Master of Computer Applications

OMC102
Computer Networks

Directorate of Distance and Online Education

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Syllabus

Program	Master of Computer Applications
Semester	I
Course Title	Computer Networks
Course Code	OMC102
Course Credit	3
Course Type	Core Theory Course

1. Course Summary

This course deals with the concepts and technologies used in modern computer networking and data communication. A computer network interconnects two or more computing devices. Since implementing computer networking software is a highly complex task, it has been implemented in different layers. Every layer has a well-defined service to perform. This course facilitates the students to understand the function of different layers and IEEE standards employed in computer networking. The students are taught the methods to enhance network performance such as routing and congestion control. Fundamental concepts of computer networks, different network models, and topologies are covered.

2. Course Outcomes (COs)

After the successful completion of this course, the student will be able to

CO-1. Explain the principles, mechanisms, and functionalities of network applications, transport layer protocols, network layer design, and link layer services in computer networks. (L2)

CO-2. Illustrate the principles and architectures of network applications, including protocols such as HTTP, FTP, SMTP, POP3, IMAP, and DNS. (L2)

CO-3. Demonstrate the use of different computer network components, including hardware, media, and topologies. (L3)

CO-4. Compare error-detection and correction techniques, multiple access protocols, and Ethernet technologies in the context of link-layer services and local area networks. (L4)

CO-5. Evaluate routing algorithms (such as link-state and distance vector) in terms of their efficiency, scalability, and adaptability to various network environments. (L5)

3. Course Contents

Sr. No	Units	Unit Outcomes After the successful completion of the unit, the learner should be able to
1	**Unit 1:** **Introduction:** • Data Communication	1. Outline the basic concepts of data communication and the Internet. 2. Explain the different network

	Basics • History of Computer Networking and the Internet. • Internet • Protocol • Services **Computer Network**: • Hardware • Media • Topology	components including the hardware and medium of communication. 3. Identify the different network topologies.
2	**Unit 2:** **Protocol layering:** • The OSI Reference Model and the TCP/IP protocol stack. • Internet Access Networks. Circuit and Packet Switching **Delays:** • Processing, Queuing, Transmission, and Propagation delays.	1. Describe the OSI reference model and the TCP/IP protocol stack. 2. Differentiate between the Circuit and Packet Switching networks. 3. Define the different data transmission delays.
3	**Unit 3:** **Application Layer**: • Principles and Architectures of Network Applications. • Application Layer Protocols The Web and HTTP • Persistent and Non-persistent connections • HTTP message format • Cookies • Proxy server • Conditional GET • File Transfer Protocol.	1. Examine conceptual and implementation aspects of network applications. 2. Explain the working of the File Transfer Protocol.
4	**Unit 4:** **Email**: • SMTP • Mail message formats **Mail access protocols:** • POP3,IMAP,MIME. **DNS**:	1. Explain the working of the Mail Transfer Protocol. 2. Describe Domain Name Service

	• Services • How it works • Root, Top-Level and Authoritative DNS servers • Resource Records • DNS messages • A simple Introduction to p2p files distribution: Bit Torrent	
5	**Unit 5:** **Transport Layer**: • Introduction and Services • Transport layer in the internet • Difference between Connection-Oriented and Connectionless services. **UDP**: • Segment structure, checksum in UDP.	1. Differentiate between Connection-Oriented and Connectionless services. 2. Describe the UDP segment structure.
6	**Unit 6:** **TCP**: • The principles behind connection-oriented data transfer • Stop-and-wait, Go Back N, Selective Repeat. • Connection Establishment • TCP header • Round Trip Time • Designing a reliable data transfer protocol	1. Identify various connection-oriented transfer protocols. 2. Describe the TCP segment header.
7	**Unit 7:** **Network Layer:** • Network Layer Design Issues • Packet Forwarding and Routing • Difference between Virtual Circuits and Datagram networks • The Internet Protocol (IP), Datagram format, IP fragmentation, IPv4 addressing, subnets • CIDR classful addressing • DHCP	1. Describe the host-to-host communication service. 2. Compare Virtual Circuit and Datagram Networks 3. Explain the addressing in IP networks.
8	**Unit 8:**	1. Describe the IPv6 header.

	Network Layer: • Network Address Translation (NAT). • IPv6 Header • Moving from IPv4 to IPv6: tunneling • Dual stack and header translation. **Routing Algorithms:** • Link state (LS) • Distance Vector (DV). **Routing on the Internet:** • RIP, OSPF, BGP.	2. Identify different routing algorithms. 3. Compare Link-State and Distance-Vector routing algorithms.
9	**Unit 9:** **Link Layer and Local Area Network: Introduction and Services:** • Service provided by the LL **Error-Detection and Correction Techniques:** • Parity checks • Check-summing methods • Cyclic Redundancy Check (CRC). **Multiple Access Protocols:** • Channel partitioning • Random access. **Ethernet:** • Frame structure • CSMA/CD • Ethernet technologies.	1. Summarize several important link-layer concepts and technologies. 2. Identify error detection and correction methods. 3. Identify and describe the different Link Layer Protocols
10	**Unit 10:** **Signals:** • Analog and digital signals • Periodic and Aperiodic signals **Digital Data Conversion:** • Unipolar, Polar, Bipolar **Analog data conversion**: • PAM, PCM • Sampling **Modulation techniques**: • ASK, FSK, PSK • AM, FM, PM	1. Define data and signals in the context of communication. 2. Differentiate between analog and digital signals. 3. Discuss the conversion of digital data to digital signals. 4. Describe different modulation techniques.

4. Course Articulation Matrix (CO-PO-PSO Map)

	Program Outcomes (POs)												Programme Specific Outcomes (PSOs)			
	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6	PO-7	PO-8	PO-9	PO-10	PO-11	PO-12	PSO-1	PSO-2	PSO-3	PSO-4
CO-1	3										2		3		1	1
CO-2	3										3		3		2	1
CO-3	3	2									3		3		2	1
CO-4	3	3		2							3		3	2	2	2
CO-5	3	3	2	2	2						3		3	2	2	3
3: Very Strong Contribution, 2: Strong Contribution, 1: Moderate Contribution																

5. **Course Resources**

a. Essential Reading

1. Course Self-Learning Material
2. James F. Kurose and Keith W. Ross, 2017, Computer Networking: A Top-Down Approach, 7th Edition, Prentice Hall.

b. Recommended Reading

1. Andrew S. Tanenbaum and David J. Wetherall, 2014, Computer Networks, 5th Edition, Pearson
2. Computer Networks: A Top-Down Approach by Behrouz A. Forouzan and Firouz Mosharraf. New York, NY: McGraw-Hill, 2012.

c. Websites

1. https://www.coursera.org/
2. http://nptel.ac.in/

Contents

Unit 1
Introduction

Structure of the Unit

1.1 Unit Outcomes

After the successful completion of this unit, the student will be able to:

- Outline the basic concepts of data communication and the Internet.
- Explain the different network components including the hardware and medium of communication.
- Identify the different network topologies.

1.2 Introduction

A communication system is a system built to exchange information between two points and the process of sharing information is called communication. This sharing can be verbal or non-verbal, local or remote. The term telecommunication means communication at a distance and includes telegraphy, telephony, radio, television, and the Internet.

Any communication system consists of three important physical components: Transmitter or Sender, Receiver, and Communication medium through which the message or information travels.

The main topics covered in the following sections are:

- Definition of Data Communication and its block diagram.
- A brief history of Computer Networks and the Internet.

- Protocols and services in the context of the Internet.
- Hardware components, medium of communication, and networking topologies.

