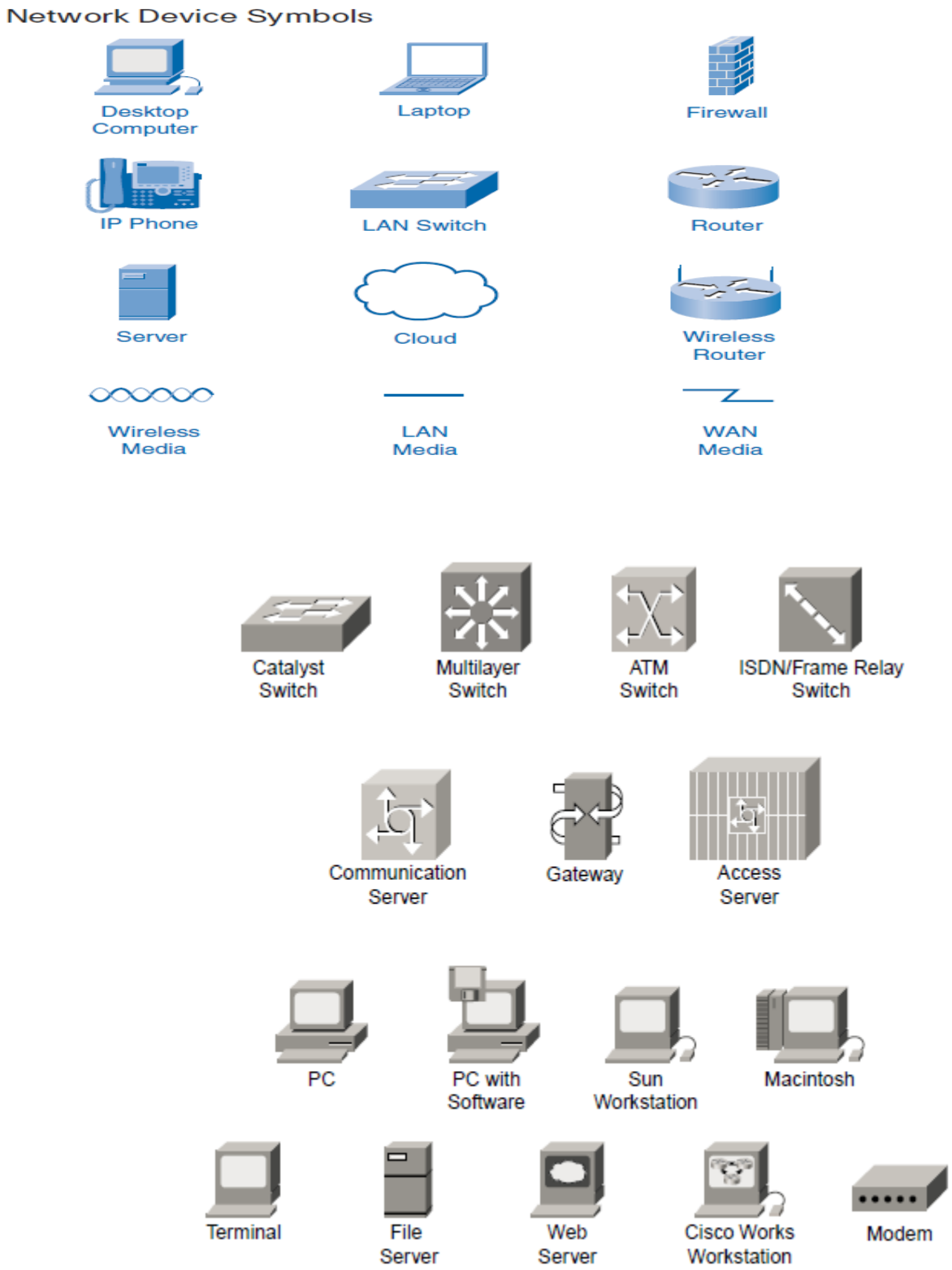

Network Device Symbols
Desktop Computer
Laptop
Firewall
IP Phone
LAN Switch
Router
Server
Cloud
Wireless Router
Wireless Media
LAN Media
WAN Media
Catalyst Switch
Multilayer Switch
ATM Switch
ISDN/Frame Relay Switch
Communication Server
Gateway
Access Server
PC
PC with Software
Sun Workstation
Macintosh
Terminal
File Server
Web Server
Cisco Works Workstation
Modem

Communicating in a Network-Centric World

Humans depend on the interaction with others for daily needs. Throughout human history, people, with few exceptions, have depended on the structure of various community networks for safety, food, and companionship. People have been networking for a very long time.
Now, the Internet allows people to instantaneously share all types of communication—documents, pictures, sound, and video—with thousands of people near and far away using compute

Communication: An Essential Part of Our Lives

Communication in our daily lives takes many forms and occurs in many environments. We have different expectations depending on whether we are chatting through the Internet or participating in a job interview. Each situation has its corresponding expected behaviors and styles.
These expectations are the rules of communication, and some of the elements are universal.
Taking a closer look at the way humans communicate will introduce many of the necessary elements of network communication as well.

Quality of Communication

Successful communication between computer networks devices, just as is true with communication between people, occurs when the meaning of the message understood by the recipient matches the meaning intended by the sender.
There are many potential barriers to successful communication between computers on a network. The process of sending a message on a computer network can be complex and have many steps and conditions, and any step poorly performed or condition not properly met can potentially ruin the message. The steps and conditions, or factors, can be separated into internal and external groups.

The external factors stem from the complexity of the network and the number of devices handling the message route to the destination.

Examples of external factors include the following:

The quality of the pathway between the sender and the recipient
The number of times the message has to change form
The number of times the message has to be redirected or readdressed
The number of other messages being transmitted simultaneously on the communication network
The amount of time allotted for successful communication

Internal factors include the following:

The size of the message
The complexity of the message
The importance of the message
More complex messages can be more difficult for the recipient to understand, and larger messages have a greater potential to be distorted or incomplete at the destination.

The Network as a Platform (Communicating over Networks)

- The ability to reliably communicate to anyone, anywhere, is becoming increasingly important to our personal and business lives. Adding to the demand of immediacy is the requirement that different types of messages, such as phone, text, and video, be accommodated as normal forms of communication. To support the immediate delivery of the millions of various messages being exchanged among people all over the world, we rely on a web of interconnected networks. The following sections describe communication over networks, different elements that make up a network, and convergence.
- Networks directly impact how we live, and the role of networks is increasingly important to people in all parts of the world. The task of reliably delivering millions of messages simultaneously would be too much for any one network to perform. Therefore, a web of smaller, interconnected networks of various sizes and capabilities delivers the many messages and data streams around the world.

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.

"Computer network" is a collection of autonomous computers interconnected by a single technology. Two computers are said to be interconnected if they are able to exchange information.

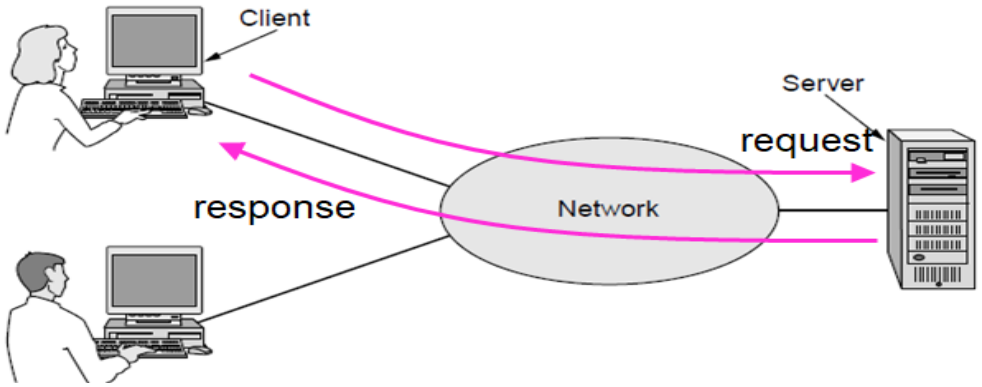
- Networks come in many sizes, shapes and forms, as we will see later.
- They are usually connected together to make larger networks, with the Internet being the most well-known example of a network of networks.

Why Networks? (Benefits of Network) (Tasks of Networks):

1. Data Exchange 2. Sharing Resources

Data exchange in a network is the process of sharing and transferring data between two or more connected systems, this includes: email, VoIP, and e-commerce

Companies use networks and computers for **resource sharing** with the client-server model:



USES OF COMPUTER NETWORKS

- ✓ Communication. ...
- ✓ Resource Sharing. ...
- ✓ Data and Application Sharing. ...
- ✓ Security and Surveillance. ...

- ✓ Business Applications. ...
- ✓ Education and E-Learning. ...
- ✓ Banking and Financial Services. ...
- ✓ E-Commerce.

The effectiveness of a data communications system

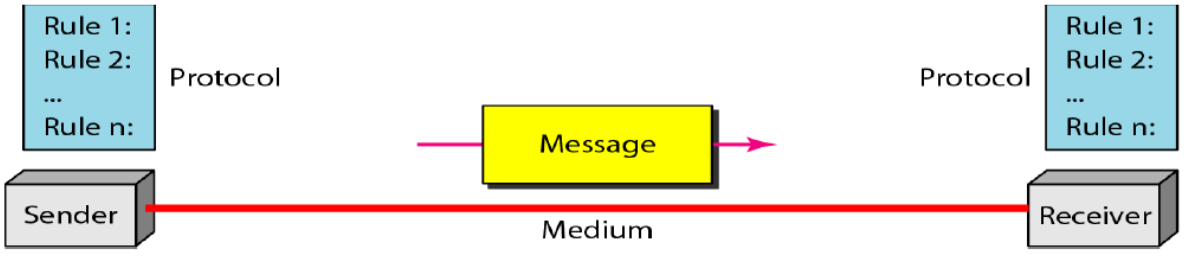
It depends on four fundamental characteristics: delivery, accuracy, timeliness, and jitter.

- **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.

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

- **Timeliness**
  The system must deliver data in a timely manner. Data delivered late are useless. In the case of video and audio, timely delivery means delivering data as they are produced, in the same order that they are produced, and without significant delay. This kind of delivery is called real-time transmission.
- **Jitter**
  Jitter refers to the variation in the packet arrival time. It is the uneven delay in the delivery of audio or video packets. For example, let us assume that video packets are sent every 30 ms. If some of the packets arrive with 30-ms delay and others with 40-ms delay, an uneven quality in the video is the result.

