2. Data Communication and Services

A) Concept of data, signal, channel and circuits, channel speed and bandwidth, throughput, bit rate and baud rate, maximum data rate of a channel, propagation time, transmission time.

Data:

Data is any sequence of one or more symbols given meaning by specific act of interpretation. Data requires interpretation to become information. To translate data to information, there must be several known factors considered.

Signal:

A signal is an electrical or electromagnetic current that is used for carrying data from one device or network to another. A signal can be either analog or digital.

Channel:

A channel is a portion of the circuit that is used to transmit a single voice or data signal, which can be either a 4 kHz signal in analog transmission or 64 Kb/s signal in digital transmission. A channel is used to convey an information signal, for example a digital bit stream, from one or several senders (or transmitters) to one or several receivers. A channel has a certain capacity for transmitting information, often measured by its bandwidth in Hz or its data rate in bits per second.

Circuits:

A circuit is a path between two or more points along which an electrical current flows. In data communication, we may consider a circuit as a specific path between two or more points along which signals can be carried. A circuit may contain many channels together.

Bandwidth:

Bandwidth is also the amount of data that can be transmitted in a fixed amount of time. For digital devices, the bandwidth is usually expressed in bits per second(bps) or bytes per second. For analog devices, the bandwidth is expressed in cycles per second, or Hertz (Hz).

Throughput

Throughput refers to how much data can be transferred from one location to another in a given amount of time. It is used to measure the performance of hard drives and RAM, as well as Internet and network connections.

Bit and Baud rate

Bit rate is a measure of the number of data **bits**(that's 0's and 1's) transmitted in one second. A figure of 2400 **bits** per second means 2400 zeros or ones can be transmitted in one second, hence the abbreviation 'bps'. **Baud rate** by definition means the number of times a signal in a communications channel changes state.

The **baud rate** is the **rate** at which information is transferred in a communication channel. In the **serial** port context, “9600 **baud**” means that the **serial** port is capable of transferring a maximum of 9600 bits per second. If the information unit is one **baud** (one bit), the bit **rate** and the **baud rate** are identical.

Maximum data rate (channel capacity) :
Channel capacity is a much-used metric for the maximum amount of traffic or signal that can move over a particular infrastructure channel.

Propagation Delay vs Trasmission delay
Propagation delay is how long it takes one bit to travel from one end of the "wire" to the other (it's proportional to the length of the wire, crudely). Transmission delay is how long it takes to get all the bits into the wire in the first place (it's packet_length/data_rate).
The transmission delay is the amount of time required for the router to push out the packet.
The propagation delay, is the time it takes a bit to propagate from one router to the next.

B) Analog and Digital Transmission:

Analog transmission uses a continuous signal varying in amplitude, phase, or another property that is in proportion to a specific characteristic of a variable. Analog transmission could mean that the transmission is a transfer of an analog source signal which uses an analog modulation method. FM and AM are examples of such a modulation. The transmission could also use no modulation at all. It is most notably an information signal that is constantly varying.

Data transmission/digital communications is a literal transfer of data over a point to point transmission medium –such as copper wires, optical fibres, wireless communications media, or storage media. The data that is to be transferred is often represented as an electro-magnetic signal (such as a microwave). Rather than being a continuously variable wave form, it is a series of discrete pulses, representing one bits and zero bits. Digital transmission transfers messages discretely. These messages are represented by a sequence of pulses via a line code. However, these messages can also be represented by a limited set of wave forms that always vary.

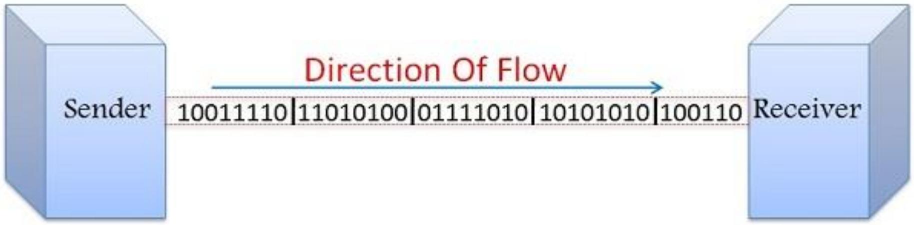
Difference between Analog and Digital Signal:

BASIS FOR COMPARISON	ANALOG SIGNAL	DIGITAL SIGNAL
Basic	An analog signal is a continuous wave that changes over a time period.	A digital signal is a discrete wave that carries information in binary form.
Representation	An analog signal is represented by a sine wave.	A digital signal is represented by square waves.
Description	An analog signal is described by the amplitude, period or frequency, and phase.	A digital signal is described by bit rate and bit intervals.
Range	Analog signal has no fixed range.	Digital signal has a finite range i.e. between 0 and 1.
Distortion	An analog signal is more prone to distortion.	A digital signal is less prone to distortion.
Transmit	An analog signal transmit data in the form of a wave.	A digital signal carries data in the binary form i.e. 0 nad 1.
Example	The human voice is the best example of an analog signal.	Signals used for transmission in a computer are the digital signal.

C) Asynchronous and Synchronous Transmission:

Definition of Synchronous Transmission

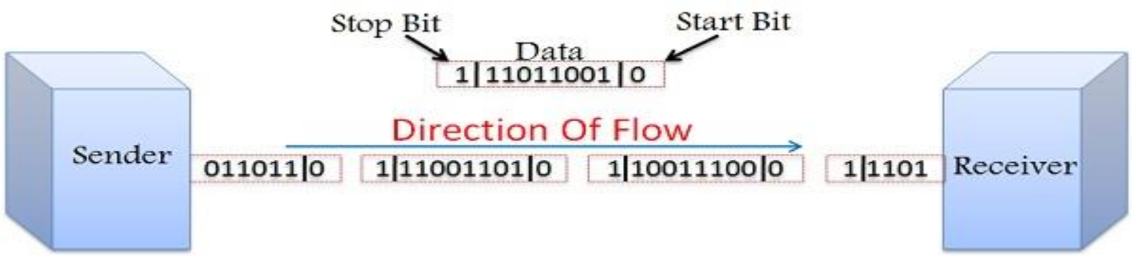
In Synchronous Transmission, data flows in a full duplex mode in the form of blocks or frames. Synchronization between the sender and receiver is necessary so that the sender know where the new byte starts (since there is no gap between the data).



Synchronous Transmission is efficient, reliable and is used for transferring a large amount of data. It provides real-time communication between connected devices. Chat Rooms, Video Conferencing, telephonic conversations, as well as face to face interactions, are some of the examples of Synchronous Transmission.

Definition of Asynchronous Transmission

In Asynchronous Transmission data flows in a half duplex mode, 1 byte or a character at a time. It transmits the data in a continuous stream of bytes. In general, the size of a character sent is 8 bits to which a parity bit is added i.e. a start and a stop bit that gives the total of 10 bits. It does not require a clock for synchronization; rather it uses the parity bits to tell the receiver how to interpret the data.



It is simple, fast, economical and does not require a 2-way communication. Letters, emails, forums, televisions and radios are some of the examples of Asynchronous Transmission.

Key Differences Between Synchronous and Asynchronous Transmission

- In Synchronous Transmission data is transferred in the form of frames on the other hand in Asynchronous Transmission data is transmitted 1 byte at a time.
- Synchronous Transmission requires a clock signal between the sender and receiver so as to inform the receiver about the new byte. Whereas, in Asynchronous Transmission sender and receiver does not require a clock signal as the data sent here has a parity bit attached to it which indicates the start of the new byte.
- Data transfer rate of Asynchronous Transmission is slower than that of Synchronous Transmission.
- Asynchronous Transmission is simple and economic whereas, Synchronous Transmission is complex and expensive.
- Synchronous Transmission is efficient and has lower overhead as compared to the Asynchronous Transmission.

D) Data Encoding Techniques:

Encoding is the process of converting the data or a given sequence of characters, symbols, alphabets etc., into a specified format, for the secured transmission of data. Decoding is the reverse process of encoding which is to extract the information from the converted format.

Data Encoding

Encoding is the process of using various patterns of voltage or current levels to represent 1s and 0s of the digital signals on the transmission link.

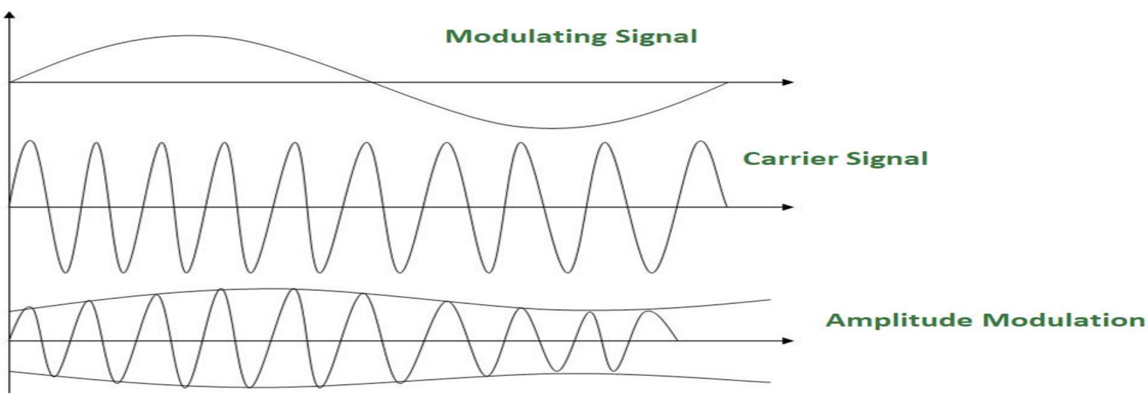
I. Analog Data to Analog signal Conversion (Modulation)

Analog-to-analog conversion, or modulation, is the representation of analog information by an analog signal. It is a process by virtue of which a characteristic of carrier wave is varied according to the instantaneous amplitude of the modulating signal. This modulation is generally needed when a **bandpass channel** is required. Bandpass is a range of frequencies which are transmitted through a bandpass filter which is a filter allowing specific frequencies to pass preventing signals at unwanted frequencies.

Analog to Analog conversion can be done in three ways:

1. AMPLITUDE MODULATION:

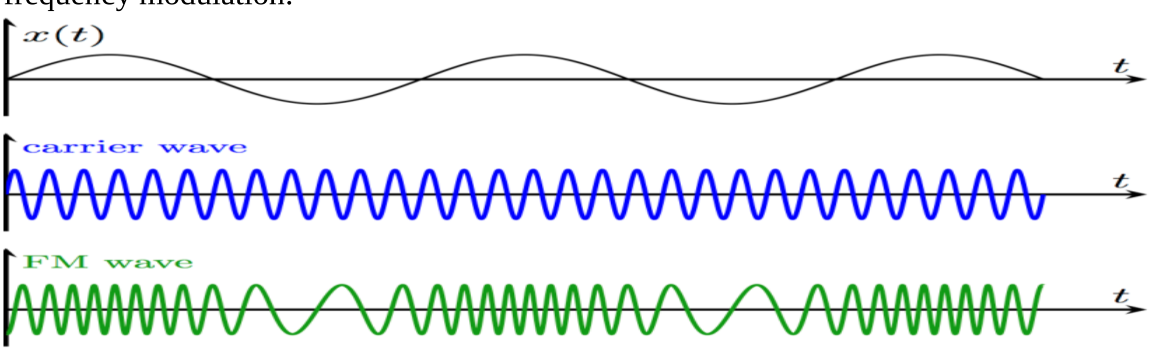
The modulation in which the amplitude of the carrier wave is varied according to the instantaneous amplitude of the modulating signal keeping phase and frequency as constant. The modulating signal is the envelope of the carrier. The figure below shows the concept of amplitude modulation:



The modulation creates a bandwidth that is twice the bandwidth of the modulating signal and covers a range centered on the carrier frequency. **Bandwidth= 2fm**

2. FREQUENCY MODULATION –

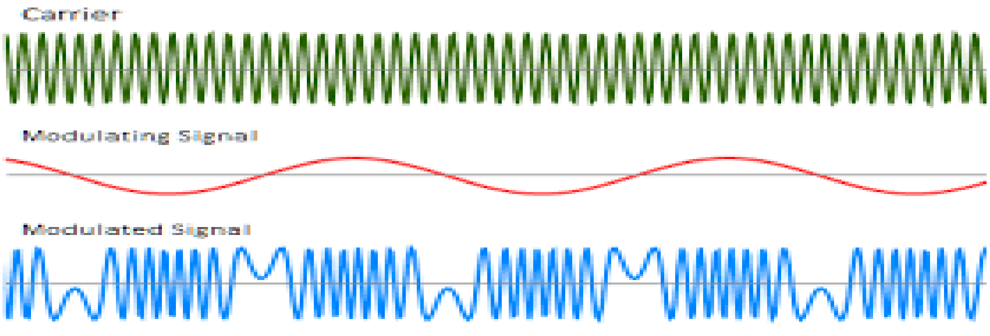
The modulation in which the frequency of the carrier wave is varied according to the instantaneous amplitude of the modulating signal keeping phase and amplitude as constant. The figure below shows the concept of frequency modulation:



FM is normally implemented by using a voltage-controlled oscillator as with FSK. The frequency of the oscillator changes according to the input voltage which is the amplitude of the modulating signal.

