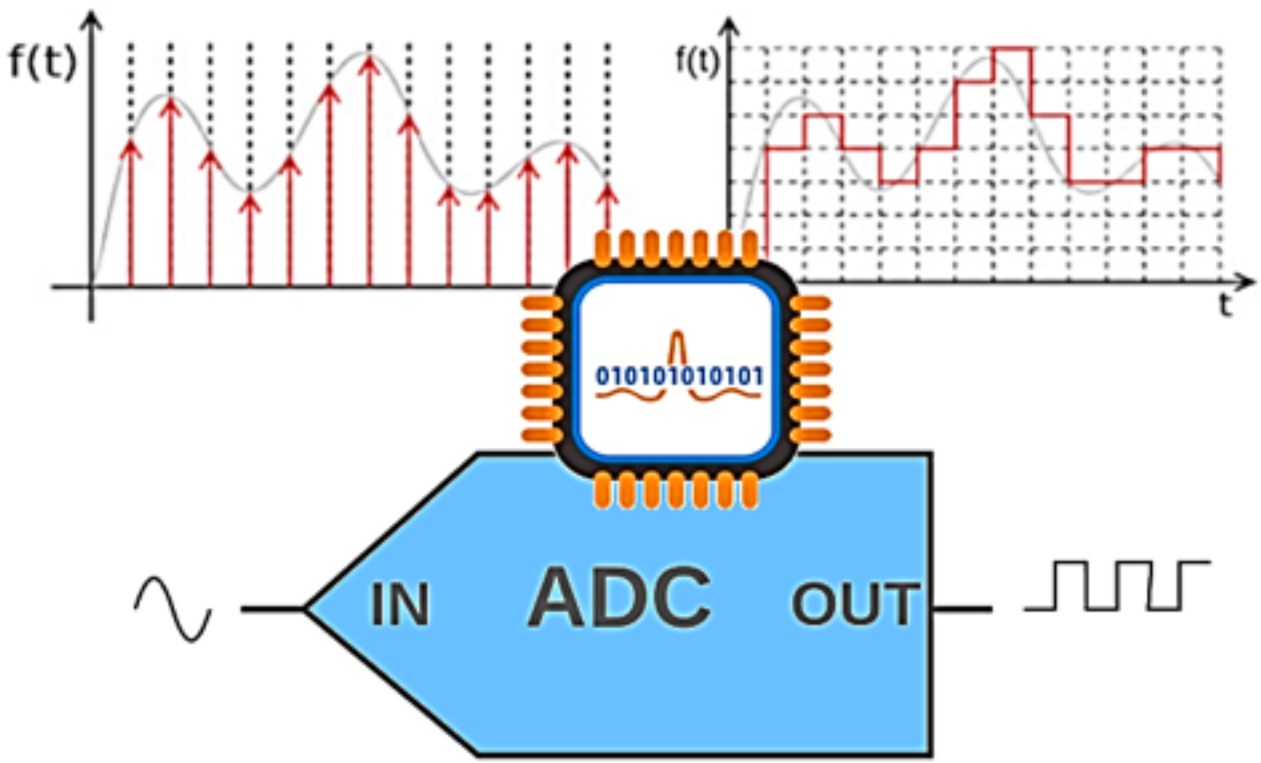
Baseband Transmission – Network



REViEW

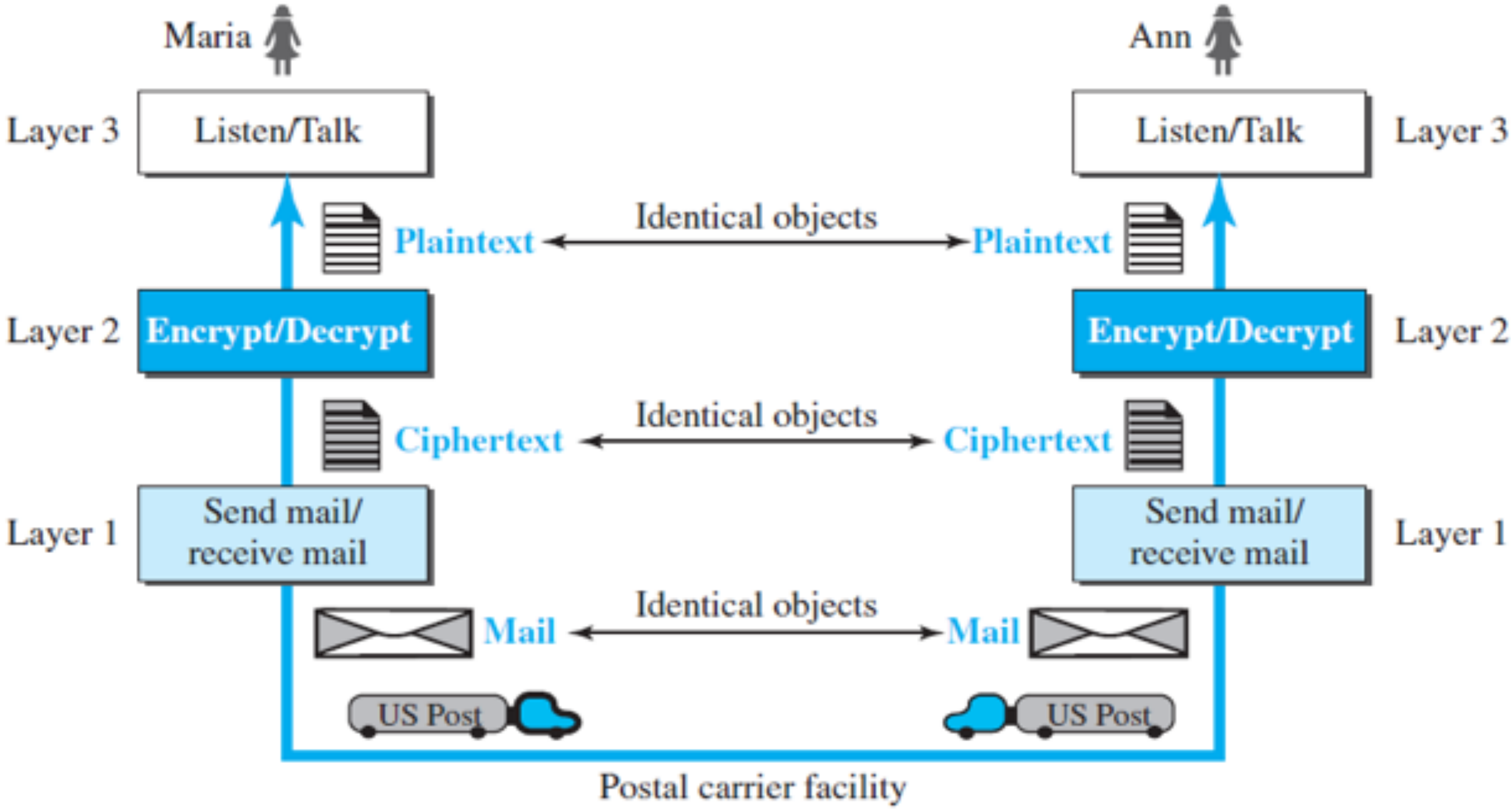

Rule 1:
Rule 2:
...
Rule n:
Protocol
Message
Protocol
Rule 1:
Rule 2:
...
Rule n:
Sender
Transmission medium
Receiver

REViEW

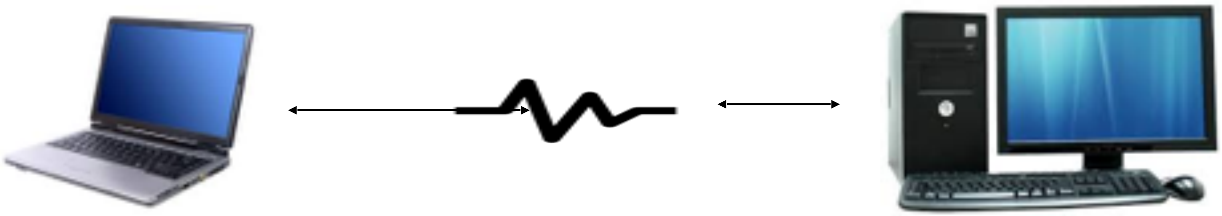


Data must be transformed to electromagnetic signals to be transmitted. Data can be analog or digital. Analog data are continuous and take continuous values. Digital data have discrete states and take discrete values.

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.


Maria
Ann
Layer 3
Listen/Talk
Listen/Talk
Layer 3
Plaintext
Identical objects
Plaintext
Layer 2
Encrypt/Decrypt
Encrypt/Decrypt
Layer 2
Ciphertext
Identical objects
Ciphertext
Layer 1
Send mail/
receive mail
Send mail/
receive mail
Layer 1
Mail
Identical objects
Mail
US Post
US Post
Postal carrier facility

TRANSMISSION IMPAIRMENT



- Signals travel through transmission media, which are not perfect.
- The imperfection causes signal impairment.
- This means that the signal at the beginning of the medium is not the same as the signal at the end of the medium.

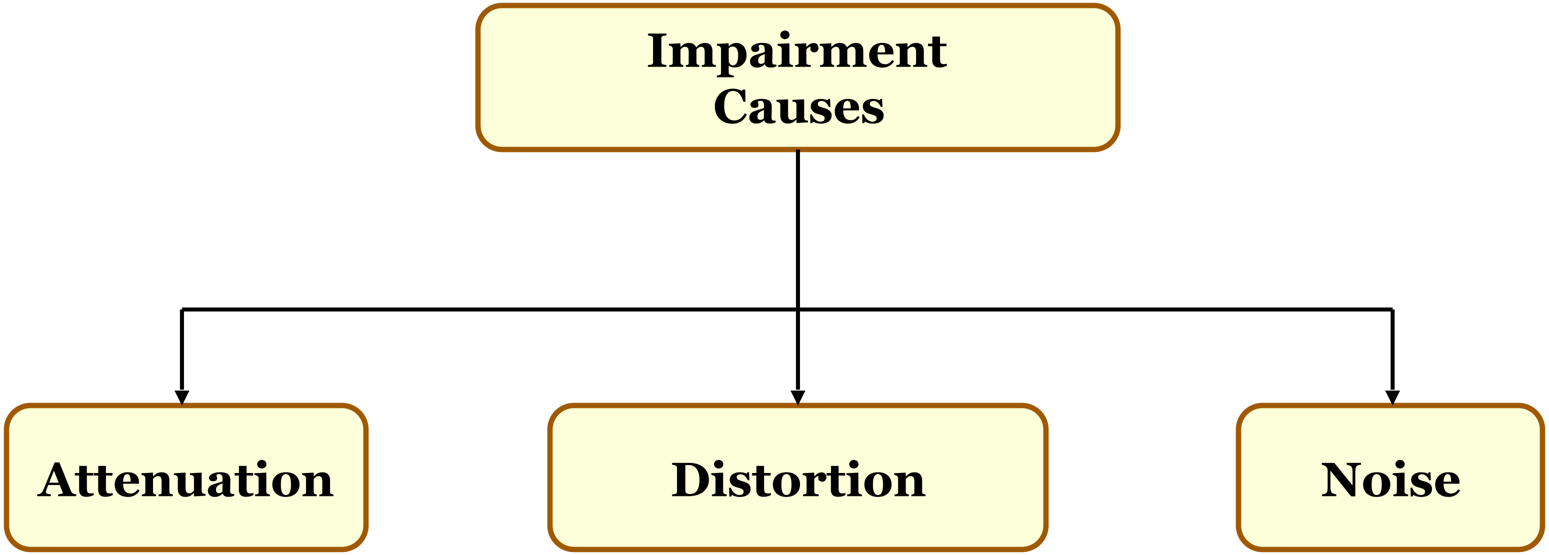
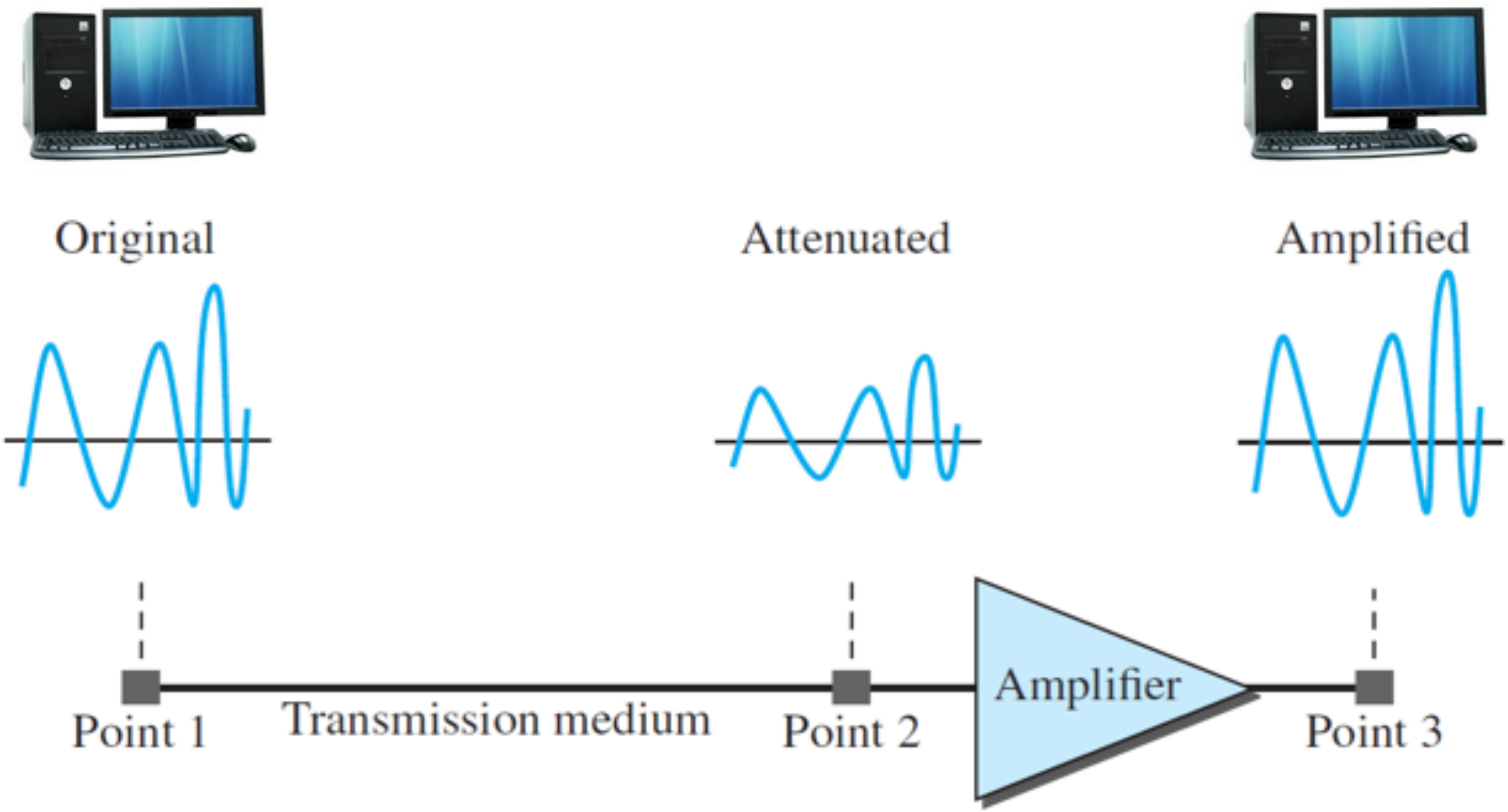


Figure : Causes of impairment

Attenuation

- Attenuation means a loss of energy.
- When a signal, simple or composite, travels through a medium, it loses some of its energy in overcoming the resistance of the medium.
- That is why a wire carrying electric signals gets warm, if not hot, after a while. Some of the electrical energy in the signal is converted to heat.
- To compensate for this loss, amplifiers are used to amplify the signal.


Original
Attenuated
Amplified
Amplifier
Point 1
Transmission medium
Point 2
Point 3

Decibel

- To show that a signal has lost or gained strength, engineers use the unit of the decibel.
- The decibel (dB) measures the relative strengths of two signals or one signal at two different points.

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

Variables P1 and P2 are the powers of a signal at points 1 and 2, respectively. Note that the decibel is negative if a signal is attenuated and positive if a signal is amplified.

Example 1:

Suppose a signal travels through a transmission medium and its power is reduced to one-half.