Components of Network (The Elements of a Network):

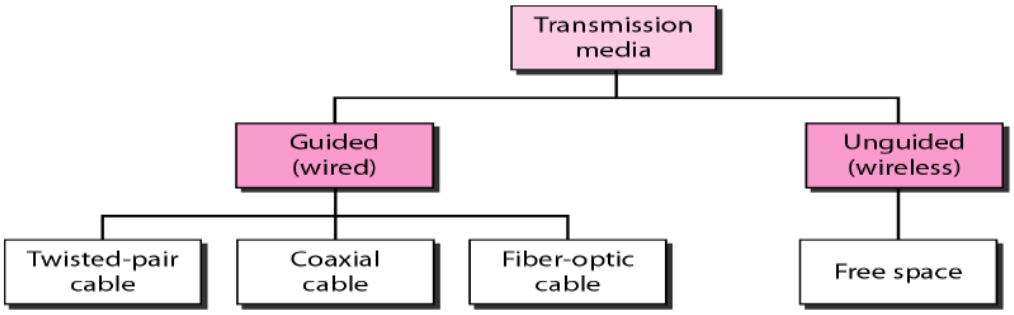


- ✓ **Devices** : They are used to communicate with one another
  They send and receive the data message. They can be a computer, workstation, telephone handset, video camera, and so on.
- ✓ **Medium**: The transmission medium is the physical path by which a message travels from sender to receiver. The main two types of transmission media are weird (guide) and wireless (unguided) .

- ✓ **Messages** Information that travels over the medium. The message is the information (data) to be communicated. Information includes text, numbers, pictures, audio, and video.
- ✓ **Protocols** or Rules that Governs how messages flow across network.
  It represents an agreement between the communicating devices. Without a protocol, two devices may be connected but not communicating, just as a person speaking French cannot be understood by a person who speaks only Japanese.
- ✓ **Intermediary (Networking) Devices**.
  Intermediary devices connect the individual hosts to the network and can connect multiple individual networks to form an internetwork.
  Some work inside the LAN performing switching functions, and others help route messages between networks. The Below Table lists some intermediary devices and their functions.

Device Type	Description
Network access devices	Connect end users to their network. Examples are hubs, switches, and wireless access points.
Internetwork devices	Connect one network to one or more other networks. Routers are the main example.
Communication servers	Route services such as IPTV and wireless broadband.
Modems	Connect users to servers and networks through telephone or cable.
Security devices	Secure the network with devices such as firewalls that analyze traffic exiting and entering networks.

Classes of transmission media



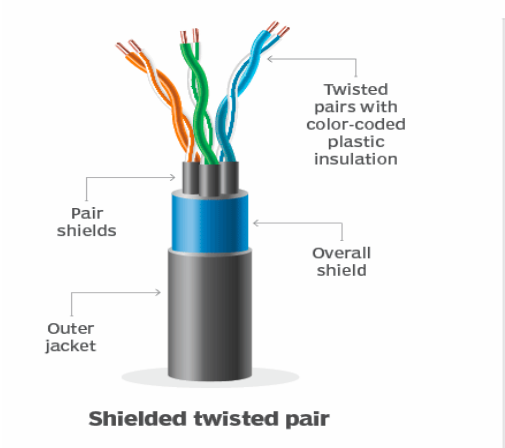
Guided (Wired) Media

Guided media, which are those that provide a medium from one device to another, include twisted-pair cable, coaxial cable, and fiber-optic cable.

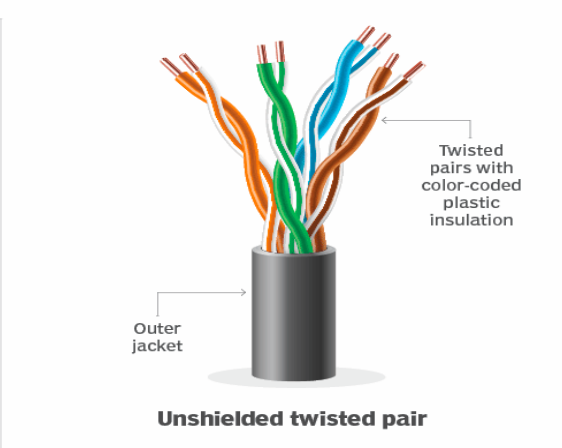
The main types of network cables are :

- ❖ **Twisted pair cables** (UTP and STP) are widely used in Ethernet LANs, with UTP being the most common and STP providing better noise resistance.
- ❖ **Coaxial cables**, unshielded twisted pair (UTP), shielded twisted pair (STP). They are used for transmitting high-frequency signals.
- ❖ **Fiber optic cables** that are reserved for high-speed, long-distance applications due to its superior speed and bandwidth.

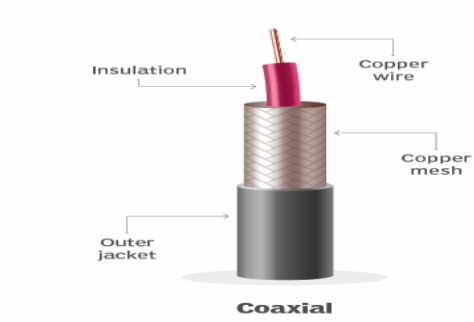
- The other is wireless or unguided transmission medium (e.g.: Infrared, Radio link, Microwave link, Satellite link, Bluetooth, WIFI)



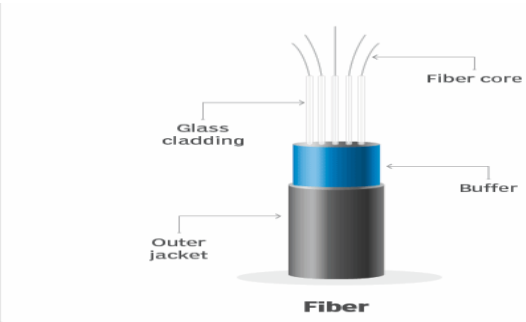
Shielded twisted pair



Unshielded twisted pair



Coaxial



Fiber

Wireless Transmission

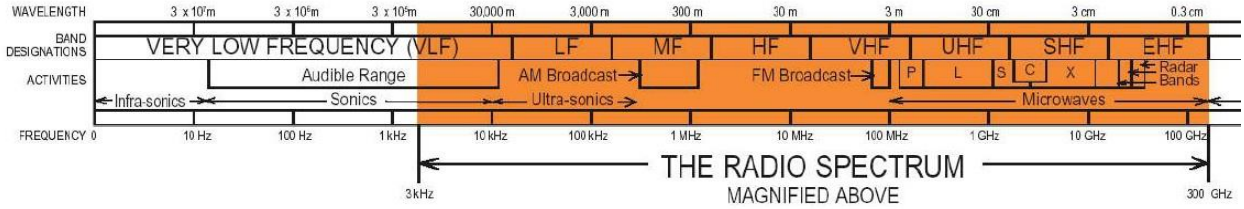
- Wireless transmission media are communication channels that transmit data **without physical cables**, using electromagnetic waves through air or space.
- Instead of copper wires or fiber optics, signals travel as waves.
- Wireless transmission uses **electromagnetic signals** to carry information between sender and receiver through:
  - Air
  - Vacuum (space)
  - Water (in special cases)
- **Examples of wireless Transmissions are** Bluetooth , Wi-Fi , Microwave , Mobile and Satellite communications.

Signal & Transmission Basics

- To be transmitted, data (text , image, voice and movies) must be transformed to electromagnetic signals (RF).

What is RF?

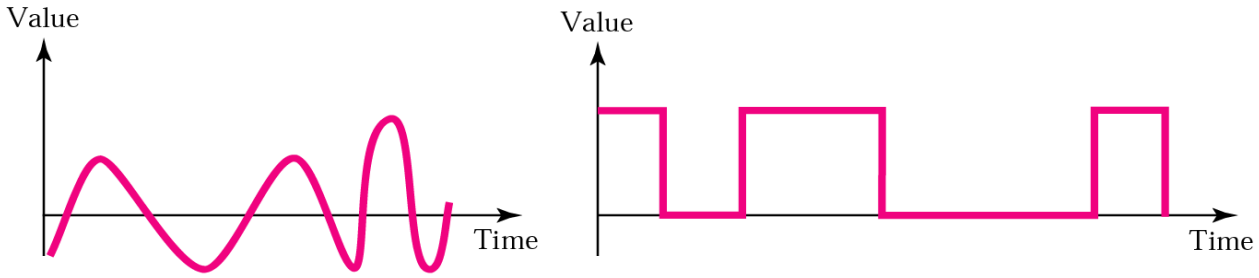
Radio Frequency is an electromagnetic signal with a frequency between 3 kHz and 300 Ghz



RF signals carry analog or digital information

- Analog: Information content varies continuously over time
  - *Example: radio and TV stations*
- Digital: Information content consists of discrete units (e.g., 0s and 1s)
  - *Example: Cell phones and wireless networks*

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

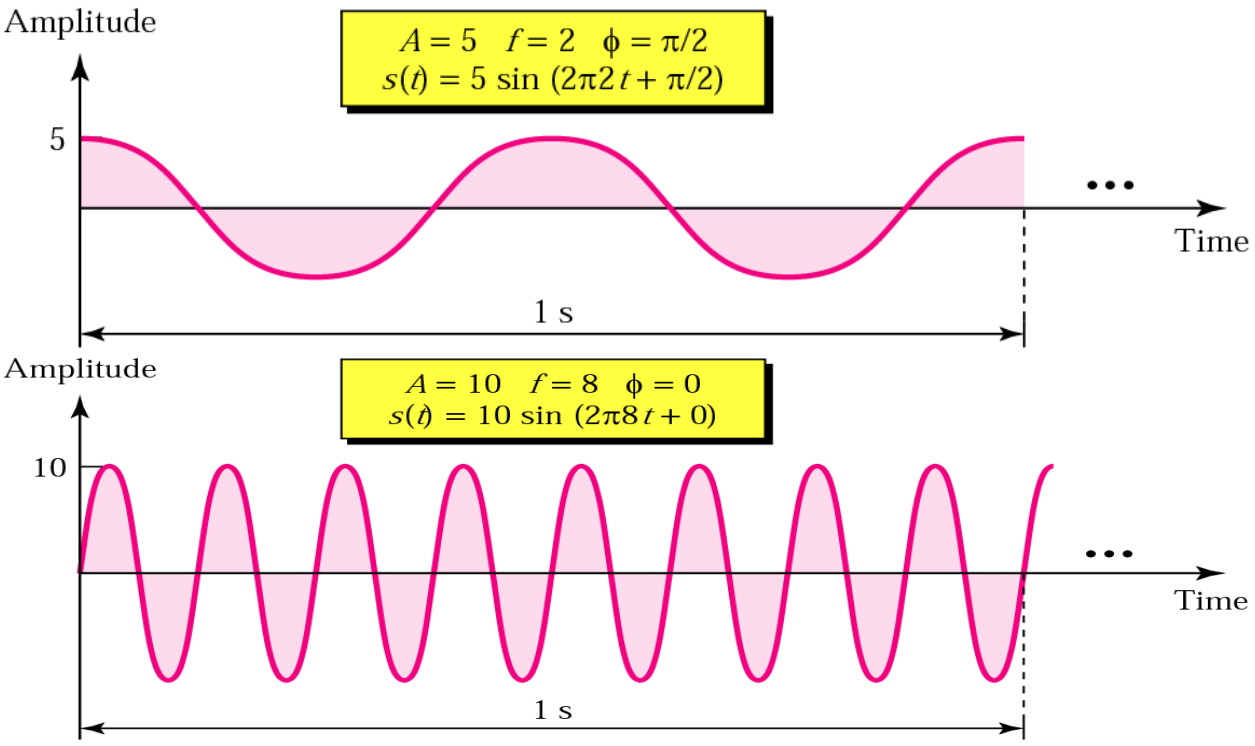


a. Analog signal b. Digital signal

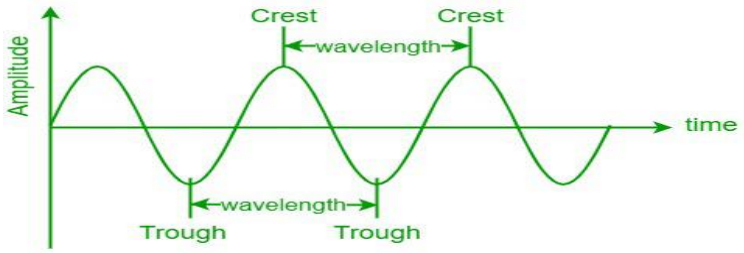
- In data communication, we commonly use **periodic analog signals and aperiodic digital signals**.
- Any Periodic Signal can formulated as :

