voice communication as well as for data communication.

5. Data communication is less efficient than voice communication.
6. The Circuit switching technique mainly takes place at the physical layer.

In Circuit-switched networks, the data transfer mode mainly involves a dedicated end-to-end connection. Until the end of the communication, this dedicated path is maintained. After the communication is over the link is released.

**Advantages of circuit switching**

1. Offers Dedicated Transmission
2. No Delay in Transmission

**Disadvantages of circuit switching**

1. Dedicated links cannot be used by other devices.
2. Need more bandwidth for dedicated paths.
3. Utilization of resources is not done properly as they are allocated for a dedicated links.
4. These links become more inefficient when there is no data transfer on these links.
5. Connection establishment between devices takes longer time.
6. This technique is costly.

**Packet switched networks:**

1. Packet Switching is a technique of switching in which the message is usually divided into smaller pieces that are known as packets.
2. All packets consist of destination information which helps the packets to route between the devices.
3. Unique numbers are given to each packet to identify them at the receiving end.
4. The Internet is the example of packet switched network.

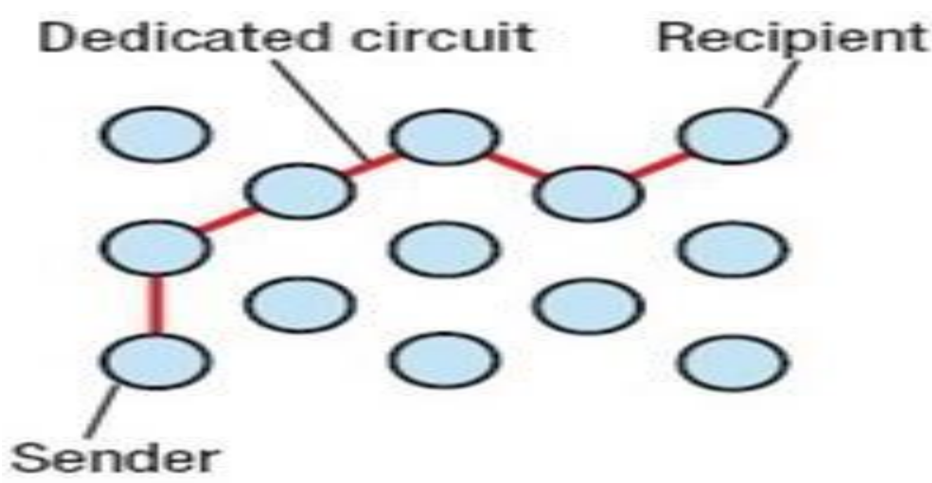



Fig.2.11. Circuit switched network.

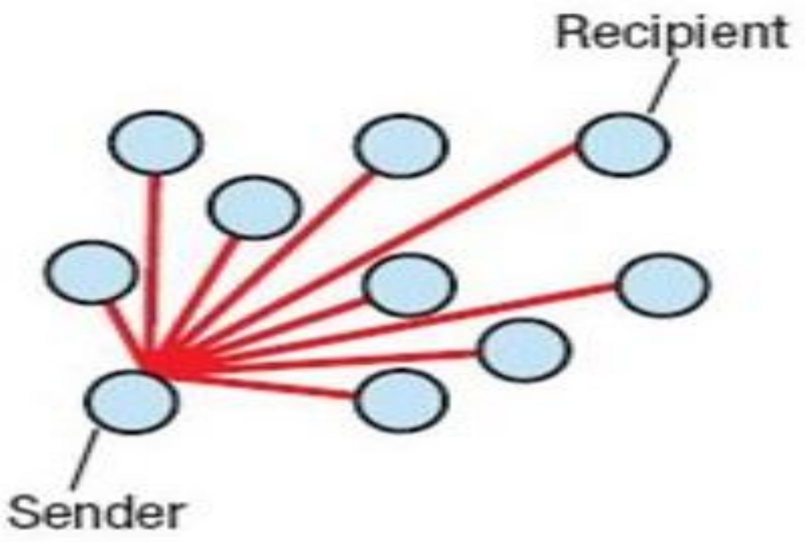



Fig.2.12. Packet switched network.

5. These packets have a header and a payload. The header consists of routing information, and payload contains the data that is to be transferred.
6. Switching is done by store and forward method.
7. No resource allocation is made. It is done on demand.
8. These packets travel independently in the network and are reassembled at the destination.
9. If the packets reach the destination in correct order, then acknowledgement is given to the sender and in case of missing packets also information is given to the sender.

**Broadcast Network**

1. A network in which a group of devices communicate with each other is called broadcast networks.
2. These networks are used for local terrestrial communication.
3. Here the network delivers one copy of the message to all the devices in the network.
4. When, such packets are received by the devices they check for MAC address.
5. The MAC address of such packets is set to FF:FF:FF:FF:FF:FF.
6. The IP address 255.255.255.255 is set in the destination IP address of all the packets.

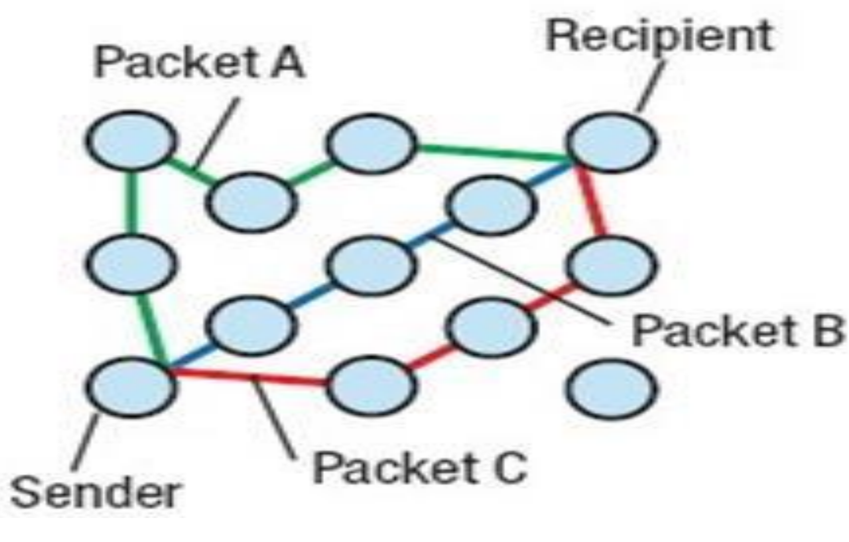


Fig.2.13. Broadcast network.

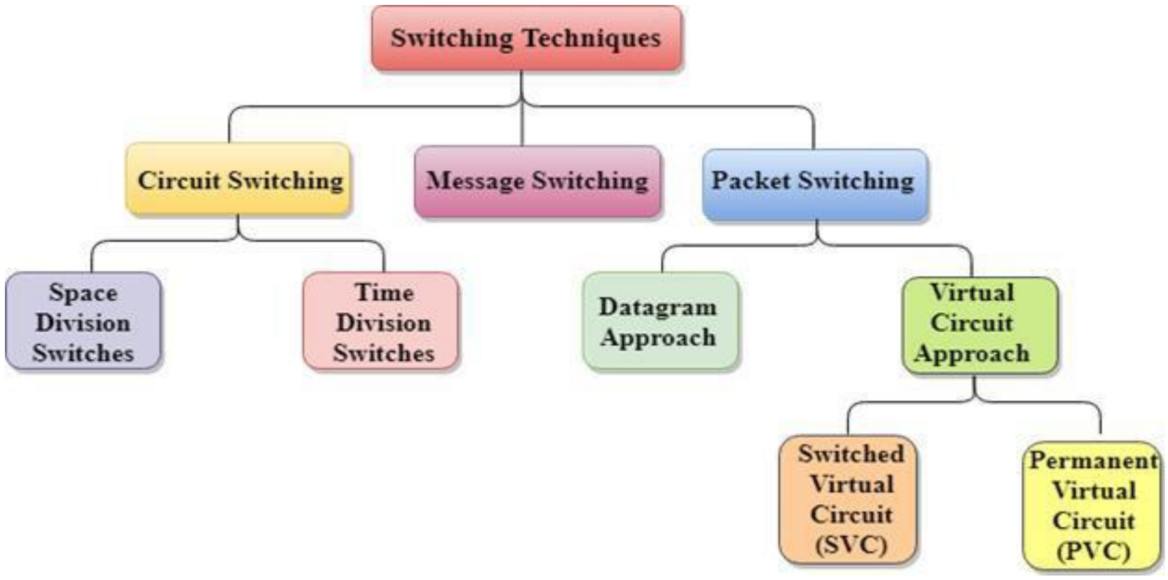



Fig.2.14. Broader classification of switching.

