Chapter 2
Physical Layer

Dr. Nilesh M. Patil

Associate Professor, DJSCE

Unit	Description	Duration	CO	Marks
II	**Physical Layer**: Introduction to Digital Communication System **Guided Transmission Media**: Twisted pair, Coaxial, Fiber optics. **Unguided Media (Wireless Transmission)**: Radio Waves, Microwave, Bluetooth.	06	CO2	15

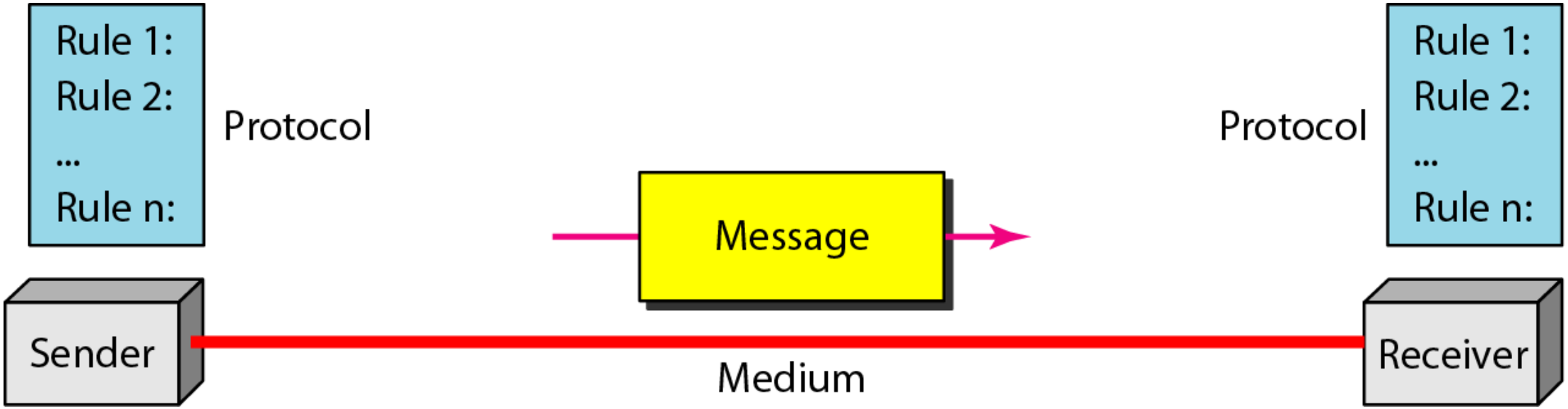
Introduction to Communication System

- **Data** refers to the raw facts that are collected while **information** refers to processed data that enables us to take decisions.
- Example: When result of a particular test is declared it contains data of all students, when you find the marks you have scored you have the information that lets you know whether you have passed or failed.
- Data Communication is a process of exchanging data or information.
- In case of computer networks this exchange is done between two devices over a transmission medium.
- This process involves a communication system which is made up of hardware and software.
- The hardware part involves the sender and receiver devices and the intermediate devices through which the data passes.
- The software part involves certain rules which specify what is to be communicated, how it is to be communicated and when. It is also called as a **Protocol**.

Characteristics of Data Communication

- **Delivery**: The data should be delivered to the correct destination and correct user.
- **Accuracy**: The communication system should deliver the data accurately, without introducing any errors. The data may get corrupted during transmission affecting the accuracy of the delivered data.
- **Timeliness**: Audio and Video data has to be delivered in a timely manner without any delay; such a data delivery is called real-time transmission of data.
- **Jitter**: It is the variation in the packet arrival time. Uneven Jitter may affect the timeliness of data being transmitted.

Components of Data Communication



Components of a data communication system

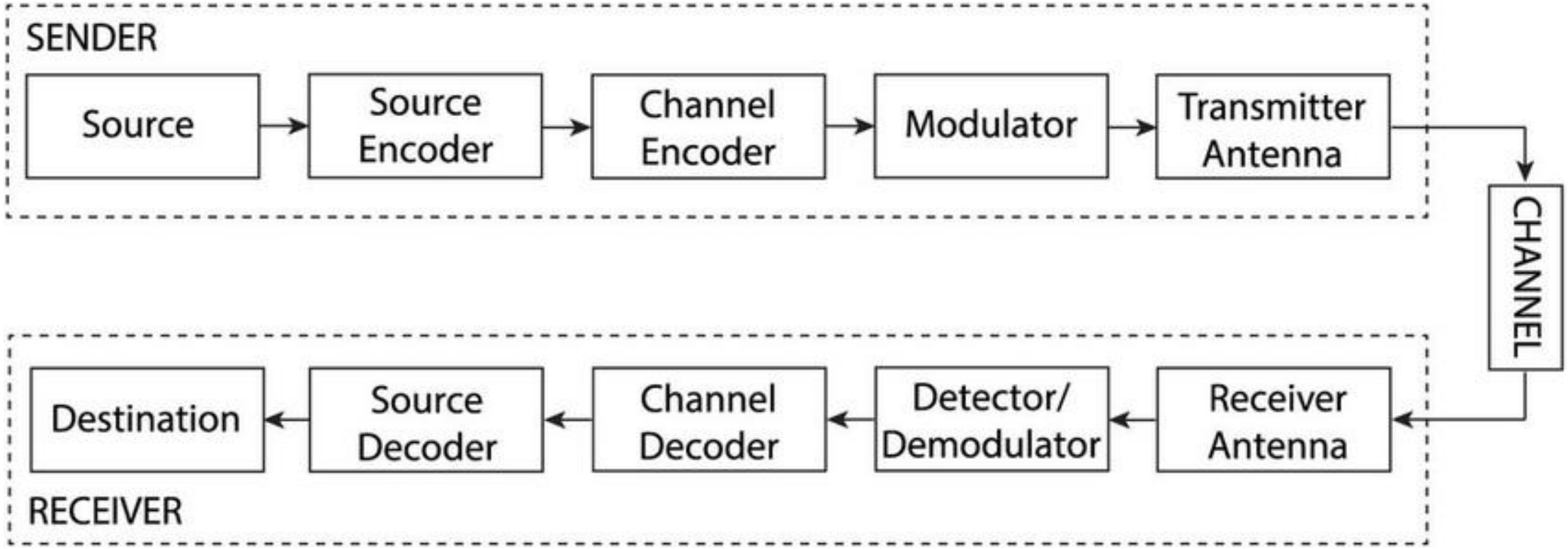
1. Message. The message is the information (data) to be communicated. Popular forms of information include text, numbers, pictures, audio, and video.
2. Sender. The sender is the device that sends the data message. It can be a computer, workstation, telephone handset, video camera, and so on.
3. Receiver. The receiver is the device that receives the message. It can be a computer, workstation, telephone handset, television, and so on.
4. Transmission medium. The transmission medium is the physical path by which a message travels from sender to receiver. Some examples of transmission media include twisted-pair wire, coaxial cable, fiber-optic cable, and radio waves.
5. Protocol. A protocol is a set of rules that govern data communications. 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. The key elements of a protocol are syntax, semantics and timing.

a) Syntax : Refers to the structure or format of the data, means the order in which they are presented.

b) Semantics : Refers to the meaning of each section of bits, means how a particular pattern is to be interpreted, and what action is to be taken based on that interpretation.

c) Timing : Means that data should be sent and how fast they can be sent.