3. PHASE MODULATION:

The modulation in which the phase of the carrier wave is varied according to the instantaneous amplitude of the modulating signal keeping amplitude and frequency as constant. The angle is varied with the modulating signal. The figure below shows the concept of frequency modulation:



Phase Modulation

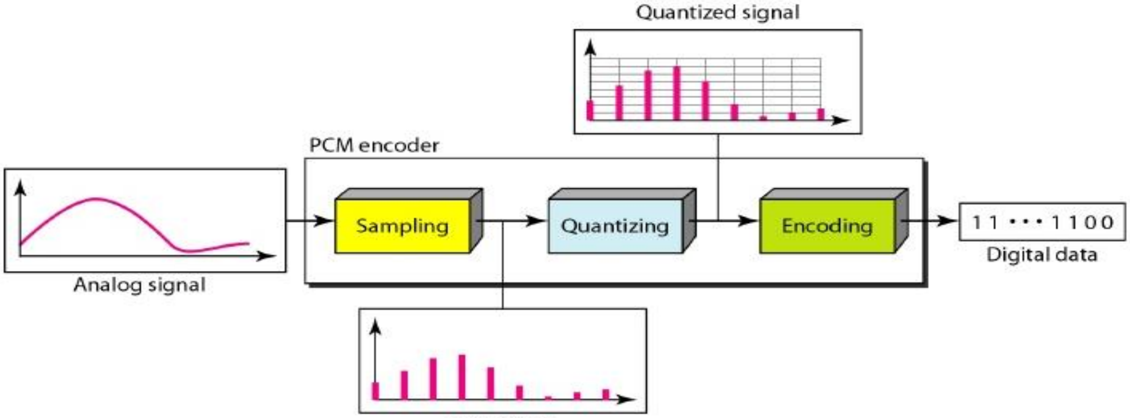
Phase modulation is practically similar to Frequency Modulation, but in Phase modulation frequency of the carrier signal is not increased. It is normally implemented by using a voltage-controlled oscillator along with a derivative.

II. Analog to digital conversion

The following techniques can be used for Analog to Digital Conversion:

a. PULSE CODE MODULATION:

The most common technique to change an analog signal to digital data is called pulse code modulation (PCM).



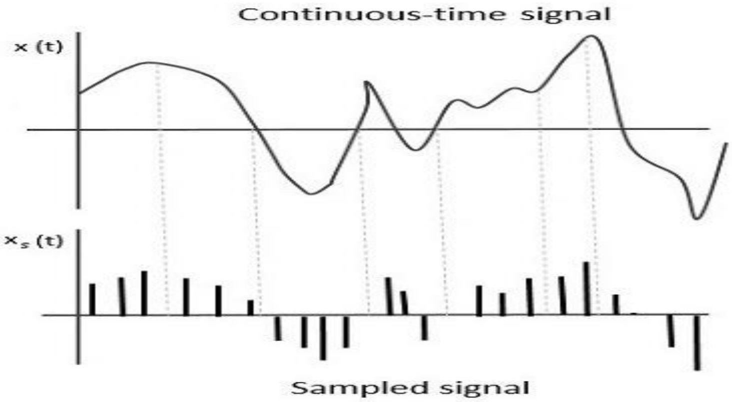
A PCM encoder has the following three processes:

1. Sampling
2. Quantization
3. Encoding

Low pass filter :

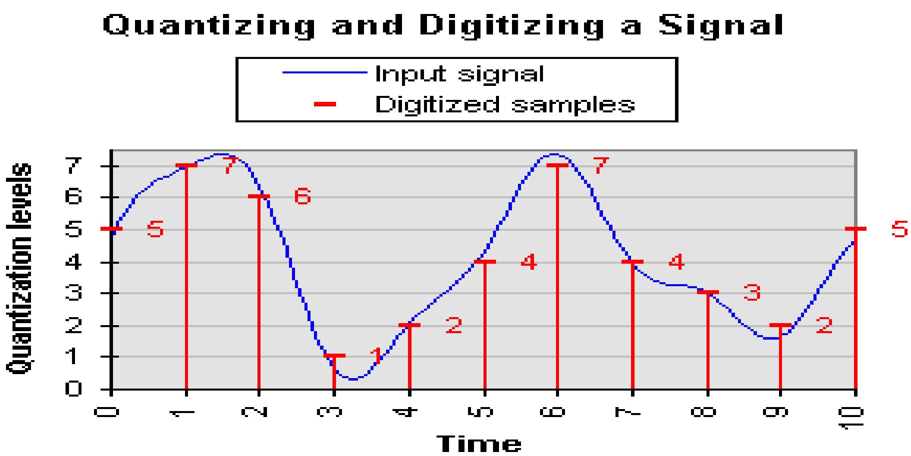
The low pass filter eliminates the high frequency components present in the input analog signal to ensure that the input signal to sampler is free from the unwanted frequency components. This is done to avoid aliasing of the message signal.

1. **Sampling** – The first step in PCM is sampling. Sampling is a process of measuring the amplitude of a continuous-time signal at discrete instants, converting the continuous signal into a discrete signal.



Nyquist Theorem:
One important consideration is the sampling rate or frequency. According to the Nyquist theorem, the sampling rate must be at least 2 times the highest frequency contained in the signal. It is also know as the minimum sampling rate and given by:
Fs =2*fh

2. **Quantization –**
   The result of sampling is a series of pulses with amplitude values between the maximum and minimum amplitudes of the signal. The set of amplitudes can be infinite with non integral values between two limits. The quantizing of an analog signal is done by discretizing the signal with a number of quantization levels. **Quantization** is representing the sampled values of the amplitude by a finite set of levels, which means converting a continuous-amplitude sample into a discrete-time signal.



3. **Encoding –**
   The digitization of analog signal is done by the encoder. After each sample is quantized and the number of bits per sample is decided, each sample can be changed to an n bit code. Encoding also minimizes the bandwidth used. Encoding is the process of translate the discrete set of sampled values to a more appropriate form of signal.

b. Delta Modulation :
Since PCM is a very complex technique, other techniques have been developed to reduce the complexity of PCM. The simplest is delta Modulation. Delta Modulation finds the change from the previous value.
Modulator – The modulator is used at the sender site to create a stream of bits from an analog signal. The process records a small positive change called delta. If the delta is positive, the process records a 1 else the process records a 0. The modulator builds a second signal that resembles a staircase. The input signal is then compared with this gradually made staircase signal.

We have the following rules for output:

1. If the input analog signal is higher than the last value of the staircase signal, increase delta by 1, and the bit in the digital data is 1.
2. If the input analog signal is lower than the last value of the staircase signal, decrease delta by 1, and the bit in the digital data is 0.

c. Adaptive Delta Modulation:

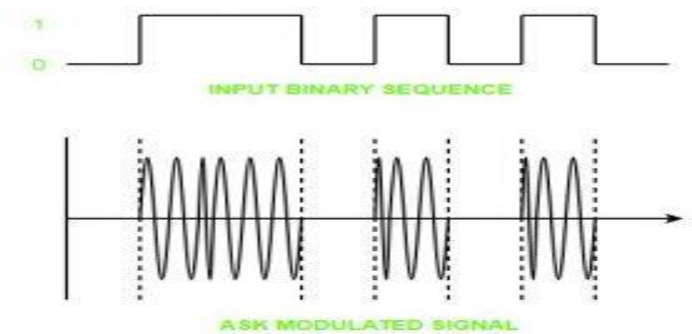
The performance of a delta modulator can be improved significantly by making the step size of the modulator assume a time-varying form. A larger step-size is needed where the message has a steep slope of modulating signal and a smaller step-size is needed where the message has a small slope. The size is adapted according to the level of the input signal. This method is known as adaptive delta modulation (ADM).

III. Digital to Analog Conversion

The following techniques can be used for Digital to Analog Conversion:

1. Amplitude Shift keying – Amplitude Shift Keying is a technique in which carrier signal is analog and data to be modulated is digital. The amplitude of analog carrier signal is modified to reflect binary data.

The binary signal when modulated gives a zero value when the binary data represents 0 while gives the carrier output when data is 1. The frequency and phase of the carrier signal remain constant.



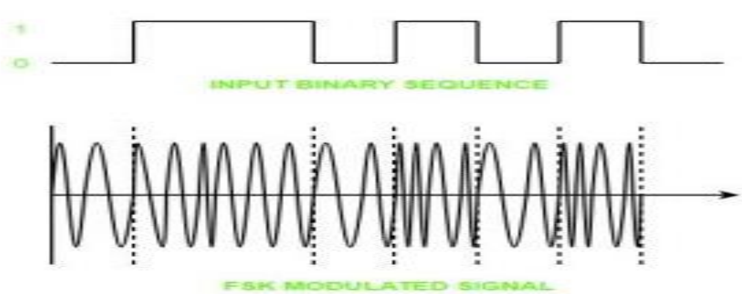
Advantages of amplitude shift Keying –

- It can be used to transmit digital data over optical fiber.
- The receiver and transmitter have a simple design which also makes it comparatively inexpensive.
- It uses lesser bandwidth as compared to FSK thus it offers high bandwidth efficiency.

Disadvantages of amplitude shift Keying –

- It is susceptible to noise interference and entire transmissions could be lost due to this.
- It has lower power efficiency.

2. Frequency Shift keying – In this modulation the frequency of analog carrier signal is modified to reflect binary data. The output of a frequency shift keying modulated wave is high in frequency for a binary high input and is low in frequency for a binary low input. The amplitude and phase of the carrier signal remain constant.



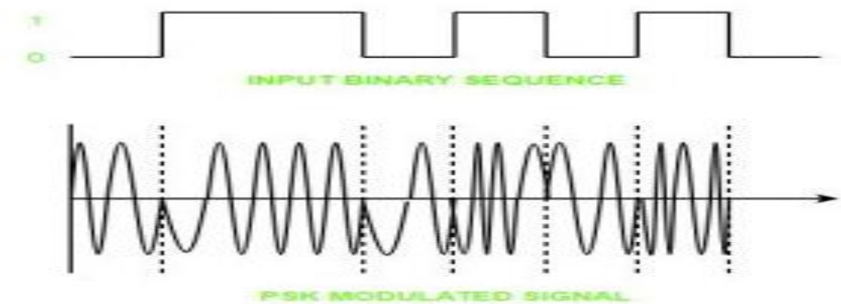
Advantages of frequency shift Keying –

- Frequency shift keying modulated signal can help avoid the noise problems beset by ASK.
- It has lower chances of an error.
- It provides high signal to noise ratio.
- The transmitter and receiver implementations are simple for low data rate application.

Disadvantages of frequency shift Keying –

- It uses larger bandwidth as compared to ASK thus it offers less bandwidth efficiency.
- It has lower power efficiency.

3. Phase Shift keying – In this modulation the phase of the analog carrier signal is modified to reflect binary data. The amplitude and frequency of the carrier signal remains constant.



It is further categorized as follows:

1. **Binary Phase Shift Keying (BPSK):**
   BPSK also known as phase reversal keying or 2PSK is the simplest form of phase shift keying. The Phase of the carrier wave is changed according to the two binary inputs. In Binary Phase shift keying, difference of 180 phase shift is used between binary 1 and binary 0.
   This is regarded as the most robust digital modulation technique and is used for long distance wireless communication.
2. **Quadrature phase shift keying:**
   This technique is used to increase the bit rate i.e we can code two bits onto one single element. It uses four phases to encode two bits per symbol. QPSK uses phase shifts of multiples of 90 degrees.
   It has double data rate carrying capacity compare to BPSK as two bits are mapped on each constellation points.

Advantages of phase shift Keying –

- It is a more power efficient modulation technique as compared to ASK and FSK.
- It has lower chances of an error.
- It allows data to be carried along a communication signal much more efficiently as compared to FSK.

Disadvantages of phase shift Keying –

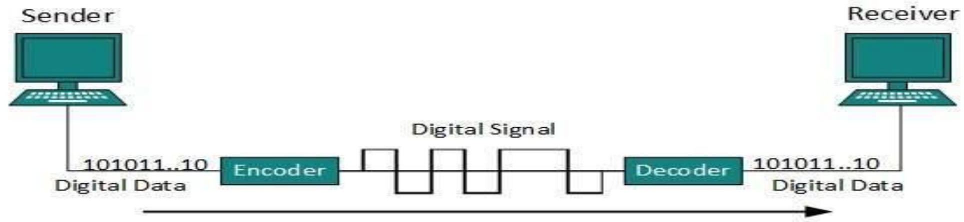
- It offers low bandwidth efficiency.
- The detection and recovery algorithms of binary data is very complex.
- It is a non coherent reference signal.