This means that P2 = 1/2 P1 In this case, the attenuation (loss of power) can be calculated as

$$10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{0.5P_1}{P_1}$$

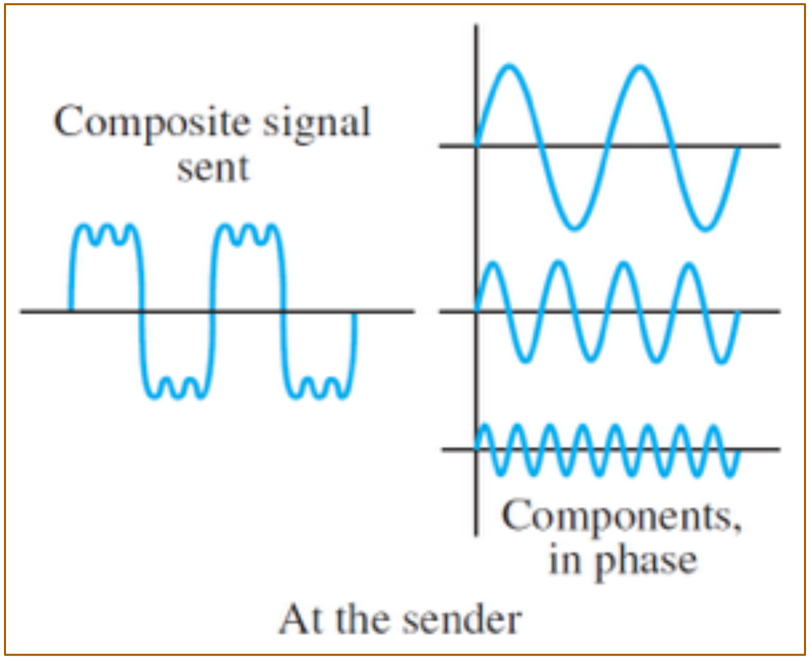
$$10 \log_{10} 0.5 = 10(-0.3) = -3 \text{ dB}$$

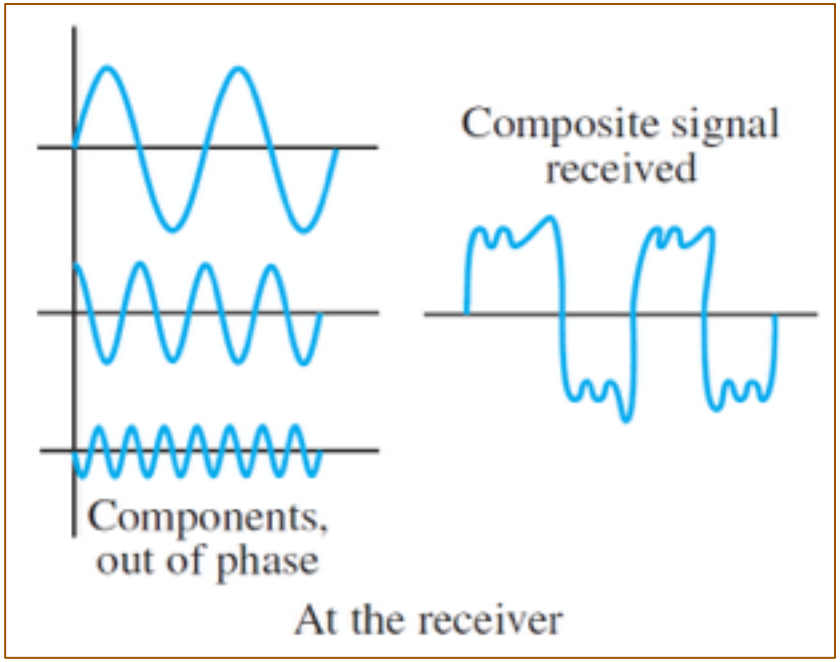
Distortion

- Distortion means that the signal changes its form or shape. Distortion can occur in a composite signal made of different frequencies.

- Each signal component has its own propagation speed (see the next section) through a medium and, therefore, its own delay in arriving at the final destination.

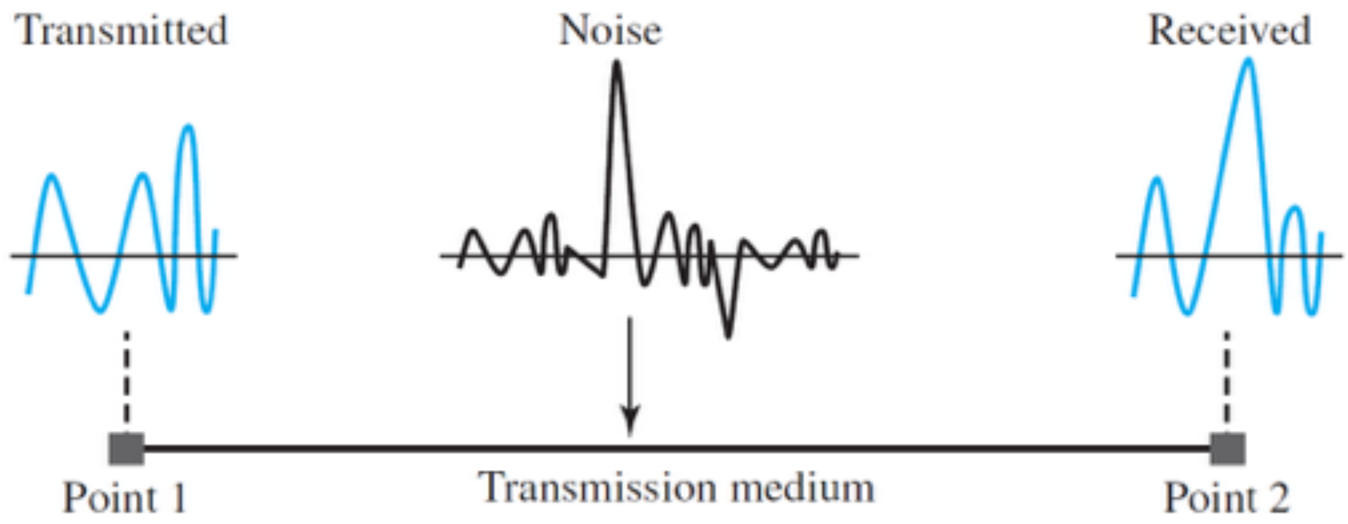
- Differences in delay may create a difference in phase if the delay is not exactly the same as the period duration.


Composite signal
sent
Components,
in phase
At the sender


Composite signal
received
Components,
out of phase
At the receiver

Noise

Noise is another cause of impairment. Several types of noise, such as thermal noise, induced noise, crosstalk, and impulse noise, may corrupt the signal.



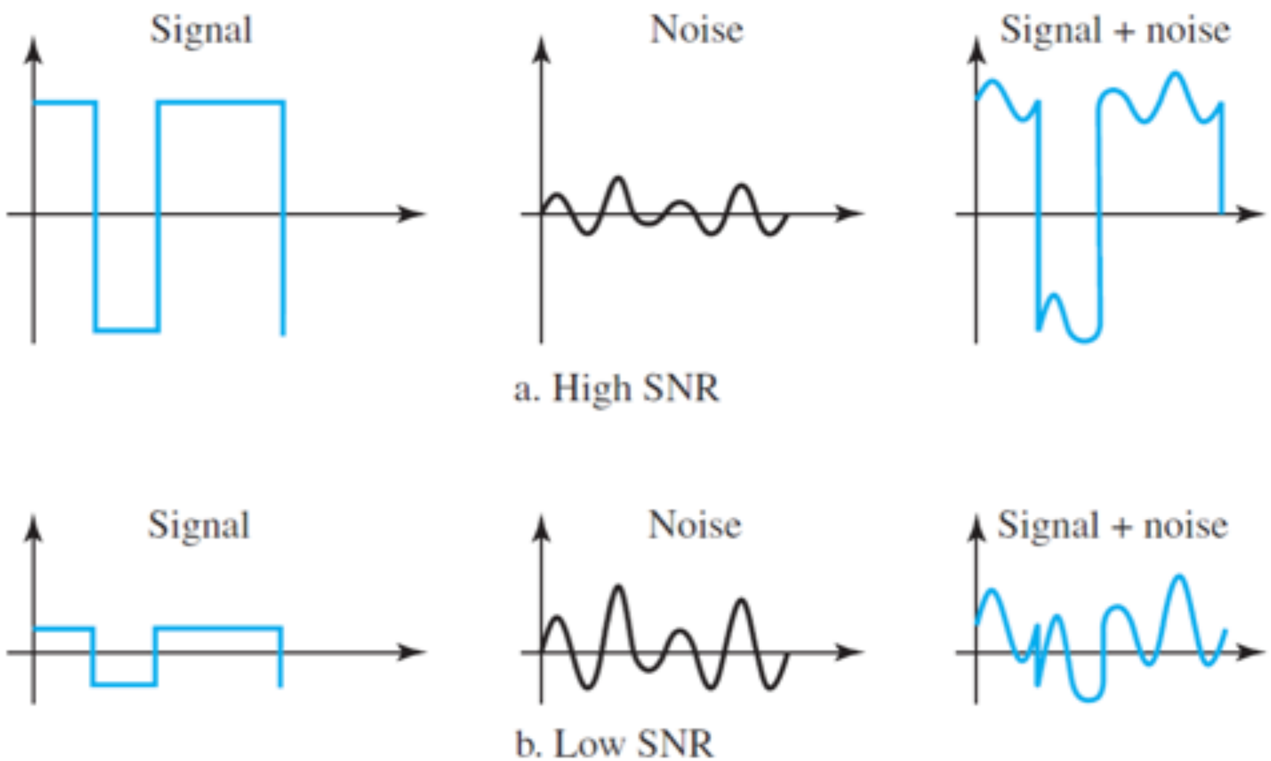
- **Thermal noise** is the random motion of electrons in a wire, which creates an extra signal not originally sent by the transmitter.

- **Induced** noise comes from sources such as motors and appliances. These devices act as a sending antenna, and the transmission medium acts as the receiving antenna.

- **Crosstalk** is the effect of one wire on the other. One wire acts as a sending antenna and the other as the receiving antenna.

- **Impulse noise** is a spike (a signal with high energy in a very short time) that comes from power lines, lightning, and so on.

Signal-to-Noise Ratio (SNR)



$$\text{SNR} = \frac{\text{average signal power}}{\text{average noise power}}$$

- SNR is actually the ratio of what is wanted (signal) to what is not wanted (noise). A high SNR means the signal is less corrupted by noise; a low SNR means the signal is more corrupted by noise.

- Because SNR is the ratio of two powers, it is often described in decibel units, SNR_{dB}, defined as

$$\boxed{\mathrm{SNR}_{\mathrm{dB}} = 10 \log_{10} \mathrm{SNR}}$$

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)

Two theoretical formulas were developed to calculate the data rate: one by Nyquist for a noiseless channel, another by Shannon for a noisy channel.

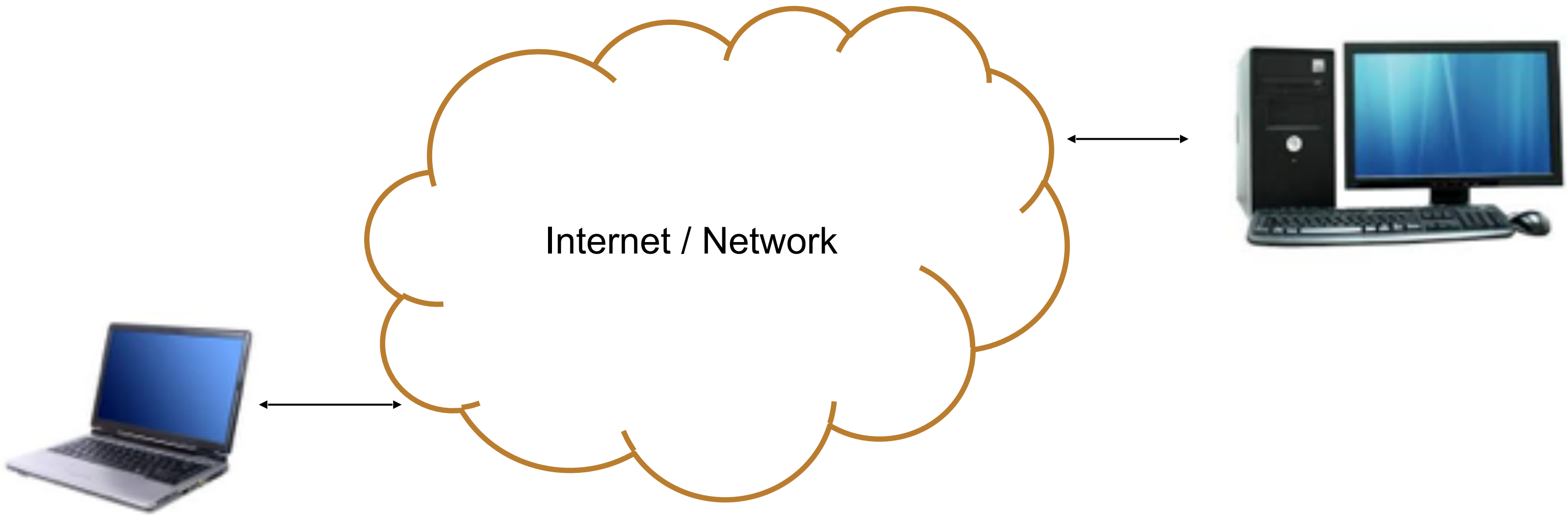
Noiseless Channel: Nyquist Bit Rate

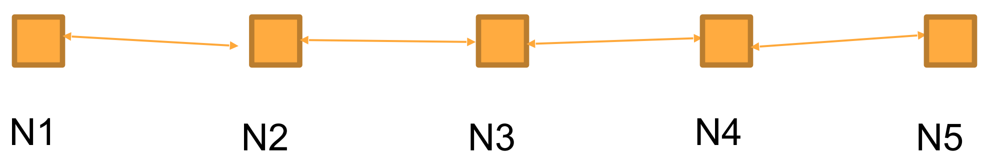
Increasing the levels of a signal may reduce the reliability of the system.

$$\boxed{\text{BitRate} = 2 \times \text{bandwidth} \times \log_2 L}$$

Noisy Channel: Shannon Capacity

$$\boxed{\text{Capacity} = \text{bandwidth} \times \log_2(1 + \text{SNR})}$$


Internet / Network


N1
N2
N3
N4
N5

Digital-to-digital Conversion:

- **Line coding** is used to convert digital data to a digital signal.
- **Block coding**, which is used to create redundancy in the digital data before they are encoded as a digital signal. Redundancy is used as an inherent error detecting tool.
- The **scrambling**, a technique used for digital-to-digital conversion in long-distance transmission.

Analog-to-digital conversion:

- **Pulse code modulation (PCM)** is described as the main method used to sample an analog signal.
- **Delta modulation (DM)** is used to improve the efficiency of the pulse code modulation.

LINE CODING

- Line coding is the process of converting digital data to digital signals.
- We assume that data, in the form of text, numbers, graphical images, audio, or video, are stored in computer memory as sequences of bits.
- Line coding converts a sequence of bits to a digital signal.
- At the sender, digital data are encoded into a digital signal; at the receiver, the digital data are recreated by decoding the digital signal.

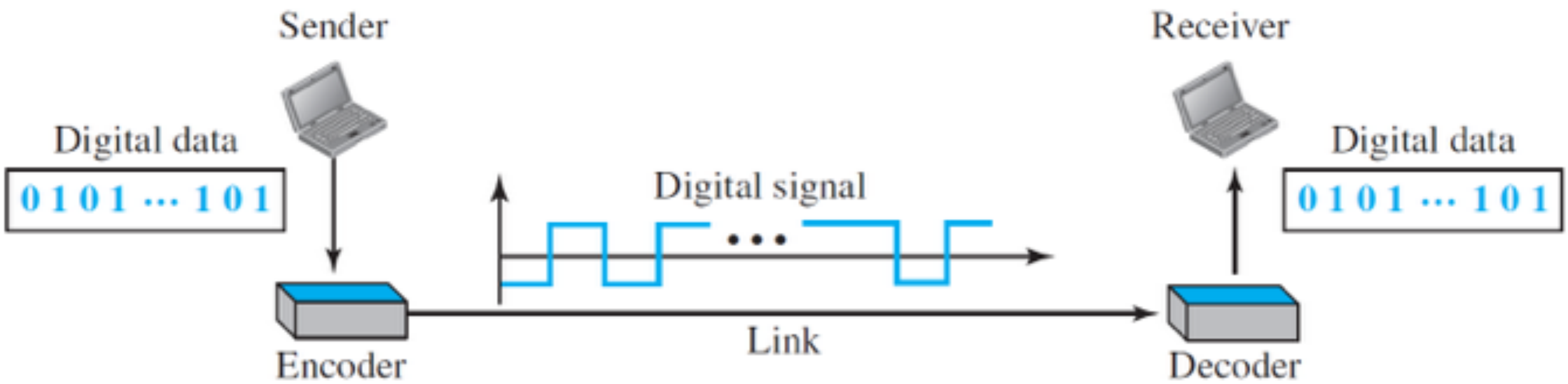


Figure : Line coding and decoding

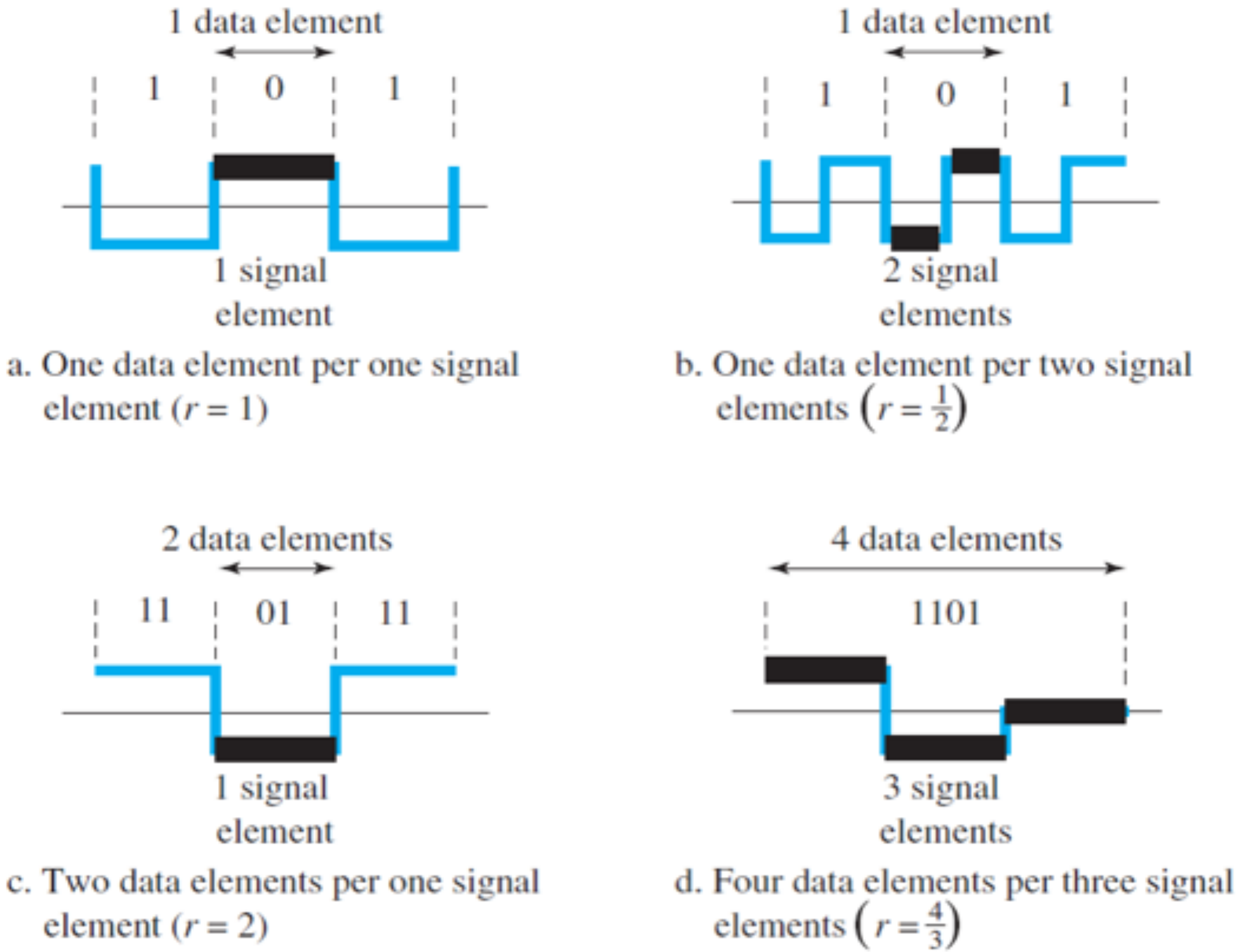


Figure : Signal element versus data element

Data Rate Versus Signal Rate

- The data rate defines the number of data elements (bits) sent in 1s. The unit is bits per second (bps).
- The signal rate is the number of signal elements sent in 1s. The unit is the baud.
- There are several common terminologies used in the literature.
- The data rate is sometimes called the bit rate; the signal rate is sometimes called the pulse rate, the modulation rate, or the baud rate.

