



## Unit – 2

UNIT - II Wireless Transmission - Communication Satellites - Telephone System: Structure, Local Loop, Trunks and Multiplexing and Switching. Data Link Layer: Design Issues - Error Detection and Correction.

---

---

### Wireless Transmission

Wireless transmission is a form of unguided media. Wireless communication involves no physical link established between two or more devices, communicating wirelessly. Wireless signals are spread over in the air and are received and interpreted by appropriate antennas.

When an antenna is attached to electrical circuit of a computer or wireless device, it converts the digital data into wireless signals and spread all over within its frequency range. The receptor on the other end receives these signals and converts them back to digital data.

#### The Electromagnetic Spectrum

When electrons move, they create electromagnetic waves that can propagate through space (even in a vacuum).

#### Frequency

The number of oscillations per second of a wave is called its frequency,  $f$ , and is measured in Hz.

#### Wavelength

The distance between two consecutive maxima (or minima) is called the wavelength, which is universally designated by the Greek letter  $\lambda$  (lambda).

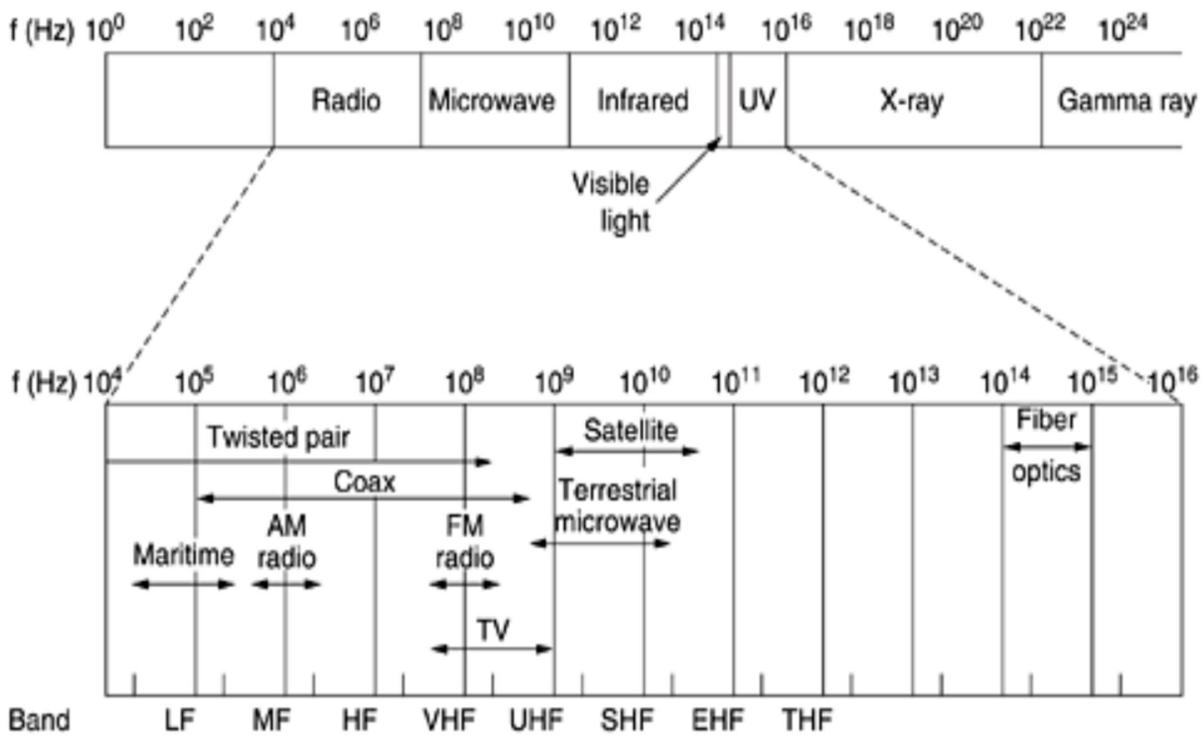
#### Electromagnetic Spectrum

When an antenna of the appropriate size is attached to an electrical circuit, the electromagnetic waves can be broadcast efficiently and received by a receiver some distance away. All wireless communication is based on this principle.

In vacuum, all electromagnetic waves travel at the same speed, no matter what their frequency. This speed, usually called the speed of light,  $c$ , is approximately  $3 \times 10^8$  m/sec.

The fundamental relation between  $f$ ,  $\lambda$ , and  $c$  (in vacuum) is

$$\lambda f = c$$



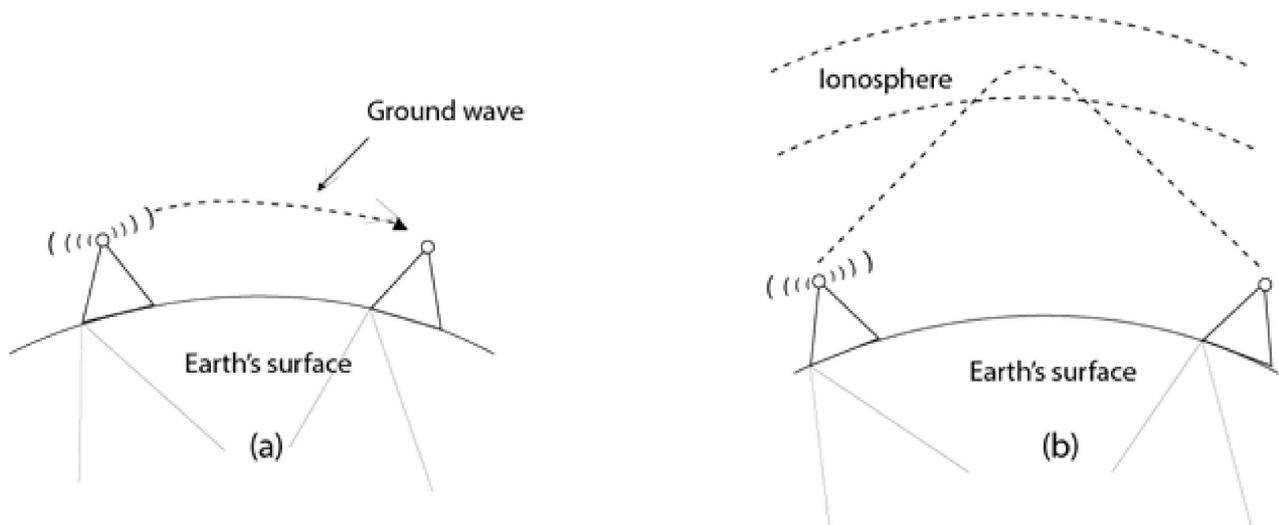
The electromagnetic spectrum is shown in the above fig. The radio, microwave, infrared, and visible light portions of the spectrum can all be used for transmitting information by modulating the amplitude, frequency, or phase of the waves. Ultraviolet light, X-rays, and gamma rays would be even better, due to their higher frequencies, but they are hard to produce and modulate, do not propagate well through buildings, and are dangerous to living things.

The terms LF, MF, and HF refer to low, medium, and high frequency, respectively. Clearly, when the names were assigned, nobody expected to go above 10 MHz, so the higher bands were later named the Very, Ultra, Super, Extremely, and Tremendously High Frequency bands.

## Radio Transmission

### Radio waves

- Radio waves are the electromagnetic waves that are transmitted in all the directions of free space.
- Radio waves are omnidirectional, i.e., the signals are propagated in all the directions.
- The range in frequencies of radio waves is from 3Khz to 1 khz.
- In the case of radio waves, the sending and receiving antenna are not aligned, i.e., the wave sent by the sending antenna can be received by any receiving antenna.
- An example of the radio wave is **FM radio**.



### Applications Of Radio waves:

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

### Advantages Of Radio transmission:

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

### Microwaves

Microwaves are of two types:

- Terrestrial microwave
- Satellite microwave communication.

### Terrestrial Microwave Transmission

- Terrestrial Microwave transmission is a technology that transmits the focused beam of a radio signal from one ground-based microwave transmission antenna to another.
- Microwaves are the electromagnetic waves having the frequency in the range from 1GHz to 1000 GHz.
- Microwaves are unidirectional as the sending and receiving antenna is to be aligned, i.e., the waves sent by the sending antenna are narrowly focussed.
- In this case, antennas are mounted on the towers to send a beam to another antenna which is km away.
- It works on the line of sight transmission, i.e., the antennas mounted on the towers are the direct sight of each other.

### **Characteristics of Microwave:**

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

### **Advantages Of Microwave:**

- Microwave transmission is cheaper than using cables.
- It is free from land acquisition as it does not require any land for the installation of cables.
- Microwave transmission provides an easy communication in terrains as the installation of cable in terrain is quite a difficult task.
- Communication over oceans can be achieved by using microwave transmission.

### **Disadvantages of Microwave transmission:**

- **Eavesdropping:** An eavesdropping creates insecure communication. Any malicious user can catch the signal in the air by using its own antenna.
- **Out of phase signal:** A signal can be moved out of phase by using microwave transmission.
- **Susceptible to weather condition:** A microwave transmission is susceptible to weather condition. This means that any environmental change such as rain, wind can distort the signal.
- **Bandwidth limited:** Allocation of bandwidth is limited in the case of microwave transmission.

### **Satellite Microwave Communication**

- A satellite is a physical object that revolves around the earth at a known height.
- Satellite communication is more reliable nowadays as it offers more flexibility than cable and fibre optic systems.
- We can communicate with any point on the globe by using satellite communication.

### **How Does Satellite work?**

The satellite accepts the signal that is transmitted from the earth station, and it amplifies the signal. The amplified signal is retransmitted to another earth station.

### **Advantages Of Satellite Microwave Communication:**

- The coverage area of a satellite microwave is more than the terrestrial microwave.
- The transmission cost of the satellite is independent of the distance from the centre of the coverage area.

- Satellite communication is used in mobile and wireless communication applications.
- It is easy to install.
- It is used in a wide variety of applications such as weather forecasting, radio/TV signal broadcasting, mobile communication, etc.

#### **Disadvantages Of Satellite Microwave Communication:**

- Satellite designing and development requires more time and higher cost.
- The Satellite needs to be monitored and controlled on regular periods so that it remains in orbit.
- The life of the satellite is about 12-15 years. Due to this reason, another launch of the satellite has to be planned before it becomes non-functional.

