I have not failed, but found 1000 ways to not make a light bulb.

Thomas Edison

2

Physical Layer

2.1 Overview

- The physical layer is the lowest layer of the reference model.
- It is the only layer that deals with the physical connectivity of two different nodes.
- It defines the electrical, timing and other interfaces by which bits are sent as signals over channel.
- The data link layer provides data frames to physical layer which converts them to electrical pulses that represent binary data.
- The properties of different kinds of physical channels determine the network performance (i.e. throughput, latency, and error rate) of the network.

2.2 Network Performance

The following measures are often considered important:

2.2.1 Bandwidth

- Bandwidth can be interpreted in different contexts with two different measuring values: bandwidth in hertz (Hz) and bandwidth in bits per second (bps).

Bandwidth in Hertz

- Usually, for a *wire*, the amplitudes of signal are transmitted mostly undiminished from 0 to up to some frequency, f_c, called cut-off frequency, with all frequencies above this frequency attenuated.

- The width of the frequency range transmitted without being strongly attenuated is called the **bandwidth**, whose quantity is measured in *Hertz (Hz)*. In other words, *it is the range of frequencies a channel can pass*.

- The *bandwidth of a composite signal* is the difference between the highest and the lowest frequencies contained in that signal.

Filters are often used to further limit the bandwidth of a signal.

- For example, 802.11 wireless channels are allowed to use up to roughly 20 MHz; Traditional (analog) television channels occupy 6 MHz each, on a wire or over the air, bandwidth of a subscriber telephone line is 4 KHz.

Bandwidth in Bits per Second

- The term bandwidth can also refer to the number of bits per second that a channel, a link, or even a network can transmit.

- For example, one can say the bandwidth of a Fast Ethernet network (or the links in this network) is a maximum of 100 Mbps. This means that this network can send 100 Mbps.

2.2.2 Throughput

- It is the actual rate that information can is transferred. It is the measure of how fast we can send data through the network.

- Throughput and bandwidth are similar terms. Both have same unit, bits per second. Bandwidth is the theoretical maximum rate whereas throughput is the actual bit send or received.

- For example:, we may have a link with a bandwidth of 1 Mbps, but the devices connected to the end of the link may handle only 200 kbps. This means that we cannot send more than 200 kbps through this link. Thus, the throughput of the link is 200 kbps.

Example: A network with bandwidth of 10 Mbps can pass only an average of 12,000 frames per minute with each frame carrying an average of 10,000 bits. What is the throughput of this network?

Solution:

We can calculate the throughput as:

$$\textbf{Throughput} = (12,000x10,000)/60 = 2Mbps$$

2.2.3 Latency(Delay)

- The latency or delay defines how long it takes for an entire message to completely arrive at the destination form the time the first bit is sent from the source.
- Latency is made of four components: propagation time, transmission time, queuing time and processing delay.

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

- Network latency is the delay that is introduced by the network,
- Several kinds of delays that happens in data communication over a network.
- Low Latency: Network which experience low delay.
- High Latency: Network which experience high delay.

Propagation Time

- Propagation time measures the time required for a bit to travel form the source to the destination.

Propagation time = Distance/(Propagation Speed)

Transmission Time

- Transmission time measures the time required to send all the bits into transmission channel.
- Also called store and forward delay.
- Function of Packet length.
- Nothing to do with distance between the nodes.

Transmission time = (Message size)/Bandwidth

Example: What are the propagation time and the transmision time for 5-MB message (an image) if the bandwidth of the network is 1 Mbps? Assume that the distance between the sender and the receiver is 12,000 km and that light travels at $2.4 \times 10^8 m/s$.

Solution:

We can calculate the propagation time and transmission time as:

$$\textbf{Propagation time} = (12,000 \times 10,000)/2.4 \times 10^8 m/s = 50 \ ms$$

$$\textbf{Transmission time} = (5,000,000 \times 8)/10^6 = 40 \ s$$

Queuing Time

- Queuing time measures the time needed for each intermediate or end device to hold the message before it can processed. The queuing time is not fixed factor; it changes with the load imposed on the network.
- When there is heavy traffic on the network,the queuing time increases.

2.2.4 Bandwidth Delay Product

- Bandwidth and delay are two performance metrics of a link.
- The bandwidth-delay product defines the number of bits that can be fill the link.

Example Case 1: Let us assume that we have a link with a bandwidth of 1 bps. We also assume that the delay of the link is 5 second. We want to see what the bandwidth-delay product means in this case. Looking at the figure 2.1, we can say that this product 1×5 is the maximum number of bits can fill the link. There can be no more than 5 bits at an time on the link.

- This measurement is important if we need to send data in bursts and wait for the acknowledgement of each burst before sending the next one.
- To use the maximum capacity of the link, we need to make the size of our burst 2 times the product of bandwidth and delay.
- A network with a large bandwidth-delay product(i.e. greater than 10^5 bits) is commonly known as a **long fat network** (shortened to **LFN**).

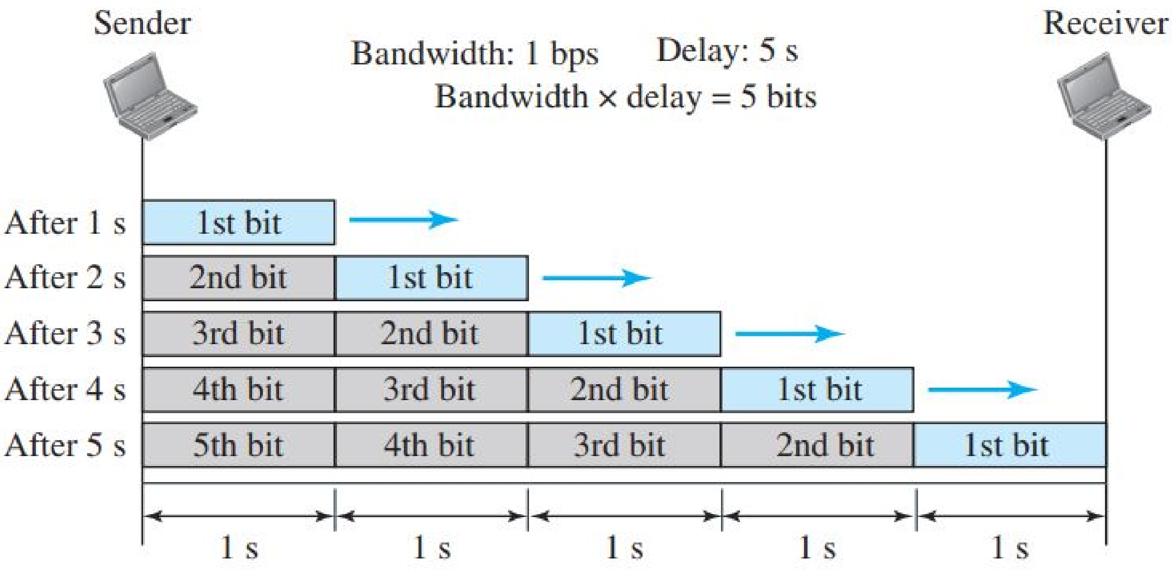


Figure 2.1: Filling the link with bits for case 1

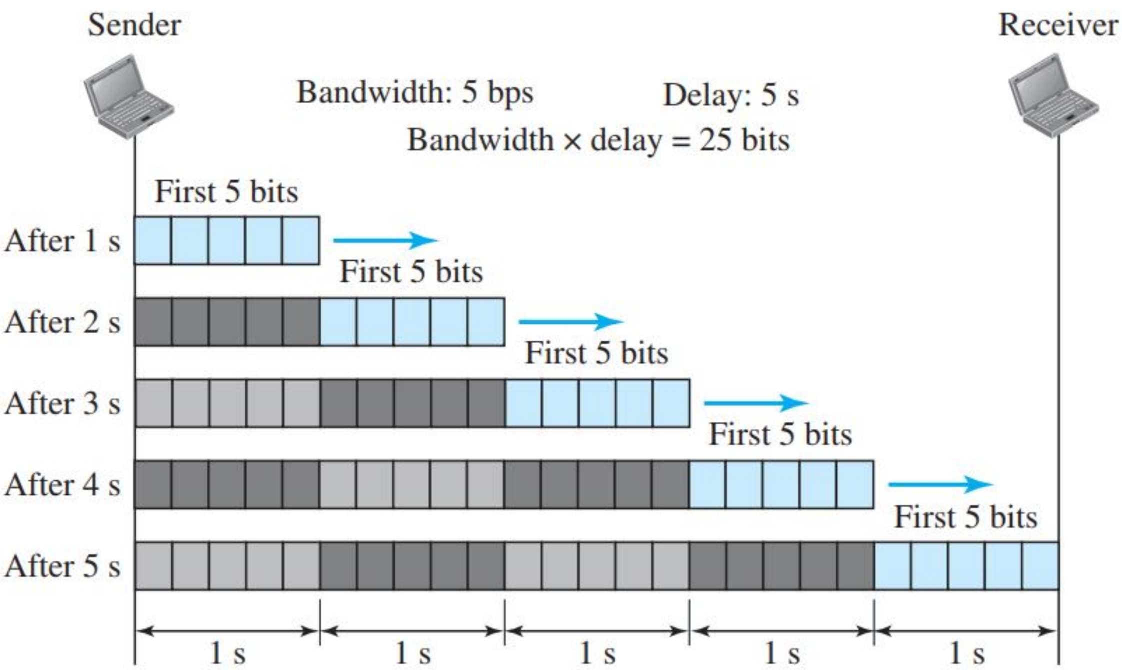


Figure 2.2: Filling the link with bits for case 2

2.2.5 Jitter

- Jitter is the variation in the time between packets arriving, caused by the network congestion, timing drift, or route changes, and the application using the data at the receiver site is time-sensitive (audio and video data, for example).

- If the delay for the first packet is 20 ms, for the second is 45 ms, and for the third is 40 ms, then the real-time application that uses the packets endures jitter.

- Causes of jitter are electromagnetic interference (EMI) and cross talk with other signals.

2.3 Transmission Impairments

- Signals travel through transmission media, which is not perfect. The imperfection causes signal impairments i.e. the signal that is received may differ from the signal that is transmitted.
- For analog signals, these impairments introduce various random modification that degrade the signal quality.
- For digital signals, bit errors may be introduced, such that binary 1 is transformed into a binary 0 and vice-versa.
- The most significant attenuation are:

• Attenuation and attenuation distortion
• Delay distortion
• Noise

2.3.1 Attenuation and Attenuation Distortion

- Attenuation refers to loss of the strength of signal with distance over any transmission media.
- For guided media, attenuation is generally exponential and expressed as in decibles per unit distance.
- For unguided media, attenuation is a more complex function of distance and the makeup of the atmosphere.
- Attenuation introduces three consideration has for transmission engineers:

1. A received signal must have sufficient strength so that the electronic circuitry in the receiver can detect and interpret the signal.
2. The signal must maintain a level sufficiently higher than noise to be received without error.
3. Attenuation is greater at higher frequencies, and this cause distortion.

- The first and second considerations can overcome using amplifiers or repeaters to boost the signal at regular interval of the link.
- While, the third consideration, known as **attenuation distortion**, is particularly noticeable for analog signal. Because attenuation is different for different frequencies, and

the signal is made up of components at different frequencies, the received signal is not only reduced in strength but also distorted at receiver. **Equalization technique** can be employed to over attenuation distortion problem. For example, this is commonly done for voice-grade telephone lines.
- Attenuation distortion is less present for digital signal transmission.

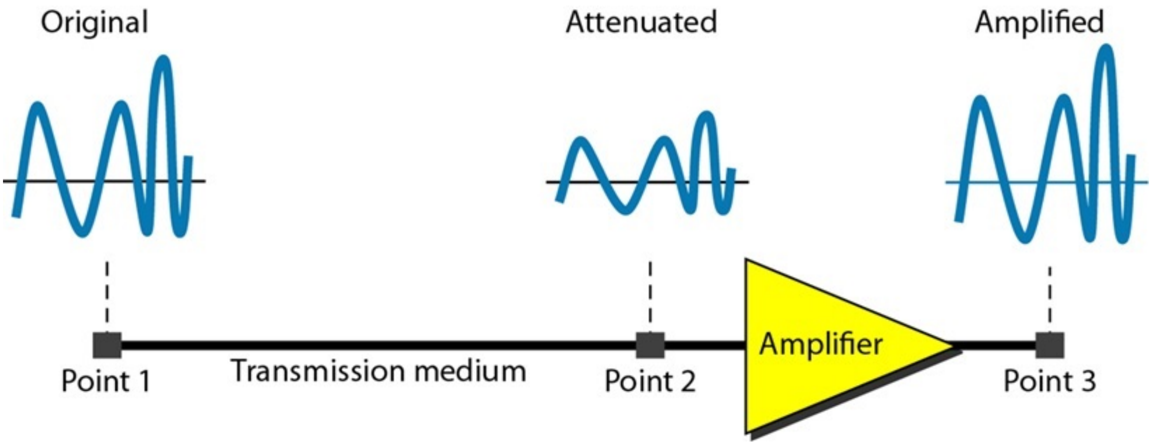


Figure 2.3: Attenuation

2.3.2 Delay Distortion

- Distortion refers to the change in shape or form of the original signal.
- When the components of different frequencies of a composite signal arrive at receiver with varying delay, then delay distortion occurs.
- This phenomenon occurs only in guided media (twisted pair, coaxial cable, and optical fiber); it does not occur when signal is transmitted through the air by mean of air or vacuum.
- Delay distortion is particularly critical for digtal data; it could cause **intersymbol interference**. Equalizing technique can also be used for delay distortion.

2.3.3 Noise

- The unwanted/undesired signal added to the original signal during transmission is called noise, that causes the transmission impairment.
- Noise is the major limiting factor in communications system performance.
- Noise may be divided into four categories:

- Thermal noise
- Intermodulation noise

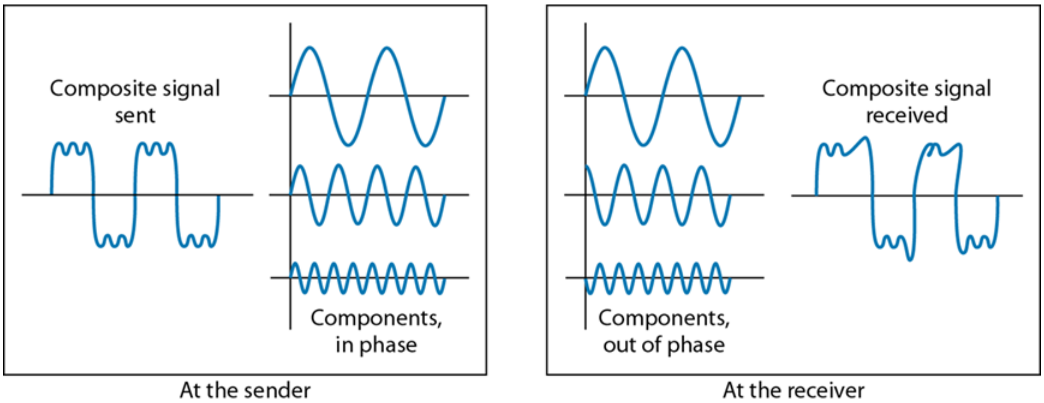


Figure 2.4: Delay Distortion

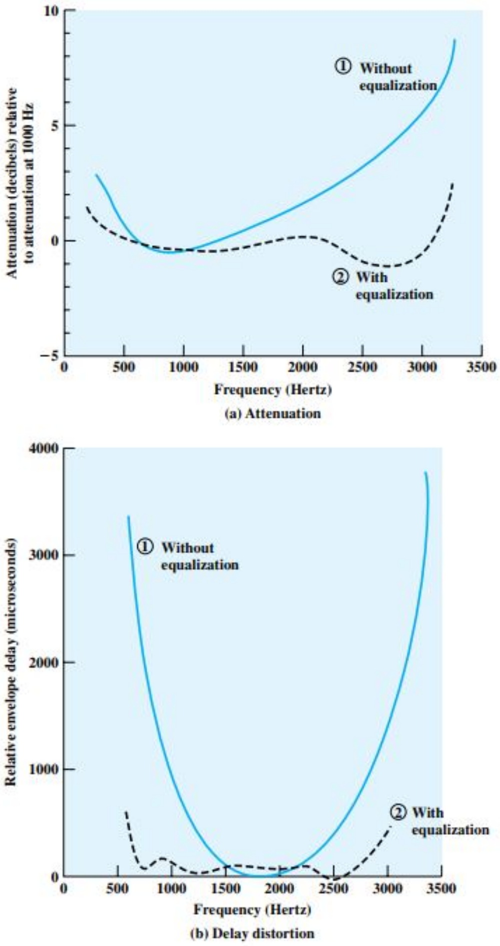


Figure 2.5: Attenuation and Delay Distortion Curves for a Voice Channel

- Crosstalk
- Impulse noise

Thermal noise

- Thermal noise is due to thermal agitation of electrons.

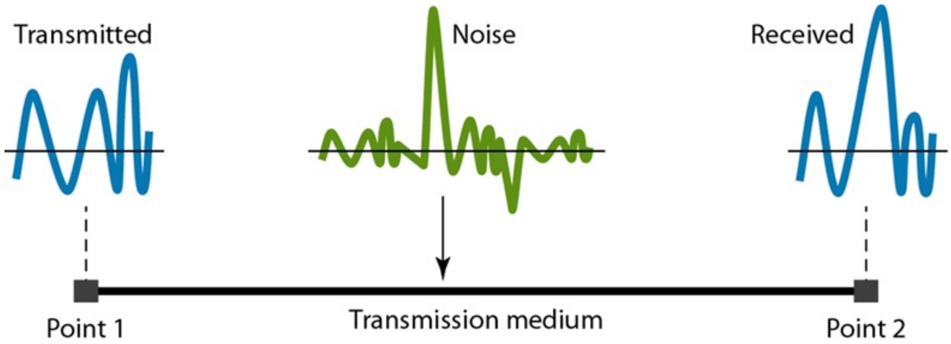


Figure 2.6: Noise

- It is present is all electronics device and transmission media and function of temperature.
- Uniform across bandwidths, so, also called as white noise.
- cannot be eliminated.
- particularly significant in satellite communication, due to weakness of the signal received by satellite.

Intermodulation noise

- When signals at different frequencies share the same transmission medium, the result may be intermodulation noise.
- caused by non-linearities of receiver, transmitter and/or transmission medium.
- Its effect is, it produce signals of frequency that is sum or difference of two original frequencies or multiples of those frequencies.

Crosstalk

- induced noise on the channel by another, due to the magnetic filed around the adjacent pairs of wires in the cable; it is unwanted coupling between signal path. Example: crosstalk on telephone line, microwave antenna picking unwanted signal

Impulse Noise

- Impulse noise is non-continuous, consisting of irregular pulses or noise spikes of short duration and of relatively high amplitude.
- Caused by external electromagnetic disturbances, such as lighting, and faults in the communications system.

- It is primary source of error in digital data communication.

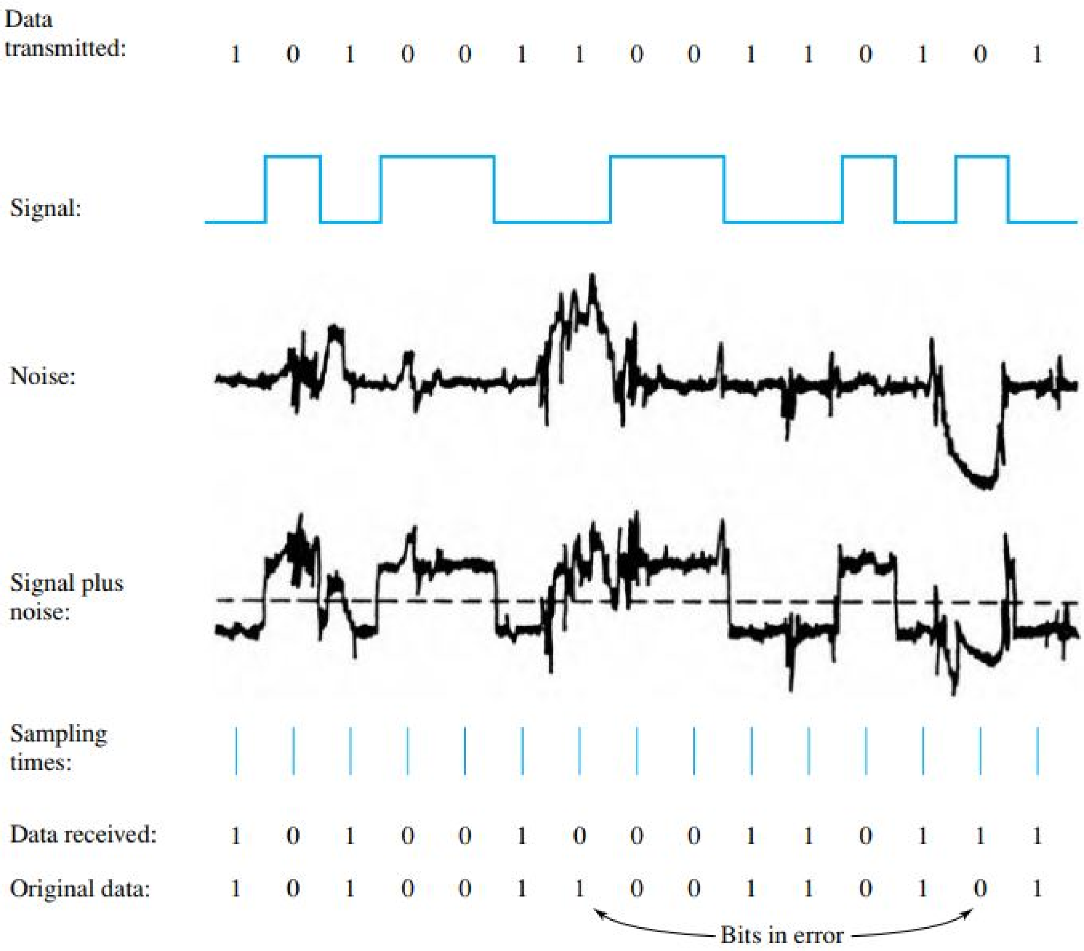


Figure 2.7: Effect of noise on a Digital Signal

2.4 Transmission Media

- A transmission medium can be defined as anything that can carry information from a source to a destination.

