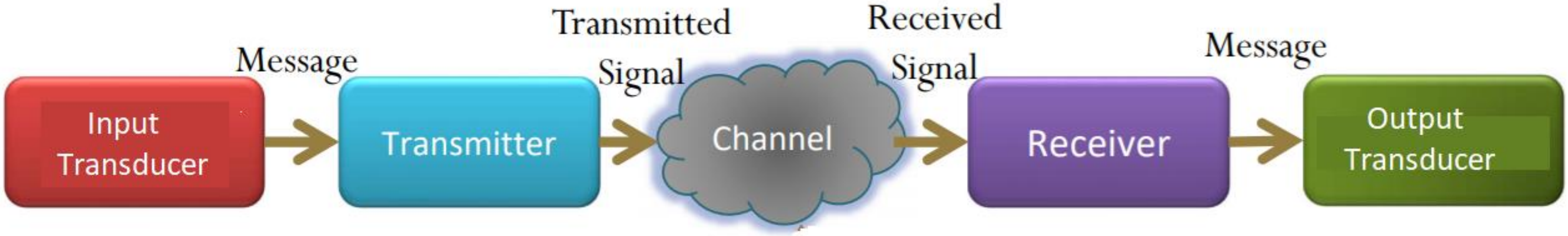
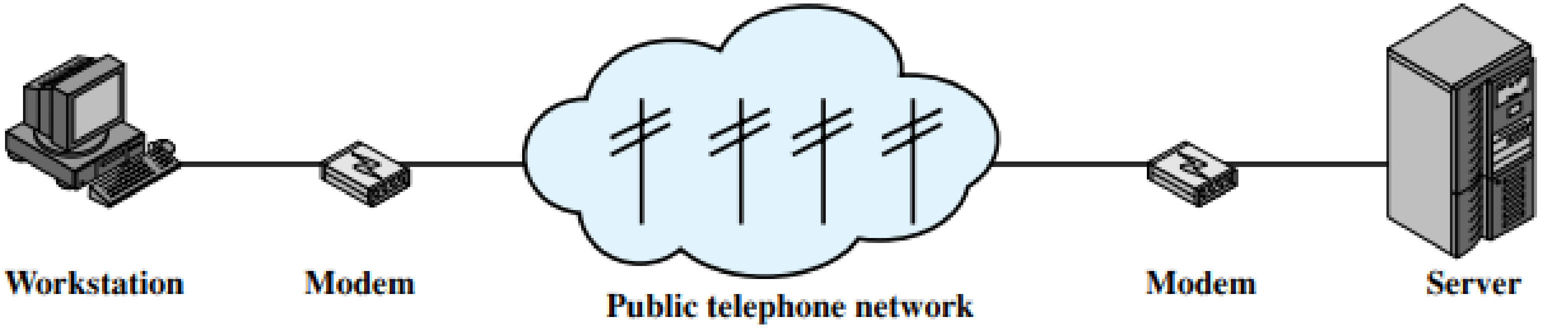
20IS709
Communication Systems For Industrial Networking

Communication System

Communication System

- Model for a single-link communication system

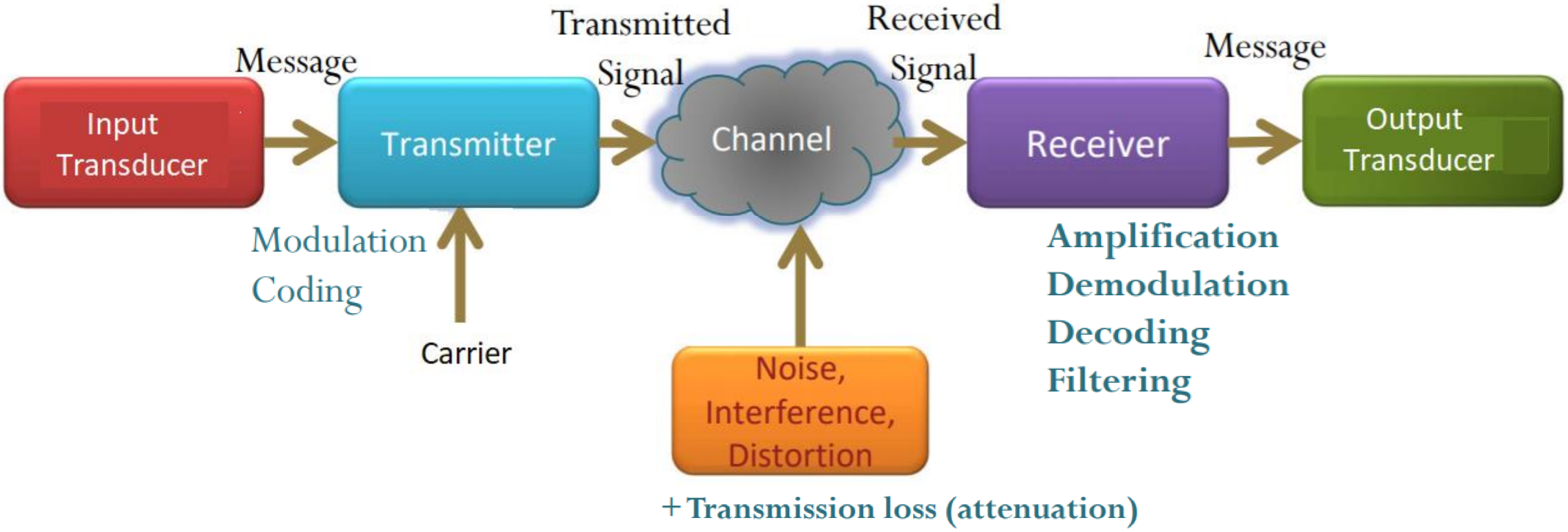




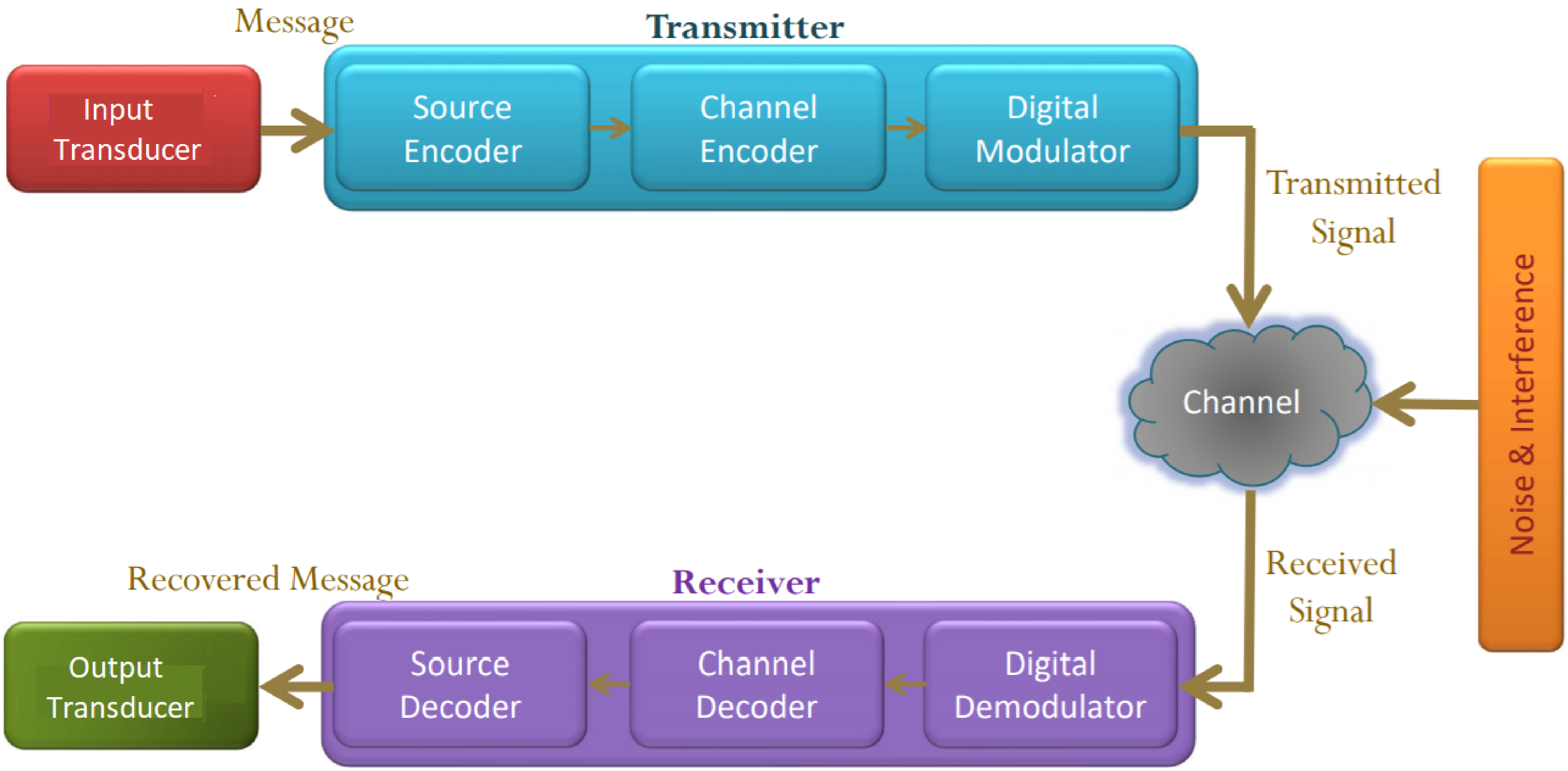
Example

Communication System

- Model for a single-link communication system



Elements of Digital Communication Systems



Channel Characteristics

Noise Sources

- Internal noise – resistors, solid-state active devices
- External noise - atmospheric, man-made, and extraterrestrial sources
- Atmospheric noise generated by the natural electrical discharges – *static*
- Short-duration bursts referred as *impulsive*
- Man-made noise due to interfering transmitters - *radiofrequency interference* (RFI)

Types of Transmission Channels

- Electromagnetic-wave propagation channels,
- Guided electromagnetic-wave channels, and
- Optical channels

