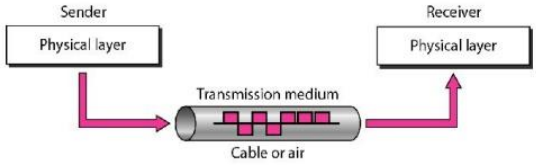
6.2 Explores signal transmission media

Learning Outcomes:
How latency, bandwidth, noise, attenuation, and distortion affect signal transmission

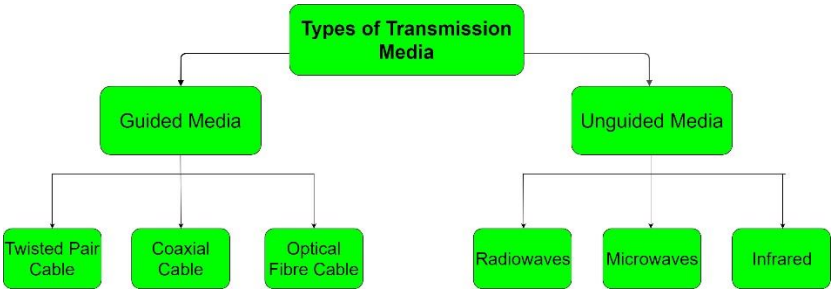
Data transmission media

- Transmission media refer to the media through which data can be carried from a source to a destination. Data is transmitted from one device to another through electromagnetic signals.



The different categories of transmission media

1. *guided* (or *wired*)
2. *unguided* (or *wireless/ Free space)*



1. Guided Media:
A wire is the physical medium used to transfer data from one network device to another. Wires are often called guided media because they guide the data transfer data from one point to another without altering the frequencies, data, impairment are therefore reduced.

There are 3 major types of Guided Media:

1. twisted pair (UTP and STP)
2. Coaxial Cables
3. Fiber Optic Cables

Twisted pair (UTP and STP)

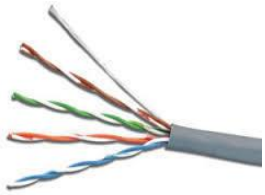
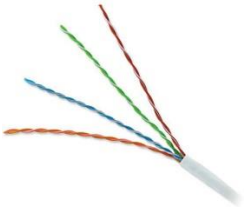
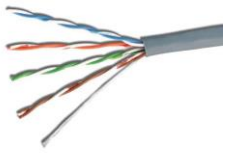
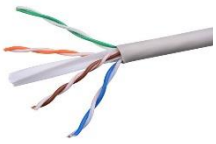
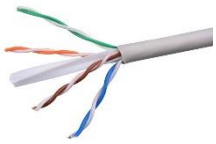
Twisted pair is the ordinary copper wire that connects home and many business computers to the telephone company. To reduce crosstalk or electromagnetic induction between pairs of wires, two insulated copper wires are twisted around each other. Each connection on twisted pair requires both wires. Since some telephone sets or desktop locations require multiple connections, twisted pair is sometimes installed in two or more pairs, all within a single cable. For some business locations, twisted pair is enclosed in a shield that functions as a ground.

- Shielded twisted pair (STP).
- unshielded twisted pair (UTP)

Difference between Unshielded Twisted Pair (UTP) and Shielded Twisted Pair (STP) cables:

	UTP	STP
1.	UTP stands for Unshielded twisted pair.	STP stands for Shielded twisted pair.
2.	In UTP grounding cable is not necessary.	While in STP grounding cable is required.
3.	Data rate in UTP is slow compared to STP.	Data rate in STP is high.
4.	The cost of UTP is less.	While STP is costlier than UTP.
5.	In UTP much more maintenance are not needed.	While in STP much more maintenance are needed.
6.	In UTP noise is high compared to STP.	While in STP noise is less.
7.	In UTP the generation of crosstalk is also high compared to STP.	While in STP generation of crosstalk is also less.
8.	In UTP, attenuation is high in comparison to STP	While in STP attenuation is low.