- It is the physical path between transmitter and receiver.

- The transmission medium is usually free space, metallic cable or fiber-optic cable. it can be guided or unguided.

- The characteristic and quality of a data transmission are determined by the both the characteristic of the medium and the characteristic of the medium.

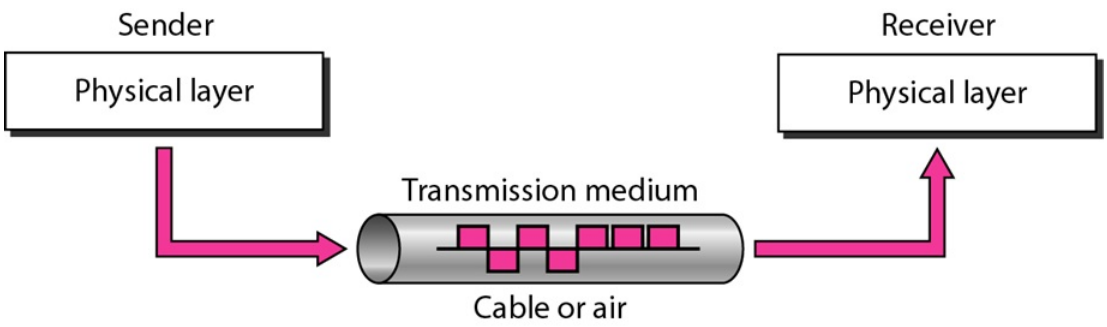


Figure 2.8: Transmission medium and physical layer

2.5 Design Factor

- In considering the design of data transmission system, key concerns are data rate and distance: the greater the data rate and distance, the better.

- A number of design factor that determine the data rate and distance of the transmission media are:

1. Bandwidth
2. Transmission Impairments
3. Interference
4. Number of Receivers

2.6 Types of Transmission Media

It is classified as:

1. Guided
   (a) Twisted pair cable
   (b) Coaxial cable
   (c) Power Lines
   (d) Fiber-optic cable
2. Unguided
   (a) Radio waves
   (b) Microwave
   (c) Bluetooth
   (d) Infrared

2.7 Guided Media

- Guided Transmission media uses a cabling system that guides the data signals along a specific path.
- Guided media also known as **Bounded media**, provide a physical path along which the signals are propagated; these include twisted pair, coaxial cable, and optical fiber.
- Out of these, twisted-pair cable, coaxial cable transport signals in the form of electric signals and fiber-optic cable transport signals in the form of light.

2.7.1 Twisted Pairs

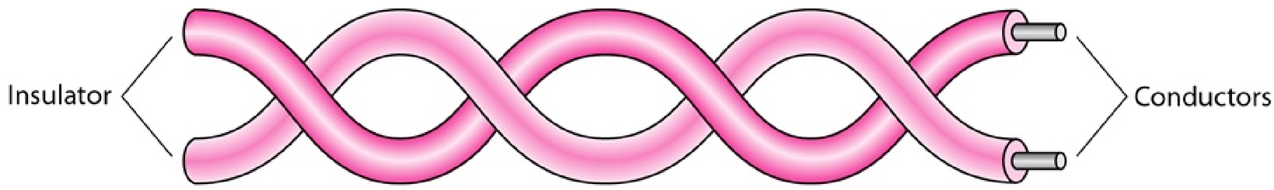


Figure 2.9: Twisted pair

- Twisted pair cable is the least expensive and widely used guided transmission medium.
- A twisted pair consists of two insulated copper wires. The wires are twisted together in helical form, just like a DNA molecule.
- Twisting is done because two parallel wires constitute a fine antenna. When the wires are twisted, the wave from different twists cancel out, so the wire radiates less effectively, hence tends to decrease the crosstalk interference between adjacent pairs in cable.
- A signal is usually carried as the difference in voltage between the two wires in the pair. This provides better immunity to external noise because the noise tends to affect both wires the same, leaving the differential voltage unchanged.

- Twisted pair comes in two varieties:

1. Unshielded twisted pair cable
2. Shielded twisted pair cable

2.7.1.1 Unshielded twisted pair cable

- It consists of one or more twisted-pair cables, typically enclosed within an overall thermoplastic jacket.

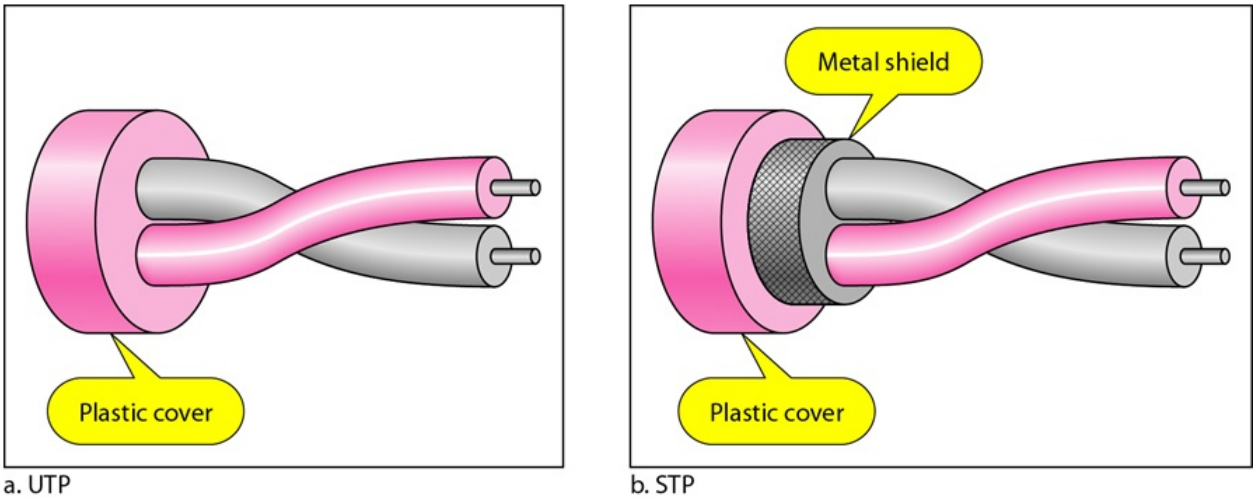


Figure 2.10: Twisted pair types

- Unshielded twisted pair is subject to external electromagnetic interference,including interference from nearby twisted pair and from noise generated in the environment.
- Unshielded twisted pair (UTP) is ordinary telephone wire.

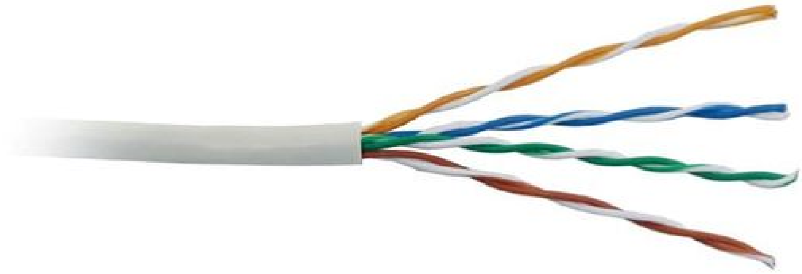
2.7.1.2 Shielded twisted pair cable

- Shielded twisted pair cable have shielding on the individual twisted pair, as well as around the entire cable (but inside the plastic protective sheath).
- Shielding reduces the susceptibility to external interference and crosstalk and provides better performance at higher data rates.
- But, it is bulky and expensive.

- Twisted-pair cabling comes in different varieties, cat1, cat2, cat3, cat4, cat5, cat6 and cat7.
- RJ-45 connectors are used for twisted pair cable.

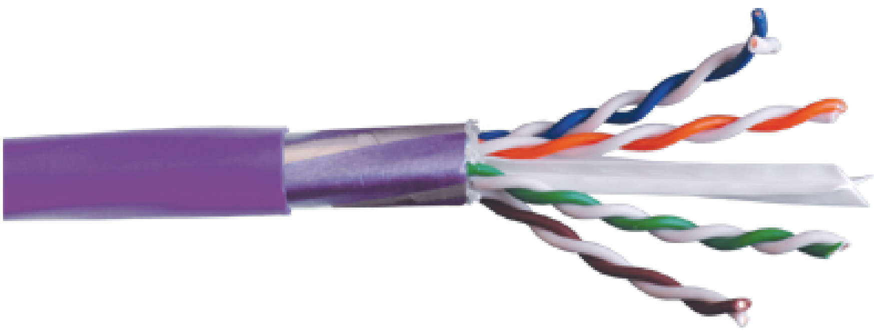
2.7.2 Coaxial Cable

- As name suggest, coaxial cable consists of two conductor that are parallel to each other.
- Like twisted pair cable, it has two conductors but is constructed differently to permit to operate over a wider range of frequencies.
- Coaxial cable (Coax) has a central core conductor of solid or stranded wire (usually

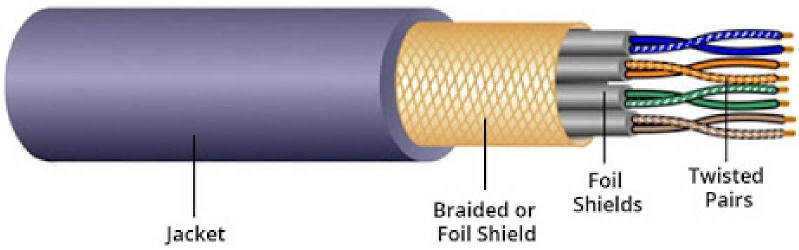


(a) Unshielded Twisted Pair (UTP)

(b) Foil Twisted Pair (FTP)



(c) Screened Twisted Pair (F/UTP)



(d) Shielded/Foil Twisted Pair (S/FTP)

Figure 2.11: Different variations of Twisted Pair

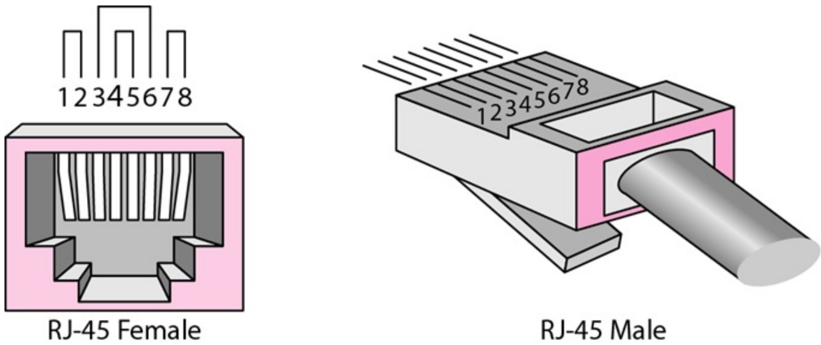


Figure 2.12: UTP connectors

	Frequency Range	Typical Attenuation	Typical Delay	Repeater Spacing
Twisted pair (with loading)	0 to 3.5 kHz	0.2 dB/km @ 1 kHz	50 μs/km	2 km
Twisted pairs (multipair cables)	0 to 1 MHz	0.7 dB/km @ 1 kHz	5 μs/km	2 km
Coaxial cable	0 to 500 MHz	7 dB/km @ 10 MHz	4 μs/km	1 to 9 km
Optical fiber	186 to 370 THz	0.2 to 0.5 dB/km	5 μs/km	40 km

Figure 2.13: Point-to-point transmission characteristic of guided media.

copper) enclosed in an insulating sheath, which is, in turn, encased in an outer conductor of metal foil, braid, or a combination of the two. The whole cable is protected by a plastic cover.

- The construction and shielding of coaxial cable give it a good combination of high bandwidth and excellent noise immunity.

- Two kind of coaxial cable are widely used, 50-ohm cable (**Baseband cable**)and 75-ohm cable (**Broadband cable**). 50-ohm cable is used for digital transmission while 75-ohm is intended for analog transmission and cable television.

Application

Coaxial cable is a versatile transmission medium, used in variety of applications. The most important of these are:

- Television distribution
- Long-distance telephone transmission
- Short-run computer system links
- Local area network

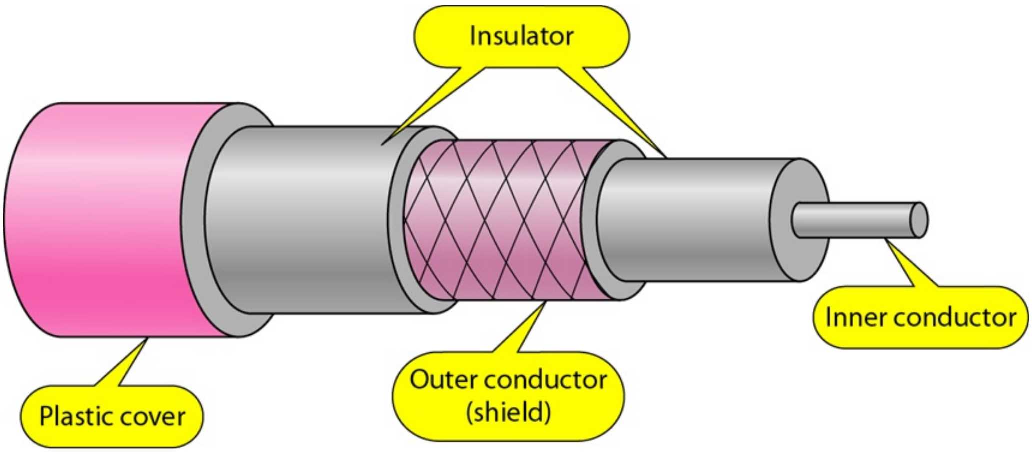


Figure 2.14: Coaxial cable

Transmission Characteristic

- Coaxial cable is used to transmit both analog and digital signals. Analog signal of up to 500 MHz can propagate through it; while repeaters are needed every kilometers for digital signalling.
- It can be used at higher frequencies and data data rates.
- It is less susceptible to interference and cross talk in compared to twisted pair.
- The principal constraints on performance are attenuation, thermal noise, and inter-modulation noise.
- Using frequency division multiplexing (FDM), a coaxial cable can carry over 10,000 voice channels simultaneously.

A coaxial cable's type is designated by radio guide (RG), a composite rating that accounts for many characteristics, including w ire thickness, insulation thickness, and electrical properties. Table 2.15 summarizes the different types of coaxial cable, their ohm values. and applications.

Coaxial Cable Connectors

To connect coaxial cable to device, we need coaxial connectors. The most common type of connector used today is the Bayone-Neil-Conelman(BNC) connector. Three types of connectors: the BNC connector, the BNC T connector, and the BNC terminator. The BNC connector is used to connect the end of the cabe to a device, such as TV set. The BNC T connector is used in Ethernet networks to branch out to a connection to a computer or other device. The BNC terminator is used at the end of the cable to prevent the reflection of the signal.

Type of Cable	Ohm Rating	Application/Comments
RG-6	75 Ohm	Cable television, satellite television, and cable modems
RG-8	50 Ohm	Older Ethernet local area networks; RG-8 is being replaced with RG-58
RG-11	75 Ohm	Broadband Ethernet local area networks and other video applications
RG-58	50 Ohm	Baseband Ethernet local area networks
RG-59	75 Ohm	Closed-circuit television; cable television (but RG-6 is better here)
RG-62	93 Ohm	Interconnection of IBM 3270 computer terminals

Figure 2.15: Coaxial category

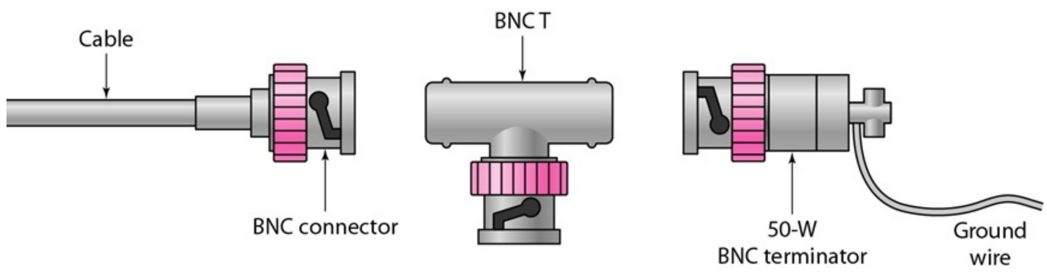


Figure 2.16: BNC connectors for coaxial cable

2.7.3 Fiber-Optic Cable

- Fiber-optic cable a thin (2 to 125 μm), flexible medium, made up of glass or plastic, capable of guiding an optical ray i.e. signal transmit in the form of light.

- The bit are encoded on the fiber as light impulses which spread out in length.

- It has a cylindrical shape and consists of three concentric sections: the *core*, the *cladding*, and the *jacket*.

- The **core** is the innermost section which consists fiber made of glass or plastic. - A typical core has diameter is in the range of 8 to 50 microns.

- Core is surrounded by a **cladding**, a glass or plastic coating.

- Typically cladding has a diameter of 125 micro meter.

- The optical properties (i.e. refractive index) of core and cladding are different and light propagate through the core by process called the **total internal reflection**.
- The outermost layer is the **jacket**, made of plastic or other material and used for protection against moisture, abrasion, crushing, and other environmental dangers.

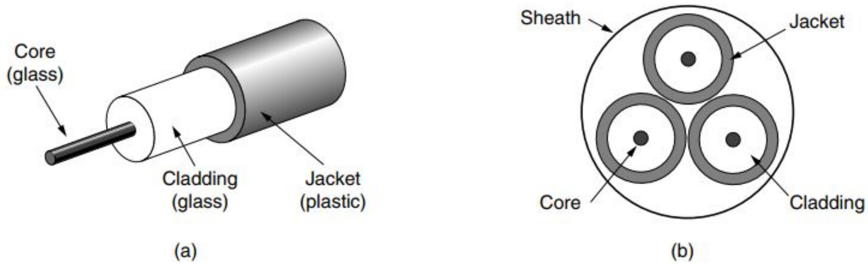
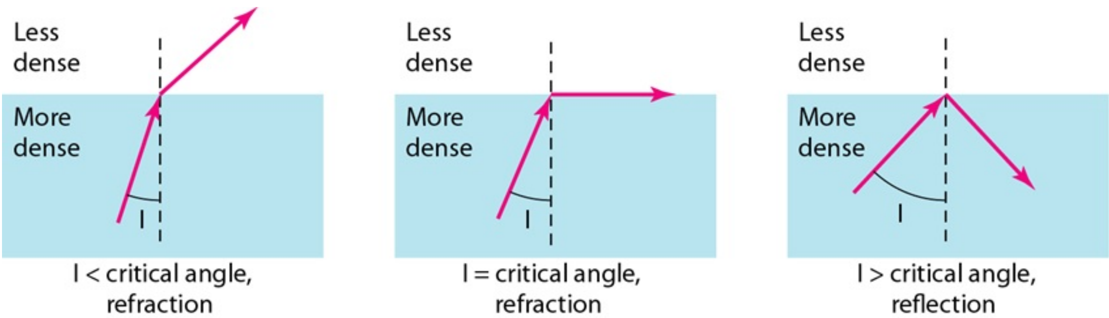


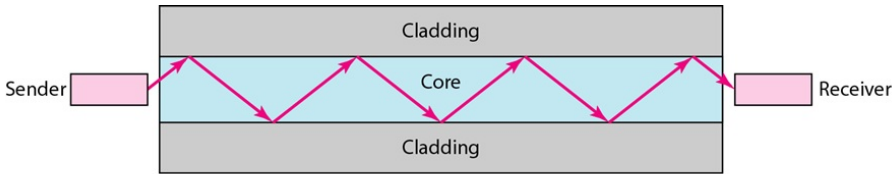
Figure 2.17: (a) Side view of a single fiber. (b) End view of a sheath with three fibers.

2.7.3.1 Principle of fiber-optic

- It is based on the principle of total internal reflection. Optical fiber use reflection to guide through a channel. - A glass or plastic core is surrounded by a cladding of less dense or plastic. The difference in density of the two materials must be such that a beam of light moving through the core is reflected off the cladding instead of being refracted into it as shown in figure 2.18.



(a) Bending of light ray



(b) Propagation of light in fiber-optic through total internal reflection.

Figure 2.18: Principle of fiber-optic cable

2.7.3.2 Advantages of fiber-optic cable

1. **Greater Capacity**: The potential bandwidth, and hence data rate, of optical fiber is immense; data rates of hundreds of Gbps over tens of kilometers have been demonstrated. Compare this to the practical maximum of hundreds of Mbps over about 1 km for coaxial cable and just a few Mbps over 1 km or up to 100 Mbps to 10 Gbps over a few tens of meters for twisted pair.
2. **Smaller size and lighter weight**:Optical fibers are considerably thinner than coaxial cable or bundled twisted-pair cable.
3. **Lower Attenuation**:Attenuation is significantly lower for optical fiber than for coaxial cable or twisted pair.
4. **Electromagnetic Isolation**: Optical fiber systems are not affected by external electromagnetic fields. Thus the system is not vulnerable to interference, impulse noise, or crosstalk. By the same token, fibers do not radiate energy, so there is little interference with other equipment and there is a high degree of security from eavesdropping. In addition, fibers do not leak light and are difficult to tap. These properties give fiber good security against potential wiretappers.
5. **Non-corrosive**: Fiber-optic is non affected by corrosive chemicals in the air, unlike coaxial cable or twisted pair, which are affected by air, water and moisture.
6. **Greater repeater spacing**: Repeater spacing in the tens of kilometers (every 50 km) for optical fiber is common, and repeater spacings of hundreds of kilometers have been demonstrated. Coaxial and twisted-pair systems generally have repeaters every few kilometers (5 km for copper).
7. **Lighter Weight**: Fiber is much lighter than copper. One thousand twisted pairs 1 km long weigh 8000 kg. Two fibers have more capacity and weigh only 100 kg, which reduces the need for expensive mechanical support systems that must be maintained.
8. **No spark if cut**.
9. **No shock hazard**.
10. **Cabling of the future**.