Consider the relationship between data rate (N) and signal rate (S) in which “r” is ratio This relationship, of course, depends on the value of r.

$$\boxed{S = N/r}$$

It also depends on the data pattern. If we have a data pattern of all 1s or all 0s, the signal rate may be different from a data pattern of alternating 0’s and 1’s.

$$\boxed{S_{\text{ave}} = c \times N \times (1/r) \qquad \textbf{baud}}$$

Example :

A signal is carrying data in which one data element is encoded as one signal element ($r = 1$). If the bit rate is 100 kbps, what is the average value of the baud rate if c is between 0 and 1?

We assume that the average value of c is $1/2$.

Solution

We assume that the average value of c is $1/2$. The baud rate is then

$$S = c \times N \times (1 / r) = 1/2 \times 100{,}000 \times (1/1)$$
$$= 50{,}000$$
$$= 50 \text{ kbaud}$$

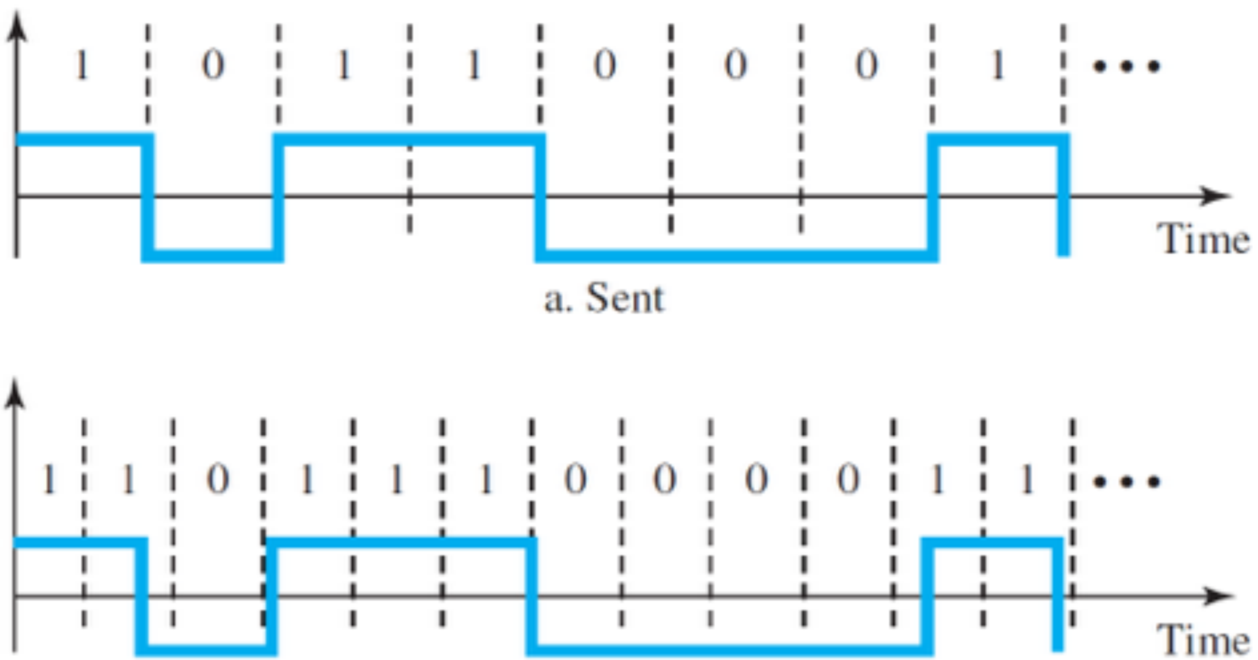
Example :

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

Effect of lack of synchronization



a. Sent

b. Received

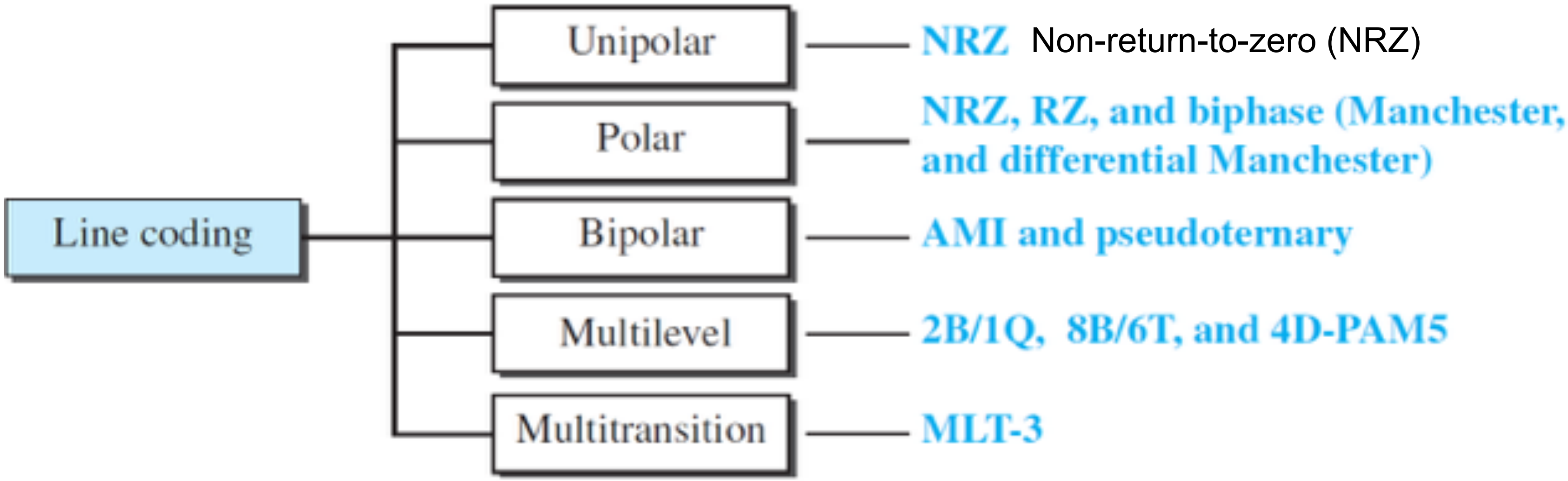
At 1 kbps, the receiver receives 1001 bps instead of 1000 bps.

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**

Line Coding Schemes



Non-return-to-zero (NRZ)

Two binary, one quaternary (2B1Q),
Eight binary, six ternary (8B6T).
Four-dimensional fivelevel pulse amplitude modulation (4D-PAM5)

Summary of Line Coding Schemes

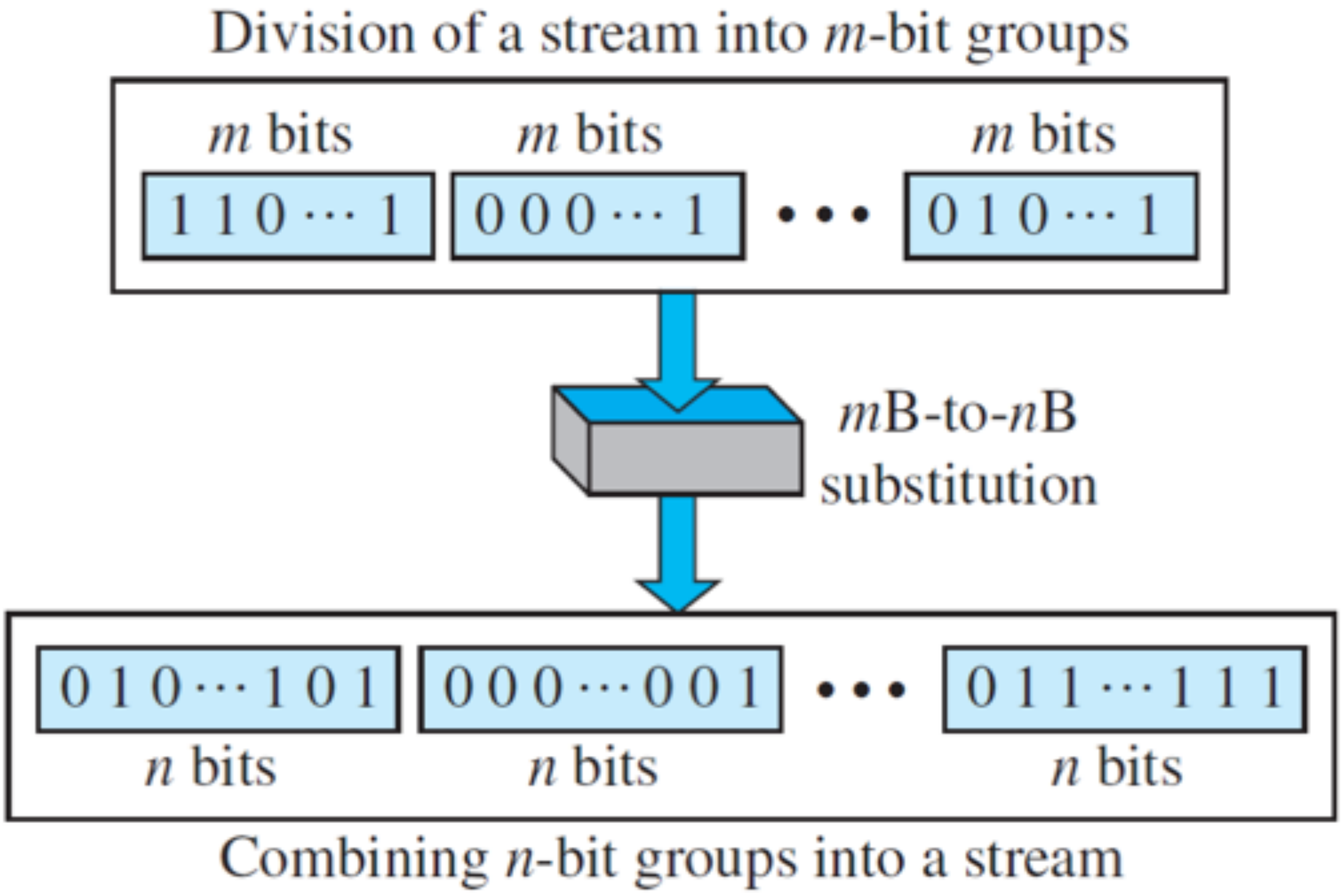
Category	*Scheme*	*Bandwidth (average)*	*Characteristics*
Unipolar	NRZ	$B = N/2$	Costly, no self-synchronization if long 0s or 1s, DC
Polar	NRZ-L	$B = N/2$	No self-synchronization if long 0s or 1s, DC
	NRZ-I	$B = N/2$	No self-synchronization for long 0s, DC
	Biphase	$B = N$	Self-synchronization, no DC, high bandwidth
Bipolar	AMI	$B = N/2$	No self-synchronization for long 0s, DC
Multilevel	2B1Q	$B = N/4$	No self-synchronization for long same double bits
	8B6T	$B = 3N/4$	Self-synchronization, no DC
	4D-PAM5	$B = N/8$	Self-synchronization, no DC
Multitransition	MLT-3	$B = N/3$	No self-synchronization for long 0s

BLOCK CODING

Block coding is normally referred to as *mB/nB* coding; it replaces each *m*-bit group with an *n*-bit group.

- We need redundancy to ensure synchronization and to provide some kind of inherent error detecting.
- Block coding can give us this redundancy and improve the performance of line coding.
- In general, block coding changes a block of m bits into a block of n bits, where n is larger than m.

Block coding concept



SCRAMBLING

scrambling, as opposed to block coding, is done at the same time as encoding. The system needs to insert the required pulses based on the defined scrambling rules.

Two common scrambling techniques are B8ZS and HDB3.

Deliberate distortion or encoding of audio/ video signals, or a data stream, through an electronic device (scrambler) to prevent unauthorized reception in 'plain' or 'readable' form.

Bandwidth Utilization: Multiplexing and Spectrum Spreading

In real life, we have links with limited bandwidths. The wise use of these bandwidths has been, and will be, one of the main challenges of electronic communications

- Sometimes we need to combine several low-bandwidth channels to make use of one channel with a larger bandwidth.
- Sometimes we need to expand the bandwidth of a channel to achieve goals such as privacy and antijamming.

MULTIPLEXING

- Multiplexing is the set of techniques that allow the simultaneous transmission of multiple signals across a single data link.

- As data and telecommunications use increases, so does traffic.

- We can accommodate this increase by continuing to add individual links each time a new channel is needed; or we can install higher-bandwidth links and use each to carry multiple signals.

MULTIPLEXING

Multiplexing is a method by which multiple analog or digital signals are combined into one signal over a shared medium. The aim is to share a scarce resource.

- The multiplexed signal is transmitted over a communication channel such as a cable.
- The multiplexing divides the capacity of the communication channel into several logical channels, one for each message signal or data stream to be transferred.
- A reverse process, known as demultiplexing, extracts the original channels on the receiver end.

A device that performs the multiplexing is called a multiplexer (MUX), and a device that performs the reverse process is called a demultiplexer (DEMUX or DMX).