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

Where A is amplitude , f is frequency and Ø is phase shift



- **Parodic time (T)** is the time of 1 full cycle T=1/f.
- **The wavelength (λ)** of a wave **describes how long the wave is**.
- The distance from the "crest" (top) of one wave to the crest of the next wave is the wavelength. Alternately, we can measure from the "trough" (bottom) of one wave to the trough of the next wave and get the same value for the wavelength.

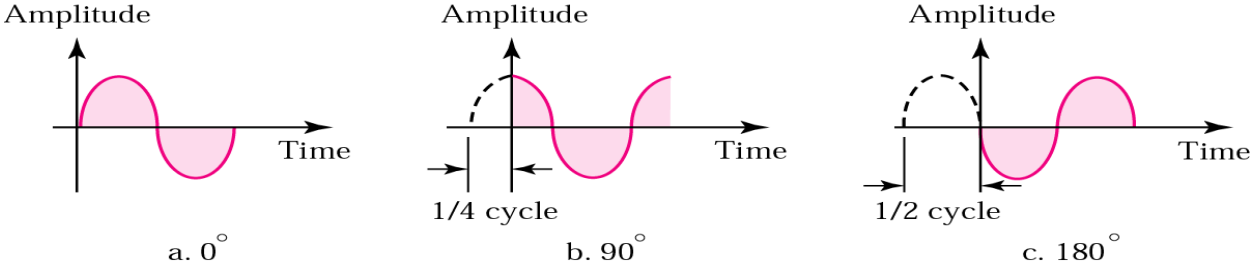


The relationship between frequency and wavelength is described by this equation:

$$\lambda = c / f$$

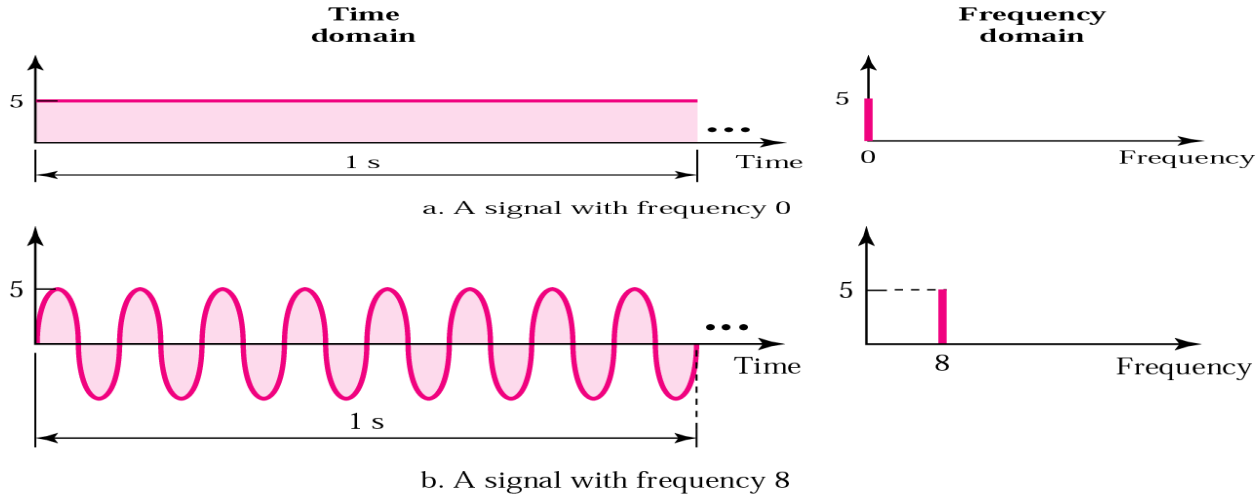
c is a constant that represents the speed of light in space , its value of 3.00 x 108 m/s.

- **Phase** describes the position of the waveform relative to time zero.

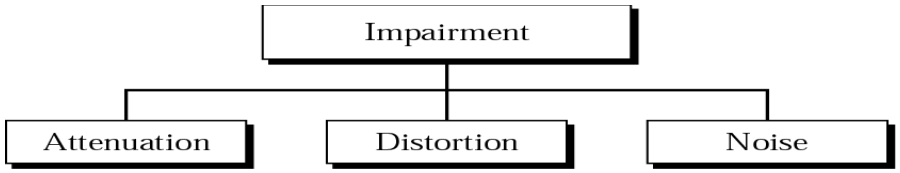


a. 0° b. 90° c. 180°

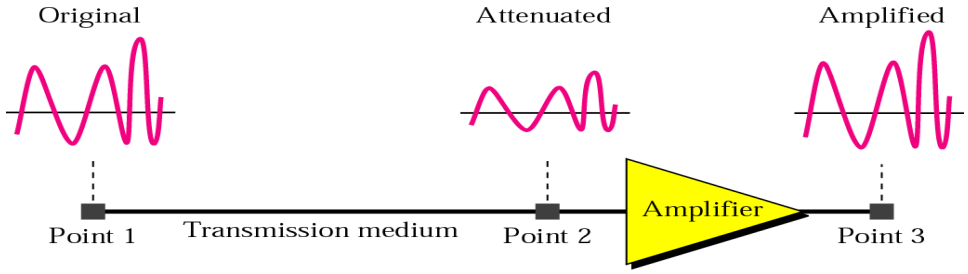
- **Signal Transformation :**
  - ✓ Transforming a signal means looking at a signal from a different angle so as **to gain new simplicities and properties.**
- ***An analog signal is best represented in the frequency domain.***



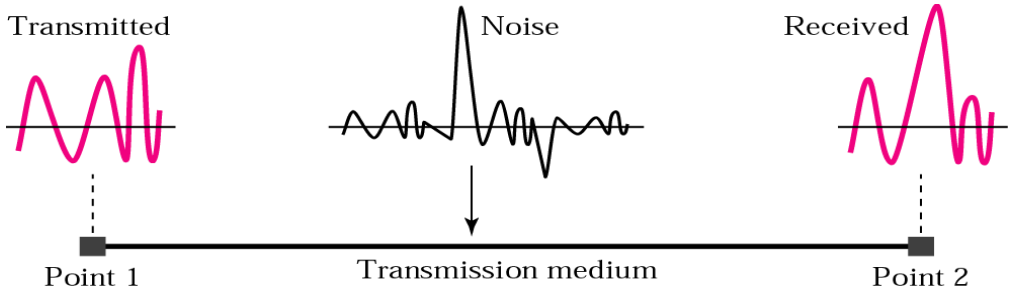
- **Signal Impairments :**



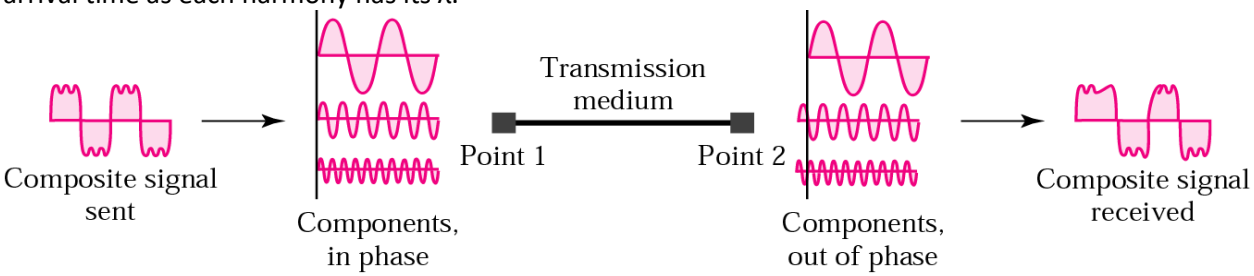
- **Attenuation** is the reduction in power of signal due passing signal via medium or space.



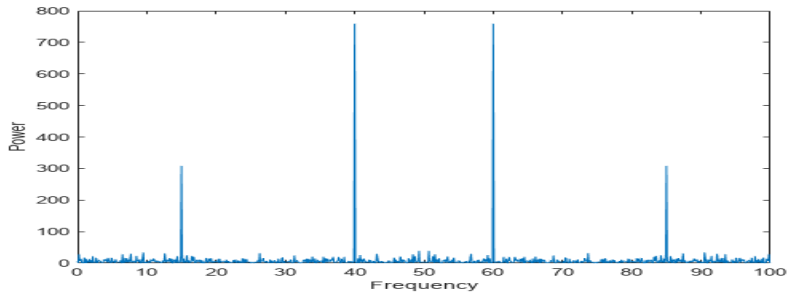
- **Noise**: any other signal that interferes the main signal, it may be :
  - ✓ Internal Noise : it is generated from system its self, mainly due to temperature the (Thermal noise) .
  - ✓ External Noise : interference generated from other systems.



- **Distortion**: the corruption of signal due to transmitting a signal from point to point due to the variation in arrival time as each harmony has its λ.



- **The bandwidth** is a property of a medium: It is the difference between the highest and the lowest frequencies that the medium can satisfactorily pass. **$BW = f_H - f_L$**
- **Frequency spectrum** of a signal is the range of frequencies contained by a signal.