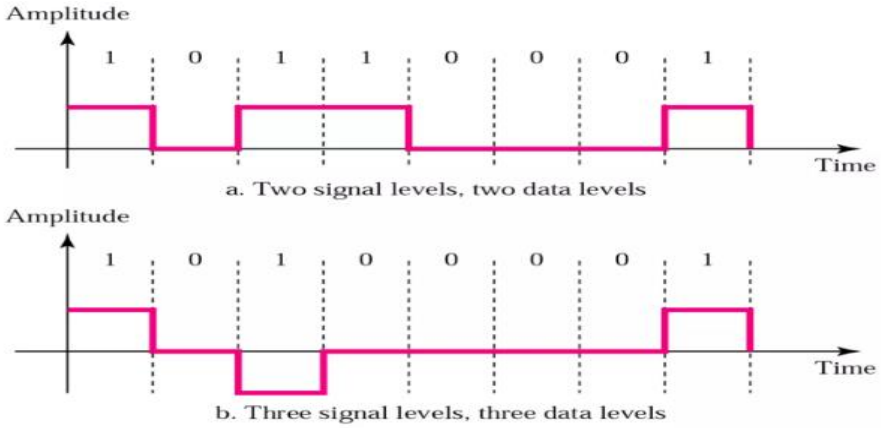
Digital Communication System



Maximum Data Rate of a Channel

- The maximum data rate limit over a medium is decided by following factors:

1. Bandwidth of channel
2. Signal levels
3. Channel quality



- Depending upon the channel type (noiseless channel or noisy channel), the data rate is calculated by two different formulas.

1. For noiseless channel – Nyquist Bit Rate
2. For noisy channel – Shannon Capacity

Nyquist Bit Rate

- Nyquist bit rate defines the theoretical maximum bit rate for a noiseless channel or ideal channel.
- The formula for maximum bit rate in bits per second (bps) is:

$$\textbf{Maximum Bit Rate} = 2 \times \textbf{BW} \times \log_2 \textbf{L}$$

where, BW = Bandwidth of channel

L = Number of signal levels used to represent data

Q1. Determine the data rate for a noiseless channel having bandwidth of 3kHz and two signal levels are used for signal transmission.

Solution: For a noiseless channel, the maximum data rate is given by Nyquist bit rate as

$$\text{Maximum Bit Rate} = 2 \times \text{BW} \times \log_2 \text{L}$$
$$\text{Maximum Bit Rate} = 2 \times (3 \times 10^3) \times \log_2 2$$
$$\text{Maximum Bit Rate} = 6000\text{bps}$$

Q2. Calculate the bandwidth of a noiseless channel having a maximum bit rate of 12kbps and four signal levels.

Solution: For a noiseless channel, the maximum data rate is given by Nyquist bit rate as

$$\text{Maximum Bit Rate} = 2 \times \text{BW} \times \log_2 \text{L}$$

$$12 \times 10^3 = 2 \times \text{BW} \times \log_2 4$$

$$\text{BW} = \frac{12 \times 10^3}{4} = 3000 \text{ Hz} = 3\text{kHz}$$

Shannon Capacity

- An ideal noiseless channel never exists. The maximum data rate for any noisy channel is:

$$\mathbf{C = BW \times \log_2\left(1 + \frac{S}{N}\right)}$$

where, C = Channel capacity in bits per second

BW = Bandwidth of channel

$\frac{S}{N}$ = Signal-to-Noise ratio

Q3. Calculate the capacity of a telephone channel. The channel bandwidth is 3000 Hz and $\frac{S}{N}$ is 3162.

Solution: The telephone channel is a noisy channel.

$$C = BW \times \log_2\left(1 + \frac{S}{N}\right)$$

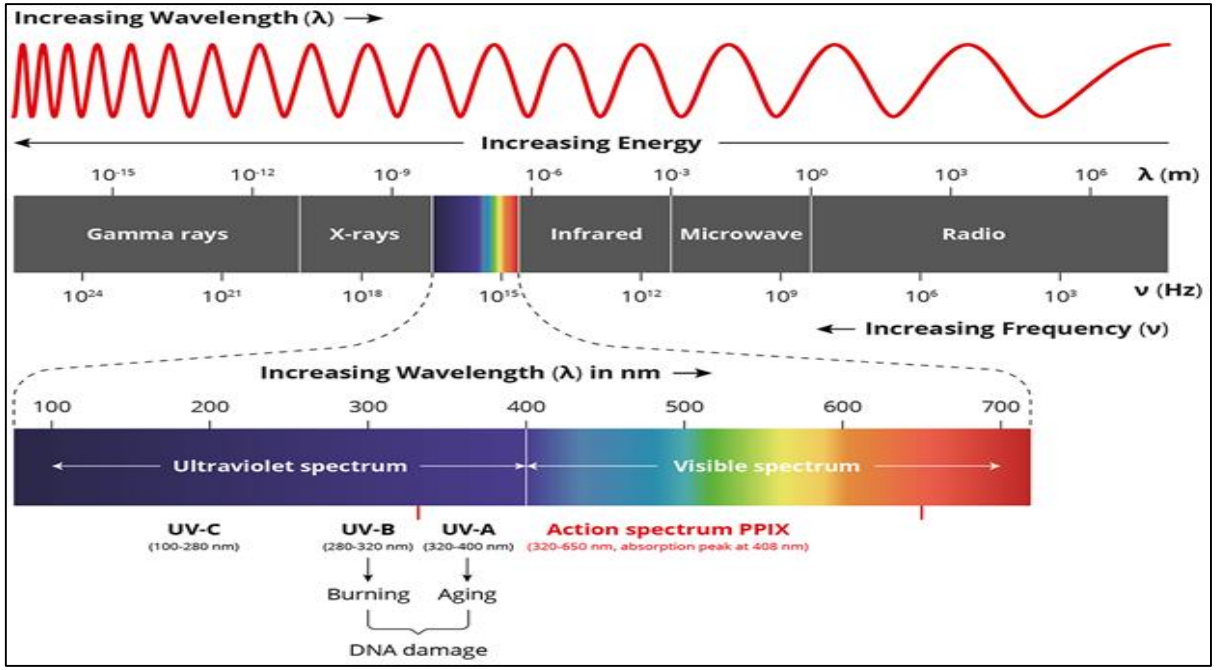
$$C = 3000 \times \log_2(1 + 3162) = 34881 \text{ bps}$$