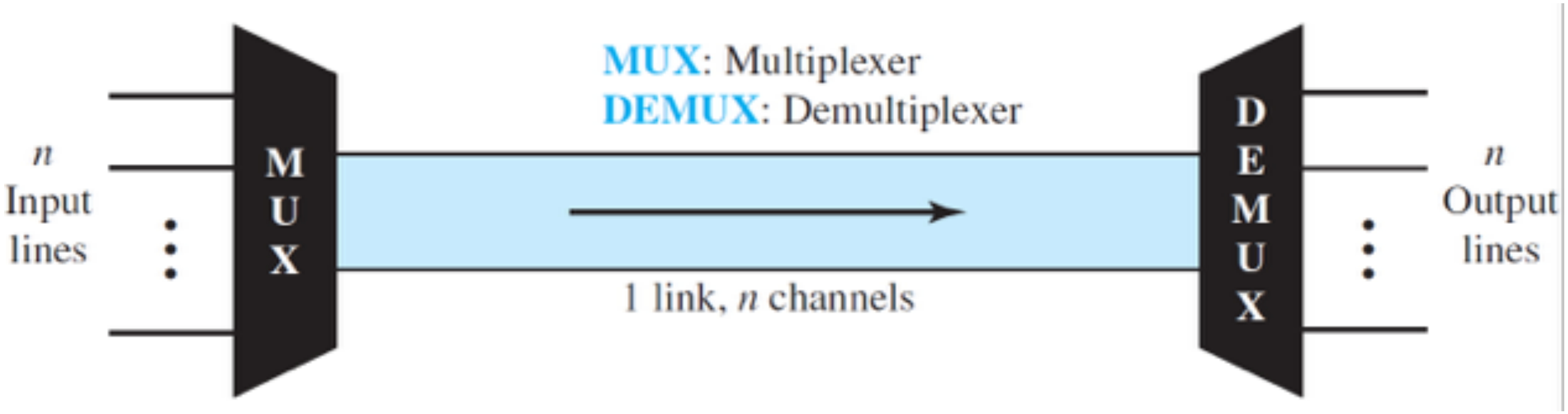


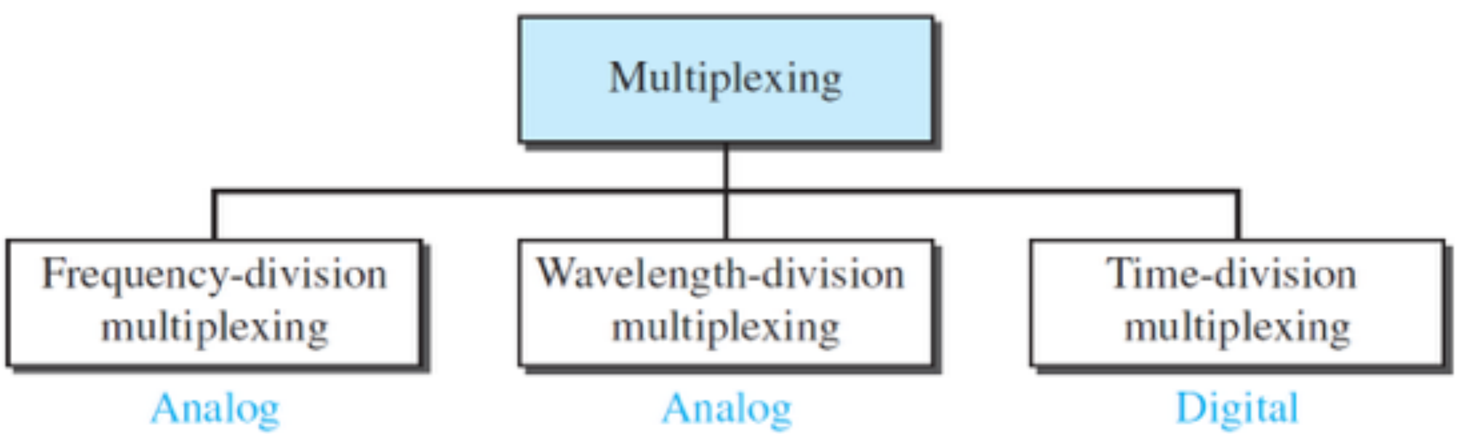
Fig : Dividing a link into channels

Types

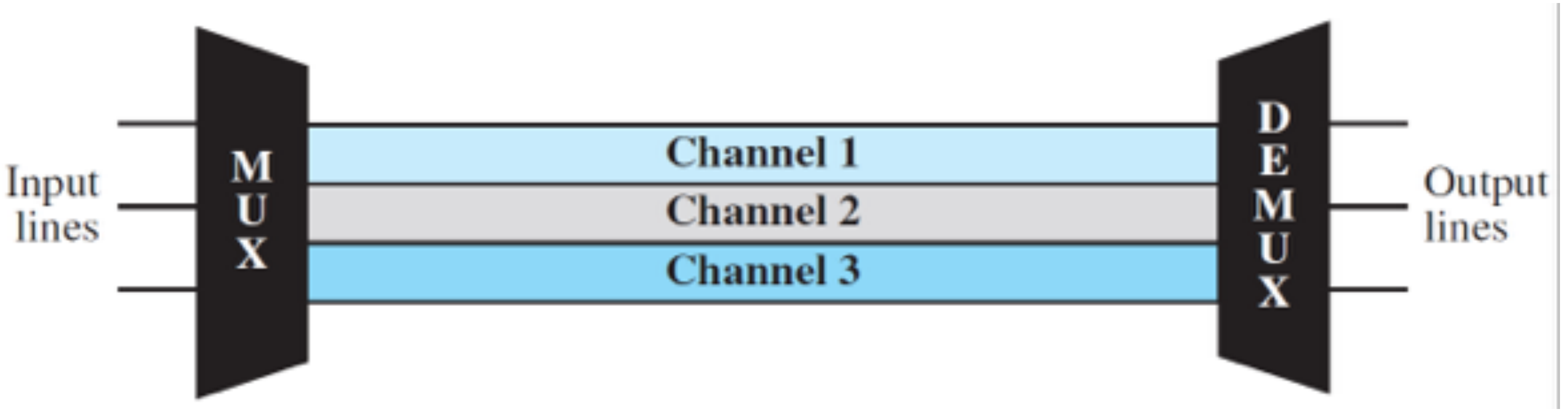
- Frequency-division multiplexing
- Time-division multiplexing
- Code-division multiplexing
- Wavelength Division Multiplexing
- Space-division multiplexing
- Polarization-division multiplexing
- Orbital angular momentum multiplexing

- Focusing on three basic multiplexing techniques: frequency-division multiplexing, wavelength-division multiplexing, and time-division multiplexing.

- The first two are techniques designed for analog signals, the third, for digital signals



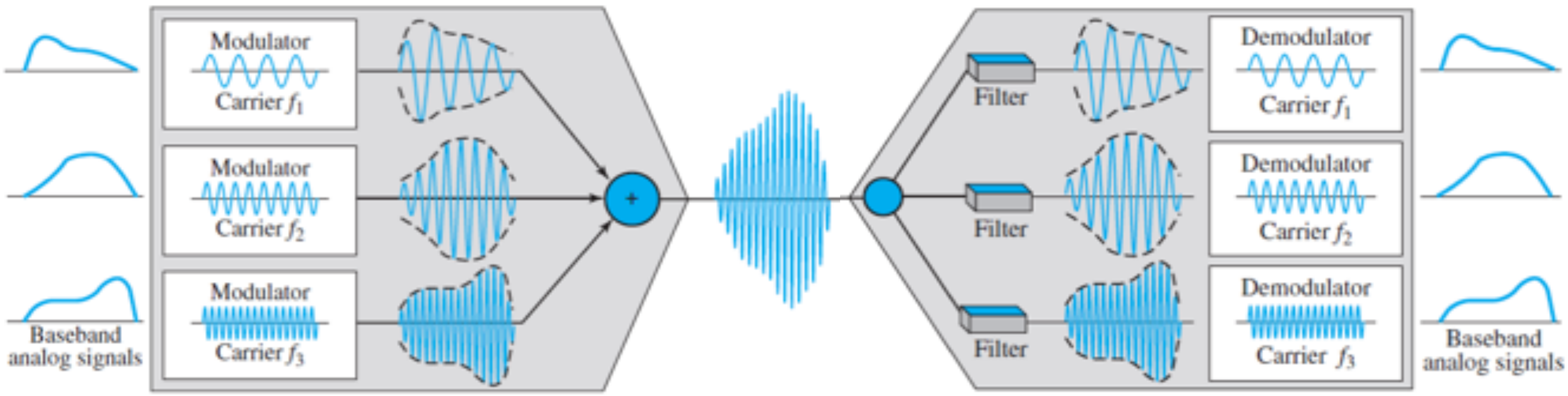
Frequency-Division Multiplexing



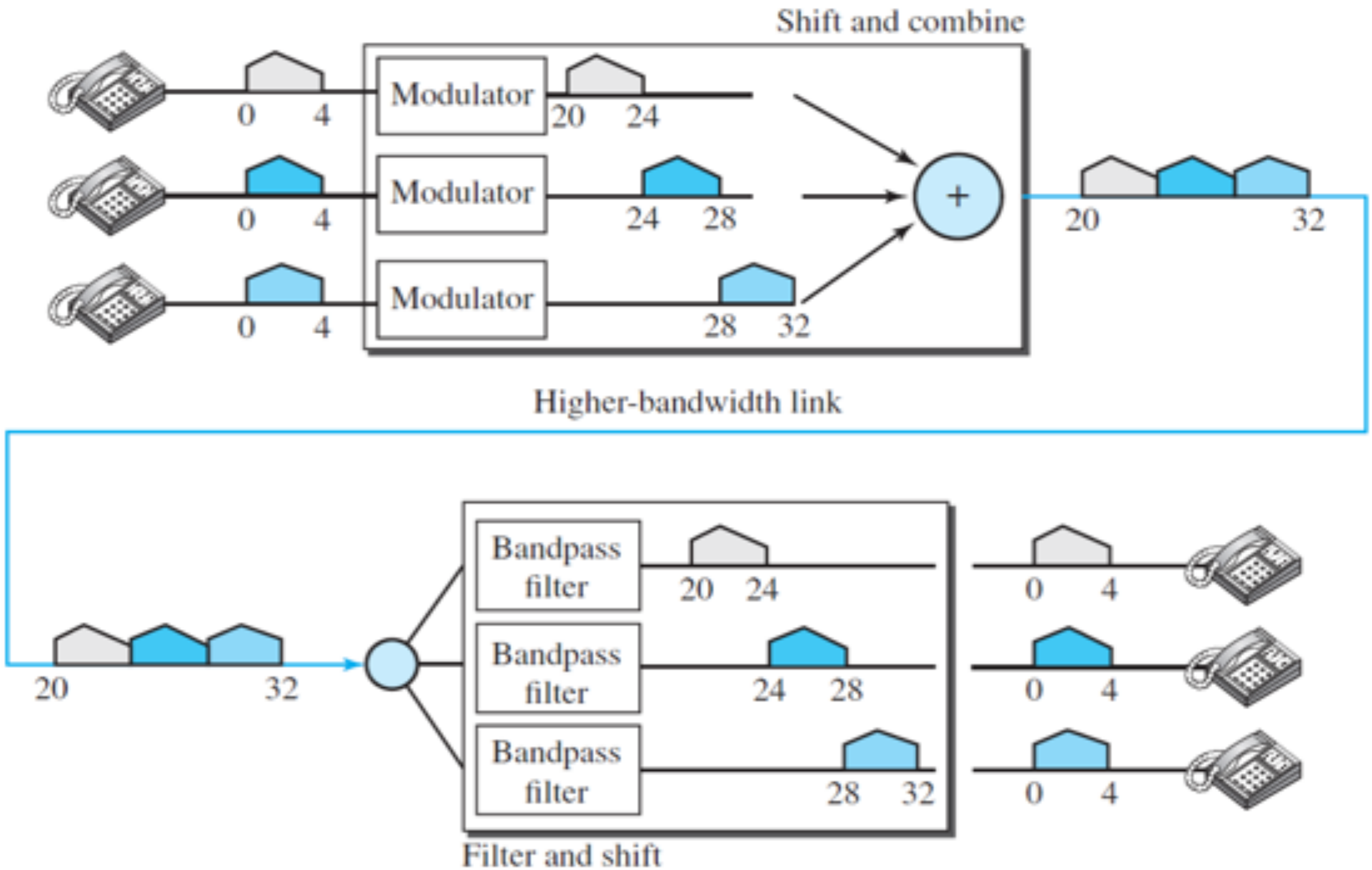
Frequency-division multiplexing (FDM) is a technique by which the total bandwidth available in a communication medium is divided into a series of non-overlapping frequency bands, each of which is used to carry a separate signal.

- In FDM, signals generated by each sending device modulate different carrier frequencies.
- These modulated signals are then combined into a single composite signal that can be transported by the link.
- Carrier frequencies are separated by sufficient bandwidth to accommodate the modulated signal.
- These bandwidth ranges are the channels through which the various signals travel.
- Channels can be separated by strips of unused bandwidth—guard bands—to prevent signals from overlapping.
- In addition, carrier frequencies must not interfere with the original data frequencies.

Multiplexing Process **Demultiplexing Process**

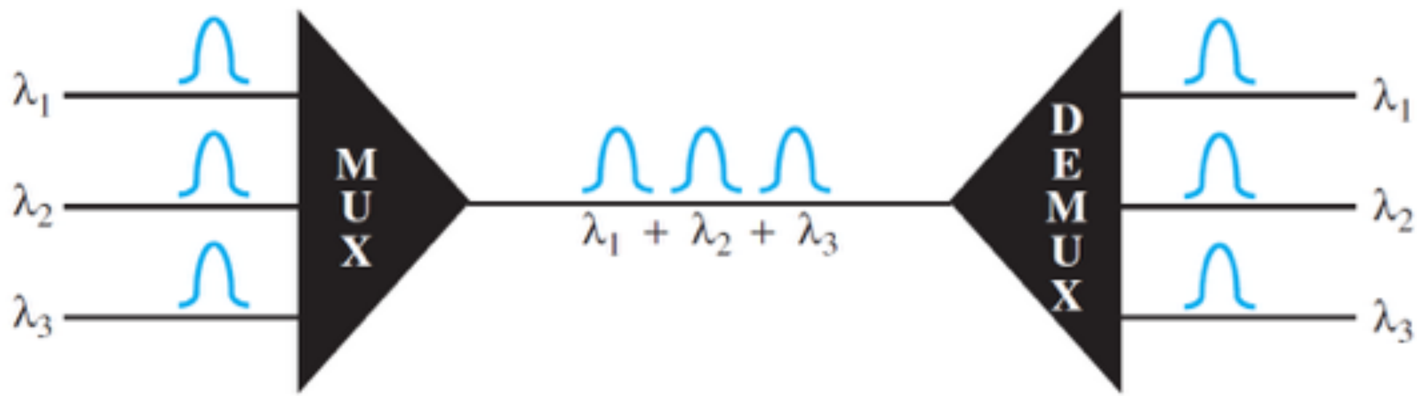


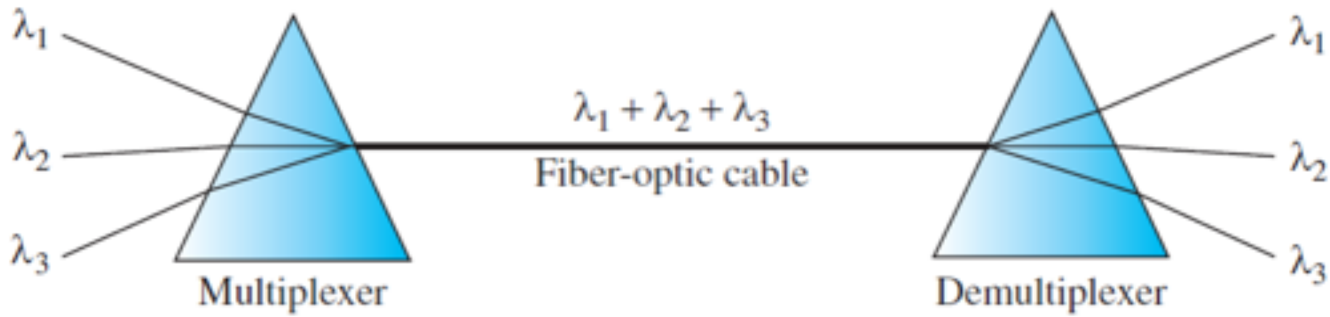
EXAMPLE

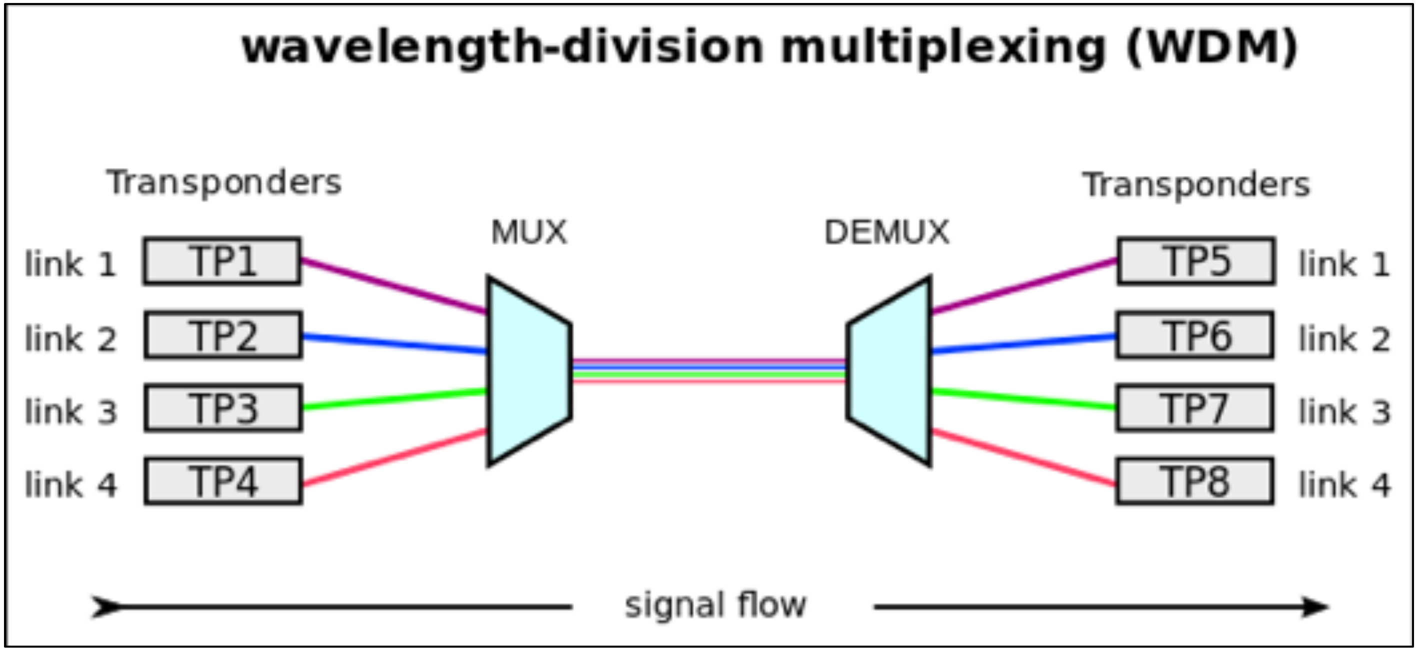

Shift and combine
Modulator
Modulator
Modulator
0 4
0 4
0 4
20 24
24 28
28 32
+
20 32
Higher-bandwidth link
20 32
Bandpass filter
Bandpass filter
Bandpass filter
20 24
24 28
28 32
0 4
0 4
0 4
Filter and shift

Wavelength-Division Multiplexing

Wavelength-division multiplexing (WDM) is a technology which multiplexes a number of optical carrier signals onto a single optical fiber by using different wavelengths (i.e., colors) of laser light - Enables bidirectional communications.




λ_1
λ_2
λ_3
$\lambda_1 + \lambda_2 + \lambda_3$
Fiber-optic cable
Multiplexer
Demultiplexer
λ_1
λ_2
λ_3


wavelength-division multiplexing (WDM)
Transponders
Transponders
MUX
DEMUX
link 1
TP1
link 2
TP2
link 3
TP3
link 4
TP4
TP5
link 1
TP6
link 2
TP7
link 3
TP8
link 4
signal flow

WDM is an analog multiplexing technique to combine optical signals.