### 2.8.2 Modems

1. Modems are used to modulate and demodulate the electrical signals.
2. They convert the electrical signal to bits and vice-versa.
3. They provide access to the receiving devices from the signals transmitted by Internet service provider (ISP).
4. These devices are typically connected to the router providing internet access. They use Ethernet cable, Digital Subscriber Lines (DSL) or fiber or wireless mediums.
5. ISP's usually provide modems which are capable of routing the packets.

### Characteristics of Modems in Computer networks

1. Signal Conversion: Convert the signals from analog and digital and vice-versa
2. Data Transmission: Enable transmission on one or more channels. Facilitates efficient and reliable data transmission.
3. Modulation and Demodulation: Utilizes modulation techniques to encode data and employs demodulation to extract original data at receiving end.
4. Speed and Bandwidth: They work at various speeds and bandwidth capabilities. Ensures compatibility and interoperability between devices such as DSL, ADSL,

DOCIS(Data over service interface specification.

5. Error Correction: Incorporate error detection and correction techniques such as forward error correction (FEC), retransmission to ensure reliability in networks.
6. Network addressing: Play a role in connections and routing packets.
7. Security Features: They use firewalls, encryption, access control to safeguard the data packets between local network to broader networks.
8. Integration and Compatibility: They can be connected to computers, routers, switches, or other network equipment to establish network connections and enable data transmission

**Types of Modems:** There are several types of modems used in computer networks. They are given below.

**a) External Modem**

1. Connected to a computer or any system.
2. Connected using a serial cable
3. Simple and easy to install devices supporting higher data rates.
4. Expensive but still used because of high-speed data transmission.
5. Provides uninterrupted network access.

**b) Internal Modem**

1. Installed inside a system such as motherboard in a computer.
2. looks like electronic circuit.
3.Supports slow data transfer.
4. Used for dedicated connections due to its complexity.

**c) Wireless modem**

1. Connect to devices without cables.
2. Simple and cost effective to be used for personal use.
3. Uses radio frequency over air for data transmission and support fast transmission speeds.

**d) Dial-Up Modem**

These connect to computer to ISP over traditional telephone line. Uses public switched telephone network at a speed of 56 Kbps.

**Cable Modem:** These are referred to as a broadband service and enables the computers to communicate with ISP via a landline connection. Uses a coaxial for landline and ethernet cable for computer.

**DSL Modem:** Abbreviated as Digital subscriber lines. Supports fast data transmission over a standard telephone line. Widely use for business and residence. Can be connected to computer or router to provide internet access though USB port. They are of two types of DSL and ADSL.

**e) Satellite Modem**

1.Expensive
2. Do not require a phone or a internet connection.
3. Used in satellite to transmit and receive data.
4. Speed is slower than a DSL or a cable modem.

**Half-Duplex Modem**
Permits data transmission in one direction at a time.

**c) Full Duplex Modem**

Communicates in both directions without interruption.

**d) Four-Wire Modem**

Divides a pair of wires into two for incoming and outgoing data carries. Allows transmission at same frequency on both ends.

e) **Two-Wire Modem**
It uses a pair of wires, hence the name "two-wire modems."

**Advantages of modems**

1. Easy to install.
2. Cost-effective
3. Compatibility
4. Access to the Internet

**Disadvantages of Modems**

1. Slow Speeds
2. Limited Range
3. Security Concerns
4. Dependence on Service Provider

### 2.8.3 Multiplexing

Multiplexing is a technique used to combine and send the multiple data streams over a single medium. Multiplexing is done by a device called Multiplexer (**MUX**) that combines n input lines to generate a single output line. Multiplexing follows many-to-one, i.e., n input lines and one output line.

Demultiplexing is achieved by using a device called Demultiplexer (**DEMUX**) available at the receiving end. DEMUX separates a signal into its component signals called as one-to-many approach.

Need for Multiplexing:

1. The transmission medium is used to send the signal from sender to receiver. The medium can only have one signal at a time.
2. If there are multiple signals to share one medium, then the medium must be divided in such a way that each signal is given some portion of the available bandwidth.
3. When multiple signals share the common medium, there is a possibility of collision. Multiplexing concept is used to avoid such collision. Transmission services are very expensive.

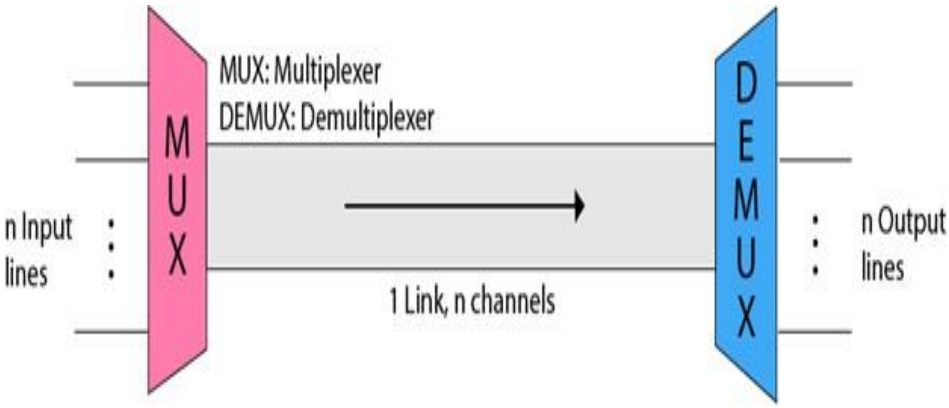



Fig.2.15. Multiplexing and Demultiplexing of Signals.

**Advantages of Multiplexing**

1. More than one signal can be sent over a single medium.
2. The bandwidth of a medium can be utilized effectively.

## 2.9 Performance of Computer Networks

1. Bandwidth and Latency:

Bandwidth of a network is given by number of bits that can be transmitted over the network in a certain period (1sec).

Ex: A network having a bandwidth of 10 million bits/sec meaning able to deliver 10 million bits per second. It means the capability of the network. It is also sometimes useful to fill how long it will take to transmit each bit of data.

Latency: This corresponds to how long it takes a message to travel from one end of the network to the other. It is measured in terms of time. We call this as round trip transmit time. (RTT of the network)

Latency has three components: This delay occurs because a bit on a wire can travel than the speed of light. If we know the distance between the two points, we can calculate the speed of signal. Signals travel with a speed f 2.3*10^8m/sec in cable and 2*10^8 in Fiber optic cable.

1. Second amount of time it takes to transmit a unit of data. This is the function of network bandwidth and size of the packet in which the data is carried.

2. Queuing delays inside the network as packets have t be stored before forwarding the then on a outbound link.

3. So total latency

latency = propagation + transmit + Queuing Propagation = Distance / speed of light Transmit = Size / Bandwidth

The common units f networking are MB, Mbps, KB and kbps. b – stands for bits.
B – stands for Bytes M – Mega K – Kilo
Mega can mean either $2^{20}$ or $10^6$. Similarity, kilo can be either $2^{10}$ or $10^3$

Bit interval: Bit interval is the time required to send one single bit.
Bit rate is the number of bits sent in one second usually expressed in bits per second.
(bps) Ex: Find the bit interval f a signal having a bit rate of 2000bps.
Bit interval = 1/Bit rate = 1/2000 = 0.5ms = 500 microseconds.