Channel Characteristics

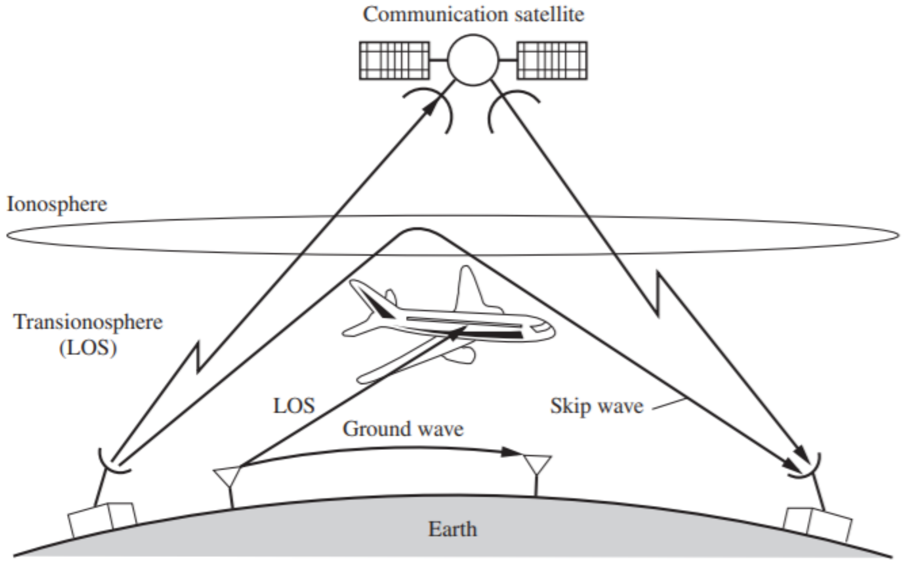
Types of Transmission Channels

Electromagnetic-wave propagation channels

- Coupling of electromagnetic energy into a propagation medium (free space or atmosphere) by means of a radiation element referred to as an *antenna*.

Table : Frequency Bands with Designations

Frequency band	Name	Microwave band (GHz)	Letter designation
3–30 kHz	Very low frequency (VLF)		
30–300 kHz	Low frequency (LF)		
300–3000 kHz	Medium frequency (MF)		
3–30 MHz	High frequency (HF)		
30–300 MHz	Very high frequency (VHF)		
0.3–3 GHz	Ultrahigh frequency (UHF)	1.0–2.0	L
		2.0–3.0	S
3–30 GHz	Superhigh frequency (SHF)	3.0–4.0	S
		4.0–6.0	C
		6.0–8.0	C
		8.0–10.0	X
		10.0–12.4	X
		12.4–18.0	Ku
		18.0–20.0	K
		20.0–26.5	K
30–300 GHz	Extremely high frequency (EHF)	26.5–40.0	Ka
43–430 THz	Infrared (0.7–7 μm)		
430–750 THz	Visible light (0.4–0.7 μm)		
750–3000 THz	Ultraviolet (0.1–0.4 μm)		



The various propagation modes for electromagnetic waves (LOS stands for line of sight).

Channel Characteristics

Types of Transmission Channels

Electromagnetic-wave propagation channels

- At higher frequencies, above 1 or 2 GHz, atmospheric gases, water vapor, and precipitation absorb and scatter radio waves - attenuation of the received signal.

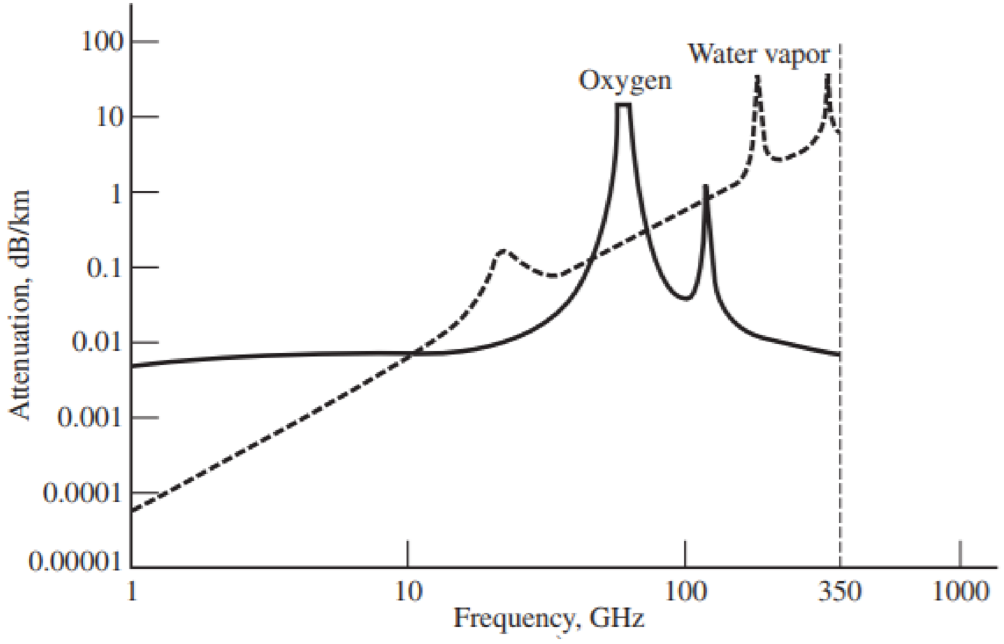


Table: Selected Frequency Bands for Public Use and Military Communications

Use		Frequency
Radio navigation		6–14 kHz; 90–110 kHz
Loran C navigation		100 kHz
Standard (AM) broadcast		540–1600 kHz
ISM band	Industrial heaters; welders	40.66–40.7 MHz
Television:	Channels 2–4	54–72 MHz
	Channels 5–6	76–88 MHz
FM broadcast		88–108 MHz
Television	Channels 7–13	174–216 MHz
	Channels 14–83	420–890 MHz
	(In the United States, channels 2–36 and 38–51 are used for digital TV broadcast; others were reallocated.)	
Cellular mobile radio	AMPS, D-AMPS (1G, 2G)	800 MHz bands
	IS-95 (2G)	824–844 MHz/1.8–2 GHz
	GSM (2G)	850/900/1800/1900 MHz
	3G (UMTS, cdma-2000)	1.8/2.5 GHz bands
Wi-Fi (IEEE 802.11)		2.4/5 GHz
Wi-MAX (IEEE 802.16)		2–11 GHz
ISM band	Microwave ovens; medical	902–928 MHz
Global Positioning System		1227.6, 1575.4 MHz
Point-to-point microwave		2.11–2.13 GHz
Point-to-point microwave	Interconnecting base stations	2.16–2.18 GHz
ISM band	Microwave ovens; unlicensed spread spectrum; medical	2.4–2.4835 GHz
		23.6–24 GHz
		122–123 GHz
		244–246 GHz

Channel Characteristics

Types of Transmission Channels

Guided Electromagnetic-Wave Channels

- Long-distance telephone network that uses wire lines (10 kHz)
- Multipair and coaxial-cable lines (few MHz)

Optical Channels

- Uses fiber-optic cables
- Optical links are capable of carrying more voice channels per cable (>13,000)

Transmission Terminology

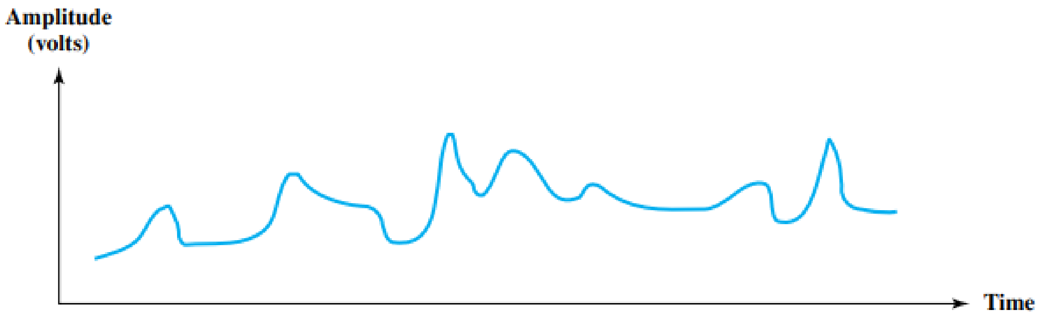
- *Guided media* – the waves are guided along a physical path - twisted pair, coaxial cable, and optical fiber
- *Unguided media* - called wireless
- Direct link - the transmission path between two devices - signals propagate directly from transmitter to receiver with no intermediate devices
- *Point to point* - provides a direct link between two devices - only two devices sharing the medium.
- *Multipoint guided* configuration - more than two devices share the same medium
- *Simplex* transmission - signals are transmitted in only one direction; one station is transmitter and the other is receiver.
- *Half-duplex* operation - both stations may transmit, but only one at a time.
- *Full-duplex* operation - both stations may transmit simultaneously

Frequency and Spectrum

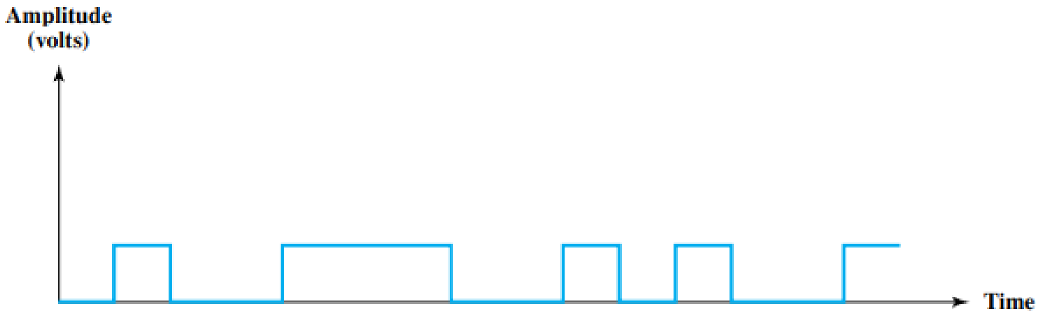
Time domain concepts

- A signal is generated by the transmitter and transmitted over a medium.
- The signal is a function of time, but can also be expressed as a function of frequency - the signal consists of components of different frequencies.
- Frequency domain view of a signal is more important to an understanding of data transmission than a time domain.
- Viewed as a function of time, an electromagnetic signal can be either analog or digital

- An analog signal is one in which the signal intensity varies in a smooth fashion over time – continuous.
- A digital signal is one in which the signal intensity maintains a constant level for some period of time and then abruptly changes to another constant level.