- WDM is conceptually the same as FDM, except that the multiplexing and demultiplexing involve optical signals transmitted through fiber-optic channels.
- The idea is the same: We are combining different signals of different frequencies.
- The difference is that the frequencies are very high.

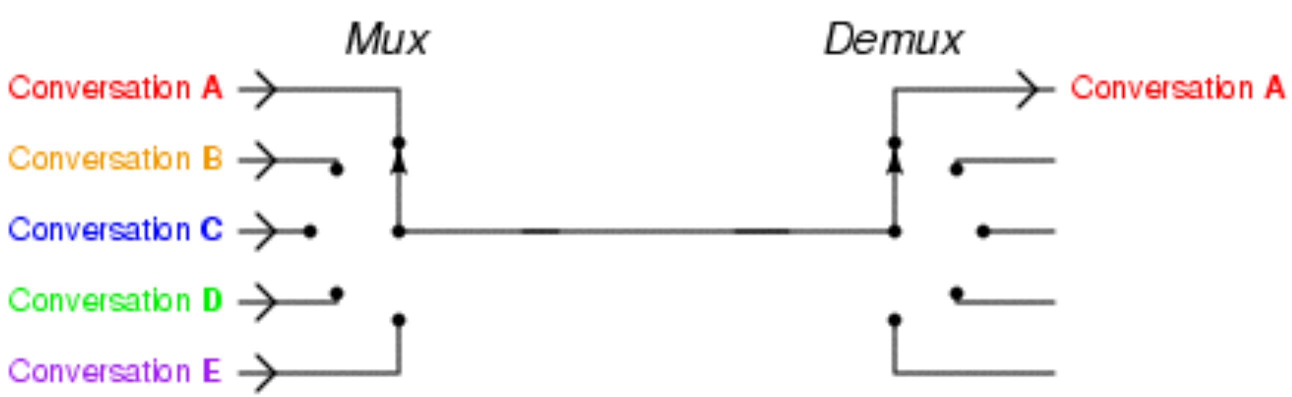
Time-Division Multiplexing

Time-division multiplexing (TDM) is a method of transmitting and receiving independent signals over a common signal path by means of synchronized switches at each end of the transmission line so that each signal appears on the line only a fraction of time in an alternating pattern.

TDM is a digital multiplexing technique for combining several low-rate channels into one high-rate one.

Time-division multiplexing (TDM) is a digital process that allows several connections to share the high bandwidth of a link.

Instead of sharing a portion of the bandwidth as in FDM, time is shared. Each connection occupies a portion of time in the link.



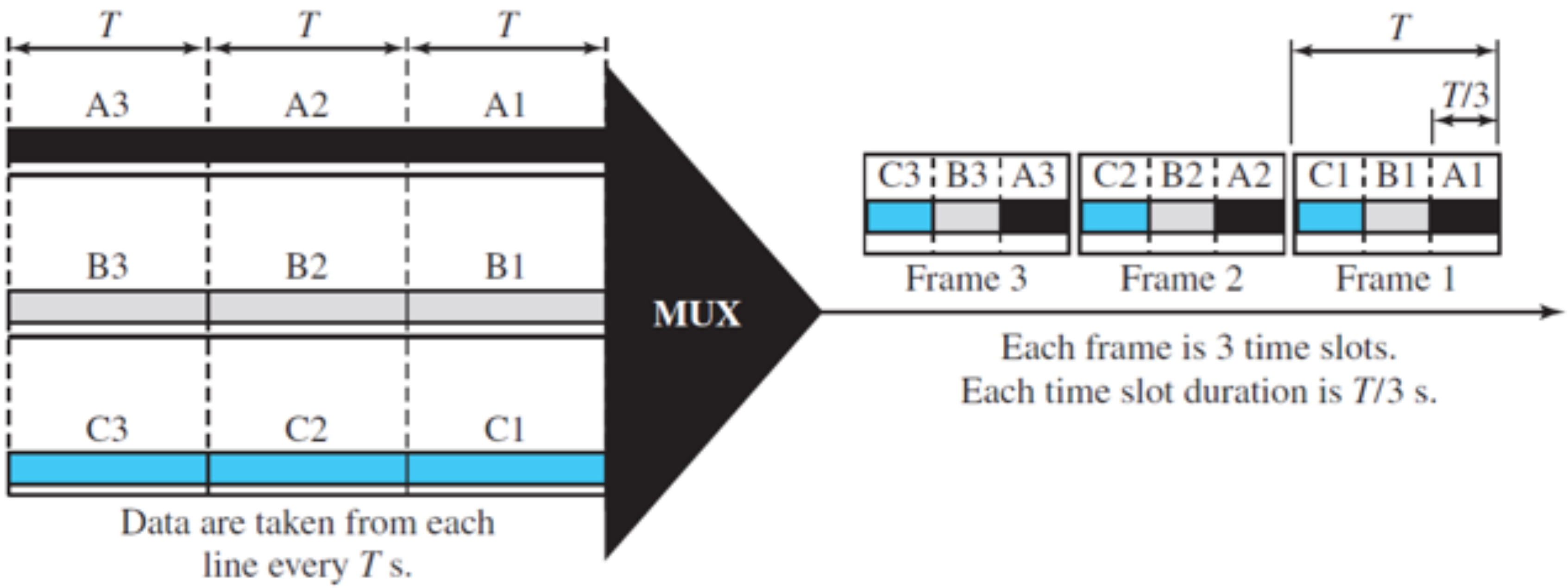


Fig: Synchronous time-division multiplexing

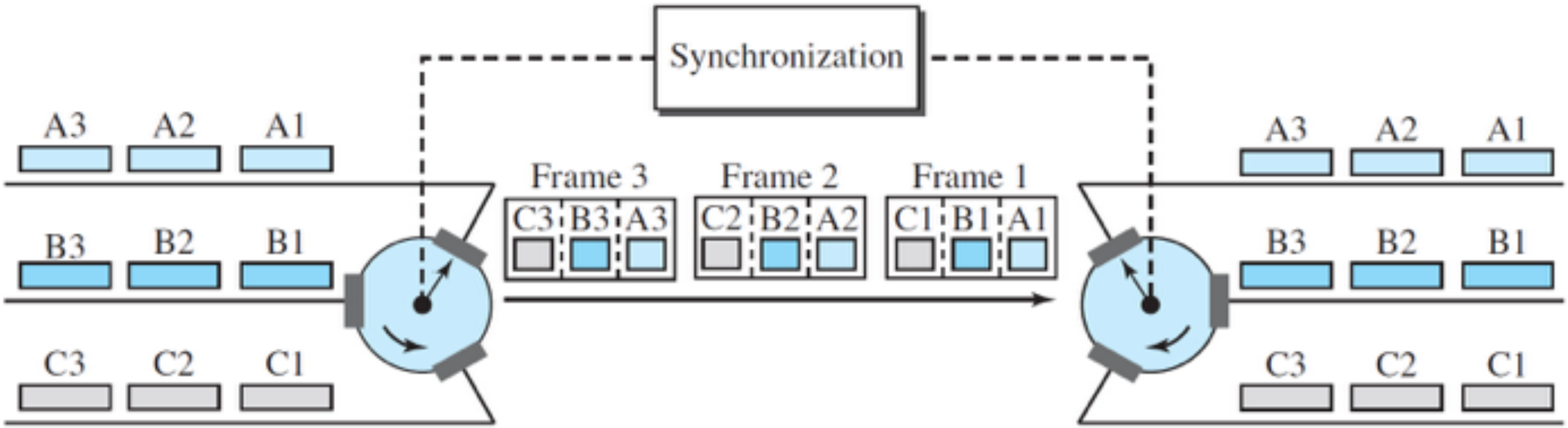


Fig: Interleaving – Synchronization process of Time-division multiplexing (TDM)

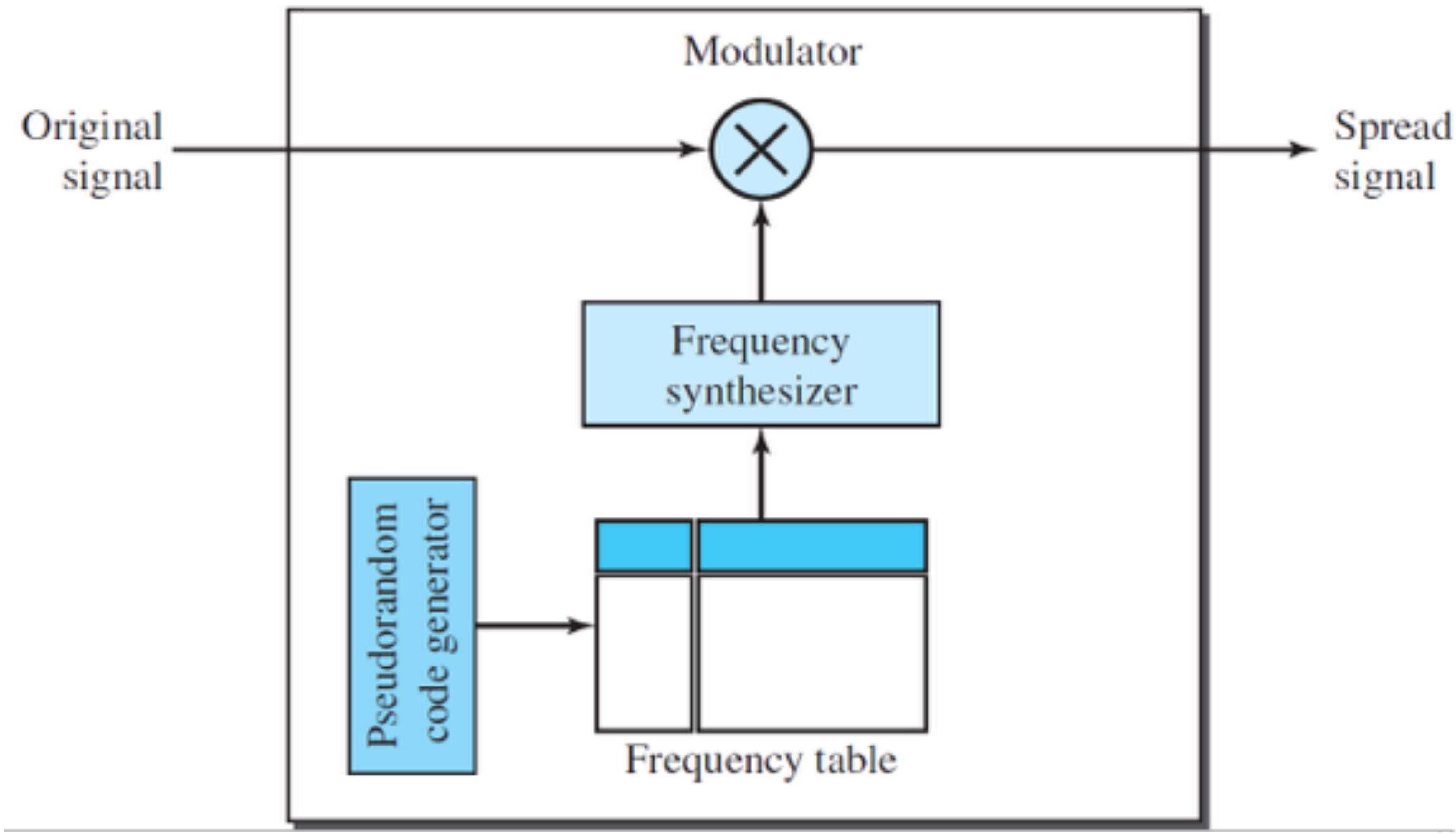
SPREAD SPECTRUM

- In spread spectrum (SS), we also combine signals from different sources to fit into a larger bandwidth, but our goals are somewhat different.

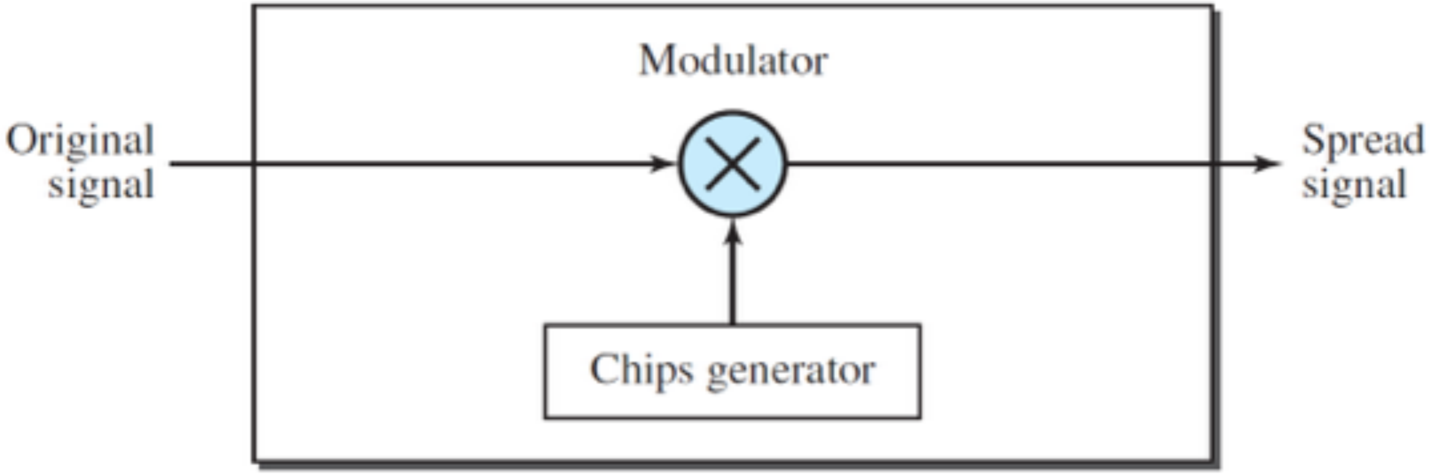
- Spread spectrum is designed to be used in wireless applications (LANs and WANs).

- In these types of applications, we have some concerns that outweigh bandwidth efficiency. In wireless applications, all stations use air (or a vacuum) as the medium for communication.

Frequency Hopping Spread Spectrum (FHSS)



Direct Sequence Spread Spectrum



SWITCHING - INTRODUCTION

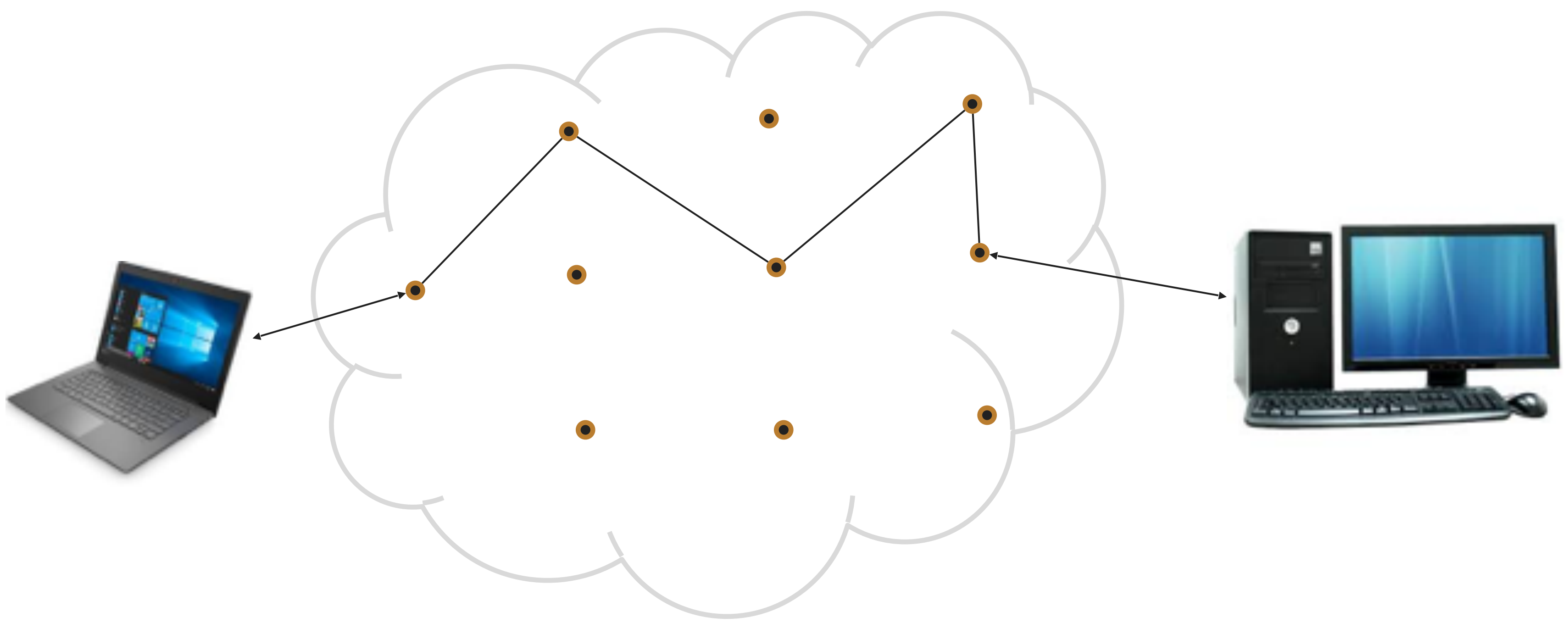
- A network is a set of connected devices. Whenever we have multiple devices, we have the problem of how to connect them to make one-to-one communication possible.

Solutions :

- point-to-point connection between each pair of devices.
- central device and every other device.
- Different Topologies.
- Different Architecture.

...