To better understand the concept the Bandwidth and latency watch this video. https://www.youtube.com/watch?v=TVpg7StOxgg

Transmission Impairment

1. Attenuation: It means loss of energy of the signal when it travels through a medium. This loss in energy occurs when the signal travels through the medium.
2. Distortion: Change in shape of the signal is called distortion.
3. Noise: Unwanted signals added during transmission.

Throughput

The throughput is the number of bits allowed to cross a particular point in a network at a given time.

Problems

1. Calculate the maximum bit rate of a signal with four signal levels having a bandwidth of 2000Hz.

Sol: Bit Interval = 1/Bit rate = 1/2000 = 0.5* $10^3$sec = 500μsec.

2. What if the bit of each of the following signals?
1. 1bit lasts for 2msec
2. 10bits lasts of 20μsec
3. 1000 bits lasts for 250bps.

Sol: 1. Bit rate = 1/Bit interval = 1/0.001 = 1000bps = 1kbps.
2. Given time taken for 10 bits we must calculate the time taken for 1 bit.
$20*10^{-6}$ /10 = $2*10^{-6}$. So, bit rate = 1/bit interval = 0.5mbps.
3. 1000 bits time interval = $250*10^{-12}$ /1000 = 0.25 $*10^{-12}$ So,
Bit rate = 1/0.25 $*10^{-12}$ = $4*10^{12}$bps.

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

Sol: Throughput = 12000*10000/60 = 2Mbps.

4. What is the propagation time and transmission time for a 205Kbyte message if the bandwidth of the network is 1Gbps. Distance between the sender and receiver is 12,000Km and light travels at speed of $2.4*10^8$ m/sec.

Sol: Propagation time = Distance/time = 12,000*1000/ $2.4*10^8$

Transmission time = size of message/ bandwidth = $2.5*10^8$ *8 / $10^9$ = 0.02ms.

5. Frames of 1000 bits are sent over a $10^6$-bps duplex link between two hosts. The propagation time is 25ms. Frames are transmitted into the link maximally packed in transmit. What is the maximum number of bits required to represent the sequence numbers distinctly? Assume that no time gap needs to be given between transmission of two frames.

Sol: Transmission time = size of message / Bandwidth = 1000/$10^6$ =$10^{-3}$ =1ms
Give a propagation time for complete messages is 25 milliseconds. Each frame takes one millisecond. The number of frames is 25. The sender transfers twenty five frames before first frame reaches the destination. The number of bids acquired to represent 25 different frames is 5.

6. Calculate the total time required to transfer 1.5 MB 5 assuming a round trip transmit time (RTT) of 80milliseconds, a packet size of 1KB, and an initial 2*RTT of handshaking time before the data is sent.
a) The Bandwidth is 10Mbps and data packet can be sent continuously.
b) The bandwidth is 10Mbps but after we finish sending the data packet, we must wait one

RTT before sending the next packet.

c) The link allows infinitely fast transmission but limits the bandwidth such that only 20 packets can be sent in one RTT.

d) Zero transmit time in C, bit during first RTT we can send one packet, during the second RTT we can send two packets and during third RTT we send 3 packets and so on.

Sol: a) 2*initial RTT + Size of message / bandwidth (transmission time) + RTT /2 (propagation time) = $80*10^{-3}*2$ +$1.5*10^6*8$ / $10*10^6$ + $40*10^{-3}$ = 160ms + 40ms + 1.2 = 1.4sec.

b) number of packets = $1.5*10^6$ *8 / $1*10^3$ = 15*1000 = 1500 packets.

So for each packet we have an addition of 80msec. So, total time to wait is 1.4 + 120 = 121.4 sec.

c) 20 packets for one RTT means 1500/20 = 75sets of 20 packets. Then number of packets (set of 20) = $1.5*10^6$ *8 /20* $1*10^3$ = $0.6*10^3$ = 60.

So, time taken for each set of packets is $60*80*10^{-3}$ = 4.8sec.

So, time taken for complete file is 1.4 + 4.8 = 6.2

d) Right after the handshaking is done we send one packet. One RTT after the handshaking we send two packets. At n RTT's past the initial handshaking we have sent 1+2+4+….+2n = 2n+1-1 packets. At n-10 we have thus been able to send all 1000 packets, the last batch arrives 0.5 RTT later. Total time is 2 + 10.5 RTTs or 1second.

7) Calculate the latency for the following [from the first bit to last bit] a) 10Mbps ethernet with a single store and forward switch in the path and a packet size of 5000bits. Assume the each link introduces a propagation delay of 10µsec and that the switch begins retransmitting after it has received the packet. b) same as (a) assume the switch implements "cut through" the packet after the first 200 bits have been received.

Sol: Propagation delay for each link 10µsec. One switch has two links so
transmission delay = message size/ bandwidth = 500µsec.

b) 4*500 + 04*10 =2.04sec

c) with cut through switch delays the packet by 200bits = $200/10*10^6$ = 20µsec.

There is still one 500µsec delay waiting for the last bit and 20µsec of propagation delay. So, 500 + 3*20 + 4*10 = 600 µsec.

8) Calculate the bandwidth delay product for the following links. Use one way delay measured from first bit sent to first bit received. a) 10Mbps ethernet with the delay of 10 µsec. b) 10Mbps ethernet with single store and forward switch in the path and a packet size of 5000bits. Assume delay of 10 µsec and that the switch begins retransmitting immediately after it has finished receiving the packet. c) 1.5Mbps T1 link, with a transcontinental one way delay of 50msec. d) 1.5Mbps T1 link through a satellite in geosynchronous orbit at 35,900Km high. The only delay is speed of light propagation.

Sol: 10Mbps – bandwidth, delay = $10*10^6$ so bandwidth *delay product = $10*10^6$ + 10 + 10

$+10^{-6}$ = 100bits = 12.5bytes.
b) the first bit delay is $5000/10*10^6 + 10*2 = 500 + 20 = 520$ µsec. Bandwidth propagation delay for 10Mbps for 10Mbps is $10*10^6 = 10^7$ bits /sec. do for 520 bits it is $10*10^6*520*10^{-6}$ = 5200 bits otherwise each link can hold 5000bits.
c) $1.5*10^6$ bits/sec * $10*10^{-3}$ = 75000 bits = 9375 bits [propagation delay of T1 link $50*10^{-3}$
d) $1.2*10^6$ * {$35900*10^8$} *2 = 179.50*2 =35,900 = 45Kbytes.

9. Consider a MAN with average source and destination 20Km apart one -way delay of 100µsec. At which data rate does the round trip delay equal the transmission delay for 1KB packet?

Sol: Distance = 20KM propagation delay (Tp) = 100 µsec.
Packet size = KB
RTT = 2*propagation delay = Transmission delay, substituting the values we have
2*100 µsec = 1KB/Bandwidth
Bandwidth =1KB/200 µsec = $2^{10}$x$10^6$/200 bytes per sec.
Bandwidth 512Mbps or 40.9Mbps.

10. What is the throughput in MBps achievable in stop and wait protocol by a maximum packet size of 1000 bytes and network span of 10Km. Assume the speed for a 1KB packet ?