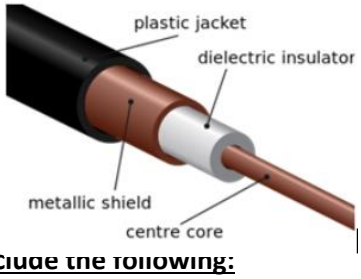
UTP Categories - Copper Cable				
UTP Category	**Data Rate**	**Max. Length**	**Cable Type**	**Application**
CAT1	Up to 1Mbps	-	Twisted Pair	Old Telephone Cable
CAT2	Up to 4Mbps	-	Twisted Pair	Token Ring Networks
CAT3	Up to 10Mbps	100m	Twisted Pair	Token Rink & 10BASE-T Ethernet
CAT4	Up to 16Mbps	100m	Twisted Pair	Token Ring Networks
CAT5	Up to 100Mbps	100m	Twisted Pair	Ethernet, FastEthernet, Token Ring
CAT5e	Up to 1 Gbps	100m	Twisted Pair	Ethernet, FastEthernet, Gigabit Ethernet
CAT6	Up to 10Gbps	100m	Twisted Pair	GigabitEthernet, 10G Ethernet (55 meters)
CAT6a	Up to 10Gbps	100m	Twisted Pair	GigabitEthernet, 10G Ethernet (55 meters)
CAT7	Up to 10Gbps	100m	Twisted Pair	GigabitEthernet, 10G Ethernet (100 meters)

UTP Cat 1	UTP Cat 2	UTP Cat 3
used companies providing ISDN and PSTN services	support computer network and telephone traffic	used in commercial phone systems like **PBX**(private branch exchange)and VOIP(Voice over Internet Protocol)
		
UTP Cat 4	**UTP Cat 5**	**UTP Cat 5e**
specified in ANSI(The American National Standards Institute**) /EIA** (Environmental Impact Assessment **)/TIA 568 (**Telecommunications Industry Association **)and ISO/IEC 11801**	Computer networks such as Ethernet over twisted pair. Used to carry other signals such as telephony and video.	network cabling is used as a cabling infrastructure for 10BASE-T Supports Gigabit Ethernet (1000 Base-T) standard with transmission bandwidth of up to 100MHz and backwards compatible
		
UTP Cat 6	**UTP Cat 6a**	**UTP Cat 7**
Supports Gigabit Ethernet (1000 Base-T) standard with transmission bandwidth of up to 250MHz.	provides transmission performance beyond 650MHz	The Cat 7 standard provides performance of up to 600 MHz and can be used up to a maximum length of 100 meters
		

Coaxial Cables

- It an electrical cable which transmits radio frequency (RF) signals from one point to another.
- The technology has been around since the early 20th century, with these cables mainly being used to connect satellite antenna facilities to homes and businesses thanks to their durability and ease of installation.

- Coax cable is used for connecting a cable television, satellite receiver, cable modems, VCR, cable box, digital router, antenna, computer network connections, digital audio, converter box and for other audio and visual purposes



The advantages of coax include the following:

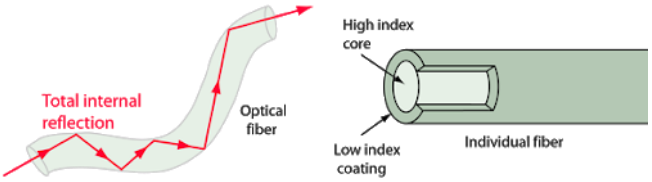
- **Broadband system—**Coax has a sufficient frequency range to support multiple channels, which allows for much greater throughput.
- **Greater channel capacity—**each of the multiple channels offers substantial capacity. The capacity depends on where you are in the world. In the North American system, each channel in the cable TV system is 6MHz wide, according to the National Television Systems Committee (NTSC) standard. In Europe, with the Phase Alternate Line (PAL)
- **Greater bandwidth—**compared to twisted-pair, coax provides greater bandwidth system wide, and it also offers greater bandwidth for each channel. Because it has greater bandwidth per channel, it supports a mixed range of services. Voice, data, and even video and multimedia can benefit from the enhanced capacity.