1.3 Data communication

Data communication can be defined as a process of exchanging digital data between two computing devices using some form of transmission medium such as a wire. For the process to be possible, the system must include communicating devices, consisting of physical equipment (hardware) and programs (software).

1.3.1 Components of a Data Communication System

A data communication system comprises **five** components, each having a specific functionality:

1. **Message:** It is the information to be shared between the devices.
   Eg: Text, Images, Videos, or Files.
2. **Sender:** It is the device used to send the information to be transferred to a receiver. This device uses appropriate mechanisms to encode the data in a format that helps in transferring the data in a secure, accurate, and timely manner.
   Eg: Computers, Mobile phones, Laptops, workstations, etc.
3. **Receiver:** It is a device that receives the encoded information, decodes it to extract meaningful information from it, and provides an acknowledgment to the sender.
   Eg: Computers, Mobile phones, Laptops, workstations, etc.
4. **Transmission Medium / Communication Channels:** It is the channel or medium through which the data get transferred from the sender to the receiver.
   Eg: Cable or Air (space) in the case of wired and wireless transmission respectively.
5. **Protocols (Set of Rules):** These are a set of rules agreed upon by the sender and receiver and they govern the complete data exchange process. They make communication possible.
   Eg: Transmission Control Protocol (TCP) and Internet Protocol (IP)

Fig. 1.1 shows the components of a Data Communication System.

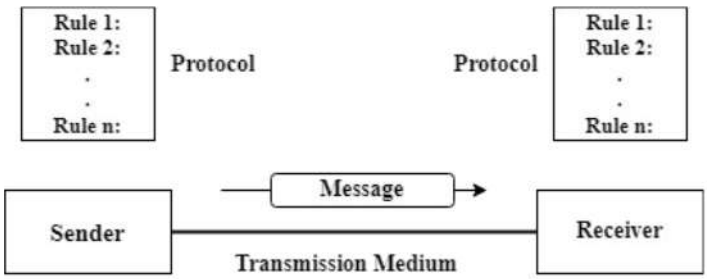

Fig. 1.1: Components of a Data Communication System

1.3.2 Fundamental Characteristics of Data Communication

A data communication system should be designed and built to possess the following fundamental characteristics:

1. **Delivery:** This characteristic helps the system to deliver the data to the correct destination
2. **Accuracy:** This allows the data to be delivered accurately without any alteration during transmission.
3. **Timeliness:** This allows data to be delivered in a timely manner.
4. **Jitter:** Data is divided into small segments called packets before transmission. Jitter occurs due to a variation in the arrival time of the packets at the destination.

1.3.3 Data Representation

In the present time, data on a communication network can have different representations such as Text, Numbers, Images, Audio, and Video.

1. **Text:** It is represented as a bit pattern which is a sequence of bits. Text symbols are represented as a different set of bit patterns and each set is called *CODE*. A coding system called *Unicode* –uses 32 bits to represent a character or symbol in any language in the world and another popular system called *ASCII* - uses a 7-bit code providing code for 128 symbols.
2. **Numbers:** Numbers are represented by bit patterns. They are directly converted to binary form to simplify mathematical operations
3. **Images:** An image is made up of a matrix of pixels (dots). The size of the pixel depends on the resolution and each pixel is assigned a pattern. The size and value of the pixel pattern depend on the image.

   Eg: A black-and-white image has a 1-bit pattern, a Grayscale uses a 2-bit pattern, and a Color image uses a combination of red, green, and blue colors (RGB) for different shades of color. The intensity of each color is measured and a bit pattern is assigned.
4. **Audio:** Here sound or music is recorded and broadcasted. It is a continuous process and not discrete.
5. **Video:** Here picture or movie is recorded and broadcast. A video can be a continuous entity or combination of images(discrete), arranged in a sequence to convey the idea of motion.

1.3.4 Transmission Modes

Transmission modes deal with the direction of flow of the data on the channel or medium. Based on the direction of data flow between two communicating devices, there are three modes of transmission: Simplex, Half-duplex, and Full-duplex. Fig.1.2 shows the three modes of transmission.

1. **Simplex:** Here communication happens in one direction. So only one device on a link can transmit at a time and it uses the entire channel capacity.
   Eg: Keyboard, Monitors, etc.
2. **Half-Duplex:** In this mode, each device can transmit and receive, but not simultaneously. Each device uses the full capacity of the channel during transmission.
   Eg: Walkie-talkie, Citizen-band (CB) radio.
3. **Full-duplex:** Here both the devices on a link can transmit and receive simultaneously. So the link gets shared and the capacity of the channel gets divided. But if there are two separate links for transmission and reception, the full channel capacity is available.
   Eg: Cellular phones, Video Conferencing, etc.

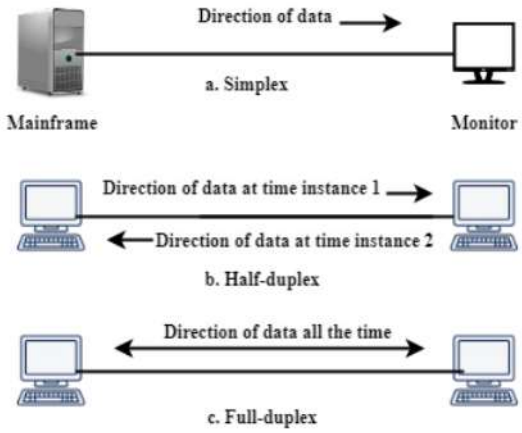

Fig. 1.2: Modes of Transmission

1.4 History of Computer Networking and the Internet

The evolution of networking and the Internet can be divided into four stages of development from 1961 till today starting with the development of packet switching to today's high-speed broadband Internet access to homes, the creation of social networks, deployment of private networks, and online service providers by Google and Microsoft, and also deployment of cloud services by Amazon, Microsoft and Google.

1.4.1 Development of Packet Switching (1961 to 1972)

Telephone networks were the dominant communication networks till the early 1960s. They used circuit switching to transmit voice from a sender to a receiver at a constant rate. In the late 1960s, a few time-shared computers were connected together which were geographically distributed. As the traffic generated here was found to be bursty and at intervals of time, packet switching was found to be efficient and a better alternative to circuit switching.

The first work on packet switching was published by Leonard Kleinrock, MIT. In 1964, Paul Bran at the MIT, Rand Institute and Donald Davis and Roger Scantlebury at the National Physical Laboratory in England were developing ideas on packet switching. The first packet-switched computer network was developed under the leadership of J.C.R Licklider and Lawrence Roberts through a computer science program at the Advanced Research Projects Agency (ARPA) in the USA. In 1969 the first packet switch was installed at the University of California, Los Angeles (UCLA) and then three other switches were installed at Stanford Research Institute (SRI), UC Santa Barbara, and University of Utah. Remote Login was first performed from UCLA to SRI, but unfortunately, the process crashed the system.

In 1972, 15 nodes were connected in the ARPAnet, and the first host-to-host protocol known as network-control protocol (NCP) was used. With the use of NEP, the first e-mail program was written by Ray Tomlinson in 1972.

1.4.2 Proprietary Networks and Internetworking (1972 to 1980)

The earlier ARPAnet required that any host to be connected to this network had to be another ARPAnet

IMP, as it was a single, closed network. From the earlier 1970 to the mid of it, many private packet switching networks like ALOHAnet, DARPAnet, Telenet, Cyclades, Tymnet, etc. were developed in different parts of the world. An architecture to connect all these networks was first ideated by Vinton Cerf and Robert Kahn of the Defence Research Project Agency (DARPA) in 1974. Their work was called internetting, and this was a step to create a network of networks. The earlier versions of Transmission Control Protocol (TCP) used the above architecture and this version of TCP combined the functionality of today's TCP and Internet Protocol (IP), which included a reliable in-sequence delivery of data with end-system retransmission and forwarding.