Sol: In the given question, we are not provided with the network's bandwidth. So, in the above formula of throughput, we have ignored the term Tt from the denominator.
-Although it is incorrect, but we still ignore it for solving the question.
Now, Given-
L = 1000 bytes
d = 10 km = 10^4 m
v = 70% of 3 x 10^8 m/sec = 2.1 x 10^8 m/sec
Substituting the values in the above relation, we get-
Throughput
= 1000 bytes / [ 2 x 10^4 m / (2.1 x 10^8 m/sec)]
= 1.05 x 10^7 bytes per sec
= 10.5 MBps

## Summary

The physical layer is the last layer of the communication paradigm. In this layer the data is converted to electrical signals for bits. It is then kept in the physical communication link. This layer checks the bandwidth of both the transmitter and receiver and sets the electrical signals. It also selects the speed at which the data is to be transmitted. Bandwidth, Throughout and quality io service are discussed in accordance with the physical. It also takes care of topology in which the devices are connected to each other.

Self-Assessment questions

1. What is the term used to describe the physical pathway through which data travels in a network?
Data Link Layer b) Transmission Media c) Network Interface Card (NIC)
Protocol

2. Which transmission media uses electrical signals to transmit data and is commonly used for short-distance connections within a network?
Coaxial Cable b) Fiber-optic Cable c) Twisted Pair Cable d) Wireless

3. What type of transmission media is best known for its immunity to electromagnetic interference and high bandwidth capabilities?
Coaxial Cable b) Fiber-optic Cable c) Twisted Pair Cable d) Wireless

4. Which transmission media is commonly used for long-distance connections, such as undersea cables and high-speed internet backbones?
Coaxial Cable b) Fiber-optic Cable c) Twisted Pair Cable d) Wireless

5. What is the primary advantage of using twisted pair cable as transmission media?
High data transfer rates b) Immunity to electromagnetic interference
c) Low cost and easy installation d) Long transmission distances

6. Which transmission media is susceptible to eavesdropping and interception of data signals?
Coaxial Cable b) Fiber-optic Cable c) Twisted Pair Cable d) Wireless

7. Which of the following devices is responsible for connecting multiple computers within a local area network (LAN)?
Router b) Modem c) Switch d) Bridge

8. What is the function of a modem in computer networking?
To connect multiple devices in a network
To convert analog signals to digital signals
To route data packets between networks
To provide wireless connectivity to devices

9. In telecommunication, what is a trunk?
A type of cable used for transmitting data
A high-speed network connection between switches or exchanges
A device used for multiplexing signals
A protocol for secure data transmission

10.What is multiplexing?

The process of converting analog signals to digital signals

The process of combining multiple signals into a single transmission medium

The process of routing data packets between networks

The process of converting digital signals to analog signals

Practice problems

1. Calculate the total time required to transfer a 1.5-MB file in the following cases, assuming an RTT of 80 ms, a packet size of 1 KB and an initial 2×RTT of "handshaking" before data is sent.
(a) The bandwidth is 10 Mbps, and data packets can be sent continuously. (b) The bandwidth is 10 Mbps, but after we finish sending each data packet we must wait one RTT before sending the next. (c) The link allows infinitely fast transmit, but limits bandwidth such that only 20 packets can be sent per RTT. (d) Zero transmit time as in (c), but during the first RTT we can send one packet, during the second RTT we can send two packets, during the third we can send four = 23−1, and so on.

2. Consider a point-to-point link 2 km in length. At what bandwidth would propagation delay (at a speed of 2*1^8) equal transmit delay for 100-byte packets? What about 512-byte packets?

3. One property of addresses is that they are unique; if two nodes had the same address it would be impossible to distinguish between them. What other properties might be useful for network addresses to have? Can you think of any situations in which network (or postal or telephone) addresses might *not* be unique?

4. Suppose a 100-Mbps point-to-point link is being set up between Earth and a new lunar colony. The distance from the moon to Earth is approximately 385,000 km, and data travels over the link at the speed of light—3 × 108 m/s. (a) Calculate the minimum RTT for the link. (b) Using the RTT as the delay, calculate the delay × bandwidth product for the link. (c) What is the significance of the delay × bandwidth product computed in (b)? (d) A camera on the lunar base takes pictures of Earth and saves them in digital format to disk. Suppose Mission Control on Earth wishes to download the most current image, which is 25 MB. What is the minimum amount of time that will elapse between when the request for the data goes out and the transfer is finished?

5. Calculate the effective bandwidth for the following cases. For (a) and (b) assume there is a steady supply of data to send; for (c) simply calculate the average over 12 hours. (a) 10-Mbps Ethernet through three store-and-forward switches as in Exercise 18(b). Switches can send on one link while receiving on the other. (b) Same as (a) but with the sender having to wait for a 50- byte acknowledgment packet after sending each 5000-bit data packet.
(c) Overnight (12-hour) shipment of 100 compact disks (650 MB each).
6. What is the total delay (latency) for a frame of size 5 million bits that is being sent on a

link with 10 routers each having a queuing time of 2 Ils and a processing time of 1 Ils. The length of the link is 2000 Km. The speed of light inside the link is 2 x *108 mls.* The link has a bandwidth of 5 Mbps. Which component of the total delay is dominant? Which one is negligible?

7. Hosts A and B are each connected to a switch S via 10-Mbps links as in Figure 1.25. The propagation delay on each link is 20 µs. S is a store-and forward device; it begins retransmitting a received packet 35 µs after it has finished receiving it. Calculate the total time required to transmit 10,000 bits from A to B (a) as a single packet
(b) as two 5000-bit packets sent one right after the other


8. Suppose a host has a 1-MB file that is to be sent to another host. The file takes 1 second of CPU time to compress 50%, or 2 seconds to compress 60%. (a) Calculate the bandwidth at which each compression option takes the same total compression + transmission time. (b) Explain why latency does not affect your answer.

9. Consider a closed-loop network (e.g., token ring) with bandwidth 100 Mbps and propagation speed of 2 × 108 m/s. What would the circumference of the loop be to exactly contain one 250- byte packet, assuming nodes do not introduce delay? What would the circumference be if there was a node every 100 m, and each node introduced 10 bits of delay?

10. Consider a source computer S transmitting a file of size 106 bits to a destination computer D over a network of two nodes R1 and R2 and three links L1, L2 and L3. L1 connects S to R1, L2 connects for R1 to R2 and L3 connects from R2 to D. Le each link be of length 100Km. Assume signals travel over each link at a speed of 10^8 m/sec. Le the file be broken down to 1000 packets each of size 1000 bits. Find the total sum of transmission and propagation delay in transmitting the file from S to D?

Terminal Questions

1. How are Network types classified?
2. Explain different types of networks?
3. Differentiate guided and unguided transmission media?
4. Explain the transmission characteristics of a network?
5. Explain the network topologies with their advantages, disadvantages, and application?
6. What is an internet? What is the Internet?
7. Why are protocols needed?
8. Why are standards needed?
9. List the layers of the Internet model.
10. Which layers in the Internet model are the network support layers?

11. Which layer in the Internet model is the user support layer?
12. What is the difference between network layer delivery and transport layer delivery?
13. What is a peer-to-peer process?
14. How does information get passed from one layer to the next in the Internet model?
15. What are headers and trailers, and how do they get added and removed?
16. What are the concerns of the physical layer in the Internet model?
17. What are the responsibilities of the data link layer in the Internet model?
18. What are the responsibilities of the network layer in the Internet model?
19. What are the responsibilities of the transport layer in the Internet model?
20. What is the difference between a port address, a logical address, and a physical address?
21. Name some services provided by the application layer in the Internet model.
22. How do the layers of the Internet model correlate to the layers of the OSI model?