Electromagnetic Spectrum

- Electromagnetic spectrum in simple terms is defined as the range of all types of electromagnetic radiation.
- The entire range (electromagnetic spectrum) is given by radio waves, microwaves, infrared radiation, visible light, ultra-violet radiation, X-rays, gamma rays and cosmic rays in the increasing order of frequency and decreasing order of wavelength.

Type of Radiation	Frequency Range (Hz)	Wavelength Range
gamma-rays	$10^{20} – 10^{24}$	$< 10^{-12}$ m
x-rays	$10^{17} – 10^{20}$	1 nm – 1 pm
Ultraviolet	$10^{15} – 10^{17}$	400 nm – 1 nm
Visible	$4 – 7.5x10^{14}$	750 nm – 400 nm
near-infrared	$1x10^{14} – 4x10^{14}$	2.5 μm – 750 nm
Infrared	$10^{13} – 10^{14}$	25 μm – 2.5 μm
Microwaves	$3x10^{11} – 10^{13}$	1 mm – 25 μm
radio waves	$< 3x10^{11}$	> 1 mm

1. **Radio:** Radio waves are mainly used for TV/mobile communication.
2. **Microwave:** This type of radiation is found in microwaves and helps in cooking at home/office. It is also used by astronomers to determine and understand the structure of nearby galaxies and stars.
3. **Infrared:** It is used widely in night vision goggles. These devices can read and capture the infrared light emitted by our skin and objects with heat.
4. **X-ray:** X-rays can be used in many instances. For example, a doctor can use an x-ray machine to take an image of our bone or teeth. Airport security personnel use it to see through and check bags.
5. **Gamma-ray:** It has a wide application in the medical field. Gamma-ray imaging is used to see inside our bodies.
6. **Ultraviolet:** Sun is the main source of ultraviolet radiation. It causes skin tanning and burns.
7. **Visible:** Visible light can be detected by our eyes. Light bulbs, stars, etc. emit visible light.



Transmission Media

- Transmission media is a communication channel that carries information from the sender to the receiver.
- Data is transmitted through electromagnetic signals.
- The electrical signals can be sent through the copper wire, fiber optics, atmosphere, water, and vacuum.
- Transmission media is of two types: guided (also called wired or bounded) media and unguided (also called wireless or unbounded) media.
- In wired media, medium characteristics are more important whereas, in wireless media, signal characteristics are more important.
- Different transmission media have different properties such as bandwidth, delay, cost and ease of installation and maintenance.

Selection of Transmission Media

- The selection of transmission media depends on following factors:

1. Design factors
2. Guided or unguided media

Design Factors

- Some factors need to be considered for designing the transmission media:

- **Bandwidth**: The greater the bandwidth of a medium, the higher the data transmission rate of a signal.
- **Transmission impairment**: When the received signal is not identical to the transmitted one, it is due to the transmission impairment. The quality of the signals will get destroyed due to transmission impairment.
- **Interference:** An interference is defined as the process of disrupting a signal when it travels over a communication medium on the addition of some unwanted signal.
- **Number of receivers**: A guided media is used either for point-to-point link or a shared link with multiple attachments. In multiple attachments, each attachment introduces some attenuation and distortion on the link; this limits the distance and data rate.

- **Causes of Transmission Impairment**:

- **Attenuation:** Attenuation means the loss of energy, i.e., the strength of the signal decreases with increasing the distance which causes the loss of energy.

- **Distortion:** Distortion occurs when there is a change in the shape of the signal.

Guided Transmission Medium

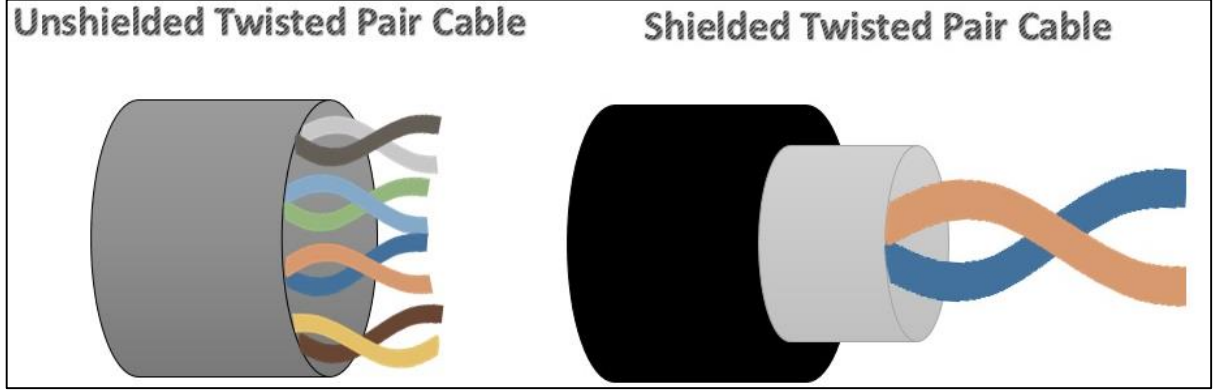
- It is defined as the physical medium through which the signals are transmitted.
- It is also known as Bounded media or wired media.
- Types of Guided Media

1. Magnetic Media
2. Twisted Pair
3. Coaxial Cable
4. Fiber Optic Cable

Magnetic Media

- Data is written on magnetic tape or floppy disk or CD ROM.
- Bandwidth is excellent i.e. upto 19 Gbps.
- Cost effective way to transmit large amount of data.
- High delay in accessing data. It takes minutes to hours to days to physically transport cassette from one location to another.

Twisted Pair



- Twisted pair cable is the most common transmission medium for LANs.
- It is comprised of copper wires individually surrounded by a PVC insulating layer and twisted around each other in a spiral.
- The wires are twisted to improve the transmission characteristics by reducing the interference.
- It can be used for either analog or digital transmission.
- Bandwidth depends on the thickness of the wire and the distance travelled.
- Twisted pair is relatively inexpensive and easy to install and terminate.
- There are two types of twisted pair cable: Unshielded twisted pair (UTP) and shielded twisted pair (STP).