The next stage of development in this area was the User datagram protocol (UDP) protocol and this was the result of recognizing the importance of an unreliable, non-flow controlled, and end-to-end transport service for transferring packetized voice. At this stage, the IP protocol was separated from the IP. At the end of the 1970s, the three important internet protocols were conceptually in place.

During the same time, Norman Abramson was developing ALOHAnet in Hawaii. This was a packet-radio network used to connect and communicate between multiple remote sites on Hawaiian Island. The ALOHA protocol was the first multiple-access protocol that allowed users who were distributed geographically, to share a single-broadcast communication medium. In 1976, this protocol was used by Metcalfe and Boggs, to develop the Ethernet protocol which connected personal computers, printers, and shared disks in a Local Area Network.

1.4.3 A Growth of Networks (1980 to 1990)

During this phase, the number of hosts connected in a network increased. Two hundred hosts were connected to the ARPAnet by the end of the 1970s and by the end of 1980, it reached a hundred thousand. Most of these networks connected universities together. In the northeast, BITNET was used to transfer e-mails among the universities, and CSNET (computer science network) was used by researchers who did not have access to ARPAnet. NSFNET was another network created in 1986 used to provide access to the NSF-sponsored supercomputing centers. The initial data transfer speeds were at 56 kbps and improved to 1.5Mbps by 1990.

On January 1, 1983, TCP/IP was deployed as the standard host protocol for ARPAnet, replacing the NCP protocol. Host-based Congestion control was added to TCP in the late 1980s. The Domain Name Service (DNS) was also developed to map an IP address to its human-readable Internet name. ARPAnet served hosts only in the United States but during the same time in the 1980s, the Minitel project was launched in France with the help of its government, to bring data networking into everyone's homes. This was a public packet-switched system consisting of Minitel servers and inexpensive terminals with built-in modems. This system was a huge success as Minitel gave access to free telephone directory sites and a few paid private sites. So, Minitel gave the French homes an Internet system 10 years before the US had even heard about.

1.4.4 The Internet Explosion (The 1990s)

The World Wide Web (WWW) emerged in the 1990s and brought the Internet into millions of homes

and businesses around the world. The web served as a platform for many applications for searching (Google and Bing), Internet commerce (Amazon and e-Bay), and social networks such as Facebook. This was made possible by the emergence of many commercial Internet Service Providers in 1995.

The web was invented by Tim Berners and Lee at European Organization for Nuclear Research (CERN) between 1989 and 1991. They developed the four important components of the Internet: HTML, HTTP, a Server, and a Browser. Their work was based on the earlier work on hypertext in the 1940s by Vannevar Bush and in the 1960s by Ted Nelson.
By the end of 1993, there were around 200 web servers in operation.

A GUI-based web browser called Netscape Navigator was developed by Marc Andreessen and Jim Clark and was used by university students in 1995. In 1996, Microsoft also started making a browser that took over the Netscape browser and is the most widely used browser today.

By the second half of the 1990s, there was tremendous growth of the Internet as thousands of startups and corporations created Internet products and services, and by the end of the millennium, there were four important applications developed for the Internet: E-mail, the Web, Instant messaging and Peer-to-peer file sharing.

1.4.5 The New Millennium

Two types of networks combine to form today's Internet: The access networks which connect the hosts to the Internet services and the high-speed backbone or core networks which connect the access networks globally. Advancements in these areas have resulted in the deployment of faster routers and higher transmission speeds. There are five major developments that can be seen in the area of Internet and its services:

- Aggressive deployment of broadband Internet access to homes with fiber coming into use along with cable modems and DSL. This has increased the transfer speeds by many folds and has paved the way for many video applications including user-generated videos (eg: YouTube, on-demand streaming of movies and television shows (eg: Netflix), and video conferencing (eg: Skype).
- High-speed (54 Mbps) public WiFi networks and medium-speed (a few Mbps) Internet access via 3G and 4G cellular telephony networks have made Internet access ubiquitous and also connectivity on the move. Also, high-speed wireless access had increased the use of handheld computers (iPhones, Androids, iPads, etc).
- Emergence of online social networks like Facebook and Twitter has increased the number of users on the Internet.
- Deployment of extensive private networks by online service providers (ISPs) such as Microsoft and Google has resulted in search results and email access faster as they have large data centers distributed globally which help in peering with the lower-tier ISPs bypassing the Internet.
- Cloud companies such as Amazon, Google, and Microsoft are running their applications in the "cloud", providing a large storage environment and scalable computing, and implicit access to high-speed private networks for many applications. Many universities and companies have

migrated their Internet applications such as email and web hosting to the cloud.

1.5 The Internet

The Internet we describe here is a specific public computer network. The study of the Internet involves three important concepts: an understanding of the hardware and software components that build the Internet (Section 1.5.1) and an understanding of the infrastructure of the Internet which provides the different services to the distributed applications (Section 1.5.2), set of rules or protocols used for communicating between the devices.

1.5.1 Description of the Internet

In this section, we look into the infrastructure that helps in providing Internet access to the end users. The internet is a network interconnecting different networks. The different networks that constitute the Internet are owned, operated, and managed by different people, companies, or organizations. This network interconnects millions of computing devices throughout the world. The computing devices connected to the earlier Internet were only desktop personal computers, Linux workstations, and server systems storing and transmitting e-mail messages and web pages. But today the devices connected are laptops, smartphones, TVs, tablets, gaming consoles, automobiles, web cameras, home electrical and security systems, environmental sensing devices, wearable devices, etc. These devices are called hosts or end systems. While some of the devices are always connected to the internet, some of them are intermittently connected.

All the end systems are connected together by a network of communication links and packet switches. The communication links can be different physical media such as copper wire, coaxial cable, fiber optic cable, and radio frequency signals. These links transmit data at different rates measured in bits/second.

The sending system divides the actual information or data into small segments and adds header information to each segment. This package of data and header is known as a packet. The packet is transmitted to a destination system, where all the packets are reassembled into the original data. Packet switches have many incoming and outgoing links. They receive the packets on an incoming link and forward the packet to an appropriate outgoing link. Today's Internet uses two types of switches: Routers and Link-layer switches. Routers are used in the network core whereas link-layer switches are used in access networks.

Internet Service Providers (ISPs) are used to provide Internet access to the end systems, in the form of residential broadband access, high-speed local area network (LAN) access, wireless access, and 56kbps dial-up modem access (not used today). There are ISPs at various levels providing Internet services, such as Residential ISPs which are the local cable or telephone companies, Corporate ISPs, University ISPs, and ISPs providing WiFi access in airports, hotels, coffee shops, and other public places. Every ISP is a network of packet switches and communication links and ISPs at every level must be interconnected.

All the components of an Internet run protocols, which are rules that control the sending and receiving of information within the Internet. There are two important protocols governing the operations on the Internet: Transmission Control Protocol (TCP) and Internet Protocol (IP). They are collectively known as TCP/IP. TCP is used to establish a connection, maintain it, and then terminate the connection between devices on the Internet. IP protocol specifies the structure and format of the packets which are sent and received among end systems and routers on the Internet.

Fig. 1.3 shows a conceptual (not geographical) view of the Internet.
Here the backbone is the network core and is part of a computer network that interconnects and provides a path for the exchange of information between different LANs or subnetworks. A backbone can connect together diverse networks in the same building, in different buildings in a campus environment, or over wide areas. The capacity of a backbone is greater than the individual networks connected to it. They create links to provide communication up to 150 miles. Usually, they use a mesh topology (discussed in section 1.8.1).