**References of books, sites, links**

| **Text Books** | |
|---|---|
| 1 | TCP/IP Protocol Suite, Behrouz A.Ferouzan, Fourth Edition |
| 2 | The DHCP Handbook, Ralph Droms, and Ted Lemon, Second Edition |
| 3 | Enabling Enterprise Multi homing With Cisco IOS Network Address Translation (NAT), Praveen Akkiraju, Cisco Consulting Engineering Kevin Delgadillo, Cisco IOS Product Marketing Yakov Rekhter, Cisco Fellow |
| 4 | PRO DNS and Bind, Ronald G.F.Aitchison, |
| 5 | Cisco certified Network Associate (200-120) |
| **Web References** | |
| 1 | http://dkim.org/ |
| 2 | Data and Computer Communications, William Stallings, Tenth Edition |
| 3 | https://notes.shichao.io/tcpv1/ch8/ |
| 4 | David D. Clark (July 1982), IP Datagram Reassembly Algorithms .pdf (Type in Google) |
| 5 | https://docs.microsoft.com/en-us/previous-versions/windows/it-pro/windows-server-2012-R2-and-2012/hh945104(v=ws.11) |

# Chapter -3
## Data Link Layer

### 3.1 Introduction to data link layer

This layer enables hop-to-hop communication facility. This layer is the second layer of the OSI model and TCP/IP reference models. It provides services to the upper layer i.e., the network layer and to the lower layer i.e., the physical layer. Hop-to-hop or node-to-node delivery is the most important functionality of the data link layer.

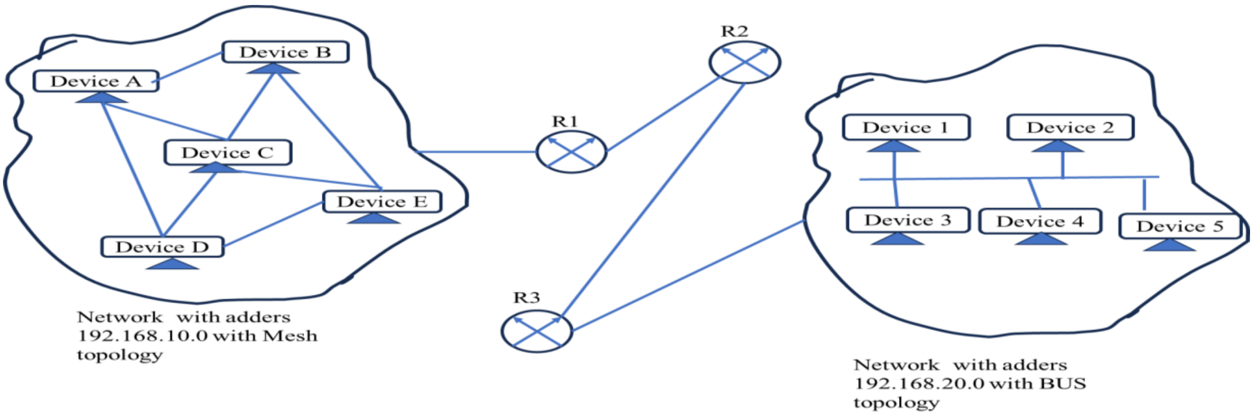



Fig.3.1. Example of network.

In the above example we have two networks with network address 192.168.10.0 and 192.168.20.0. These networks are named as network A and B respectively. The devices in the network A are connected in mesh topology and network B are connected in Bus topology. The first responsibility of data link layer is to communicate with in a network i.e., here if the two are more devices in network A want to communicate with each other, then such communication will be done with the help of data link layer. This communication is done with the help if MAC address or the physical address of the devices.

Network A and B are situated at different places, for example Delhi and Vijayawada. These two networks are interconnected with network devices called as routers (which route the packets- will be introduced in CO2). Now let us assume device D of network A wants to communicate with device 4 of network B, which is as shown above. The devices cannot communicate with other as such because they must follow some path and rules. The routers ae also called as nodes in a network.

Link layer takes care of the communication that will happen between nodes i.e., link layer with find out to which node it must send the inforamtion from the network. Once reaching on the first node in the path, it will take the responsibility of sending it to the next node in the path of reaching the destination.

The router $R_1$, $R_2$ and $R_3$ may be connected to many other networks in between. Once the information has reached to $R_1$ the link layer with check that it must send the data from $R_1$ $R_2$ and $R_2$ $R_3$ and for $R_3$ to device 4 of network B. The primary function of link layer is to communicate between node to node.

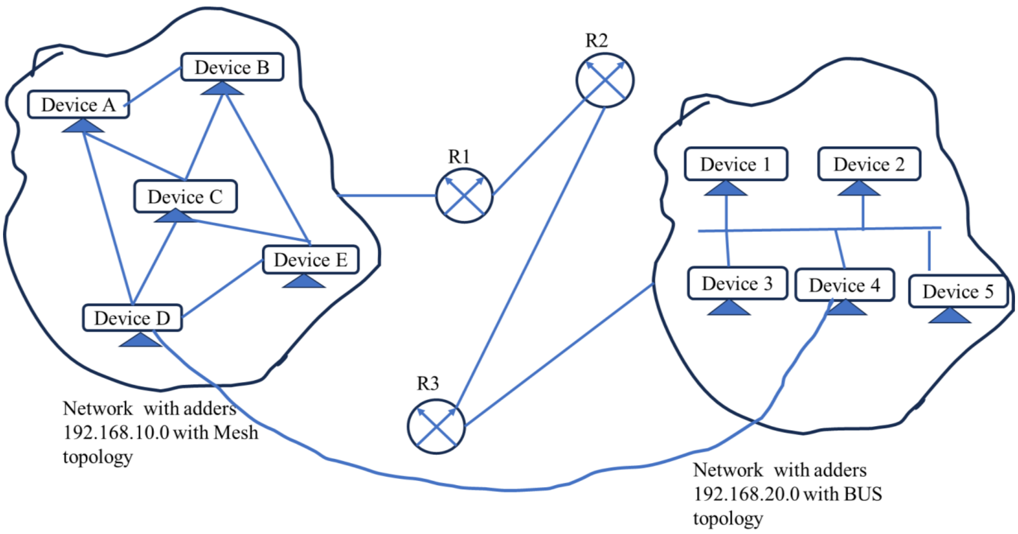



Fig.3.2. Communication to be established between device D of network A to device 4 of network B.

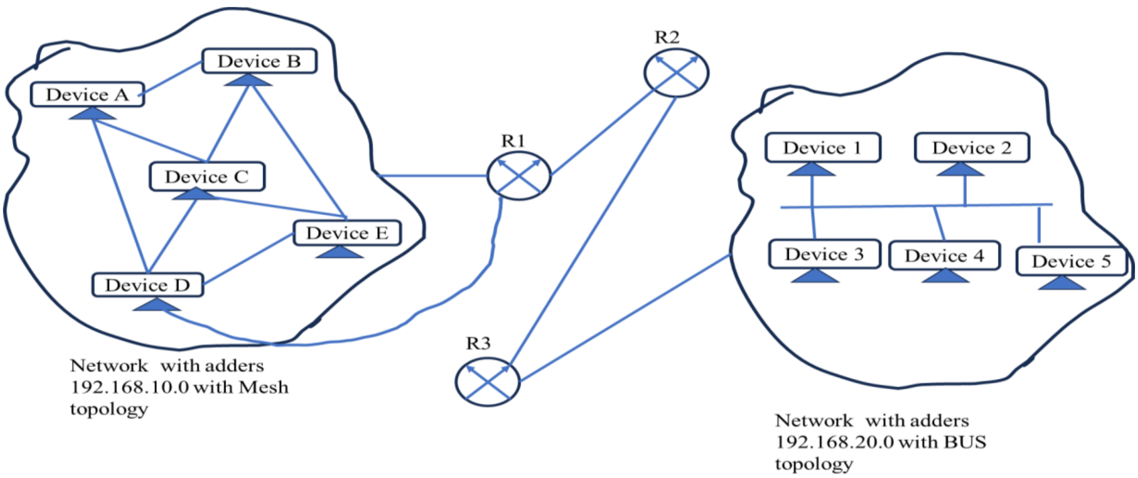



Fig.3.3. Communication to be established between device D of network A to router $R_1$.