Unshielded Twisted Pair (UTP)

- UTP is a set of twisted pairs of cable within a plastic sheet.
- There is no additional shielding for the twisted pairs.
- It is used for telephonic applications.
- UTP has data rate of 10 – 100 Mbps.
- UTP is less expensive than fiber optic cable and coaxial cable.
- Maximum cable segment of UTP is 100 metres.
- UTP cable is very flexible and easy to work.
- UTP cables consist of 2 or 4 pairs of twisted cable. Cable with 2 pair use **RJ-11** connector and 4 pair cable use **RJ-45** connector.
- Most susceptible to electrical interference or crosstalk.

Advantages of UTP

- UTP is easy to terminate.
- Cost of installation is less.

Disadvantages of UTP

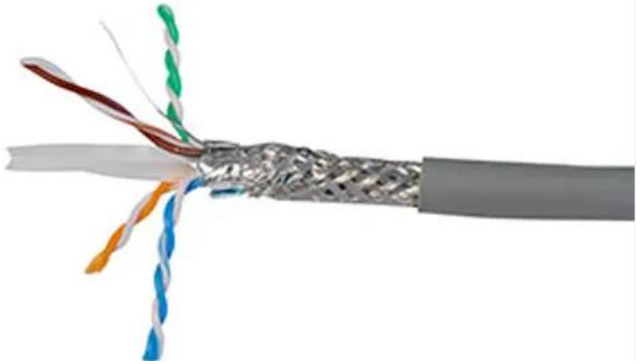
- It is very noisy.
- It covers less distance.
- UTP suffers from interference.

RJ11 Male & Female Telephone / Computer Connectors

Categories of UTP

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)

Shielded Twisted Pair (STP)



- STP cable consists of twisted pair of wires that are not only individually insulated, but also surrounded by a shield made of a metallic substance such as aluminium foil.
- The shielding also ensures that the electromagnetic field generated in one pair will not interfere with the signal in an adjacent pair.
- STP has data rate of 150 Mbps.
- Maximum cable segment of STP is 500 metres.
- Less susceptible to interference or crosstalk.
- Very easy to install.
- Little costly as compared to UTP.

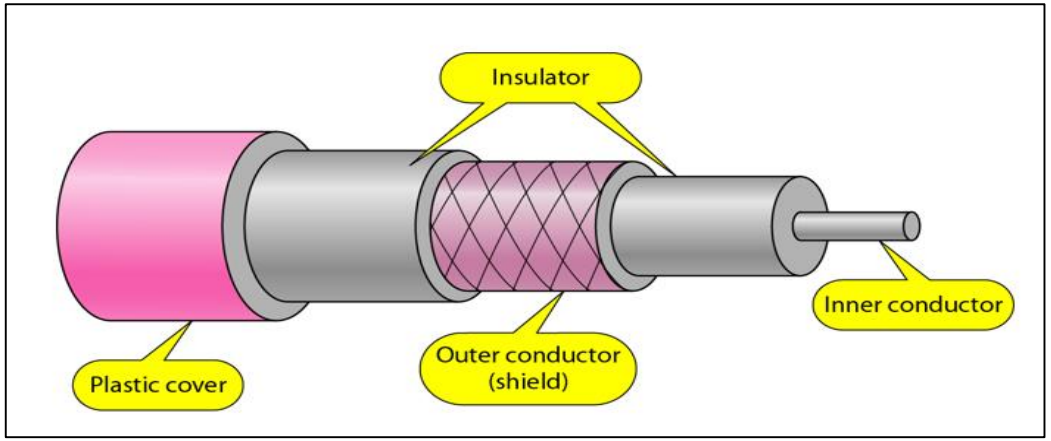
Advantages of STP

- Can be used for Analog or Digital transmission
- Increases the signaling rate
- Higher capacity than unshielded twisted pair
- Eliminates crosstalk

Disadvantages of STP

- Difficult to manufacture
- Heavy

Coaxial Cable



- Coaxial is called by this name because it contains two conductors that are parallel to each other.
- Copper is used in this as centre conductor which can be a solid wire or a standard one.
- It is surrounded by PVC installation, a sheath which is encased in an outer conductor of metal foil, braid or both.
- Outer metallic wrapping is used as a shield against noise and as the second conductor which completes the circuit.
- The outer conductor is also encased in an insulating sheath.
- The outermost part is the plastic cover which protects the whole cable.
- To connect coaxial cable to devices, we need coaxial connectors. The most common type of connector used today is the Bayonet Neill-Concelman (BNC) connector.

Classification of Coaxial Cable

1. Based on Impedance

a. 50 Ohm: Used for digital transmission

b. 75 Ohm: Used for analog transmission

2. Based on Frequency

a. Baseband (0 – 4 kHz): Used for telephone cabling

b. Broadband (4 kHz): Used for cable television cabling

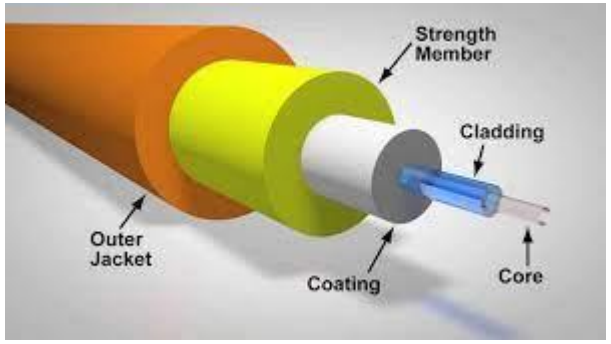
Advantages of Coaxial Cable:

- Bandwidth is high.
- Used in long distance telephone lines.
- Transmits digital signals at a very high rate of 10Mbps.
- Much higher noise immunity
- Data transmission without distortion.