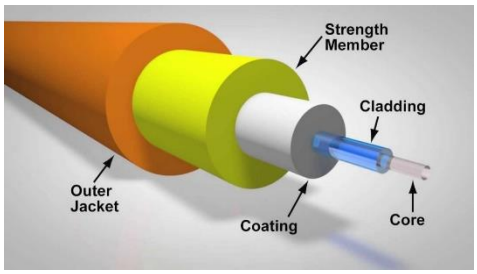
The main disadvantages of coax are

- **Problems with the deployment architecture—**the bus topology in which coax is deployed is susceptible to congestion, noise, and security risks.
- **Great noise—**the return path has some noise problems, and the end equipment requires added intelligence to take care of error control.
- **High installation costs—**Installation costs in the local environment are high.
- **Susceptible to damage from lightning strikes—**Coax may be damaged by lightning strikes.

Fiber optics

- It sends information coded in a beam of light down a glass or plastic pipe.
- It was originally developed for endoscopes in the 1950s to help doctors see inside the human body without having to cut it open first.
- In the 1960s, engineers found a way of using the same technology to transmit telephone calls at the speed of light (normally that's 186,000 miles or 300,000 km per second in a vacuum, but slows to about two thirds this speed in a fiber-optic cable).
- fiber-optic cable is made up of incredibly thin strands of glass or plastic known as optical fibers; one cable can have as few as two strands or as many as several hundred. Each strand is less than a tenth as thick as a human hair and can carry something like 25,000 telephone calls, so an entire fiber-optic cable can easily carry several million calls.
- Light travels down a fiber-optic cable by bouncing repeatedly off the walls.





Types of fiber-optic cables

Single Mode cable

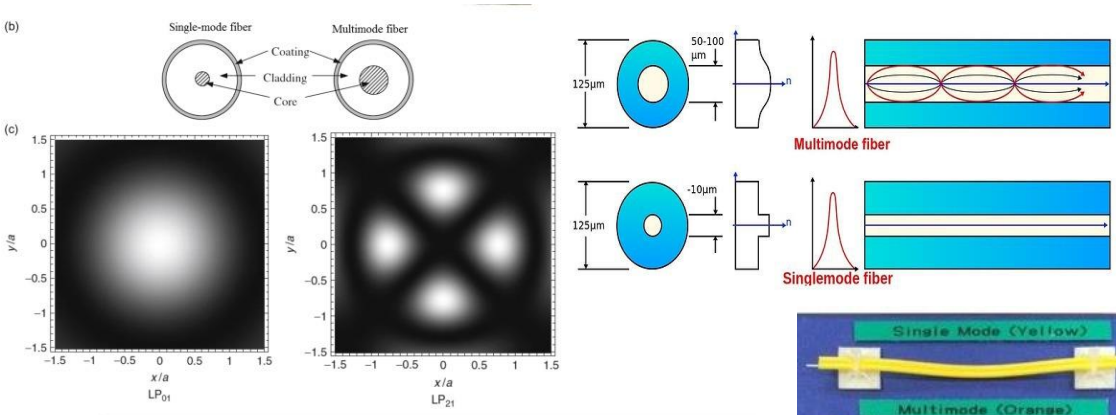
- Single mode means the fiber enables one type of light mode to be propagated at a time

Multi-Mode cable

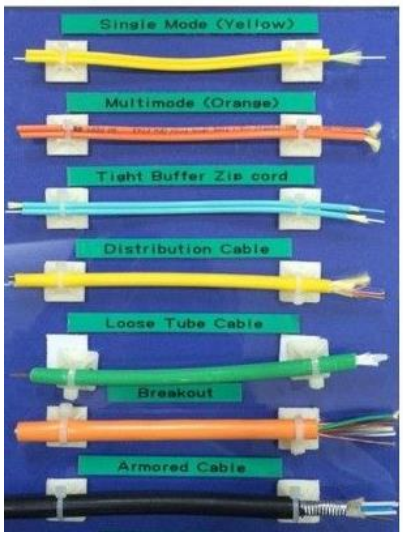
- Multimode means the fiber can propagate multiple modes.

- The differences between single mode and multimode fiber mainly lies in fiber core diameter, wavelength & light source, bandwidth, color sheath, distance and cost.
- Single mode fiber is suitable for long-distance applications, while multimode optical fiber is designed for short-distance runs.