---

#### **Infrared Transmission**

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

#### **Characteristics Of Infrared:**

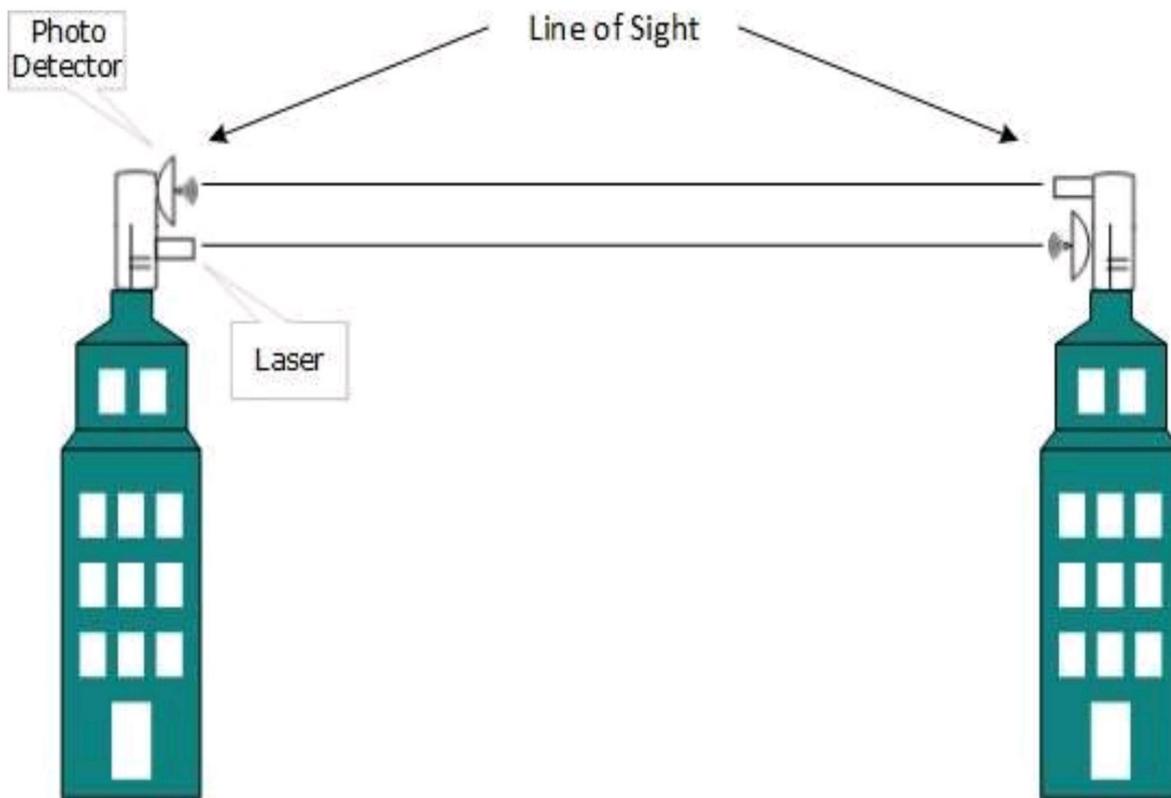
- It supports high bandwidth, and hence the data rate will be very high.
- Infrared waves cannot penetrate the walls. Therefore, the infrared communication in one room cannot be interrupted by the nearby rooms.
- An infrared communication provides better security with minimum interference.
- Infrared communication is unreliable outside the building because the sun rays will interfere with the infrared waves.

---

#### **Lightwave Transmission**

Highest most electromagnetic spectrum which can be used for data transmission is light or optical signaling. This is achieved by means of LASER.

Because of frequency light uses, it tends to travel strictly in straight line. Hence the sender and receiver must be in the line-of-sight. Because laser transmission is unidirectional, at both ends of communication the laser and the photo-detector needs to be installed. Laser beam is generally 1mm wide hence it is a work of precision to align two far receptors each pointing to lasers source.



Laser works as Tx (transmitter) and photo-detectors works as Rx (receiver).

Lasers cannot penetrate obstacles such as walls, rain, and thick fog. Additionally, laser beam is distorted by wind, atmosphere temperature, or variation in temperature in the path.

Laser is safe for data transmission as it is very difficult to tap 1mm wide laser without interrupting the communication channel.

# Communication Satellites

Communication satellites have some interesting properties that make them attractive for many applications. In its simplest form, a communication satellite can be thought of as a big microwave repeater in the sky. It contains several transponders, each of which listens to some portion of the spectrum, amplifies the incoming signal, and then rebroadcasts it at another frequency to avoid interference with the incoming signal. The downward beams can be broad, covering a substantial fraction of the earth's surface, or narrow, covering an area only hundreds of kilometers in diameter. This mode of operation is known as a bent pipe.

## GEO (Geostationary Earth Orbit)

- If a satellite should appear in fixed in the sky, it requires a period of 24 hours. Using the equation of distance earth and satellite,  $r = (\frac{g \cdot r^2}{2 \cdot r \cdot f})^{1/3}$  and the period of 24 hours  $f = 1/24 \text{ h}$ , the resulting distance is **35,786 km**. the orbit must have an inclination of 0 degree.
- Geostationary satellites have a distance of almost 36,000 km to the earth. Examples are almost all TV and radio broadcast satellites, any weather satellites and satellites operating as backbones for the telephone network.
- Objects in GEO moves around the earth at the same speed as the earth rotates. This means geostationary satellites remain in the same position relative to the surface of earth.

## Advantages of GEO satellite

- Three Geostationary satellites are enough for a complete coverage of almost any spot on earth.
- Receivers and senders can use fixed antenna positions, no adjusting is needed.
- GEOs are ideal for TV and radio broadcasting.
- Lifetime expectations for GEOs are rather high, at about 15 years.
- Geostationary satellites have a 24 hour view of a particular area.
- GEOs typically do not need handover due to the large footprints.
- GEOs don't exhibit any Doppler shift because the relative movement is zero.

## Disadvantages of GEO satellite

- Northern or southern regions of the earth have more problems receiving these satellites due to the low elevation above latitude of 60 degree, i.e. larger antennas are needed in this case.
- Shading of the signals in cities due to high buildings and the low elevation further away from the equator limits transmission quality.
- The transmit power needed is relatively high (about 10 W) which causes problems for battery powered devices.
- These satellites can't be used for small mobile phones.
- The biggest problem for voice and also data communication is high latency of over 0.25s one way-retransmission schemes which are known from fixed networks fail.

- Transferring a GEO into orbit is very expensive.

### **LEO (Low Earth Orbit)**

- As LEOs circulate on a lower orbit, it is obvious that they exhibit a much shorter period (the typical duration of LEO periods are 95 to 120 minutes). Additionally, LEO systems try to ensure a high elevation for every spot on earth to provide a high quality communication link.
- Each LEO satellite will only be visible from the earth for about ten minutes.
- A further classification of LEOs into little LEOs with low bandwidth services (some 100 bit/s), big LEOs (some 1,000 bit/s) and broadband LEOs with plans reaching into the Mbits/s range can be found in Comparetto (1997).
- LEO satellites are much closer to earth than GEO satellites, ranging from 500 to 1,500 km above the surface. LEO satellites do not stay in fixed position relative to the surface, and are only visible for 15 to 20 minutes each pass.

### **Advantages of LEO satellite**

- Using advanced compression schemes, transmission rates of about 2,400 bit/s can be enough for voice communication.
- LEOs even provide this bandwidth for mobile terminals with omni-directional antennas using low transmit power in the range of 1 W.
- A LEO satellite smaller area of coverage is less of a waste of bandwidth.
- Using advanced compression schemes, transmission rates of about 2,400 bit/s can be enough for voice communication.
- A LEO satellite's proximity to earth compared to a Geostationary satellite gives it a better signal strength and less of a time delay, which makes it better for point to point communication.
- Smaller footprints of LEOs allow for better frequency reuse, similar to the concepts used for cellular networks.

### **Disadvantages of LEO satellite**

- The biggest problem of the LEO concept is the need for many satellites if global coverage is to be reached.
- The high number of satellites combined with the fast movement's results in a high complexity of the whole satellite system.
- The short time of visibility with a high elevation requires additional mechanism for connection handover between different satellites.
- One general problem of LEO is the short lifetime of about five to eight years due to atmospheric drag and radiation from the inner Van Allen belt.
- The low latency via a single LEO is only half of the story.
- Other factors are the need for routing of data packets from satellite to satellite (or several times from base stations to satellites and back) if a user wants to communicate around the world.

- A GEO typically does not need this type of routing, as senders and receivers are most likely in the same footprints.

### **3. MEO (Medium Earth Orbit)**

- A MEO satellite situates in orbit somewhere between 6,000 km to 20,000 km above the earth's surface.
- MEO satellites are similar to LEO satellites in the context of functionality.
- MEO satellites are similar to LEO satellite in functionality.
- Medium earth orbit satellites are visible for much longer periods of time than LEO satellites usually between 2 to 8 hours.
- MEO satellites have a larger coverage area than Low Earth Orbit satellites.
- MEOs can be positioned somewhere between LEOs and GEOs, both in terms of their orbit and due to their advantages and disadvantages.

#### **Advantages of MEO**

- Using orbits around 10,000km, the system only requires a dozen satellites which is more than a GEO system, but much less than a LEO system.
- These satellites move more slowly relative to the earth's rotation allowing a simpler system design (satellite periods are about six hours).
- Depending on the inclination, a MEO can cover larger populations, so requiring fewer handovers.
- A MEO satellite's longer duration of visibility and wider footprint means fewer satellites are needed in a MEO network than a LEO network.

#### **Disadvantages of MEO**

- Again due to the larger distance to the earth, delay increases to about 70-80 ms.
- The satellites need higher transmit power and special antennas for smaller footprints.
- A MEO satellite's distance gives it a longer time delay and weaker signal than LEO satellite.

# Telephone System

## The Public Switched Telephone Network

PSTN (Public Switched Telephone Network), were usually designed many years ago, with a completely different goal in mind: transmitting the human voice in a more-or-less recognizable form. Their suitability for use in computer-computer communication is often marginal at best.

The main goal of PSTN is to transmit the voice signal. This system provides cheap and best connectivity.

### Structure of the Telephone System

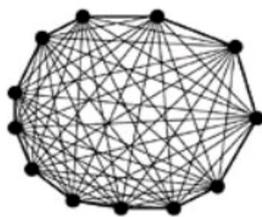
#### 1. Connection Topologies:

##### a. Mesh Topology:

Initially, the mesh topology was followed to connect a person with 'n' person as shown in fig.1-(a). As per the topology, if the city has 'n' number of telephones and each connected with others,  $n*(n-1)/2$  connections are possible. Each node has (n-1) connections. So the street and city were made up of fully with wires.

Fig.1

**(a) Fully-interconnected network.**



(a)

##### b. Centralized switch:

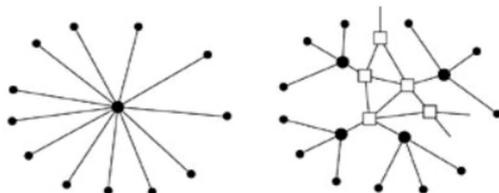
To overcome the problem in mesh topology, centralized switching mechanism is introduced by Graham bell. This is manual mechanism. All the nodes are connected to a centralized switching office through cables.

When a customer wants to connect a call with other person, he/she first connected to the switching office operator and inform about the connection. The operator later manually connects the callee using jumping cable.

One Switching office alone did not meet the requirements of the users to connect long distances. So Multi level switching offices were established in order to connect users of long distances.