IV. Digital-to-Digital Conversion

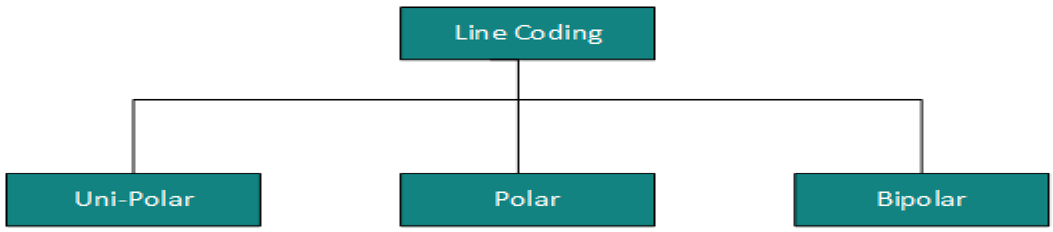
This section explains how to convert digital data into digital signals. It can be done in two ways, line coding and block coding. For all communications, line coding is necessary whereas block coding is optional.

1. Line Coding

The process for converting digital data into digital signal is said to be Line Coding. Digital data is found in binary format.It is represented (stored) internally as series of 1s and 0s.

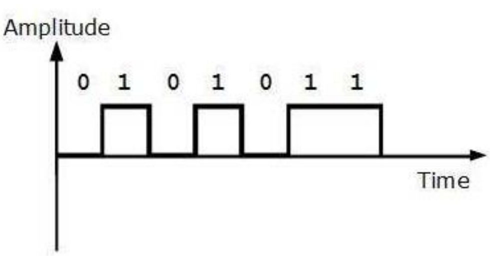


Digital signal is denoted by discreet signal, which represents digital data.There are three types of line coding schemes available:



a) Uni-polar Encoding

Unipolar encoding schemes use single voltage level to represent data. In this case, to represent binary 1, high voltage is transmitted and to represent 0, no voltage is transmitted. It is also called Unipolar-Non-return-to-zero, because there is no rest condition i.e. it either represents 1 or 0.



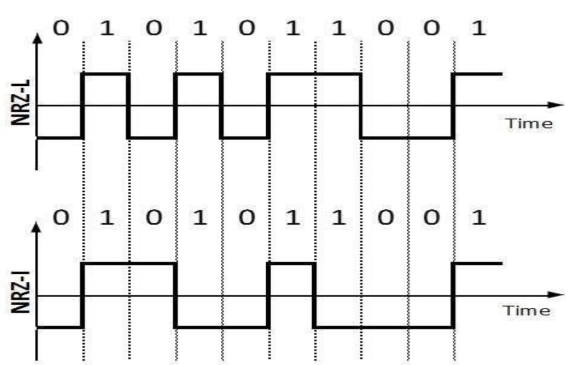
b) Polar Encoding

Polar encoding scheme uses multiple voltage levels to represent binary values. Polar encodings is available in four types:

- **Polar Non-Return to Zero (Polar NRZ)**

  It uses two different voltage levels to represent binary values. Generally, positive voltage represents 1 and negative value represents 0. It is also NRZ because there is no rest condition.

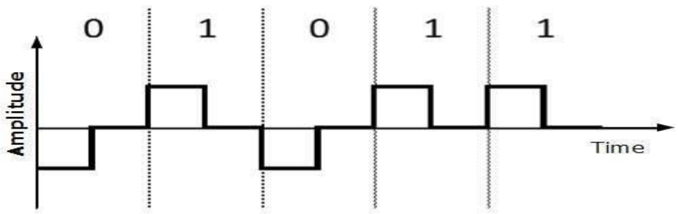
  NRZ scheme has two variants: NRZ-L and NRZ-I.



  NRZ-L changes voltage level at when a different bit is encountered whereas NRZ-I changes voltage when a 1 is encountered.

- **Return to Zero (RZ)**

  Problem with NRZ is that the receiver cannot conclude when a bit ended and when the next bit is started, in case when sender and receiver's clock are not synchronized.



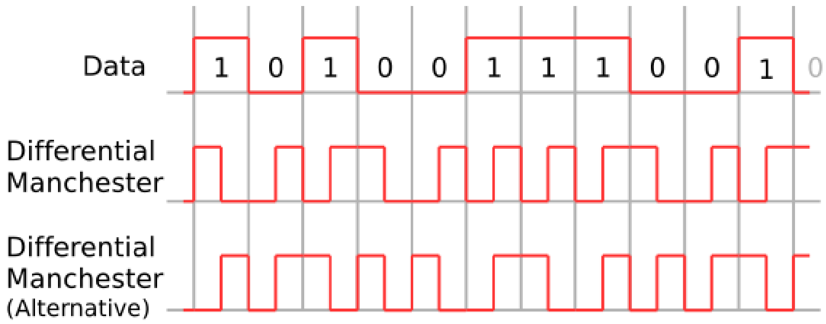
  RZ uses three voltage levels, positive voltage to represent 1, negative voltage to represent 0 and zero voltage for none. Signals change during bits not between bits.

- **Manchester**

  This encoding scheme is a combination of RZ and NRZ-L. Bit time is divided into two halves. It transits in the middle of the bit and changes phase when a different bit is encountered.

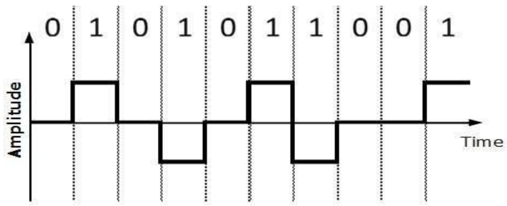
- **Differential Manchester**

  This encoding scheme is a combination of RZ and NRZ-I. It also transit at the middle of the bit but changes phase only when 1 is encountered.



c) Bipolar Encoding

Bipolar encoding uses three voltage levels, positive, negative and zero. Zero voltage represents binary 0 and bit 1 is represented by altering positive and negative voltages.



2. Block Coding

To ensure accuracy of the received data frame redundant bits are used. For example, in even-parity, one parity bit is added to make the count of 1s in the frame even. This way the original number of bits is increased. It is called Block Coding.

Block coding is represented by slash notation, mB/nB. Means, m-bit block is substituted with n-bit block where n > m. Block coding involves three steps:

- Division,
- Substitution
- Combination.

After block coding is done, it is line coded for transmission.

E) Multiplexing and DE-multiplexing:

Multiplexing is a popular networking technique that integrates multiple analog and digital signals into a signal transmitted over a shared medium.

Demultiplex (DEMUX) is the reverse of the multiplex (MUX) process – combining multiple unrelated analog or digital signal streams into one signal over a single shared medium, such as a single conductor of copper wire or fiber optic cable. Thus, demultiplex is reconverting a signal containing multiple analog or digital signal streams back into the original separate and unrelated signals.

Although demultiplex is the reverse of the multiplex process, because the multiple signals are not related, it is not the opposite of multiplexing.

The opposite of multiplexing is inverse multiplexing (IMUX), which breaks one data stream into several related data streams. Thus, the difference between demultiplexing and inverse multiplexing is that the output streams of demultiplexing are unrelated; but the output streams of inverse multiplexing are related.

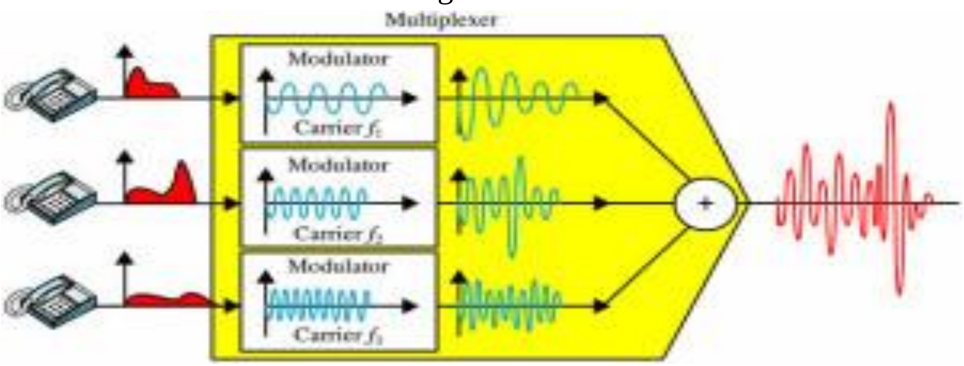
Types of multiplexing

Different type of multiplexing is used in communication. In this article, the following three major multiplexing techniques are discussed:

- Frequency division multiplexing
- Wavelength division multiplexing
- Time division multiplexing

1. Frequency Division Multiplexing

The FDM is an analog multiplexing that combines analog signals. Frequency division multiplexing is applied when the bandwidth of the link is greater than the combined bandwidth of the signals to be transmitted.



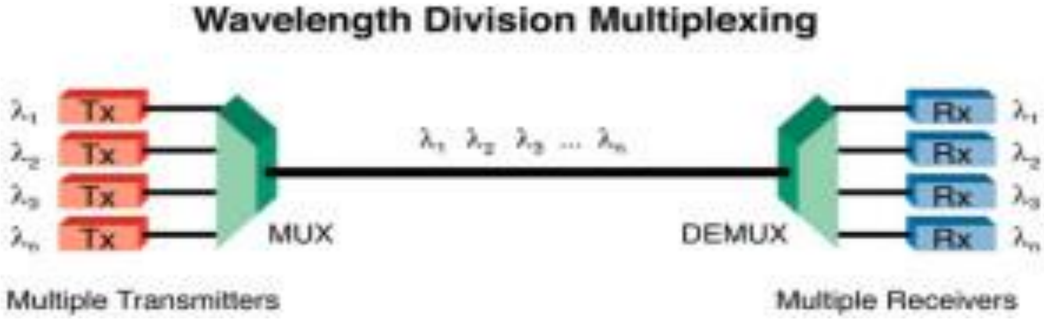
In this type of multiplexing, signals are generated by sending different device-modulated carrier frequencies, and these modulated signals are then combined into a single signal that can be transported by the link. To accommodate the modulated signal, the carrier frequencies are separated with enough bandwidth, and these bandwidth ranges are the channels through which different signals travel. These channels can be separated by unused bandwidth. Some of the examples for the time division multiplexing include radio and television signal transmission.

2. Wavelength Division Multiplexing

Wavelength division multiplexing (WDM) is a technology in fiber optic communications; and, for the high capacity communication systems, wavelength division multiplexing is the most promising concept. This system uses multiplexer at transmitter to join signals and demultiplexer to split the signals apart, at the receiver end.

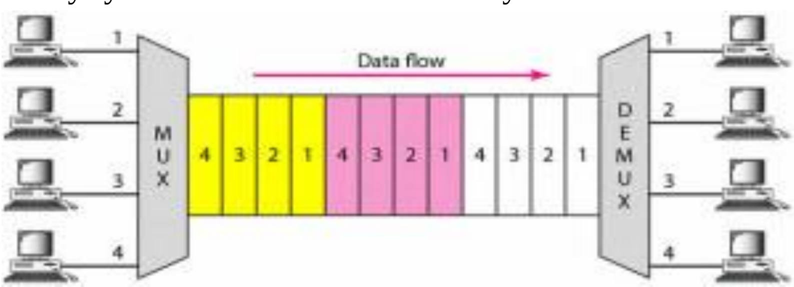
The purpose of WDM is to combine multiple light sources into a single light source at the multiplexer; and, at the demultiplexer the single light is converted into multiple light sources.

WDM is designed to use the high data rate capability of the fiber optic cable. The data rate of this cable is higher than the metallic transmission cable's data rate. Conceptually, the wavelength division multiplexing is same as the frequency division multiplexing, except for the transmission through the fiber optic channels wherein the multiplexing and demultiplexing involves optical signals.



3. Time-Division Multiplexing

Time division multiplexing is a technique used to transmit a signal over a single communication channel by dividing the time frame into slots – one slot for each message signal. Time-division multiplexing is primarily applied to digital signals as well as analog signals, wherein several low speed channels are multiplexed into high-speed channels for transmission. Based on the time, each low-speed channel is allocated to a specific position, where it works in synchronized mode. At both the ends, i.e., the multiplexer and demultiplexer are timely synchronized and simultaneously switched to the next channel.