	Single Mode Fiber Cable	Multimode Fiber Cable
Core Diameter	9/10μm	50/62.5μm
Transmission Mode	One mode	Multiple modes
Working Wavelengths	1310/1550nm	850/1310nm
Transmission Distance	Short (1-2km)	Long(over 4km)



Cable Type	Color
Multimode 50 μm and 62.5 μm (OM1, OM2)	Orange
Multimode 50 μm, laser optimized (OM3)	Aqua
Single-mode (OS1/OS2)	Yellow
Outside Plant (OSP) - MDPE	Black
Indoor/Outdoor (I/O)	Black



Advantages of Optical Fiber

- **Greater bandwidth & faster speed**—Optical fiber cable supports extremely high bandwidth and speed. The large amount of information that can be transmitted per unit of optical fiber cable is its most significant advantage.
- **Thinner and light-weighted**—Optical fiber is thinner, and can be drawn to smaller diameters than copper wire. They are of smaller size and light weight than a comparable copper wire cable, offering a better fit for places where space is a concern.
- **Higher carrying capacity**—optical fibers are much thinner than copper wires, more fibers can be bundled into a given-diameter cable. This allows more phone lines to go over the same cable or more channels to come through the cable into your cable TV box.
- **Light signals**—unlike electrical signals transmitted in copper wires, light signals from one fiber do not interfere with those of other fibers in the same fiber cable. This means clearer phone conversations or TV reception.
- **Long lifespan**—Optical fibers usually have a longer life cycle for over 100 years.

Disadvantages of Optical Fiber

- **Low power**—Light emitting sources are limited to low power. Although high power emitters are available to improve power supply, it would add extra cost.
- **Fragility**—Optical fiber is rather fragile and more vulnerable to damage compared to copper wires. You'd better not to twist or bend fiber optic cables too tightly.
- **Distance**—the distance between the transmitter and receiver should keep short or repeaters are needed to boost the signal.
- **High cost**—optical fiber cable High cost than copper wire.

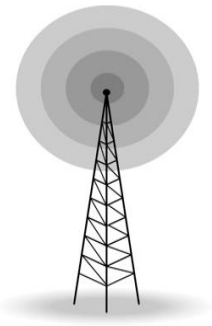
2. Free space Or Unguided media

- An unguided transmission transmits the electromagnetic waves without using any physical medium. Therefore it is also known as **wireless transmission**.
- In unguided media, air is the media through which the electromagnetic energy can flow easily.

Unguided transmission is broadly classified into three categories

1. Radio waves
2. Micro waves
3. Infrared waves

Radio waves



- Electromagnetic waves ranging in frequencies between 3 KHz and 1 GHz are normally called radio waves.
- Radio waves are omnidirectional, i.e., the signals are propagated in all the directions.
- In the case of radio waves, the sending and receiving antenna are not aligned, i.e., the wave sent by the sending antenna can be received by any receiving antenna.
- Radio waves, particularly with those of low and medium frequencies, can penetrate walls. This characteristic can be both an advantage and a disadvantage. It is an advantage because, an AM radio can receive signals inside a building. It is a disadvantage because we cannot isolate a communication to just inside or outside a building.

- A Radio wave is useful for multicasting when there is one sender and many receivers.
- An FM radio, television, cordless phones are examples of a radio wave.

Advantages of Radio transmission:

- Radio transmission is mainly used for wide area networks and mobile cellular phones.
- Radio waves cover a large area, and they can penetrate the walls.
- Radio transmission provides a higher transmission rate.

Frequency bands and their common uses

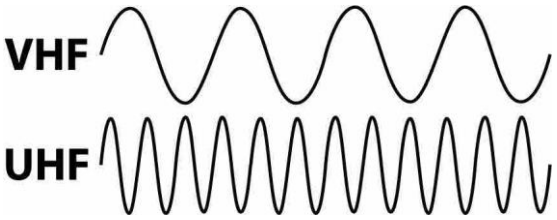
Band Name	Frequency	Wavelength	Applications
Extremely low frequency (ELF)	30 to 300 Hz	10000 to 1000 Km	Powerline frequencies
Voice Frequency (VF)	300 to 3000 Hz	1000 to 100 Km	Telephone communications
Very low frequency (VLF)	3 to 30 KHz	100 to 10 Km	Marine communications
Low frequency (LF)	30 to 300 KHz	10 to 1 Km	Marine communications
Medium frequency (MF)	300 to 3000 KHz	100 to 100 m	AM broadcasting
High frequency (HF)	3 to 30 MHz	100 to 10 m	Long-distance aircraft / ship communications
Very high frequency (VHF)	30 to 300 MHz	10 to 1 m	FM broadcasting
Ultra high frequency (UHF)	300 to 3000 MHz	100 to 10 cm	Cellular telephone
Super high frequency (SHF)	3 to 30 GHz	10 to 1 cm	Satellite communications, microwave links
Extremely high frequency (EHF)	30 to 300 GHZ	10 to 1 mm	Wireless local loop
Infrared	300 GHz to 400 THz	1 mm to 400 nm	Consumer electronics
Visible light	400 THz to 900 THz	770 nm to 330 um	Optical communications