2.7.3.3 Disadvantages of fiber-optic

1. **Installation and Maintenance are Difficult**: Fiber is a less familiar technology requiring skills not all engineers have, and fibers can be damaged easily by being

bent too much. It also require special connections and connectors.

2. **Unidirectional Light Propagation**: Since optical transmission is inherently unidirectional, two-way communication requires either two fibers or two frequency bands on one fiber.
3. **High Cost**:Fiber interfaces cost more than electrical interfaces.

2.7.3.4 Mode of Propagation of Fiber-optic

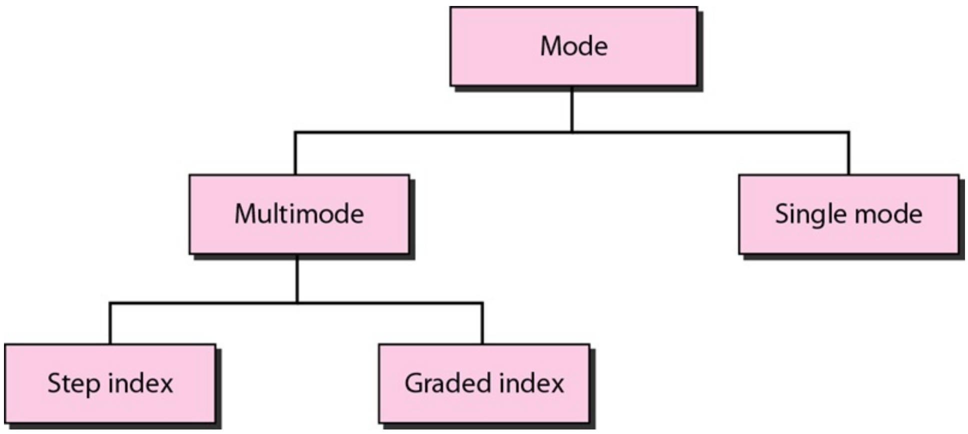


Figure 2.19: Classification of propagation modes of fiber-optic

Multimode

- Multimode fiber typically uses LED emitters that do not create a single coherent light wave. Instead light from an LED enters the multimode fiber at different angels.
i - Because light entering the fiber at different angles takes different amounts of time to travel down the fiber, long runs may result in the pulses becoming blurred on reception end.
- In multimode propagation, multiple beams from a light source move through the core in different paths. How these beams move within the cable depends on the structure of the core. It is of two types:

1. Multimode step index
2. Multimode graded index

Multimode Step Index

- In multimode step index, the density(i.e. refractive index) of the core remains constant form the center to the edge.
- Core diameter ranges from 100 to 970 micro meter.

- - A beam of light moves through this constant density in a straight line until it reached the interface of the core and the cladding. At the cladding, there is an abrupt change due to a lower density; this alters the angle of the beam's motion.
- There are many paths though which light can travels and lights exits in different time duration, the phenomena called **model dispersion**.
- Step index multimode is used for transmission over very short distances.

Multimode graded Index

- In the multimode graded index, the refractive index of core gradually decreases from the center to edge.
- Core diameter: 50 to 85 micro meter.
- Cladding diameter: 125 micro meter.
- Improved version of multimode step index fiber.
- Because the light travels faster through the lower refractive index of refraction, the light at the fiber core travels more slowly than the light nearer the surface.
- Rather than zig-zagging off the clading, light in the core curves helically because of the graded index, reducing its travel distance.
- Therefore, the light rays arrive at the exit point at almost the same time in the core axis, thus reducing the modal dispersion.
- Graded index fibers are often used in local area networks.

Single mode step index

- Single-mode optical fiber carries a single ray of light, usaully emitted form a laser.
- Because the laser light is unidirectional and travels down the center of the fiber almost horizontally, this type of fiber can transmit optical pulses for very long distances.
- Core diameter: 5 to 10 micro meter.
- Cladding diameter: 125micro meter.

2.7.3.5 Light Source of fiber optic

- Two different types of light soruce are used in fiber optic system: the **light emitting diode (LED)** and **the injection laser diode (ILD)**. Both are semiconductor devices that emit a beam of light when a voltage is applied.
- They can be tuned in wavelength by inserting Fabry-perot or Mach-Zehnder interfer-

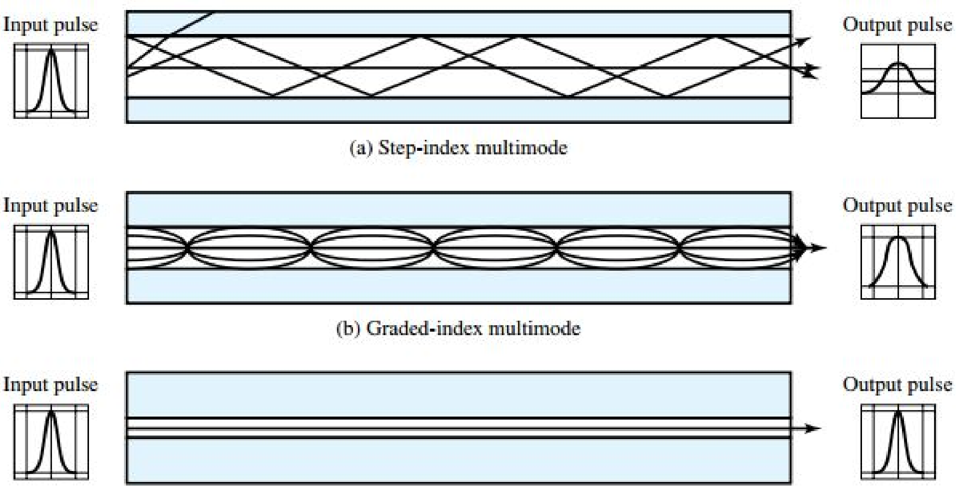


Figure 2.20: Propagation modes of fiber-optic

ometers between the source and the fiber.

Item	LED	LASER
Data Rate	Low	High
Fiber Type	Multi-mode	Multi-mode or single-mode
Distance	Short	Long
Lifetime	Long Life	Short Life
Temperature Sensitivity	Minor	Substantial
Cost	Low Cost	Expensive

Table 2.1: A comparison of semiconductor diodes and LEDs as light sources.

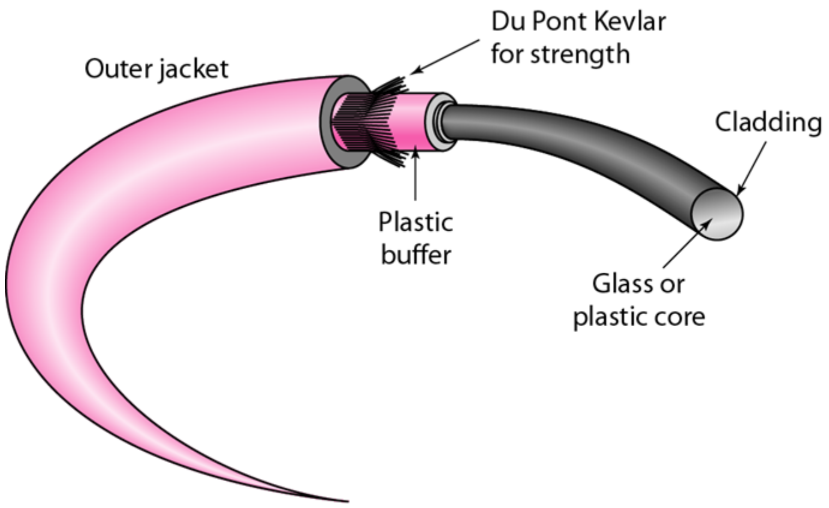


Figure 2.21: Fiber construction

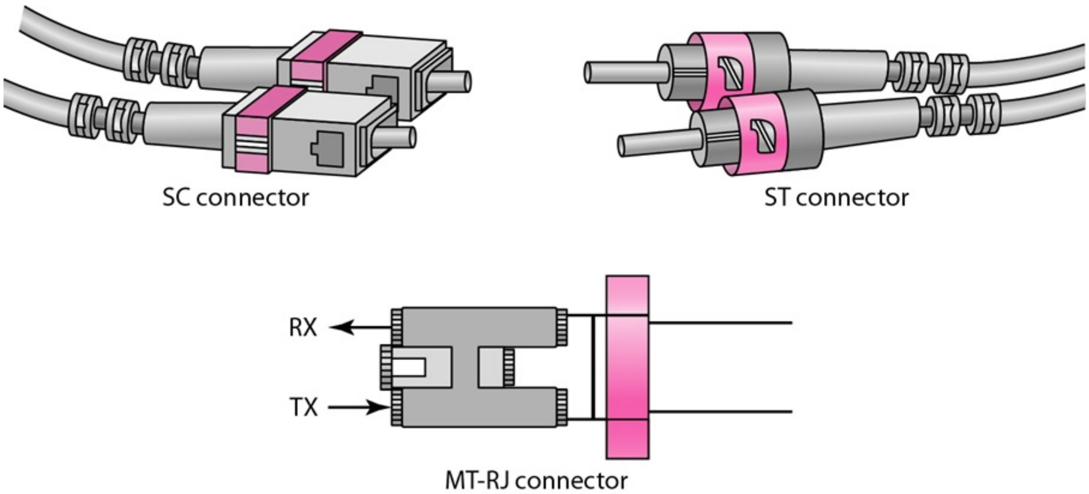


Figure 2.22: Fiber connectors

2.7.3.6 Application of fiber-optics

: Five basic categories of application have become important for optical fiber:

- Long-haul trunks
- Metropolitan trunks
- Rural exchange trunks
- Subscriber loops
- Local area networks

2.8 Unguided Media

- Also called, unbounded media, or wireless media.

- Unguided media transport electromagnetic waves through medium, air, vacuum, or water, without physical connection.

- For unguided media, transmission and reception are achieved by means of antenna. For transmission, the antenna radiates electromagnetic energy into the medium i.e air and for reception, the antenna picks up the electromagnetic wave from the surrounding medium.

- This type of communication that uses unguided media is referred to as a wireless communication. Antenna used are either directional antenna, or omni-directional antenna , depending upon the application area.

Figure 2.24 shows the electromagnetic spectrum, ranging from 3 KHz to 900 THz, used for wireless communication. Electromagnetic wave ranging in frequencies be-

Type of Conducted Medium	Typical Use	Maximum Data Rate	Maximum Transmission Range	Advantages	Disadvantages
Twisted pair Category 1, 3	Telephone systems	<2 Mbps	5–6 kilometers (3–4 miles)	Inexpensive, common	Noise, security, obsolete
Twisted pair Category 5, 5e, 6, 7	LANs	100–1000 Mbps	100 m (328 feet)	Inexpensive, versatile	Noise, security
Thin Coaxial Cable (baseband single channel)	LANs	10 Mbps	100 m (328 feet)	Low noise	Security
Thick Coaxial Cable (broadband multichannel)	LANs, cable TV, long-distance telephone, short-run computer system links	10–100 Mbps	5–6 kilometers (3–4 miles) (at lower data rates)	Low noise, multiple channels	Security
LED Fiber-Optic	Data, video, audio, LANs	Gbps	300 meters (approx. 1000 feet)	Secure, high capacity, low noise	Interface expensive but decreasing in cost
Laser Fiber-Optic	Data, video, audio, LANs, WANs, MANs	100s Gbps	100 kilometers (approx. 60 miles)	Secure, high capacity, very low noise	Interface expensive

Figure 2.23: A summary of the characteristics of conducted media.s

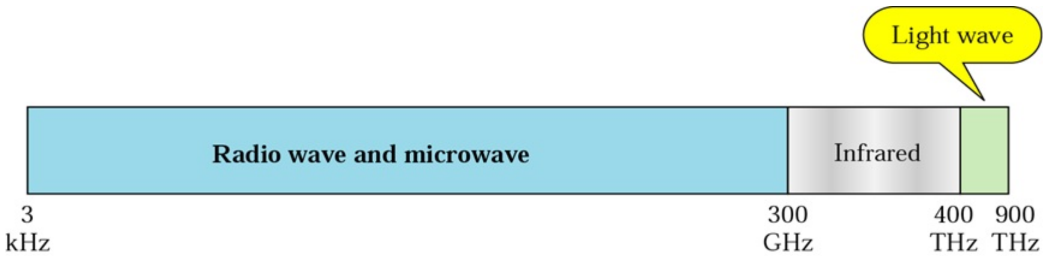


Figure 2.24: Electromagnetic spectrum

tween *3 KHz and 1GHz* are normally called **radio waves**. Electromagnetic waves having frequencies between *1 and 300 GHz* are called **microwaves**. **Infrared signals** with frequencies ranges from *300 GHz to 400 GHz* can be used for short range communication.And **light wave** ranges form *400 THz to 900 THz*.

2.8.1 Wireless Propagation

A signal radiated from antenna can travel along one of three mode:

1. Ground Wave Propagation
2. Sky wave propagation
3. Line-of-Sight (LOS) propagation

Figure 2.26 shows in which frequency range each predominates.

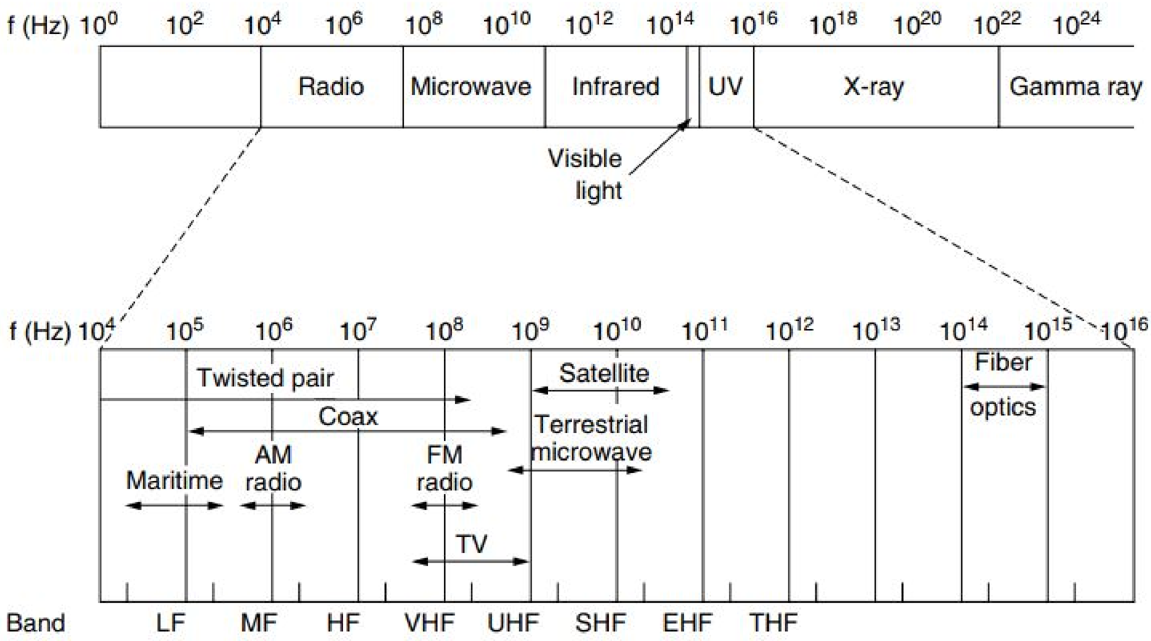


Figure 2.25: The electromagnetic spectrum and its uses for communication

2.8.1.1 Ground Wave Propagation

- Uses radio waves up to 2 MHz.

- Propagates through the lower portion of atmosphere i.e. follow the curvature of the earth.

- Distance covers depends upon the power of the signal, greater power greater distance.

- Example: AM radio.

Reason behind groundwave propagation:

Several factors account for the tendency of electromagnetic wave in this frequency band to follow the earth's curvature. One factor is that the electromagnetic wave induces a current in the earth's surface, the result of which is to slow the wavefront near the earth, causing the wavefront to tilt downward and hence follow the earth's curvature. Another factor is diffraction, which is a phenomenon having to do with the behaviour of electromagnetic waves in the presence of obstacles. Electromagnetic waves in this frequency range are scattered by the atmosphere in such a way that they do not penetrate the upper atmosphere

2.8.1.2 Sky wave propagation

Sky wave propagation is used for amateur radio, CB radio, and international broadcasts such as BBC and Voice of America. With sky wave propagation, a signal from an earth-

Band	Frequency Range	Free-Space Wavelength Range	Propagation Characteristics	Typical Use
ELF (extremely low frequency)	30 to 300 Hz	10,000 to 1000 km	GW	Power line frequencies; used by some home control systems.
VF (voice frequency)	300 to 3000 Hz	1000 to 100 km	GW	Used by the telephone system for analog subscriber lines.
VLF (very low frequency)	3 to 30 kHz	100 to 10 km	GW; low attenuation day and night; high atmospheric noise level	Long-range navigation; submarine communication
LF (low frequency)	30 to 300 kHz	10 to 1 km	GW; slightly less reliable than VLF; absorption in daytime	Long-range navigation; marine communication radio beacons
MF (medium frequency)	300 to 3000 kHz	1,000 to 100 m	GW and night SW; attenuation low at night, high in day; atmospheric noise	Maritime radio; direction finding; AM broadcasting.
HF (high frequency)	3 to 30 MHz	100 to 10 m	SW; quality varies with time of day, season, and frequency.	Amateur radio; international broadcasting, military communication; long-distance aircraft and ship communication
VHF (very high frequency)	30 to 300 MHz	10 to 1 m	LOS; scattering because of temperature inversion; cosmic noise	VHF television; FM broadcast and two-way radio, AM aircraft communication; aircraft navigational aids
UHF (ultra high frequency)	300 to 3000 MHz	100 to 10 cm	LOS; cosmic noise	UHF television; cellular telephone; radar; microwave links; personal communications systems
SHF (super high frequency)	3 to 30 GHz	10 to 1 cm	LOS; rainfall attenuation above 10 GHz; atmospheric attenuation due to oxygen and water vapor	Satellite communication; radar; terrestrial microwave links; wireless local loop
EHF (extremely high frequency)	30 to 300 GHz	10 to 1 mm	LOS; atmospheric attenuation due to oxygen and water vapor	Experimental; wireless local loop
Infrared	300 GHz to 400 THz	1 mm to 770 nm	LOS	Infrared LANs; consumer electronic applications
Visible light	400 THz to 900 THz	770 nm to 330 nm	LOS	Optical communication

Figure 2.26: Frequency bands and their applications

based antenna is reflected from the ionized layer of the upper atmosphere (ionosphere) back down to earth.Although it appears the wave is reflected from the ionosphere as if the ionosphere were a hard reflecting surface, the effect is in fact caused by refraction. Refraction is described subsequently.

A sky wave signal can travel through a number of hops, bouncing back and forth between the ionosphere and the earth's surface. With this propagation mode, a signal can be picked up thousands of kilometers from the transmitter.

2.8.1.3 Line-of-Sight (LOS) propagation

Above 30 MHz, neither ground wave nor sky wave propagation modes operate, and communication must be by line of sight. For satellite communication, a signal above 30 MHz is not reflected by the ionosphere and therefore a signal can be transmitted between an earth station and a satellite. For ground-based communication, the transmitting and receiving antennas must be within an effective line of sight of each other.

2.8.2 Types of unguided transmission media

1. Radio Transmission
2. Microwave Transmission
3. Infrared Transmission

2.8.2.1 Radio Transmission

- **Radio** is a general term used to encompass frequencies in the range of 3 kHz to 300 GHz.

- We are using the informal term **broadcast radio** to cover the VHF and part of the UHF band: 30 MHz to 1 GHz. This range covers FM radio and UHF and VHF television.

- Radio frequency (RF) waves are easy to generate, can travel long distances, and can penetrate buildings easily, so they are widely used for communication, both indoors and outdoors.

Radio waves also are *omnidirectional*, meaning that they travel in all directions from the source, so the transmitter and receiver do not have to be carefully aligned physically.

- Unlike the higher frequencies of the microwave region, broadcast radio waves are less sensitive to attenuation from rainfall. However, the properties of radio waves are frequency dependent. At low frequencies, radio waves pass through obstacles well, but the power falls off sharply with distance from the source - at least as fast as $\frac{1}{r^2}$ in air.