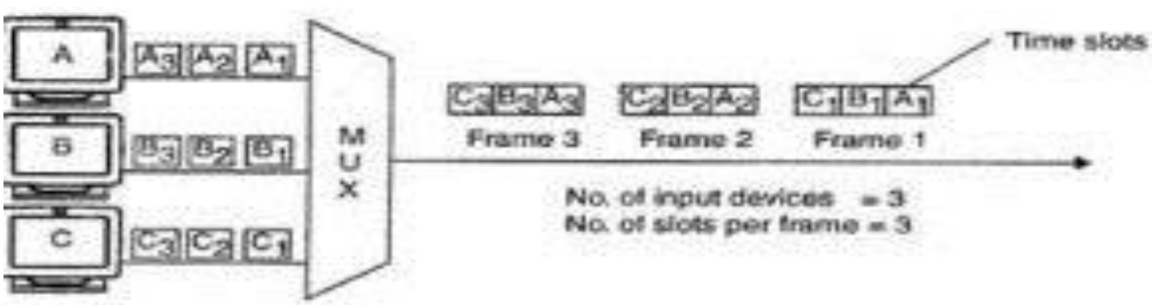


Types of TDM

Time division multiplexing is classifieds into four types:

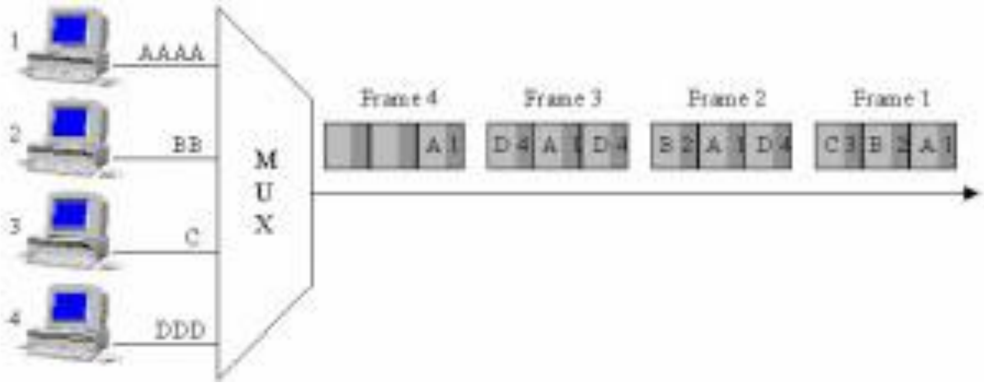
a) **Synchronous Time Division Multiplexing**

Synchronous time division multiplexing can be used for both analog and digital signals. In synchronous TDM, the connection of input is connected to a frame. If there are ‘n’ connections, then a frame is divided into ‘n’ time slots – and, for each unit, one slot is allocated – one for each input line. In this synchronous TDM sampling, the rate is same for all the signals, and this sampling requires a common clock signal at both the sender and receiver end. In synchronous TDM, the multiplexer allocates the same slot to each device at all times.



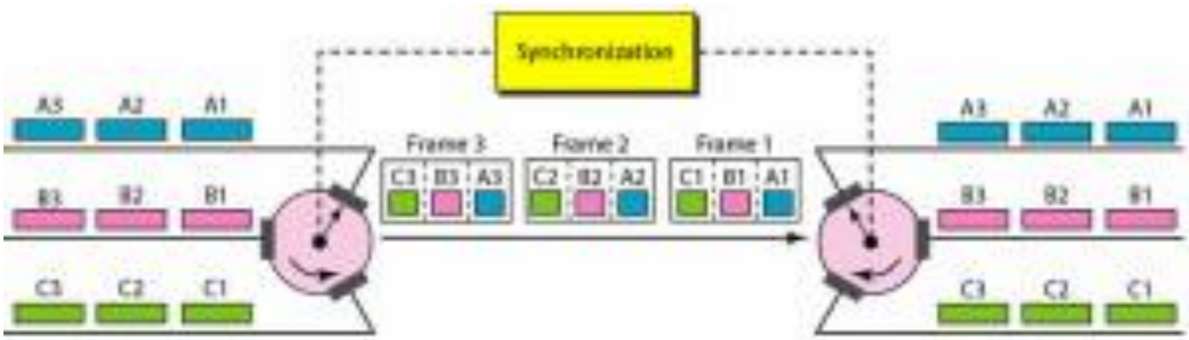
b) **Asynchronous Time-Division Multiplexing**

In asynchronous time-division multiplexing, the sampling rate is different for different signals, and it doesn’t require a common clock. If the devices have nothing to transmit, then their time slot is allocated to another device. Designing of a commutator or de-commutator is difficult and the bandwidth is less for time-division multiplexing. This type of time-division multiplexing is used in asynchronous transfer mode networks.



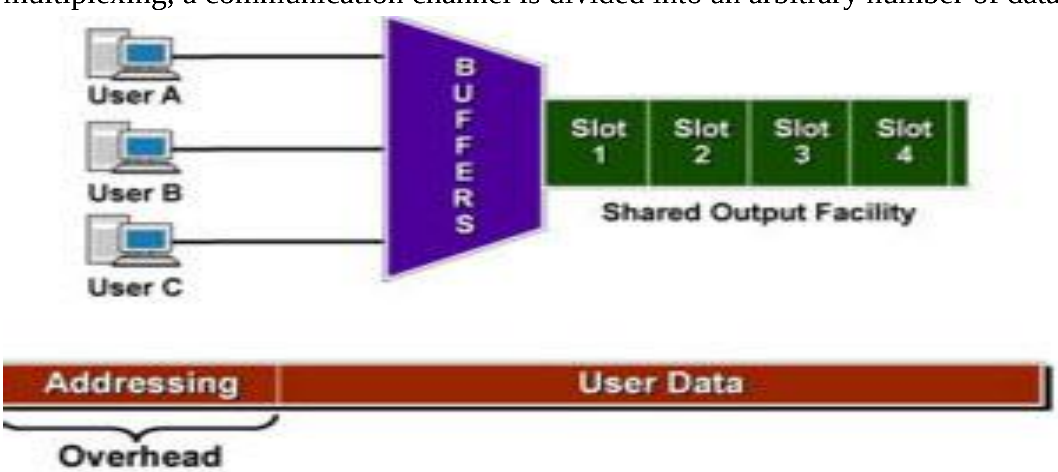
c) **Interleaving**

Time-division multiplexing can be visualized as two fast rotating switches on the multiplexing and demultiplexing side. At the same speed these switches rotate and synchronize, but in opposite directions. When the switch opens at the multiplexer side in front of a connection, it has the opportunity to send a unit into the path. In the same way, when the switch opens on the demultiplexer side in front of a connection that has the opportunity to receive a unit from the path. This process is called interleaving.



d) **Statistical Time-Division Multiplexing**

Statistical time-division multiplexing is used to transmit several types of data concurrently across a single transmission cable. This is often used for managing data being transmitted via LAN or WAN. The data is simultaneously transmitted from the input devices that are connected to the network including printers, fax machines, and computers. This type of multiplexing is also used in telephone switch board settings to manage the calls. Statistical TDM is similar to dynamic bandwidth allocation, an in this type of time-division multiplexing, a communication channel is divided into an arbitrary number of data streams.



F) Transmission Media

Transmission media is a pathway that carries the information from sender to receiver. We use different types of cables or waves to transmit data. Data is transmitted normally through electrical or electromagnetic signals.

Types of Transmission Media:

1. Wired or Guided Media or Bound Transmission Media :

Bound transmission media are the cables that are tangible or have physical existence and are limited by the physical geography.

2. Wireless or Unguided Media or Unbound Transmission Media :

Unbound transmission media are the ways of transmitting data without using any cables. These media are not bounded by physical geography. This type of transmission is called Wireless communication.

There are 3 major types of Guided Media:

a) Twisted Pair Cable

This cable is the most commonly used and is cheaper than others. It is lightweight, cheap, can be installed easily, and they support many different types of network. Some important points :

- Its frequency range is 0 to 3.5 kHz.
- Typical attenuation is 0.2 dB/Km @ 1kHz.
- Typical delay is 50 µs/km.
- Repeater spacing is 2km.

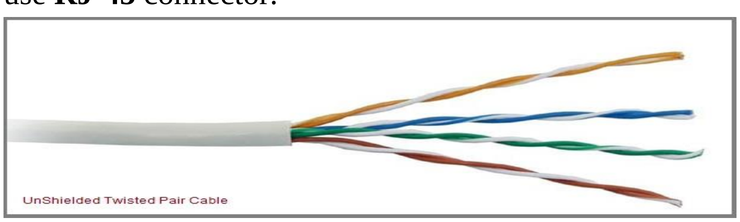
A twisted pair consists of two conductors(normally copper), each with its own plastic insulation, twisted together. One of these wires is used to carry signals to the receiver, and the other is used only as ground reference. The receiver uses the difference between the two. In addition to the signal sent by the sender on one of the wires, interference(noise) and crosstalk may affect both wires and create unwanted signals. If the two wires are parallel, the effect of these unwanted signals is not the same in both wires because they are at different locations relative to the noise or crosstalk sources. This results in a difference at the receiver.

Twisted Pair is of two types:

i. Unshielded Twisted Pair Cable

It is the most common type of telecommunication when compared with Shielded Twisted Pair Cable which consists of two conductors usually copper, each with its own colour plastic insulator. Identification is the reason behind coloured plastic insulation.

UTP cables consist of 2 or 4 pairs of twisted cable. Cable with 2 pair use **RJ-11** connector and 4 pair cable use **RJ-45** connector.



Types of UTP cables

The five categories of UTP cable are defined by the TIA/EIA 568 standard:

- CAT3: Rarely used today, CAT3 is usually deployed in phone lines. It supports 10 Mbps for up to 100 meters.
- CAT4: Typically used in token ring networks, CAT4 supports 16 Mbps for up to 100 meters.

- CAT5: Used in Ethernet-based LANs, CAT5 contains two twisted pairs. It supports 100 Mbps for up to 100 meters.
- CAT5e: Used in Ethernet-based LANs, CAT5e contains four twisted pairs. It supports 1 Gbps for 100 meters.
- CAT6: Used in Ethernet-based LANs and data center networks, CAT6 contains four tightly wound twisted pairs. It supports 1 Gbps for up to 100 meters and 10 Gbps for up to 50 meters.

Advantages of Unshielded Twisted Pair Cable

- Installation is easy
- Flexible
- Cheap
- It has high speed capacity,
- 100 meter limit
- Higher grades of UTP are used in LAN technologies like Ethernet.

It consists of two insulating copper wires (1mm thick). The wires are twisted together in a helical form to reduce electrical interference from similar pair.

Disadvantages of Unshielded Twisted Pair Cable

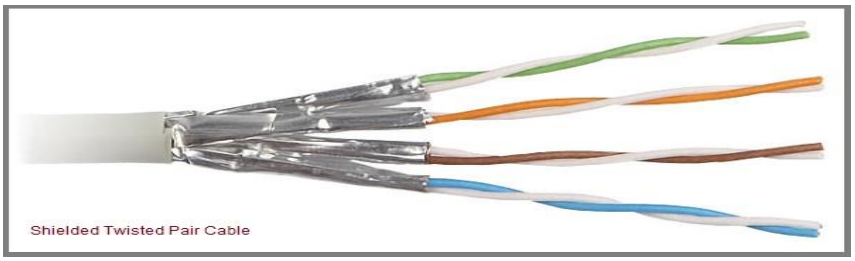
- Bandwidth is low when compared with Coaxial Cable
- Provides less protection from interference.

ii. Shielded Twisted Pair Cable

This cable has a metal foil or braided-mesh covering which encases each pair of insulated conductors. Electromagnetic noise penetration is prevented by metal casing. Shielding also eliminates crosstalk. It has same attenuation as unshielded twisted pair. It is faster the unshielded and coaxial cable. It is more expensive than coaxial and unshielded twisted pair.

Category	Maximum data rate	Usual application
CAT 1 (de facto name, never a standard)	Up to 1 Mbps (1 MHz)	analog voice (POTS) Basic Rate Interface in ISDN Doorbell wiring
CAT 2(de facto name, never a standard)	4 Mbps	Mainly used in the IBM cabling system for Token Ring networks
CAT 3	16 Mbps	Voice (analog most popular implementation) 10BASE-T Ethernet
CAT 4	20 Mbps	Used in 16 Mbps Token Ring, otherwise not used much. Was only a standard briefly and never widely installed.
CAT 5	100 MHz	100 Mbps TPDDI 155 Mbps ATM No longer supported; replaced by 5E. 10/100BASE-T 4/16MBps Token Ring Analog Voice

CAT 5E	100 MHz	100 Mbps TPDDI 155 Mbps ATM Gigabit Ethernet Offers better near-end crosstalk than CAT 5
CAT 6	Up to 250 MHz	Minimum cabling for data centers in TIA-942. Quickly replacing category 5e.
CAT 6E	MHz (field-tested to 500 MHz)	Support for 10 Gigabit Ethernet (10GBASE-T) May be either shielded (STP, ScTP, S/FTP) or unshielded (UTP)
CAT 7 (ISO Class F)	600 MHz 1.2 GHz in pairs with Siemon connector	Fully Shielded (S/FTP) system using non-RJ45 connectors but backwards compatible with hybrid cords. Until February 2008, the only standard (published in 2002) to support 10GBASE-T for a full 100m.