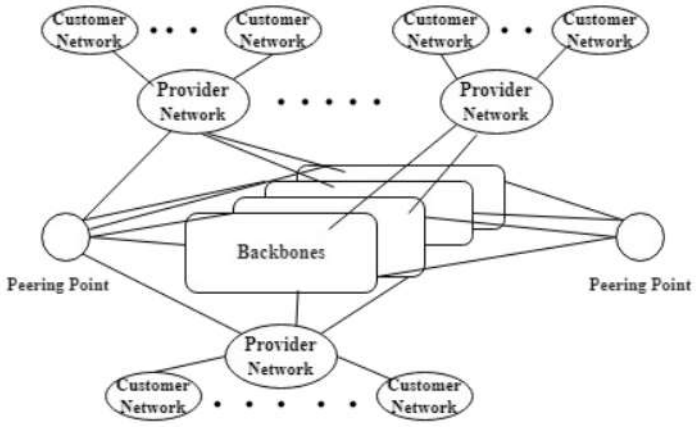

Fig. 1.3: The Internet Today

- A network provider or network service provider (NSP) is a company that owns and operates the Internet backbone infrastructure and sells access to the services for its customers.
- Peering Point is the highest level of Internet Service Providers (ISPs) having a global reach.
- A customer network can include personal computers, active and passive data network equipment, and equipment for telecommunication network applications.

Fig. 1.4 shows only a small part of the Internet with three networks: a Mobile Network, a Home Network, and an Enterprise Network all connected through a Regional ISP and a Global ISP.

The devices in the Mobile Network or the cellular network use the services from a national or Global Internet Service Provider. The **Home Network** is usually a Local Area Network, wired or wireless. It uses the services from a local or regional Internet Service Provider. The **Enterprise Network** is a Wide Area Network and uses the services from a local or regional Internet Service Provider.

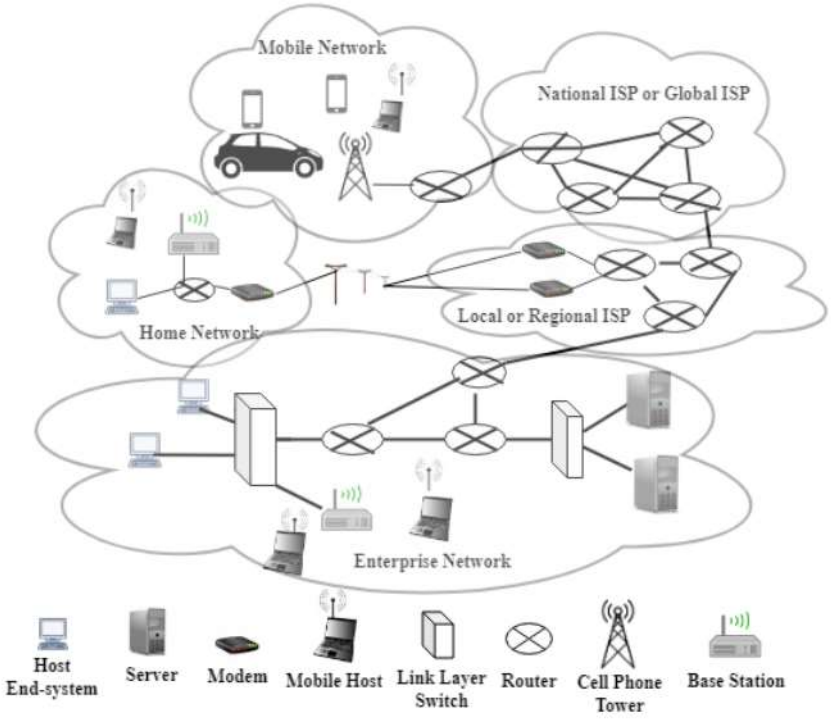

Fig. 1.4: A Part of the Internet

1.5.2 Services on the Internet

In the previous section, we looked into the infrastructure that helps in providing access to the Internet for the end users. Internet access in turn provides services to various applications running on the end users' systems. These applications include Web surfing, social networks, electronic mail(e-mail), instant messaging, Voice over IP (VoIP), file sharing, distributed games, video streaming, etc.

All the above applications run on the end systems and not on the packet switches. Packet switches only help in the exchange of data among the end systems. Applications run on the end systems and are written in some high-level language such as C, Java, or Python. The Internet applications run on systems that are distributed over an area and so they are required to send data to each other. For this process to happen, the application programs running on each end system will have to instruct the Internet infrastructure to deliver data to another application program running on another end system. This functionality is provided through an Application Programming Interface (API), which is a set of rules to be followed by a sending program to deliver the data to the receiving program.

The Internet provides many services to its applications and the appropriate service must be chosen for a given application.

1.5.3 Protocols

In general, protocols are a set of rules to be followed by any two communicating entities for effective communication. In computer networks, a protocol defines the format and the order of the messages exchanged between two end devices and all the intermediate devices. Also, a protocol specifies what action is to be taken during the transmission and reception of a message.

Fig. 1.5 shows a human protocol and a computer network protocol. In human protocol, there are two

greeting messages exchanged before a man asks the time of the day to a woman and receives a reply. Here specific messages are sent and specific actions are taken in response to the replies received within a specific amount of time. These sets of actions done, messages transmitted, and received play a very important role in the human protocol. If people run different protocols that is, if only one person greets or one person does not reply within a specified time, then the protocols do not operate and communication does not happen effectively. The same concept holds good in networking.

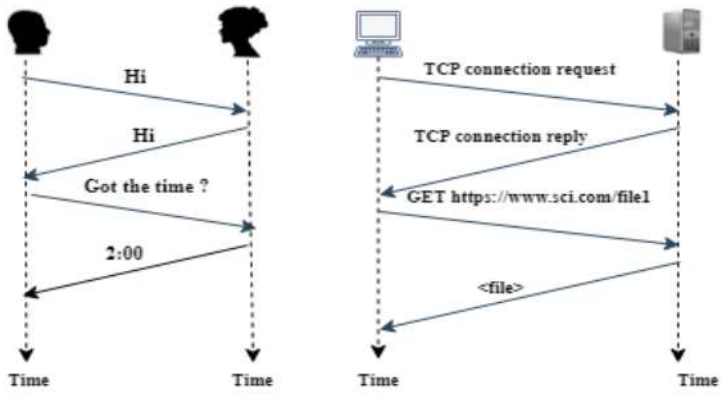

Fig. 1.5: A human protocol and a computer network protocol

In the figure, the working of a computer network protocol is shown where a user makes a request to a web server by typing the URL or address of the web page on his browser. First, the connection request message is sent to a server and the user's computer waits for the reply. The server will acknowledge with a connection-done reply message. Then the required Web document is requested with a GET message with the name of the file. The server then sends the appropriate file in response to the GET message to the user.

NOTE: The Internet uses many protocols. Different protocols are used for performing different communication tasks.

1.6 Computer Networks: Hardware

A network is a collection of devices interconnected for the purpose of communication. Each device on a network also known as a host can be a desktop, laptop, workstation, cellular phone, or security system. It can also be a connecting device such as a router, a switch, a modem, etc. Connecting devices are used when networks grow in size and complexity and also when a host in one network wants to get connected to a host in another network.

This section discusses a computer network's physical structure, important hardware components that a network is built with, and different topologies.

1.6.1 Physical Structure

A network consists of two or more devices connected through links and a link is a communication pathway used to transfer data from one device to another also called media. There are two types of connection between nodes: Point-to-point and Multipoint.

In a point-to-point connection, the medium or channel is shared between two devices.

In a Multipoint connection, the medium is shared among many devices.
Fig. 1.6 shows the types of connection between nodes.