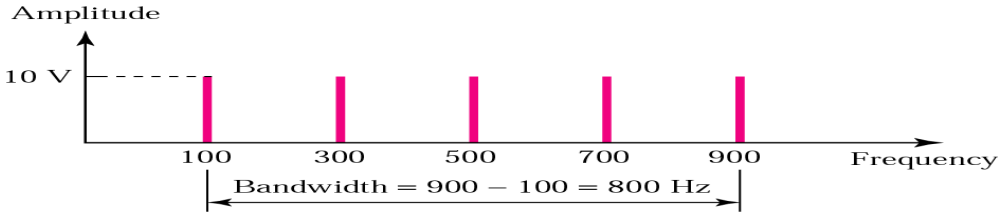


- **Example:** If a periodic signal is decomposed into five sine waves with frequencies of 100, 300, 500, 700, and 900 Hz, what is the bandwidth? Draw the spectrum, assuming all components have maximum amplitude of 10 V.

  Solution:

  $B = f_h - f_l = 900 - 100 = 800$ Hz

  The spectrum has only five spikes, at 100, 300, 500, 700, and 900



Baseband and Broadband Signals:

In data communication, signals are transmitted over a medium in different ways. Two major transmission types are Baseband and Broadband. Understanding their differences helps us choose the right technology for a given network.

Baseband signal:

- **Definition**: Sends the original digital signal directly over the medium without modulation.
- **Characteristics:**
  - It is a signal that occupies the frequency range from 0 Hz up to a certain cutoff.
  - It is called the baseband because it occupies the base or the lowest range of the spectrum.

- In baseband transmission is mostly digital.
- Mostly used for short distances (e.g., LANs).

- **Example**s: Ethernet (10Base-T, 100Base-TX).
- **Advantages**:
  - Simple and inexpensive.
  - High data integrity for short distances.
  - No need for modulation hardware.
- **Disadvantages:**
  - Limited distance.
  - Cannot send multiple signals simultaneously

Broadband signal:

- **Definition**: Modulates the digital signal onto a carrier wave to allow multiple signals to share the medium.
- **Characteristics**:
  - It is a signal that occupies the highest frequency range .
  - It is called the broadband because it passes long distances via space or medium
  - It is used In broadband transmission, it is analog and Common in wireless communication.
  - Bandwidth is divided into multiple frequency channels. Each channel carries a separate signal.
- **Examples:** Cable TV, DSL, Satellite Communication**.**
- **Advantages:**
  - Multiple channels for simultaneous transmission.
  - Longer transmission distance.
  - Supports multimedia applications.
- **Disadvantages:**
  - More complex and costly.
  - Requires modulation/demodulation.
  - May experience interference between channels.

Comparison: Baseband vs Broadband

Feature	Baseband	Broadband
Signal Type	Digital	Analog (modulated)
Bandwidth Usage	Entire bandwidth for one signal	Divided into multiple channels
Transmission Medium	Wired (LANs)	Wired or wireless
Distance	Short	Long
Multiplexing	Not possible	FDM (Frequency Division)
Example	Ethernet	Cable TV, DSL, Wi-Fi

Basic Definitions

Data Rate is the speed at which data is transferred within path or channel. Or the amount of data transmitted per second over a communication channel.

It includes useful data + overhead bits (headers, error correction, etc.).

Example: If a link transmits 1 Mbps of total data (including headers), the data rate = 1 Mbps.

Bit Rate: It is the number of bits transmitted or received per second. Often used as a synonym for data rate.

Sometimes refers to the raw transmission speed before encoding or redundancy is added.

Information Rate: it t is the rate of useful information only (excluding overhead, redundancy, or control bits).

It represents the net information flow that carries meaning. It is Always less than or equal to the data rate.

Example: If Data rate = 100 kbps and Overhead = 20% Then⇒ Information rate = 80 kbps

Link Rate: It is the theoretical maximum speed of a physical link between two devices (e.g., Wi-Fi, Ethernet). It is determined by the technology or standard being used.

Example: Wi-Fi 6 → link rate = up to 1200 Mbps. Ethernet 100Base-T → link rate = 100 Mbps.

Throughput: The actual rate of successful data delivery over a network or communication channel.

It measures how much useful data actually reaches the destination per second, including all real-world effects such as delays, congestion, and retransmissions.

It depends on: Network congestion, Signal quality (errors and retransmissions) , Protocol overhead and Processing delays.

Relationship Summary: Throughput ≤ Information Rate ≤ Data Rate ≈ Bit Rate ≤ Link Rate.

In short:

- **Bit rate and data rate** describe how fast bits are sent.
- **Information rate** describes how much meaning those bits carry.
- **Link rate :** describes maximum speed of a physical
- **Throughput** describes how much useful data actually arrives**.**

Term	Meaning	Includes Overhead?	Real or Theoretical?	Example
Bit Rate	Number of bits transmitted per second	Yes	Theoretical	100 Mbps
Data Rate	Total data sent (useful + control bits)	Yes	Theoretical	100 Mbps
Link Rate	Maximum speed of the physical link	Yes	Theoretical	100 Mbps
Information Rate	Useful information bits only	No	Theoretical	80 Mbps
Throughput	Actual data successfully delivered	No	Real (measured)	60 Mbps

Example Suppose:

Link Rate = 200 Mbps (theoretical maximum) **,**

Data Rate = 100 Mbps (raw transmission rate)

Information Rate = 80 Mbps (useful bits after overhead)

Throughput = 60 Mbps (what the receiver actually gets, due to network delays, interference, etc.)

Modulation

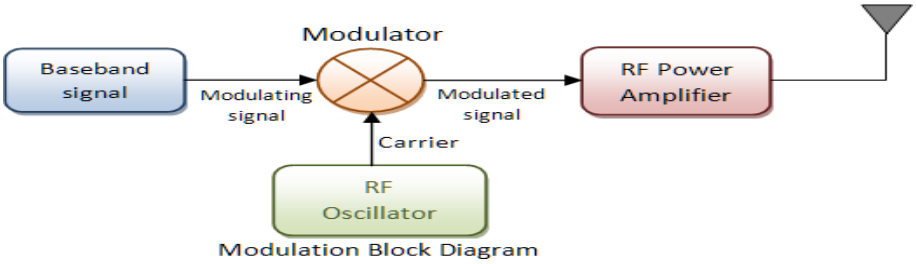
- It is the process of carrying a signal of a lower frequency (Information) on another signal of higher frequency (Carrier). Modulation has a huge number of advantages, the most important are summarized here :
- **Efficient Transmission**: Baseband signals have low frequency and cannot travel long distances effectively. Modulation shifts them to high frequencies suitable for transmission.
- **Smaller Antenna Size**: Higher carrier frequencies reduce the required antenna length, making practical antennas possible.
- **Multiplexing**: Allows multiple users or channels to share the same medium using different carrier frequencies (FDM). 4.
- **Channel Compatibility:** Communication media (radio, optical fiber, satellite) are designed for specific frequency ranges, requiring modulation

  Noise and Interference immunity: Higher frequency signals are more immune to noise than lower frequency signals. Carrying the information on a high frequency carrier ensures that it will reach the destination with minimum noise distortion. It is possible to send more than one signal in the air without their interference as every signal can be carried on a different carrier frequency.

Types of Modulation

According to information Signal:

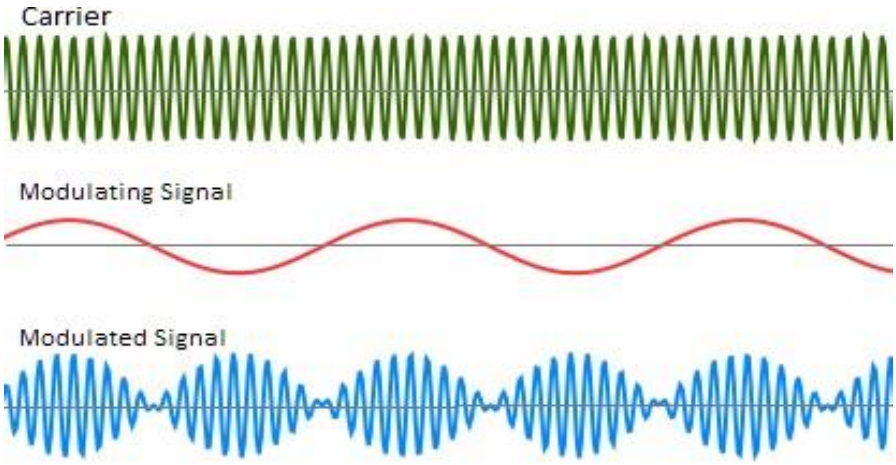
1. Analog Modulation (AM, FM and PM) **2. Digital Modulation (ASK, FSK, QPSK, 8PSK , QAM)**



Modulation Block Diagram

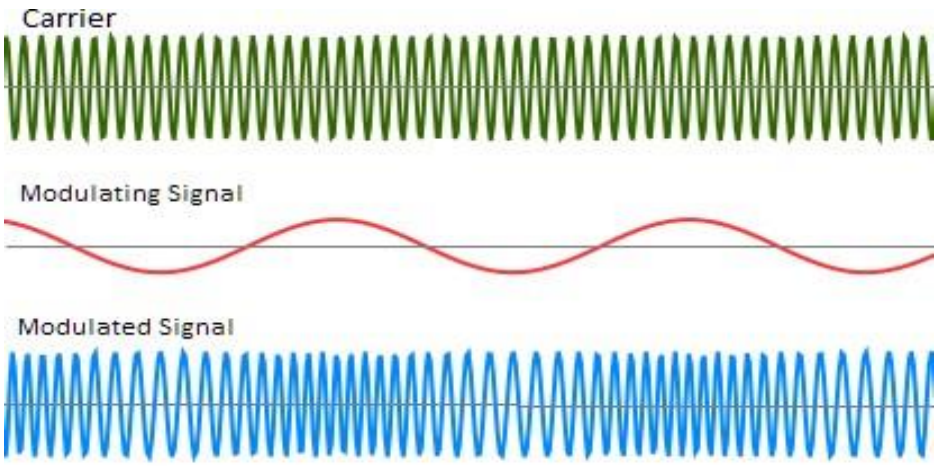
Analog Modulation: varying amplitude, frequency or phase of carrier signal accordingly with the instantaneous amplitude of the message signal.

Analog Modulation (AM) : It is a type of modulation in which amplitude of Carrier is changed according to information signal.