(a) Analog



(b) Digital

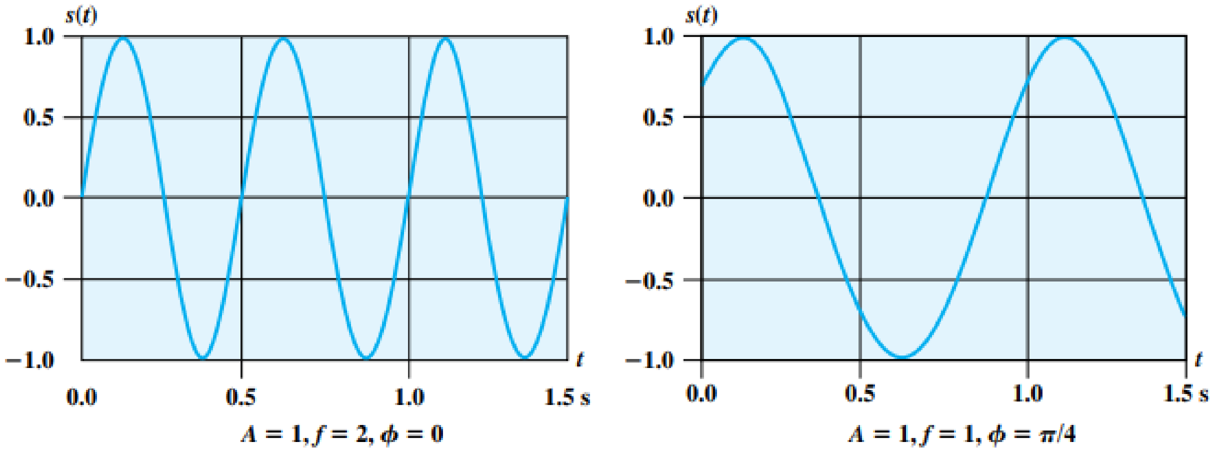
Frequency and Spectrum

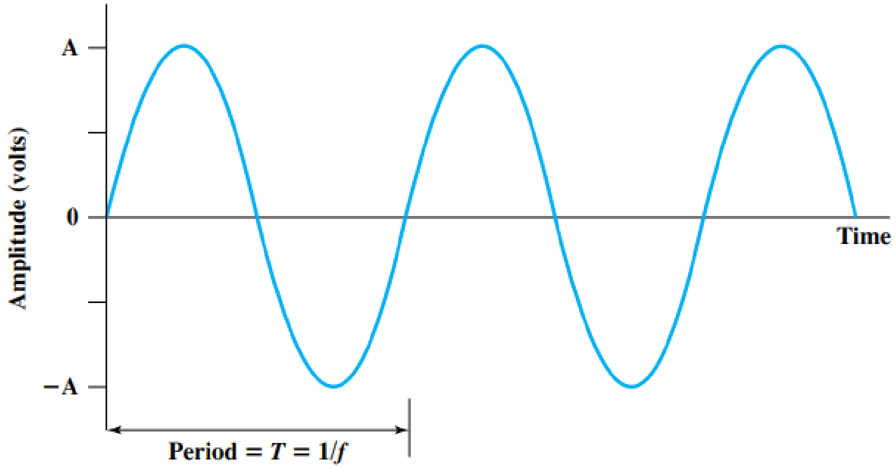
- Periodic signal - signal pattern repeats over time

$$s(t + T) = s(t) \qquad -\infty < t < +\infty$$

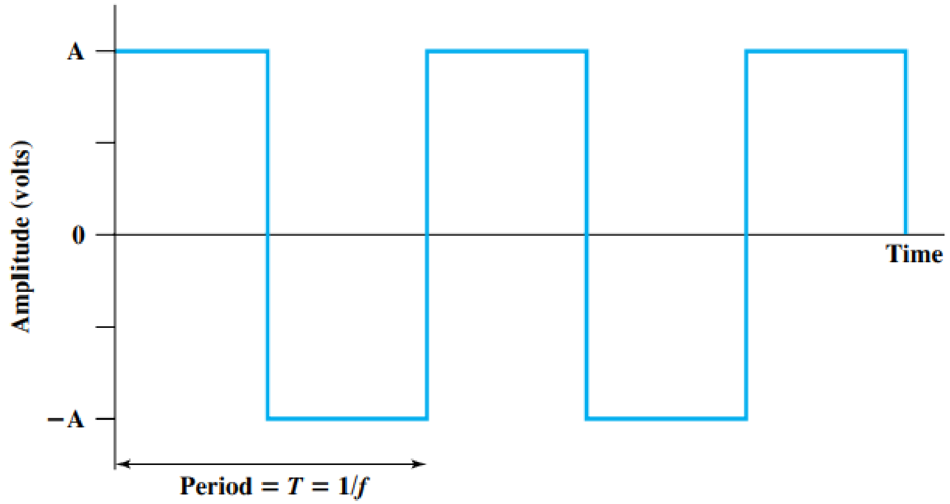
- Aperiodic signal - signal pattern not repeated over time
- The peak amplitude is the maximum value or strength of the signal over time
- Frequency is the rate at which the signal repeats
- Phase is a measure of the relative position in time within a single period of a signal

$$s(t) = A \sin(2\pi f t + \phi)$$





(a) Sine wave



(b) Square wave

Frequency and Spectrum

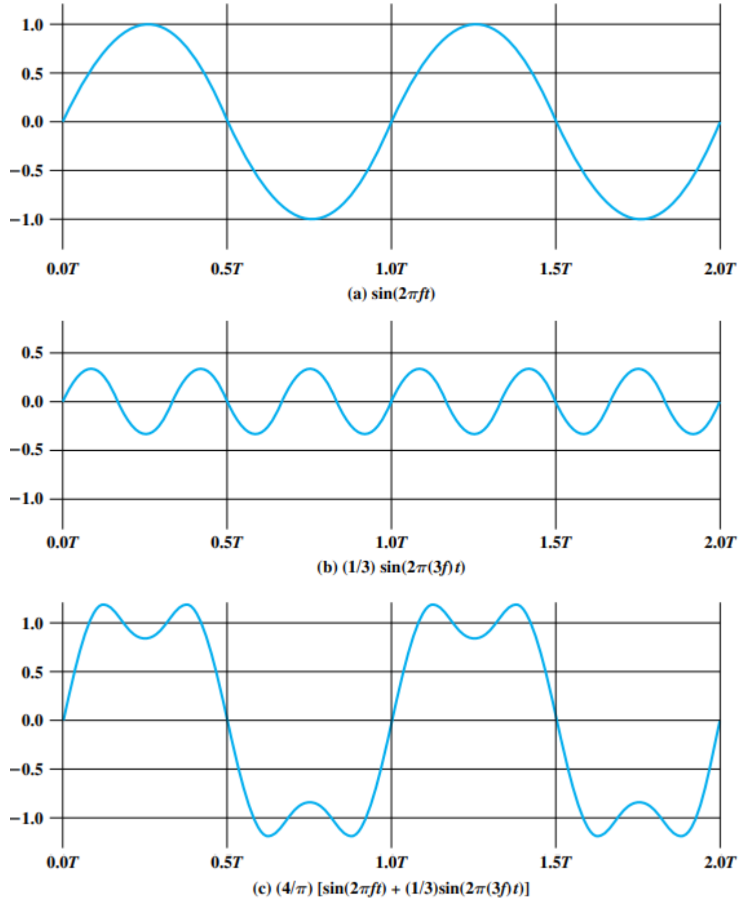
Frequency domain concepts

- Value of a signal at a given point in time as a function of distance.
- The *wavelength* of a signal is the distance occupied by a single cycle, or, the distance between two points of corresponding phase of two consecutive cycles.
- If the signal is traveling with a velocity v, then the wavelength is related to the period by

$$\lambda = vT.$$

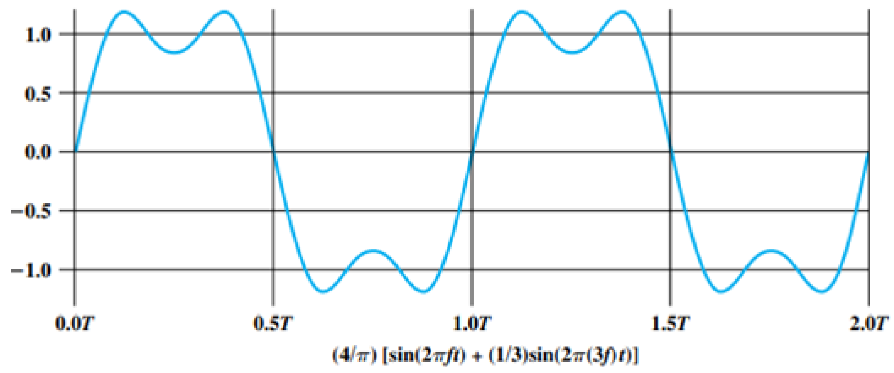
- In practice, an electromagnetic signal will be made up of many frequencies.