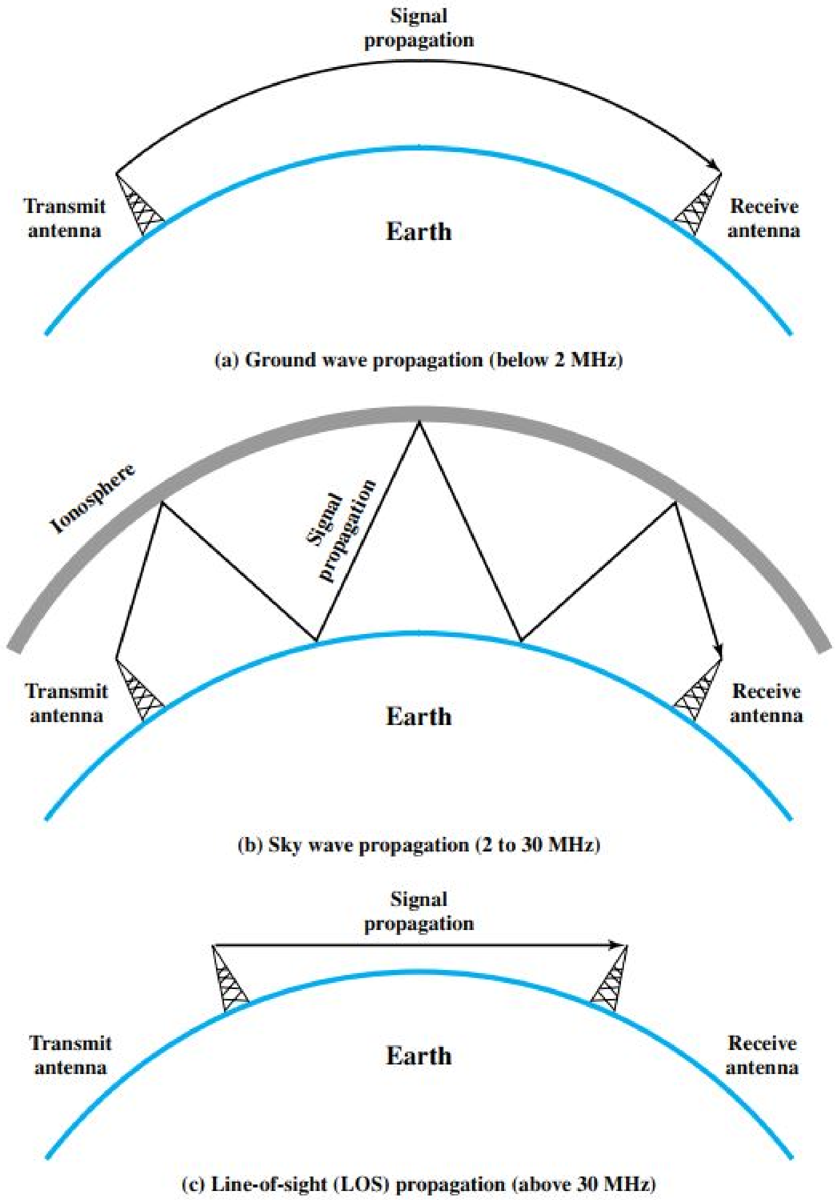


Figure 2.27: Wireless propagation modes

This attenuation is called **path loss**.

- A prime source of impairment for broadcast radio waves is *multipath interference*. Reflection from land, water, and natural or human-made objects can create multiple paths between antennas. This effect is frequently evident when TV reception displays multiple images as an airplane passes by.

2.8.2.2 Microwave Transmission

- Electromagnetic waves having frequencies between 1 and 300 GHz are called microwaves.

- Microwaves are unidirectional, that is, it travels in a straight line; so if the towers are

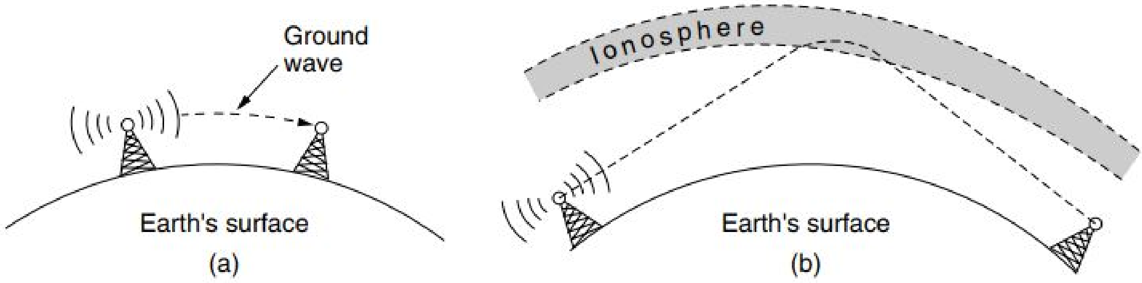


Figure 2.28: (a) In the VLF, LF, and MF bands, radio waves follow the curvature of the earth. (b) In the HF band, they bounce off the ionosphere.

too far apart, the earth will get in the way. Thus, repeaters are needed periodically. The higher the towers are, the farther apart they can be. The distance between repeaters goes up very roughly with the square root of the tower height. For 100-meter-high towers, repeaters can be 80 km apart.
- Unlike low frequency radio waves, microwaves cannot penetrate walls or buildings; so they operate in line-of-sight.
- Parabolic dish antenna and horn antenna are used for this means of transmission.

Application: - The primary use for terrestrial microwave systems is in long-haul telecommunications service (4-GHz to 6-GHz), as an alternative to coaxial cable or optical fiber.
- Commonly used for both voice and television transmission (TV broadcasting: 12-GHz band)
- Another increasingly common use of microwave is for short point-to-point links between buildings (22-GHz band).
- Another important use of microwave is in cellular systems (mobile communication).
- Used in satellite communication.

- Microwaves transmission suffers from multipath fading .
- The higher microwave frequencies are less useful for longer distances because of increased attenuation but are quite adequate for shorter distances. Attenuation is increased with rainfall. The effects of rainfall become especially noticeable above 10 GHz.
- Another source of impairment is interference. With the growing popularity of microwave, transmission areas overlap and interference is always a danger.Thus the as-

signment of frequency bands is strictly regulated.

Band (GHz)	Bandwidth	Data Rate (Mbps)
2	7	12
6	30	90
11	40	135
18	220	274

Table 2.2: Typical digital microwave performance

Table 2.2 shows that The higher the frequency used, the higher the potential bandwidth and therefore the higher the potential data rate.

2.8.2.3 Infrared Transmission

- Infrared signals, with frequencies ranges from 300 GHz to 400 GH,z are widely for short range communication in using LOS. The remote controls used for televisions, VCRs, and stereos all use infrared communication.
- They are relatively directional, cheap, and easy to build but, they do not pass through solid objects/walls. This helps to prevent interference between one system and another. Infrared Transmission in one room cannot be affected by the infrared transmission in another room.
- Transceivers must be within the line of sight of each other either directly or via reflection from a light-colored surface such as the ceiling of a room.
- Furthermore, no goverment license is needed to operate infrared system in contrast to radio system.
- Infrared band, often 400 THz band, has an excellent potential for data transmission. Transfer digital data is possible with a high speed with a very high frequency. There are number of computer devices which are used to send the data through infrared medium e.g. keyboard mice, PCs and printers. There are some manufacturers provide a special part called the IrDA (Infrared Data Assosication) port that allows a wireless keyboard to communicate with a PC.
- However, it cannot be used outside a building because the sun's ray contain infrared waves that can interfere with the communication.
- If long exposure to skin, or eyes, can skins burns, or and eyes cataracts.

2.9 Communications Satellites

- A communication satellite is a microwave repeater (microwave relay station) in the sky.
- It is used to link two or more ground-based microwave transmitter/receivers, known as **earth stations**, or **ground stations**.
- It contains the several **transponders** that amplifies the incoming signal and broadcast into another frequency back to earth. This mode of operation is called **bent pipe**.
- Thus, one Earth Station sends a transmission frequency to the satellite. This is called a **Uplink**. The satellite transponder converts the signal into another frequency and sends it down to the second earth station. This is called a **Downlink**.
- There are two common configurations for satellite communications. They are:

1. Point-to-point link: provides communication between two distance ground stations antennas.
2. Broadcast link: provides communications between one ground-based transmitter and a number of ground-based receivers.

2.9.1 Conditions for effective satellite communication

1. It is generally required that the satellite remain stationary with respect to its position over the earth. Otherwise, it would not be within the line of sight of its earth stations at all times. To remain stationary, the satellite must have a period of rotation equal to the earth's period of rotation. This match occurs at a height of 35,863 km at the equator.
   - Two satellites using the same frequency band, if close enough together, will interfere with each other. To avoid this, current standards require a 4^0 spacing (angular displacement as measured from the earth) in the 4/6-GHz band and a 3^0 spacing at 12/14 GHz. Thus the number of possible satellites is quite limited.
   - Another issue is the presence of the *Van Allen belts*, layers of highly charged particles trapped by the earth's magnetic field. Any satellite flying within them would be destroyed fairly quickly by the particles. These factors lead to three regions in which satellites can be placed safely.

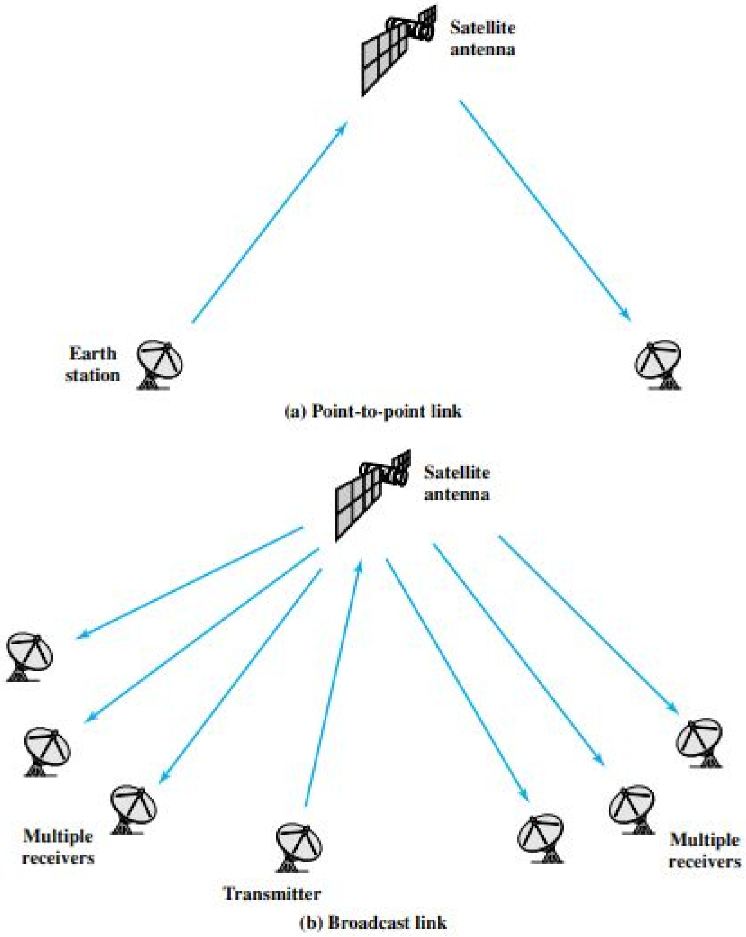


Figure 2.29: Satellite communication configurations

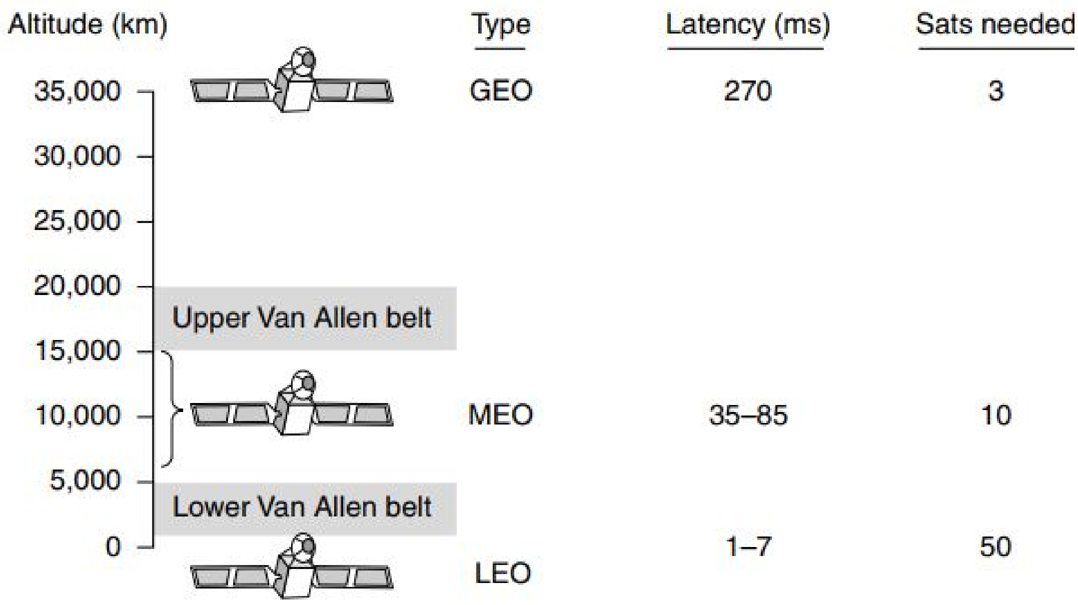


Figure 2.30: Communication satellites and some of their properties, including altitude above the earth, round-trip delay time, and number of satellites needed for global coverage.

2.9.2 Satellite Orbits

:

1. Low Earth Orbit (LEO)
2. Middle Earth Orbit (MEO)
3. Geosynchronous Earth Orbit (GEO)
4. Highly Elliptical Earth Orbit (HEO)

2.9.2.1 Low Earth Orbit (LEO)

- LEO satellites are closest to the Earth.

- Low-Earth-orbit satellites are used primarily for the wireless transfer of electronic mail, worldwide mobile telephone networks, spying, remote sensing, and video conferencing.

2.9.2.2 Middle Earth Orbit (MEO)

- They are found between two Van Allen belts.

- Approximately, there are launched 8000 to 18000 Km height from the earth surface.

- Middle-Earth-orbit satellites are used primarily for **global positioning system** surface navigation applications.

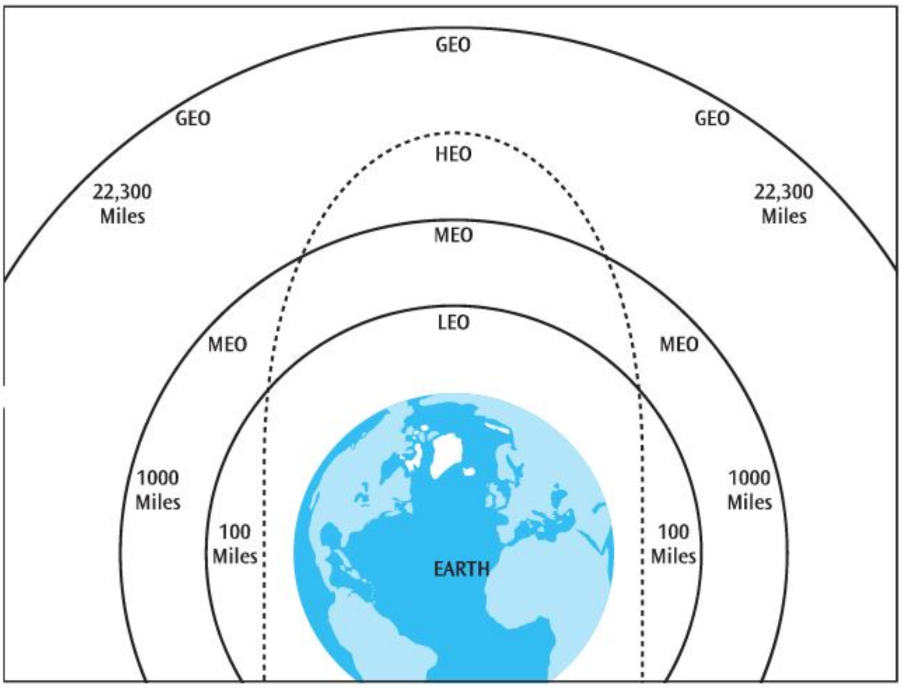


Figure 2.31: Earth and the four earth orbits.

- Global positioning systems are complex, but it is worthwhile to take a brief look at how they work. The global positioning system (GPS) is a system of 24 satellites that were launched by the U.S. Department of Defense and are used for identifying locations on Earth. By triangulating signals from at least four GPS satellites (each of which provides the directional coordinates X, Y, Z, and time), a receiving unit can pinpoint its own current location to within a few yards anywhere on Earth.

2.9.2.3 Geosynchronous Earth Orbit (GEO)

- These satellites are in orbit 35,863 km(nearly 36000 Km) above the earth's surface along the equator.
- Objects in Geostationary orbit revolve around the earth at the same speed as the earth rotates. This means GEO satellites remain in the same position relative to the surface of earth.
- At the Geostationary orbit the satellite covers 42.2 % of the earth's surface.
- Theoretically 3 geostationary satellites provides 100% earth coverage.
- Geosynchronous-Earth-orbit satellites are most commonly used for signal relays for broadcast, cable, and direct television; meteorology; government intelligence operations; and mobile maritime telephony.

- The primary advantage of GEO satellites is their capacity for delivering high-speed, high-quantity bulk transmissions that can cover up to one-third of the surface of the Earth.

Highly Elliptical Orbit (HEO)

HEO satellites are used by governments for spying (via satellite photography) and by scientific agencies for observing celestial bodies.

- An HEO satellite follows an elliptical pattern, as shown in figure 2.32. When the satellite is at its perigee (closest point to the Earth), it takes photographs of the Earth. When the satellite reaches its apogee (farthest point from the Earth), it transmits the data to the ground station. At its apogee, the satellite can also photograph objects in space.

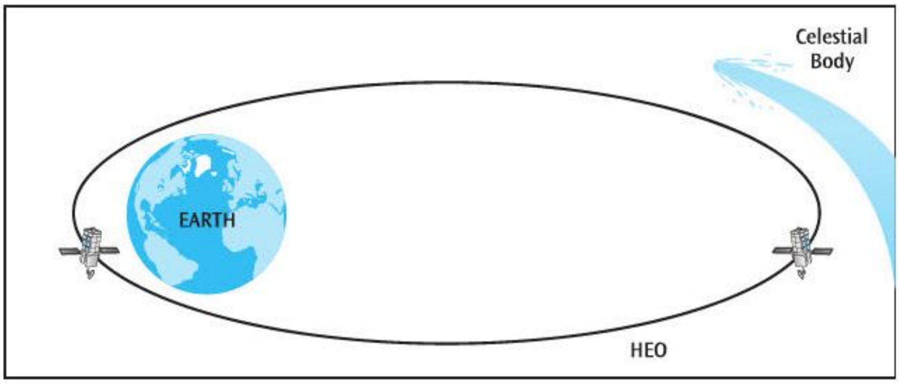


Figure 2.32: Diagram of HEO satellite.

2.9.3 Frequency Band

The optimum frequency range for satellite transmission is in the range 1 to 10 GHz. Below 1 GHz, there is significant noise from natural sources, including galactic, solar, and atmospheric noise, and human made interference from various electronic devices. Above 10 GHz, the signal is severely attenuated by atmospheric absorption and precipitation.

Generally there are three bands widely used in satellite communication as shown in 2.33.

Band (GHz)	Uplink (GHz)	Downlink(GHz)
4/6	5.9 to 6.4	3.7 to 4.2
12/14	14 to 14.5	11.7 to 12.2
20/30	27.5 to 30	17.7 to 20.2

Figure 2.33: Frequency bands.

2.9.4 Radar Bands

In additions, IEEE and NATO have designated the following radar bands (Figure 2.34) used in microwave transmission.

Radar Band	Frequency	Common Use
L	~1–2 GHz	GPS, government use, GSM cell phones
S	2–4 GHz	Weather systems, digital satellite radio system
C	4–8 GHz	Commercial satellite systems
X	~7–12.5 GHz	Some communication satellites, weather
Ku	12–18 GHz	NASA, television station remotes to station
KA	18–40 GHz	Communication satellites
V	50–75 GHz	Not heavily used
W	75–111 GHz	Misc (military, car radar systems)

Figure 2.34: Radar bands.

Note:

Note the overlap between the two naming conventions. The SHF radio band (3- 30 GHz) shares the same frequencies as the L and S radar bands (1- 2 GHz and 2-4 GHz, respectively).

2.9.5 Application of satellites

Among the most important applications for satellites:

- **Television distribution**: Due to broadcast nature, the direct broadcast satellite (DBS) is used these days, in which satellite video signals are transmitted directly to the home user. The decreasing cost and size of receiving antennas have made DBS economically feasible.
- **Long-distance telephone transmission**: Satellite transmission is also used for point-to-point trunks between telephone exchange offices in public telephone networks.

- **Private business networks**: There are a number of business data applications for satellite. The satellite provider can divide the total capacity into a number of channels and lease these channels to individual business users. A user equipped with the antennas at a number of sites can use a satellite channel for a private network. Traditionally, such applications have been quite expensive and limited to larger organizations with high-volume requirements. A recent development is the very small aperture terminal (VSAT) system, which provides a low-cost alternative.
- Global positioning

2.9.6 Advantages of Satellites

The advantages of satellite communication over terrestrial communication are:

- The coverage area of a satellite greatly exceeds that of a terrestrial system.
- Transmission cost of a satellite is independent of the distance from the center of the coverage area.
- Satellite to satellite communication is very precise.
- Higher bandwidth are available for use.

2.9.7 Disadvantages of Satellite

- Launching satellites into orbit is costly.
- Satellite bandwidth is being congested.

2.10 Multiplexing

- 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 a technique in which several message signals are combined into a composite signal for transmission over a common channel.
- In order to transmit a number of these signals over the same channel, the signals must be kept apart so that they do not interfere with each other, and hence they can be separated easily at the receiver.
- A device that performs the multiplexing is called a **multiplexer (MUX)**, and a device that performs the reverse process is called a **demultiplexer (DEMUX or DMX)**.