VHF, (very high frequency)

- A range of radio frequencies from 30 MHz to 300 MHz
- VHF radios are better suited for outdoor use where line of sight or open terrain is involved. If you need communication at a festival or construction site, these are the right radios for you. VHF radios are used exclusively in maritime and aviation communications.

UHF (ultra-high frequency)

- UHF radios pick up radio signals with very short waves.
- It operate at the higher end of the radio frequency spectrum. They can more easily penetrate metal and concrete structures, which makes UHF radios a good choice in built-up areas like towns and cities

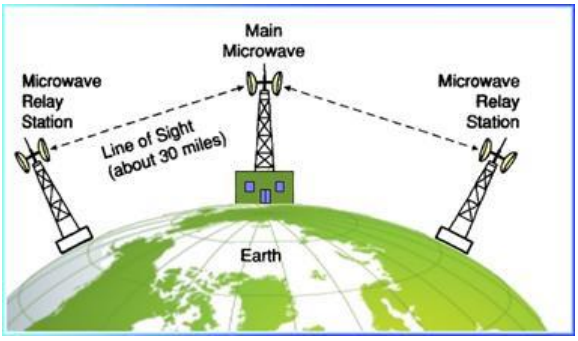


- Wavelength is inversely proportional to the frequency. Lower frequencies have longer wavelengths while higher frequencies have shorter wavelengths. Lower frequencies with their longer wavelengths tend to travel longer distances in open spaces outside, curving with the distant horizon while higher frequencies, with their shorter wavelengths, tend to travel in straight lines and do not bend with the curvature of the earth.

Microwaves

Waves within the frequencies 1GHz to 300GHz are called microwaves.

- Microwaves travel in straight lines, and so the transmitter and receiver stations should be accurately aligned to each other.
- Microwave propagation is line – of – sight propagation. So, towers hoisting the stations should be placed so that the curvature of the earth or any other obstacle does not interfere with the communication.



- Since it is unidirectional, it allows multiple receivers in a row to receive the signals without interference.
- Microwaves do not pass through buildings. So, indoor receivers cannot be used effectively.
- Microwaves are often refracted by the atmospheric layers. The refracted rays take longer time to reach the destination than the direct rays. This causes out of phase transmission, called multipath fading.
- Microwave currents can flow through a thin layer of a cable

Characteristics of Microwave:

- Frequency range: The frequency range of terrestrial microwave is from 4-6 GHz to 21-23 GHz.
- Bandwidth: It supports the bandwidth from 1 to 10 Mbps.
- Short distance: It is inexpensive for short distance.
- Long distance: It is expensive as it requires a higher tower for a longer distance.
- Attenuation: Attenuation means loss of signal. It is affected by environmental conditions and antenna size

Advantages of Microwaves

- Supports larger bandwidth and hence more information is transmitted. For this reason, microwaves are used for point-to-point communications.
- More antenna gain is possible.
- Higher data rates are transmitted as the bandwidth is more.
- Antenna size gets reduced, as the frequencies are higher.
- Low power consumption as the signals are of higher frequencies.
- Effect of fading gets reduced by using line of sight propagation.
- Provides effective reflection area in the radar systems.
- Satellite and terrestrial communications with high capacities are possible.
- Low-cost miniature microwave components can be developed.
- Effective spectrum usage with wide variety of applications in all available frequency ranges of operation.

Disadvantages of Microwaves

- Cost of equipment or installation cost is high.
- They are hefty and occupy more space.
- Electromagnetic interference may occur.
- Variations in dielectric properties with temperatures may occur.
- Inherent inefficiency of electric power.