So, finally the link layer will communicate between the node to node and reach to different networks. This is called as hop-to-hop or node-to-node delivery. Link layer has other responsibilities such as framing, addressing, flow control, error control and medium access control. It adds a header to the data units called frames. In this header source and destination MAC (Medium Access link layer) address are defined to reach to a specific destination.

This layer addresses the problem of overwhelming of data at the receiver by implementing a mechanism called as flow control. It adds reliability to the physical layer by adding mechanism to detect and retransmit damaged, duplicate and lost frames. When devices are connected to the same link then devices should be accessed such that collision domains are not formed.

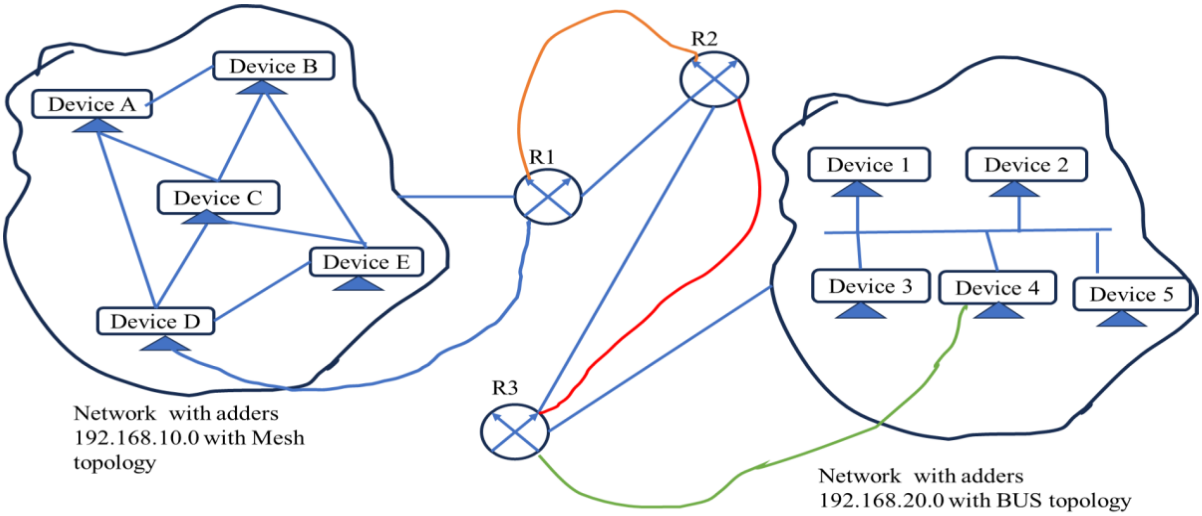



Fig.3.4. Communication to be established between device D of network A to device 4 of network B.

### 3.1.1 Error detection and correction

During transmission of data from one node to another data can be corrupted. For a reliable transmission it is required to detect and correct the errors. There are two types of errors, they are 1. Single bit error 2. Burst error.

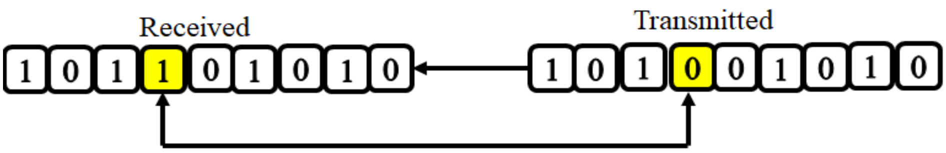



Fig.3.5. Single bit error.

Single bit error is most likely to happen in a serial transmission. Let us assume that sender is sending a data at the rate of 1Mbps i.e., each bit lasts for 1/1000000 sec or 1µsec. But usually, noise has more duration than this. So, in serial transmission it is less likely to happen. In parallel transmission where 8 bits are sent on 8 different lines where if one line is noisy there is a possibility of occurrence of single bit error.

Burst error means 2 or more bits in the data are corrupted. Burst means that the error occurs in consecutive bits. The length of the burst is measured form the first corrupted bit to the last corrupted bit. Some bits in between may not have been corrupted. This type of error is most likely to happen in serial communication. The duration of noise is normally greater that the duration of bits. The number of bits affected depends on the data rate and duration of noise.

Redundancy

The concept of adding extra bits to the transmitted data for detection and correction of errors is called redundancy. These redundant bits are discarded as soon as the transmission accuracy is determined.

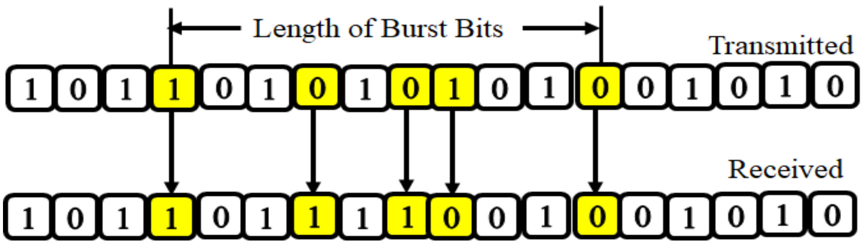



Fig.3.6. Burst error.

## 3.2 Methods of error detection

There are many methods of error detection and correction. Parity check, Cyclic redundancy check, Check sum and Hamming code are some common methods used for error detection and correction in data communication.

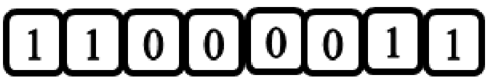
### 3.2.1 Parity check

This is the most common method and the least expensive mechanism for error detection. **It is done in single and two dimensions.**

**Single bit parity check**

In this method a redundant bit is added to every data unit so that the total number of 1's in the unit (including parity bit) becomes odd or even. The procedure for performing even parity is given below.

1. For example, take a data word as given here.




2. The transmitted data word will be as given below. Here the last bit will be the parity bit representing even parity. If it is odd parity, then it will be '1'

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |

Fig.3.7. Data word representing even parity.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |

Fig.3.8. Data word representing odd parity.

3. The receiver has the prior information of what parity is used.
4. When the receiver receives the transmitted data it checks for error using the known parity and understands whether the data word is correct or wrong.
5. The receiver also has the information at which place the parity bit is added to the data word.
6. In the example given here, even parity is used, and the parity bit is the right most bit.
7. If the number of 1’s in the data word is even then the parity bit should be zero.
8. It checks the parity bit if it is ‘0’ then received data is correct. If it is ‘1’ then the transmitted data word is wrong.
9. The main disadvantage of this method is that we cannot recognize at which bit position the error has occurred.
10. If error has occurred for even number of times, we cannot identify the error in data transmission. This is same for odd parity also.

**Two-dimensional parity check**

This is a better method than single bit parity. In this method the data is divided in to sets and arranged into rows. Then the parity bits are added at the end of the row and column. At the last all rows are transmitted sequentially to the receiver. At the receiver the data is rearranged and checked for parity. In this method we can identify where the error has occurred.

Example: 1011 1001 0001 1111 0101 0111 0110. Let us implement even parity on the transmitted data.

Tab.3.1. Transmitted data word.

| Data word | | | | Parity bit |
|---|---|---|---|---|
| 1 | 0 | 1 | 1 | 1 |
| 1 | 0 | 0 | 1 | 0 |
| 0 | 0 | 0 | 1 | 1 |
| 1 | 1 | 1 | 1 | 0 |
| 0 | 1 | 0 | 1 | 0 |
| 0 | 1 | 1 | 1 | 1 |
| 0 | 1 | 1 | 0 | 0 |
| 1 | 0 | 0 | 0 | 1 |

The row and column which are coloured are the parity bits which are added. The transmitted data will be 10111 10010 00011 11110 01010 01111 01100 10001. At the receiver the data word is rearranged into the table and parity bits are checked. If the parity bits are according to the implemented data, then the transmitted data is correct. Let us consider two error occurred at two different places.