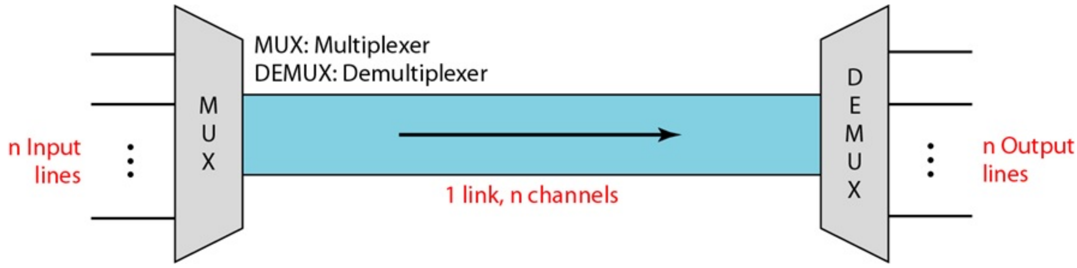


Figure 2.35: Multiplexer and demultiplexer

Types of Multiplexing

There are four basic type of multiplexing techniques shown in figure 2.36. Frequency-division multiplexing and wavelength-division multiplexing are designed for analog signals, while time-division multiplexing and code division multiplexing for digital signals.

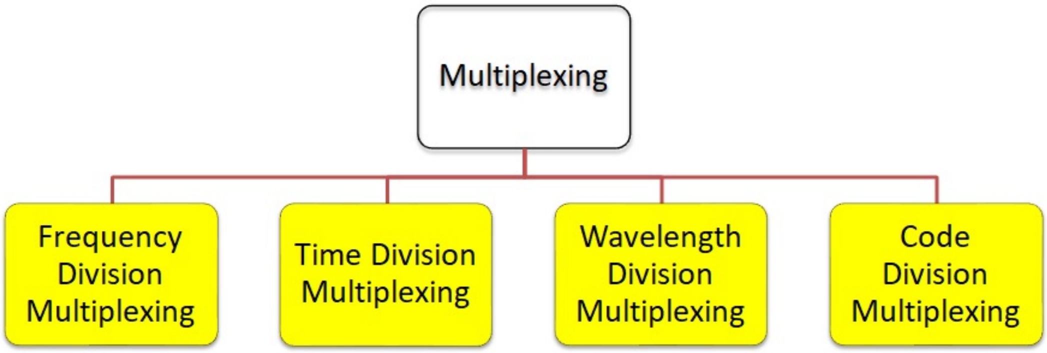


Figure 2.36: Categories of multiplexing

2.10.1 Frequency Division Multiplexing (FDM)

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

- FDM is an analog technique that can be applied when the bandwidth of a link (in hertz) is greater than the combined bandwidths of the signals to be transmitted.

- To allow multiple users to share a single medium, FDM assigns each user a separate **channel**. A channel is an assigned set of frequencies that is used to transmit the user's signal.

- In FDM, each signals is modulated onto a different carrier frequency and the result-

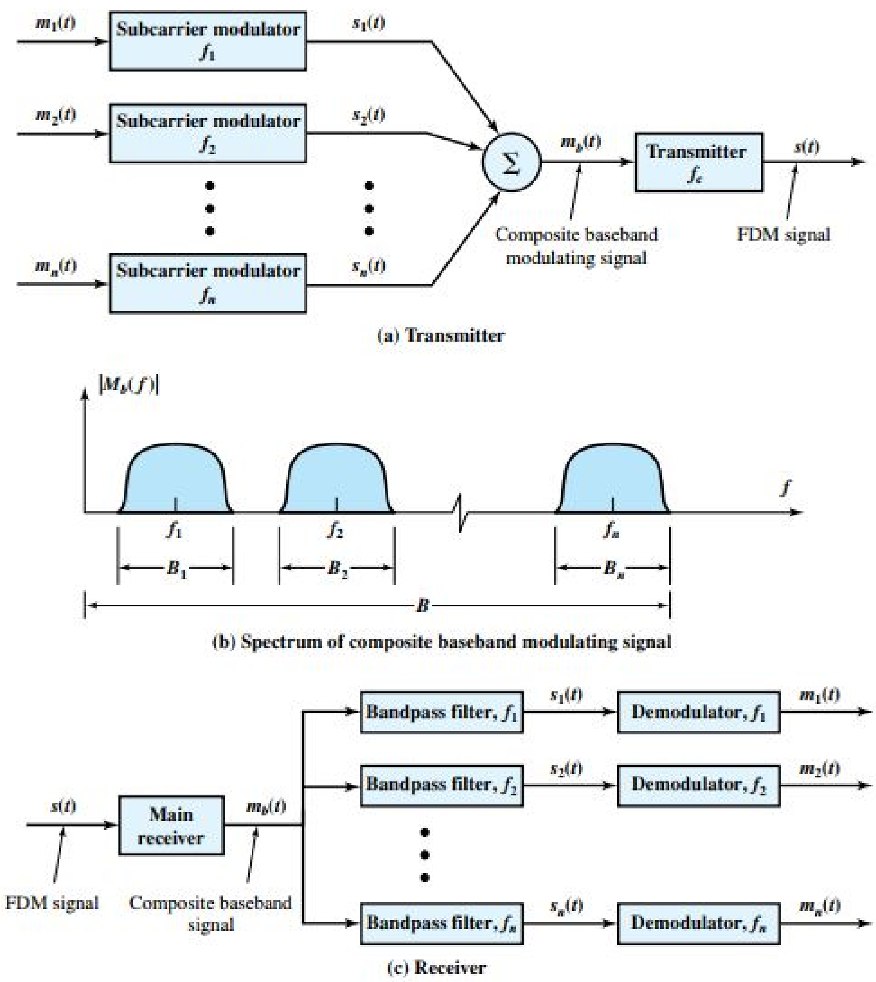


Figure 2.37: FDM system

ing modulated signals are then combined into a single composite signal that is sent out over a media link that has enough bandwidth to accommodate it. The composite signal transmitted across the medium is analog.

- To prevent interference, the channels are separated by **guard bands**, which are unused portion of the spectrum.

- Example: Radio and TV Broadcasting, Cable Television, Cell Phone System (1st generation).

2.10.1.1 Applications of FDM

- A very common application of FDM is AM and FM radio broadcasting. Radio uses the air as the transmission medium. A special band from 530 to 1700 kHz is assigned to AM radio. All radio stations need to share this band. Each AM station needs 10 kHz of bandwidth. Each station uses a different carrier frequency, which means it is shifting its

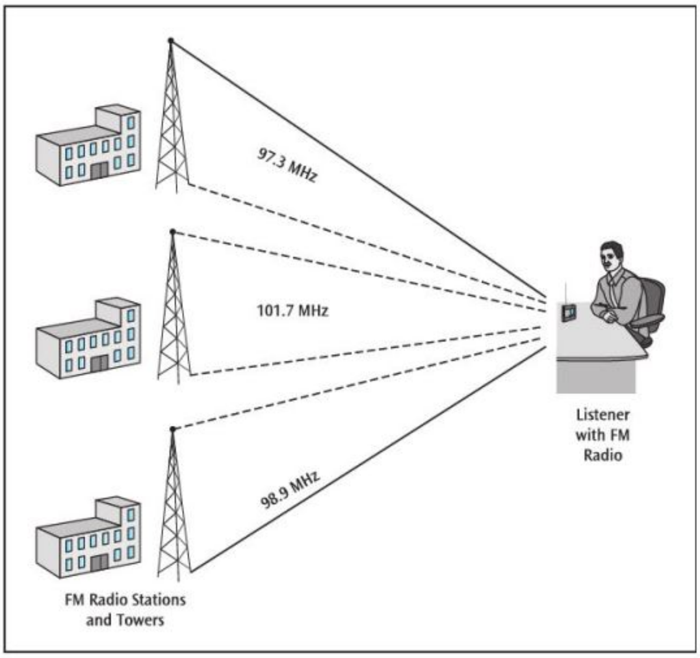
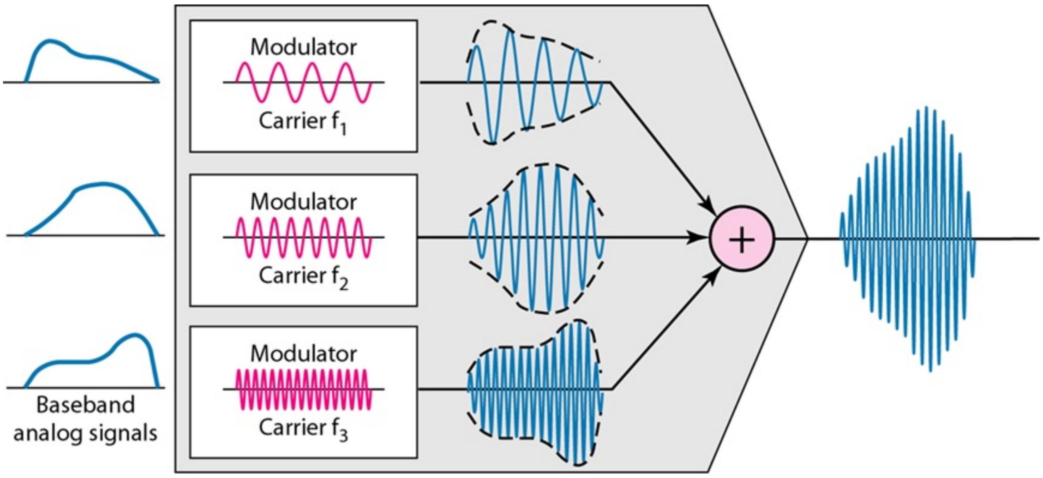


Figure 2.38: FDM example

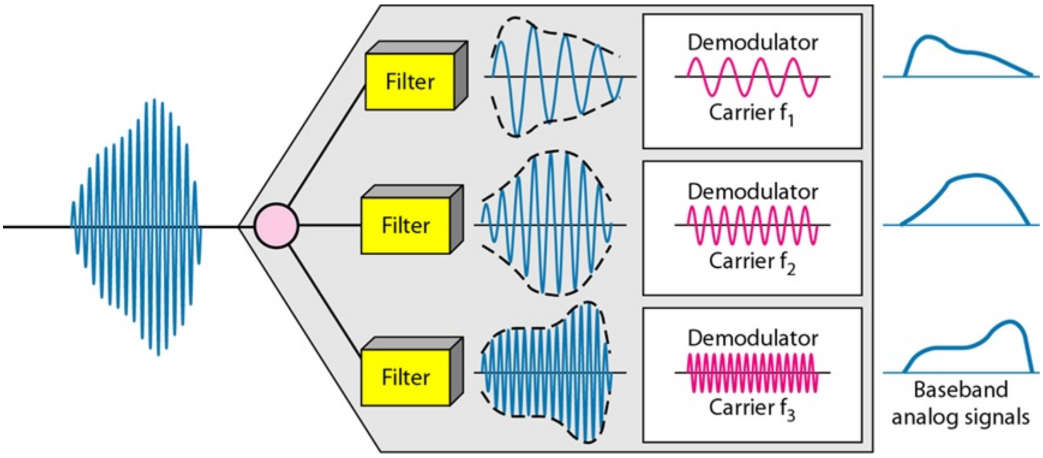
signal and multiplexing. The signal that goes to the air is a combination of signals. A receiver receives all these signals, but filters (by tuning) only the one which is desired. Without multiplexing, only one AM station could broadcast to the common link, the air.
- The situation is similar in FM broadcasting. However, FM has a wider band of 88 to 108 MHz because each station needs a bandwidth of 200 kHz.
- Another common use of FDM is in television broadcasting. Each TV channel has its own bandwidth of 6 MHz.
- The first generation of cellular telephones also uses FDM. Each user is assigned two 30-kHz channels, one for sending voice and the other for receiving. The voice signal, which has a bandwidth of 3 kHz (from 300 to 3300 Hz), is modulated by using FM.Remember that an FM signal has a bandwidth 10 times that of the modulating signal, which means each channel has 30 kHz (10×3) of bandwidth. Therefore, each user is given, by the base station, a 60-kHz bandwidth in a range available at the time of the call.

2.10.1.2 Two problems with FDM

- FDM suffers from cross talk if the spectra of adjacent component signals overlap significantly.
- Another potential problem is intermodulation noise. On a long link, the non-linear



(a) FDM multilplexing process



(b) FDM demultilplexing process

Figure 2.39: FDM multiplexing and demultiplexing process example.

effects of amplifiers on a signal in one channel could produce frequency components in other channels.

2.10.2 Wavelength Division Multiplexing

- WDM is a technology in which multiple beams of lights at different wavelength are transmitted on the optical fiber. That is, various light waves from different source are combined to form a composite light signal that is transmitted across the channel to the receiver.

- It is a basically a analog form of frequency division multiplexing.

- With WDM, the light streaming through the fiber consists of many colors, or wavelengths, each carrying a separate channel of data.

- A single fiber-optic line can support simultaneous transmission speeds such as 51.84

Mbps, 155.52 Mbps, 622.08 Mbps, and 2.488 Gbps.

- In addition, a single fiber-optic line can support a number of different transmission formats such as SONET, Asynchronous Transfer Mode (ATM), and others, in various combinations (Figure 2.41).

- When the number of channels is very large and the wavelengths are spaced close together, the system is referred to as **DWDM (Dense WDM)**.

- One less expensive variation on dense wavelength division multiplexing is coarse wavelength division multiplexing. **Coarse wavelength division multiplexing (CWDM)** is a less expensive technology because it is designed for short-distance connections and has only a few channels, with a greater space between channels.

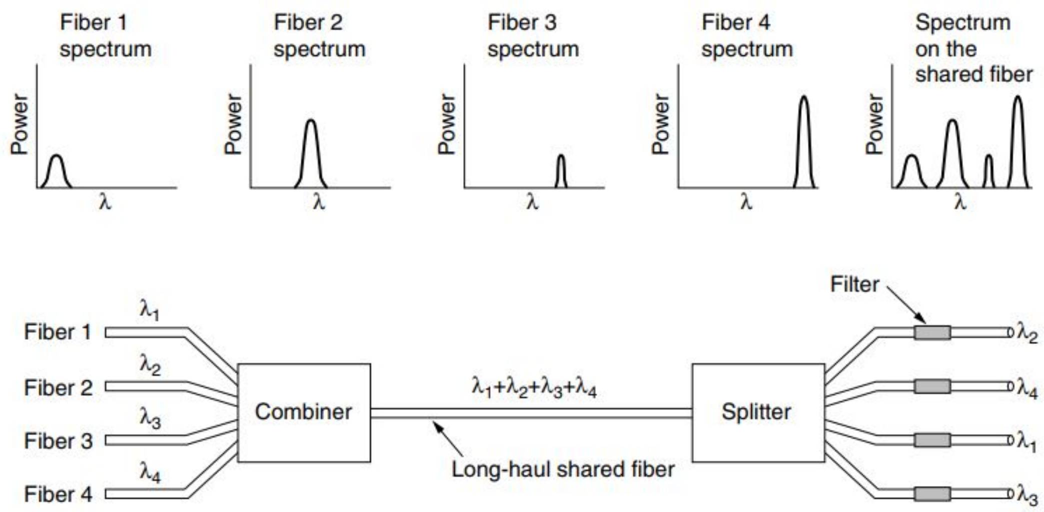


Figure 2.40: Wavelength division multiplexing

2.10.3 Time Division Multiplexing

- All senders use the same frequency but at different point in time.

- Total time available in the channel is divided between several users.

- Each user is allocated a particular time interval called **time slot** or slice (in a round-robin fashion).

- TDM is a digital technology in which incoming signals are divided into equal fixed-length time slots and each user can transmit data within the provided time slot only.

- Digital signals are divided in **frames**, equivalent to time slot .

- After multiplexing, these signals are transmitted over a shared medium and reassem-

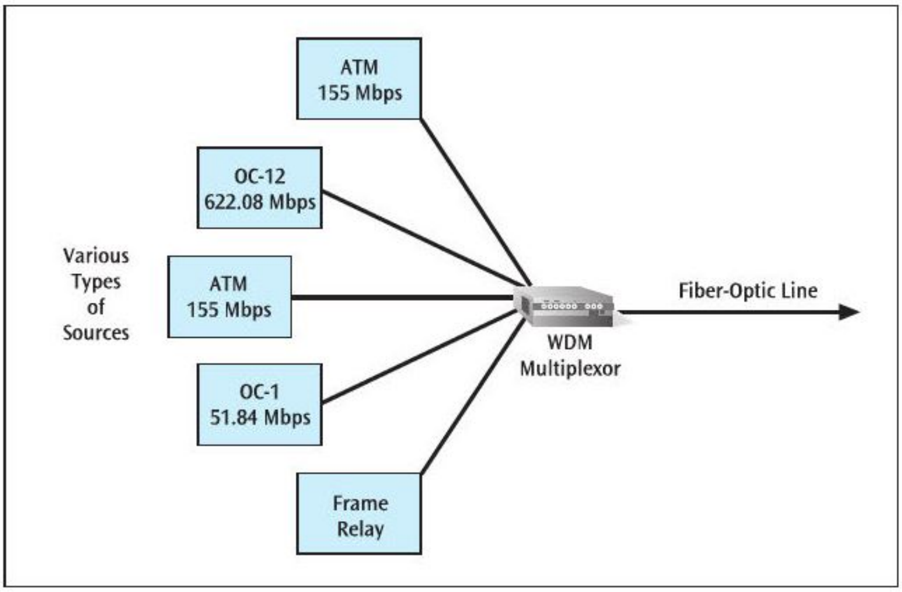


Figure 2.41: Wavelength division multiplexing

bled into their original format after de-multiplexing.
- Two types of TDM:

1. Synchronous Time Division Multiplexing
2. Statistical Time Division Multiplexing

2.10.3.1 Synchronous Time Division Multiplexing

- In synchronous TDM, a round of data units from each input connection is collected into a frame.
- If we have n connections, a frame is divided into *n* time slots and one slot is allocated for each unit, one for each input line.
- If the duration of the input unit is *T*, the duration of each slot is *T/n* and the duration of each frame if *T*.

- Time slots are grouped into frames.
- A frame consists of one complete cycle of time slots, with one slot dedicated to each sending device.
- If a system with *n* input lines, each frame has *n* slots, with each slot allocated to carrying data from specified input line.

- Synchronous TDM is called synchronous not because synchronous transmission is

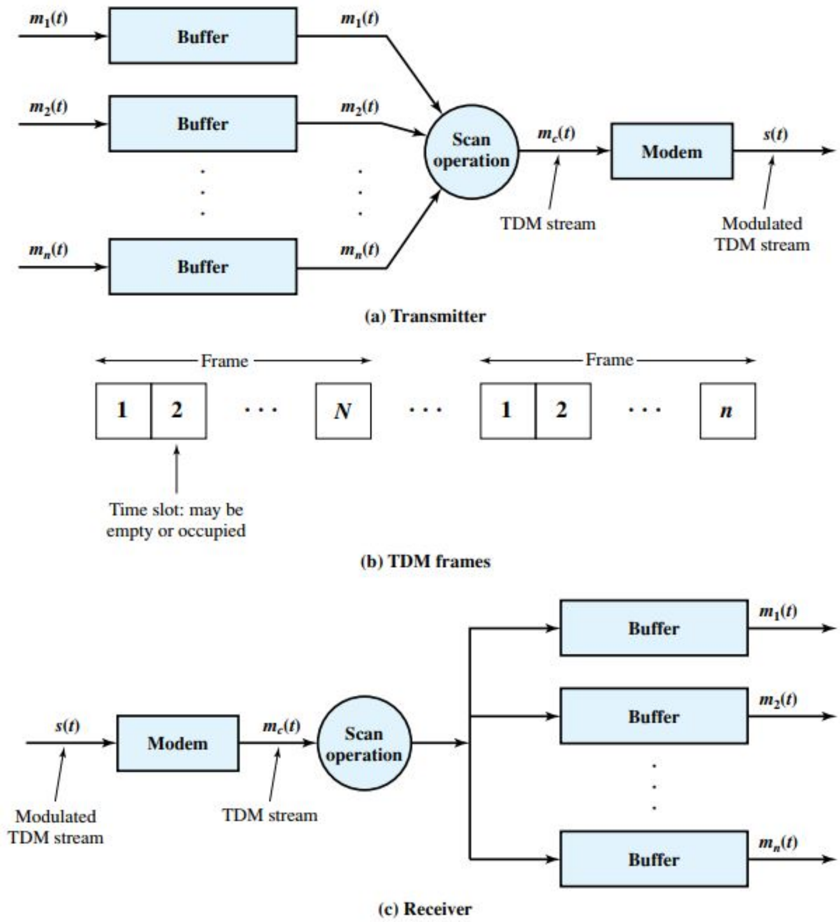


Figure 2.42: Synchronous TDM system

used, but because the time slots are preassigned to sources and fixed. The time slots for each source are transmitted whether or not the source has data to send (which is the major draw back of Synchronous TDM).

- Two types of synchronous time division multiplexing that are popular today are *T-1 multiplexing* and *SONET/SDH*.

Empty Slot

- Synchronous TDM is not as efficient as it could be. If a source does not have data to send, the corresponding slot in the output frame is empty.
- Figure 2.44: The first output frame has three slots filled, the second frame has two slots filled, and the third frame has three slots filled. No frame is full.