Fig 2:

**(b) Centralized switch. (c) Two-level hierarchy.**



(b)

(c)

#### 2. Components of Telephone System

The telephone system consists of three major components:

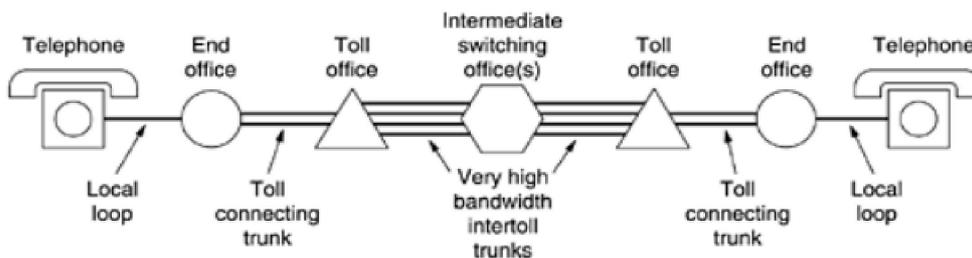
1. Local loops (analog twisted pairs going into houses and businesses).

2. Trunks (digital fiber optics connecting the switching offices).
3. Switching offices (where calls are moved from one trunk to another).

The telephone system model is organized as a highly redundant, multilevel hierarchy. It comprises of the following components –

- Telephone of the subscriber or end user
- End office – Local central office directly connected to end user at a distance of 1 – 10km.
- Local loop – A two-way connection between the telephone and the end office.
- Toll office – switching centres which are called tandem offices when located within the same local area.
- Toll connecting trunk – Lines that connect end offices with toll offices.
- Intermediate switching offices – Interconnected non-hierarchical switching offices for connecting toll offices.
- Inter toll trunk – Very high bandwidth channels that connect either two toll offices via intermediate switching offices.

Fig 3: Components of telephone system connection



The Fig 3 illustrates the components and connectivity places to connect the telephones of two persons which are located too long.

### 3. Connection Establishment Levels

The Connection establishment is done at three levels by the caller to callee based on the locations of the customer.

- a. Both caller and callee are attached to same end office –  
In this case, a direct electrical connection is set up between the local loops of the subscribers by the switching mechanism of the end office.
- b. Caller and callee are attached to different end offices –  
In this case, the end office of the caller sets up a connection with one or more connected toll offices, which then performs the switching job. This again has two cases –
  - If the end offices of the caller and the callee have a common toll office, then the toll office establishes a connection within itself.
  - If there are no common toll office between the caller and callee, then a path is established between the different toll offices, through intermediate switching office via intertoll trunks.

#### Transmission Media Used

- Local loop – analog twisted pair cables.
- Toll connecting trunk – fibre optic links
- Between switching offices – fibre optic cables and microwaves

#### Local Loops: Modems, ADSL, and Wireless

The Local loop is a two-wire connection existing between the telephone user and end office. This local loop was used to transmit the analog voice signal from the caller to callee for short and long distance.

To support the digital data transmission over the telephone lines, telephone modems are used. The ADSL methodology is used for broadband technologies. Nowadays, the traditional copper wire systems are replaced by fiber optics in local loops.

### 1. Telephone Modems

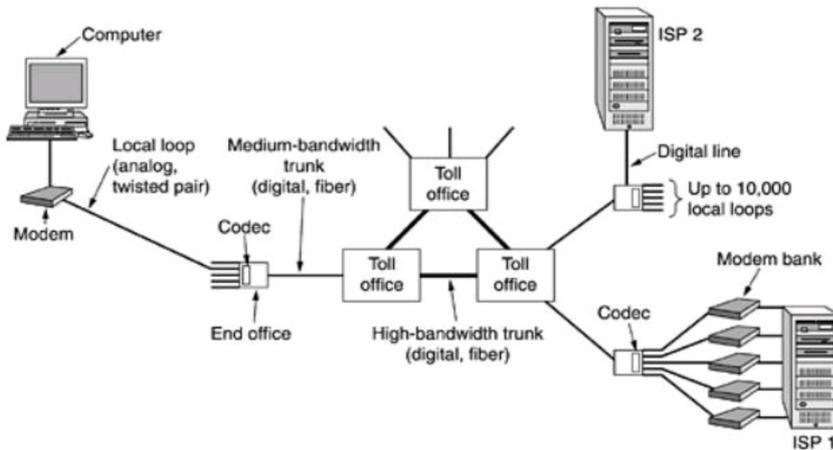
The Telephone modems (Modulator and Demodulator) convert the signal in one form to another form.

The computers are digital devices that are connected via analog local loops of the telephone networks. So modems convert the bits to analog signals so that they can be transmitted via the physical channels.

And conversely, modem converts analog signals received from the local loops to computer understandable bits.

The modem is inserted between the (digital) computer and the (analog) telephone system.

**Figure- The use of both analog and digital transmission for a computer to computer call. Conversion is done by the modems.**



### Modulation

The digital bits are converted in to analog signals by modem using any one of the modulation techniques:

1. Frequency modulation
2. Amplitude modulation and
3. Phase modulation.

#### 1. Frequency modulation:

Two different frequencies are used to represent the bits 0 and 1. This modulation is called as Frequency Shift Keying (FSK). It cannot transmit over long distances, have a smaller range.

#### 2. Amplitude modulation:

Two different amplitudes are used to represent the bits 0 and 1. This modulation is called as Amplitude Shift Keying (ASK). It can transmit over long distances.

#### 3. Phase modulation:

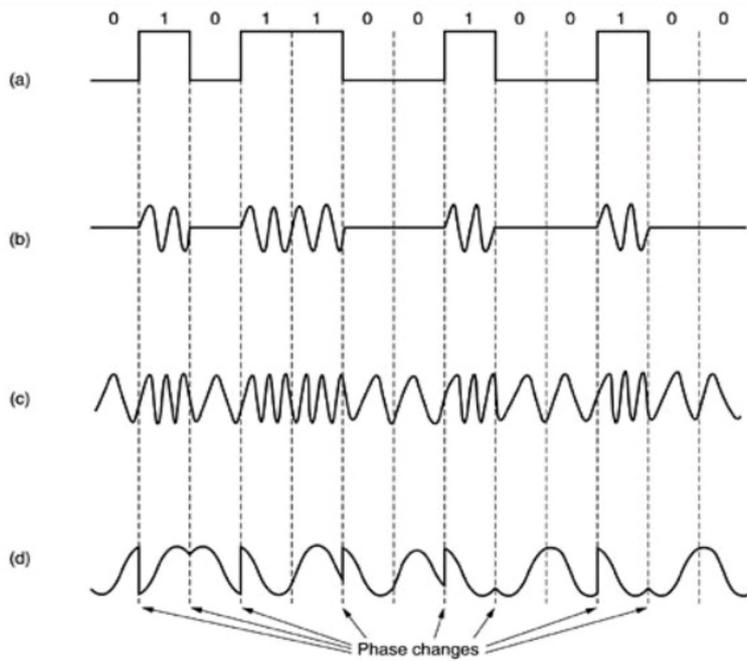
Two different phases are used to represent the bits 0 and 1. This modulation is called as Phase Shift Keying (PSK). In the simplest form of phase modulation, the carrier wave is systematically shifted 0 or 180 degrees at uniformly spaced intervals. A better scheme is to use shifts of 45, 135, 225, or 315 degrees to transmit 2 bits of information per time interval. Also, always requiring a phase shift at the end of every time interval makes it is easier for the receiver to recognize the boundaries of the time intervals.

The more phase shifting tends to more bit transmission, but complexity is high.

The Following Figure illustrates the three modulation techniques on a digital bit sequence

101100100100

**Figure 2-24. (a) A binary signal. (b) Amplitude modulation. (c) Frequency modulation. (d) Phase modulation.**



#### Modem-Speed Standards

Standard	Baud	bps	Comment
V.29		9600	Used for Class 3 fax machines.
V.32	2400	4800/9600	Provides error correction. Full-duplex.
V.32bis	2400	14,400	An improved version of V.32.
V.32fast	2400	28,800	An extension of V.32 and V.32 bis.
V.34 or V.fast	2400	28,800	Allows optional higher speeds of 31.2 Kbps and 33.6 Kbps.

#### Baud Rate:

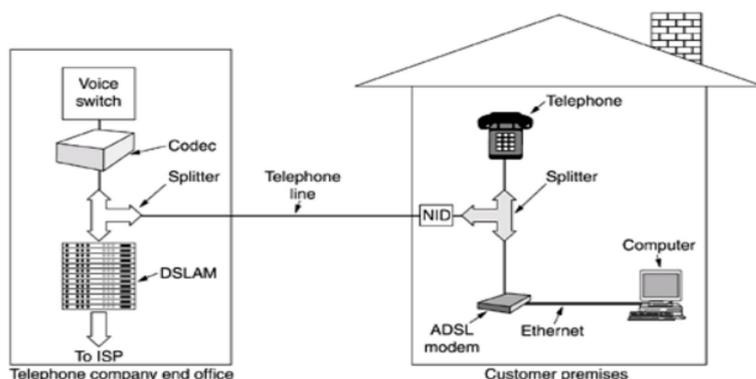
The number of symbols (signals) per second is measured as baud rate (Bd). It is also referred as symbol rate or modulation rate. One bit or symbol is sent during each baud. In analog, the baud rate is change in the symbols. For Example: 1000 baud means, communication by means of sending 1000 symbols per second. But in digital, 1 Bd means 1 bit/second.

#### 2. ADSL (*Asymmetric Digital Subscriber Line*)

- *Asymmetric Digital Subscriber Line*, is a telco service that provides subscribers with **high-speed digital telephone services**.

- ADSL specifies how to implement high-speed, full-duplex transmission over the existing twisted-pair copper cabling of the [Plain Old Telephone Service \(POTS\)](#).
- Used to simultaneously transmit voice and data over a single telephone line and can support high-speed Internet access for both homes and businesses.
- When the data link go down, POTS voice service would still be available using ADSL.

**Figure 2-29. A typical ADSL equipment configuration.**



- A telephone company technician must install a NID (Network Interface Device) on the customer's premises.
- Close to the NID is a splitter, an analog filter that separates the 0-4000 Hz band used by POTS from the data.
- The POTS signal is routed to the existing telephone or fax machine, and the data signal is routed to an ADSL modem.
- Since most current ADSL modems are external, the computer must be connected to it at high speed.
- This is done by putting an Ethernet card in the computer and operating a very short two-node Ethernet containing only the computer and ADSL modem.
- At the other end of the wire, on the end office side, a corresponding splitter is installed.
- Here the voice portion of the signal is filtered out and sent to the normal voice switch.
- The signal above 26 kHz is routed to a new kind of device called a DSLAM (Digital Subscriber Line Access Multiplexer).
- A DSLAM, is a network distribution device that aggregates individual subscriber lines into a high-capacity uplink. These high capacity uplinks may be Gigabit Ethernet which connects subscribers to their Internet service providers (ISPs).
- Once the digital signal has been recovered into a bit stream, packets are formed and sent off to the ISP.
- A voice codec is a way to encode and compress the voice and send it from one device to another over a network. It reconstructs the voice signal through decoding.

### **Fiber to Home**

- The local loop copper wires degrade the performance of ADSL and telephone modems.
- So fiber optic cables are deployed in the local loop.
- Fiber optics are directly connected to homes or small organizations. Hence called FTTH (Fiber-To0The-Home) or FTTP (Fiber-To-The-Premises).
- FTTH provides broadband connections to the households for internet access, telephone services.

- ⊙ It is 20 to 100 times faster than DSL or telephone modems.