Infrared

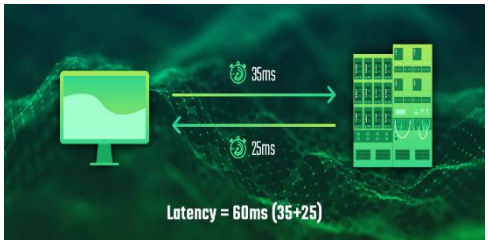
- An infrared transmission is a wireless technology used for communication over short ranges.
- The frequency of the infrared in the range from 300 GHz to 400 THz.
- It is used for short-range communication such as data transfer between two cell phones, TV remote operation, data transfer between a computer and cell phone resides in the same closed area.

Characteristics of Infrared:

- It supports high bandwidth, and hence the data rate will be very high.
- An infrared communication provides better security with minimum interference.
- Infrared communication is unreliable outside the building because the sun rays will interfere with the infrared waves.

Signal transmission Properties

1. **Latency**
   Network Latency is an expression of how much time it takes for a unit of data to travel from one point to another. Latency is usually measured in milliseconds.



There are four main components that affect network latency, including:

1. **Transmission medium:** The physical path between the start point and the end point. The type of medium can impact latency.

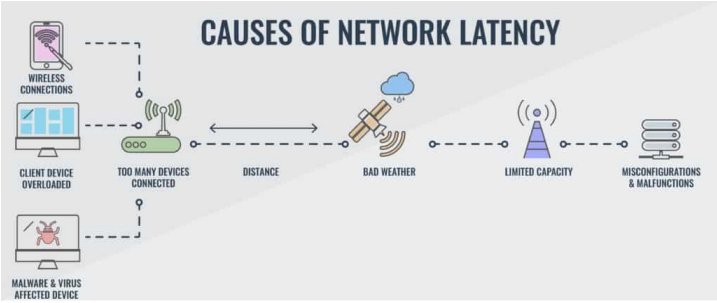
   Example old copper cable-based networks have a higher latency than modern optic fibers.

2. **Propagation:** The further apart two nodes are the more latency there is as latency is dependent on the distance between the two communicating nodes.

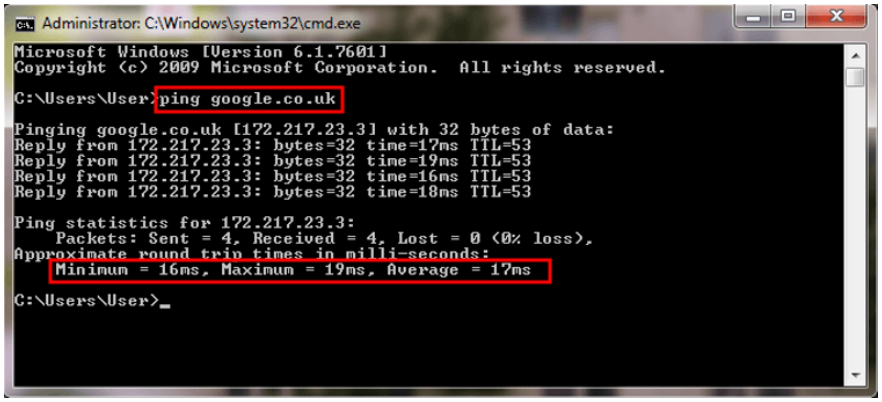
   Example latency of a packet going on a round trip across the world is 133ms. Such a round trip takes longer,
   Though latency is decreased when direct connections through network backbones are achieved.

3. **Routers:** The efficiency in which routers process incoming data has a direct impact on latency. Router to router hops can increase latency.

4. **Storage delays:** Accessing stored data can increase latency as the storage network may take time to process and return information.

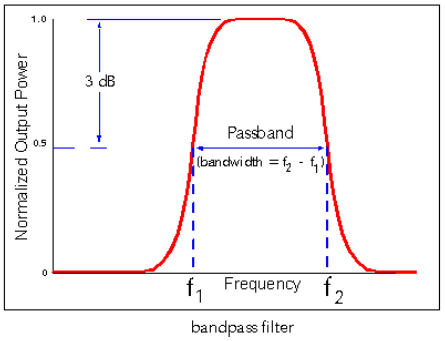


- Testing network latency can be done by using **ping, trace route, or My Trace Route (MTR) tool**.