... etc.,



Computer Networking - Illustration

A better solution is switching.

A switched network consists of a series of interlinked nodes, called switches. Switches are devices capable of creating temporary connections between two or more devices linked to the switch.

- In a switched network, some of these nodes are connected to the end systems (computers or telephones, for example).
- Others are used only for routing.

Switching circuit theory

- Switching circuit theory is the mathematical study of the properties of networks of idealized switches.

- Such networks may be strictly combinational logic, in which their output state is only a function of the present state of their inputs;

- or may also contain sequential elements, where the present state depends on the present state and past states;

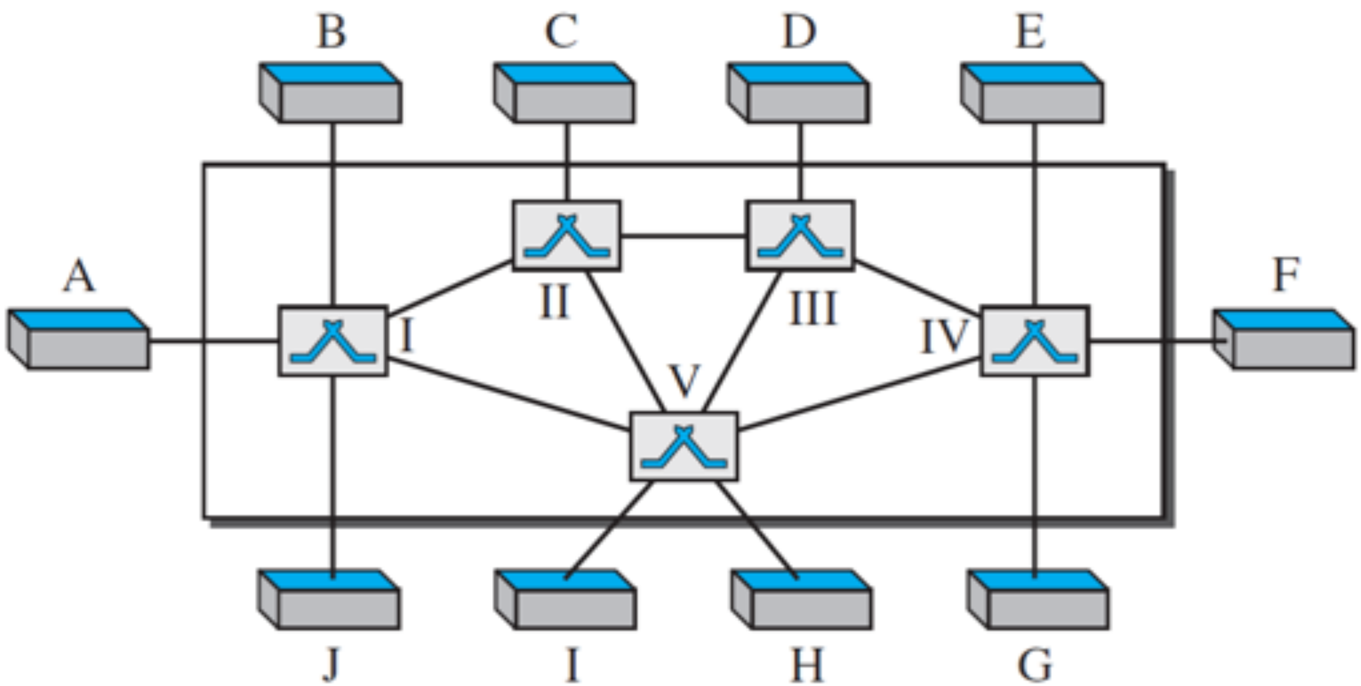


Figure: Switched network

The end systems (communicating devices) are labeled A, B, C, D, and so on, and the switches are labeled I, II, III, IV, and V. Each switch is connected to multiple links.

- Switching is process to forward packets coming in from one port to a port leading towards the destination.

- When data comes on a port it is called ingress, and when data leaves a port or goes out it is called egress.

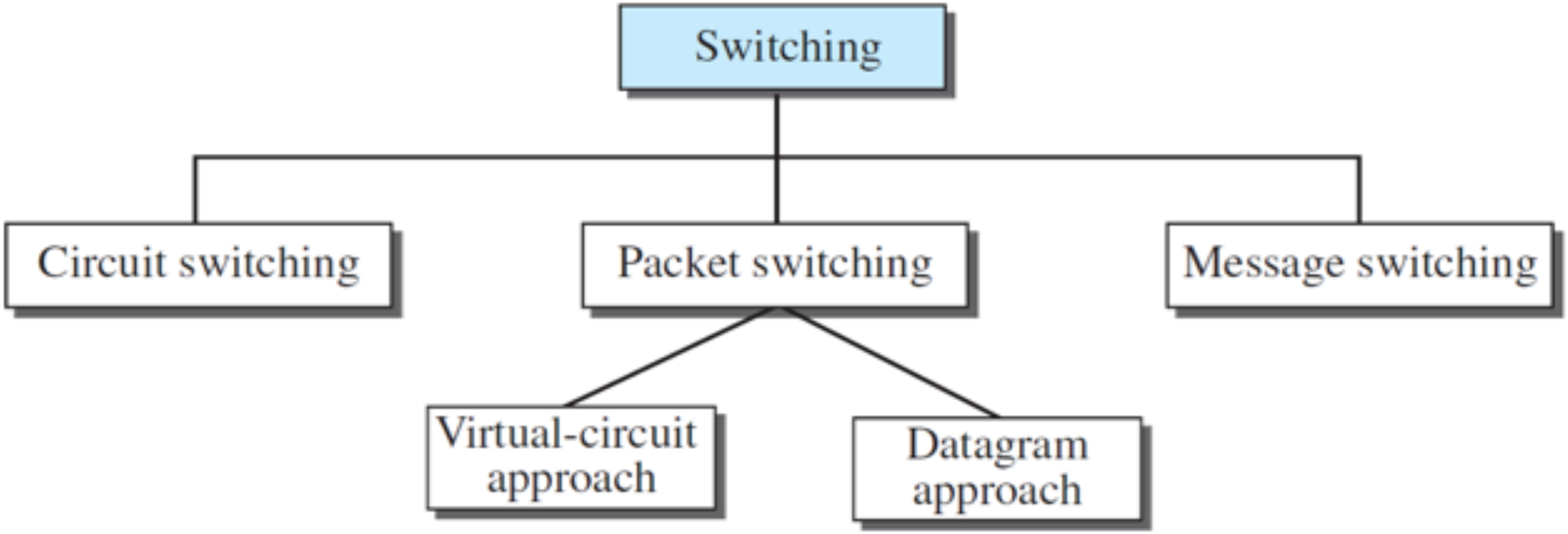
- A communication system may include number of switches and nodes.

At broad level, switching can be divided into two major categories:

- **Connectionless:** The data is forwarded on behalf of forwarding tables. No previous handshaking is required and acknowledgements are optional.

- **Connection Oriented:** Before switching data to be forwarded to destination, there is a need to pre-establish circuit along the path between both endpoints. Data is then forwarded on that circuit. After the transfer is completed, circuits can be kept for future use or can be turned down immediately.

Three Methods of Switching



Taxonomy of switched networks

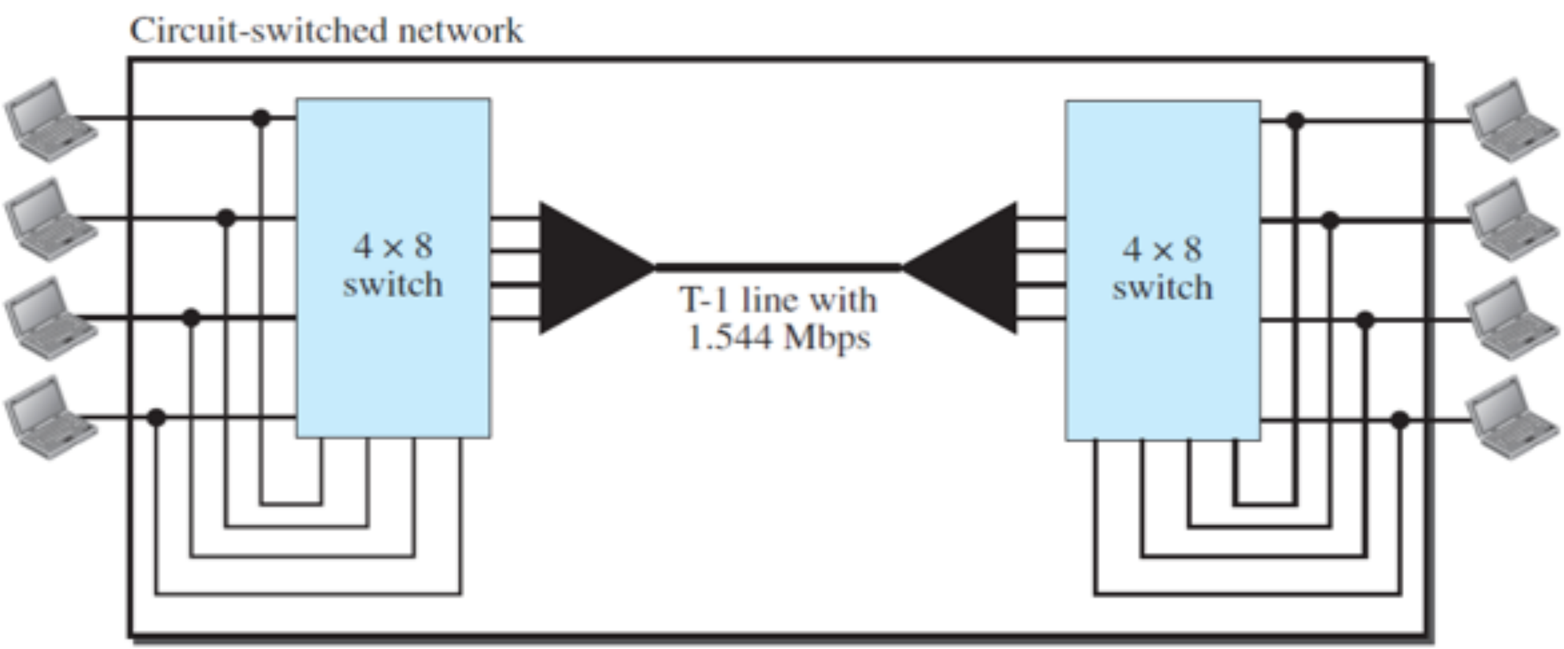
CIRCUIT-SWITCHED NETWORKS

A circuit-switched network is made of a set of switches connected by physical links, in which each link is divided into *n* channels.

- A circuit-switched network consists of a set of switches connected by physical links.
- A connection between two stations is a dedicated path made of one or more links. However, each connection uses only one dedicated channel on each link.
- Each link is normally divided into n channels by using FDM or TDM

The actual communication in a circuit-switched network requires three phases:

1. Connection setup,
2. Data transfer, and
3. Connection teardown.



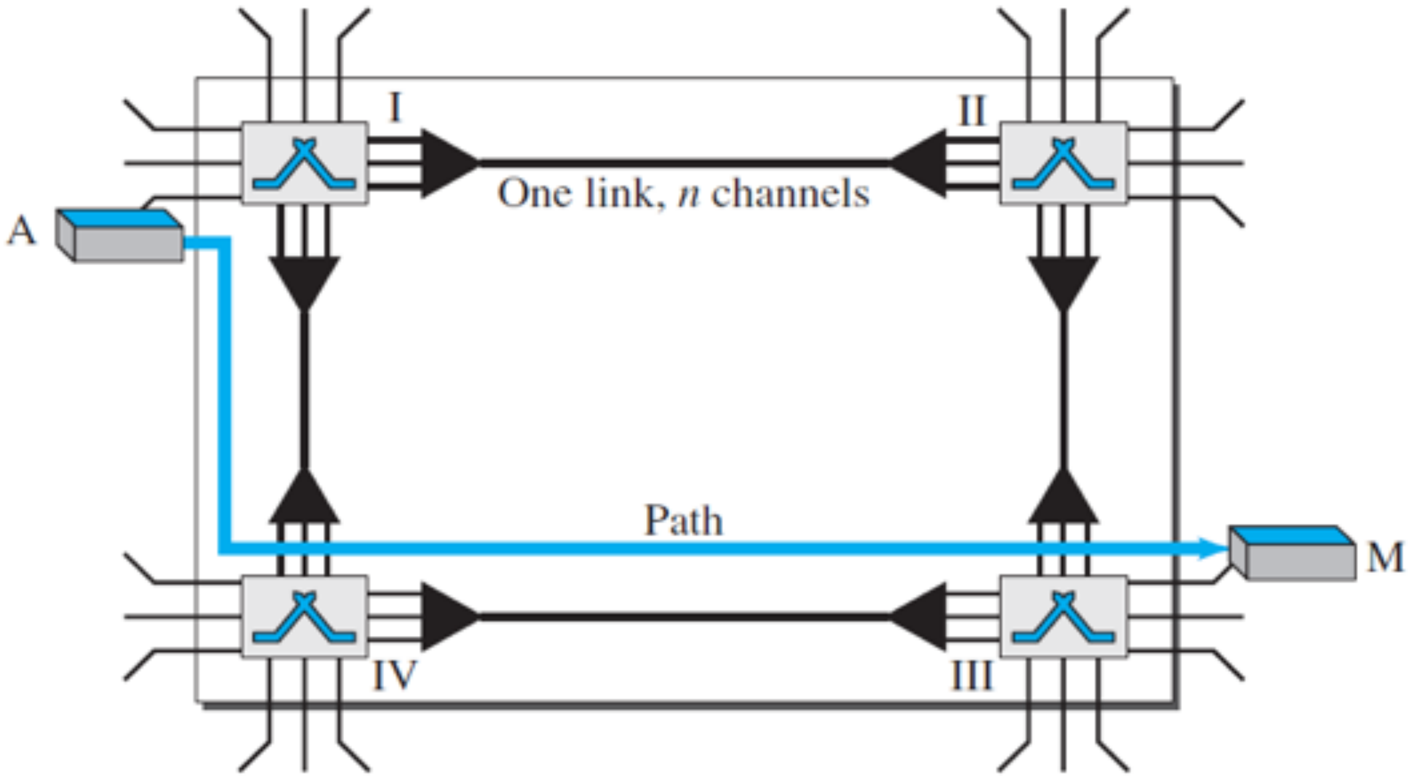


Figure: A trivial circuit-switched network

- Circuit switching takes place at the physical layer.
- Before starting communication, the stations must make a reservation for the resources to be used during the communication.
- Data transferred between the two stations are not packetized (physical layer transfer of the signal).
- The data are a continuous flow sent by the source station and received by the destination station, although there may be periods of silence.
- There is no addressing involved during data transfer.

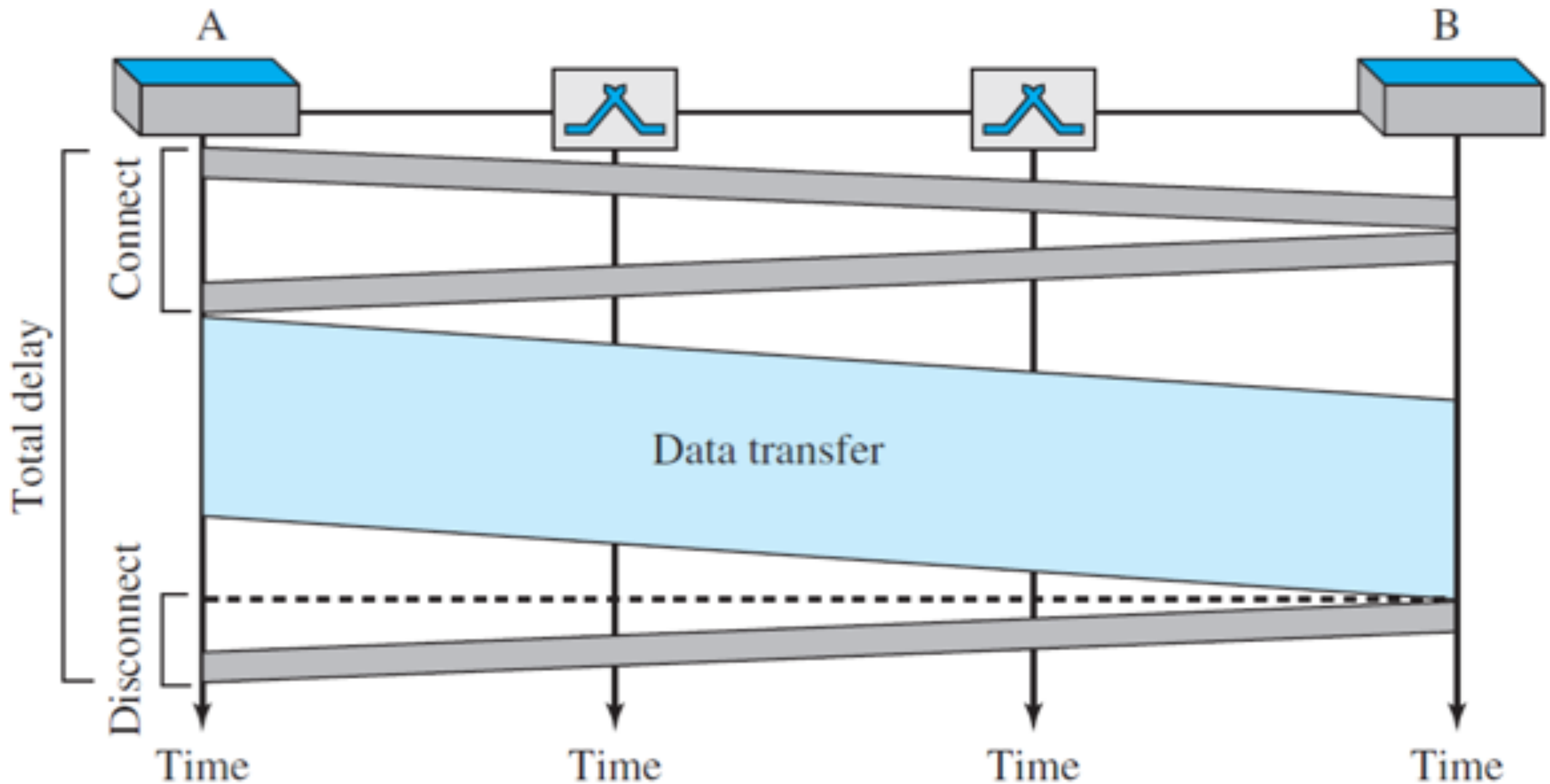


Figure : Delay in a circuit-switched network

Circuit Switching - SUMMARY

- Circuit switching is a switching technique that establishes a dedicated path between sender and receiver.
- In the Circuit Switching Technique, once the connection is established then the dedicated path will remain to exist until the connection is terminated.
- Circuit switching in a network operates in a similar way as the telephone works.
- A complete end-to-end path must exist before the communication takes place.