Advantages of Shielded Twisted Pair Cable
- Easy to install
- Performance is adequate
- Can be used for Analog or Digital transmission
- Increases the signalling rate
- Higher capacity than unshielded twisted pair
- Eliminates crosstalk

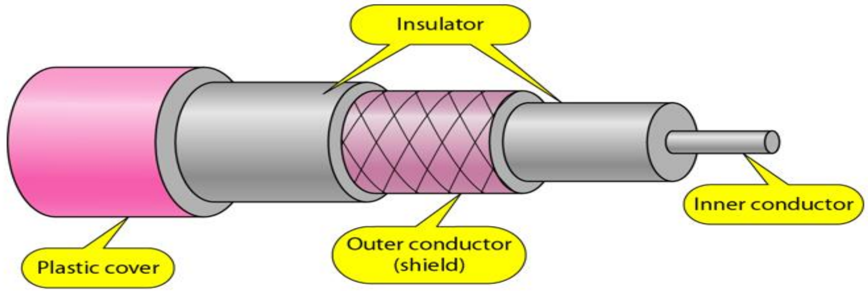
Disadvantages of Shielded Twisted Pair Cable
- Difficult to manufacture
- Heavy

b) Coaxial Cable

Coaxial is called by this name because it contains two conductors that are parallel to each other. Copper is used in this as centre conductor which can be a solid wire or a standard one. It is surrounded by PVC installation, a sheath which is encased in an outer conductor of metal foil, barid or both.

Outer metallic wrapping is used as a shield against noise and as the second conductor which completes the circuit. The outer conductor is also encased in an insulating sheath. The outermost part is the plastic cover which protects the whole cable.

Here the most common coaxial standards.
- 50-Ohm RG-7 or RG-11 : used with thick Ethernet.
- 50-Ohm RG-58 : used with thin Ethernet
- 75-Ohm RG-59 : used with cable television
- 93-Ohm RG-62 : used with ARCNET.



There are two types of Coaxial cables:

i. **BaseBand**

This is a 50 ohm (Ω) coaxial cable which is used for digital transmission. It is mostly used for LAN's. Baseband transmits a single signal at a time with very high speed. The major drawback is that it needs amplification after every 1000 feet.

ii. **BroadBand**

This uses analog transmission on standard cable television cabling. It transmits several simultaneous signal using different frequencies. It covers large area when compared with Baseband Coaxial Cable.

Advantages of Coaxial Cable

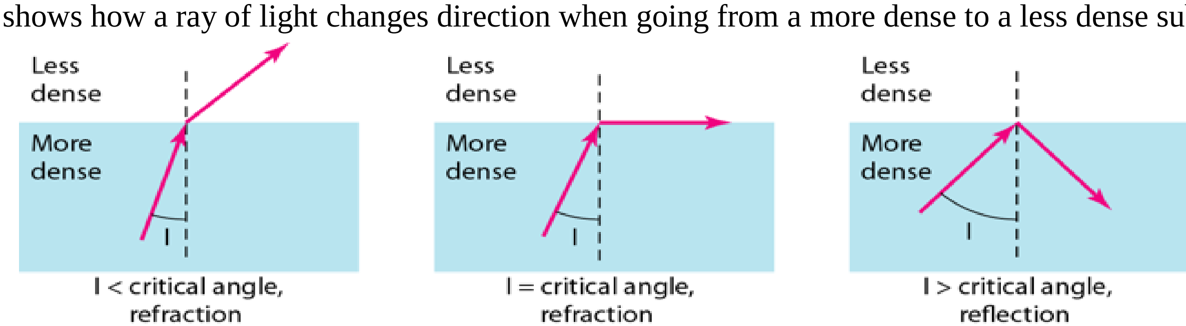
- Bandwidth is high
- Used in long distance telephone lines.
- Transmits digital signals at a very high rate of 10Mbps.
- Much higher noise immunity
- Data transmission without distortion.
- The can span to longer distance at higher speeds as they have better shielding when compared to twisted pair cable

Disadvantages of Coaxial Cable

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

c) Fiber Optic Cable

A fibre-optic cable is made of glass or plastic and transmits signals in the form of light.
For better understanding we first need to explore several aspects of the **nature of light**. Light travels in a straight line as long as it is mobbing through a single uniform substance. If ray of light travelling through one substance suddenly enters another substance (of a different density), the ray changes direction. The below figure shows how a ray of light changes direction when going from a more dense to a less dense substance.



Bending of a light ray

As the figure shows:

- If the **angle of incidence I**(the angle the ray makes with the line perpendicular to the interface between the two substances) is **less** than the **critical angle**, the ray **refracts** and moves closer to the surface.
- If the angle of incidence is **greater** than the critical angle, the ray **reflects**(makes a turn) and travels again in the denser substance.
- If the angle of incidence is **equal** to the critical angle, the ray refracts and **moves parallel** to the surface as shown.

Note: *The critical angle is a property of the substance, and its value differs from one substance to another.*

Optical fibres use reflection to guide light through a channel. A glass or plastic core is surrounded by a cladding of less dense glass 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.

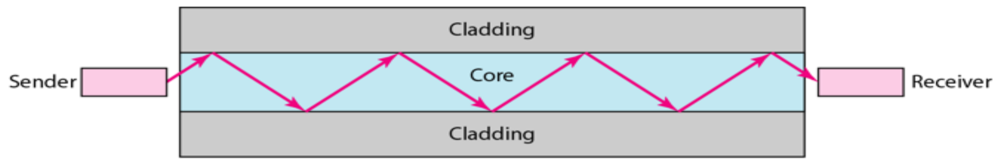
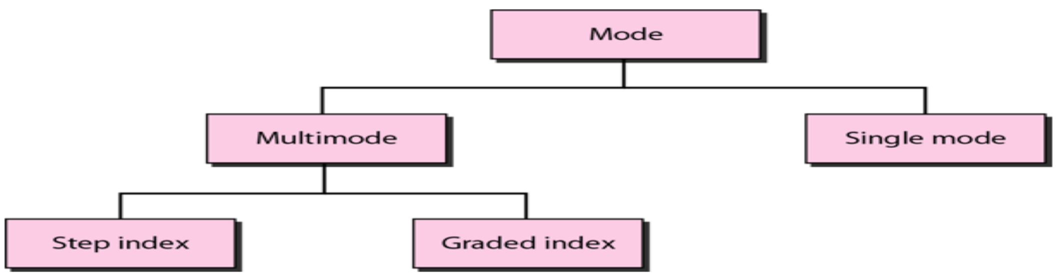


FIG: Internal view of an Optical fibre

Propagation Modes of Fiber Optic Cable

Current technology supports two modes(**Multimode** and **Single mode**) for propagating light along optical channels, each requiring fibre with different physical characteristics

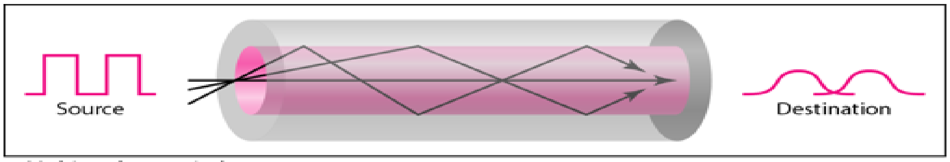


i. Multimode Propagation Mode

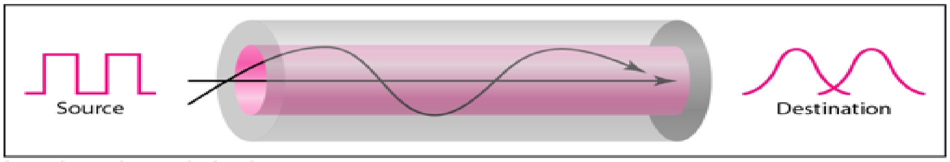
Multimode is so named because multiple beams from a light source move through the core in different paths. How these beams move within the cable depends on the structure of the core as shown in the below figure.

- In **multimode step-index fibre**, the density of the core remains constant from the centre to the edges. A beam of light moves through this constant density in a straight line until it reaches the interface of the core and the cladding.

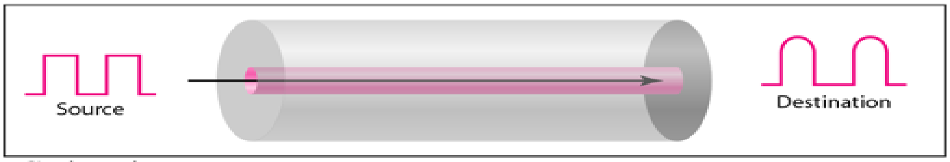
  The term step-index refers to the suddenness of this change, which contributes to the distortion of the signal as it passes through the fibre.
- In **multimode graded-index fibre**, this distortion gets decreases through the cable. The word index here refers to the index of refraction. This index of refraction is related to the density. A graded-index fibre, therefore, is one with varying densities. Density is highest at the centre of the core and decreases gradually to its lowest at the edge.



a. Multimode, step index



b. Multimode, graded index



c. Single mode

ii. Single Mode

Single mode uses step-index fibre and a highly focused source of light that limits beams to a small range of angles, all close to the horizontal. The single-mode fibre itself is manufactured with a much smaller diameter than that of multimode fibre, and with substantially lower density.

The decrease in density results in a critical angle that is close enough to 90 degree to make the propagation of beams almost horizontal.

Advantages of Fibre Optic Cable

Fibre optic has several advantages over metallic cable:

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

Disadvantages of Fibre Optic Cable

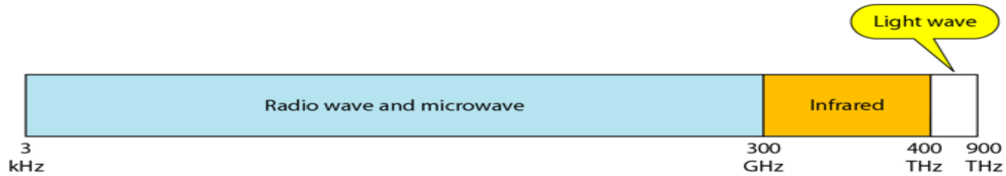
There are some disadvantages in the use of optical fibre:

- Installation and maintenance
- Unidirectional light propagation
- High Cost

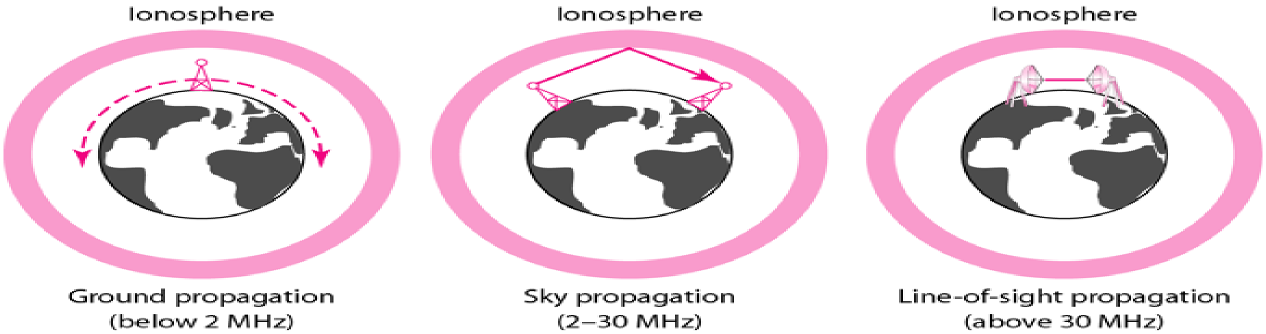
2) UnBounded or UnGuided Transmission Media

Unguided medium transport electromagnetic waves without using a physical conductor. This type of communication is often referred to as wireless communication. Signals are normally broadcast through free space and thus are available to anyone who has a device capable of receiving them.

The below figure shows the part of the electromagnetic spectrum, ranging from 3 kHz to 900 THz, used for wireless communication.



Unguided signals can travel from the source to the destination in several ways: **Gound propagation**, **Sky propagation** and **Line-of-sight propagation** as shown in below figure.



Propagation Modes

- **Ground Propagation:** In this, radio waves travel through the lowest portion of the atmosphere, hugging the Earth. These low-frequency signals emanate in all directions from the transmitting antenna and follow the curvature of the planet.
- **Sky Propagation:** In this, higher-frequency radio waves radiate upward into the ionosphere where they are reflected back to Earth. This type of transmission allows for greater distances with lower output power.
- **Line-of-sight Propagation:** in this type, very high-frequency signals are transmitted in straight lines directly from antenna to antenna.