Interleaving

TDM can be visualized as two fast-rotating switches, one on the multiplexing side and the other on the demultiplexing side. The switches are synchronized and rotate at the

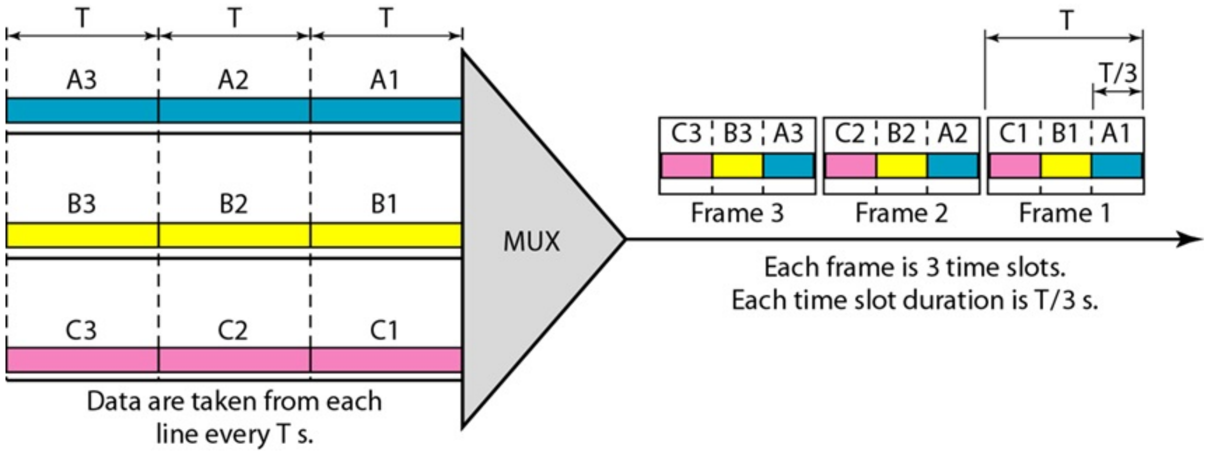


Figure 2.43: Synchronous TDM

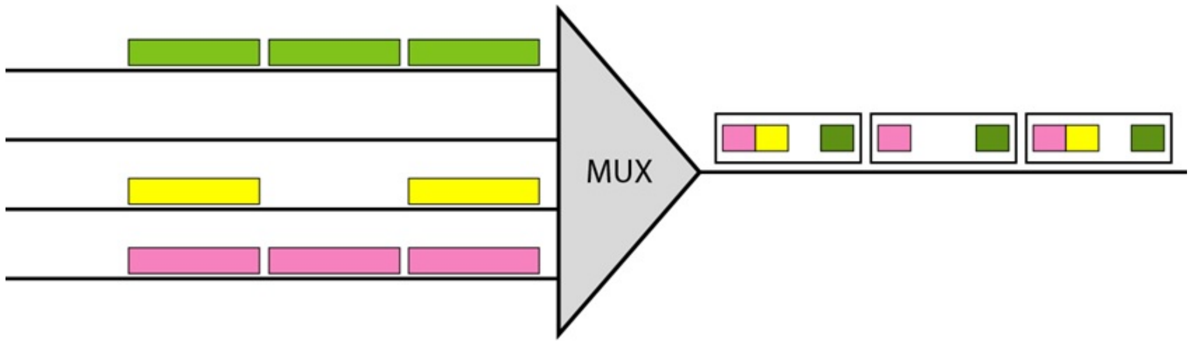


Figure 2.44: Empty slots.

same speed, but in opposite directions. On the multiplexing side, as the switch opens in front of a connection, that connection has the opportunity to send a unit onto the path. This process is called **interleaving**.

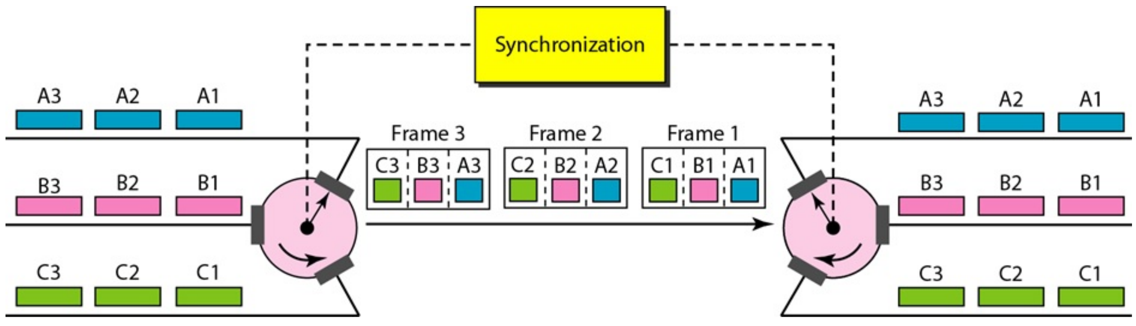


Figure 2.45: Interleaving.

Frame Synchronization

The implementation of TDM is not as simple as that of FDM. Synchronization between the multiplexer and demultiplexer is a major issue. If the multiplexer and the demultiplexer are not synchronized, a bit belonging to one channel may be received by the wrong channel. For this reason, one or more synchronization bits are usually added to the beginning of each frame. These bits, called **framing bits** or **synchronization bits**, follow a pattern, frame to frame, that allows the demultiplexer to synchronize with the incoming stream so that it can separate the time slots accurately. In most cases, this synchronization information consists of 1 bit per frame, alternating between 0 and 1. (Figure 2.46).

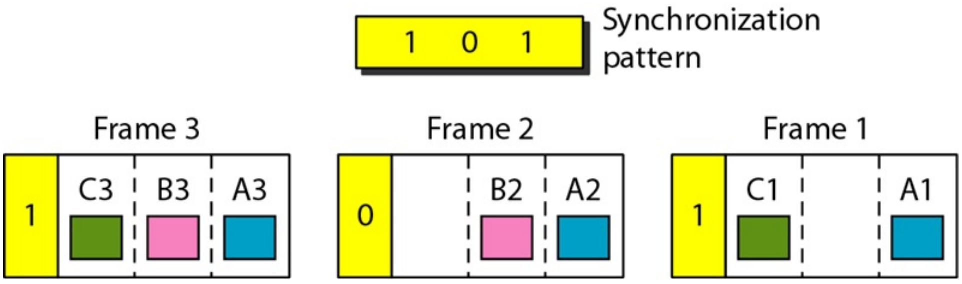


Figure 2.46: Frame synchronization.

2.10.3.2 Statistical Time Division Multiplexing

- Also, referred as asynchronous time division multiplexing.
- Statistical TDM dynamically allocates the time slots to the user on demand and do not transmit empty time slot like in synchronous TDM.
- To transmit data only from active users, the multiplex creates a more complex frame that contains data only from those input sources that have something to send. As well as, frame contains the address information to assure proper delivery. Thus, there is more overhead per slot for statistical TDM because each slot carries an address as well as data.
- In statistical multiplexing, the number of slots in each frame is less than the number of input lines. That is, if statistical multiplexer has n I/O lines, but only k, where $k<n$, time slots are available on the TDM frame.
- Because statistical TDM takes advantage of the fact that the attached devices are not all transmitting all of the time, the data rate on the multiplexed line is less than the sum of the data rates of the attached devices. Thus, a statistical multiplexer can use a lower data rate (Bandwidth) to support as many devices as a synchronous multiplexer. Alternatively, if a statistical multiplexer and a synchronous multiplexer both use a link of the same data rate, the statistical multiplexer can support more devices.

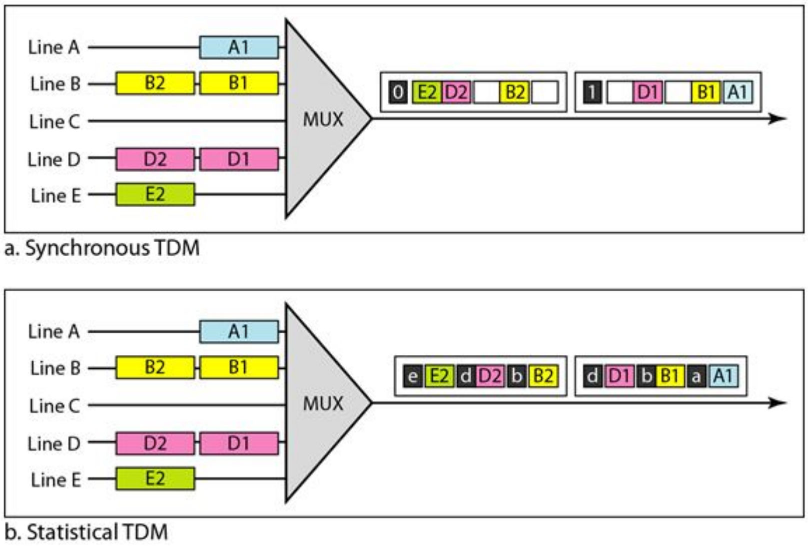


Figure 2.47: Time slot comparison.

Figure 2.47 shows a synchronous and a statistical TDM example. In the former, some slots are empty because the corresponding line does not have data to send. In the latter, however, no slot is left empty as long as there are data to be sent by any input line. An output slot in synchronous TDM is totally occupied by data; in statistical TDM, a slot needs to carry data as well as the address of the destination. In synchronous TDM, there is no need for addressing; synchronization and preassigned relationships between the inputs and outputs serve as an address.

Statistical time division multiplexing is a good choice for connecting a number of lower-speed devices that do not transmit data on a continuous basis to a remote computer system. Examples of these systems include data-entry systems,point-of-sale systems, and many other commercial applications in which users enter data at computer terminals.

2.10.4 Code Division Multiplexing

- **CDM (Code Division Multiplexing)** is a form of **spread spectrum** communication in which a narrowband signal is spread out over a wider frequency band. It is commonly called code division multiple access. (CDMA).

- Code division multiplexing allows multiple users to share same frequency band by assigning a unique digital code to user.

- It is a relatively new technology that has been used extensively by both the military and cellular telephone companies.

- In CDMA, each bit time is subdivided into m short intervals called **chips**. Typically, there are 64 or 128 chips per bit, but in the example given here we will use 8 chips/bit for simplicity. Each station is assigned a unique *m*-bit code called a **chip sequence**.

- To transmit a 1 bit, a station sends its chip sequence. To transmit a 0 bit, it sends the negation of its chip sequence. No other patterns are permitted. Thus, for m = 8, if station A is assigned the chip sequence (-1 -1 -1 +1 +1 -1 +1 +1), it is send a 1 bit by transmitting the chip sequence and a 0 by transmitting (+1 +1 +1 -1- +1 -1 -1).
- All chip sequences are pairwise **orthogonal**. **Walsh codes** are used to generate such chip sequence.

Example: Let us say mobile user A transmits a binary 1, mobile user B transmit a binary 0, and mobile user C transmits a binary 1. Figure 2.48 shows what actually transmitted is and how the data is received by the receiver.

Mobile user A sends a binary 1 (11110000), or + + + + − − − −
Mobile user B sends a binary 0 (01010101), or − + − + − + − +
Mobile user C sends a binary 1 (00110011), or − − + + − − + +

The receiver receives all three signals at the same time and adds the voltages as shown below:

	+	+	+	+	−	−	−	−
	−	+	−	+	−	+	−	+
	−	−	+	+	−	−	+	+
Sums:	−1	+1	+1	+3	−3	−1	−1	+1

Then, to determine what each mobile user transmitted, the receiver multiplies the sums by the original code of each mobile user, expressed as + and − values, and then takes the sum of those products:

Sums:	−1	+1	+1	+3	−3	−1	−1	+1
Mobile user A's code:	+1	+1	+1	+1	−1	−1	−1	−1
Products:	−1	+1	+1	+3	+3	+1	+1	−1
Sum of Products:	+8							

Because the Sum of Products is near +8 in this 8-bit example, the value transmitted must have been a binary 1. In the real world, with the 64-bit system, the Sum of Products would have to be near 64. If the Sum of Products were near −8 (or near −64 using real codes), the value transmitted would have been a binary 0.

Figure 2.48: CDMA example

2.10.5 Discrete Multitone (DMT)

- Discrete Multitone is a multiplexing technique commonly found in DSL systems.
- DSL is a technology that allows a high-speed data signal to traverse a standard copper-based telephone line which highest transmission speed we can achieve with a standard dial-up telephone line is only 56 kbps. Using DMT, DSL can achieve speeds of millions bit per second. However,it suffers greatly from too much noise.
- DMT essentially combines hundreds of different signals, or subchannels, into one stream; unlike the previously discussed multiplexing techniques, however, DMT is designed such that all these subchannels are destined for a single user.
- The real power of DMT is the fact that each of the subchannels can perform its own **quadrature amplitude modulation (QAM)**.
- Present ADSL/DMT designs employ 256 downstream subchannels. In theory,with each 4-kHz subchannel carrying 60 kbps, it would be possible to transmit at a rate of 15.36 Mbps. In practice, transmission impairments prevent attainment of this data rate. Current implementations operate at from 1.5 to 9 Mbps, depending online distance and quality.

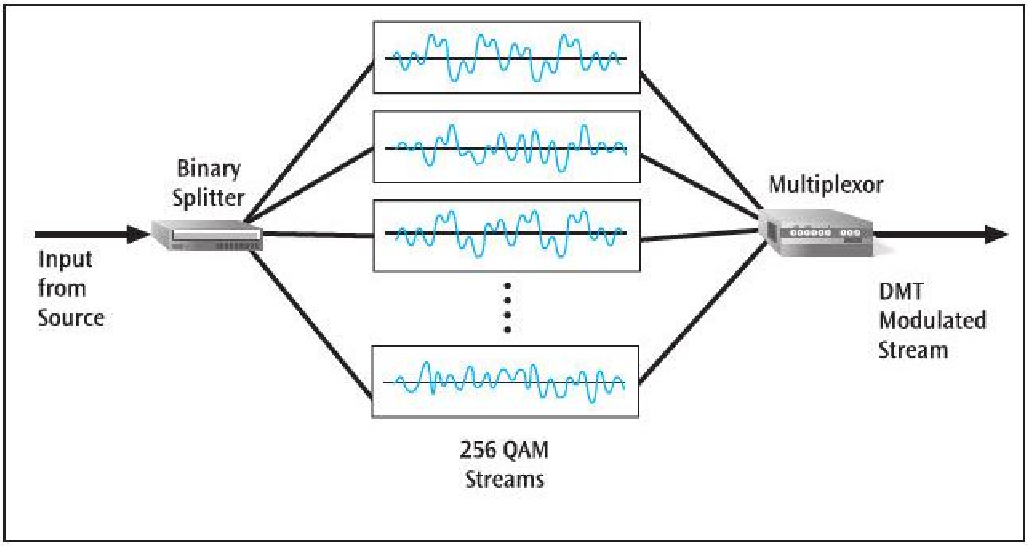


Figure 2.49: 256 quadrature amplitude modulated streams combined into one DMT signal for DSL service.

2.10.6 Additional Multiplexing Techniques

1. Optical Spatial Division Multiplexing
2. Orthogonal Frequency Division Multiplexing

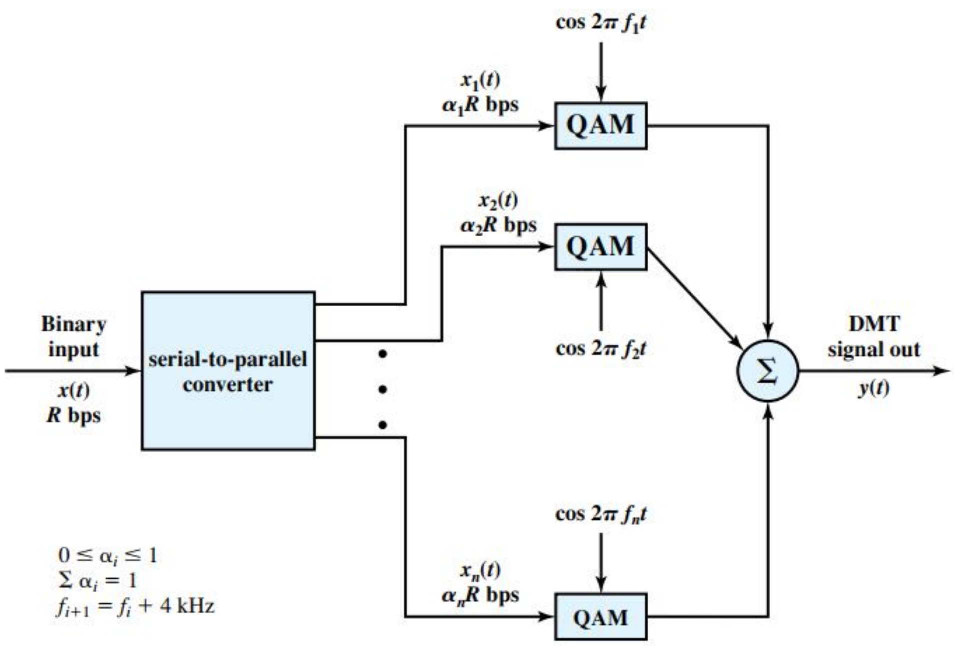


Figure 2.50: DMT transmitter.

3. Optical Time Division Multiplexing

2.11 Switching

- Switching is the process of forwarding data/packets coming in one node to a another till they reach the intended destination.
- Switching is done through a switched network. A switched network consists of a series of interlinked nodes, called **switches**. Switches are devices capable of creating temporary connections between two or more devices linked to the switch.

- Node-station links are generally dedicated point-to-point links. Node-node links are usually multiplexed, using either frequency division multiplexing (FDM) or time division multiplexing (TDM).
- To enhance the reliability of the network, there can be more than one possible path through the network for each pair of station.

Depending on the way the nodes switch information from one link to another on the way from source to destination, switching technology is classified as shown in figure 2.52.

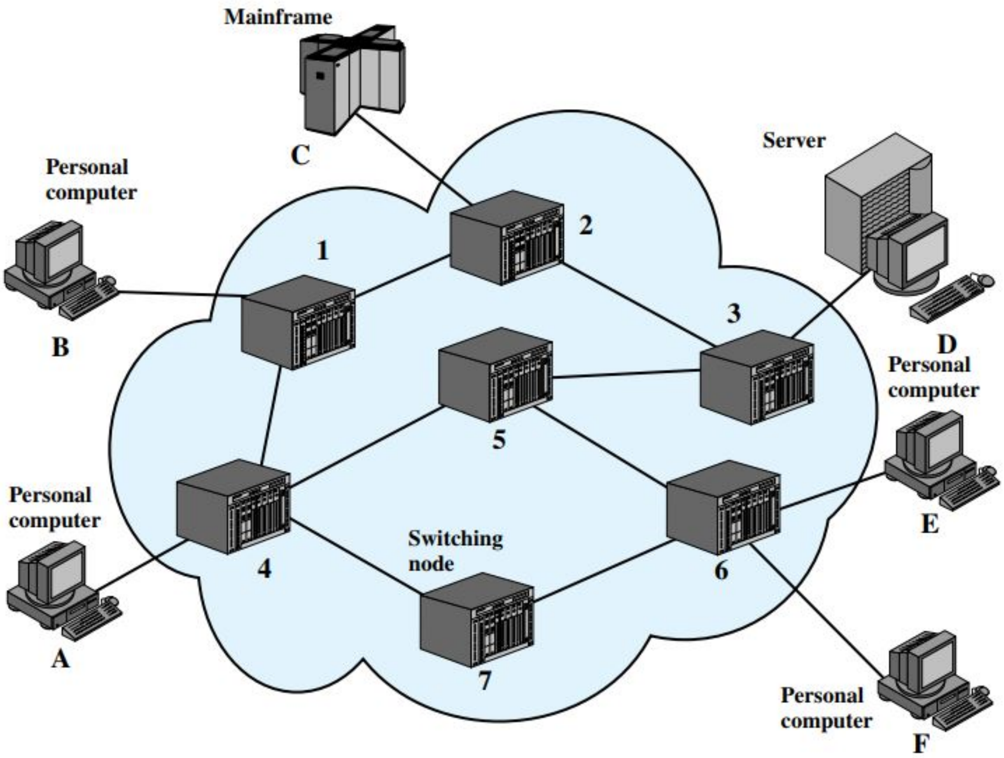


Figure 2.51: A switched network.

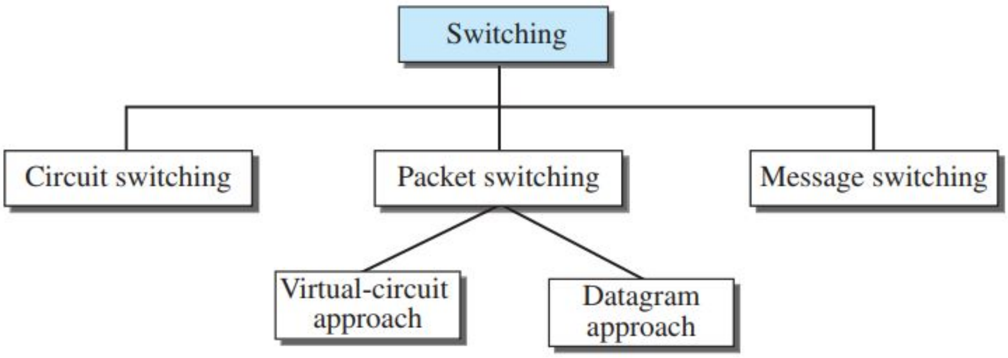


Figure 2.52: A classification of switched networks.

2.11.1 Circuit Switching

- In circuit switching network, two station communicated through a **dedicated path** between them.

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

section.
- Communication via circuit switching involves three phases:

1. Connection Establishment Phase (Setup Phase)
2. Data transfer Phase
3. Connection Termination Phase (Teardown Phase)

- Note the connection has to be established before data transmission begins. In addition, the resources has to be reserved during the setup phase; the resources remain dedicated for the entire duration of data transfer until the teardown phase.

Circuit switching can use either of two technologies:

1. Space Division Switching
   (a) Crossbar Switch
   (b) Multistage Switch
2. Time Division Switching

2.11.1.1 Applications of Circuit Switching

- Circuit switching was developed to handle voice traffic but is now also used for data traffic. The best-known example of a circuit-switching network is the public telephone network (Figure 2.57).
- Another well-known application of circuit switching is the private branch exchange (PBX), used to interconnect telephones within a building or office.
- Circuit switching is also used in private networks. Typically, such a network is set up by a corporation or other large organization to interconnect its various sites.
- A final common example of the application of circuit switching is the data switch. The data switch is similar to the PBX but is designed to interconnect digital data processing devices, such as terminals and computers.