### 3. Wireless local loops

- A cheaper alternative to the traditional twisted-pair local loop is the WLL (Wireless Local Loop).
- A telephone using a wireless local loop is a bit like a mobile phone.
- WLL operation was initiated at 1998.

#### MMDS (Multichannel Multipoint Distribution Service)

- The 198 MHz was put to use for wireless local loops as a service called MMDS (Multichannel Multipoint Distribution Service).
- At these frequencies, the microwaves are 10–12 cm long. They have a range of about 50 km and can penetrate vegetation and rain moderately well.
- MMDS can be regarded as a MAN (Metropolitan Area Network).
- The big advantage of this service is that the technology is well established and the equipment is readily available.
- The disadvantage is that the total bandwidth available is modest and must be shared by many users over a fairly large geographic area.

Number of cycles or waves per second	Frequency (SI units)
1	1 hertz (Hz)
1,000	1 kilohertz (kHz)
1,000,000	1 megahertz (MHz)
1,000,000,000	1 gigahertz (GHz)
1,000,000,000,000	1 terahertz (THz)
1,000,000,000,000,000	1 petahertz (PHz)
1,000,000,000,000,000,000	1 exahertz (EHz)

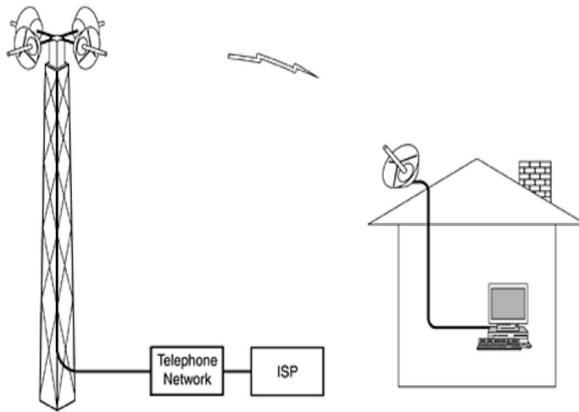
#### LMDS Service (Local Multipoint Distribution Service)

- A new wireless local loop service called LMDS (Local Multipoint Distribution Service) is allocated with 1.3 GHz.
- They use millimeter waves for radio communication. Millimeter wave (MM wave), also known as millimeter band, is **the band of spectrum with wavelengths between 10 millimeters (30 GHz) and 1 millimeter (300 GHz)**. It is also known as the extremely high frequency (EHF) band by the International Telecommunication Union (ITU).
- It uses Fixed Wireless Access (FWA) technique.

#### The operation of LMDS:

- A tower will be installed with multiple antennas on it, each pointing in a different direction.
- Since millimeter waves are highly directional, each antenna defines a sector, independent of the other ones.
- At this frequency, the range is 2–5 km, which means that many towers are needed to cover a city.
- LMDS uses an asymmetric bandwidth allocation favouring the downstream channel.
- Each sector can have 36 Gbps downstream and 1 Mbps upstream, shared among all the users in that sector.
- To keep the delay reasonable, no more than 9000 active users should be supported per sector.
- With four sectors, an active user population of 36,000 could be supported.

## Architecture of an LMDS system



### Limitations of LMDS

Millimeter waves propagate in straight lines, so,

1. There must be a clear line of sight between the roof top antennas and the tower.
2. The tower must be high enough to avoid having trees in the line of sight.
3. Rain also absorbs these waves

### Standard for LMDS

- ⦿ IEEE set up a committee called 802.16 to draw up a standard for LMDS.
- ⦿ The 802.16 standard was published in April 2002. IEEE calls 802.16 a wireless MAN.
- ⦿ IEEE 802.16 was designed for digital telephony, Internet access, connection of two remote LANs, television and radio broadcasting, and other uses.

## Trunks

The Telephone communication provides connectivity between end offices to toll offices using the high bandwidth channels. These channels are called as trunks.

A Trunk is communication line or link provided between switching offices and shared by multiple users' signals.

To maximize the bandwidth, trunks can have a single high-capacity link over which many signals are multiplexed.

Trunking is the mechanism used to form an internetwork or Internet, comprised of LAN's, Virtual LANs or WANs. The network switches are interconnected to establish these networks using trunking.

## Multiplexing

In Telecommunication or data communication system, running dedicated lines between users does not utilize the bandwidth fully.

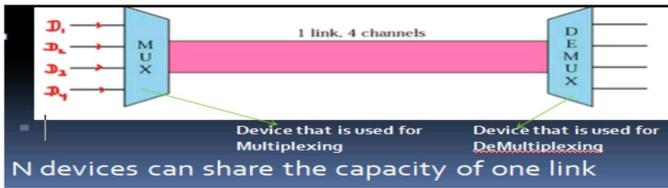
The unutilized part of the communication bandwidth or time can be used by other users who are connected with the same communication line. It will reduce the cost of communication system and increase the maximum utilization of bandwidth.

***Multiplexing is combining multi user's data in to single stream and transmitting them in to the medium simultaneously.***

Thus Multiplexing allows effective utilization of the medium bandwidth and send multi users data simultaneously. Hence the waiting time of the user is reduced.

Multiplexing processing is done at the sender's side. At the receiver's side, the single stream is separated and sent to the receivers. This process is called demultiplexing.

### Multiplexing and Demultiplexing



**MUX: Device that is used for Multiplexing**

**DEMUX: Device that is used for Demultiplexing.**

**Link : Physical Link – Trunk**

**Channel : Refers to portion of path that carry transmission data.**

There are three kinds of Multiplexing:

1. Frequency Division Multiplexing (FDM)
2. Wave Length Division Multiplexing (WDM)
3. Time Division Multiplexing (TDM)

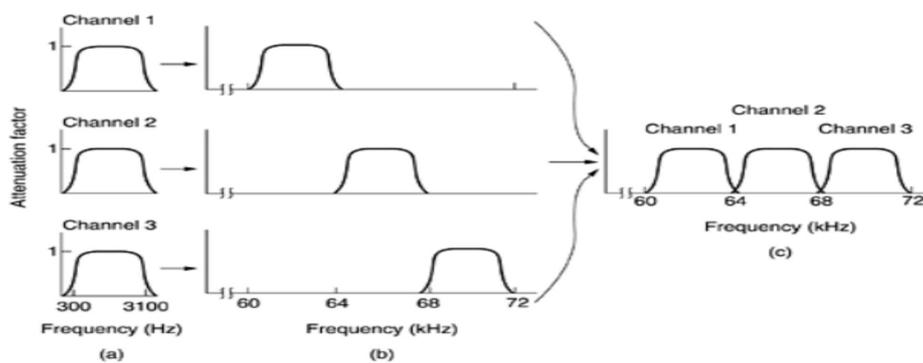
FDM and WDM work on analog signals and TDM works on digital signals.

#### 1. Frequency Division Multiplexing (FDM)

- A technique of sending two or more signals over the same phone line.
- Each signal is transmitted as a unique range of frequencies within the bandwidth of the channel as a whole, enabling several signals to be transmitted simultaneously.
- Bandwidth of link will be greater than the combined bandwidth of signals.
- Bandwidth is divided in to small bandwidth and they act as separate channel.
- Each Sending device modulates different carrier frequency, which is combined in to composite signal for transmitting.

Figure 2.0 shows how three voice-grade telephone channels are multiplexed using FDM.

Figure 2.0. Frequency division multiplexing. (a) The original bandwidths. (b) The bandwidths raised in frequency. (c) The multiplexed channel.

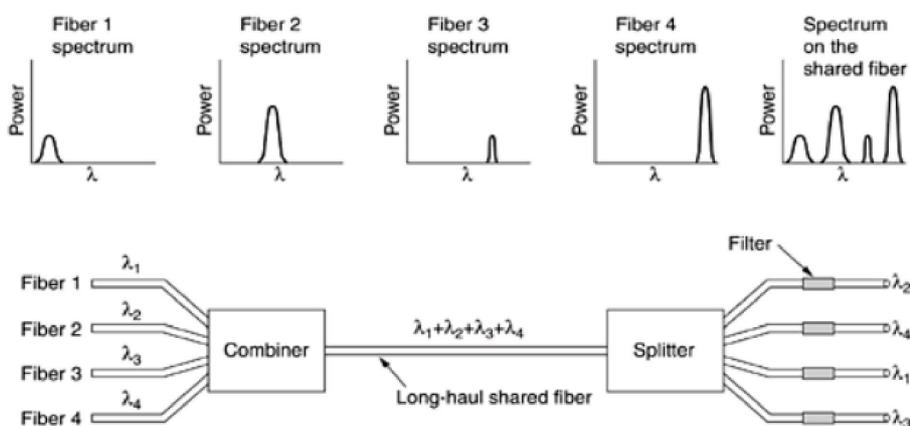


- Filters limit the usable bandwidth to about 3100 Hz per voice-grade channel. When many channels are multiplexed together, 4000 Hz is allocated to each channel to keep them well separated.
- First the voice channels are raised in frequency, each by a different amount. Then they can be combined because no two channels now occupy the same portion of the spectrum.
- Channels are separated by strips of unused bandwidth guard bands to prevent signals from overlapping.

## 2. Wave Length Division Multiplexing (WDM)

- Wavelength division multiplexing (WDM) is a technique for combining optical signals.
- Same as FDM, except the light signals are transmitted through fiber optics cable.
- The basic principle of WDM on fibers is depicted in Fig. 2-1. Here four fibers come together at an optical combiner, each with its energy present at a different wavelength. The four beams are combined onto a single shared fiber for transmission to a distant destination. At the far end, the beam is split up over as many fibers as there were on the input side.
- Each output fiber contains a short, specially-constructed core that filters out all but one wavelength. The resulting signals can be routed to their destination or recombined in different ways for additional multiplexed transport.

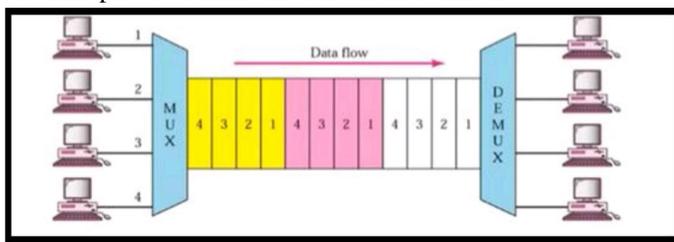
Figure 2-1. Wavelength division multiplexing.



This is just frequency division multiplexing at very high frequencies. As long as each channel has its own frequency (i.e., wavelength) range and all the ranges are disjoint, they can be multiplexed together on the long-haul fiber.

## 3. Time Division Multiplexing (TDM)

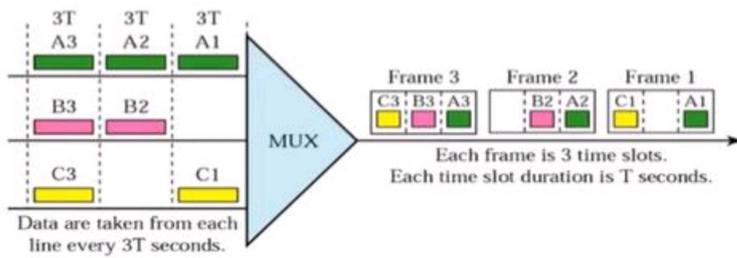
- In Time Division Multiplexing, each sender is given the entire possession of the whole bandwidth of the channel for a fixed duration of time.
- After this, the control is moved to the next sender, and the process continues on a round-robin basis.
- i.e., Divide the channel in to time slots using Round Robin fashion.
- An example of TDM is the television broadcast.