The yellow colour data bits in the table.1.3 are the incorrect bits. In that table the red colour bits do not match the parity bits. Thus, the receiver will understand the transmitted bits are wrong. In this case also if even number of bits are corrupted in a row, we cannot identify them.

Advantages of 1D and 2D parity check
1. Simple.
2. Ease to apply.
3. Has some accuracy than sending raw data
Disadvantages of 1D and 2D parity check
1. Limited error detection.
2. Errors are not detected clearly
3. Number of false alarms is high
4. Provides basic security

Tab.3.2. Received data word (correct).

| Data word | | | | Parity bit |
|---|---|---|---|---|
| 1 | 0 | 1 | 1 | 1 |
| 1 | 0 | 0 | 1 | 0 |
| 0 | 0 | 0 | 1 | 1 |
| 1 | 1 | 1 | 1 | 0 |
| 0 | 1 | 0 | 1 | 0 |
| 0 | 1 | 1 | 1 | 1 |
| 0 | 1 | 1 | 0 | 0 |
| 1 | 0 | 0 | 0 | 1 |

Tab.33. Received data word (incorrect).

| Data word | | | | Parity bit |
|---|---|---|---|---|
| 1 | 0 | 1 | 1 | 1 |
| 1 | 1 | 0 | 1 | 0 |
| 0 | 0 | 0 | 1 | 1 |
| 1 | 1 | 0 | 1 | 0 |
| 0 | 1 | 0 | 1 | 0 |
| 0 | 1 | 1 | 1 | 1 |
| 0 | 1 | 1 | 0 | 0 |
| 1 | 0 | 0 | 0 | 1 |

### 3.2.2 Cycle redundancy check (CRC)

This one of the most powerful methods of error checking. In this method a string of bit's is added to the given data word. Cycle redundancy check is done in the following procedure.
1. The given data word is divided by a polynomial.
2. The polynomial should have all the terms. If any term is missing, then replace the quotient of that term is to be taken as zero.
3. The polynomial should be of one variable. The coefficients these polynomials should be

either one or zero. The division is the set of all the coefficients of such polynomial.

4. Division performed here is also called as Ex-or addition. Before dividing with the divisor – the set of coefficients of the polynomial n number of zeros are added after the LSB bit of the dividend. n = m-1 where m is the number of bits in the divisor.
5. After division the remainder is taken and replaced in the number of zeros added and transmitted. At reception same procedure is again repeated and if the remainder is zero then the transmitted data is correct.
6. Otherwise it is in-correct.
7. Some of the standard polynomials are given in the table below

Tab.3.4. Some standard polynomial used in networks.

| Standard | Polynomial | Place where it is used |
|---|---|---|
| CRC-8 | $X^8 + X^2 + X + 1$ | ATM header |
| CRC-10 | $X^{10} + X^9 + X^5 + X^4 + X^2 + 1$ | HDLC |
| ITU-16 | $X^{16} + X^{12} + X^5 + 1$ | LAN'S |
| ITU-32 | $X^{32} + X^{26} + X^{22} + X^{16} + X^{12} + X^{11} + X^{10} + X^8 + X^7 + X^4 + X^2 + X + 1$ | LAN'S |

**The CRC generator**

1. Let us assume the polynomial as $X^3 + X + 1$.
2. Then the binary conversion of the polynomial is $X^3 + X^2 + X + 1$.
3. Now the term in the polynomial has coefficients of '1' or '0', i.e., $1*X^3 + 0*X^2 + 1*X + 1$.
4. So the divisor is 1011. Let us assume the data word to be 1011011001.
5. Now we have to append the data with n number of zeros. n = m-1 where m = number of bits in divisor. Here m = 4, so n = 4-1 = 3.
6. By appending the data with 3 zeros it will be 1011011001000.
7. During division if first bit is 1 then perform Ex-or by given divisor, if not perform the division be all zeros in the place of divisor. It is performed as below.
8. Now the remainder of the division is considered by removing the MSB bit then it will be 110. The redundant bits will be replaced by 110 and then the transmitted word will be 1011011001110.
9. The same action is performed at the receiver and if the remainder is all zeros, then the transmitted data is correct. It not the data is corrupted, and receiver will ask for retransmission.
10. CRC is very effective error detection method. If the divisor is chosen according to the rule.\
11. CRC can detect all burst errors that effect odd number of '1'
12. CRC can detect all bust errors of length les than or equal to degree to the polynomial.

Advantages of Cycle redundancy check

1. It is easy to implement 2. Robust 3. This method can detect the errors caused by noise,

interference and other factors which influence the accuracy of the signals.

Disadvantages of Cycle redundancy check

1. More complex while handling large data.

### 3.2.3 Check Sum

In this method all the data is divided into equal segments of n bits.

1. These segments are added using binary addition.
2. If we got a carry in binary addition then, the carry is to be added to the sum before adding the next set of bits. This addition is shown in fig.2.7 where the carry bits are in yellow colour.
3. The procedure to be continued till the end of the data.
4. Once the total sum is obtained then, we must take one's complement of the result.
5. These bits will be added to the data and are transmitted to the receiver. This is done at the transmitter the data sent in this example is 1011 0001 1010 1110 0000 0101 1001.
6. The total sum achieved after addition is 0100. The Ones's complement of it is 1011.
7. Now the transmitted message is 1011 0001 1010 1110 0000 0101 1001 1011.
8. At the receiver same procedure is performed and one's complement of the result is computed. If the answer after performing one's complement is all zeros, then the received data is correct otherwise the received data is wrong.

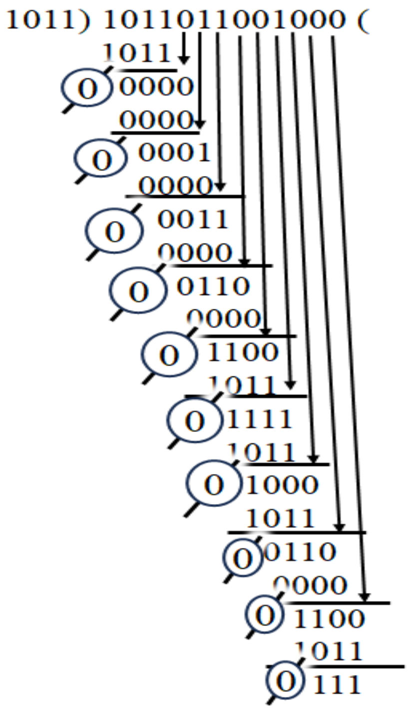



Fig.3.9. CRC Check at the transmitter.

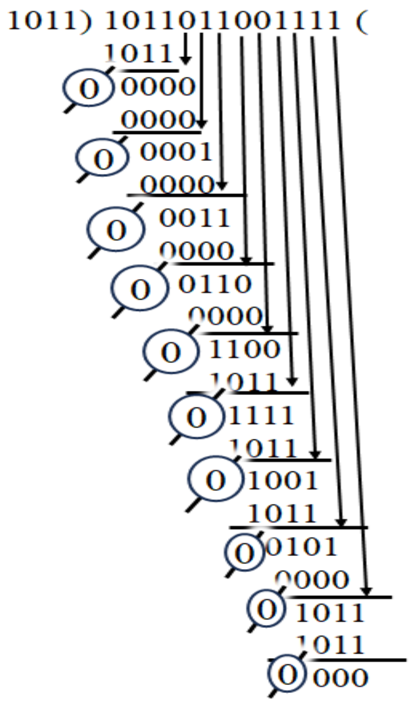



Fig.3.10. CRC Check at the receiver.