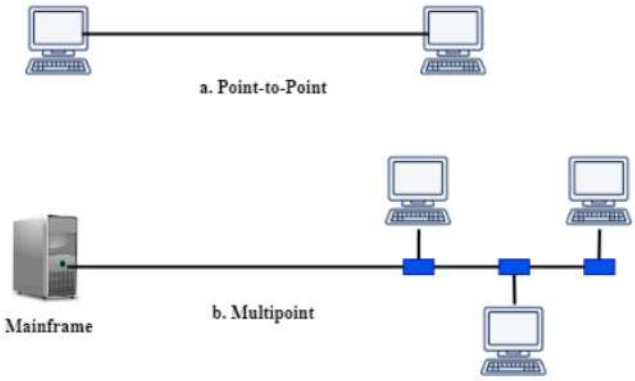

Fig. 1.6: Types of Connection

1.6.2 Hardware Components

The important components of a computer network are Network Interface Card (NIC), Connecting Devices (Repeater, Hub, Bridge, Switch, Router), Modem, and Server.

1.6.2.1 Network Interface Card:

For a computer to be connected to a network, this is the first piece of hardware, which provides a physical interface between the computer and the medium or the cabling. A standard NIC is a circuit board plugged into the computer motherboard. A NIC is also known as a Network Interface Controller, Network adapter, or Local Area Network (LAN) adapter.

When transmitting data, the NIC converts digital data from a computer into signals and transmits them on the medium. It also controls the flow of data and access to the medium to which the computer is connected. When receiving data, it translates the data into bytes for the CPU to understand.
There are four types of NICs:

- Wired - In a wired NIC, cables, and connectors are used to act as a medium to transfer data. Used in Ethernet LANs (Local Area Networks).
- Wireless - In the wireless card, an antenna is used for the connection. Here transmission and reception happen through radio waves. These are used for Wi-Fi connections.
- USB – Here the NICs provide a network connection through a device plugged into the USB port.
- Fiber Optics - These NICs are more expensive and complex devices used for high-speed data transmission. Usually, they are used on server systems where two or more NICs are used in order to split the load.

NOTE: There are four transfer rates supported by a NIC: 10Mbps, 100 Mbps, 1000 Mbps, and 1 Gbps.

1.6.2.2 Connecting devices

The important functionality of connecting devices in a computer network are as given below:

- They allow more nodes to be connected to a network.

- They help in extending the distance between the nodes or extending the network itself.
- They can merge two networks.
- They help in localizing the network traffic.
- They help in isolating network problems and diagnosing them.

The important connecting devices are repeaters, hubs, bridges, switches, and routers. Fig. 1.7 helps us in understanding the use of different connecting devices and they are discussed in detail below.

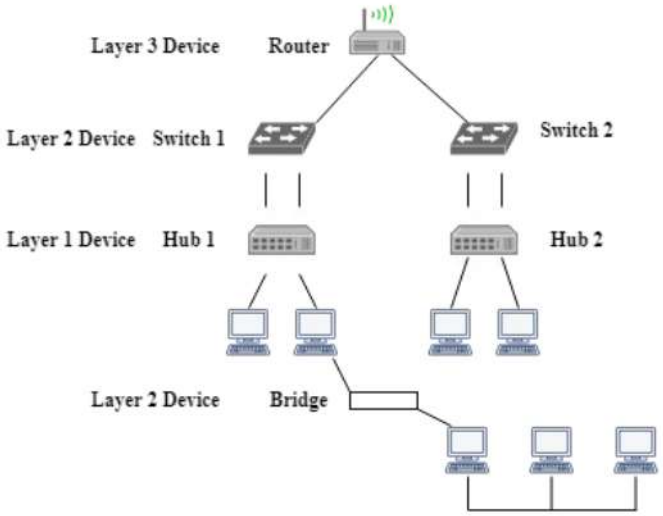

Fig. 1.7: Different Connecting Devices used in Networking

Repeater

A repeater is a two-port physical layer device (Section 2.2.1). It is used to regenerate the signal at the input port and transmit it at the output port before it is very weak. So they are incorporated into the networks in order to extend the coverage area. A repeater removes noise and interference from the incoming signal, amplifies it, and retransmits it.

There are two types of repeaters based on the type of signal:

1. **Analog Repeaters:** Used to amplify the analog signals.
2. **Digital Repeater:** Used to amplify digital signals.

Hub

A hub is a device or another node in a network used to connect/link several computers together within the same network. It is a multiple port repeater and so it is a physical layer or layer-1 device. The computer to be connected to a network gets plugged into one of these ports. It only receives a signal from one port and broadcasts it to all the other ports. Hence it consumes more bandwidth. It does not have the intelligence to find the best path and forward the incoming data to a specific destination. It basically acts like a centralized distribution point for all the data transmission in a network and is used in Ethernet-based LANs. Data transfer speeds are 100 Mbps.

There are three types of Hubs based on how it treats incoming data: Active, Passive, and Intelligent.

1. Active Hub:

These hubs are built with circuits to amplify and clean up the signals before being broadcast to other ports. They combine the functionality of a wiring center and a repeater and can be used to extend the maximum distance between nodes.

2. Passive Hub:

Passive Hubs are not powered and connect only to Active Hubs. These hubs are used to connect all ports together electrically. These hubs are cheaper as they do not amplify or regenerate the incoming signals. The mode of transmission is half-duplex.

3. Intelligent Hub:

Intelligent hubs support the amplification and regeneration of incoming signals and give better performance than active and passive hubs. It also includes functionalities of a bridge, switch, router, and network management. They can detect collisions and isolate the problem computers.

Bridge

A bridge is a layer-2 device (Section 2.2.1). that basically is an intelligent repeater, with the functionality of filtering input data by reading the physical addresses of the source and destination. It is used to connect two LANs working on the same protocol. It is a 2 port device with a single input and single output port.

There are two types of Bridges: Transparent and Source routing

1. **Transparent Bridges**

These are devices that do not affect the configuration of the devices when they are added or deleted from the network. They make use of two processes i.e. bridge forwarding and bridge learning.

2. **Source Routing Bridges**

Here the source station discovers the route for a frame by sending a special frame called the discovery frame. Using the physical address, the complete route from source to destination is decided for the data frame to follow.

Switch

The switch is a network component that is used to connect two or more networks using a Layer-3 switch and two or more nodes in the same network using a Layer-2 switch (Section 2.2.1). A switch provides a dedicated path between the sender and receiver and transfers data at a higher speed, so the available bandwidth is shared between them. The switch is more intelligent and expensive than works like a multiport bridge. It regenerates or amplifies the incoming data frames, checks the physical address, and with the help of a switching table decides on which port the frame is to be sent. Data transfer speeds are 10 Mbps/ 100 Mbps and 1 Gbps.

There are two basic categories of switches: Fixed and Modular.

Fixed switches have a fixed number of ports for connections, whereas Modular switches are expandable.

These types can be further categorized into five types: Managed, Unmanaged, Power over Ethernet (PoE), LAN switch, and Stackable switches.

1. Managed Switch

These switches are used in complex and large organizations providing high security and complete management of a network as they are configured using the Simple Network Management Protocol(SNMP). They are expensive but provide high scalability and flexibility. They are used to connect devices in a Virtual LAN (VLAN).

2. Unmanaged Switch

These switches are used in home networks and in small businesses. They are cheap do not need to be configured and can be easily set up by plugging them into the network. They can be used to connect two computers in a home network or a computer to a printer.

3. Power over Ethernet (PoE) Gigabit Ethernet Switch

These switches use PoE technology, which combines the data and power transmission over the same cable. So the devices connected to such are able to receive both electricity as well as data over the same line offering more flexibility.