$$s(t) = [4/\pi) \times (\sin(2\pi f t) + (1/3)\sin(2\pi(3f)t)]$$

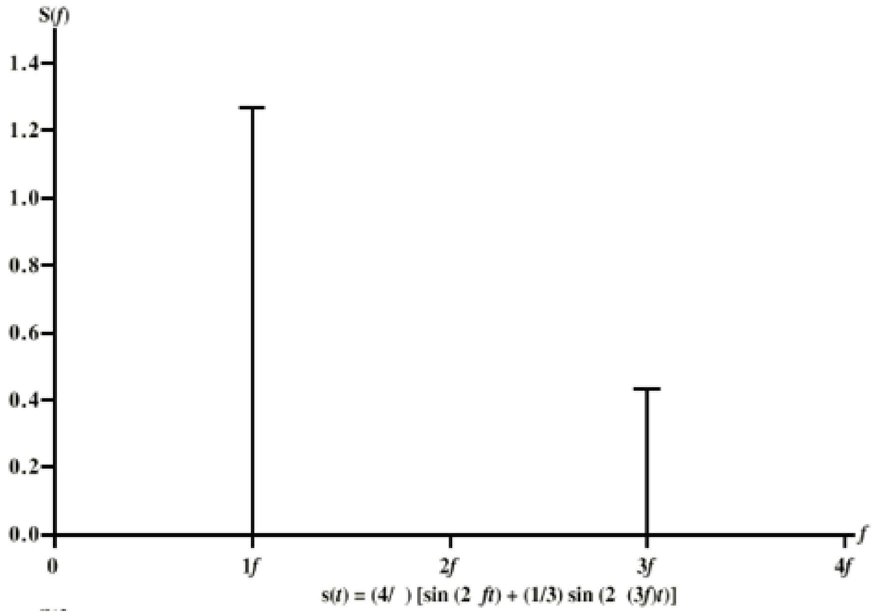


Frequency and Spectrum

- Each signal has a time domain function *s(t)* that specifies the amplitude of the signal at each instant in time.
- Similarly, there is a frequency domain function *S(f)* that specifies the peak amplitude of the constituent frequencies of the signal

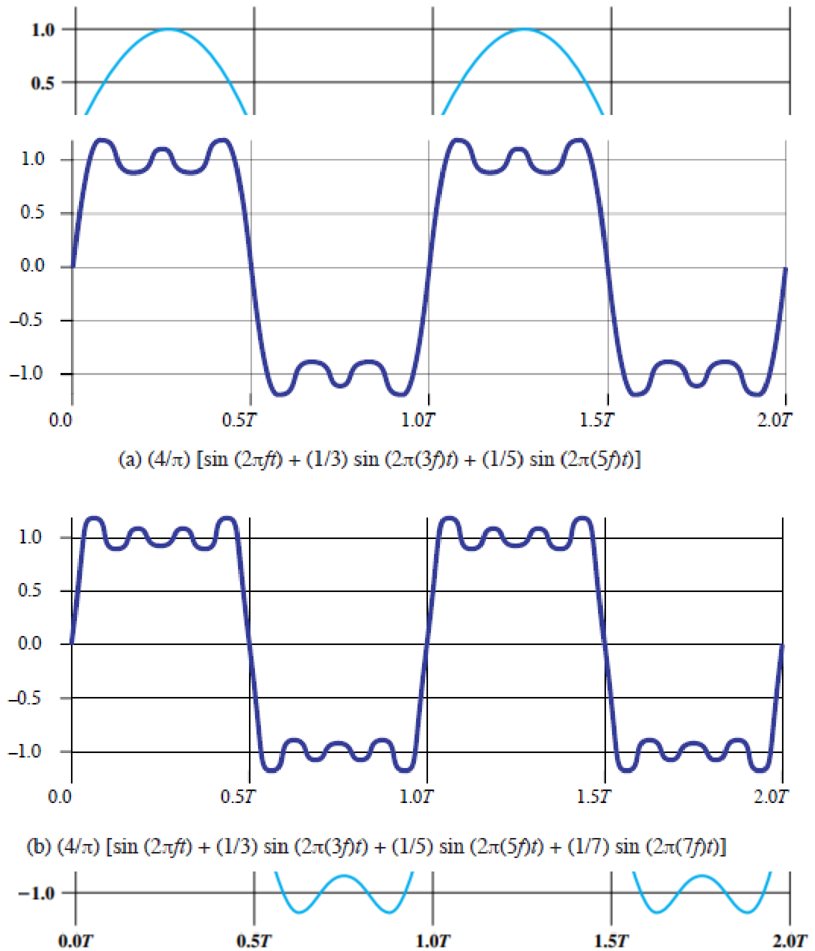


- The *spectrum* of a signal is the range of frequencies that it contains. [*f* to 3*f*]
- The *absolute bandwidth* of a signal is the width of the spectrum. [2*f*]
- Most of the energy in the signal is contained in a relatively narrow band of frequencies - bandwidth



Bandwidth and Data Rate

- Any transmission system accommodate only a limited band of frequencies.
- Square wave has an infinite number of frequency components and hence an infinite bandwidth
- Additional odd multiples of *f*, suitably scaled, the resulting waveform approaches that of a square wave.
- The duration of each pulse is 1/(2*f*), thus the data rate is 2*f* bits per second (bps).
- Consider waveform in (a)
- Bandwidth 5f – f = 4MHz
- Fundamental frequency f = 1MHz
- The period of fundamental frequency => 1/f = 10^{-6} = 1μs.
- One wave takes two data bits, Data rate = 2 Mbps



(a) $(4/\pi)\,[\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t) + (1/5)\sin(2\pi(5f)t)]$

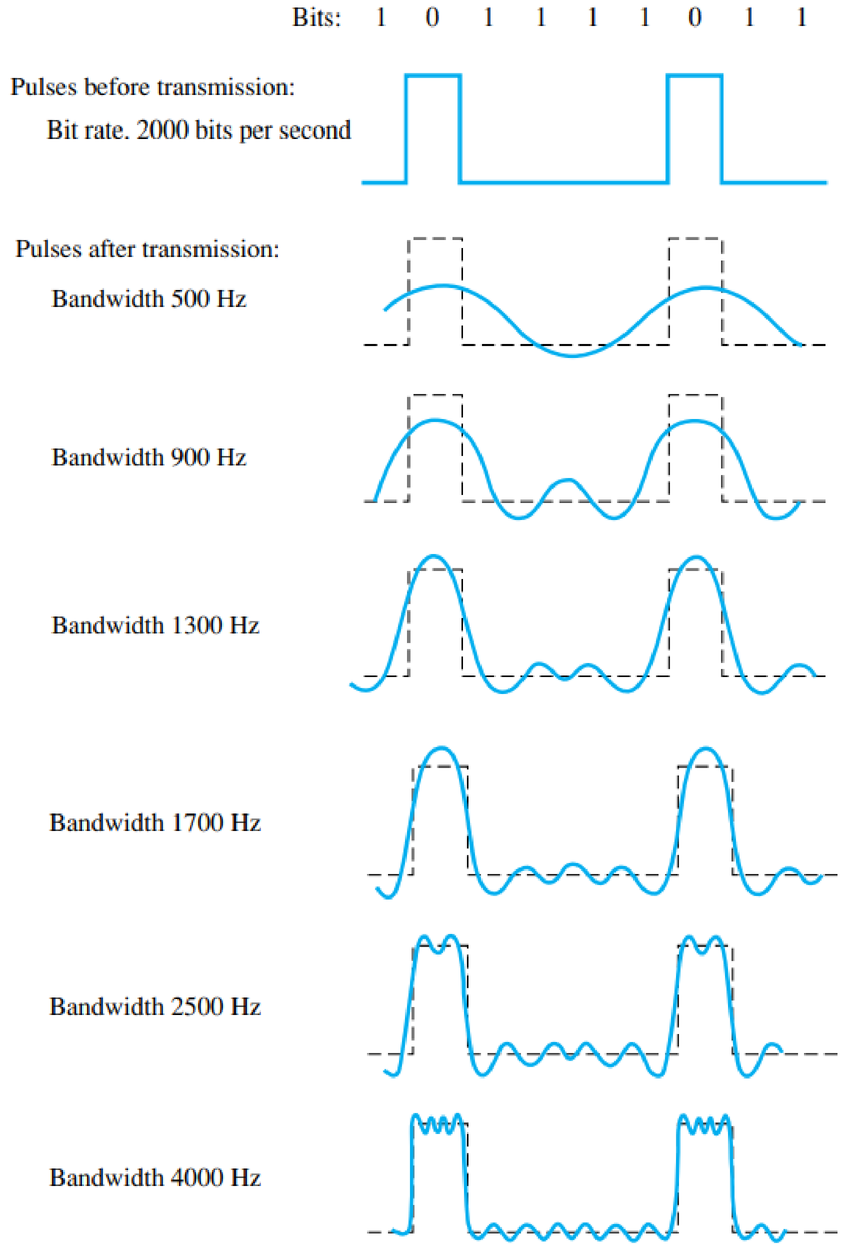
(b) $(4/\pi)\,[\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t) + (1/5)\sin(2\pi(5f)t) + (1/7)\sin(2\pi(7f)t)]$

(c) $(4/\pi)\,[\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t)]$

Bandwidth and Data Rate

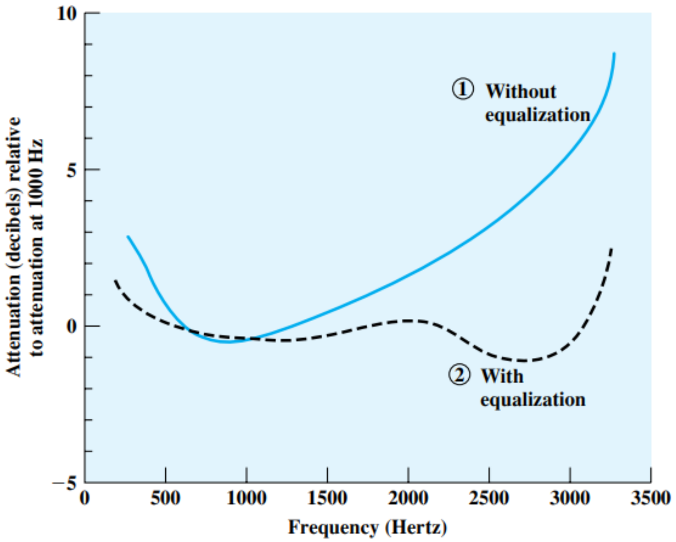
- Transmission system will limit the bandwidth that can be transmitted.
- For any given medium, the greater the bandwidth transmitted, the greater the cost.
- Limiting the bandwidth creates distortions, which makes the task of interpreting the received signal more difficult.
- More limited the bandwidth, the greater the distortion, and the greater the potential for error by the receiver.