2.11.1.2 Advantages of Circuit Switching

- It is suitable for long continuous transmission, since a continuous transmission route is established, that remains connected through out the conversion.
- The dedicate path ensures a steady data rate of transmission. (for example: 64 kbps for PSTN).

- No intermediate delay is found in switches once connection is established. So, Suitable for voice (PSTN) and data transfer (DSL).

2.11.1.3 Disadvantages of Circuit Switching

- Once the dedicated path is established, the only delay occurs in the speed of data transmission.
- It takes a long time to establish a connection approx 10 seconds during which no data can be transmitted.
- It is more expensive than other switching techniques as a dedicated path is required for each connection i.e it consumes more bandwidth.
- It is inefficient to use because once the path is established and no data is transferred, then the capacity of the path (i.e Bandwidth) is wasted.
- In this case, the connection is dedicated therefore no other data can be transferred even if the channel is free.

2.11.2 Packet Switching

- In packet switching network, data is broken down into smaller chunks called **packets** and a certain **control information** (i.e. header, trailer) is added for **routing** purpose and transmitted through network.
- There is no need to set up dedicated path in advance, unlike in circuit switching. It is up to **routers** to use *store-and-forward transmission* to send each packet on its way to the destination on its own.
- Internet today uses packet switched network.

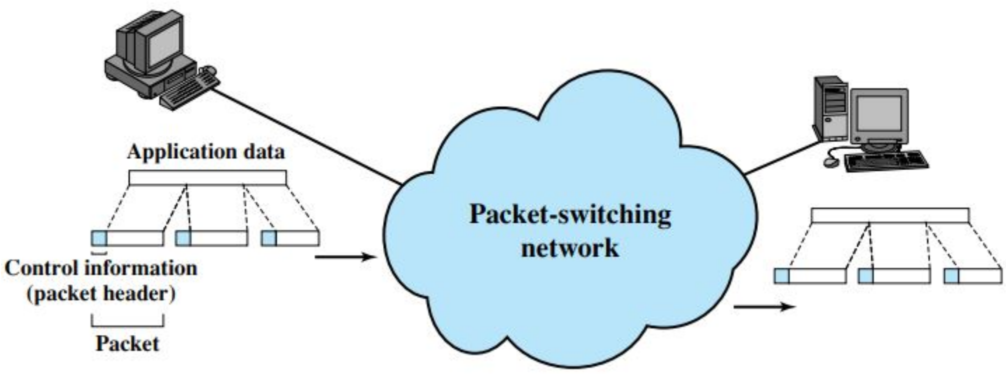


Figure 2.53: The use of packet.

Packet switching has a number of advantages over circuit switching:

- Line efficiency is greater, because a single node-to-node link can be dynamically shared by many packets over time. Also, packets from multiple applications can be multiplexed over the link.
- A packet-switching network can perform data-rate conversion.Two stations of different data rates can exchange packets because each connects to its node at its proper data rate.
- When traffic becomes heavy on a circuit-switching network, some calls are blocked; that is, the network refuses to accept additional connection requests until the load on the network decreases. On a packet-switching network, packets are still accepted, but delivery delay increases.
- Priorities can be used. If a node has a number of packets queued for transmission, it can transmit the higher-priority packets first. These packets will therefore experience less delay than lower-priority packets.

There are two common approach to packet switching. They are:

1. Datagram approach
2. Virtual approach

2.11.2.1 Datagram Approach

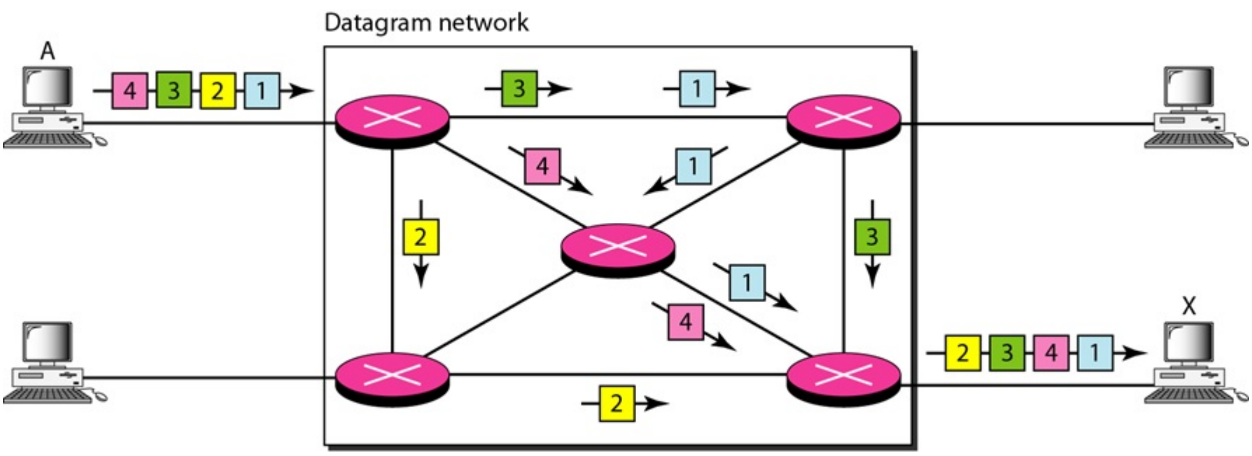


Figure 2.54: Packet Switching: Datagram Approach

- In datagram approach, each packet is treated independently of all others, with no reference to packets that have gone before. Packets in this approach are referred to as **datagrams**.
- Each packet is routed independently through the network.

- Therefore packets contain a header with the full information about the destination.
- The intermediate nodes examine the header of a packet and select an appropriate link to another node which is nearer to the destination.
- Packets do not follow a pre-established route, and the intermediate nodes do not require knowledge of the routes that will be used.
- The individual packets which form a data stream may follow different paths between the source and the destination.
- Packets may arrive at the destination out of order.
- When this occurs, the packets will have to be reassembled to form the original message.
- Because each packet is switched independently, there is no need for connection setup and no need to dedicate bandwidth in the form of a circuit(Connection less).
- Datagram packet switches use a variety of techniques to forward traffic; they are differentiated by how long it takes the packet to pass through the switch and their ability to filter out corrupted packets.
- A datagram network is a best effort network. - Delivery is not guaranteed.
- Reliable delivery must be provided by the end systems (i.e. user's computers) using additional protocols.

2.11.2.2 Virtual Circuit Approach

- Virtual circuit switching is a packet switching methodology whereby a logical path is established between the source and destination before data transmission.
- All the packets will go through same path which is called a virtual circuit.
- To the user, the connection appears to be a dedicated physical circuit.
- It is connection oriented; so the connection is reliable and packets are delivered in order since they follow the same route.
- Before the data transfer begins, the source and destination identify a suitable path for the virtual circuit.
- Additional parameters, such as the maximum packet size, are also exchanged between the source and the destination during call setup.
- The virtual circuit is cleared after the data transfer is completed.

A virtual-circuit network is a cross between a circuit-switched network and a datagram network. It has some characteristics of both.

1. As in a circuit-switched network, there are setup and teardown phases in addition to the data transfer phase.
2. Resources can be allocated during the setup phase, as in a circuit-switched network, or on demand, as in a datagram network.
3. As in a datagram network, data are packetized and each packet carries an address in the header.
4. As in a circuit-switched network, all packets follow the same path established during the connection.
5. A virtual-circuit network is normally implemented in the data-link layer, while a circuit-switched network is implemented in the physical layer and a datagram network in the network layer. But this may change in the future.

2.11.2.3 Differences between virtual and datagram approach

Issue	VC Networks	Datagram Networks
Connectivity	Virtual – circuits are connection oriented networks.	Datagram networks are connectionless.
Path	In these networks, the path between the source and the destination nodes that is followed by first data packet gets allocated. All other data packets transmitted between them will use the same path.	Since the datagrams are treated as independent units, no dedicated path is fixed for data transfer. Each datagram is routed by the intermediate routers using dynamically changing routing tables. So two successive packets from the source may follow completely separate routes to reach destination.

Resource Allocation	All the resources like buffers, processors and bandwidth get reserved before the transmission. The same resources are consumed by all the data packets and are released only after the transmission ends.	No prior resources allocation is done for the individual packets before the transmission commences. When a packet arrives at a router, the resources are allocated on demand on a First-Come First-Serve (FCFS) basis.
Communication Phases	There are three phases of transmission: set up, data transfer and teardown.	No such communication phases exists.
Header	All the packets belonging to a message contain the same header information since they belong to the same virtual circu	The header information is different for the independent datagram packets, even if they belong to the same message.
Addressing	The addressing and route is determined at the setup phase. So, each packet contains only the VC number.	Each datagram packet contains the full source and destination addresses.
Cost	Virtual circuits are more expensive in terms of installation and maintenance.	Datagram networks are much cheaper to install and maintain.
Reliability and Complexity	They provide greater reliability and less complexity owing to fixed paths and fixed resources.	They require more complex logic. Also, they are less reliable than virtual circuits due to error-prone dynamic resource allocation techniques.
Application Area	Virtual Circuits are implemented in networks using Asynchronous Transfer Mode (ATM) communications, as in making telephone calls.	Datagram communication is generally guided by User Datagram Protocol (UDP). They are applied in IP network.

Table 2.3: Differences between VC network and Datagram network.

2.11.2.4 Comparison Between Circuit Switched and Packet Switched

Item	Circuit switched	Packet switched
Call setup	Required	Not needed
Dedicated physical path	Yes	No
Each packet follows the same route	Yes	No
Packets arrive in order	Yes	No
Is a switch crash fatal	Yes	No
Bandwidth available	Fixed	Dynamic
Time of possible congestion	At setup time	On every packet
Potentially wasted bandwidth	Yes	No
Store-and-forward transmission	No	Yes
Charging	Per minute	Per packet

Figure 2.55: A key comparison between circuit switched and packet switched network

2.11.3 Message Switching

- Message switching was a technique developed as an alternate to circuit switching, before packet switching was introduced.

- In message switching, the whole message is treated as a data unit and switched through intermediate nodes of the network to the destination.

- The intermediate node receives the message, buffers (stores) it and transfer to next hop; until the next hop and the link connecting it are both available, the node stores and waits. So,it operates on store-and-forward concept.

- It is used in telegraph message and not used these days.

2.11.3.1 Advantages of Message Switching

- Channel efficiency can be greater compared to circuit-switched system, as more devices are sharing the channel.
- Traffic congestion can be reduced because message may be temporarily stored in route.
- Messages of unlimited sizes can be sent.
- Packets are deliver in order, and packets are not lost unlike in packet switching.

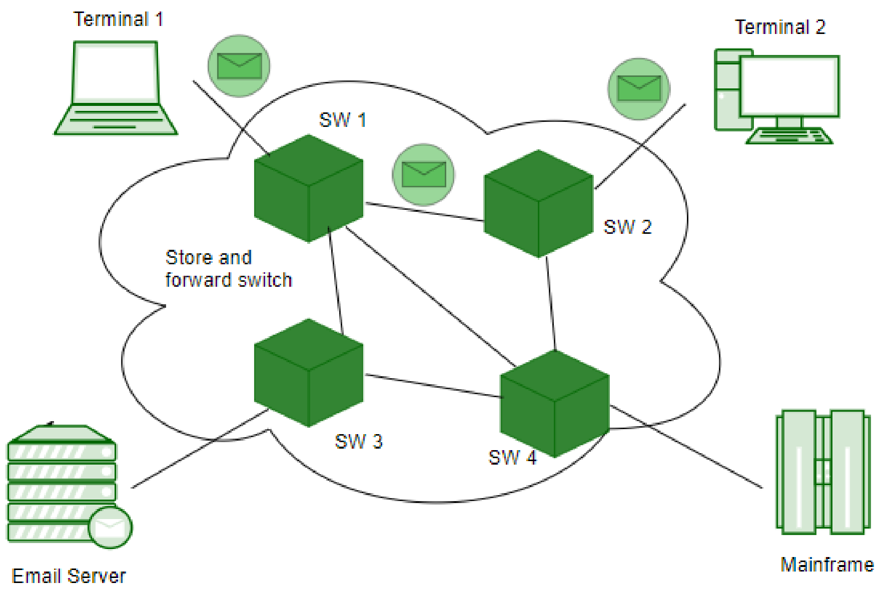


Figure 2.56: Message switched network.

2.11.3.2 Disadvantages of Message Switching

- Every switch in transit path needs enough storage (memory) to accommodate entire message.
- Store and forward method causes slow switching process between nodes. This renders it unsuitable for real time applications.

2.12 Public Switched Telephone Network

- **PSTN** (public switched telephone network) is the world's collection of interconnected voice-oriented public telephone networks.

- PSTN stands for public switched telephone network, or the traditional circuit-switched telephone network.

- PTSN comprises all the switched telephone networks around the world that are operated by local, national or international carriers. These networks provide the infrastructure and the services for public telecommunication.

- This is the system that has been in general use since the late 1800s. It's the aggregation of circuit-switching telephone networks that has evolved from the days of Alexander Graham Bell.

- Using underground copper wires, this legacy platform has provided businesses and households alike with a reliable means to communicate with anyone around the world for generations. Today, it is almost entirely digital.

- The phones themselves are known by several names, such as PSTN, landlines, Plain Old Telephone Service (POTS), or fixed-line telephones.
- PSTN phones are widely used and generally still accepted as a standard form of communication. However, they have seen a steady decline over the last decade.

2.12.1 How PSTN works?

- A public switched telephone network is a combination of telephone networks used worldwide, including telephone lines, fiber optic cables, switching centers, cellular networks, satellites and cable systems. A PSTN lets users make landline telephone calls to one another.

- A PSTN is made up of switches at centralized points on a network that function as nodes to enable communication between two points on the network. A call is placed after being routed through multiple switches. Voice signals can then travel over the connected phone lines.

- The PSTN phone line is used with traditional dial-up network modems to connect a computer to the Internet. Dial-up Internet connections support up to 56 Kbps. In the early days of the Internet, this was the main method for home Internet access but it became obsolete with the introduction of broadband Internet services.

2.12.2 PSTN Structure

- The traditional PSTN has a hierarchical architecture and a star structure.
- The individual subscriber lines are connected to a local exchange, which communicates with trunk exchanges as well as main and central exchanges.
- The lines within a local exchange typically have the same area code.
- A user who wants to call a number outside the local exchange has to add an area code.
- To make an international call, a user has to dial the country code.

A public telecommunications network can be described by using four generic architectural components:

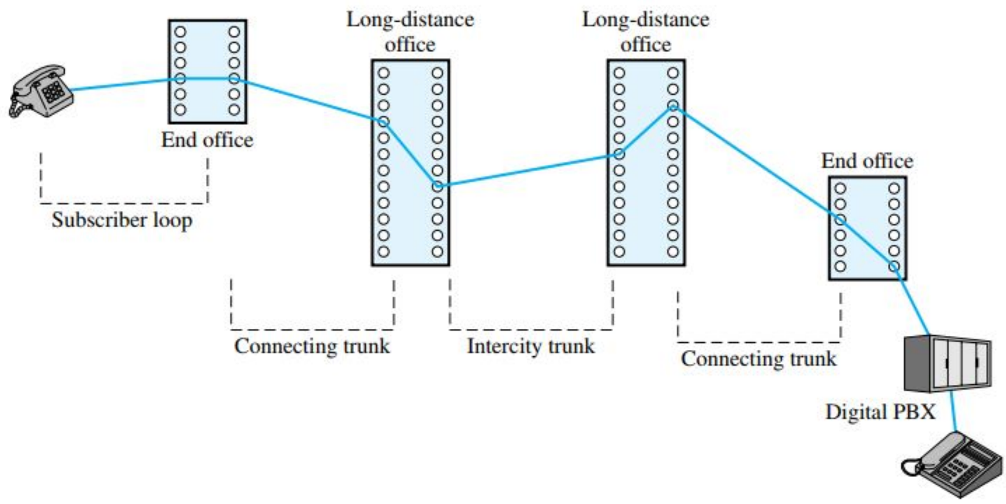


Figure 2.57: Example connection over a public circuit switching network.

- **Subscriber**: The device that attached to the network. E.g. Telephone
- **Subscriber Line**: The link between the subscriber and the network, also referred to as the *subscriber loop* or *local loop*. Almost all local loop connections use twisted-pair wire. The length of a local loop is typically in a range from a few kilometers to a few tens of kilometers.
- **Exchange**: The switching centres in the network. A switching center that directly supports subscribers is known as an end office. Typically, an end office will support many thousands of subscribers in a localized area.
- **Trunks**: The branches between exchanges. Trunks carry multiple voice frequency circuits using either FDM or synchronous TDM.

- Subscribers connect directly to an end office, which switches traffic between subscribers and between a subscriber and other exchanges.

- The other exchanges are responsible for routing and switching traffic between end offices.

- To connect two subscribers attached to the same end office, a circuit is set up between them in the same fashion as described before. If two subscribers connect to different end offices, a circuit between them consists of a chain of circuits through one or more intermediate offices.

2.12.3 Switching in PSTN

- There are four types of switching which takes place at different levels.

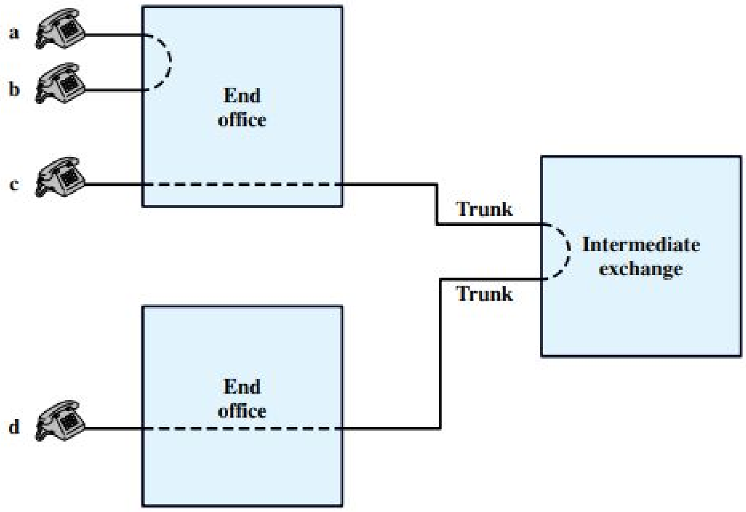


Figure 2.58: Circuit establishment.

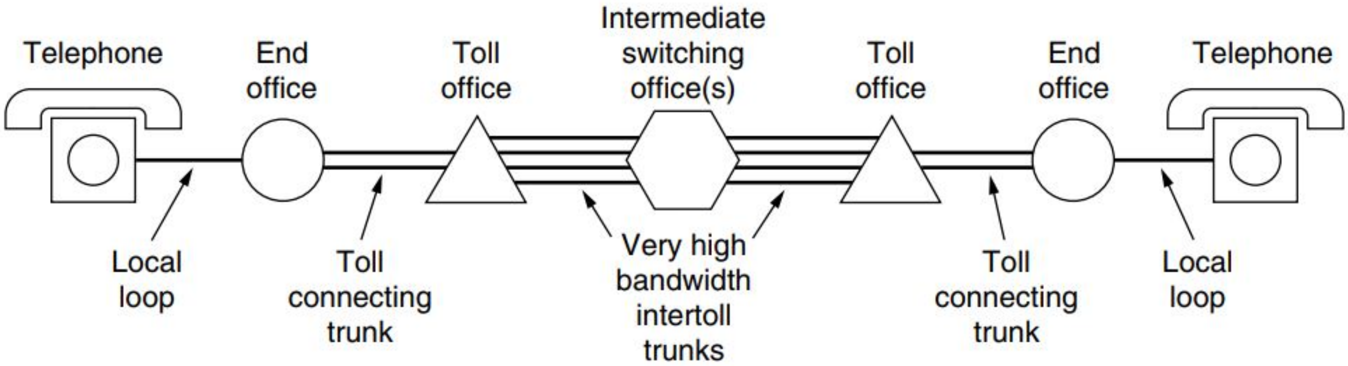


Figure 2.59: A typical circuit route for a long distance call.

1. **The Local Exchange**

   - Each telephone has two copper wires coming out of it that go directly to the telephone company's nearest **end office**.

   - It connects subscribers to a PSTN line. - Also, known as a local central office or a switching exchange, a telephone exchange may have as many as 10,000 lines.

   - All telephone are connected to the local exchange in a specific area.

   - The exchange then identifies the number being dialed, and routes it to the desired destination.

2. **The Tandem Office**

   - Also known as a junction network, a tandem office serves a large geographical area comprising several local exchanges while managing switches between local exchanges.

- The tandem office has the capability of routing calls between local exchanges.

3. **Toll Office**

   - Each end offices has a number of outgoing lines to one or more nearby switching centers, called toll offices.

   - When a number is dialled outside the geographical area of a local exchange or tandem office, it will be routed to a toll office..

   - The toll office is where long distance, domestic calls can be made. That is, this is where any national long-distance switching takes place.

4. **The International Gateway**

   - As the name implies, the international gateway is used to route calls outside of the country.

   - When a foreign number is dialled, the international gateway manages the call switching, and routes calls to the desired country.

2.12.4 Advantages of PSTN

1. Proven Reliability
2. Better Security
3. Ease of Use

2.12.5 Disadvantages of PSTN

1. More expensive
2. Fixed Phones
3. No versatility

2.12.6 PSTN and ISDN

ISDN (Integrated Services Digital Network) was developed for the digital transmission of data and voice over ordinary phone lines. ISDN provides better voice quality than PSTN. The ISDN provides 128 Kbps. One of the key features of the ISDN is that it integrates both speech and data in the same line, which is not available with ordinary telephone wires. Users can make faster calls with ISDN than with PSTN.