We can divide wireless transmission into three broad groups:

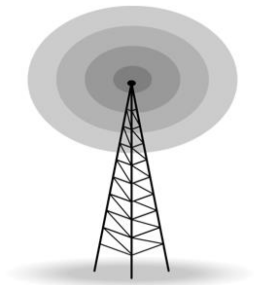
a) Radio Waves

Electromagnetic waves ranging in frequencies between 3 KHz and 1 GHz are normally called radio waves. Radio waves are omnidirectional. When an antenna transmits radio waves, they are propagated in all directions. This means that the sending and receiving antennas do not have to be aligned. A sending antenna send waves that can be received by any receiving antenna. The omnidirectional property has disadvantage, too. The radio waves transmitted by one antenna are susceptible to interference by another antenna that may send signal suing the same frequency or band.

Radio waves, particularly with those of low and medium frequencies, can penetrate walls. This characteristic can be both an advantage and a disadvantage. It is an advantage because, an AM radio can receive signals inside a building. It is a disadvantage because we cannot isolate a communication to just inside or outside a building.

Omnidirectional Antenna for Radio Waves

Radio waves use omnidirectional antennas that send out signals in all directions.



Applications of Radio Waves

- The omnidirectional characteristics of radio waves make them useful for multicasting in which there is one sender but many receivers.
- AM and FM radio, television, maritime radio, cordless phones, and paging are examples of multicasting.

b) Micro Waves

Electromagnetic waves having frequencies between 1 and 300 GHz are called micro waves. Micro waves are unidirectional. When an antenna transmits microwaves, they can be narrowly focused. This means that the sending and receiving antennas need to be aligned. The unidirectional property has an obvious advantage. A pair of antennas can be aligned without interfering with another pair of aligned antennas.

The following describes some characteristics of microwaves propagation:

- Microwave propagation is line-of-sight. Since the towers with the mounted antennas need to be in direct sight of each other, towers that are far apart need to be very tall.
- Very high-frequency microwaves cannot penetrate walls. This characteristic can be a disadvantage if receivers are inside the buildings.
- The microwave band is relatively wide, almost 299 GHz. Therefore, wider sub-bands can be assigned and a high date rate is possible.
- Use of certain portions of the band requires permission from authorities.

Applications of Micro Waves

Microwaves, due to their unidirectional properties, are very useful when unicast(one-to-one) communication is needed between the sender and the receiver. They are used in cellular phones, satellite networks and wireless LANs.

There are 2 types of Microwave Transmission :

i. Terrestrial Microwave
ii. Satellite Microwave

Advantages of Microwave Transmission

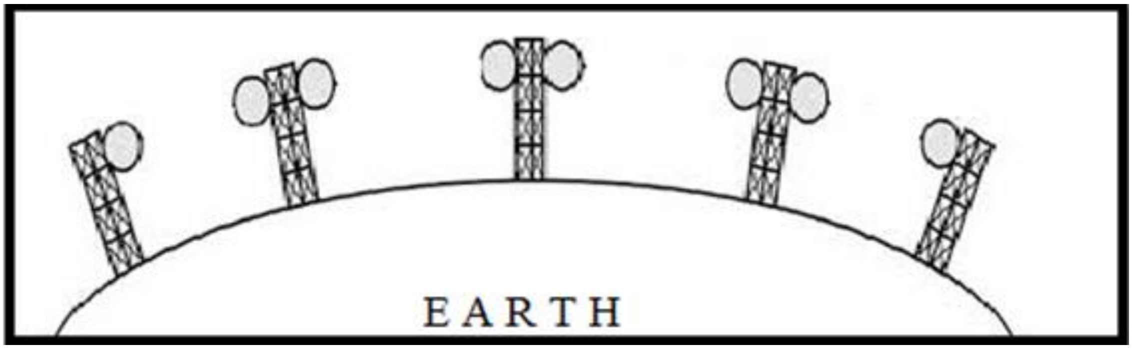
- Used for long distance telephone communication
- Carries 1000's of voice channels at the same time

Disadvantages of Microwave Transmission

- It is very costly

i. Terrestrial Microwave

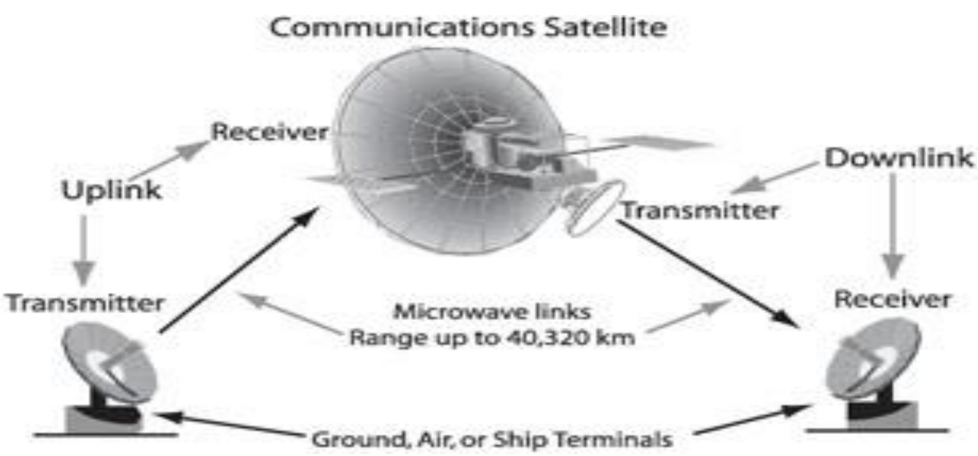
For increasing the distance served by terrestrial microwave, repeaters can be installed with each antenna .The signal received by an antenna can be converted into transmittable form and relayed to next antenna as shown in below figure. It is an example of telephone systems all over the world



ii. Satellite Microwave

This is a microwave relay station which is placed in outer space. The satellites are launched either by rockets or space shuttles carry them.

These are positioned 36000 Km above the equator with an orbit speed that exactly matches the rotation speed of the earth. As the satellite is positioned in a geo-synchronous orbit, it is stationery relative to earth and always stays over the same point on the ground. This is usually done to allow ground stations to aim antenna at a fixed point in the sky.



Features of Satellite Microwave

- Bandwidth capacity depends on the frequency used.
- Satellite microwave deployment for orbiting satellite is difficult.

Advantages of Satellite Microwave

- Transmitting station can receive back its own transmission and check whether the satellite has transmitted information correctly.
- A single microwave relay station which is visible from any point.

Disadvantages of Satellite Microwave

- Satellite manufacturing cost is very high
- Cost of launching satellite is very expensive
- Transmission highly depends on whether conditions, it can go down in bad weather

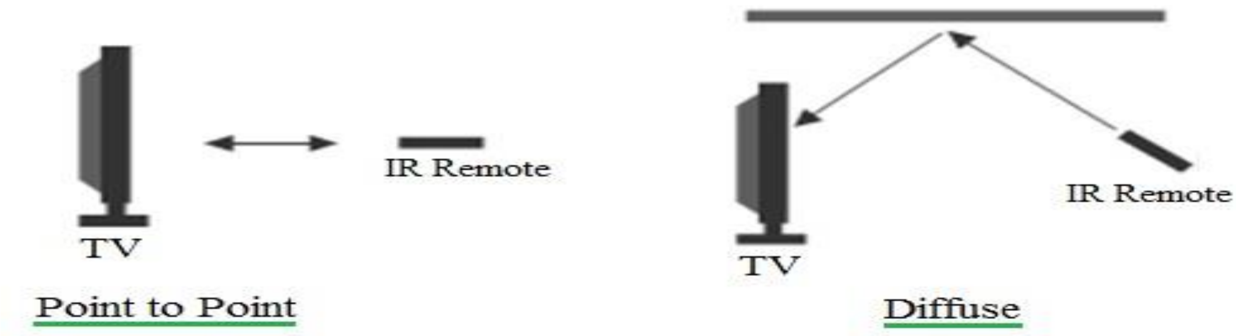
c) Infrared Waves

Infrared waves, with frequencies from 300 GHz to 400 THz, can be used for short-range communication. Infrared waves, having high frequencies, cannot penetrate walls. This advantageous characteristic prevents interference between one system and another, a short-range communication system in on room cannot be affected by another system in the next room.

When we use infrared remote control, we do not interfere with the use of the remote by our neighbours. However, this same characteristic makes infrared signals useless for long-range communication. In addition, we cannot use infrared waves outside a building because the sun's rays contain infrared waves that can interfere with the communication.

Applications of Infrared Waves

- The infrared band, almost 400 THz, has an excellent potential for data transmission. Such a wide bandwidth can be used to transmit digital data with a very high data rate.
- The Infrared Data Association(IrDA), an association for sponsoring the use of infrared waves, has established standards for using these signals for communication between devices such as keyboards, mouse, PCs and printers.
- Infrared signals can be used for short-range communication in a closed area using line-of-sight propagation.



d) VSAT:

*VSAT is a technology that represents another option for Internet connectivity in extremely remote areas and distant field locations.*VSAT is specifically designed for remote locations and is a more cost effective alternative to conventional satellite communications services such as HughesNet, Dish Network, and others.

Very Small Aperture Terminal (VSAT) is technology that is commonly referred to as a private earth station. The earth station is designed to transmit and receive data signals via a satellite signal. VSAT includes the term “very small” which refers to the size of the antenna on the VSAT dish.

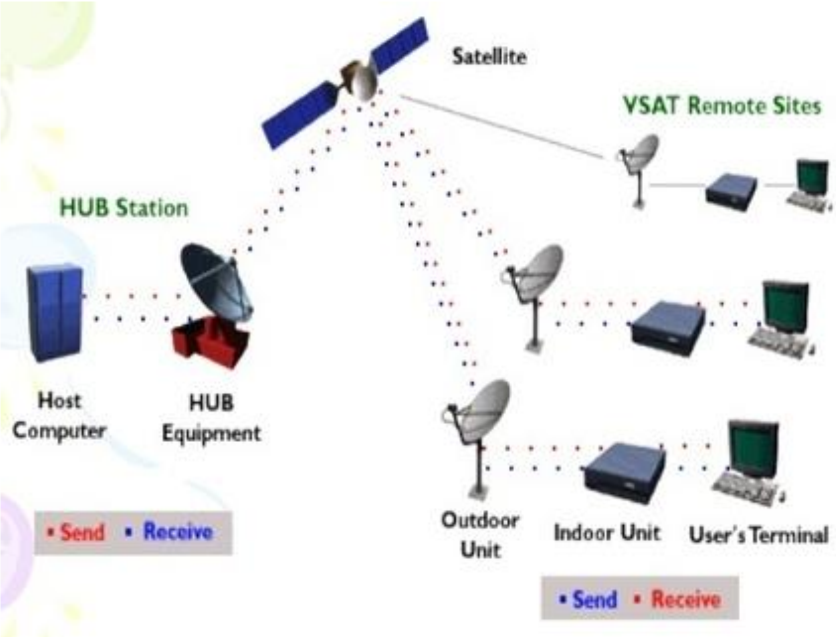
The antenna typically measures about four feet in diameter and has a low-noise converter attached to it which receives the satellite signal, and a Block Upconverter (BUC) that transmits the signals for the radio waves. The antenna can be positioned on the ground or it can be mounted on a rooftop.

A VSAT connection is established through the use of the antenna system described above. Your PC or mobile device communicates with the antenna and then the antenna uses the transceiver components to send and receive signals from the satellite. The sky satellite communicates with a station-based PC on the earth by sending and receiving signals. The station-based PC acts as the hub for the VSAT system and communicates with the end users of the VSAT configuration.
When the system is comprised of multiple users, in order to establish communications with one another the data must be transmitted to the station-based PC which sends the signal to the sky satellite. The satellite sky transponder then forwards the data transmission to the end user’s VSAT antenna and finally to the end user’s device. In addition to data transmission, a VSAT system can also handle voice and video.

Pros

- **Instant Infrastructure**: VSAT is quick to install, has a relatively low upfront investment, and per minute operating costs that are low and allow VSAT service providers to offer rates that are affordable.
- **Easy Network Management**: Network management is a lot easier since VSATs are both scalable and flexible. If new sites need to be added or an existing site must be relocated, installation can be carried out independently which reduces delays and the probability of errors.

- **Access to Recovery Systems**: VSAT technology provides a reliable architecture on which to build recovery networks. This makes a recovery solution immediately available should a terrestrial network become incapacitated for any reason.
- **Broad Coverage**: VSAT networks can leverage broad satellite coverage to reduce the cost of multiple networks, as opposed to resorting to complex development of other satellite solutions. This allows digital information to be transmitted more cost effectively and efficiently via low cost architecture and more powerful systems.
- **Security**: VSAT systems are quite secure. This is because there are typically two private layer networks. This type of technology acts as a Virtual Private Network (VPN) that fosters secure communications.
- **Affordable Cost**: The pricing for VSAT is quite affordable since there are minimal overhead costs for the provider networks. This is because the architecture allows providers to serve the same content to literally thousands of different locations without the investment in additional infrastructure.