4. Local Area Network (LAN) Switch

These switches connect devices in a LAN of an organization. They are also called data switches or Ethernet switches. They allocate bandwidth economically and thus block the overlapping of the packets. They help in reducing network congestion and bottlenecks by distributing the packets to the intended receivers only.

5. Stackable Switch

Here, some fixed switch models can be stacked together with other fixed switch models to form a stackable switch unit. They are stacked on one another and are connected together at the back with a special cable. They can provide more ports than one fixed switch and they can work as a single switch unit. All the individual switches can be managed as one switch entity.

Router

The router is a network component that is mainly used to route data packets based on their IP address, so it is a layer-3 device(Section 2.2.1). Routers are more expensive than a hub, switch, repeater, and bridge. Routers are used to connect different networks together such as two LANs or WANs. They make use of routing tables to make decisions on the routing of the incoming data packets. Data transfer speeds are 1 – 100 Mbps (wireless) and 100 Mbps – 1 Gbps (wired)

Some popular categories of Routers are Core, Edge, Brouters, Broadband, Distribution, and Wireless routers.

1. Core Routers

Core routers are mainly used by large organizations, and service providers (like AT&T, and Vodafone) or by cloud providers like (Amazon, Microsoft, and Google). These are called Core Routers as they are used in the core or backbone networks on the Internet. They provide a large bandwidth to provide connections to additional routers or switches.

2. Edge Routers

These are also called Gateway routers or gateways. They are called as edge routers as they connect a user network to the **Internet.** These routers are designed to optimize bandwidth and to connect to other routers in order to distribute data to end-users.

3. Brouters

These are special routers and which provide functionalities of both bridges and routers. They help to transfer data between networks like a bridge, and also route the data within the devices of a network as in a router.

4. **Broadband Routers**

These are routers provided by an Internet Service Provider to end-users to allow them to access broadband Internet. They are configured by the ISPs.

5. **Distribution Routers**

These routers are used to distribute data to end-users with the help of Wi-Fi connectivity while receiving the data from the edge router (or gateway) through a wired connection.

6. **Wireless Routers**

These routers combine the functionality of both distribution routers and edge routers. They provide a standard Ethernet routing in a LAN and also a WiFi connection to devices like laptops, smartphones, etc.

1.6.2.3 Modulator-Demodulator (Modem)

A modem is a short form for Modulator-Demodulator, a combination of two functions in one device. This device is used to convert information in digital form to analog (modulation) and vice-versa (demodulation). It allows a computer and other connecting devices such as the router, switch, etc to connect to the Internet.

Computers process information in digital form, but data travels on transmission lines in analog form. So, on the transmitting side, a modem superimposes the digital data onto an analog radio frequency carrier wave or encodes the digital data in an analog signal and sends it on the transmission lines toward the provider's Internet network. On the receiving side, a modem removes the digital data from the carrier or decodes the digital data from the analog signals.

Fig. 1.8 shows the use of Modems.

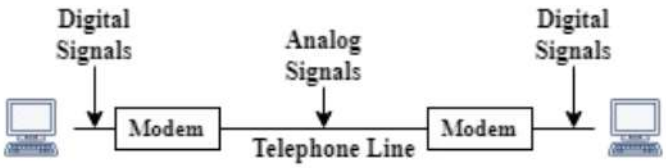

Fig. 1.8: Use of Modems in Computer Networks

NOTE: Today most of the networking devices have inbuilt modem functionality.

NOTE: There are different types of modems to work with the different transmission media.

1.6.2.4 Server

A Server is a computer program or a device that provides services to another computer program or device called a Client. Servers could be a part of a LAN, WAN, or the Internet. There are many types of servers providing different services such as Web Servers, Database Servers, File Servers, Application Servers, Virtual servers, Proxy Servers, etc.

Fig. 1.9 shows a Client-Server Network with three Client devices connected to a Server via the Internet.

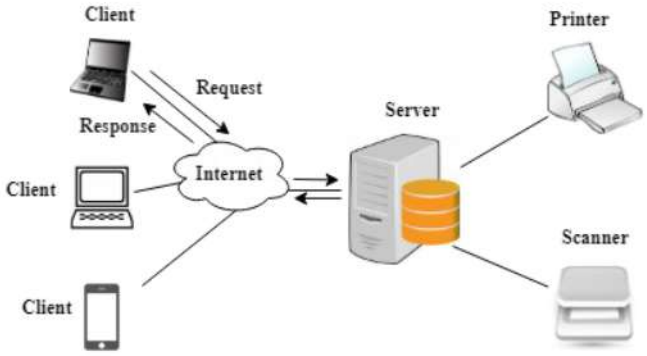

Fig.1.9: Client Server Network

1.7 Physical Media

It is the medium through which data or message travels or propagates from a transmitter to the receiver. This medium can take many forms and can be of different types for each transmitter-receiver pair along the path.

Physical media can be classified into two types: Guided and Unguided

1. Guided Media: Here the data in the form of signals or waves travel along a solid medium such as a twisted-pair copper cable, coaxial cable, or fiber-optic cable.
2. Unguided Media: Here the data travel in outer space or the atmosphere in the form of electromagnetic waves.

1.7.1 Twisted-Pair Copper Wire

It consists of a pair of insulated copper wires twisted to reduce electrical interference. A number of pairs are bundled together in a cable with a protective shield for every pair. These are less expensive and the data rates range from 10 Mbps to 10 Gbps. They are used for networking within a building as in LANs. Today, Fiber optic cables have been replacing twisted-pair cables because of their high data rates.

1.7.2 Coaxial Cable

It consists of two copper conductors which are concentric unlike parallel wires in twisted pair cables. The two conductors are insulated and shielded from each other. Data rates achieved are higher and are in the tens of Mbps. These cables are used as a guided shared medium in Cable Television and Cable Internet access.

1.7.3 Optical Fiber

It is a thin flexible fiber made of glass and conducts pulses of light. Each pulse represents a bit of binary data. A single fiber transmits data at a very high rate up to hundreds of gigabits per second. They are immune to external interference and signals can travel up to 100 kilometers without much

loss and are hard to tap. So they are used for long-distance transmission such as overseas links. Today optical fibers are replacing coaxial cables and are used for long-distance telephone networks and in the backbone networks of the Internet. The Standard Optical Carrier link speeds range from 51.8 Mbps to 39.8 Gbps and are referred to as OC-n, where n is a multiple of 51.8 Mbps.

For Eg: OC-2 is a 2 x 51.8 = 103.6 Mbps Link

1.7.4 Terrestrial Radio Channels

Today, radio frequency communication or radio communication refers to wireless communication using electromagnetic waves in the 3 kHz to 300 GHz frequency range with air as the transmission medium. A band of these frequencies is called a channel. Radio waves easily penetrate walls, can carry signals for longer distances, and can provide connectivity for a mobile user. But these characteristics of radio channels depend on the environment and the distance of propagation. Signal loss and fading occur due to long-distance propagation, signals traveling around obstructions, signal reflections around objects, and interference due to other transmissions and electromagnetic signals.

Terrestrial Radio Channels are classified into **three groups** based on the distance of propagation. The first group operates over very short distances one or two meters. Eg: Wireless headsets, keyboards, and medical devices. The second group operates over local areas covering distances of ten to a few hundred meters used for wireless LANs. The third group of channels operates over a wider area covering tens of kilometers.

1.7.5 Satellite Radio Channels

Today satellites are used for communication by using it to act as a link to connect two or more earth-based microwave transmitters/receivers known as ground stations. The satellite acts like a repeater. It receives the signals of one frequency band from an earth station (uplink), regenerates them, and retransmits them on another frequency band (downlink).