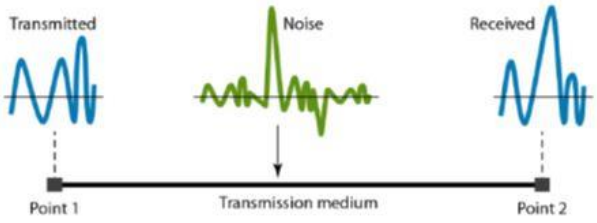
2. Bandwidth: Bandwidth is a range of frequencies and measured in Hertz.

- The bandwidth of a signal is defined as the difference between the upper and lower frequencies of a signal generated Electronic signals can form a pattern or repeat over a cycle each individual repetition time is called a Period (T).
- The period can be any measure of time, such as second, an hour, or a day. The number of events that happen in one second is described as frequency in the units called Hertz.
- Bandwidth was originally measured in bits per second and expressed as bps.
- Now it is common to see higher numbers that are denoted with Mbps, (megabits per second), Gbps (gigabits per second), or Tbps (terabits per second).
- Measuring bandwidth is typically done using software or firmware, and a network interface.
- Common bandwidth measuring utilities include the Test TCP utility (TTCP) and PRTG Network Monitor
- While there is no way to measure total available bandwidth, there are many ways to define measured bandwidth, depending on the need.
    1. Theoretical maximum
    2. Effective bandwidth
    3. Throughput
    4. Good put
    5. Total transfer method
    6. 95th percentile method



bandpass filter

3. **Noise**: Noise is a received signal that makes no sense. The random or unwanted signal that Mixes up with the original signal is called noise. There are several types of noise such as
    a. induced noise
    b. crosstalk noise
    c. thermal noise
    d. impulse noise



I. **Induced noise** comes from sources such as motors and appliances. These devices act as sending antenna and transmission medium act as receiving antenna. Induced noise is the noise generated in a circuit by a varying magnetic or electrostatic field produced by another circuit.

<u>Types and sources of induced noise</u>

1. **Electromagnetic noise**

The varying magnetic fields produced in nearby equipment induce current in the conductors of the affected equipment. Common sources for these magnetic fields include:

- AC power cables
- Cables in variable frequency drive motors
- Ground loops
- Power contactors in solenoids
- Conductors in switched mode power supplies

2. Electrostatic noise

- This noise is generated by the varying electrostatic fields from:
- Fluorescent lights
- Conductors in switched mode power supplies
- Squealing bearings
- Cables in VFD motors

II. **Thermal** noise

Thermal noise is generated as a result of thermal agitation of the charge carriers which are typically electrons within an electrical conductor. This thermal noise actually occurs regardless of the applied voltage because the charge carriers vibrate as a result of the temperature. This vibration is dependent upon the temperature - the higher the temperature, the higher the agitation and hence the thermal noise level.

III. **Crosstalk** noise is when one wire affects the other wire. **Crosstalk** is any phenomenon by which a signal transmitted on one circuit or channel of a transmission system creates an undesired effect in another circuit or channel. Crosstalk is usually caused by undesired capacitive, inductive, or conductive coupling from one circuit or channel to another.

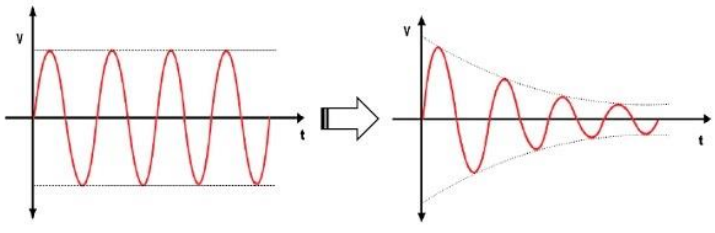
Crosstalk is a significant issue in structured cabling, audio electronics, integrated circuit design, wireless communication and other communications systems.