Cons

- **Latency**: VSAT technology uses satellites in geosynchronous orbit. This type of data transmission has a minimum delay of approximately 500 milliseconds for each round trip. This can present a problem with applications that require consistent transmission back and forth such as gaming applications.
- **Environmental Conditions**: Like other satellite systems, the weather and other environmental conditions can have an impact on the quality of the signal. The upside is it is not as noticeable as services such as Dish Network or DirecTV. VSAT can still have a weak signal though since it is dependent upon the size of the antenna, frequency band, and the power of the transmitters.
- **Clear View of the Southern Sky**: Since VSAT requires an outdoor antenna, it requires the location to have a clear view of the southern sky in order to make contact with the satellites. Sometimes a structure such as a skyscraper with an unusual roof or other type of location can be an issue.

H) Transmission Errors, Error Detection and Correction Codes:

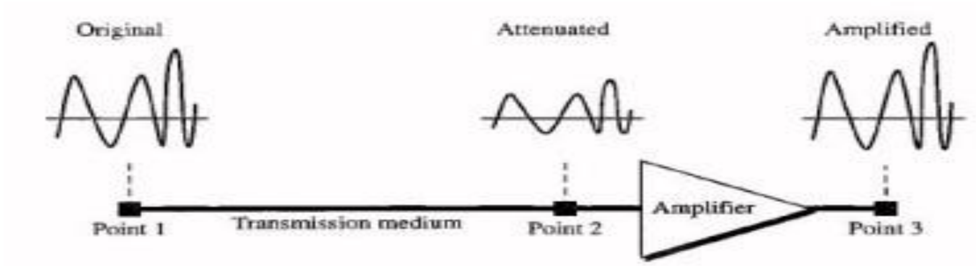
1. Transmission Impairment

In communication system, analog signals travel through transmission media, which tends to deteriorate the quality of analog signal. This imperfection causes signal impairment. This means that received signal is not same as the signal that was send.

Causes of impairment –

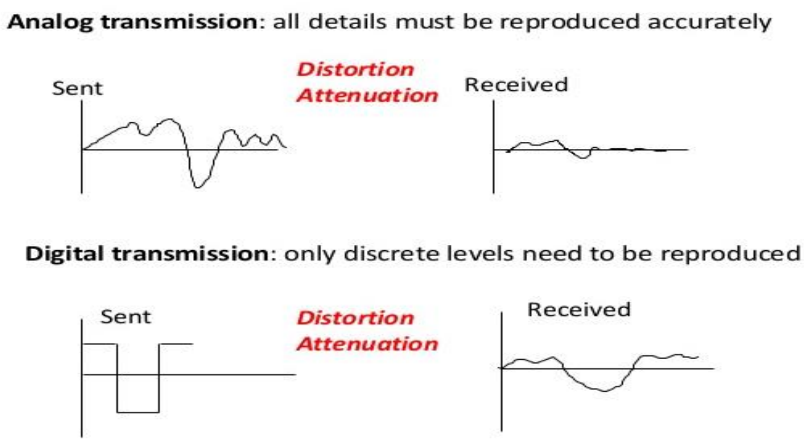
a) Attenuation:

It means loss of energy. The strength of signal decreases with increasing distance which causes loss of energy in overcoming resistance of medium. This is also known as attenuated signal. Amplifiers are used to amplify the attenuated signal which gives the original signal back.



b) **Distortion:**

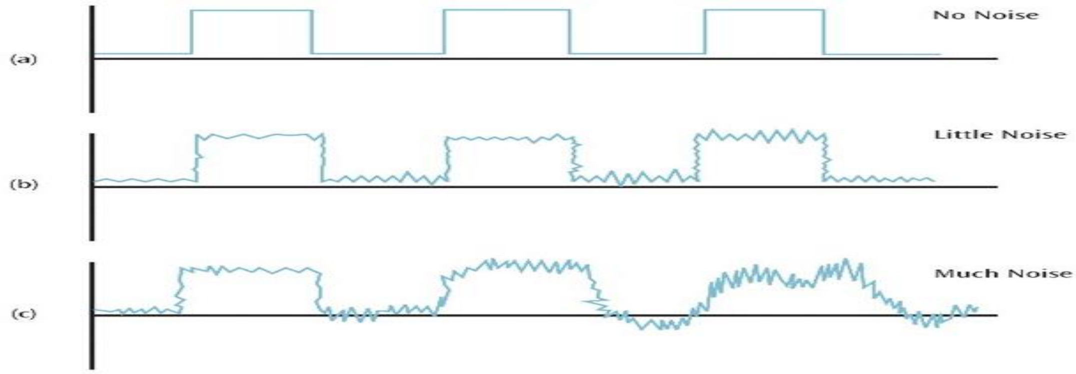
It means change in the shape of signal. This is generally seen in composite signals with different frequencies. Each frequency component has its own propagation speed travelling through a medium. Every component arrive at different time which leads to delay distortion. Therefore, they have different phases at receiver end from what they had at senders end.



c) **Noise:**

The random or unwanted signal that mixes up with the original signal is called noise. There are several types of noise such as induced noise, crosstalk noise, thermal noise and impulse noise which may corrupt the signal.

Induced noise comes from sources such as motors and appliances. These devices act as sending antenna and transmission medium act as receiving antenna. **Thermal** noise is movement of electrons in wire which creates an extra signal. **Crosstalk** noise is when one wire affects the other wire. **Impulse** noise is a signal with high energy that comes from lightning or power lines



2. Transmission Errors:

With data communications, there are some errors that may occur when the data travels through the computer channels.

a) Noise or Electrical Distortion

Depending on the length data travels, outside influences like sound waves or electrical signals can disrupt the flow of data in a computer system. This may be the result of the conductors that transmit the data across computers or software systems. Old conductors may be unable to handle heavy data traffic and physical interference from the environment in the form of noise or electricity that comes from nearby devices, like motors or power switches. One type of noise is especially harmful. Known as impulse noise, it is when energy surges through the transmission line, destroying most or all of the data communication.

b) Random Bit Errors

Random bit errors are complications that occur in the transmission of data. Bits are units of computer data, usually in the form of binary codes. A general definition of random bit errors are that these errors come in the form of disorganized bits in the transmission. For example, computer data sent over a transmission might have several thousand bits forming a long line of computer data bits to explain a computer command or information. However, there is a chance that the bits may be rearranged by accident in the transmission process. These random issues are the most common issues associated with random bit errors.

c) Burst Errors

Burst errors are considered large clumps of bit errors. Burst errors are similar to random bit errors; however, all random bit errors are isolated strains on a computer data code. Burst errors take place when there are several, inter-connected bit errors at once. The entire data chain in the computer communication may have several hundred or thousand bit errors, such as wrong placement order, throughout the chain. Because the error is interconnected, meaning there are several error codes throughout the chain, the data communication error is more complex than a simple random bit error.

d) Cross Talk and Echo

Cross talk is a term to describe how two different data communications may be synthesized together in a computer transmission. Usually, how this error occurs is when a computer line is sending data through a transmission cable that is surrounded by other transmission cables. As other data communication codes and bits go through the neighboring transmission lines, there is a high likelihood that data from other neighboring lines may cross into another line. Another type of error similar to cross talk is an echo. Like cross-talk, it is formed when conflicting data communications are merged together.

3. Error Detection and Correction Codes:

A. Error Detecting Codes

Error detection is the process of detecting the errors that are present in the data transmitted from transmitter to receiver, in a communication system. We use some redundancy codes to detect these errors, by adding to the data while it is transmitted from source (transmitter). These codes are called “Error detecting codes”.

Types of Error detection

a) Parity Checking/ Vertical Redundancy Check (VRC)

Parity bit means nothing but an additional bit added to the data at the transmitter before transmitting the data. Before adding the parity bit, number of 1’s or zeros is calculated in the data. Based on this calculation of data an extra bit is added to the actual information / data. The addition of parity bit to the data will result in the change of data string size.

This means if we have an 8 bit data, then after adding a parity bit to the data binary string it will become a 9 bit binary data string.

There is two types of parity bits in error detection, they are:

i. **Even Parity**

- If the data has even number of 1’s, the parity bit is 0. Ex: data is 10000001 -> parity bit 0
- Odd number of 1’s, the parity bit is 1. Ex: data is 10010001 -> parity bit 1

ii. **Odd Parity**

- If the data has odd number of 1’s, the parity bit is 0. Ex: data is 10011101 -> parity bit 0
- Even number of 1’s, the parity bit is 1. Ex: data is 10010101 -> parity bit 1

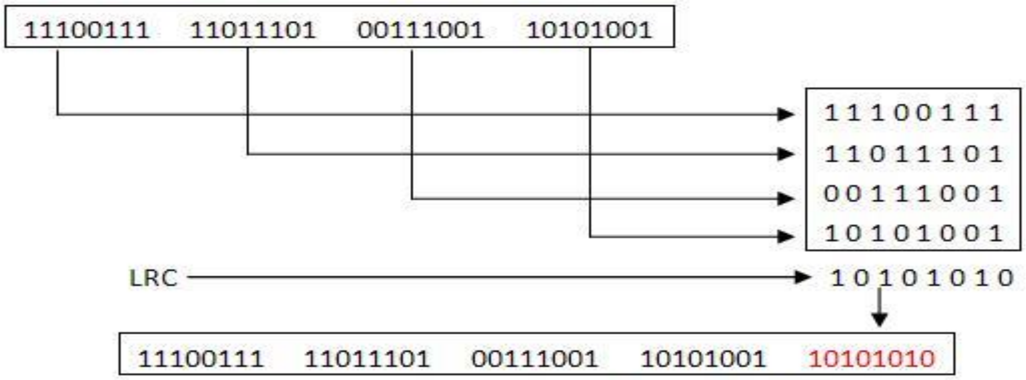
3 bit data			Message with even parity		Message with odd parity	
A	B	C	Message	Parity	Message	Parity
0	0	0	000	0	000	1
0	0	1	001	1	001	0
0	1	0	010	1	010	0
0	1	1	011	0	011	1
1	0	0	100	1	100	0
1	0	1	101	0	101	1
1	1	0	110	0	110	1
1	1	1	111	1	111	0

b) Longitudinal Redundancy Check (LRC)

In longitudinal redundancy method, a BLOCK of bits are arranged in a table format (in rows and columns) and we will calculate the parity bit for each column separately. The set of these parity bits are also sent along with our original data bits.

Longitudinal redundancy check is a bit by bit parity computation, as we calculate the parity of each column individually.

This method can easily detect burst errors and single bit errors and it fails to detect the 2 bit errors occurred in same vertical slice.



Original data message including LRC

c) Cyclic Redundancy Check (CRC)

Cyclic Redundancy Check (CRC) An error detection mechanism in which a special number is appended to a block of data in order to detect any changes introduced during storage (or transmission). The CRC is recalculated on retrieval (or reception) and compared to the value originally transmitted, which can reveal certain types of error. For example, a single corrupted bit in the data results in a one-bit change in the calculated CRC, but multiple corrupt bits may cancel each other out. This technique is more powerful than the parity check and checksum error detection.

Requirements of CRC :

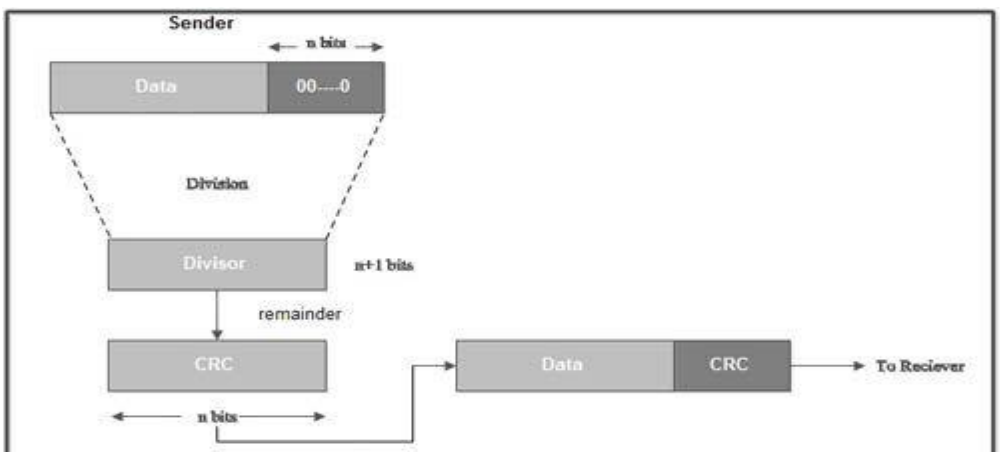
A CRC will be valid if and only if it satisfies the following requirements:

1. It should have exactly one less bit than divisor.
2. Appending the CRC to the end of the data unit should result in the bit sequence which is exactly divisible by the divisor.