TDM are implemented in two ways,

1. Synchronous TDM
2. Asynchronous TDM

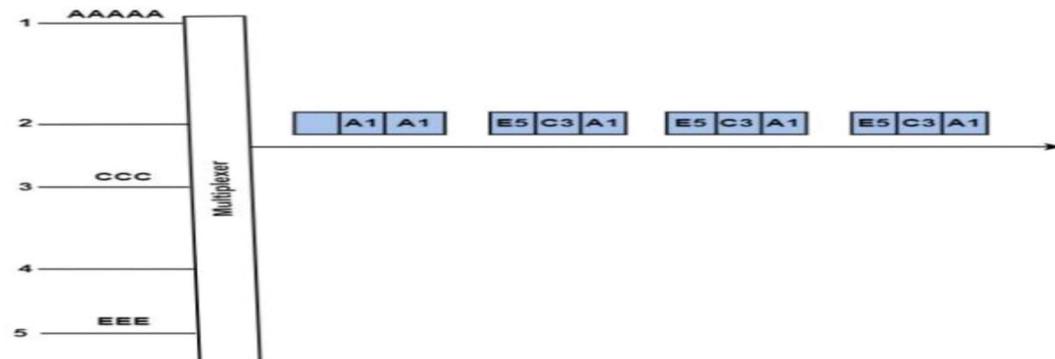
**Synchronous TDM:** Allocates exactly same time slot to each device, whether or not device has anything to send. (or) In synchronous TDM, each input connection has an allotment in the output even if it is not sending data.



**Time Slots and Frames:** In synchronous TDM, the data flow of each input connection is divided into units, where each input occupies one input time slot. A unit can be 1 bit, one character, or one block of data. 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.

**Asynchronous TDM:** In ATDM, the multiplexer scans all the input lines and accepts the portions of data till the frame is filled. When the frame is filled, it is sent across the link. If the senders don't have enough data to fill the frame, it is transmitted as partially filled.

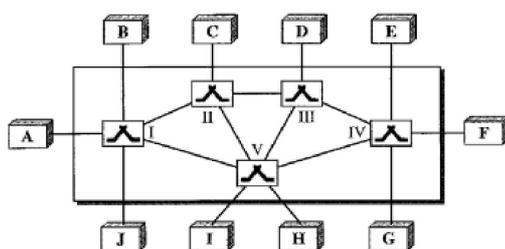


## Switching

Switching is **process to forward packets coming in from one port to a port leading towards the destination** based on the received packet destination address.

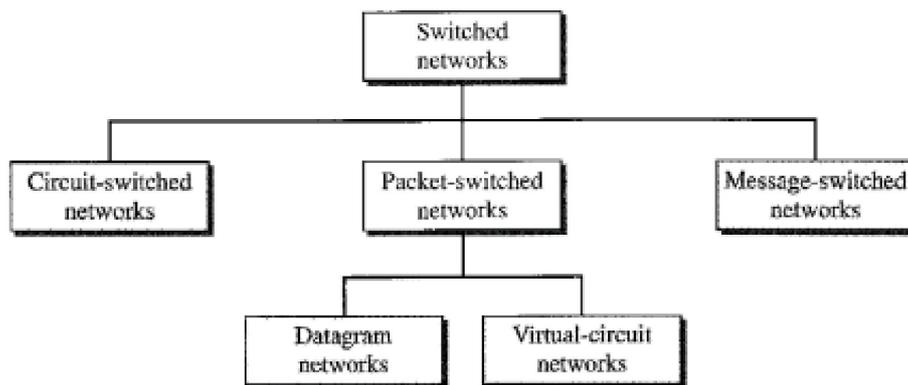
A switched network consists of a series of interlinked nodes, called switches. Switches are devices capable of creating temporary connections between two or more devices linked to the switch. In a switched network, some of these nodes are connected to the end systems (computers or telephones, for example). Others are used only for routing.

Figure 8.1 Switched network



The end systems (communicating devices) are labeled A, B, C, D, and so on, and the switches are labeled I, II, III, IV, and V. Each switch is connected to multiple links.

## Types of Switched Networks (or) Types of Switching



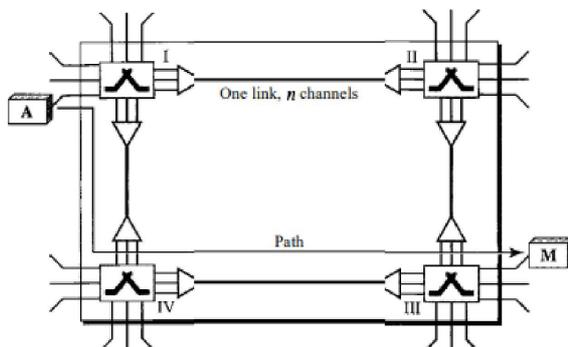
### CIRCUIT-SWITCHED NETWORKS

- A circuit-switched network is made of a set of switches connected by physical links, in which each link is divided into  $n$  channels.
- A dedicated channel or circuit is established for the duration of communication. i.e., there is a need to set up an end-to-end path before any data can be sent.
- When any user wants to send the data, voice, video, a request signal is sent to the receiver then the receiver sends back the acknowledgment to ensure the availability of the dedicated path. After receiving the acknowledgment, dedicated path transfers the data.
- Circuit switching is used in public telephone network. It is used for voice transmission.
- Fixed data can be transferred at a time in circuit switching technology.

#### Communication through circuit switching has 3 phases:

1. Connection Setup Phase
  2. Data Transfer Phase
  3. Connection Teardown phase
- In circuit switching, the resources need to be reserved during the setup phase; the resources remain dedicated for the entire duration of data transfer until the teardown phase.

Figure 8.3 A trivial circuit-switched network



In Fig 8.3, The end systems, such as computers or telephones, are directly connected to a switch. When end system A needs to communicate with end system M, system A needs to request a connection to M that must be accepted by all switches as well as by M itself. This is called the setup phase; a circuit (channel) is reserved on each link, and the combination of circuits or channels defines the dedicated path. After the dedicated path made of connected circuits (channels) is established, data transfer can take place. After all data have been transferred, the circuits are turned down.

Circuit switching takes place at the physical layer. The end-to-end addressing is used only for the circuit establishment.

#### Advantages of Circuit Switching:

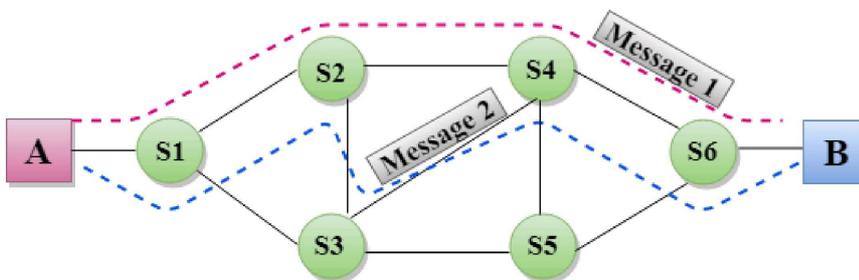
- In the case of Circuit Switching technique, the communication channel is dedicated.
- It has fixed bandwidth.

#### 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.
- It is inefficient to use because once the path is established and no data is transferred, then the capacity of the path is wasted.
- In this case, the connection is dedicated therefore no other data can be transferred even if the channel is free.

### MESSAGE SWITCHING

- Message Switching is a switching technique in which a message is transferred as a complete unit and routed through intermediate nodes at which it is stored and forwarded.
- In Message Switching technique, there is no establishment of a dedicated path between the sender and receiver.
- The destination address is appended to the message. Message Switching provides a dynamic routing as the message is routed through the intermediate nodes based on the information available in the message.
- Message switches are programmed in such a way so that they can provide the most efficient routes.
- Each and every node stores the entire message and then forward it to the next node. This type of network is known as **store and forward network**.
- Message switching treats each message as an independent entity.



#### Advantages of Message Switching

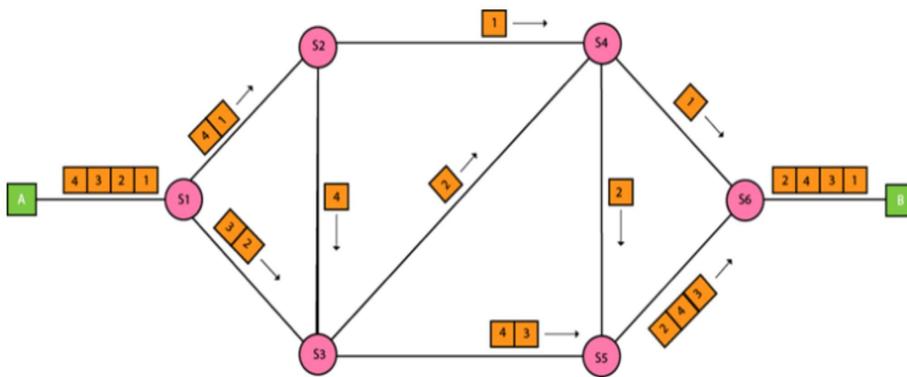
- Data channels are shared among the communicating devices that improve the efficiency of using available bandwidth.
- Traffic congestion can be reduced because the message is temporarily stored in the nodes.
- Message priority can be used to manage the network.
- The size of the message which is sent over the network can be varied. Therefore, it supports the data of unlimited size.

#### Disadvantages of Message Switching

- The message switches must be equipped with sufficient storage to enable them to store the messages until the message is forwarded.
- The Long delay can occur due to the storing and forwarding facility provided by the message switching technique.

## PACKET SWITCHING

- The packet switching is a switching technique in which the message is sent in one go, but it is divided into smaller pieces, and they are sent individually.
- The message splits into smaller pieces known as packets and packets are given a unique number to identify their order at the receiving end.
- Every packet contains some information in its headers such as source address, destination address and sequence number.
- Packets will travel across the network, taking the shortest path as possible.
- All the packets are reassembled at the receiving end in correct order.
- If any packet is missing or corrupted, then the message will be sent to resend the message.
- If the correct order of the packets is reached, then the acknowledgment message will be sent.



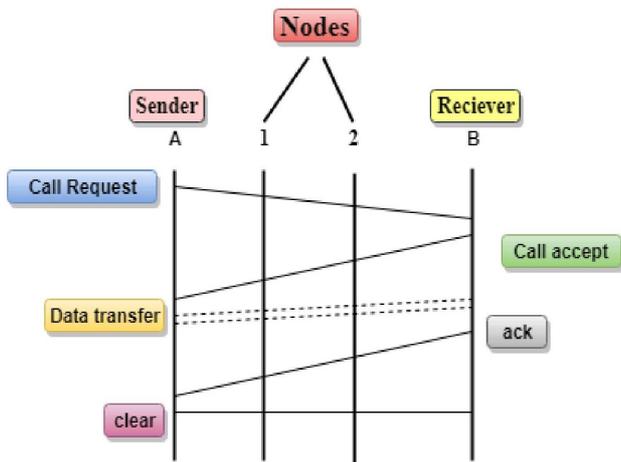
There are two approaches to Packet Switching:

### Datagram Packet switching:

- It is a packet switching technology in which packet is known as a datagram, is considered as an independent entity. Each packet contains the information about the destination and switch uses this information to forward the packet to the correct destination.
- The packets are reassembled at the receiving end in correct order.
- In Datagram Packet Switching technique, the path is not fixed.
- Intermediate nodes take the routing decisions to forward the packets.
- Datagram Packet Switching is also known as connectionless switching.