If the data rate of the digital signal is W bps, then a very good representation can be achieved with a bandwidth of $2W$ Hz

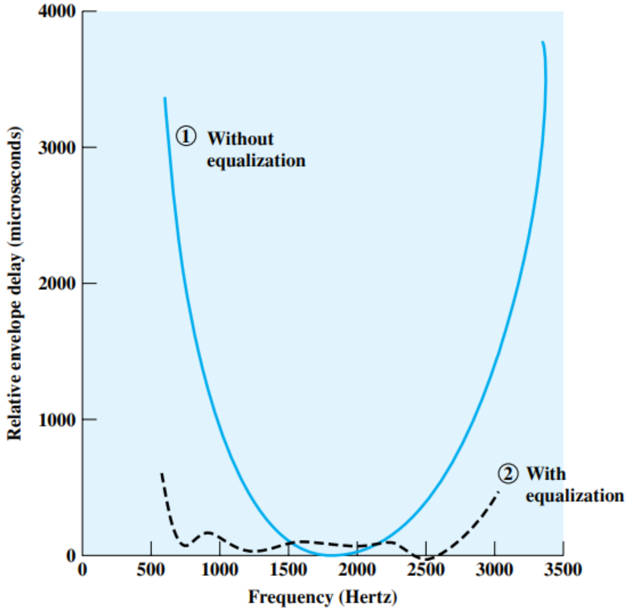


Channel Capacity

- The maximum rate at which data can be transmitted over a given communication path, or channel, under given conditions.
- In any communications system, the signal that is received may differ from the signal that is transmitted due to various transmission impairments.
- For analog signals, these impairments can degrade the signal quality.
- For digital signals, bit errors may be introduced, such that a binary 1 is transformed into a binary 0 or vice versa.
- The most significant impairments are
  - Attenuation - strength of a signal falls off with distance
  - Delay distortion - velocity of propagation of a signal through a guided medium varies with frequency
  - Noise - undesired signals



Attenuation

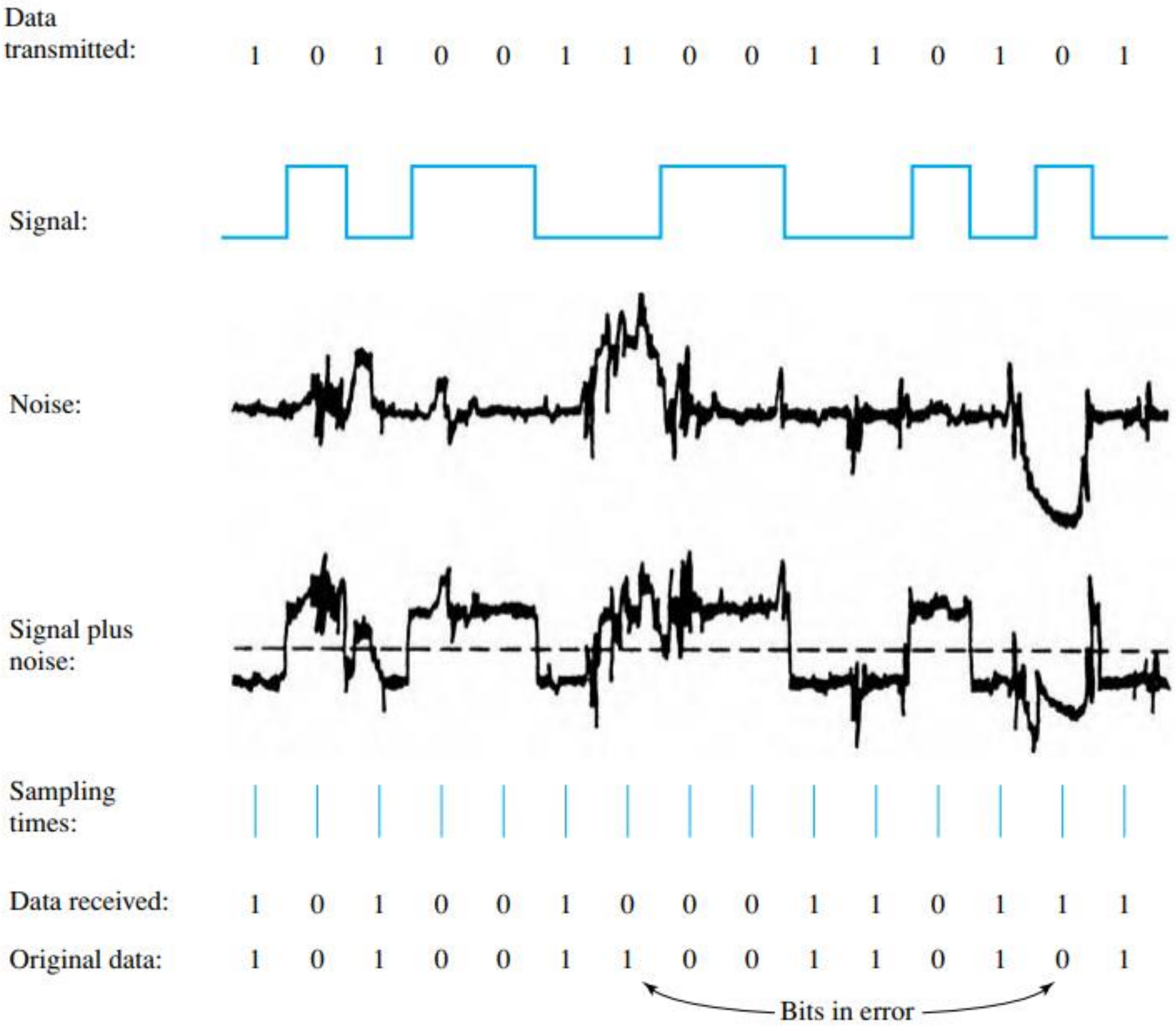


Delay distortion

Channel Capacity

Noise

- The received signal will consist of the transmitted signal, modified by the various distortions imposed by the transmission system, plus additional unwanted signals that are inserted somewhere between transmission and reception.



Channel Capacity

Nyquist Bandwidth

- In the case of a channel that is noise free, the limitation on data rate is simply the bandwidth of the signal.
- Nyquist, states that if the rate of signal transmission is 2B, then a signal with frequencies no greater than B is sufficient to carry the signal rate.
- Given a bandwidth of B, the highest signal rate that can be carried is 2B.
- If the signals to be transmitted are binary (two voltage levels), then the data rate that can be supported by B Hz is 2B bps.
- Nyquist capacity formulation becomes

$$C = 2B \log_2 M$$

M is the number of discrete signal or voltage levels.

Doubling the bandwidth doubles the data rate

Channel Capacity

Shannon Capacity Formula

- If the data rate is increased, then more bits will occur during the interval of a noise spike, and hence more errors will occur.
- For a given level of noise, a greater signal strength would improve the ability to receive data correctly in the presence of noise – key parameter is signal-to-noise ratio.
- Signal-to-noise ratio (SNR, or S/N) - the ratio of the power in a signal to the power contained in the noise that is present at a particular point in the transmission.

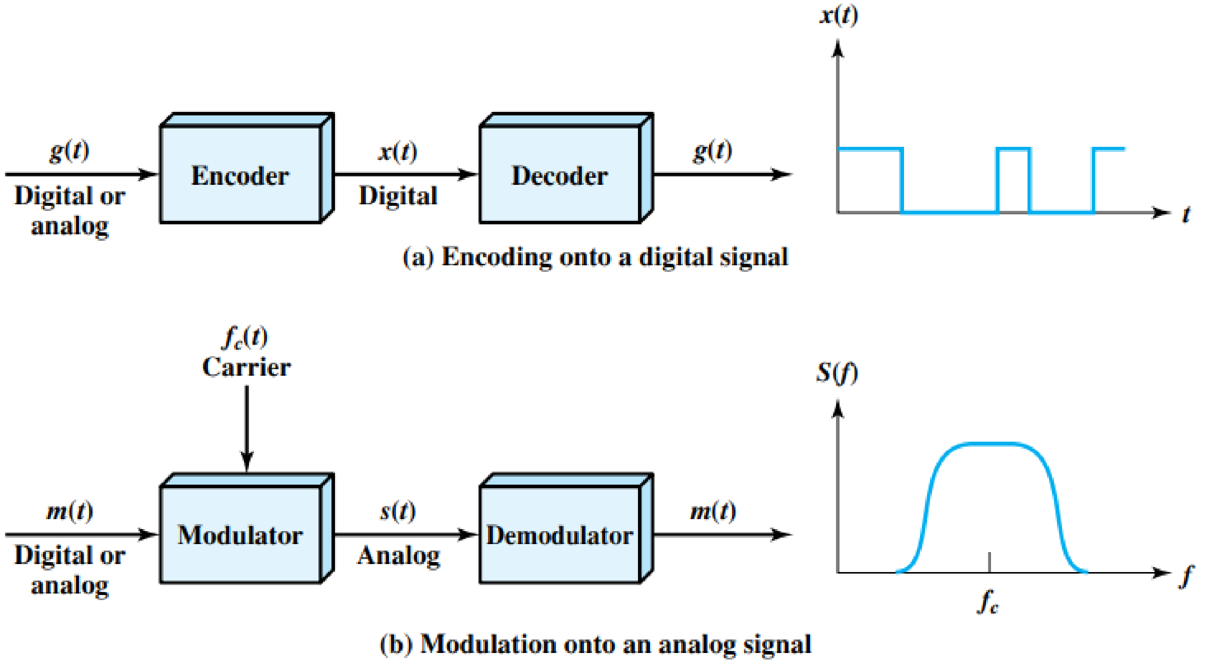
$$\mathrm{SNR_{dB}} = 10 \log_{10} \frac{\text{signal power}}{\text{noise power}}$$

- A high SNR will mean a high-quality signal and a low number of required intermediate repeaters
- The maximum channel capacity, in bits per second,

$$C = B \log_2(1 + \mathrm{SNR})$$

Modulation

- Process of encoding source data onto a carrier signal
- The encoding scheme is simply the mapping from data bits to signal elements.