The various steps followed in the CRC method are

i. A string of n as is appended to the data unit. The length of predetermined divisor is n+ 1.

ii. The newly formed data unit *i.e.* original data + string of n as are divided by the divisor using binary division and remainder is obtained. This remainder is called CRC.

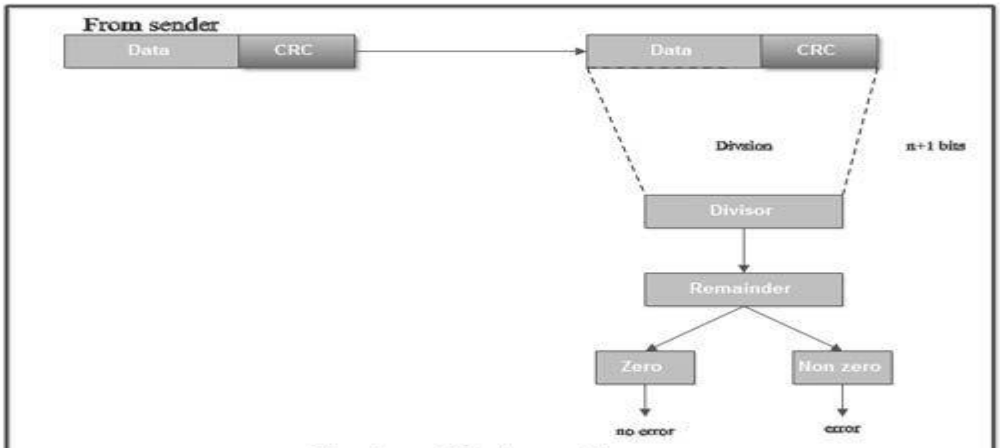


CRC Generator at sender side

iii. Now, string of n Os appended to data unit is replaced by the CRC remainder (which is also of n bit).

iv. The data unit + CRC is then transmitted to receiver.

v. The receiver on receiving it divides data unit + CRC by the same divisor & checks the remainder.

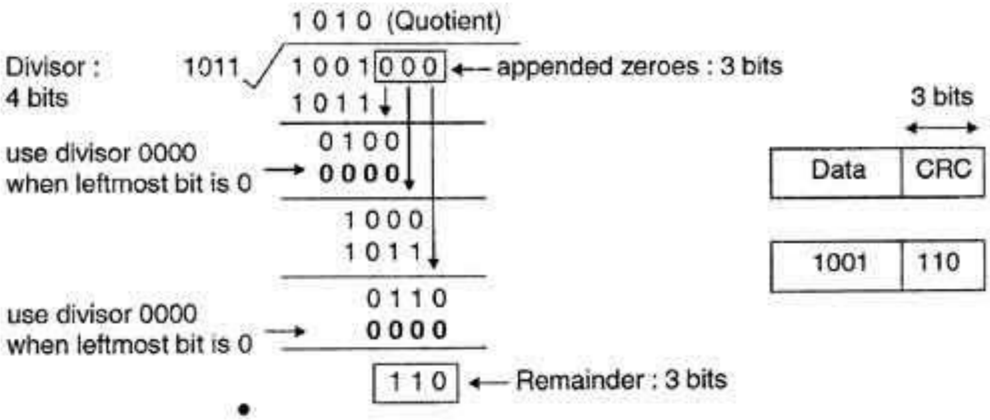


Checker at Reciever side

vi. If the remainder of division is zero, receiver assumes that there is no error in data and it accepts it.
vii. If remainder is non-zero then there is an error in data and receiver rejects it.

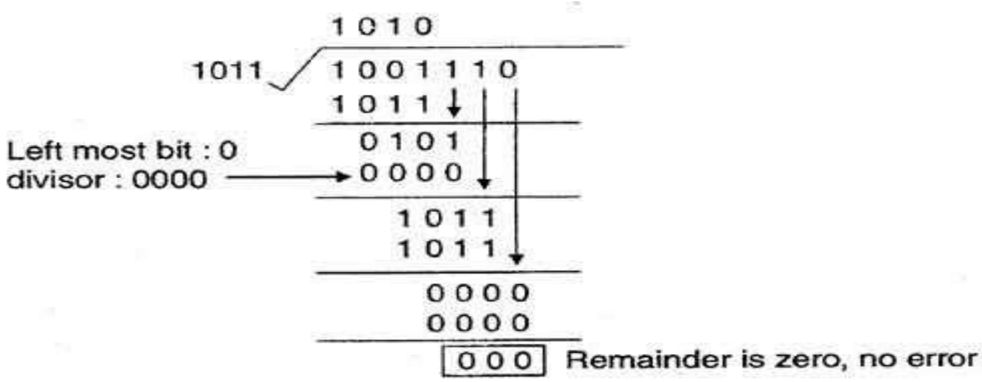
For example, if data to be transmitted is 1001 and predetermined divisor is 1011.
The procedure given below is used:

i. String of 3 zeroes is appended to 1011 as divisor is of 4 bits. Now newly formed data is 1011000.
ii. Data unit 1011000 is divided by 1011.



CRC generated (Binary division)

iii. During this process of division, whenever the leftmost bit of dividend or remainder is 0, we use a string of Os of same length as divisor. Thus in this case divisor 1011 is replaced by 0000.
iv. At the receiver side, data received is 1001110.
v. This data is again divided by a divisor 1011.
vi. The remainder obtained is 000; it means there is no error.



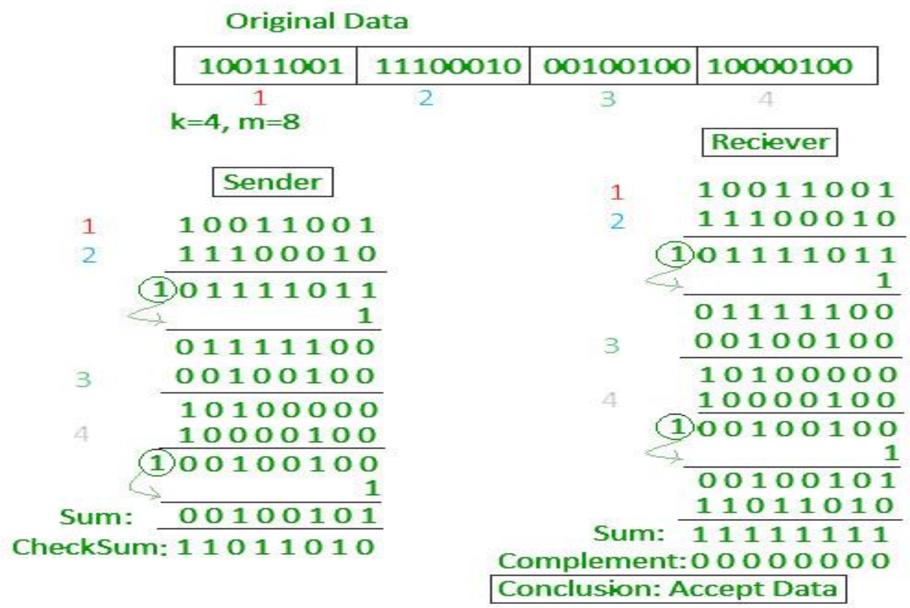
CRC decoded (binary division)

d) Checksum

Checksums are similar to parity bits except, the number of bits in the sums is larger than parity and the result is always constrained to be zero. That means if the checksum is zero, error is detected. A checksum of a message is an arithmetic sum of code words of certain length. The sum is stated by means of 1's compliment and stored or transferred as a code extension of actual code word. At receiver a new checksum is calculated by receiving the bit sequence from transmitter.

The checksum method includes parity bits, check digits and longitudinal redundancy check (LRC). A checksum may also be known as a hash sum.

- In checksum error detection scheme, the data is divided into k segments each of m bits.
- In the sender's end the segments are added using 1's complement arithmetic to get the sum. The sum is complemented to get the checksum.
- The checksum segment is sent along with the data segments.
- At the receiver's end, all received segments are added using 1's complement arithmetic to get the sum. The sum is complemented.
- If the result is zero, the received data is accepted; otherwise discarded.



B. Error Correcting Codes

The codes which are used for both error detecting and error correction are called as "Error Correction Codes". The error correction techniques are of two types. They are,

- Single bit error correction
- Burst error correction

The process or method of correcting single bit errors is called "single bit error correction". The method of detecting and correcting burst errors in the data sequence is called "Burst error correction".

Hamming code or Hamming Distance Code is the best error correcting code we use in most of the communication network and digital systems.

Hamming Code

This error detecting and correcting code technique is developed by R.W.Hamming . This code not only identifies the error bit, in the whole data sequence and it also corrects it. This code uses a number of parity bits located at certain positions in the codeword. The number of parity bits depends upon the number of information bits. The hamming code uses the relation between redundancy bits and the data bits and this code can be applied to any number of data bits.

What is a Redundancy Bit?

Redundancy means "The difference between number of bits of the actual data sequence and the transmitted bits". These redundancy bits are used in communication system to detect and correct the errors, if any.

How the Hamming code actually corrects the errors?

In Hamming code, the redundancy bits are placed at certain calculated positions in order to eliminate errors. The distance between the two redundancy bits is called "Hamming distance".

To understand the working and the data error correction and detection mechanism of the hamming code, let's see to the following stages.

Number of parity bits

As we learned earlier, the number of parity bits to be added to a data string depends upon the number of information bits of the data string which is to be transmitted. Number of parity bits will be calculated by using the data bits. This relation is given below.

$2^P >= n + P + 1$

Here, n represents the number of bits in the data string.

P represents number of parity bits.

For example, if we have 4 bit data string, i.e. n = 4, then the number of parity bits to be added can be found by using trial and error method. Let's take P = 2, then

$$2^P = 2^2 = 4 \text{ and } n + P + 1 = 4 + 2 + 1 = 7$$

This violates the actual expression.

So let's try P = 3, then

$$2^P = 2^3 = 8 \text{ and } n + P + 1 = 4 + 3 + 1 = 8$$

So we can say that 3 parity bits are required to transfer the 4 bit data with single bit error correction.

Where to Place these Parity Bits?

After calculating the number of parity bits required, we should know the appropriate positions to place them in the information string, to provide single bit error correction.

In the above considered example, we have 4 data bits and 3 parity bits. So the total codeword to be transmitted is of 7 bits (4 + 3). We generally represent the data sequence from right to left, as shown below.

bit 7, bit 6, bit 5, bit 4, bit 3, bit 2, bit 1, bit 0

The parity bits have to be located at the positions of powers of 2. I.e. at 1, 2, 4, 8 and 16 etc. Therefore the codeword after including the parity bits will be like this

D7, D6, D5, P4, D3, P2, P1

Here P1, P2 and P3 are parity bits. D1 —- D7 are data bits.

Constructing a Bit Location Table

In Hamming code, each parity bit checks and helps in finding the errors in the whole code word. So we must find the value of the parity bits to assign them a bit value.

Bit Designation Bit Location Binary Location Number	D7 7 111	D6 6 110	D5 5 101	P4 4 100	D3 3 011	P2 2 010	P1 1 001
Data Bits (Dn)				—		—	—
Parity Bits (Pn)	—	—	—		—		

By calculating and inserting the parity bits in to the data bits, we can achieve error correction through Hamming code.

Let's understand this clearly, by looking into an example.

Example:

Encode the data 1101 in even parity, by using Hamming code.

Step 1

Calculate the required number of parity bits.

Let P = 2, then

$2^P = 2^2 = 4$ and $n + P + 1 = 4 + 2 + 1 = 7$.

2 parity bits are not sufficient for 4 bit data.

So let's try P = 3, then

$2^P = 2^3 = 8$ and $n + P + 1 = 4 + 3 + 1 = 8$

Therefore 3 parity bits are sufficient for 4 bit data.

The total bits in the code word are 4 + 3 = 7

Step 2

Constructing bit location table

Bit Designation Bit Location Binary Location Number	D7 7 111	D6 6 110	D5 5 101	P4 4 100	D3 3 011	P2 2 010	P1 1 001
Data Bits (D_n)	1	1	0		1		
Parity Bits (P_n)				0		0	1

Step 3

Determine the parity bits.

For P1 : 3, 5 and 7 bits are having three 1's so for even parity, P1 = 1.

For P2 : 3, 6 and 7 bits are having two 1's so for even parity, P2 = 0.

For P3 : 5, 6 and 7 bits are having two 1's so for even parity, P3 = 0.

By entering / inserting the parity bits at their respective positions, codeword can be formed and is transmitted. It is 1100101.

NOTE: If the codeword has all zeros (ex: 0000000), then there is no error in Hamming code.

To represent the binary data in alphabets and numbers, we use alphanumeric codes.