PACKET SWITCHING

- Packet switching is a method of grouping data that is transmitted over a digital network into packets.
- Packets are made of a header and a payload.
- Data in the header is used by networking hardware to direct the packet to its destination where the payload is extracted and used by application software.
- Packet switching is the primary basis for data communications in computer networks worldwide.

PACKET SWITCHING

In data communications, we need to send messages from one end system to another. If the message is going to pass through a packet-switched network, it needs to be divided into packets of fixed or variable size. The size of the packet is determined by the network and the governing protocol.

- In packet switching, there is no resource allocation for a packet.
- This means that there is no reserved bandwidth on the links, and there is no scheduled processing time for each packet. Resources are allocated on demand.
- The allocation is done on a firstcome, first-served basis. When a switch receives a packet, no matter what the source or destination is, the packet must wait if there are other packets being processed.

In a packet-switched network, there is no resource reservation; resources are allocated on demand.

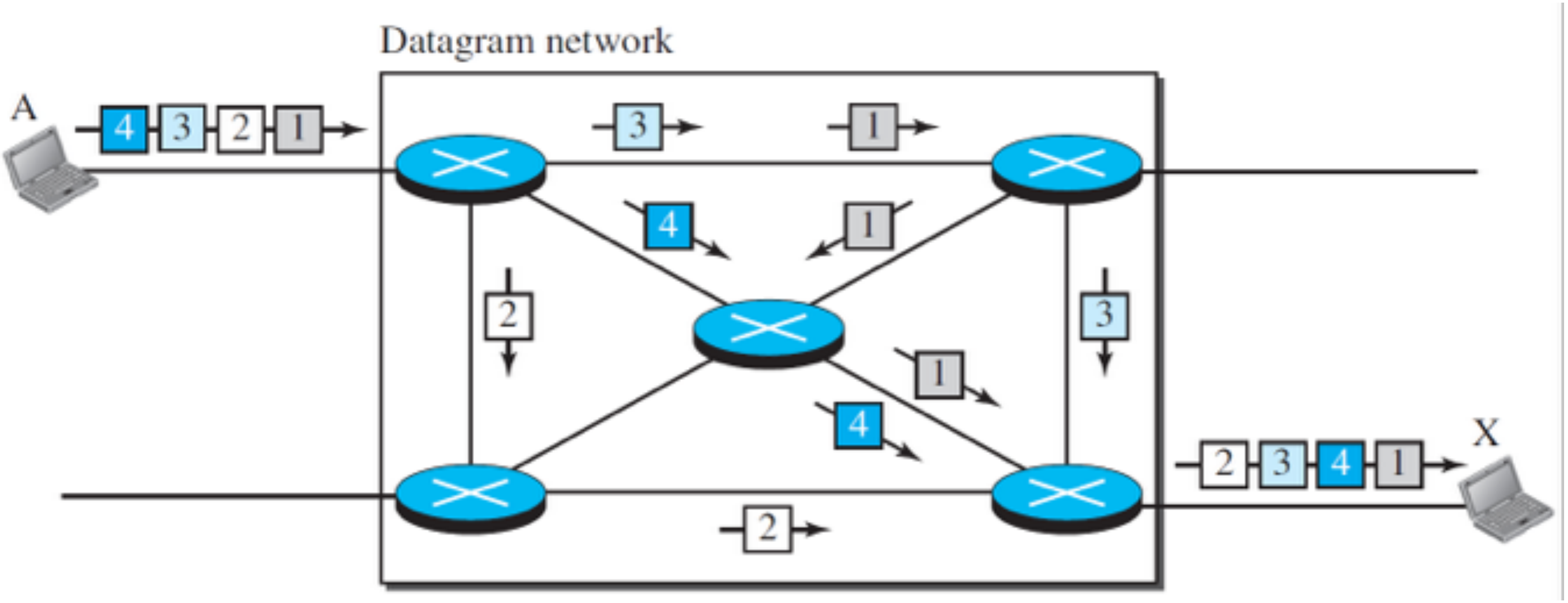


Figure : A datagram network with four switches (routers)

Datagram Networks

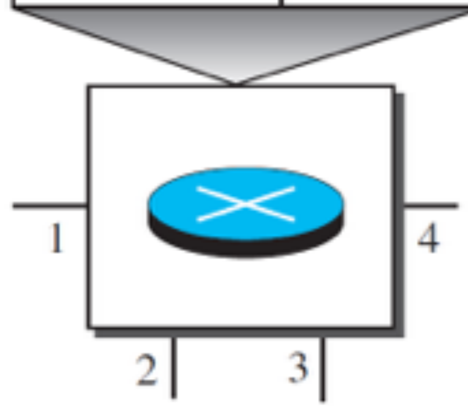
- In a datagram network, each packet is treated independently of all others. Even if a packet is part of a multipacket transmission, the network treats it as though it existed alone.
- Packets in this approach are referred to as datagrams.
- Datagram switching is normally done at the network layer.

NOTE :

The datagram networks are sometimes referred to as connectionless networks. The term connectionless here means that the switch (packet switch) does not keep information about the connection state.

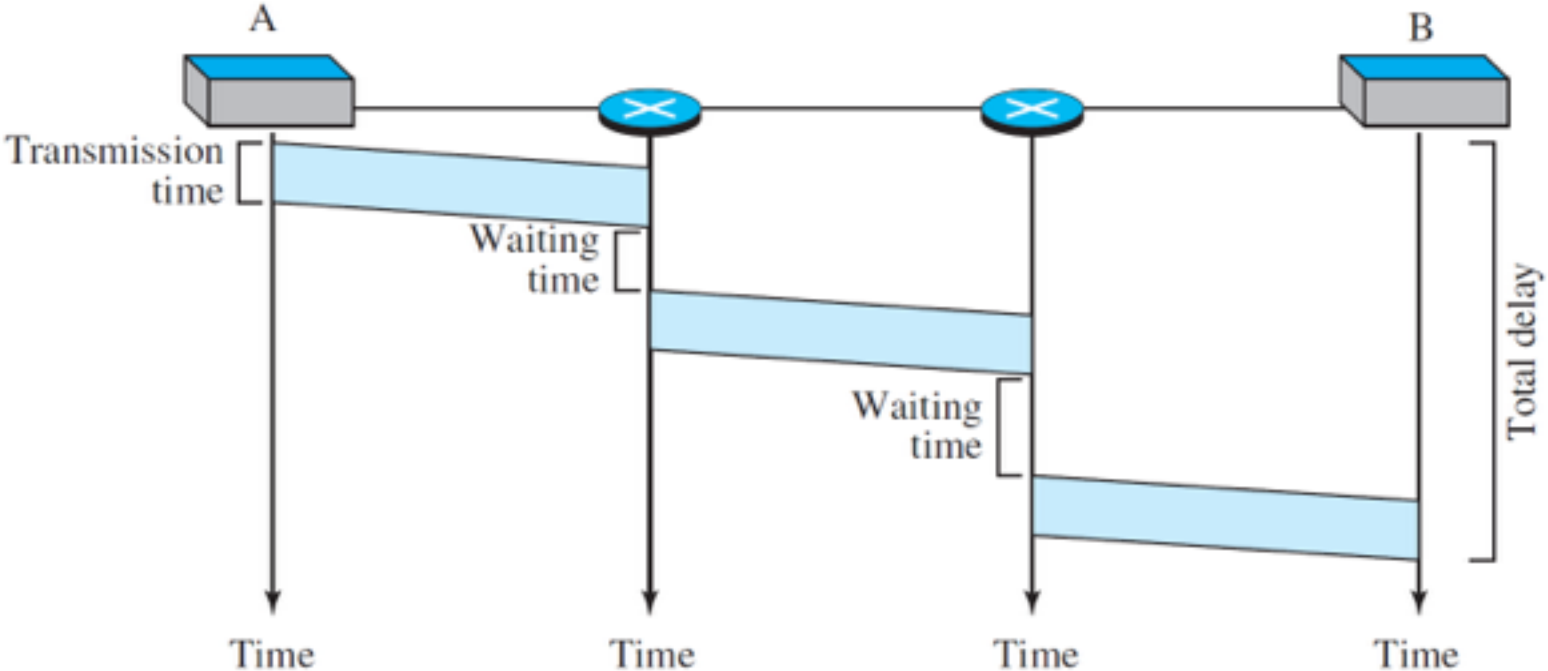
Routing Table

Destination address	Output port
1232	1
4150	2
⋮	⋮
9130	3



A switch in a datagram network uses a routing table that is based on the destination address.

Delay in a datagram network



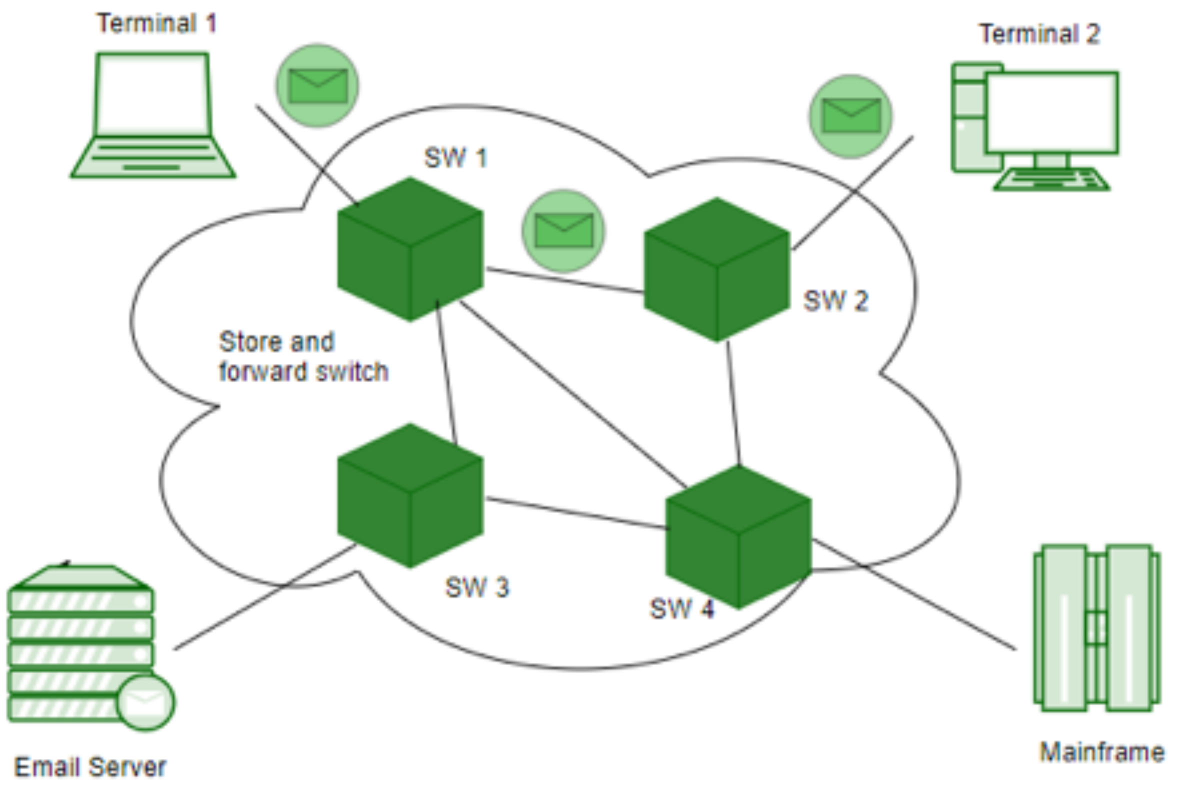
$$\textbf{Total delay} = 3T + 3\tau + w_1 + w_2$$

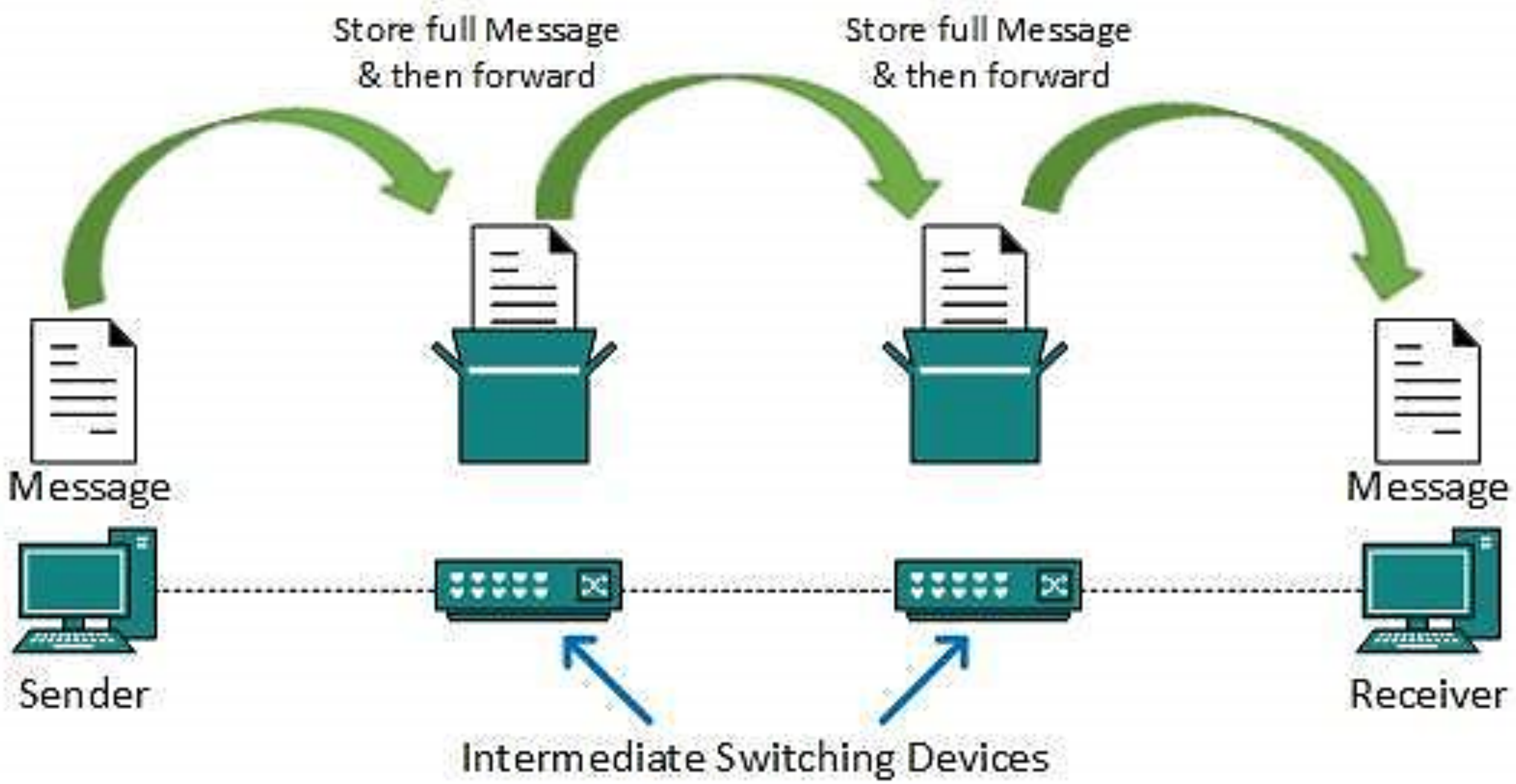
The packet travels through two switches. There are three transmission times ($3T$), three propagation delays, and two waiting times ($w_1 + w_2$). We ignore the processing time in each switch.

MESSAGE SWITCHING

- Message Switching is a switching technique in which a message is transferred as a complete unit and routed through intermediate nodes at which it is stored and forwarded.
- In Message Switching technique, there is no establishment of a dedicated path between the sender and receiver.
- The destination address is appended to the message. Message Switching provides a dynamic routing as the message is routed through the intermediate nodes based on the information available in the message.

Message switching network consists of transmission links (channels), store-and-forward switch nodes and end stations as shown in the following picture:




Store full Message
& then forward
Store full Message
& then forward
Message
Message
Sender
Receiver
Intermediate Switching Devices

- Message switches are programmed in such a way so that they can provide the most efficient routes.

- Each and every node stores the entire message and then forward it to the next node. This type of network is known as store and forward network.

- Message switching treats each message as an independent entity.

Transmission medium

A transmission medium is something that can mediate the propagation of signals for the purposes of telecommunication.

- Transmission media is a communication channel that carries the information from the sender to the receiver.
- Data is transmitted through the electromagnetic signals.
- The main functionality of the transmission media is to carry the information in the form of bits through LAN(Local Area Network).