Amplitude Modulation

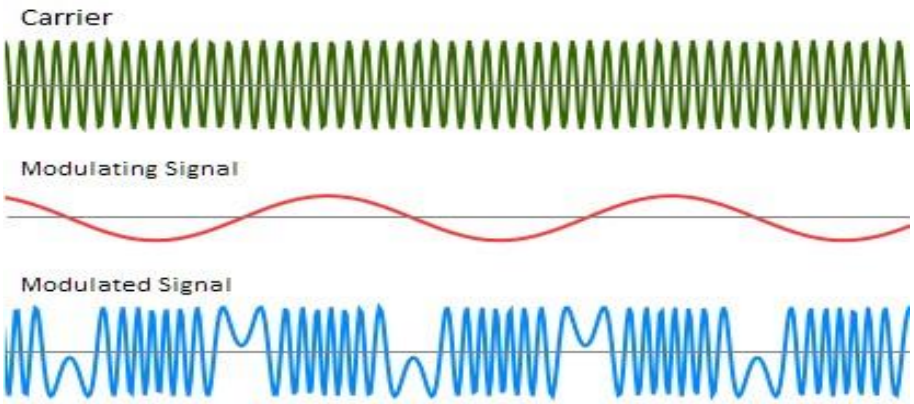
Frequency Modulation (FM) : It is a type of modulation in which Frequency of Carrier is changed according to information signal.



Frequency Modulation

AM and FM are used in Radio Broadcasting

Phase Modulation PM : It is a type of modulation in which Frequency of Carrier is changed according to information signal.

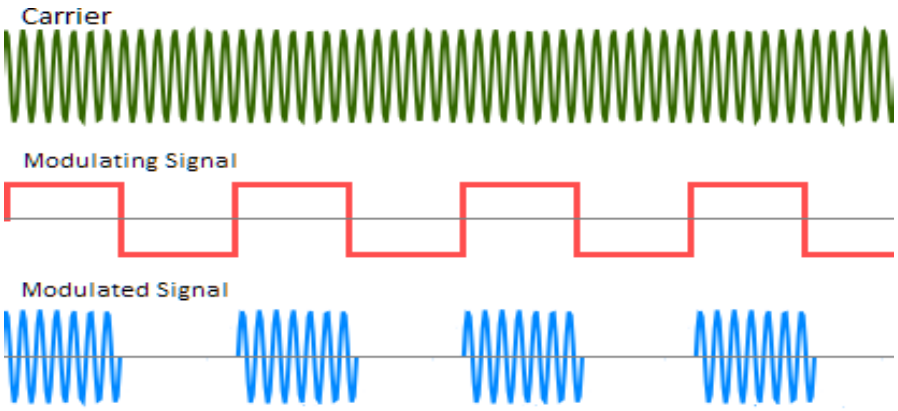


Phase Modulation

Digital Modul

Amplitude Shift Key (ASK):

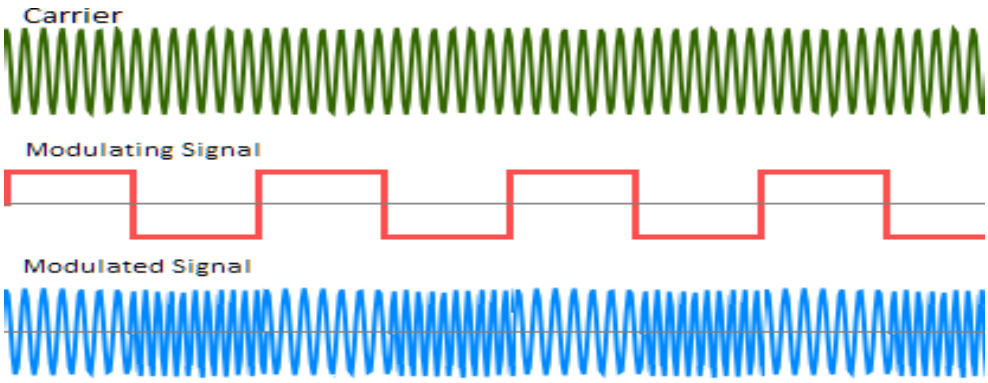
ASK modulated, gives a **zero** value for **Low (0)** input while it gives the **carrier output** for **High** (1) input. It is used in optical communications



Amplitude Shift Key

Frequency Shift Key (FSK):

FSK modulated, gives: a **frequency of f1** for **Low (0)** input , while it gives a **frequency of f2** the **carrier output** for **High** (1) input. It is used in Early modems, RFID.



Frequency Shift Key

Phase Shift Keying (PSK)

Phase Shift Keying (PSK) is a digital modulation technique in which the **phase of a carrier signal** is changed to represent binary data (0s and 1s). The amplitude and frequency remain constant, and only the **phase** varies.

Why PSK?

- More resistant to noise than amplitude-based methods.
- Efficient for digital communication (Wi-Fi, Bluetooth, 4G/5G, satellites).
- Provides higher data rates using more phase states.

Types of PSK:

1. BPSK (Binary PSK) – 2 phases (0° and 180°), 1 bit per symbol.
2. QPSK (Quadrature PSK) – 4 phases (0°, 90°, 180°, 270°), 2 bits per symbol.
3. 8-PSK – 8 phases (each 45° apart), 3 bits per symbol.
4. Higher Orders (16-PSK, 64-PSK) – used for very high-speed data.

Advantages:

- High noise immunity.
- Suitable for high-speed data transmission.
- Efficient bandwidth usage.

Disadvantages:

- Complex receiver design.
- Requires phase synchronization.
- Higher-order PSK is more sensitive to noise.

Applications:

- Wi-Fi (IEEE 802.11)
- Bluetooth
- Satellite communication
- Cellular systems (4G, 5G)

Symbol Rate (Baud Rate)

The **Symbol Rate** (or **Baud Rate**) is the number of symbols transmitted per second. Each **symbol** may represent one or more bits depending on the modulation scheme.

Formula: Symbol Rate = Bit Rate / Bits per Symbol

Examples:

- BPSK → 1 bit/symbol →Symbol Rate = Bit Rate
- QPSK → 2 bits/symbol →Symbol Rate = Bit Rate / 2
- 8-PSK → 3 bits/symbol → Symbol Rate = Bit Rate / 3
- 16PSK→ 4 bits/symbol → Symbol Rate = Bit Rate / 4
-

Example Calculation:

- If Bit Rate = 12 Mbps and QPSK is used:
- Symbol Rate = 12 Mbps / 2 = **6 M Symbols/s**

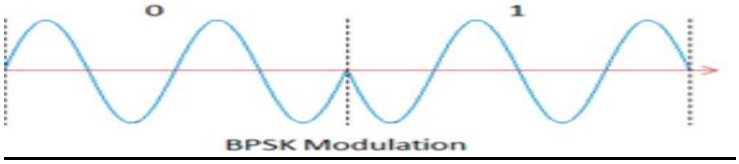
Key Points:

- More bits per symbol → lower symbol rate.
- Lower symbol rate→ less bandwidth required. → Less Money
- Higher-order modulations (16-QAM, 64-QAM) improve bandwidth efficiency.

Binary Phase Shift Key ()PBSK or 2PSK:

It is the simplest form of phase shift keying (PSK). It uses two phases which are separated by 180° and so can also be termed **2-PSK**.

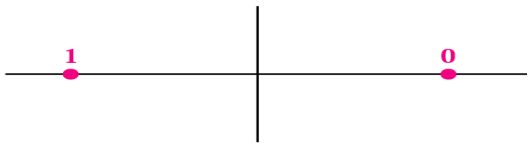
- ✓ If input signal is 0, then phase of carrier will be 0.
- ✓ if Input signal is 1, then phase of carrier will be 180



BPSK Modulation

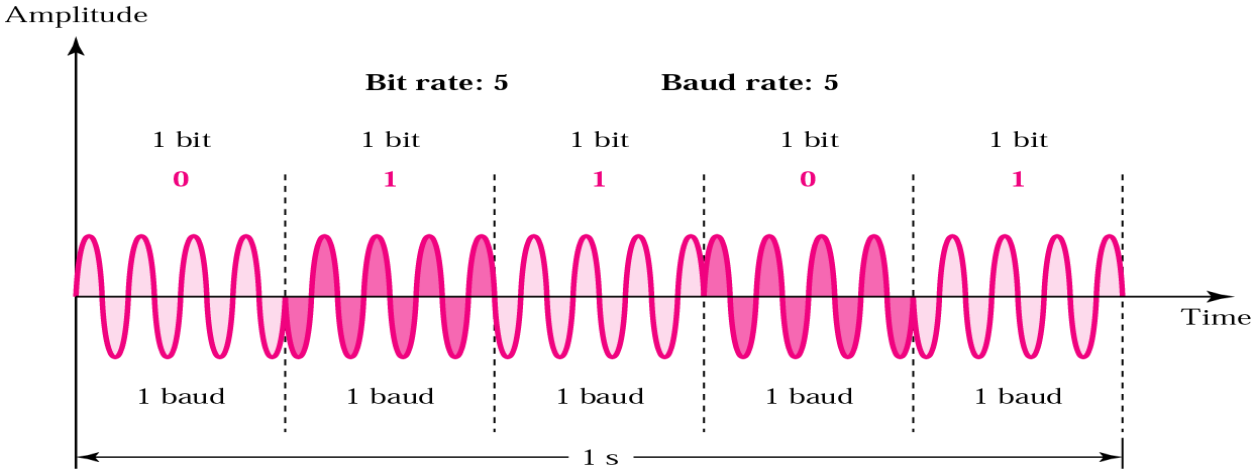
Bit	Phase
0	0
1	180

Bits



Constellation diagram

Example: Modulate information 01101 using PBSK:



Symbol Rate (Baud rate)

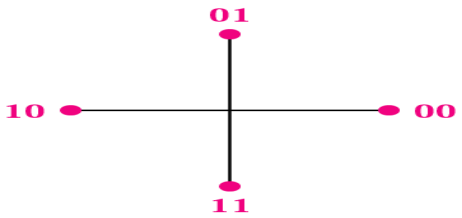
- ✓ The baud rate is the rate at which information is transferred in a communication channel. Baud rate is commonly in communication.
- ✓ It refers to the number of signal or symbol changes that occur per second. It is one of the components that determine the speed of communication over a data channel.

Quadrature Phase Shift Keying (QPSK) 4-PSK:

- ✓ (QPSK) is a form of Phase Shift Keying in which two bits are modulated at once selecting one of four possible carrier phase shifts (0, 90, 180, or 270 degrees).
- ✓ 90 degree is the span between each phase
- ✓ QPSK allows the signal to carry twice as much information as ordinary BPSK using the same bandwidth.