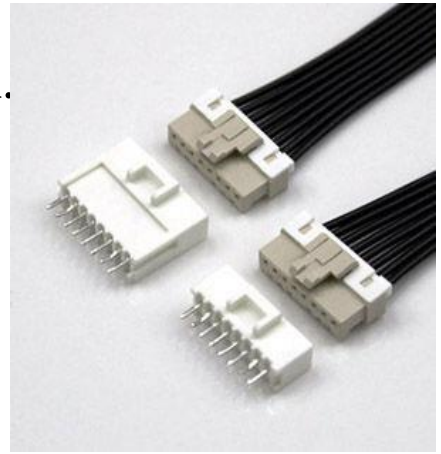
Disadvantages of Coaxial Cable:

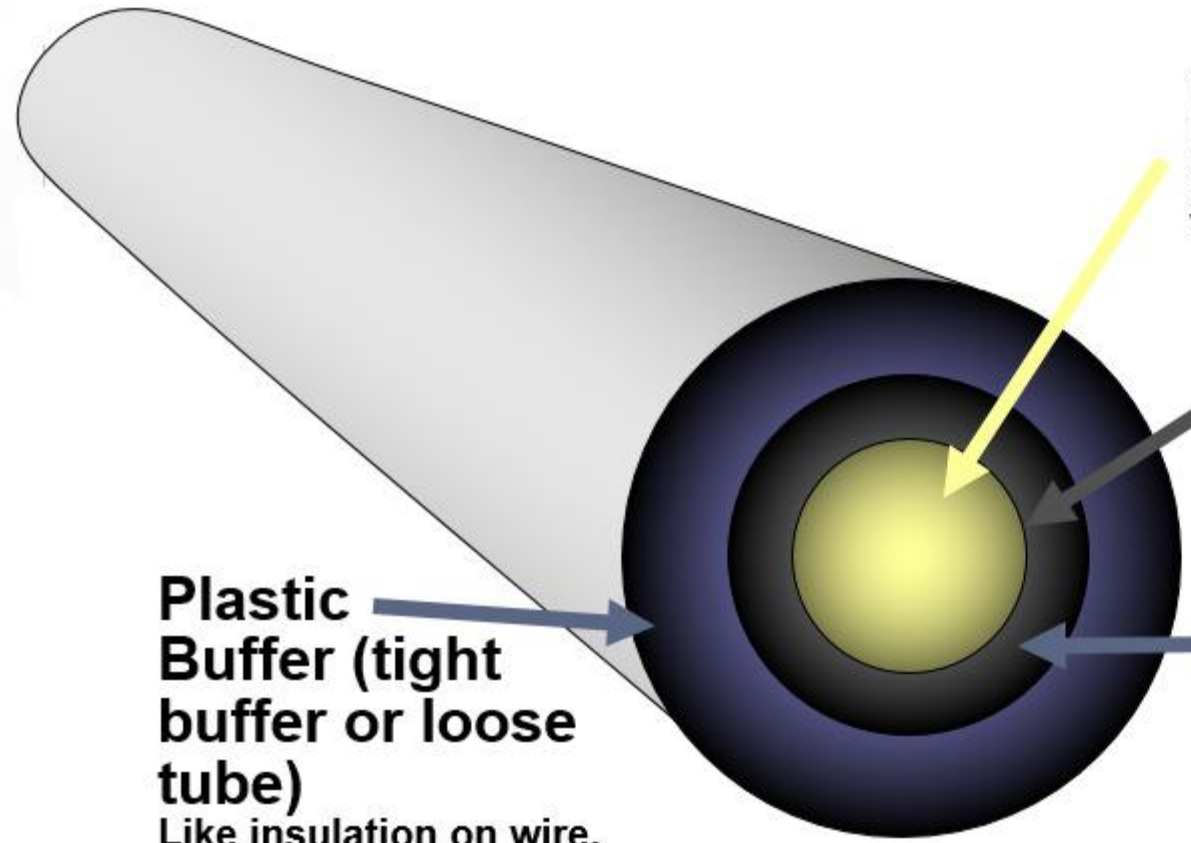
- Single cable failure can fail the entire network.
- Difficult to install and expensive when compared with twisted pair.
- If the shield is imperfect, it can lead to grounded loop.

Fiber Optic Cable



- Fiber optic cable consists of bundled fiber strands.
- Each fiber strand has a thin, inner core of optical fiber and a cladding, which is a concentric glass covering, surrounding the core.
- The core and cladding are surrounded by a protective covering.
- Fiber optic cable is able to transmit signals over long distances at very high bandwidth.
- Data is transmitted via pulsing light sent from a laser through the central fiber.
- Cladding reflects light back to the core.
- Plastic coating (or buffer) protects the fiber from damage and moisture.
- Fiber optics is not susceptible to electromagnetic or radio frequency interference.
- Fiber optic cable uses two types of connectors for connection. They are Subscriber Channel (SC) connector and Straight Line (ST) connector.





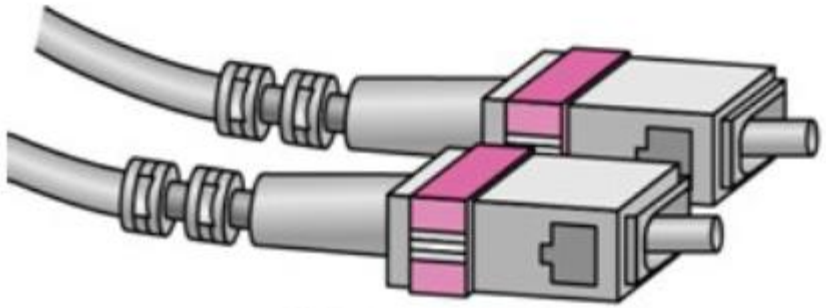
Core
Central high refractive index glass, the layer through which light travels

Cladding
Optical containment layer of glass surrounding the core

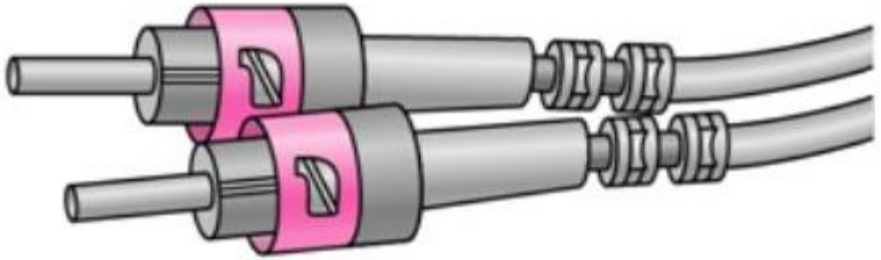
Coating
Protects glass from scratches, moisture, etc.