### Virtual Circuit Switching

- Virtual Circuit Switching is also known as connection-oriented switching.
- In the case of Virtual circuit switching, a preplanned route is established before the messages are sent.
- Call request and call accept packets are used to establish the connection between sender and receiver.
- In this case, the path is fixed for the duration of a logical connection.



- In the above diagram, A and B are the sender and receiver respectively. 1 and 2 are the nodes.
- Call request and call accept packets are used to establish a connection between the sender and receiver.
- When a route is established, data will be transferred.
- After transmission of data, an acknowledgment signal is sent by the receiver that the message has been received.
- If the user wants to terminate the connection, a clear signal is sent for the termination.

#### Advantages of Packet Switching:

- **Cost-effective:** In packet switching technique, switching devices do not require massive secondary storage to store the packets, so cost is minimized to some extent. Therefore, we can say that the packet switching technique is a cost-effective technique.
- **Reliable:** If any node is busy, then the packets can be rerouted. This ensures that the Packet Switching technique provides reliable communication.
- **Efficient:** Packet Switching is an efficient technique. It does not require any established path prior to the transmission, and many users can use the same communication channel simultaneously, hence makes use of available bandwidth very efficiently.

#### Disadvantages of Packet Switching:

- Packet Switching technique cannot be implemented in those applications that require low delay and high-quality services.
- The protocols used in a packet switching technique are very complex and requires high implementation cost.
- If the network is overloaded or corrupted, then it requires retransmission of lost packets. It can also lead to the loss of critical information if errors are not recovered.

## DATALINK LAYER DESIGN ISSUES

The data link layer in the OSI (Open System Interconnections) Model, is in between the physical layer and the network layer. This layer converts the raw transmission facility provided by the physical layer to a reliable and error-free link.

The main functions and the design issues of this layer are

- Providing services to the network layer
- Framing
- Error Control
- Flow Control

In the OSI Model, each layer uses the services of the layer below it and provides services to the layer above it. The data link layer uses the services offered by the physical layer. The primary function of this layer is to provide a well defined service interface to network layer above it.

The actual service offered can vary from system to system. Three reasonable possibilities that commonly provide are :

- 1. Unacknowledged Connectionless Service:** Source machine send independent frames to the destination machine without expecting any reply from the destination machine.
- 2. Acknowledged Connectionless Service:** Source machine send independent frames to the destination machine expecting reply from the destination machine. Frames are individually acknowledged. Here reliability is high.
- 3. Acknowledged Connection Oriented Services:** Here Connection is first established between source and receiver. Source machine send independent frames to the destination machine expecting reply from the destination machine. Frames are individually acknowledged.

## **Framing**

To provide service to the network layer, the data link layer must use the service provided to it by the physical layer. What the physical layer does is accept a raw bit stream and attempt to deliver it to the destination. This bit stream is not guaranteed to be error free. The number of bits received may be less than, equal to, or more than the number of bits transmitted, and they may have different values. It is up to the data link layer to detect and, if necessary, correct errors.

The usual approach is for the data link layer to break the bit stream up into discrete frames and compute the checksum for each frame. (Checksum algorithms will be discussed later in this chapter.) When a frame arrives at the destination, the checksum is recomputed. If the newly-computed checksum is different from the one contained in the frame, the data link layer knows that an error has occurred and takes steps to deal with it (e.g., discarding the bad frame and possibly also sending back an error report).

Breaking the bit stream up into frames is more difficult than it at first appears. One way to achieve this framing is to insert time gaps between frames, much like the spaces between words in ordinary text. However, networks rarely make any guarantees about timing, so it is possible these gaps might be squeezed out or other gaps might be inserted during transmission.

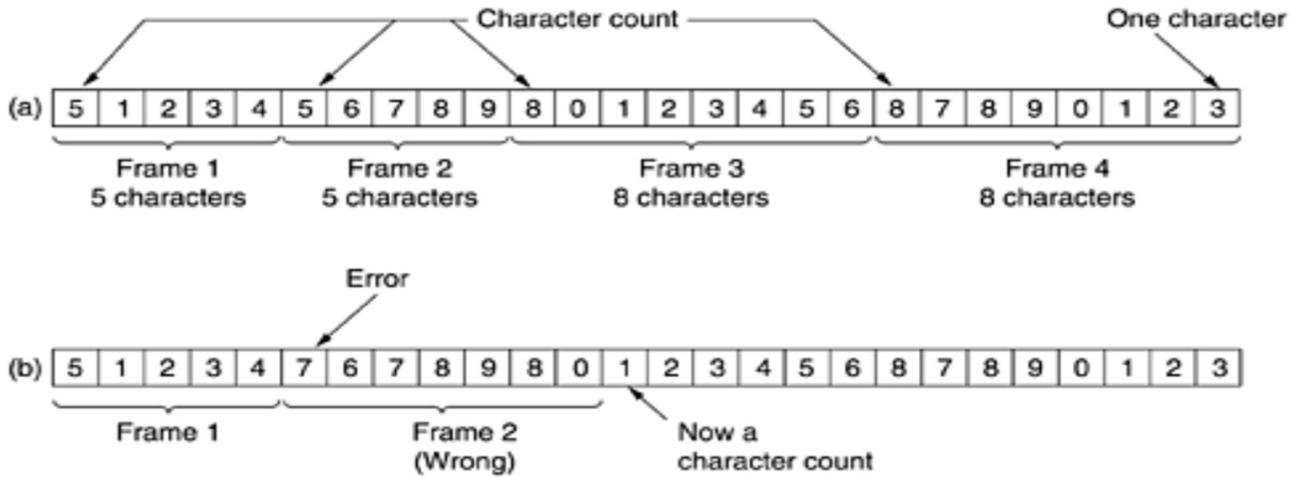
## **Framing Methods**

1. Character count.
2. Flag bytes with byte stuffing.
3. Starting and ending flags, with bit stuffing.

### **CHARATER COUNT METHOD:**

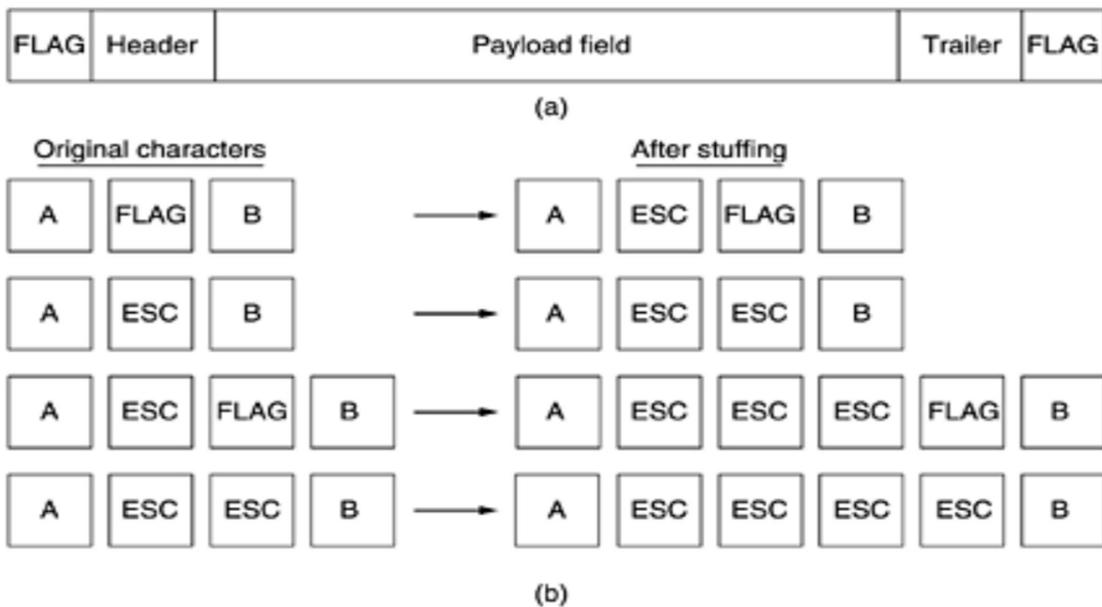
In this method a field in the header will be used to specify the number of CHARACTERS in the frame. When data link layer at the destination sees the character count, it knows how many characters follow and hence where the end of the frame is. The trouble with this algorithm is that the count can be garbed by a transmission error resulting the destination will get out of synchronization and will be unable to locate the start of the next frame. There is no way of telling where the next frame starts. For this reason this method is rarely used.

**Figure 3-4. A character stream. (a) Without errors. (b) With one error.**



**Flag bytes with byte stuffing.**

The second framing method gets around the problem of resynchronization after an error by having each frame start and end with special bytes. In the past, the starting and ending bytes were different, but in recent years most protocols have used the same byte, called a flag byte, as both the starting and ending delimiter, as shown in Fig. 3-5(a) as FLAG. In this way, if the receiver ever loses synchronization, it can just search for the flag byte to find the end of the current frame. Two consecutive flag bytes indicate the end of one frame and start of the next one.

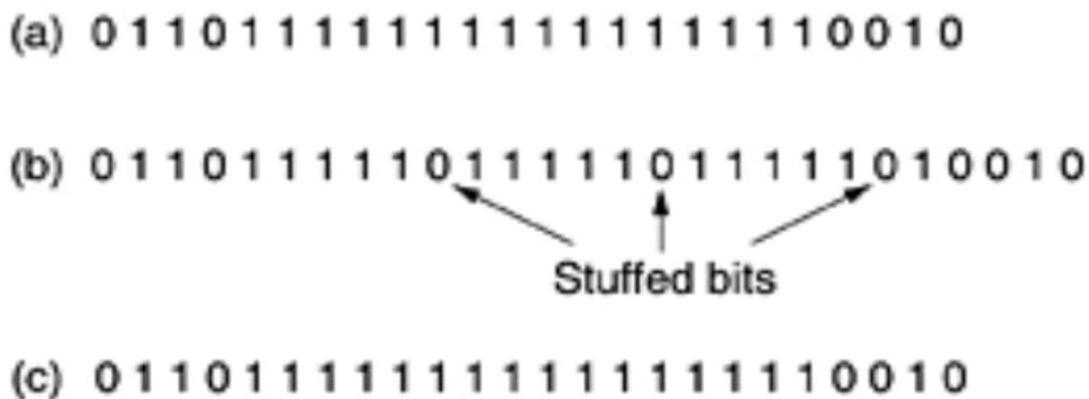


**Starting and ending flags, with bit stuffing.**

This technique allows data frames to contain an arbitrary number of bits and allows character codes with an arbitrary number of bits per character. It works like this. Each frame begins and ends with a special bit pattern, 01111110 (in fact, a flag byte).