Encoding and Modulation Techniques

Modulation

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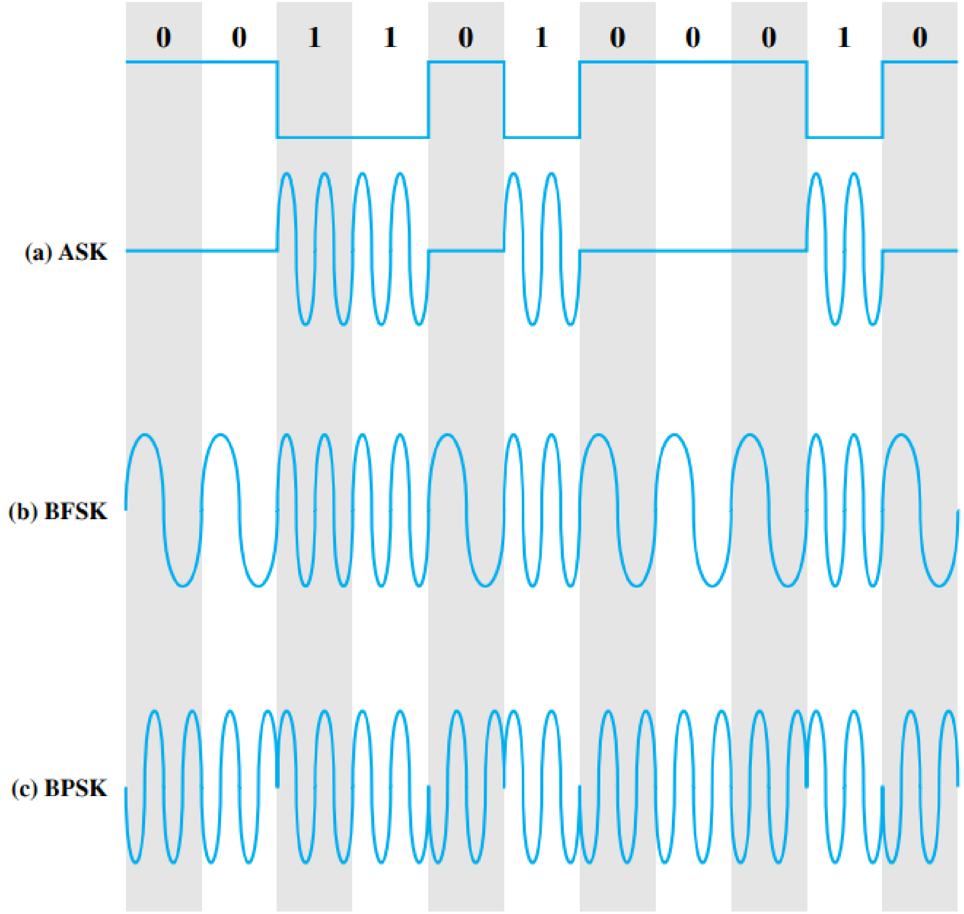
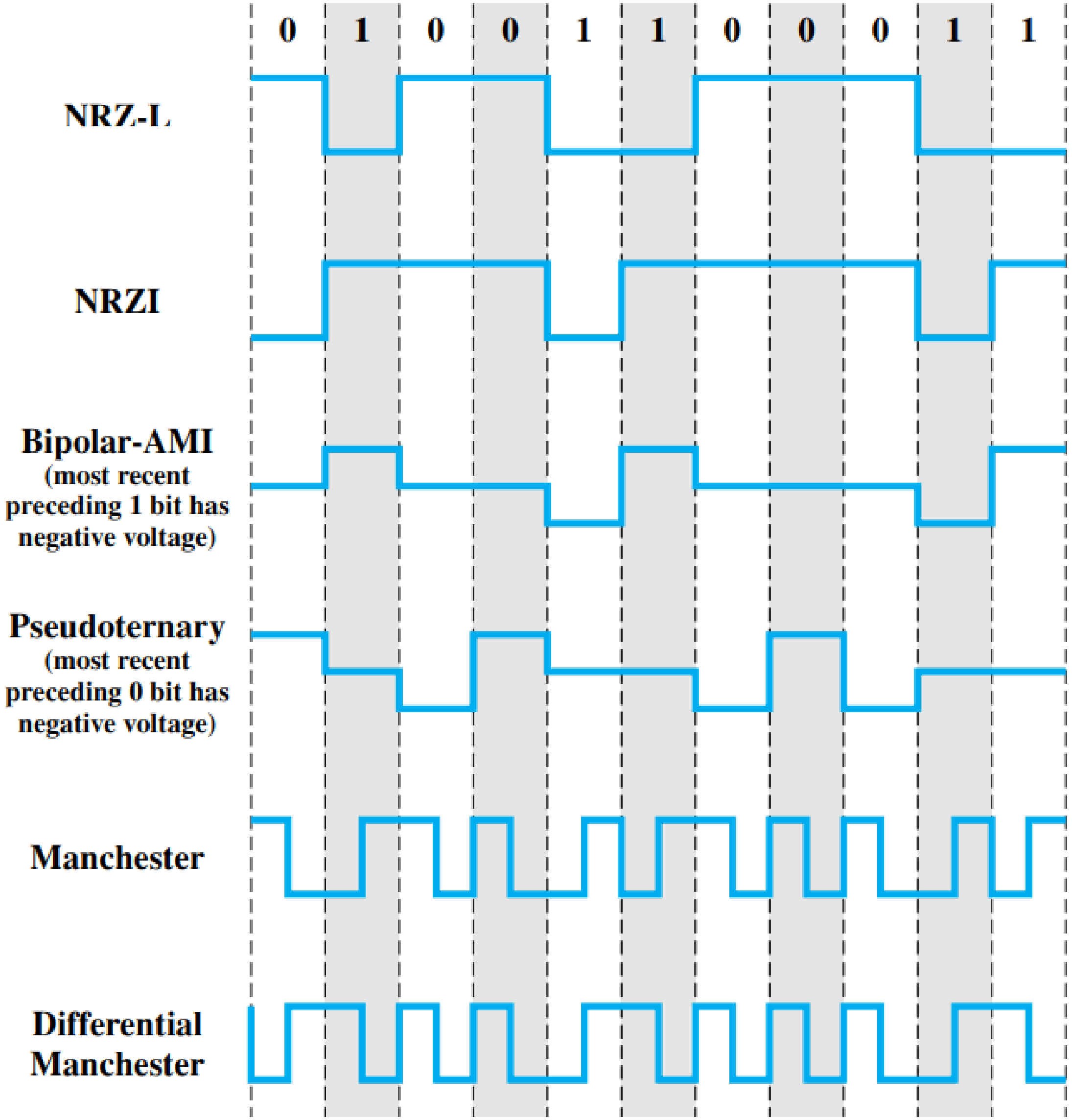


Modulation of Analog Signals for Digital Data



Digital Signal Encoding Formats

Modulation rate

- The rate at which the signal level is changed - signal elements per second
- The receiver must know with some accuracy when a bit begins and ends.
- Receiver must determine whether the signal level for each bit position is high (0) or low (1).
- Modulation rate is the rate at which signal elements are generated - the average number of transitions that occur per bit time

$$D = \frac{R}{L} = \frac{R}{\log_2 M}$$

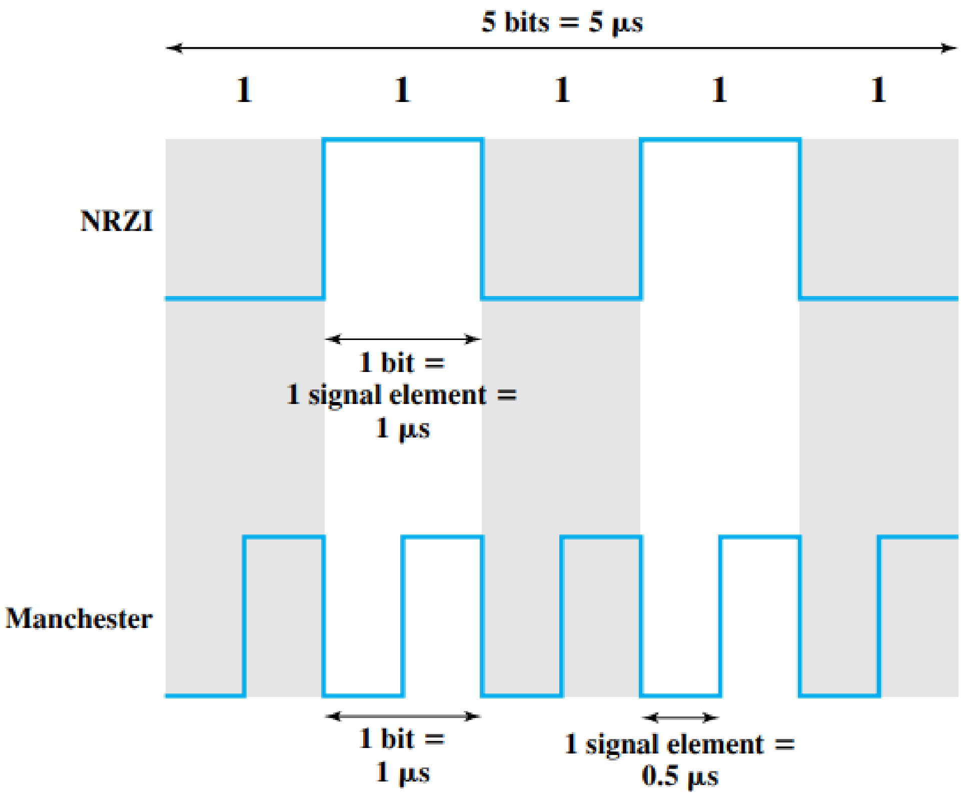
Where, D = modulation rate, baud

R = data rate, bps

M = number of different signal elements = 2^L

L = number of bits per signal element

Bit rate = number of bits / symbol x Baud rate



Throughput and Latency

- Throughput is the actual amount of data that is successfully sent/received over the communication link per unit time.
- Actual measurement of how fast data is sent - Measured in bps
- Overall effective transmission rate, takes into account things like transmission overhead, protocol inefficiencies and network traffic.
- Maximum possible utilization of the network - ratio of total throughput of the network to its data rate

$$U = \frac{\text{Throughput}}{\text{Data rate}}$$

- Latency is the time it takes for a packet to get across the network, from source to destination.
- Measured in units of time — ms.
- Four components - propagation time, transmission time, queuing time and processing delay

Latency =propagation time +transmission time +queuing time + processing delay

Throughput and Latency

- Propagation time measures the time required for a bit to travel from the source to the destination - calculated by dividing the distance by the propagation speed.

$$\text{Propagation time} = \frac{\text{Distance}}{\text{Propagation Speed}}$$

- The time required for transmission of a message depends on the size of the message and the bandwidth of the channel

$$\text{Transmission time} = \frac{\text{Message size}}{\text{Bandwidth}}$$

- Queuing time - the time needed for each intermediate or end device to hold the message before it can be processed.