Plastic Buffer (tight buffer or loose tube)
Like insulation on wire, color coded, cushions fiber from crushing & microbending

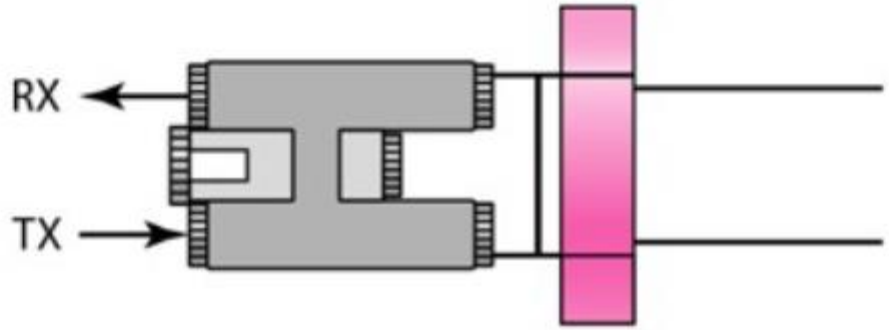
Subscriber channel connector, straight tip connector



SC connector



ST connector



MT-RJ connector

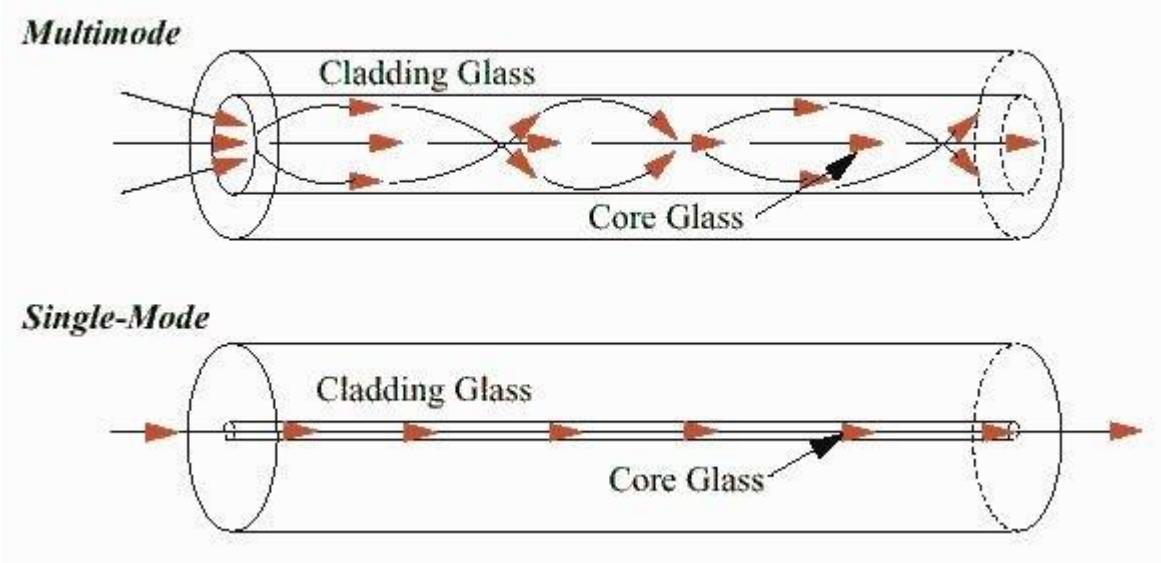
Types of Fiber Optic Cable

1. Single-mode fiber

- Have a single strand of glass fiber.
- Have small core with diameter of 8.3 to 10 microns.
- Transmit infrared laser light having wavelength 1310 or 1550nm.
- Bandwidth is nearly infinity.

2. Multimode fiber

- Have a multiple strands of glass fiber.
- Have larger core with diameter of 62.5 microns i.e. about thickness of human hair.
- Transmit infrared light having wavelength 850 to 1300nm.
- Bandwidth is 2 GHz.



Advantages of Fibre Optic Cable

- Higher bandwidth
- Less signal attenuation
- Immune to electromagnetic interference
- Resistance to corrosive materials
- Light weight
- Greater immunity to tapping

Disadvantages of Fiber Optic Cable

- Installation and maintenance is difficult
- Unidirectional light propagation
- High Cost

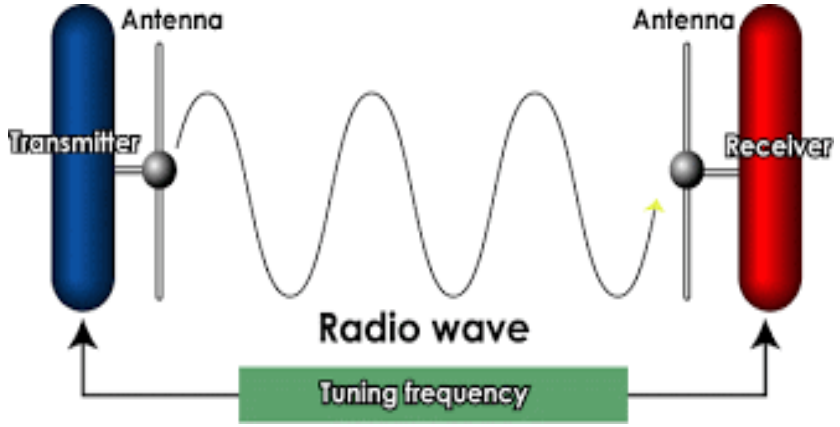
Unguided Transmission Medium

- It is also referred to as Wireless or Unbounded transmission media.
- No physical medium is required for the transmission of electromagnetic signals.
- The signal is broadcasted through air.
- Less Secure.
- Used for larger distances.
- Types of Guided Media

1. Radio Waves
2. Microwave
3. Infrared
4. Bluetooth

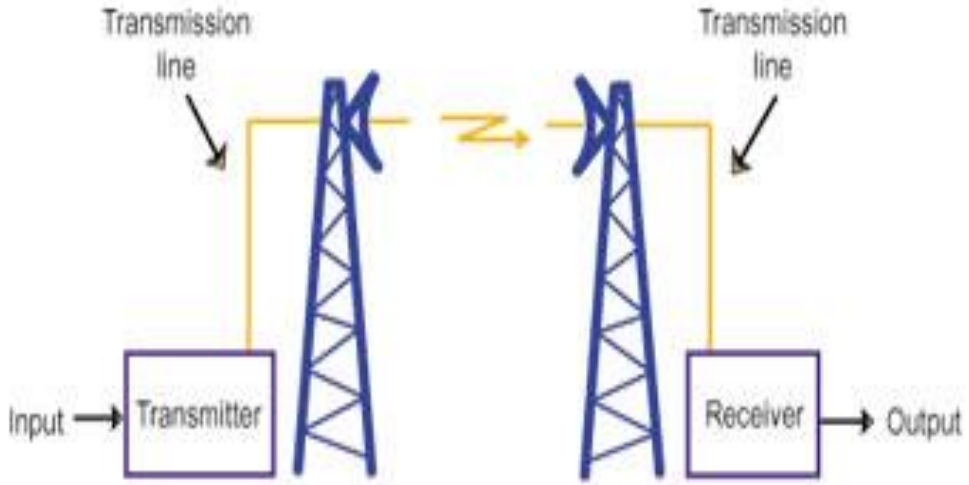
Radio Waves

- These are easy to generate and can penetrate through buildings.
- The sending and receiving antennas need not be aligned.
- Frequency Range:3KHz – 1GHz.
- AM and FM radios and cordless phones use radio waves for transmission.