Whenever the sender's data link layer encounters five consecutive 1s in the data, it automatically stuffs a 0 bit into the outgoing bit stream. This bit stuffing is analogous to byte stuffing, in which an escape byte is stuffed into the outgoing character stream before a flag byte in the data.

When the receiver sees five consecutive incoming 1 bits, followed by a 0 bit, it automatically destuffs (i.e., deletes) the 0 bit. Just as byte stuffing is completely transparent to the network layer in both computers, so is bit stuffing. If the user data contain the flag pattern, 01111110, this flag is transmitted as 011111010 but stored in the receiver's memory as 01111110.



With bit stuffing, the boundary between two frames can be unambiguously recognized by the flag pattern. Thus, if the receiver loses track of where it is, all it has to do is scan the input for flag sequences, since they can only occur at frame boundaries and never within the data.

### Flow Control

The data link layer regulates flow control so that a fast sender does not drown a slow receiver. When the sender sends frames at very high speeds, a slow receiver may not be able to handle it. There will be frame losses even if the transmission is error-free. The two common approaches for flow control are –

- Feedback based flow control
- Rate based flow control

### Error Control

The data link layer ensures error free link for data transmission. The issues it caters to with respect to error control are –

- Dealing with transmission errors
- Sending acknowledgement frames in reliable connections
- Retransmitting lost frames
- Identifying duplicate frames and deleting them
- Controlling access to shared channels in case of broadcasting

### Types of Errors

There may be three types of errors:

- **Single bit error**



In a frame, there is only one bit, anywhere though, which is corrupt.

- **Multiple bits error**



Frame is received with more than one bits in corrupted state.

- **Burst error**



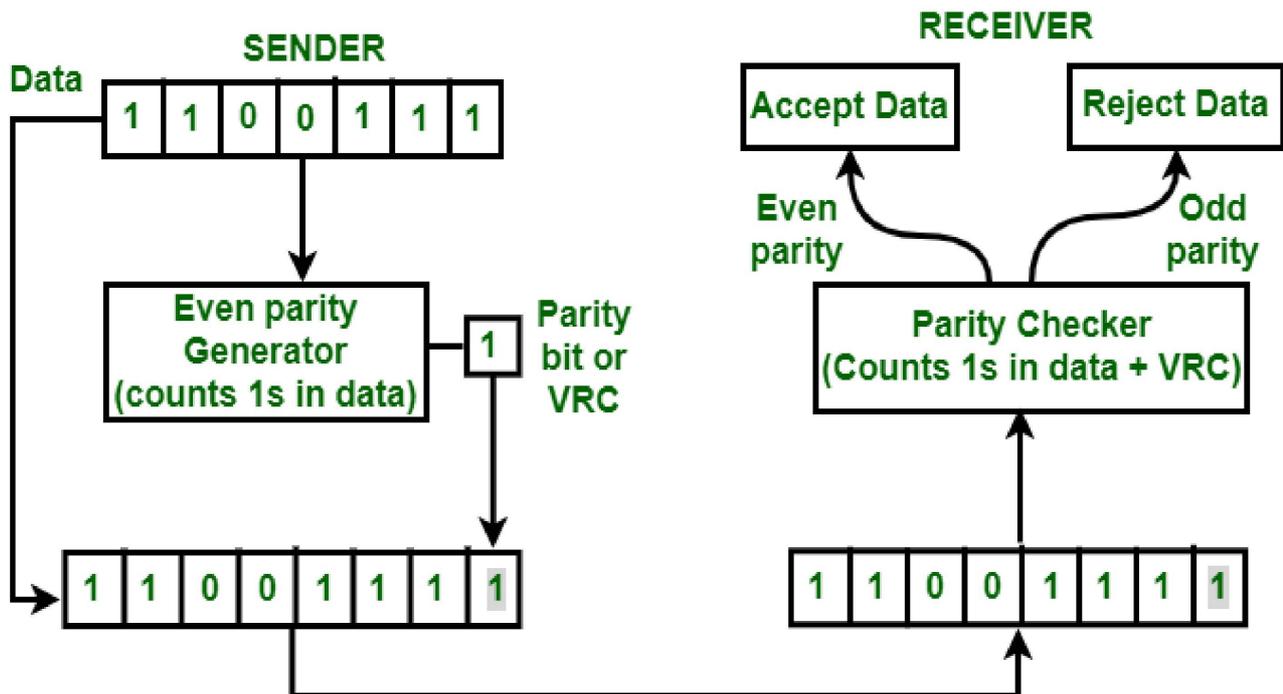
Frame contains more than 1 consecutive bits corrupted.

## Error Detection Techniques

1) **Vertical Redundancy Check** is also known as Parity Check. In this method, a redundant bit also called parity bit is added to each data unit. This method includes even parity and odd parity. Even parity means the total number of 1s in data is to be even and odd parity means the total number of 1s in data is to be odd.

**Example –**

If the source wants to transmit data unit 1100111 using even parity to the destination. The source will have to pass through Even Parity Generator.



Even parity VRC

Parity generator will count number of 1s in data unit and will add parity bit. In the above example, number of 1s in data unit is 5, parity generator appends a parity bit 1 to this data unit making the total number of 1s even i.e 6 which is clear from above figure.

Data along with parity bit is then transmitted across the network. In this case, 11001111 will be transmitted. At the destination, This data is passed to parity checker at the destination. The number of 1s in data is counted by parity checker.

If the number of 1s count out to be odd, e.g. 5 or 7 then destination will come to know that there is some error in the data. The receiver then rejects such an erroneous data unit.

**Advantages :**

- VRC can detect all single bit error.
- It can also detect burst errors but only in those cases where number of bits changed is odd, i.e. 1, 3, 5, 7, .....etc.

**Disadvantages :**

The major disadvantage of using this method for error detection is that it is not able to detect burst error if the number of bits changed is even, i.e. 2, 4, 6, 8, .....etc.

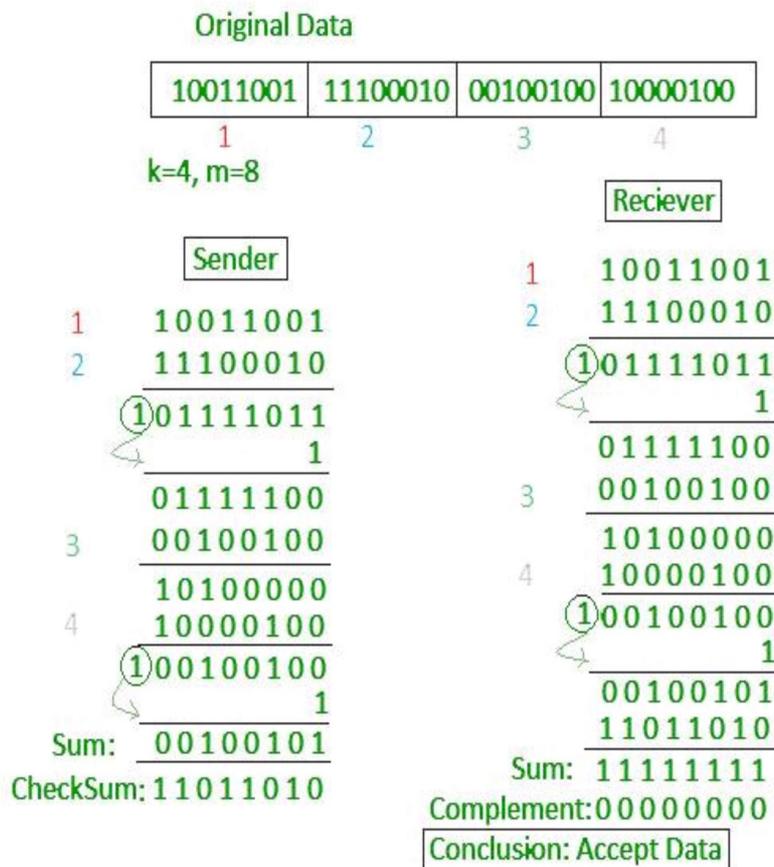


### Disadvantage:

The main problem with LRC is that, it is not able to detect error if two bits in a data unit are damaged and two bits in exactly the same position in other data unit are also damaged.

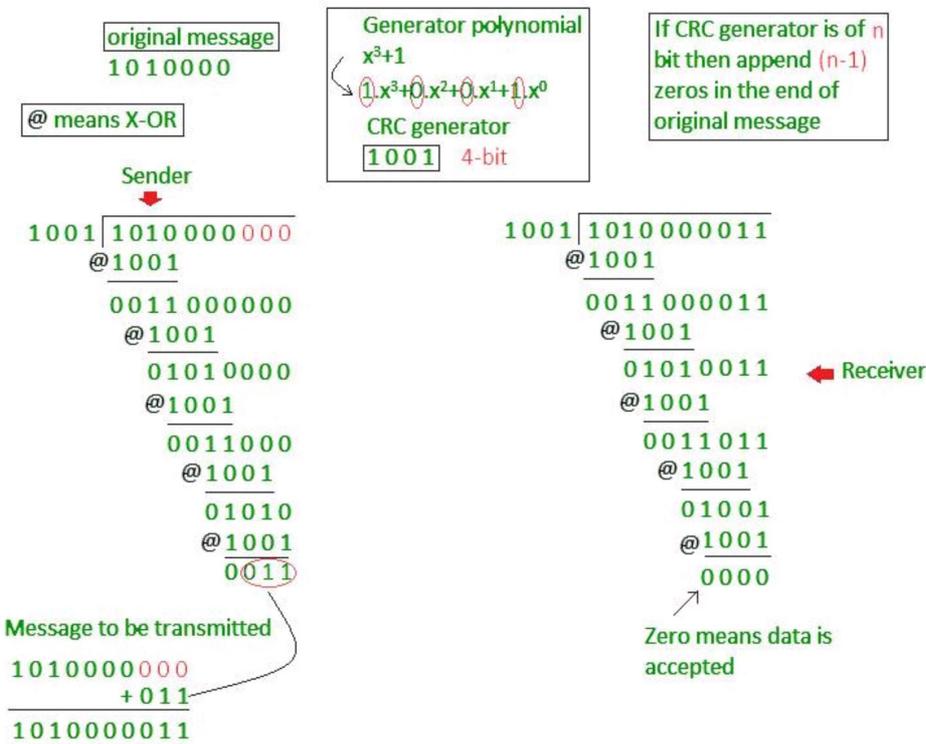
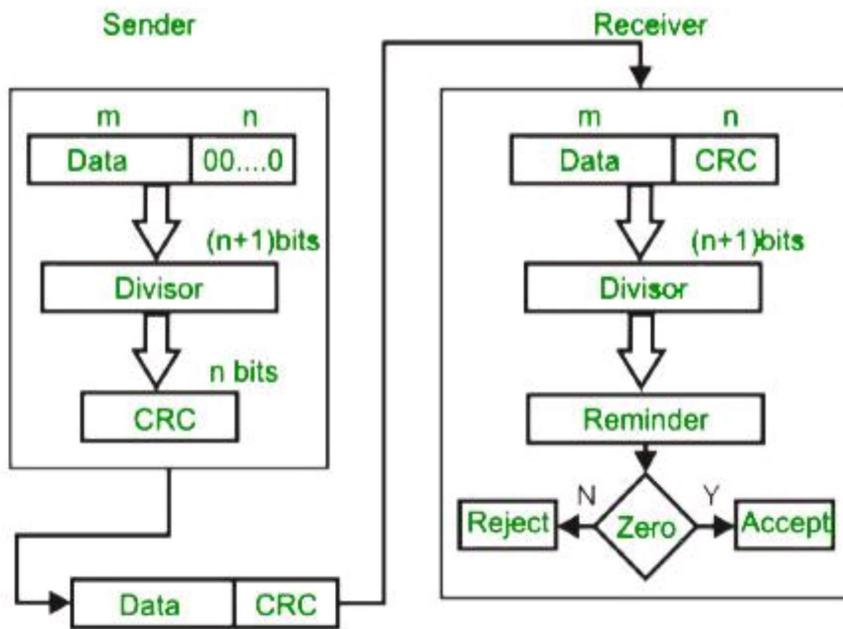
### Checksum

- 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.