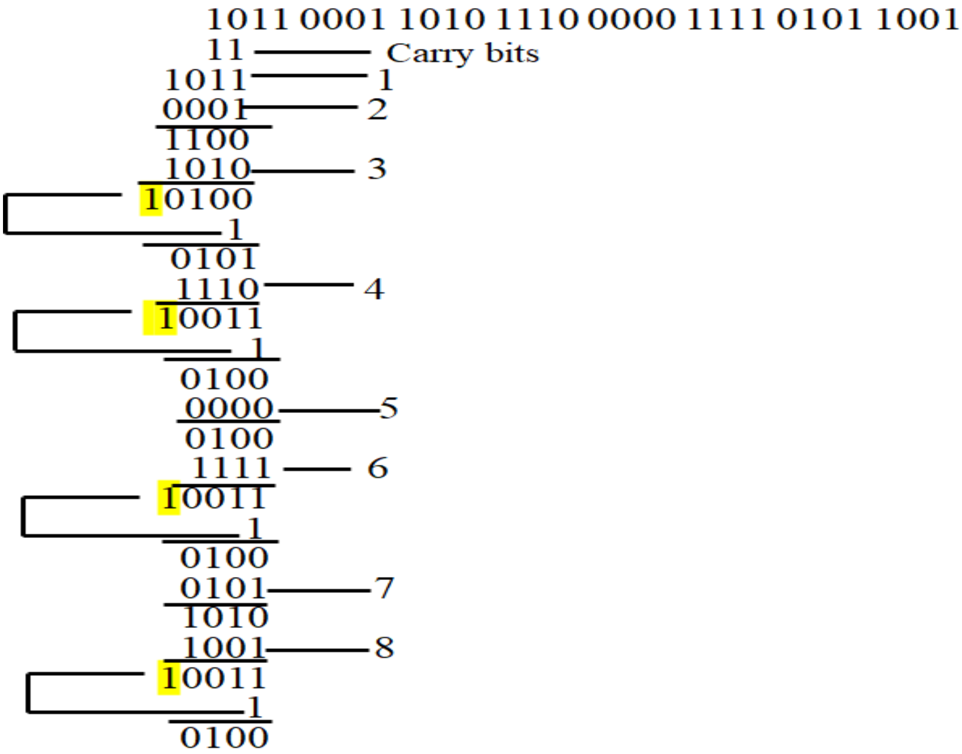



Fig.3.11. Check sum at transmitter.

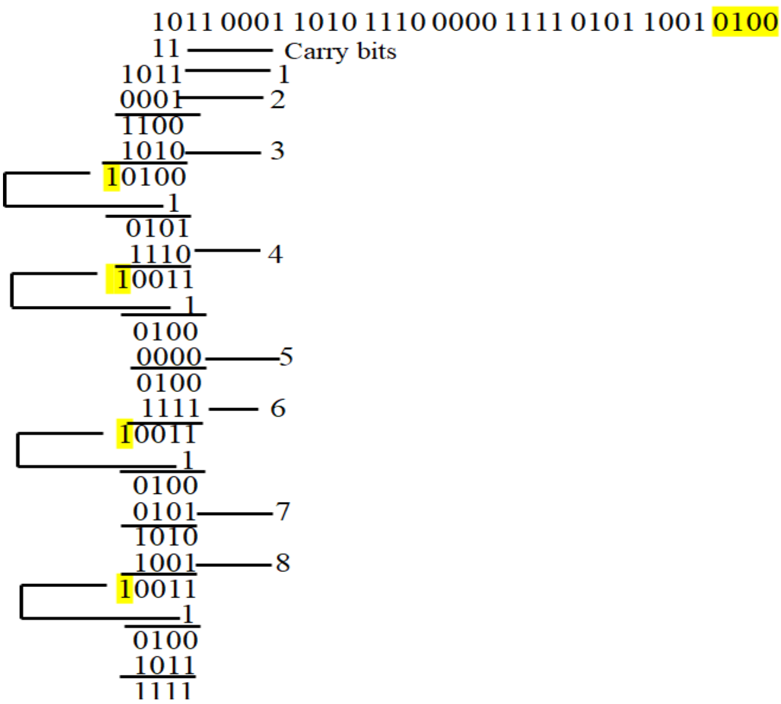



Fig.3.12. Check sum at receiver.

### .2.4 Hamming code

This is a technique of detecting and correcting single bit errors at receiver in networks. It was designed by R.W.Hamming for damage and error detection during transmission between multiple network channels. In this code some extra bits called as redundant bits are added to the given data.

Step 1: The number of redundant bits to be added is given by

$2^r >= d+r+1$, where d = number of data bits, r = number of redundant bits

and r = {1,2,3,4 ……..}

For example, let is take a data word with 4 data bits. So, the number of redundant bits to be added will be ……

r = 1, then $2^1 >= 4+1+1$, 2 >= 6 not satisfied,

r = 2, then $2^2 >= 4+2+1$, 4 >= 7, not satisfied,

r = 3, then $2^3 >= 4+3+1$, 8 >= 8, satisfied, so the number of redundant bits to be added to a 4-bit data word are 3 bits

Step 2: The redundant bits to be added will follow either even or odd parity. Let us consider even parity here.

Step 3: Place of the redundant bits in the arrangement.

It is given by $2^p$ where p = {0,1,2,3,4 ……..}. So, the parity bit positions are $2^0 = 1$, $2^1 = 2$, $2^2 = 4$. These are the parity bit positions.

Step 4: The parity bits are computed as given below.

Suppose if we want a parity bit in position 1, we will consider the data bits.

P1: 1, 3, 5, 7, 9, 11

P2: 2, 3, 6, 7, 10, 11

P4: 4, 5, 6, 7

P8: 8, 9, 10, 11

Let us take the data word as 1011

The first row represents the bit positions, second row represents the position of the data bits and parity bits, and the third row represents the data bits considered here. Binary data should be considered from left to right only then only you will get correct error detection.

| | | | | | | |
|---|---|---|---|---|---|---|
| B7 | B6 | B5 | B4 | B3 | B2 | B1 |
| D4 | D3 | D2 | P3 | D1 | P2 | P1 |
| 1 | 0 | 1 | P4 | 1 | P2 | P1 |

Parity position one: P1 ---- 1, 3, 5, 7 as we have 7 bits only. So, for P1 – 1,1,1 if we consider even parity then the P1 = 1.
Similarly, P2: 2, 3, 6, 7. So, P2 --- 1, 0, 1 if we consider even parity the P2 = 0 and
P4: 4, 5, 6, 7 i.e the third parity which is in 4$^{th}$ bit position is P4 --- 1,0,1 so P4 = 0. Here the parity bits are represented by yellow colour. The data word transmitted is 1010101. After the recepetion of data word at the receiver it checks for the parity bits. The same rule is applied at the receiver for the parity bits also.


If the parity bits are matching, then the received word is correct otherwise the information send is wrong.

Advantages of Hamming code:
1. These codes are more effective.
2. They can detect and correct single bit error in data streams.
3. Simple and easy to implement.
4. Most widely used codes in networks.

Disadvantages of Hamming code:
1. Requires more bandwidth.
2. Redundant bits reduce the bit rate at transmitter.
3. Could not detect error in two or more number of bits.

**3.3 Framing**

Data received from networks layer is divided into frames in link layer. When data is transmitted in-terms of bits it will be difficult for the receiver to discriminate different blocks of information. Framing of data is another important responsibility of data link layer. This process also ensures that data has been delivered accurately and efficiently. Problems faced in framing are 1. Detecting the start of the frame 2. How does the station detect a frame 3. Detecting end of a frame 4. Handling errors 5. Framing Overheard 6. Framing incompatibility 7. Framing efficiency.

Types of framing:
1. Character count
2. Flag bytes with bite stuffing
3. Starting and ending flags with bit stuffing
4. Physical layer coding violations

1. Data link layer provides services to network layer and the physical layer.
2. The physical layer accepts the bit stream provided by the data link layer and transmits it into the receiver. It takes care of bit synchronization only.
3. The main functions of data link layer in to divide the bit streams into frames and to compute check sum.