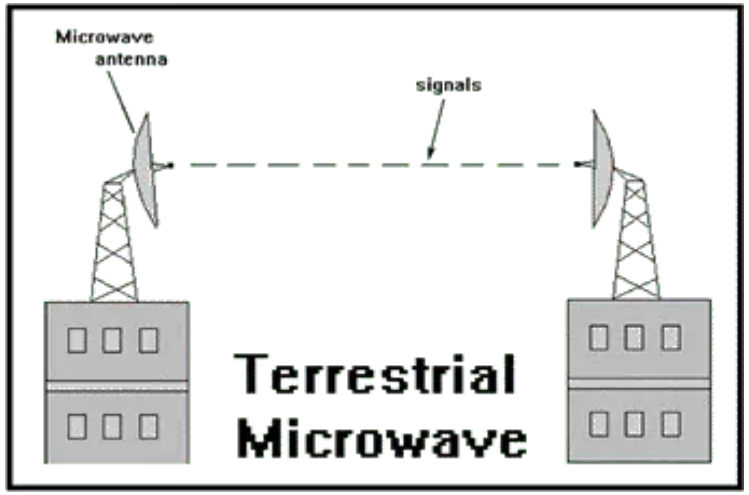


Microwave

- It is a line of sight transmission i.e. the sending and receiving antennas need to be properly aligned with each other.
- The distance covered by the signal is directly proportional to the height of the antenna.
- Frequency Range:1GHz – 300GHz.
- These are majorly used for mobile phone communication and television distribution.
- Can pass through thin solids but has difficulty in passing through buildings.
- Further Categorized as (i) Terrestrial and (ii) Satellite.

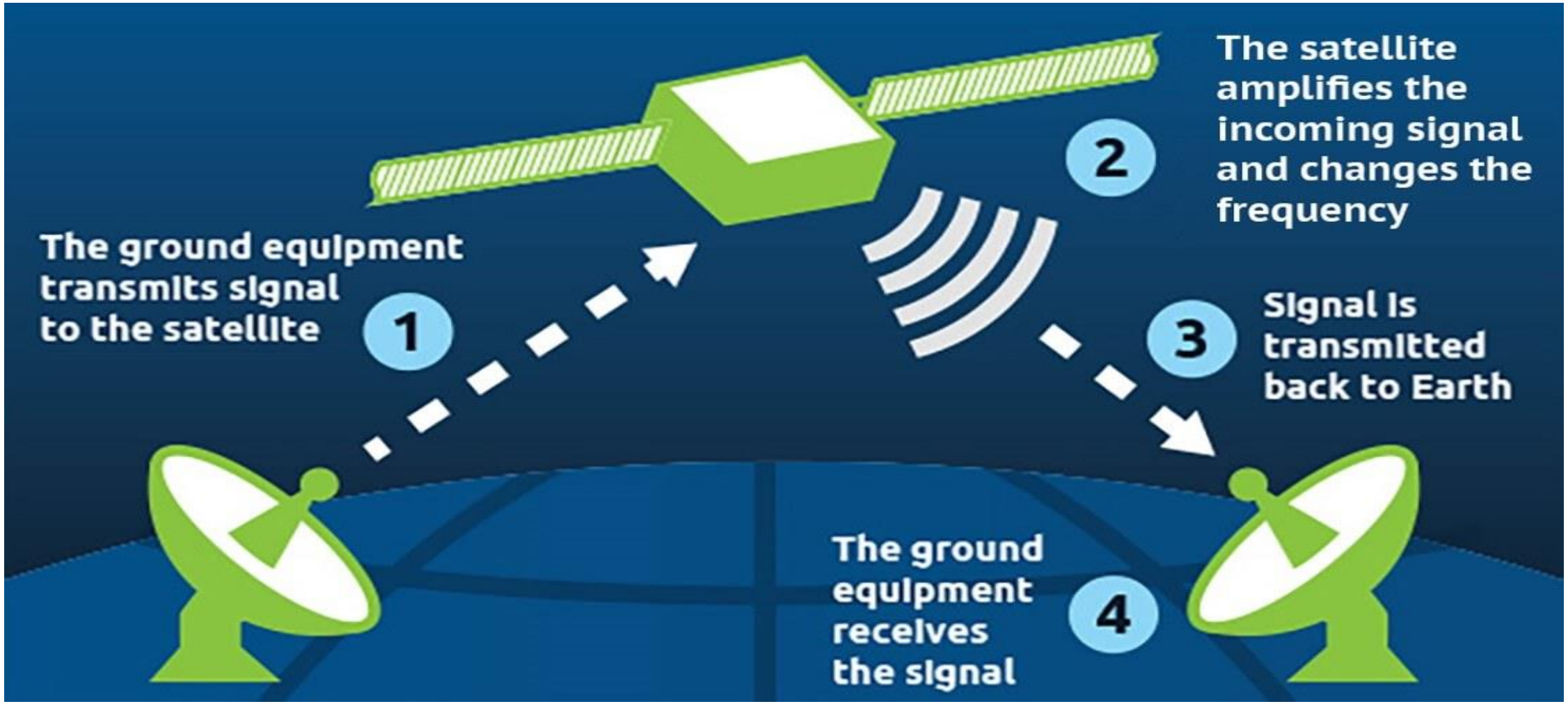


Terrestrial Microwave



- Terrestrial microwave transmissions are sent between two microwave stations on the earth.
- Common for long-distance communication.
- Operate in the low gigahertz range.
- A parabolic dish focuses a narrow beam onto a receiver antenna.

Satellite Microwave



Infrared

- Infrared waves are used for very short distance communication.
- They cannot penetrate through obstacles.
- This prevents interference between systems.
- Frequency Range:300GHz – 400THz.
- It is used in TV remotes, wireless mouse, keyboard, printer, etc.