### Cyclic redundancy check (CRC)

- Unlike checksum scheme, which is based on addition, CRC is based on binary division.
- In CRC, a sequence of redundant bits, called cyclic redundancy check bits, are appended to the end of data unit so that the resulting data unit becomes exactly divisible by a second, predetermined binary number.
- At the destination, the incoming data unit is divided by the same number. If at this step there is no remainder, the data unit is assumed to be correct and is therefore accepted.
- A remainder indicates that the data unit has been damaged in transit and therefore must be rejected.



## Error Correction Technique

When the receiver detects some error in the data received, it executes error-correcting code, which helps it to auto-recover and to correct some kinds of errors.

To correct the error in data frame, the receiver must know exactly which bit in the frame is corrupted. To locate the bit in error, redundant bits are used as parity bits for error detection. For example, we take ASCII words (7 bits data), then there could be 8 kind of information we need: first seven bits to tell us which bit is error and one more bit to tell that there is no error.

For  $m$  data bits,  $r$  redundant bits are used.  $r$  bits can provide  $2^r$  combinations of information. In  $m+r$  bit codeword, there is possibility that the  $r$  bits themselves may get corrupted. So the number of  $r$  bits used must inform about  $m+r$  bit locations plus no-error information, i.e.  $m+r+1$ .

$$2^r \geq m+r+1$$

## 1. Hamming Code:

**Parity bits:** A bit that is added to the original binary data to make sure the total number of 1s is even or odd (in case of even or odd parity respectively).

**Even parity:** To check for even parity, if the total number of 1s is even, the parity bit value is 0. If the total number of occurrences of 1s is odd, the parity bit value is 1.

**Odd Parity:** To test for odd parity, if the total number of 1s is even, the parity bit value is 1. If the total number of 1s is odd, the parity bit value is 0.

To produce  $m+r$ , an information of 'm' bits is added to the redundant bits 'r'.

Each  $(m+r)$  digit's position is assigned a decimal value.

The 'r' bits are assigned to locations  $1, 2, \dots, 2k-1$ .

**The parity bits are recalculated at the receiving end. The position of an error is determined by the decimal value of the parity bits.**

**Example: If the data to be transmitted is 1011001**

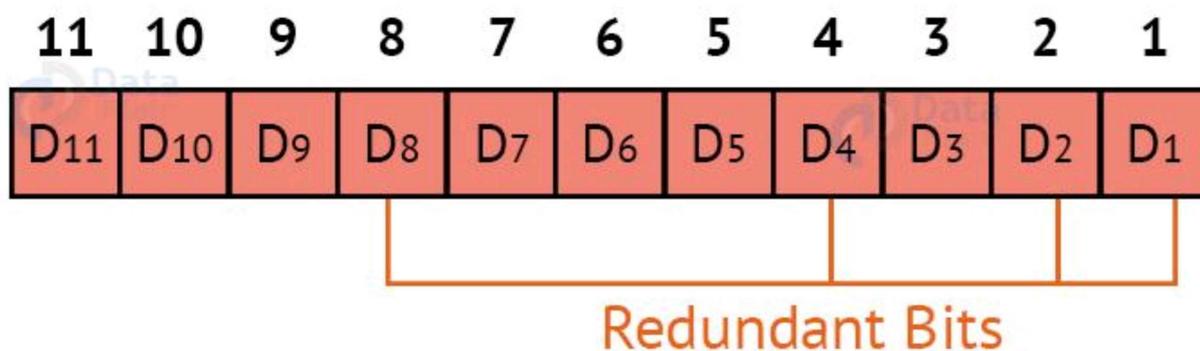
Number of data bits = 7

Thus, number of redundancy bits = 4

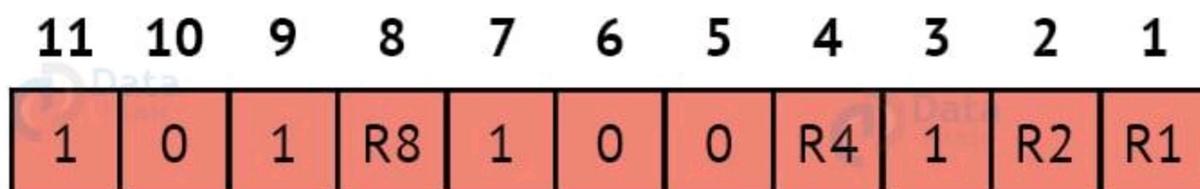
Total bits =  $7+4 = 11$

Redundant bits are always placed at positions that correspond to the power of 2, so the redundant bits will be placed at positions: 1, 2, 4 and 8.

Redundant bits will be placed here:



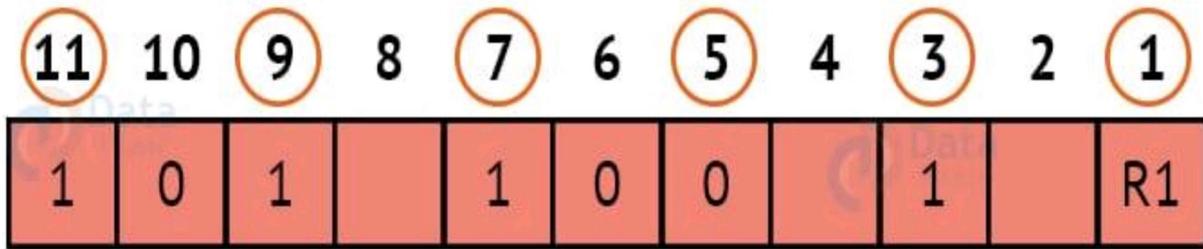
Thus now, all the 11 bits will look like this:



Here, R<sub>1</sub>, R<sub>2</sub>, R<sub>4</sub> and R<sub>8</sub> are the redundant bits.

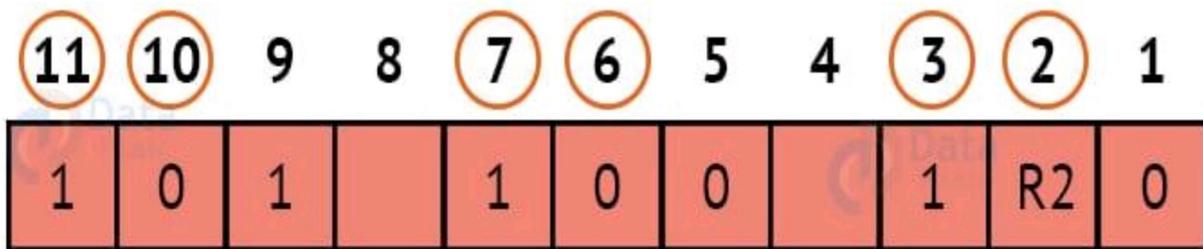
Determining the parity bits:

R1:



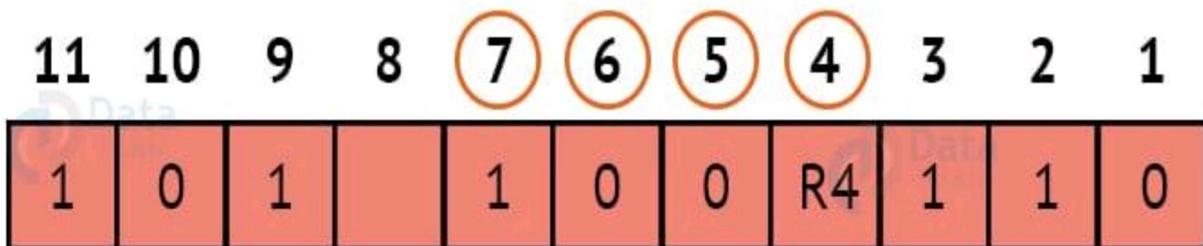
We look at bits 1,3,5,7,9,11 to calculate R1. In this case, because the number of 1s in these bits together is even, we make the R1 bit equal to 0 to maintain even parity.

R2:



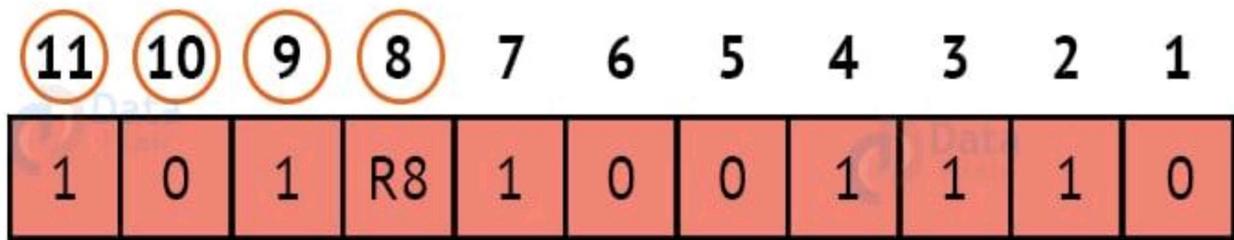
We look at bits 2,3,6,7,10,11 to calculate R2. In this case, because the number of 1s in these bits together is odd, we make the R2 bit equal to 1 to maintain even parity.

R4:



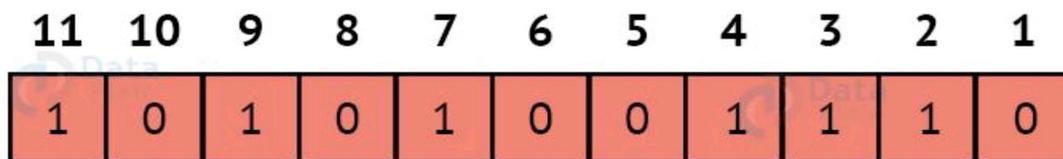
We look at bits 4,5,6,7 to calculate R4. In this case, because the number of 1s in these bits together is odd, we make the R4 bit equal to 1 to maintain even parity.

R8:



We look at bits 8,9,10,11 to calculate R8. In this case, because the number of 1s in these bits together is even, we make the R8 bit equal to 0 to maintain even parity.

Thus, the final block of data which is transferred looks like this:



The parity bits are recalculated at the receiving end. The position of an error is determined by the decimal value of the parity bits.