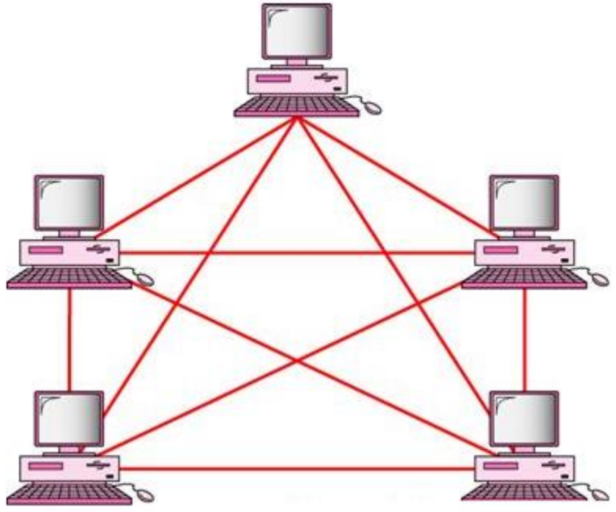
- Jitter is the variation in delay for packets belonging to the same flow.

Networks

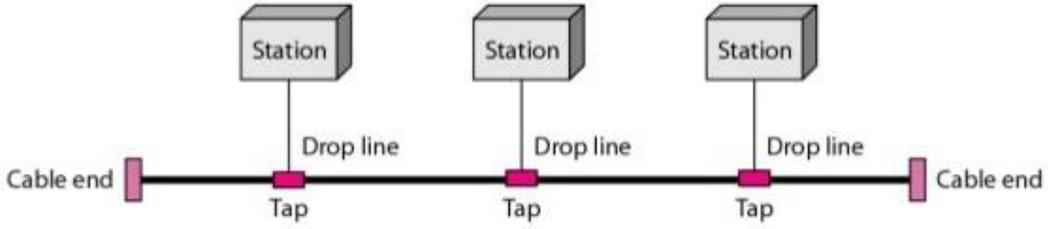
- A network is a set of devices (referred to as nodes) connected by communication links.
- A *node* can be a computer, printer, or any other device capable of sending and/or receiving data generated by other nodes on the network.
- A *link* is a communications pathway that transfers data from one device to another.
- The way in which a network is laid out physically is referred as network topology.
- Two or more devices connect to a link; two or more links form a topology.
- There are four basic topologies possible: mesh, star, bus, and ring.

Networks

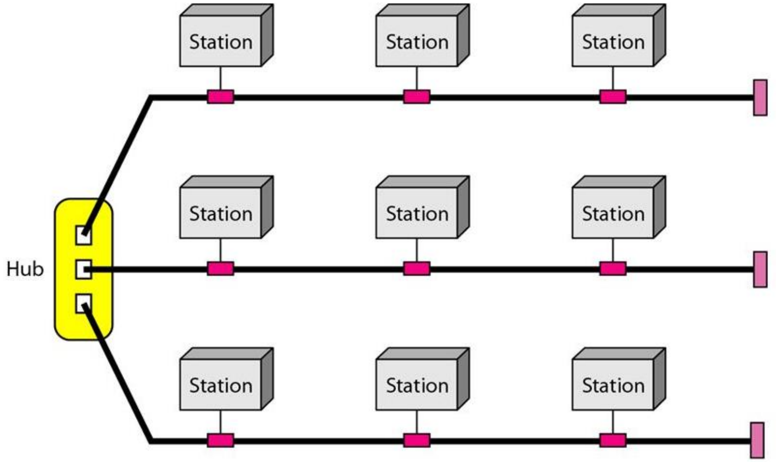
- There are four basic topologies possible: mesh, star, bus, and ring.