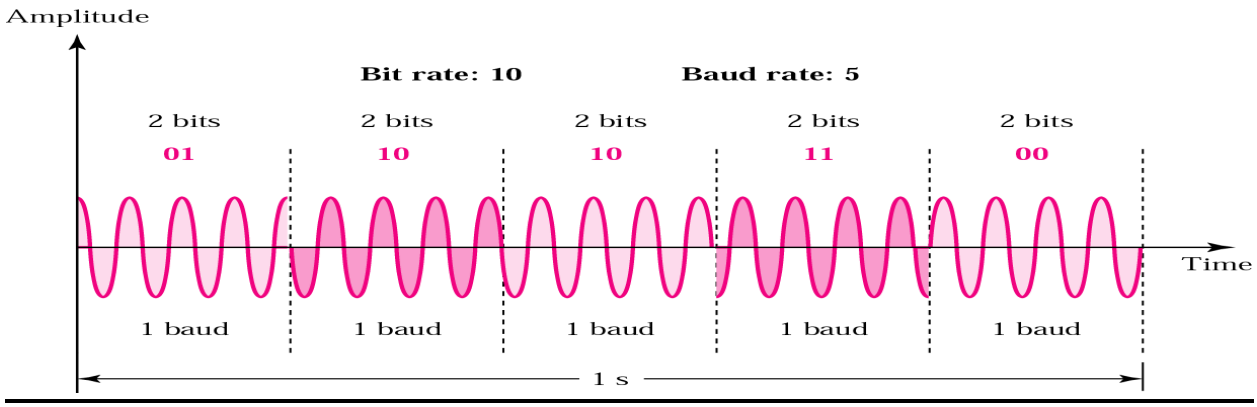
Dibit	Phase
00	0
01	90
10	180
11	270

Dibit
(2 bits)



Constellation diagram

Example:

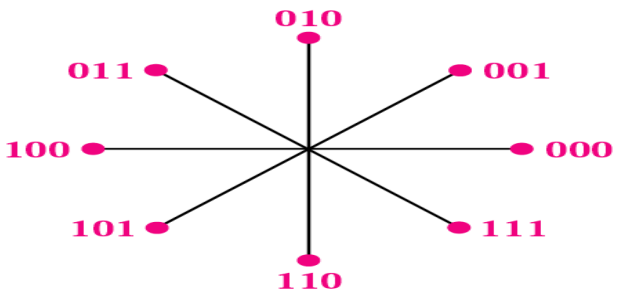


8-PSK:

- ✓ (8PSK) is a form of Phase Shift Keying in which three bits are modulated at once selecting one of eight possible carrier phase shifts (0, 45 90,135 180,225 ,270, and 315 degrees).
- ✓ 45 degree is the span between each phase
- ✓ 8PSK allows the signal to carry three times as much information as ordinary BPSK using the same bandwidth.

Tribit	Phase
000	0
001	45
010	90
011	135
100	180
101	225
110	270
111	315

Tribits
(3 bits)



Constellation diagram

16-PSK:

- ✓ (16PSK) is a form of Phase Shift Keying in which three bits are modulated at once selecting one of 16 possible carrier phase shifts (0, 22.5, 45, 67.5,90,..... degrees).
- ✓ 22.5 degree is the span between each phase
- ✓ 16PSK allows the signal to carry four times as much information as ordinary BPSK using the same bandwidth.

Relation between Data Rate, Symbol rate and Bandwidth

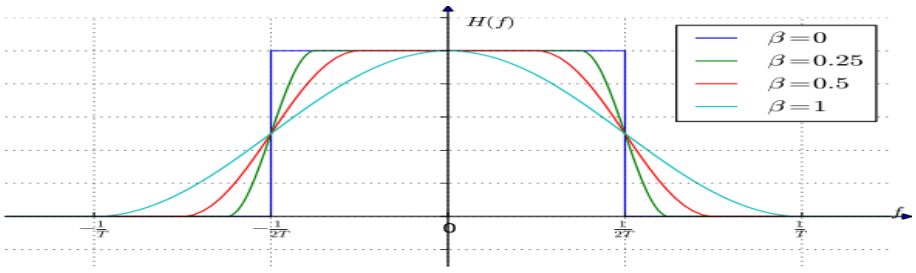
Data Rate ≈ Symbol Rate * K

where K is a content that depends on type of modulation

- ✓ In AM, FM, PM ,ASK, BPSK K=1
- ✓ in QPSK K=2 , 8PSK K=3, 16PSK =4, 0.

BW= Symbol Rate (1+ ROF)

Where (ROF) Roll OFF Factor or β is a factor depends on Hardware Efficiency, ROF value is : 0, 0.1 , 0.15, 0.2,……,1.

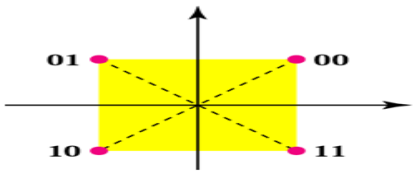


Quadrature amplitude modulation QAM:

It is a combination of ASK and PSK so that a maximum contrast between each signal unit (bit, dibit, tribit, and so on) is achieved.

4-QAM : Two bits are modulated at once selecting one of four possible scenarios mixing between ASK and PSK.

Example: 00 : A, Ø=45 , 01 : A, Ø=135 , 10 : A, Ø=225 , 11 : A, Ø=315

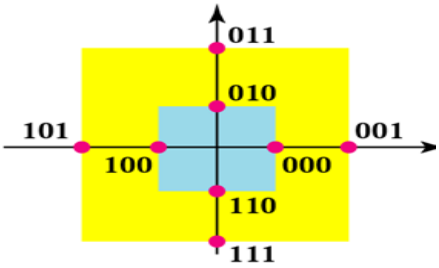


4-QAM
1 amplitude, 4 phases

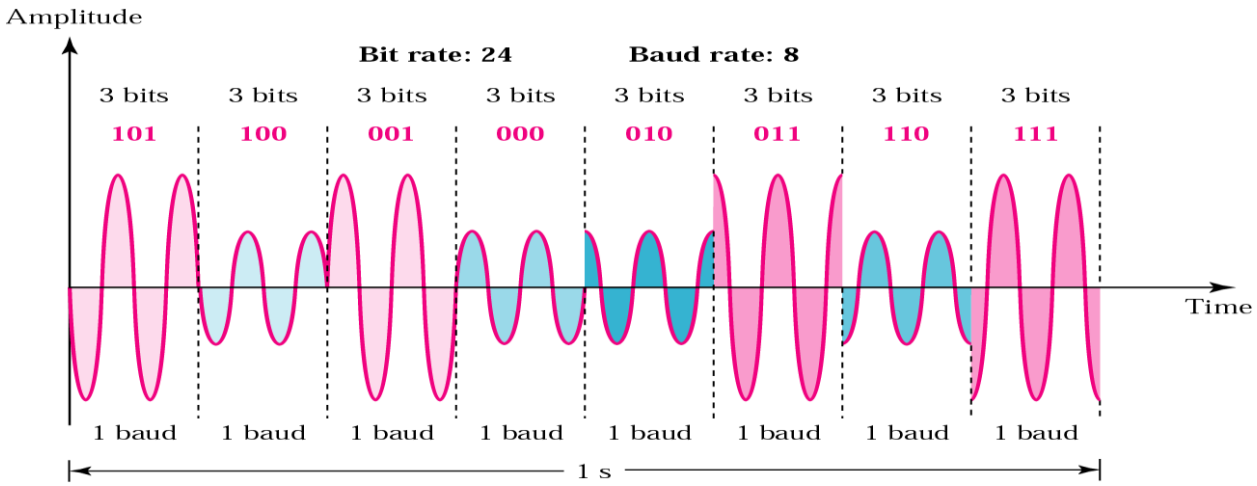
8-QAM : Three bits are modulated at once selecting one of eight possible scenarios mixing between ASK and PSK.

Example: 000 : A1, Ø=0, 001 : A2, Ø=0, 010 : A1, Ø=90, 011 : A2, Ø=90,

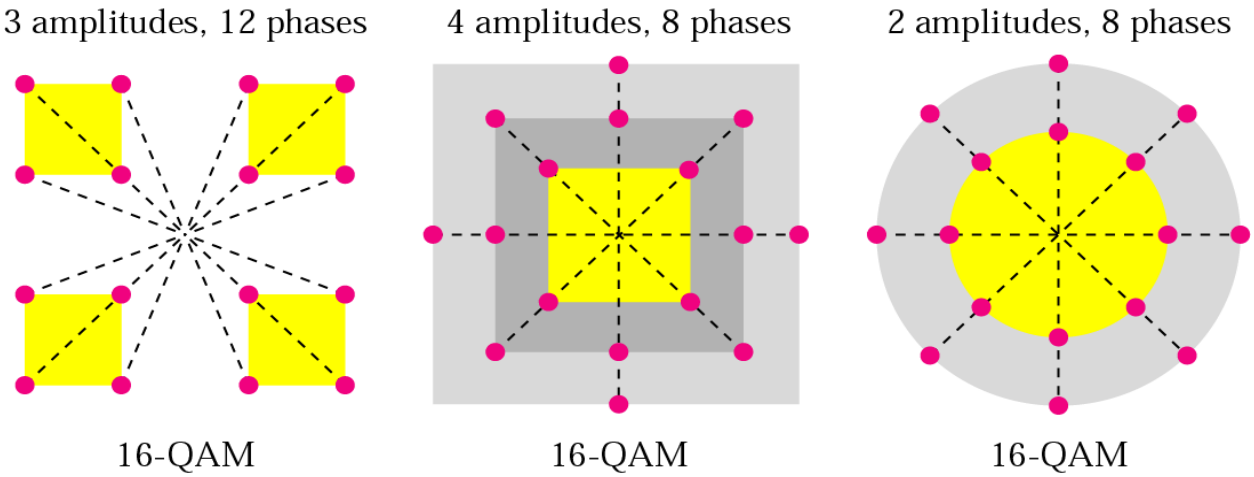
100 : A1, Ø=180, 101 : A2, Ø=180, 110 : A1, Ø=270, 111 : A2, Ø=270,



8-QAM
2 amplitudes, 4 phases



16-QAM: Four bits are modulated at once selecting one of 16t possible scenarios mixing between ASK and PSK.

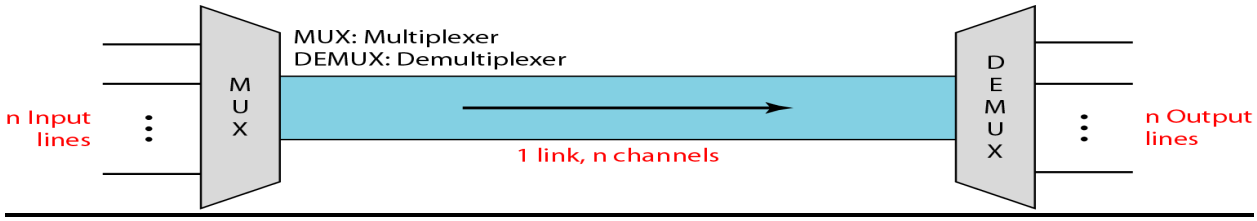


Bandwidth Utilization It is the wise use of BW, Efficiency can be achieved by multiplexing; i.e., sharing of the bandwidth between multiple users.

Multiplexing and Its Types

- ✓ 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 or medium to make efficient use of bandwidth. As data and telecommunications use increases, so does traffic.