2.12.7 PSTN and VoIP

Voice over IP (VoIP), also known as IP telephony, broadband telephony or Internet telephony, means voice communication is transmitted over the Internet or private wide ware network (WAN) service. VoIP eliminates the need for circuit-switched networks for phone calls.

VoIP uses codecs to turn audio into data packets, transmits them across an IP network and turns the packets back into audio on the receiving end of the call. Many organizations get their VoIP services from cloud unified communications providers, such as RingCentral and Vonage, or from VoIP providers, such as Dialpad and Nextiva.

VoIP has advantages over PSTN, including lower network infrastructure costs, scalability and advanced features, such as unified communications and app integrations.

Feature	**VoIP**	**PSTN**
Connection Type	Uses your internet connection to transmit data. Voice is converted into a ditial signal.	Uses dedicated POTS line for voide transmission. The voice data travels in the form of electrical signals.
Switching	It uses packet switching, which doesn't require a dedicated link.	It uses circuit switching which require a dedicated line for transmission.
Bandwidth	Uses bandwidth as per requirement. VoIp networks don't reserve any bandwith in advance and can work with as low as 10kps.	POTS require up to 64 kpbs and all bandwidth is reserved in advance.
Upgrading	Upgrading a VoIP phone system is rather easy. You need to increase bandwidth and update the software. No additional hardware required except telephone sets	Upgrading a PSTN telephone system is complex. You need dedicated lines and you have to add new hardware which makes upgrading a pain.

Setup Cost	It will cost you between 2500 and 5000 to setup and install a VoIP phone system for your business for 30 employees. Actual cost may vary depending on the features and add-ons you opt for.	It will cost you between 8000 and 12000 to setup and install a PSTN telephone system for 30 employees. Actual cost may vary depending on the features and add-ons you opt for.
Call Cost	You're not charged on the basis of distance. Free VoIP to VoIP calls and international and mobile calls might get a little expensive.	Calls are charged on the basis of distance. Local calls will be cheaper as compared to national or international calls. International and mobile calls are very expensive.
Maintenance Cost	VoIP doesn't require a lot of maintenance. But if you do, it won't cost you a lot of money since you mostly deal with software.	If you use a PBX for your business, maintenance cost will be really high. In case of normal PSTN connection, you'll need minimal maintenance.
Add-ons	Most VoIP phone networks come pre-loaded with all the add-ons and features such as voicemail, call conferencing, auto attendant, virtual faxing, line monitoring, and more.	You get basic features for free such as call waiting, caller ID, and others but if you need more features like call conference, 3 way calling, etc., you'll be charged for them.
Biggest Advantage	Very cost-effective for businesses of all sizes whether it be setup cost, maintenance cost, monthly cost, or upgrade costs.	Call stability is one of the best features of a PSTN. You'd rarely experience a call drop or voice distortion.

Biggest Drawback	Your VoIP phone system won't work in case of a power outage or no internet connection.	PSTN is expensive for businesses. You have to spend a lot of money on maintenance, upgrades, and hardware as your business grows.
Security	VoIP security depends on your internet connection.	Very secure since you use dedicated lines.

Table 2.4: Differences between VoIP and PSTN

2.13 Integrated Service Digital Network (ISDN)

ISDN are a set of communication standards for simultaneous digital transmission of voice, video, data, and other network services over the traditional circuits of the public switched telephone network. Before Integrated Services Digital Network (ISDN), the telephone system was seen as a way to transmit voice, with some special services available for data. The main feature of ISDN is that it can integrate speech and data on the same lines, which were not available in the classic telephone system.

ISDN is a circuit-switched telephone network system, but it also provides access to packet switched networks that allows digital transmission of voice and data. This results in potentially better voice or data quality than an analog phone can provide. It provides a packet-switched connection for data in increments of 64 kbps. It provided a maximum of 128 kbps bandwidth in both upstream and downstream directions. A greater data rate was achieved through channel bonding. Generally ISDN B-channels of three or four BRIs (six to eight 64 kbps channels) are bonded.

In the context of the OSI model, ISDN is employed as the network in data-link and physical layers but commonly ISDN is often limited to usage to Q.931 and related protocols. These protocols introduced in 1986 are a set of signalling protocols establishing and breaking circuit-switched connections, and for advanced calling features for the user. ISDN provides simultaneous voice, video, and text transmission between individual desktop videoconferencing systems and group videoconferencing systems.

The first generation of ISDN is called a **narrowband ISDN (N-ISDN** and it is based on the use of 64 Kbps channel as the basic unit of switching and has a circuit switching orientation which is heavily dependent on the copper cable. The main device in the narrowband ISDN is frame relay. The second generation of ISDN is referred to as the **Broadband ISDN (B-ISDN)** which supports higher data rate due to packet switching mechanism and relies mainly on the evolution of fiber-optics. This integrates the digital networking services and provides digital transmission over ordinary telephone wires, as well as over other media. Transmission is based on Asynchronous Transfer Mode (ATM). The speed of B-ISDN is around 2 Mbps to 1 Gbps.

SDN supports a variety of services. A few of them are listed below:

- Voice calls
- Video text
- Teletext
- Electronic mail
- Database access
- Data transmission and voice
- Connection to internet
- Electronic fund transfer
- Image and graphics exchange
- Document storage and transfer
- Audio and video conferencing
- Automatic alarm services to fire station, medical etc.

2.13.1 ISDN Components

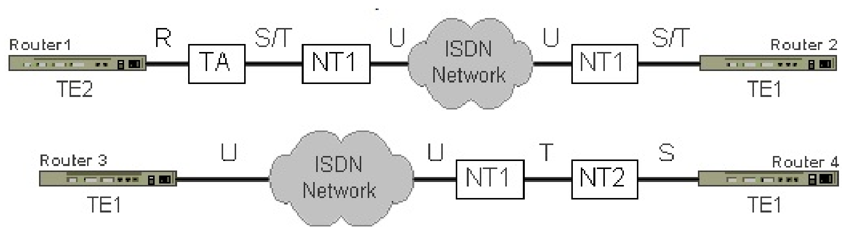


Figure 2.60: Fucntions groups and reference points.

ISDN standards use function groups and reference points to describe the various components that can be utilized in making an ISDN connection. Function groups describe a set of functions that are implemented by a device and software.

In the figure 2.60, Router 1 is a router without a BRI interface so it uses a TA (ISDN Modem) to connect to the ISDN line. Router 2 has a BRI interface without a builtin NT1. Router 3 has a BRI interface with a builtin NT1. Router 4 is attached to a line that uses a NT2 device for the local PBX.
Functions represent devices or hardware functions within ISDN

ISDN Functions and Devices

- **Terminal Adapter (TA)**: A converter device that allows non-ISDN devices to operate on an ISDN network.
- **Terminal Equipment 1 (TE1)**: A device that supports ISDN standards and that can be connected directly to an ISDN network connection. For example, routers with integrated ISDN interfaces, ISDN telephones, personal computers, or video-phones could function as TE1s.
- **Terminal Equipment 2 (TE2)**: A non-ISDN device, such as a router, analog phone or modem, which requires a TA in order to connect to an ISDN network.
- **Network Termination 1 (NT1)**: A small connection box that is attached to ISDN BRI lines. This device terminates the connection from the Central Office (CO). Converts BRI signals for use by ISDN line.
- **Network Termination 2 (NT2)**: A device that provides switching services for the internal network. This type of interface is typically used with PRI lines, when they need to be divided for several functions. For example, some channels may be used for WAN data communications and others for the telephone system (such as PBX) and/or video tele-conferencing. It is a more complex NT1 that performs layer 2 and 3 functions.

The connection between two function groups (including cabling) is called a reference point.

ISDN Reference Point

- **U** — The **U-interface** is the actual two-wire cable, also called the local loop, that connects the Customer Premise Equipment to the telecommunications provider.
- **R** — The **R-interface** is the wire or circuit that connects the TE2 to the TA.
- **S — The S-interface** is a four-wire cable from TE1 or TA to the NT1 or NT2, which is a two-wire termination point.

- **T** — The point between the NT1 and NT2, is the **T-interface**. This four-wire cable is used to divide the normal telephone company's two-wire cable into four-wires, which then allows the connection of up to eight ISDN devices.
- **S/T** — When NT2 is not used on a connection that uses NT1, the connection from the router or TA to the NT1 connection is typically called S/T. This is essentially the combination of the S and T reference points.

2.13.2 ISDN Architecture

- ISDN has capabilities of circuit switched and non-circuit switched service as well as packet switched service.
- Provides data rate of 64 kbps or greater, depending on service used.
- Connection can be established through ATM or Frame Relay methods.
- It has common-channel signaling capabilities used to control the network and provide call managment.

- In ISDN system architecture network, if the subscriber has an ISDN telephone, an ISDN terminal, and an ISDN PBX, they are connected to the network termination-1 (NT1), and NT1 is in turn connected to the ISDN switch. Non-ISDN equipment such as a PSTN telephone, or a normal computer can be connected to the ISDN interfaces through a terminal adapter (TA).
- In the ISDN architecture, four reference points are defined: R, S, T, and U interfaces. These are conceptual points to describe the interfaces between various equipment.

Types of Channels

ISDN generally contains three types of channels i.e., B-channel (Bearer channel), D-channel (Data Channel), and H-channel (Hybrid Channel).

1. **B-Channel**

   B-channel usually has 64 kbps data rate. This channel is required for voice, data, or other low data rate information. For higher data rates, two B-channel will get combined to give total of 128 kbps data rates.
2. **D-Channel**

   D-channel usually has 16 to 64 kbps data rate. This channel is required for signaling or packet-switched data. D-channel does not even carry data. It is simply

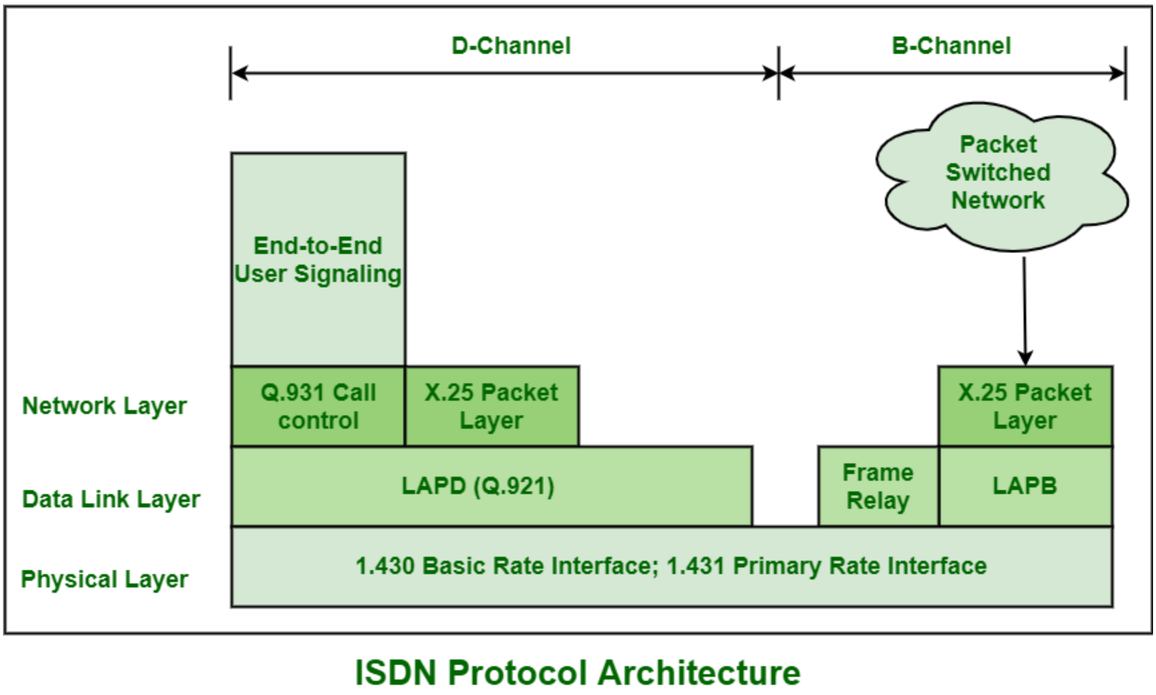


Figure 2.61: ISDN architecture.

required for carrying all of the controlling signals as establishing call, ringing, call interrupt, etc. It is common channel signaling that carries control signals for all of the using out-band signaling. Using this channel subscribes generally provide security to B connection. It is also required to carry data or information as videotext, tele-text, emergency services alarms, etc. in case of no signaling.

3. **H-Channel**

   - H Channel is a designation for groups of channels on Basic Rate Interface ISDN (BRI-ISDN) services.

   - An H channel is formed of multiple bearer B channels bonded together in a primary rate access (PRA) or primary rate interface (PRI) frame in support of applications with bandwidth requirements that exceed the B channel rate of 64 kbit/s. The channels, once bonded, remain so end-to-end, from transmitter to receiver, through the ISDN network.

   - H-channel generally has 1472 kbps, 1536 kbps, or 1920 kbps data rate. This channel is required for video, video-conferencing, high-speed data/audio, etc.

Types of Layers

SDN usually contains two different layering mechanisms out of which one is for B/H

Channels and other one for D Channel. For D-channel, ISDN contains three-layered protocol architecture. On the other hand, for B-channel, ISDN contains only one protocol layer i.e. physical layer and rest of upper layers are dependent on the application.

1. **Physical Layer**
   At this layer, B and D channels are same and uses either BRI or PRI Interface. It defines various primary aspects such as mechanical and electrical specifications of interface R, S, T, and U, Encoding, or power supply, etc. It is also based in X.21 for interfacing with public circuit switching network through an 8-pin connector.
2. **Data Link Layer**
   At this layer, B or D Channel generally uses LAPB or LAPD. B and D channels use different data link protocols i.e. LAPB (Link Access Procedure, Balanced) For B channel and LAPD (Link Access Procedure-D) for D channel.
3. **Network Layer**
   At this channel, B-channel has different options in connecting to circuit either circuit-switched, packet-switched, frame relay, or ATM networks.

2.13.3 ISDN Signaling

- The sinaling method will be Common Channel Signaling (CCS); that is signal is conveyed by addressed message.
- CCS will be operate in two modes:

1. **Associated Mode**: Signaling points, that are the origin and destination points of the messages are directly interconnected by a link.
2. **Quasi-associated Mode**: Messages pass through one or more signaling points other than those which are the origin or destination of the messages. The path is pre-determined).

2.13.4 ISDN Interface

- Also called, **ISDN service types**.
- The following are the interfaces of ISDN:

1. Basic Rate Interface (BRI)
2. Primary Rate Interface (PRI)

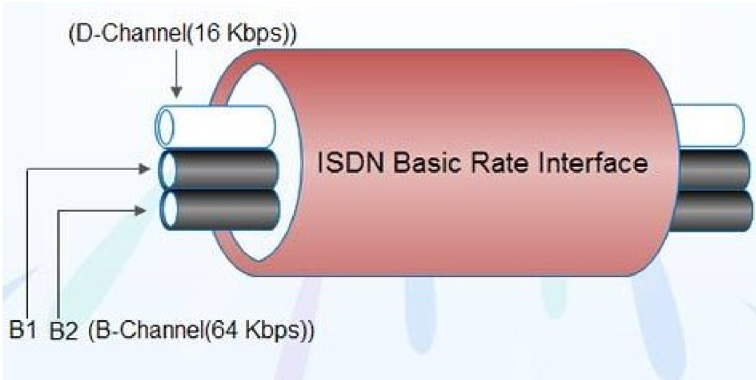


Figure 2.62: ISDN BRI

Basic Rate Interface (BRI)

- **BRI-ISDN** stands for **Basic Rate Interface ISDN**, Basic Rate Access, is an Integrated Services Digital Network (ISDN) configuration intended primarily for use in subscriber lines.
- Basic Rate Interface ISDN (BRI-ISDN) connections consist of two data bearing 64 Kbps **B channels** and one signaling 16 Kpbs **D channel**, a total of 144 Kbps (2B + D). Two B channels can be combined for providing a total rate of 128 Kbps. The two channels are independent of each other. For example, one channel is used as a TCP/IP connection to a location while the other channel is used to send a fax to a remote location. In addition, the BRI service itself require 48 Kbps operating overhead. Therefore BRI requires a digital pipe of 192 Kbps.
- The B channels carry the voice or data between the customer premises and the telco's central office (CO), while the D channel is used for establishing connections and signalling.
- BRI-ISDN is often referred to as **2B+D** because of the channels that it uses.
- BRI is intended for small enterprises and residential service.

Primary Rate Interface (PRI)

- Primary Rate Interface (PRI) is an ISDN interface standard for providing higher data rate telecommunication services to large enterprises and offices with digital private branch exchange (PBX) telephone systems.

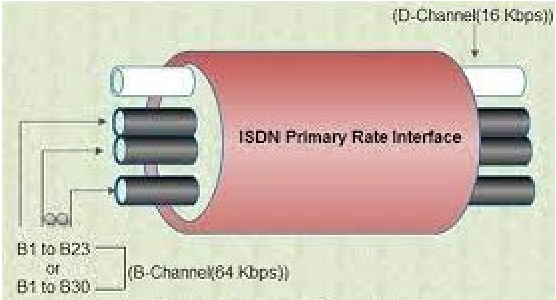


Figure 2.63: ISDN PRI

- Primary Rate Interface service consists of a D channel and either 23 or 30 B channels depending on the country you are in.
- In US, Canada, and Japan, PRI is based on T- carrier (T1) which consists of 23 B channels and one D channel, providing total bandwidth of 1.544 Mbps.
- While in Europe and Australia, PRI is based on E-carrier (E1) which consists of 30 B channel and one D channel, providing a total bandwidth 2.048 Mbps.

2.13.5 Principle of ISDN

The ISDN works based on the standards defined by ITU-T (ITU:International Telecommunication Union) (formerly CCITT) International Telegraph and Telephone Consultative Committee). The Telecommunication Standardization Sector (ITU-T) coordinates standards for telecommunications on behalf of the International Telecommunication Union (ITU) and is based in Geneva, Switzerland. The various principles of ISDN as per ITU-T recommendation are:

1. To support switched and non-switched applications.
    - both circuit and packet-switched connections
    - also supports non-switched services in the form of dedicated lines.
2. To support voice and non-voice applications.
3. Reliance on 64-kbps connections.
    - fundamental block of ISDN.
    - chosen because it was the standard rate for digitized voice.
4. Intelligence in the network.
    - sophisticated services beyond simple setup a circuit-switched call

  - sophisticated network management and maintenance capabilities.

5. Layered protocol architecture.
    - user access to ISDN protocl is a layered architecture that can be mapped to the OSI model.
6. Variety of configurations
    - more than one physical configuration is possible for implementing ISDN.

2.13.6 ISDN Standards

- SDN is referenced by a suite of ITU-T (International Telecommunications Union) standards that encompass the the OSI model's Physical, Data Link, and Network layers.
- The ISDN standard defines the hardware and call-setup scheme for end-to-end digital connectivity.
- The standards are grouped into ITU-T groups and are organized into three letter designations: I, E, and Q. Then each group is subdivided into specific protocols, preceded by the group designator.
- There are two standards for ISDN connectors:

- For accessing basic rate ISDN, a RJ-45type plug and socket (similar to a telephone plug) is used using unshielded twisted pair cable.
- Access to primary rate ISDN is through a coaxial cable.

- The ISDN passive bus, which can be a maximum of 1 km in length, is a cable in user premises. It enables up to eight user devices to be attached to the basic rate ISDN interface. Since there are only two B-channels, only two of the eight devices can communicate at anyone time. For this reason, each device must contend for access to the passive bus.

2.13.7 Advantages of ISDN

1. **Quality**: ISDN connections are very low error rate digital pipes.
2. **Flexibility**: ISDN can be thought of as a configurable leased line. Connections can be established at any time between any two locations where ISDN is available. It offers a very fast (almost transparent) call set-up, so its dialup nature is transparent to most users.

Protocol Series	Description	Examples
E	Telephone and network standards	• E.163 - Telephone numbering; • E.164 ISDN addressing
I	Methods, terminology, concepts, and interfaces	• I.100 - Terminology, structure, and concepts; • I.300 - Networking recommendations
Q	Signaling and switching standards	• Q.921 - Data Link layer LAPD procedures, • Q.931 - Network layer functions

Table 2.5: ISDN protocol series

3. **Economy**: ISDN is charged for rent like a telephone call. Usage costs are identical to the telephone service. In general, ISDN is extremely cost-effective for intermittent LAN to LAN connectivity.
4. **Availability**: ISDN is now becoming very widely available because the initiatives taken by the government of various countries.

2.13.8 Disadvantages of ISDN

- Costlier and requires special digital services. - ISDN is an outdated system which can no longer compete with IP technology and cloud-based systems such as VoIP (Voice over Internet Protocol), SIP (Session Initiation Protocol). - ISDN will be switched off in 2025, making ISDN phone systems obsolete.

2.13.9 Difference between ISDN and PSTN

The main difference between ISDN and PSTN is that the former uses digital lines and the latter uses analogue lines. While they both transmit voice and data through a network on traditional copper lines, ISDN can run multiple channels and applications over a single line, unlike PSTN. Overall, ISDN is better quality and offers more services than PSTN.

2.13.10 Difference between ISDN and DSL

Both an ISDN and a DSL (Digital Subscriber Line) work over the same kind of network, carrying signals over copper wires. The main difference between the two is that ISDN lines must be installed as they require an adapter at both ends of the line. A DSL uses existing telephone lines along with a modem. It doesn't need installation of wires as long as there's already a line in the home or organisation. Also, DSL transmits data far faster than an ISDN line can.