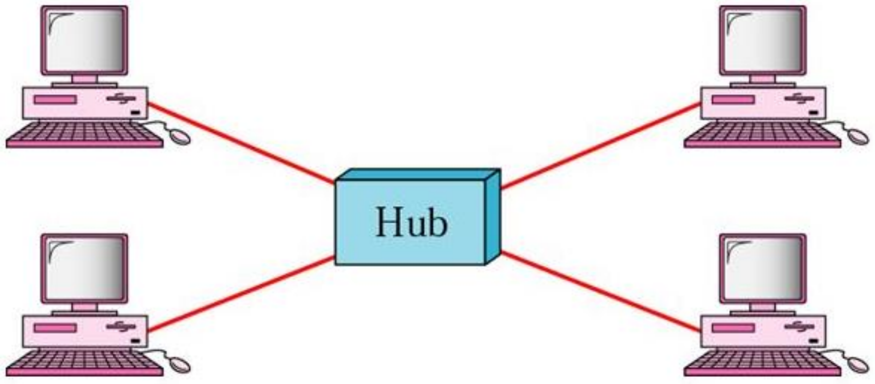


Mesh

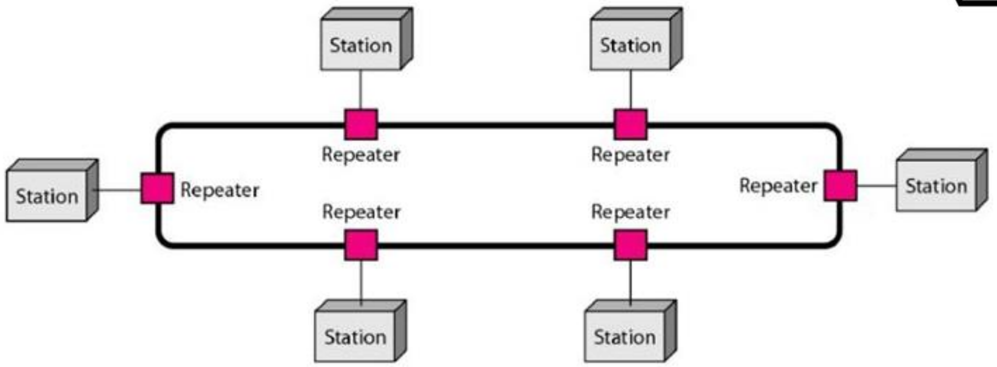


Bus





Star

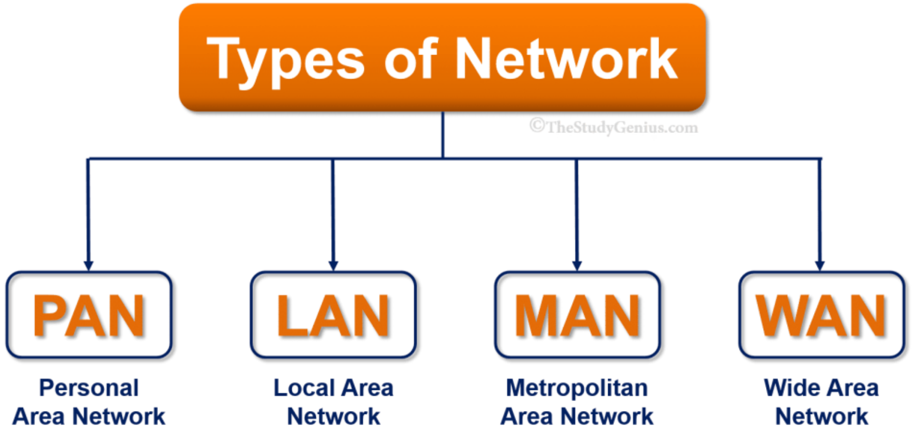


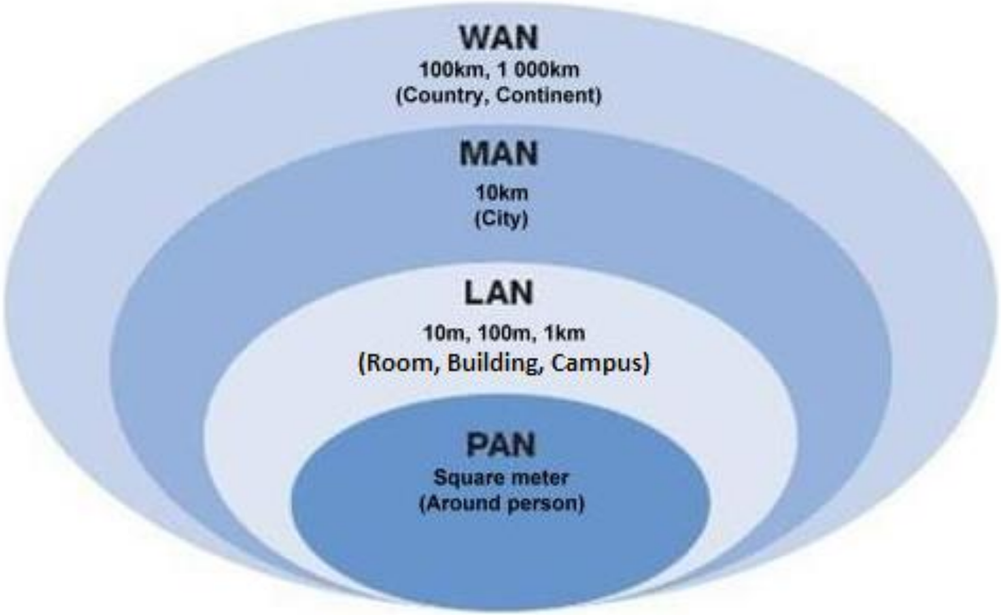
Ring

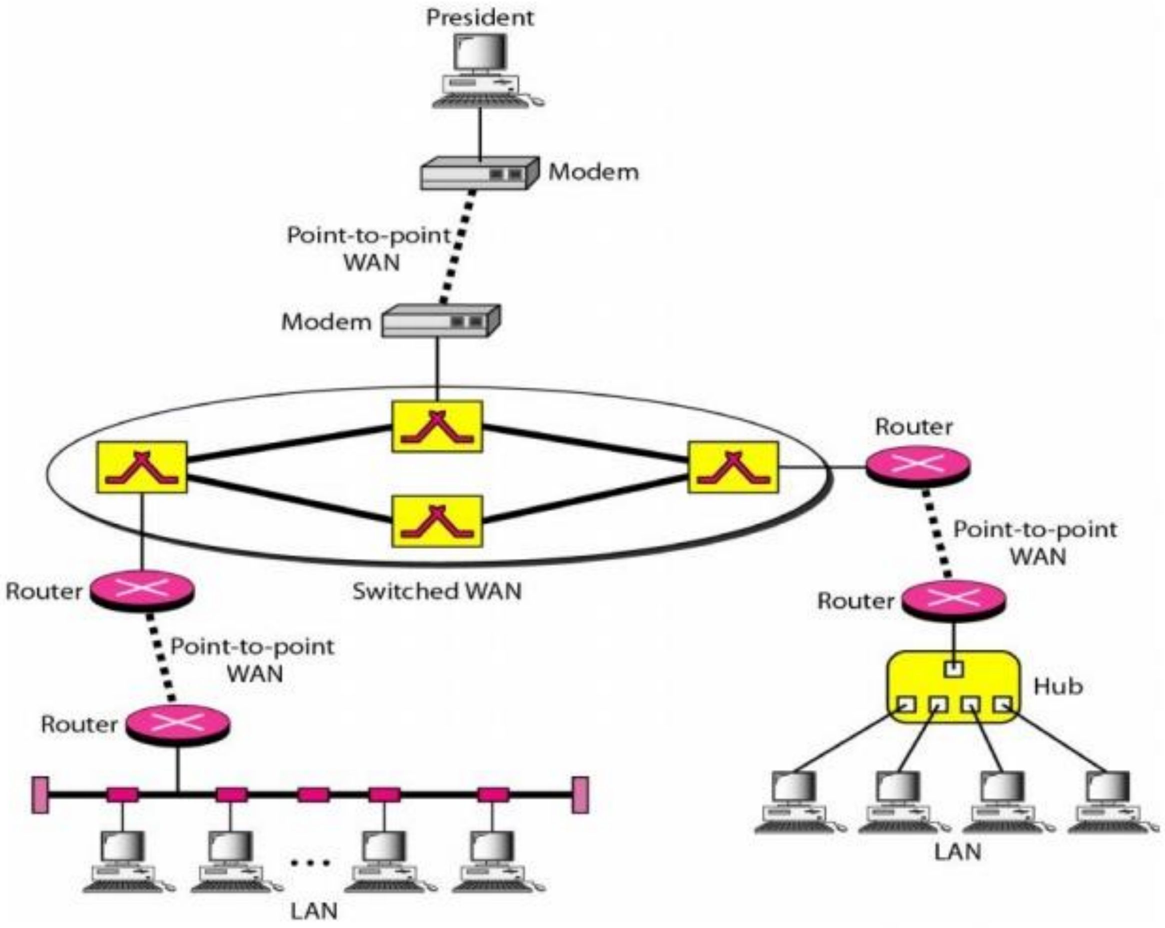
Addressing mode

- Address refers to a single system or port.
- The source node wants to send a message to a single destination node (sink - accepts the information)
- A source address is always a unicast address - the frame comes from only one station.
- The destination address can be unicast, multicast, or broadcast.
- Point-to-point transmission with exactly one sender and exactly one receiver is called unicasting.
- When a packet is transmitted, it is received and processed by every machine on the network, the mode of operation is called broadcasting.
- Transmission to a subset of the machines is known as multicasting.

Categories of Networks

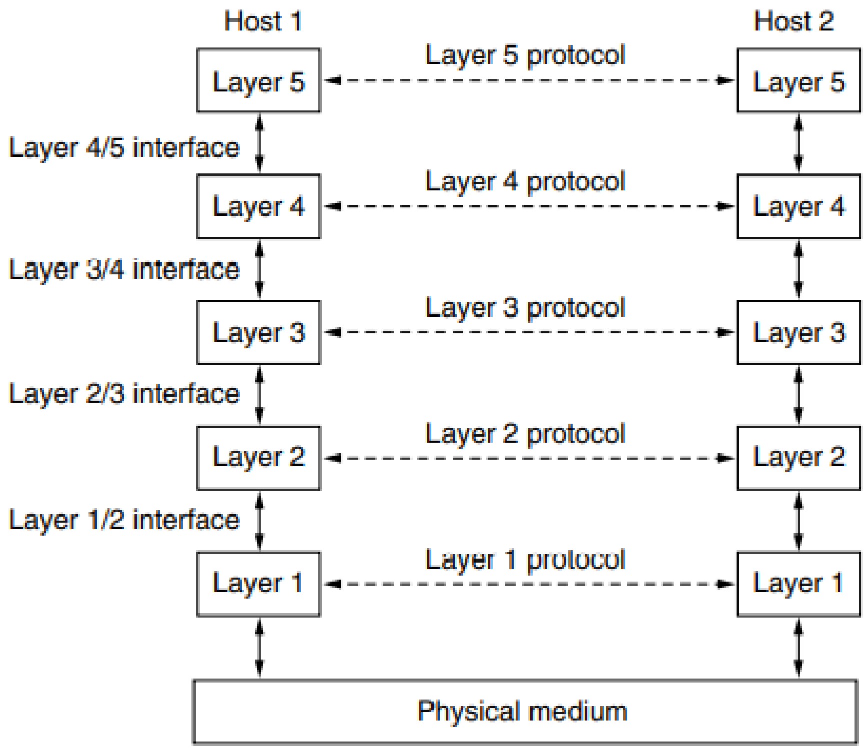






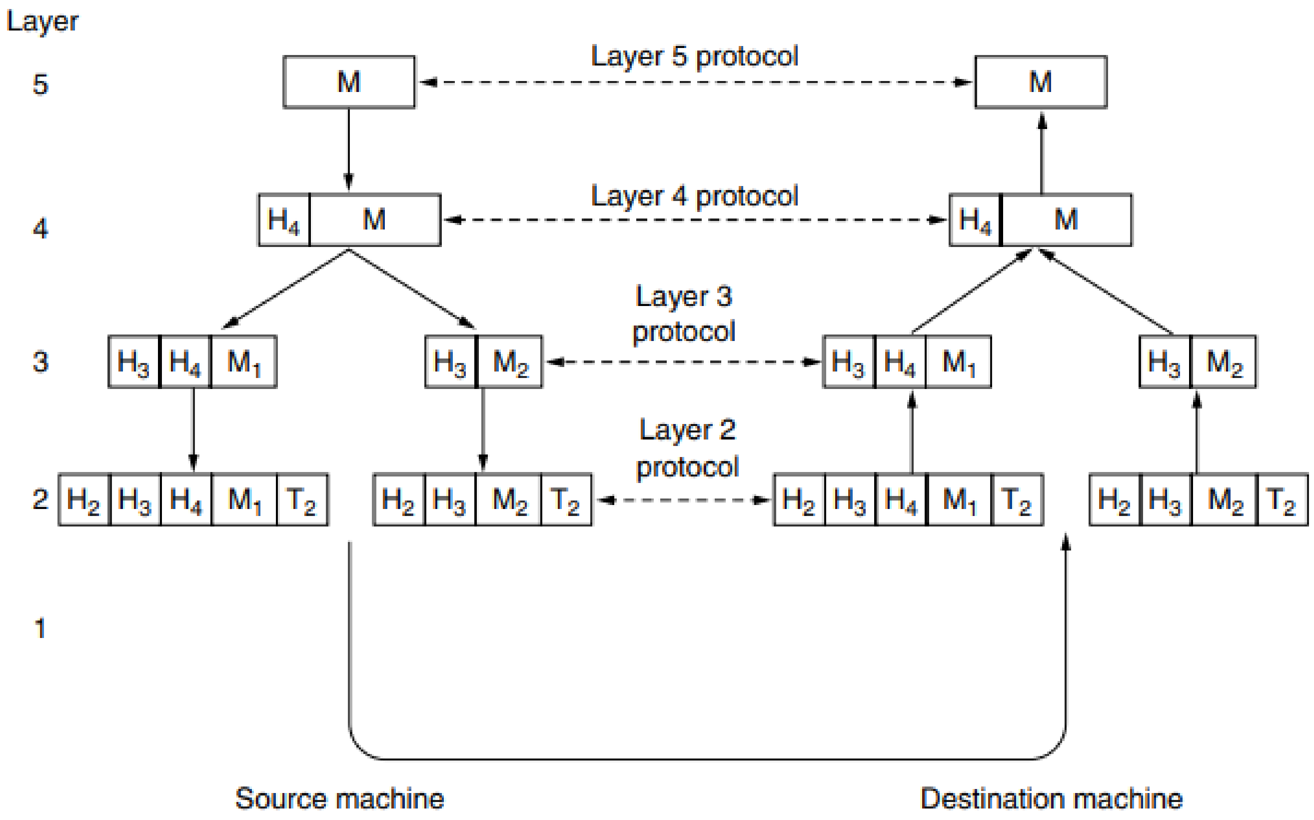
Protocols

- Networks are organized as a stack of layers or levels, each one built upon the one below it.
- The number of layers, the name of each layer, the contents of each layer, and the function of each layer differ from network to network.
- The purpose of each layer is to offer certain services to the higher layers shielding those layers from the details of how the offered services are actually implemented - each layer is a kind of virtual machine.
- When layer n on one machine carries on a conversation with layer n on another machine, the rules and conventions used in this conversation are collectively known as the layer n protocol.
- Protocol is an agreement between the communicating parties on how communication is to proceed.



Protocol Stack

- A set of layers and protocols is called a network architecture
- A list of the protocols used by a certain system, one protocol per layer, is called a protocol stack.



Wireless technologies

- Satellite communication
- Infrared communication
- Broadcast Radio
- Microwave communication
- Wi-Fi
- Mobile communication
- Bluetooth Technology