Communication Satellites are of **two** types: Geostationary and Low-earth orbiting (LEO).

Geostationary Satellites: These are permanently placed in an orbit at 36,000 kilometers above the earth's surface in the same spot above the earth. These links can operate at the speeds of hundreds of Mbps but due to long distances of travel, there is a delay of around 280 milliseconds.

Low-earth orbiting (LEO) Satellites: These are placed closer to Earth and rotate around it and communicate with each other and the ground station.

1.8 Physical Topology

Network Topology is the physical layout of the network. It gives the geometric representation of the relationship of all the links and linking devices (nodes or hosts) to one another.

There are six important network topologies: Mesh, Star, Tree, Bus, Ring, and Hybrid.

1.8.1 Mesh Topology

In this topology, every device has a dedicated point-to-point link to every other device, where every link carries bi-directional traffic between only two devices it connects.

Fig. 1.10 shows a Mesh topology with 5 nodes and 10 links.

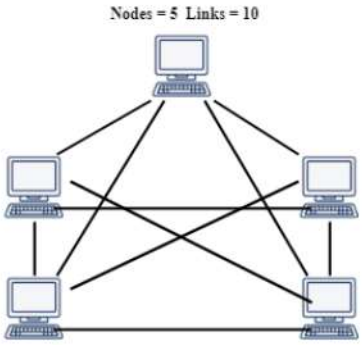

Fig. 1.10: Mesh Topology

1.8.2 Star Topology

In this topology, each device has a dedicated point-to-point link only to a central Controller called HUB. Devices are not directly connected to one another and the controller acts as an Exchange. If one device wants to send data to another, it sends the data to the controller which then relays data to other connected devices. Fig. 1.11 shows a Star topology with 4 nodes.

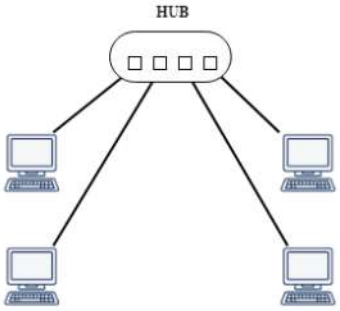

Fig. 1.11: Star Topology

1.8.3 Tree Topology

This topology is a star topology variant. It has a root node and the other nodes are connected to it in different levels of the hierarchy. It combines various star topologies in a single bus as so is known as star-bus topology. Fig. 1.12 shows a tree topology with 6 nodes. If one of the nodes connected to the secondary HUB wants to transfer data to a node connected to a central HUB, the data flows through the secondary HUB and central HUB to the destination node.

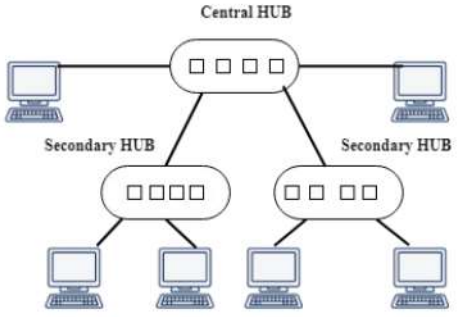

Fig. 1.12: Tree Topology

1.8.4 Bus Topology

This is a multipoint connection where one long cable acts as a backbone to link all the devices in a network. The nodes are connected to a bus cable by drop lines and taps. The drop line is the connection

running between the device and the main cable. The tap connects the drop line to the metallic core. Fig. 1.13 shows a Bus topology with 3 nodes.

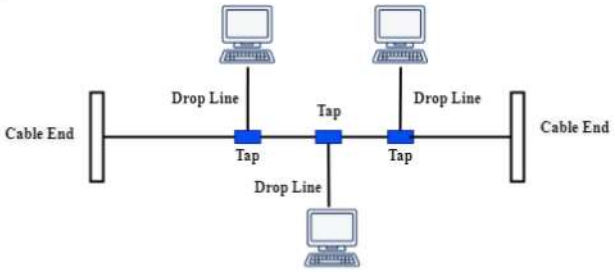

Fig. 1.13: Bus Topology

1.8.5 Ring Topology

In this topology, each device has a dedicated point-to-point connection with only two devices on either side of it. The signal passes along the ring in only one direction from device to device until it reaches its destination. Each device in the ring includes a repeater. When the device receives a signal intended for another device, it regenerates the bits and passes them along the ring. Fig. 1.14 shows a Ring topology with 4 nodes.

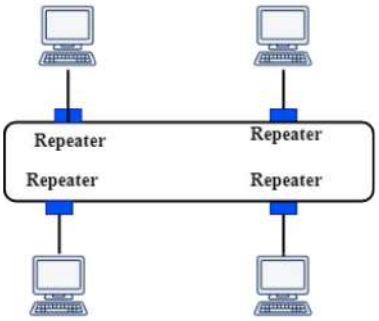

Fig. 1.14: Ring Topology

1.8.6 Hybrid Topology

This topology is a combination of two or more topologies and is used when all the nodes are free to get connected in any of the topologies. Fig. 1.15 shows the hybrid topology with a combination of star and ring topologies to connect 8 nodes.

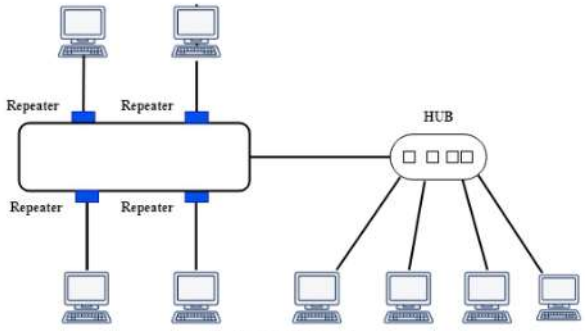

Fig. 1.15: Hybrid Topology

1.8.7 Comparison of the Network Topology

Table 1.1 gives a comparison of the four topologies based on their advantages and disadvantages.

Table 1.1: Comparison of Network Topologies

Topology	Advantages	Disadvantages
Mesh	1. A dedicated link guarantees the data load carried by each connection 2. A single link failure does not affect the entire system. 3. The message carried by a dedicated link with physical boundaries is safe from unauthorized access. 4. Fault identification and isolation are easy for the network operator.	1. Installation and reconnection are difficult. 2. Bulk of wiring can be greater than the available space. 3. Hardware required to connect each link (I/O ports and cables) is expensive.
Star	1. Less expensive. 2. Each device needs only one link and one I/O port to connect to any number of devices. 3. Easy to install and reconfigure. 4. Less cabling. 5. Addition, deletion, and moving of devices involve only one link. 6. Robustness i.e if one link fails, only that link is affected. 7. Easy fault identification and fault isolation. Hub can monitor link problems and bypass defective links.	1. If Hub goes down, entire system is dead. 2. As each node must be linked to hub, more cabling is required than bus and ring topology.
Tree	1.Node failure does not affect the entire system 2.Adding nodes is easy and fast 3.Fault detection is easy 4.Easy to manage	1. If Hub goes down, entire system is dead. 2. As each node must be linked to hub, more cabling is required than bus and ring topology.
Bus	1. Installation is easy. 2. Uses less cabling as only the backbone cable stretches.	1. Fault isolation and reconnection are difficult. 2. Difficult to add new devices.

1.9 Self-Assessment Questions

Q1. Define Data Communication. Briefly explain its five components. (5 marks, L3)

Q2. List the fundamental characteristics of Data Communication. (2 marks, L1)

Q3. Discuss the different forms of representing data on a data communication system. (6 marks, L3)

Q4. Briefly discuss the stages of the evolution of the Internet (10 marks, L3)

Q5. Briefly describe the important network topologies. (8 marks, L3)

Q6. Explain the categories of networks based on their physical size. (6 marks, L3)

1.10 Self-Assessment Activities

A1. List some example applications of Simplex, Half Duplex, and Full-Duplex communication and discuss them briefly.