Purposes of Multiplexing: To make efficient use of bandwidth →increase channel utilization → reduce cost



Types of Multiplexing

Frequency Division Multiplexing FDM

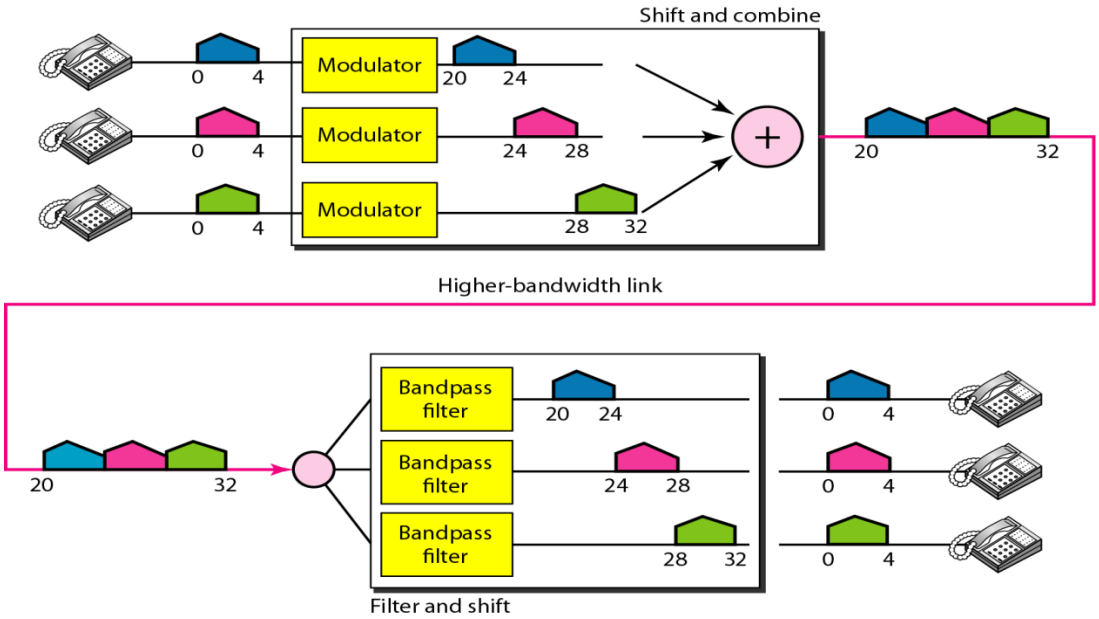
Each signal is assigned a different frequency band within the same channel. All signals are transmitted simultaneously but in separate frequency ranges.

Example: FM radio stations (e.g., 101.3 MHz, 102.5 MHz) it is used in: Analog systems, cable TV, radio broadcasting.

This technique is commonly used in narrowband communication systems where *the* available *frequency band is divided upon the number of users* where each user uses a *different* carrier frequency to transmit and receive.

Example: ***Assume that a voice channel occupies a bandwidth of 4 kHz. We need to combine three voice channels into a link with a bandwidth of 12 kHz, from 20 to 32 kHz. Show the configuration, using the frequency domain. Assume there are no guard bands.***

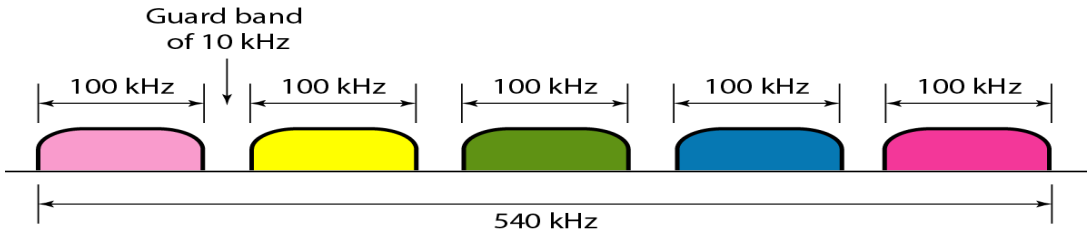
Solution: We use the 20- to 24-kHz bandwidth for the first channel, the 24- to 28-kHz bandwidth for the second channel, and the 28- to 32-kHz bandwidth for the third one. Then we combine them as shown in Figure below:



Example: Five channels, each with a 100-kHz bandwidth, are to be multiplexed together. What is the minimum bandwidth of the link if there is a need for a guard band of 10 kHz between the channels to prevent interference?

Solution: For five channels, we need at least four guard bands.

This means that the required bandwidth is at least $5 \times 100 + 4 \times 10 = 540$ kHz,



Time Division Multiplexing (*TDM*):

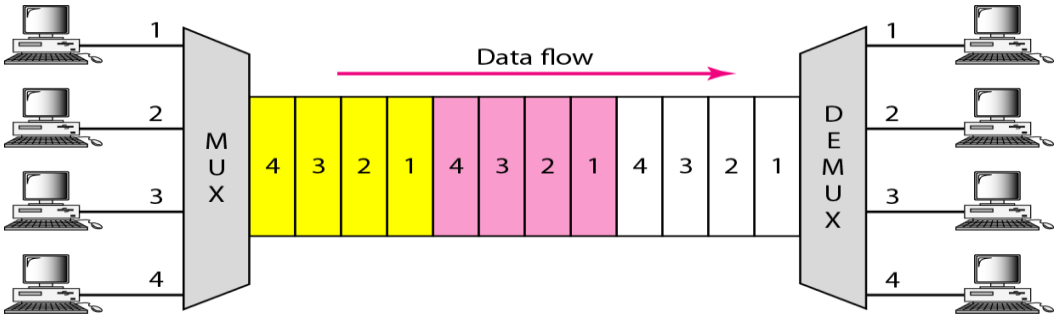
Each signal uses the same channel but at different time slots. Data from multiple sources are sent one after another in a rapid sequence.

In other words, every user is allocated the total bandwidth but users transmit information at separate times to prevent interference between users. It is used in Used in: Digital systems, telephony, computer networks

Types of TDM

Synchronous TDM: Fixed time slots (some may be empty)

Statistical TDM: Slots assigned dynamically when data is ready



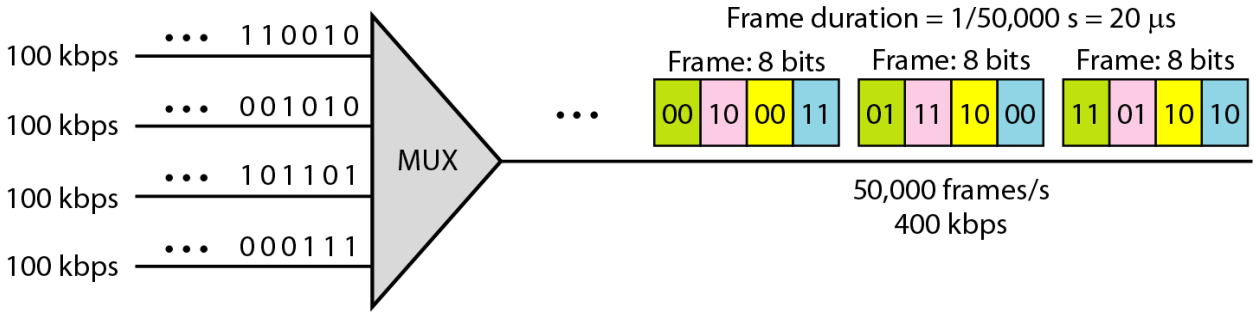
***Example**: A multiplexer combines four 100-kbps channels using a time slot of 2 bits. Show the output with four arbitrary inputs. What is the frame rate? What is the frame duration? What is the bit rate? What is the bit duration?*

Solution: The output (4x100kbps) for four arbitrary inputs. Frame Size = 8 bits

The frame rate of output link carries 400K/(8= 50,000 frames per second.

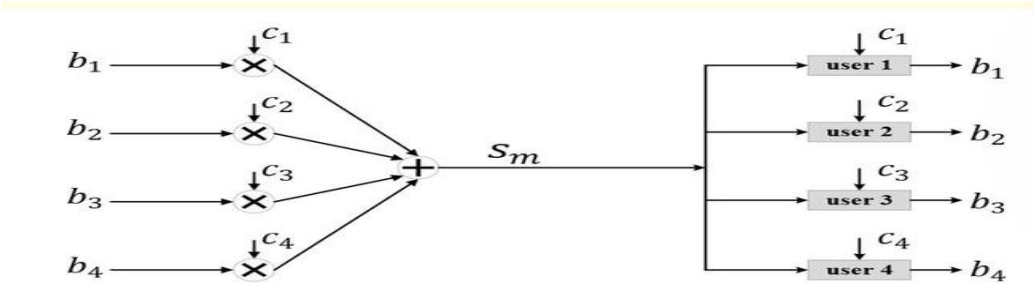
The frame duration is therefore 1/50,000 s or 20 µs.

The bit duration on the output link is 1/400,000 s, or 2.5 µs.



Code Division Multiplexing (CDM), Code Division Multiple Access (CDMA)

- IT is a multiplexing technique used to transmit multiple signals simultaneously over the same frequency band by assigning each signal a unique code.
- CDMA allows several devices to share the same bandwidth by assigning a unique code to each signal.
- **CDMA** is a short form used for **C**ode **D**ivision **M**ultiple **A**ccess. CDMA is a technique that allows multiple users to simultaneously transmit data signals over a common channel by assigning unique spreading code to each individual user
- It's mainly used in wireless systems, such as 3G, 4G (CDMA), GPS, and some satellite communications.



Basic Idea:

- In FDM, each user gets a different frequency.
- In TDM, each user gets a different time slot.
- But in CDM, all users share the same frequency and time, and are separated by unique codes.

Orthogonality: The codes used in CDMA are designed to be orthogonal to each other, meaning that when they are decoded at the receiver, there is minimal interference between different signals. This allows multiple signals to coexist within the same frequency band without causing significant degradation to each other's performance.

How CDMA works?

- CDMA uses the principle of **spread spectrum**. Due to this, the various signals are modulated after which a single signal is transmitted and is correlated at the receiving end using the spreading function to get the actual data.

Principle of Spread Spectrum?

Spread spectrum is a method of transmitting radio signals over a wide range of frequencies. It spreads the signal over a broader bandwidth than the minimum required to send the information, which provides advantages such as increased resistance to interference, improved security, and enhanced privacy.

Example for CDMA:

Assume We have two users (A and B) sending data at the same time over the same frequency band using CDM. Each user is assigned a unique orthogonal code (called chip sequences).