- In a copper-based network, the bits in the form of electrical signals.

- In a fiber based network, the bits in the form of light pulses.

- In OSI(Open System Interconnection) phase, transmission media supports the Layer 1. Therefore, it is considered to be as a Layer 1 component.

- The electrical signals can be sent through the copper wire, fibre optics, atmosphere, water, and vacuum.

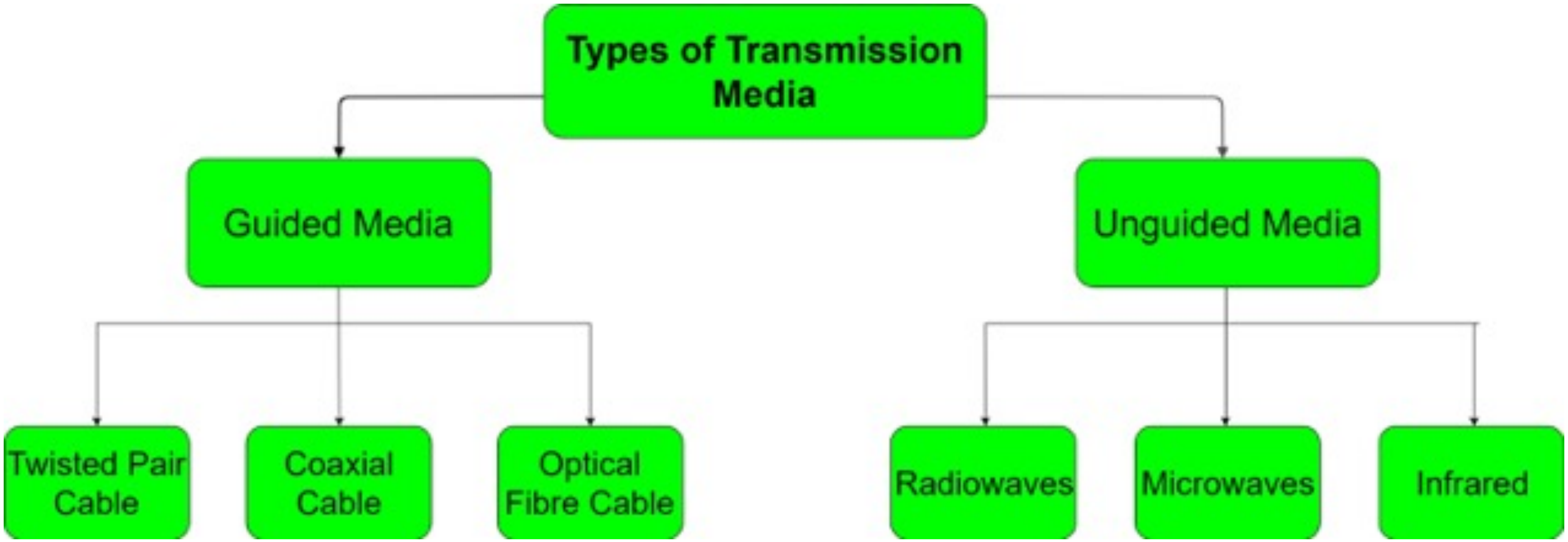
- The characteristics and quality of data transmission are determined by the characteristics of medium and signal.

- Transmission media is of two types are wired media and wireless media.

- In wired media, medium characteristics are more important whereas, in wireless media, signal characteristics are more important.

- Different transmission media have different properties such as bandwidth, delay, cost and ease of installation and maintenance.

- The transmission media is available in the lowest layer of the OSI reference model, i.e., **Physical layer**.


Types of Transmission Media
Guided Media
Unguided Media
Twisted Pair Cable
Coaxial Cable
Optical Fibre Cable
Radiowaves
Microwaves
Infrared

Types

In general, a transmission medium can be classified as a:

1. **Linear medium**, if different waves at any particular point in the medium can be superposed;
2. **Bounded medium**, if it is finite in extent, otherwise unbounded medium;
3. **Uniform medium** or homogeneous medium, if its physical properties are unchanged at different points;
4. **Isotropic medium**, if its physical properties are the same in different directions.

For telecommunications purposes in the United States, Federal Standard 1037C, transmission media are classified as one of the following:

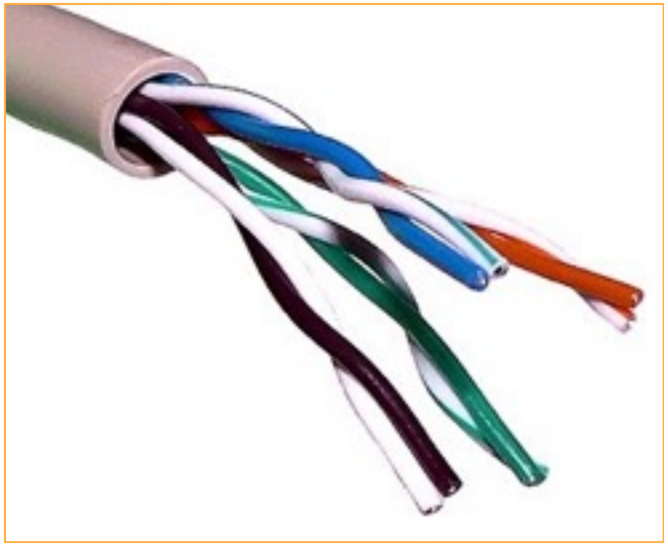
1. **Guided (or bounded)—**waves are guided along a solid medium such as a transmission line.

2. **Wireless (or unguided)—**transmission and reception are achieved by means of an antenna.

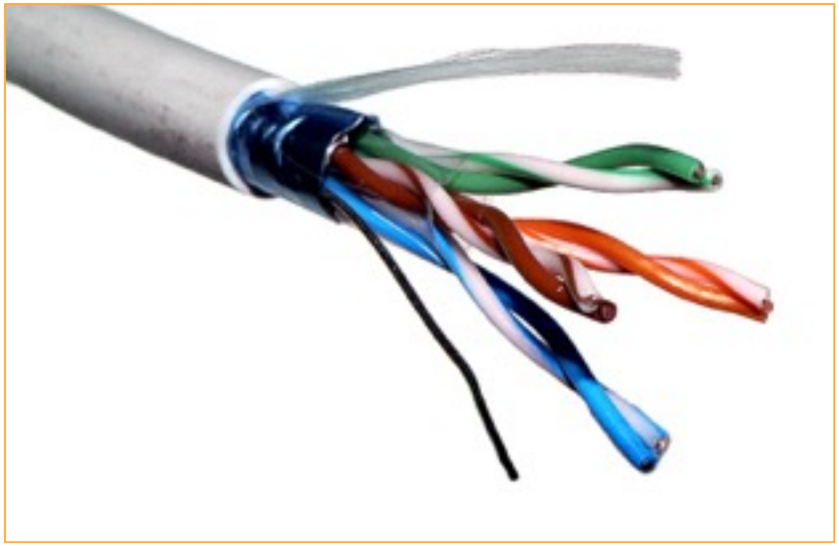
Guided (or bounded)

Twisted pair

Twisted pair cabling is a type of wiring in which two conductors of a single circuit are twisted together for the purposes of improving electromagnetic compatibility.



Unshielded twisted pair cable with different twist rates



Foil-shielded, twisted pair cable

Unshielded Twisted Pair (UTP):

This type of cable has the ability to block interference and does not depend on a physical shield for this purpose. It is used for telephonic applications.

Advantages:

- Least expensive
- Easy to install
- High speed capacity

Disadvantages:

- Susceptible to external interference
- Lower capacity and performance in comparison to STP
- Short distance transmission due to attenuation

Shielded Twisted Pair (STP):

This type of cable consists of a special jacket to block external interference. It is used in fast-data-rate Ethernet and in voice and data channels of telephone lines.

Advantages:

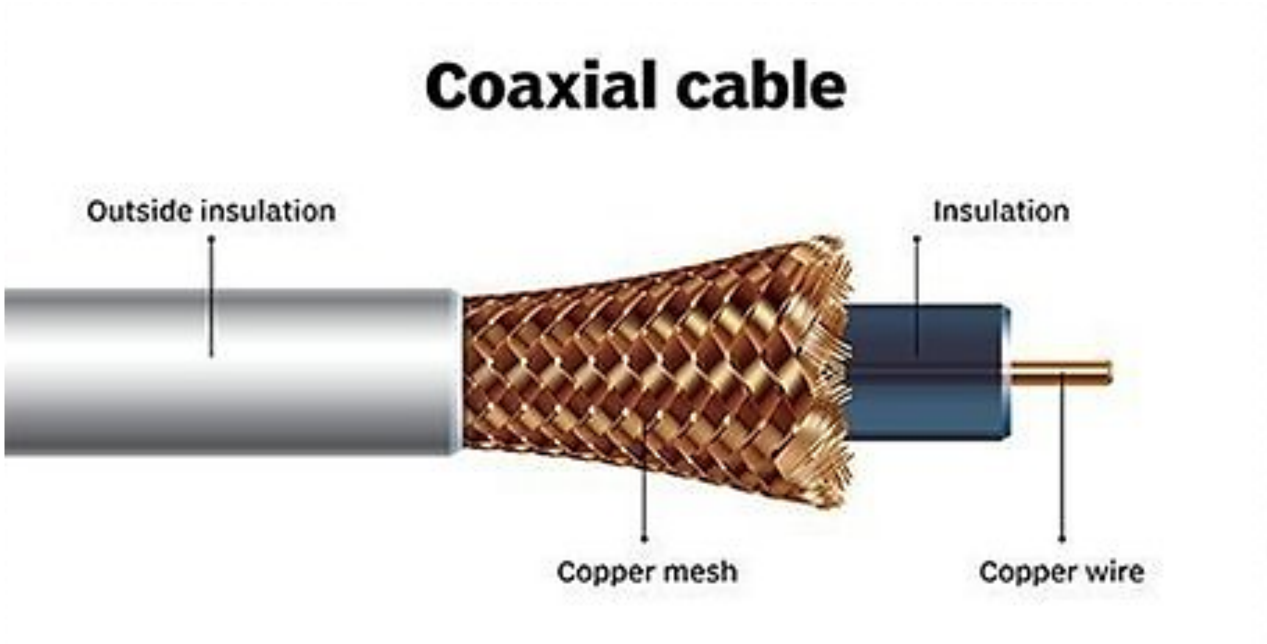
- Better performance at a higher data rate in comparison to UTP
- Eliminates crosstalk
- Comparatively faster

Disadvantages:

- Comparatively difficult to install and manufacture
- More expensive

Coaxial cable

Coaxial cable is a type of electrical cable that has an inner conductor surrounded by a tubular insulating layer, surrounded by a tubular conducting shield. Many coaxial cables also have an insulating outer sheath or jacket.



Coaxial Cable –

It has an outer plastic covering containing 2 parallel conductors each having a separate insulated protection cover. Coaxial cable transmits information in two modes: Baseband mode(dedicated cable bandwidth) and Broadband mode(cable bandwidth is split into separate ranges). Cable TVs and analog television networks widely use Coaxial cables.

Advantages:

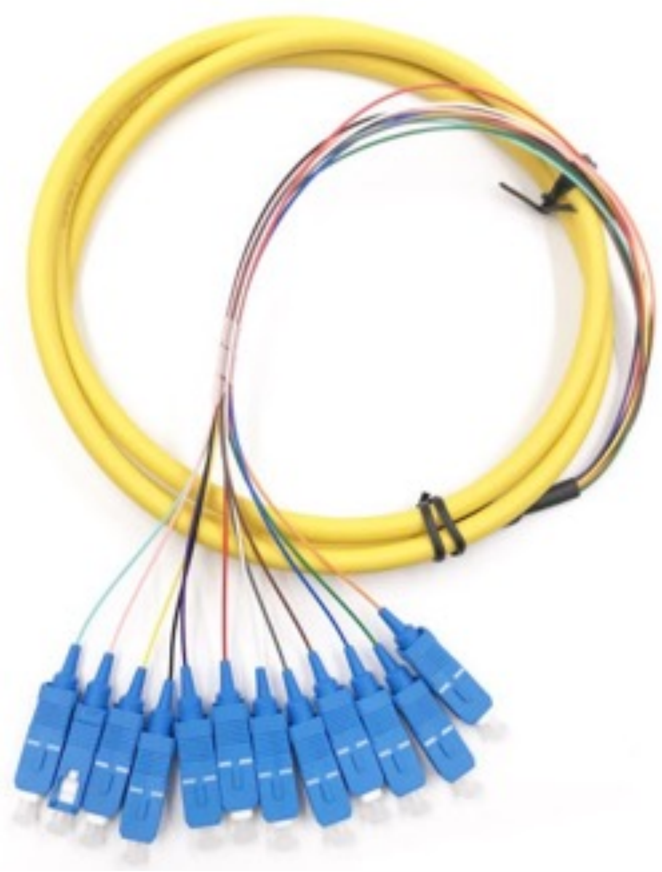
- High Bandwidth
- Better noise Immunity
- Easy to install and expand
- Inexpensive

Disadvantages:

- Single cable failure can disrupt the entire network

Optical fiber

Optical fiber is a thin strand of glass that guides light along its length. Four major factors favor optical fiber over copper- data rates, distance, installation, and costs. Optical fiber can carry huge amounts of data compared to copper.



Optical Fibre Cable – It uses the concept of reflection of light through a core made up of glass or plastic. The core is surrounded by a less dense glass or plastic covering called the cladding. It is used for transmission of large volumes of data.

Advantages:

- Increased capacity and bandwidth
- Light weight , Less signal attenuation
- Immunity to electromagnetic interference
- Resistance to corrosive materials

Disadvantages:

- Difficult to install and maintain
- High cost and Fragile
- unidirectional, ie, will need another fibre, if we need bidirectional communication

A bundle of optical fibers

A TOSLINK fiber optic audio cable with red light being shone in one end transmits the light to the other end

Unguided Media

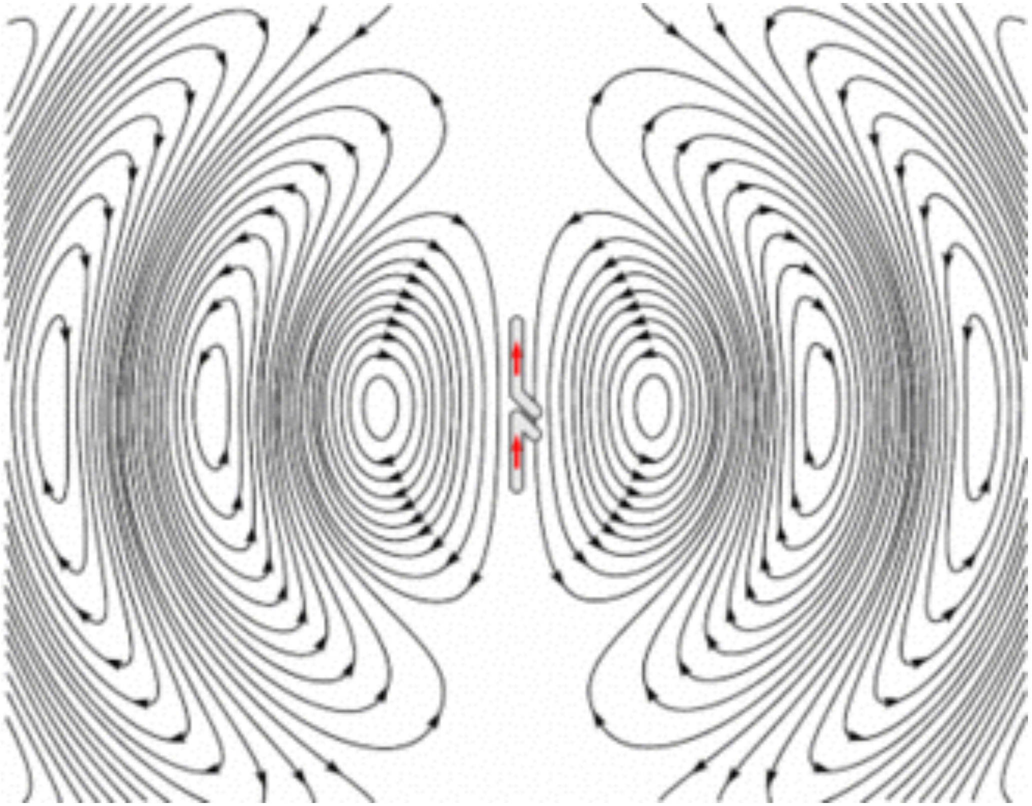
Data signals that flow through the air. They are not guided or bound to a channel to follow.

Radio

- Radio propagation is the behavior of radio waves as they travel, or are propagated, from one point to another, or into various parts of the atmosphere.
- As a form of electromagnetic radiation, like light waves, radio waves are affected by the phenomena of reflection, refraction, diffraction, absorption, polarization, and scattering.

Radio wave

Radio waves are a type of electromagnetic radiation with wavelengths in the electromagnetic spectrum longer than infrared light. Radio waves have frequencies as high as 300 gigahertz (GHz) to as low as 30 hertz (Hz).



Animation of a half-wave dipole antenna radiating radio waves, showing the electric field lines.

Microwaves

It is a line of sight transmission i.e. the sending and receiving antennas need to be properly aligned with each other. The distance covered by the signal is directly proportional to the height of the antenna. Frequency Range:1GHz – 300GHz. These are majorly used for mobile phone communication and television distribution.

Infrared

Infrared (IR), sometimes called infrared light, is electromagnetic radiation (EMR) with wavelengths longer than those of visible light. It is therefore generally invisible to the human eye, although IR at wavelengths up to 1050 nanometers (nm)s from specially pulsed lasers can be seen by humans under certain conditions.

Discussion :

Any questions, Queries regarding this session ?