IV. **Impulse** noise is a signal with high energy that comes from lightning or power lines

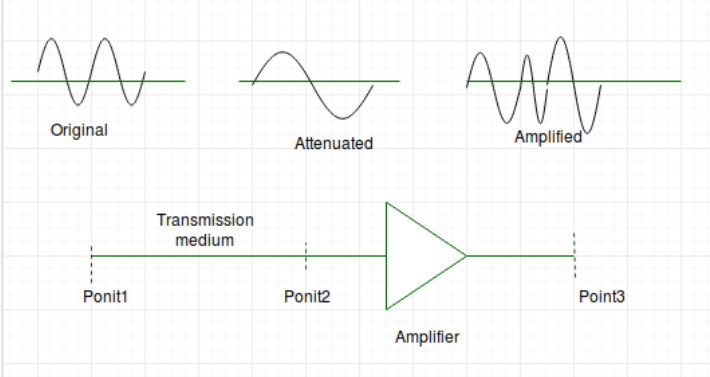
4. Attenuation

Attenuation means the loss of energy. In transmitting electronic signals, attenuation is the loss of signal strength as measured in decibels (dB).
For instance, signals transmitted from a cell tower to your phone can become distorted from increased attenuation as you walk around the corner of a building. Wireless signal strength can be attenuated (lessened) due to noise, physical barriers, and long distances. As signal attenuation increases, full signal transmission decreases.

- **Noise.** Extra noise on networks, like radio frequencies, electrical currents, and wire leakage, may interfere with the signal and cause attenuation. The more noise you have, the more attenuation you experience.
- **Physical surroundings.** Physical surroundings like temperature, wall barriers, and improper wire installation may distort the transmission.
- **Travel distance.** The further a transmission has to travel from its current location (e.g. your home or workplace) to its Central Office (C/O; the location of your connection provider), the more noise it experiences along the way.



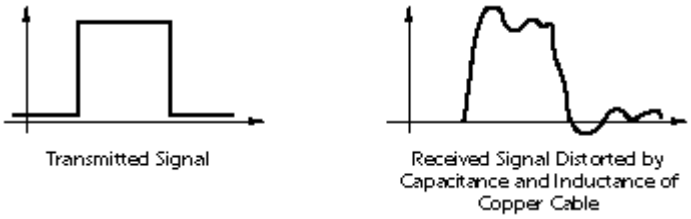
Amplifiers are used to amplify the attenuated signal which gives the original signal back and compensate for this loss.



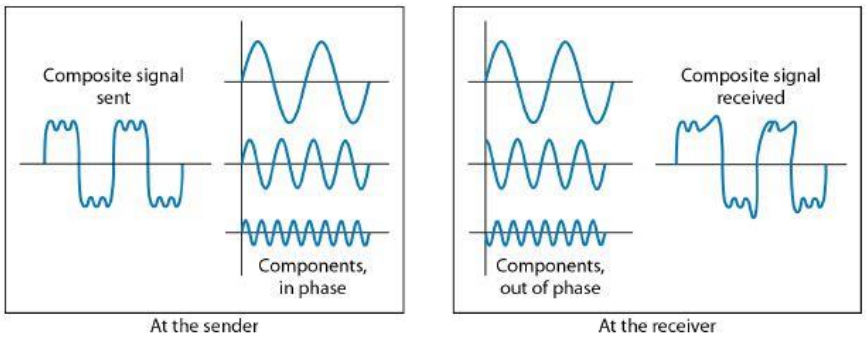
5. **Distortion –** It means changes in the form or shape of the signal. This is generally seen in composite signals made up with different frequencies.

   Each frequency component has its own propagation speed travelling through a medium. And that's why it delay in arriving at the final destination every component arrive at different time which leads to distortion.
   Therefore, they have different phases at receiver end from what they had at senders end.

   - Because the distortion came from different frequencies being attenuated by different amounts, it is called amplitude distortion or filtering.



   - 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 through a medium and, therefore, its own delay in arriving at the final destination. Differences in delay may create a difference in phase
   - The shape of the composite signal is therefore not the same.



Simple topology: point-to-point connection:

A Point-to-point topology connects two networking devices such as computers, switches, routers, or servers connected back to back using a single piece of cable.

The Point-to-Point Protocol (PPP) is used for establishing direct connectivity between two network nodes. It authenticates the connections, compresses, transmits after encryption thereby providing privacy. PPP is primarily designed for linking two networks and transporting IP packets between the two. The links are capable of providing simultaneous bi-directional functions, delivering data packets in a specific order. This protocol is a common solution to easily connect diverse types of hosts, bridges, and routers.