Steps:

- **Step 1.** Assigning the Spreading Codes . Let's choose two orthogonal codes:
  - User Codes (Chip Sequence) A: [+1, +1, -1, -1] B: [+1, -1, +1, -1]
  - These codes are orthogonal because their dot product = 0
    (+1)(+1) + (+1)(-1) + (-1)(+1) + (-1)(-1) = 1 -1 -1 +1 = 0

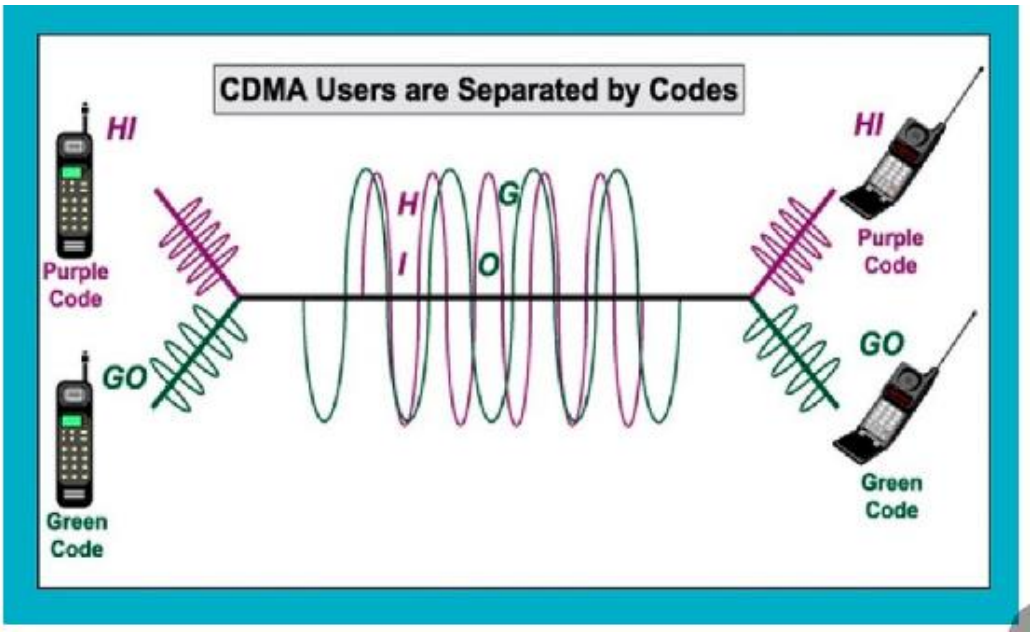
- **Step 2**. Data Bits to Send. Each user wants to send one bit of data:
  - Assume User Data Bit as follows: A→ +1 (binary 1) B→ –1 (binary 0)
- **Step 3**. Spreading the Data ; Each user multiplies their data bit by their unique code.

User	Data × Code	Result
A	+1 × [+1, +1, -1, -1]	[+1, +1, -1, -1]
B	-1 × [+1, -1, +1, -1]	[-1, +1, -1, +1]

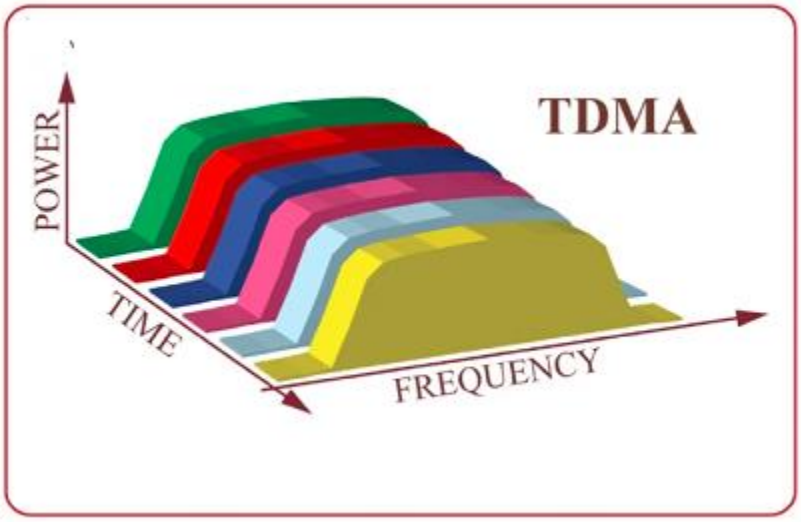
- **Step 4.** Transmitted (Combined) Signal
  - All signals are added together (superimposed in the air or medium):
  - [+1, +1, -1, -1] + [-1, +1, -1, +1] = [0, +2, -2, 0]
  - So, the transmitted signal is: [0, +2, -2, 0]
- **Step 5.** At the Receiver**;** The receiver receives the total signal [0, +2, -2, 0].
  - To extract a user's data, it correlates the received signal with that user's code.
  - Receiver A:
    - ✓ Multiply received signal by A's code [+1, +1, -1, -1]:
      (0)(+1) + (+2)(+1) + (-2)(-1) + (0)(-1) = 0 + 2 + 2 + 0 = 4
    - ✓ Then divide by number of chips (4): 4 / 4 = +1
    - ✓ So, User A's data = +1 (bit 1)
  - Receiver B:
    - ✓ Multiply received signal by B's code [+1, -1, +1, -1]:
      (0)(+1) + (+2)(-1) + (-2)(+1) + (0)(-1) = 0 -2 -2 + 0 = -4
    - ✓ Then divide by number of chips (4): -4 / 4 = -1
    - ✓ So, User B's data = -1 (bit 0)
- **Result**

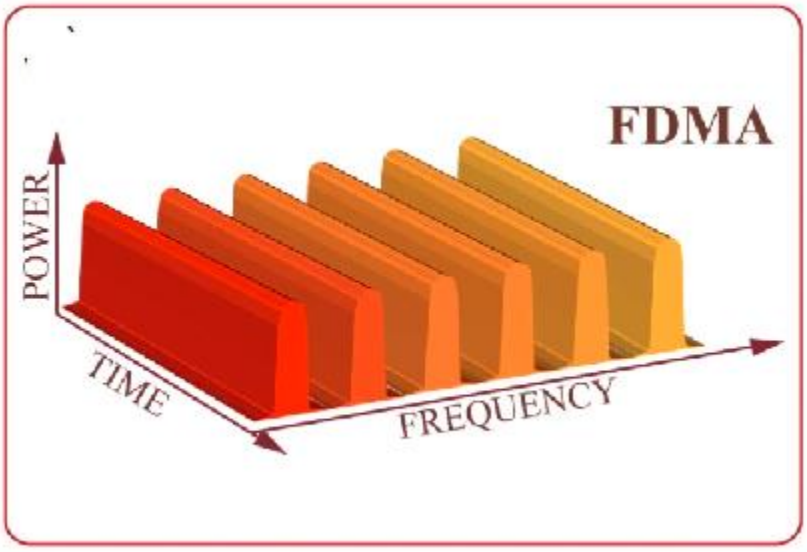
User	Original Data	Received Data	Correct?
A	+1	+1	✓
B	-1	-1	✓

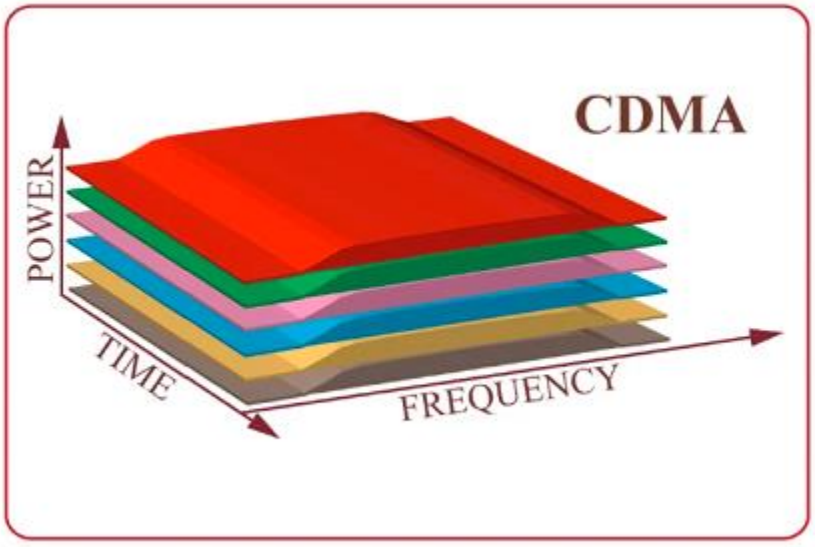
Both users successfully sent data simultaneously, over the same frequency and time, and the receiver could perfectly separate their signals using only the correct codes.



- **What are the advantages of CDMA?**
  - **Efficient Use of Bandwidth:** Multiple users can share the same frequency band, which maximizes the available bandwidth.
  - **Resistance to Interference:** CDMA's spread spectrum technology helps reduce the impact of interference and noise, ensuring reliable communication.
  - **Enhanced Security:** Since each communication stream uses a unique code, unauthorized users cannot easily intercept or decode the signal.
- **What are the important Applications of CDMA**
  - **Mobile Networks:** It was a key technology in 3G networks, allowing multiple users to share the same frequency spectrum.
  - **GPS Systems:** CDMA is used to distinguish between signals from multiple satellites, enabling accurate positioning.
  - **Drone Communication Systems:** CDMA can be used to allow multiple drones to operate in the same area without signal interference.


TDMA
POWER
TIME
FREQUENCY


FDMA
POWER
TIME
FREQUENCY


CDMA
POWER
TIME
FREQUENCY

Comparison Between FDMA, TDMA, and CDMA

Feature	FDMA	TDMA	CDMA
Basic Principle	Users have different frequencies	Users have different time slots	Users separated by different codes
Multiple Access Method	Frequency Division	Time Division	Code Division
Resource Division	BW is divided into frequency channels	Time is divided into slots	All users usesith unique codes
Synchronization Required	Frequency synchronization	Time synchronization	Code synchronization
Bandwidth Efficiency	Low (guard bands required)	Moderate (guard times needed)	High (entire bandwidth shared)
Interference	Adjacent channel interference	Time slot overlap	Cross-correlation interference
Guard Requirement	Guard bands between frequencies	Guard times between slots	No guard needed
Hardware Complexity	Simple	Moderate	Complex
Security	Low	Moderate	High (due to spreading codes)
Power Control	Not critical	Moderate	Very critical (near–far problem)
Number of Users Supported	Limited	Moderate	High (many users can share)
Example System	1G (AMPS)	2G (GSM)	3G (WCDMA, CDMA2000)
Efficiency	Fixed bandwidth per user	Shared time per user	Shared code per user
Flexibility	Low	Moderate	High
Used In	Radio, early mobile networks	GSM, satellite systems	3G, GPS, secure military systems
Main Advantage	Simple and stable	Efficient time usage	High capacity and security
Main Disadvantage	Wastes bandwidth	Needs tight synchronization	Complex and power-sensitive

Wavelength Division Multiplexing (WDM)

Optical version of FDM used in fiber optic systems. Each signal is carried on a different wavelength (color) of light. It is used **in:** High-speed fiber optic backbones

Types: CWDM (Coarse WDM) & DWDM (Dense WDM)