A2. Explore more on the basic communications tasks that define networking.

A3. Being a computer teacher in a school, if you are asked to connect all the computers in a classroom to the Internet, which topology would be appropriately chosen?

A4. A transport company has two offices situated a few miles apart. What type of transmission mode is best suitable for transmitting data between the offices?

1.11 Multiple-Choice Questions

Q1. The communication between a desktop computer and a printer is a good example of ——— communication. [1 mark, L2]

A. Full-Duplex
B. Simplex
C. Half Duplex
D. Half Multiplex

Q2. A mesh is an example of ———. [1 mark, L2]

A. Topology
B. Architecture
C. Protocol
D. Service

Q3. Which of the following device operates at layer-1 [1 mark, L1]

A. Hub
B. Switch
C. Router
D. Modem

Q4. Which of the following device uses MAC address to forward packets [1 mark, L1]

A. Hub
B. Switch
C. Router
D. Modem

Q5. Which of the following device connects different types of networks [1 mark, L1]

A. Hub
B. Switch
C. Router
D. Modem

Q6. Which of the following device uses IP address to forward packets [1 mark, L1]

A. Hub
B. Switch
C. Router
D. Modem

Q7. Which of the following device has multiple Ethernet ports to connect devices within a local network [1 mark, L1]

A. Hub
B. Switch
C. Router
D. Modem

Q8. Which of the topologies has a central hub to which all the nodes are connected? [1 mark, L1]

A. Bus Topology
B. Ring Topology
C. Star Topology
D. Tree Topology

Q9. Which of the topologies provides the best fault tolerance? [1 mark, L1]

A. Bus Topology
B. Ring Topology
C. Star Topology
D. Mesh Topology

Q10. What is the name of the network topology in which there are bi-directional links between each possible node? [1 mark, L1]

A. Ring Topology
B. Star Topology
C. Tree Topology
D. Mesh Topology

Q11. Full form of LAN is, [1 mark, L1]

A. Line Area Network
B. Land Area Network
C. Local Area Network
D. Linear Area Network

Q12. The equipment needed to connect home computers to the Internet is, [1 mark, L1]

A. Router
B. Switch
C. Modem
D. Monitor

Q13. The Server on the Internet is also known as, [1 mark, L1]

A. Hub
B. Switch
C. Gateway

D. Host

Q14. The Internet core is also called as, [1 mark, L1]

A. ISP

B. WAN

C. Backbone

D. Enterprise Network

Q15. The computer network is, [1 mark, L1]

A. Network with cable

B. Network without cable

C. None of the above

D. Both A and B

Q16. The data transmission rate is highest in, [1 mark, L1]

A. Copper wire

B. Coaxial Cable

C. Optical Fiber

D. None of the above

1.12 Keys to Multiple-Choice Questions

Q1. The communication between a desktop computer and a printer is a good example of simplex communication (B).

Q2. A mesh is an example of topology (A).

Q3. A Hub operates at layer 1 (A).

Q4. Switch (B).

Q5. Router (C)

Q6. Router (C)

Q7. Switch (B)

Q8. Star topology has a central hub. (C)

Q9. Mesh (D)

Q10. Mesh (D)

Q11. Local Area Network (C)

Q12. Modem (C)

Q13. Host (C)

Q14. Backbone (D)

Q15. Networks use both guided and unguided media for transmission (D)

Q16. Optical Fiber (C)

1.13 Summary of the Unit

This unit discusses the introductory concepts of Data Communication Systems beginning with the basics of Communication Systems in general with the topics covering its elements and types in the first section. In the first section, the components of a Data Communication System and its characteristics are discussed which differentiate it from a basic communication system. The second section of this unit

discussed the conceptual view of the Internet, and to get a better understanding, a small part of the Internet including the different hardware components of a home network, a mobile network, and an enterprise network. Data networks are built to provide services to users. Also in this section, a brief description of the popular services is studied. In order to provide services, all the components in the network need to communicate and follow certain rules to avoid data loss. These rules are implemented in the form of protocols at every layer in the TCP/IP protocol suite. The physical structure of a network, different types of physical media used for transmission of data, and networking topologies are discussed in the last section.

1.14 Glossary

1. Transmission Control Protocol (TCP): TCP is the transport layer protocol in TCP/IP networks. TCP helps in establishing a connection between two hosts for exchanging streams of data. This protocol also guarantees the delivery of data and the sequence of the packets in the same order in which they were sent.
2. Internet Protocol (IP): It is a standard protocol used to transmit data packets from source to destination in packet-switched networks and the Internet. It is a network layer protocol and forwards the packets based on the IP address.
3. Terrestrial: Related to Earth or Land.
4. Voice over Internet Protocol (VoIP): This technology uses a broadband Internet connection to make voice calls instead of a regular (or analog) phone line. Calls call be done through a computer or a specialized phone through a modem, high-speed DSL connection or a LAN. Also used for streaming video and other media over the Internet
5. Local Area Network (LAN): It is a network of computers covering a small space as a home or a building or an enterprise network with hundreds of users as in an office or a school.
6. Ethernet: It is a networking technology used in LANs.
7. Wide Area Network (WAN): It is a network of computers covering a city or many cities or countries and not tied to a single location. A WAN provider facilitates communication services and sharing of information between the users.

1.15 Recommended Learning Resources

[1] James F Kurose and Keith W Ross, Computer Networking, A Top-Down Approach, Sixth Edition, Pearson,2017.

[2] Behrouz A Forouzan, Data and Communications and Networking, Fifth Edition, McGraw Hill, Indian Edition

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[8] https://www.gdcramban.com/MCQ/networkmcq.pdf
[9] https://www.needpix.com/photo/download/642270/computers-keys-rays-personal-computer-free-pictures-free-photos-free-images-royalty-free-free-illustrations (Fig. 1.2)
[10] https://creazilla.com/nodes/21308-computer-clipart (Fig. 1.2)
[11] https://publicdomainvectors.org/en/free-clipart/V-stand-computer-monitor-vector-clip-art/21976.html (Fig. 1.2)
[12] https://publicdomainvectors.org/en/free-clipart/Wireless-router-icon-vector-illustration/13598.html (Fig. 1.4)
[13] https://creazilla.com/nodes/59576-laptop-clipart (Fig. 1.4)
[14] https://creazilla.com/nodes/7832008-car-icon (Fig. 1.4)
[15] https://creazilla.com/nodes/7832379-transmission-tower-icon (Fig. 1.4)
[16] https://www.maxpixel.net/Responsive-Mobile-Icon-Smartphone-Mobile-Phone-Gui-1976104 (Fig. 1.4)
[17] https://freesvg.org/electric-tower (Fig. 1.4)
[18] https://freesvg.org/network-switch (Fig. 1.4)
[19] https://www.google.com/search?q=server%20images&tbm=isch&hl=en&chips=q:server%2Cg_1:clip%20art:WwL_lE5jtN8%3D&tbs=il:cl&sa=X&ved=0CAAQ1vwEahcKEwjgq-fzudn9AhUAAAAAHQAAAAAQAg&biw=1081&bih=458#imgrc=tQXV4DmX1lSOJM(Fig.1.9)
[20] https://www.google.com/search?q=printer%20images&tbm=isch&hl=en&tbs=il:cl&sa=X&ved=0CAAQ1vwEahcKEwjAg9DPutn9AhUAAAAAHQAAAAAQAg&biw=1081&bih=401#imgrc=3XDuwFctSLktJM(Fig.1.9)