Television

Infrared Radiations

Remote

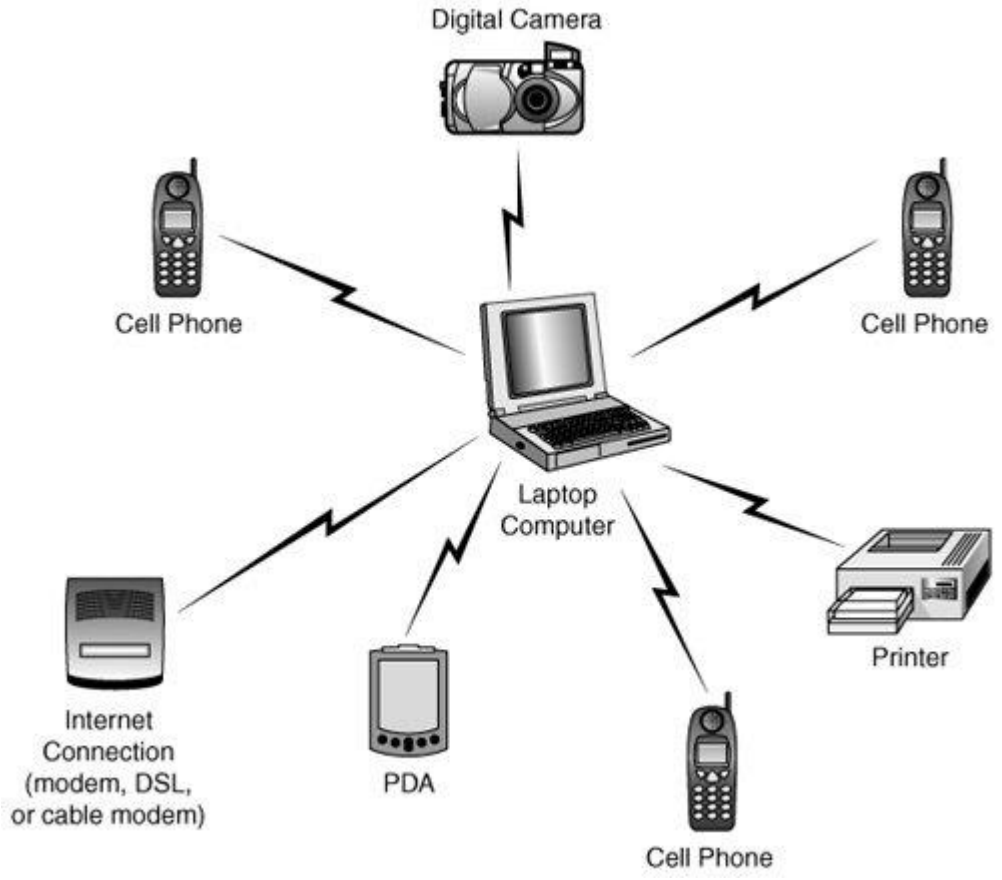
Bluetooth

- It is a Wireless Personal Area Network (WPAN) technology and is used for exchanging data over smaller distances.
- This technology was invented by Ericson in 1994.
- It operates in the unlicensed, industrial, scientific and medical (ISM) band at 2.4 GHz to 2.485 GHz.
- Bluetooth lets devices discover and connect to each other (by pairing), and then securely transfer data.
- Maximum devices that can be connected at the same time are 7.
- Bluetooth ranges upto 10 meters.
- It provides data rates upto 1 Mbps or 3 Mbps depending upon the version.
- A Bluetooth network is called **Piconet** and a collection of interconnected piconets is called **Scatternet**.

Piconet and Scatternet

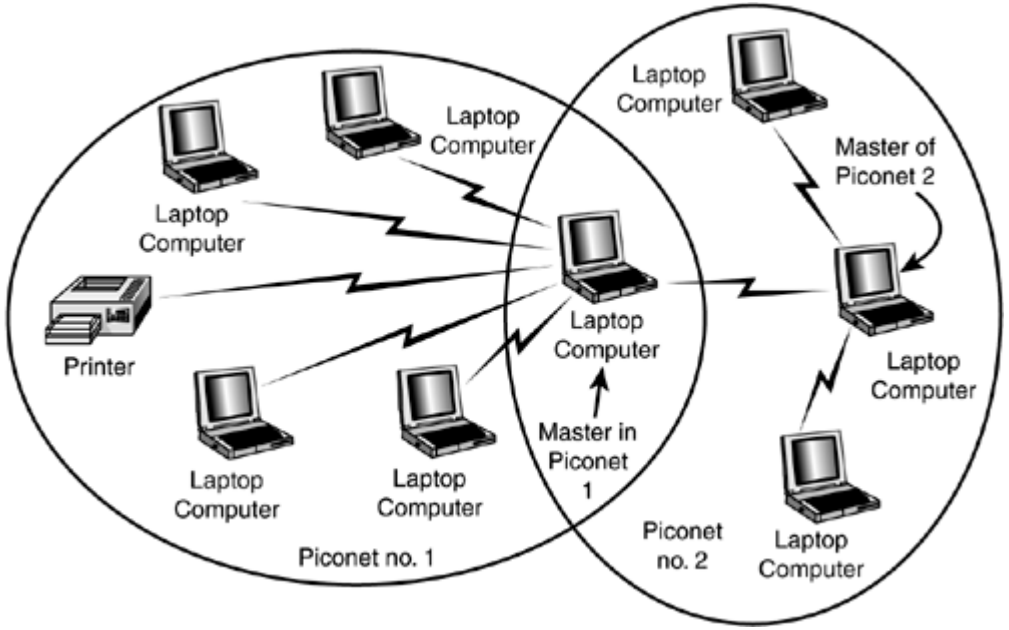
Piconet

- Piconet is a type of Bluetooth network that contains **one primary node** called master node and **seven active secondary nodes** called slave nodes.
- Thus, we can say that there are total of 8 active nodes which are present at a distance of 10 metres.
- The communication between the primary and secondary node can be one-to-one or one-to-many.
- Possible communication is only between the master and slave; Slave-slave communication is not possible.
- It also has **255 parked nodes**, these are secondary nodes and cannot take participation in communication unless it gets converted to the active state.



Scatternet

- It is formed by using **various piconets**.
- A slave that is present in one piconet can be act as master or we can say primary in other piconet.
- This kind of node can receive message from master in one piconet and deliver the message to its slave into the other piconet where it is acting as a slave.
- This type of node is called as **bridge node**.
- A station cannot be master in two piconets.



Advantages and Disadvantages of Bluetooth

Advantages of Bluetooth:

- Low cost.
- Easy to use.
- It can also penetrate through walls.
- It creates an adhoc connection immediately without any wires.
- It is used for voice and data transfer.

Disadvantages of Bluetooth:

- It can be hacked and hence, less secure.
- It has slow data transfer rate: 3 Mbps.
- It has small range: 10 meters.