1. Introduction

In simple terms a *Network* is an interconnected set of objects. We are familiar with the Radio, Television, railway, Highway, Bank and other types of networks. In recent years, the network that is making significant impact in our day-to-day life is the *Computer network*. A computer network is an interconnected set of *autonomous* computers as shown in Fig. 1.1. The term *autonomous* implies that the computers can function independent of others. However, these computers can exchange information with each other through the communication network system. Computer networks have emerged as a result of the convergence of two technologies of this century-Computer and Communication as shown in Fig. 1.2. The consequence of this revolutionary merger is the emergence of a integrated system that transmit all types of data and information.

Figure 1.1: Computer Networks

1.1 A Communications Model

A simple model of communications has been illustrated by the block diagram in Fig. 1.3a.The fundamental purpose of a communications system is the exchange of data between two parties. Fig.

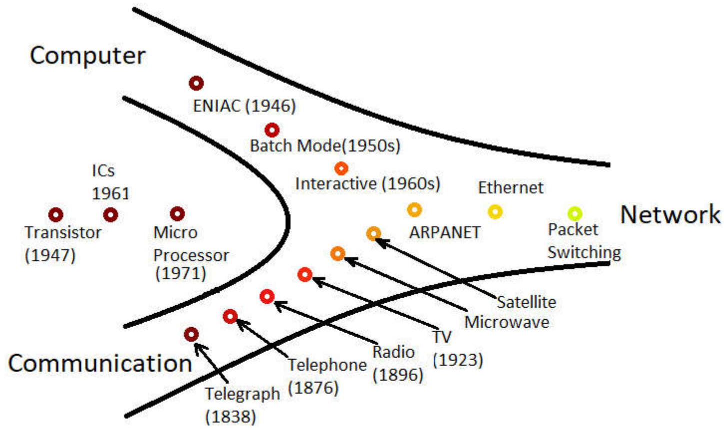

Figure 1.2: Evolution of Computer Networks

1.3b presents one particular example, which is communication between a workstation and a server over a public telephone network. Another example is the exchange of voice signals between two telephones over the same network.The key elements of the model are as follows:

- ***Source:*** This device generates the data to be transmitted; examples are telephones and personal computers.
- ***Transmitter:*** Usually, the data generated by a source system are not transmitted directly in the form in which they were generated. Rather, a transmitter transforms and encodes the information in such a way as to produce electromagnetic signals that can be transmitted across some sort of transmission system. For example, a modem takes a digital bit stream from an attached device such as a personal computer and transforms that bit stream into an analog signal that can be handled by the telephone network.
- ***Transmission system:*** This can be a single transmission line or a complex network connecting source and destination.
- ***Receiver:*** The receiver accepts the signal from the transmission system and converts it into a form that can be handled by the destination device. For example, a modem will accept an analog signal coming from a network or transmission line and convert it into a digital bit stream.
- ***Destination:*** Takes the incoming data from the receiver.

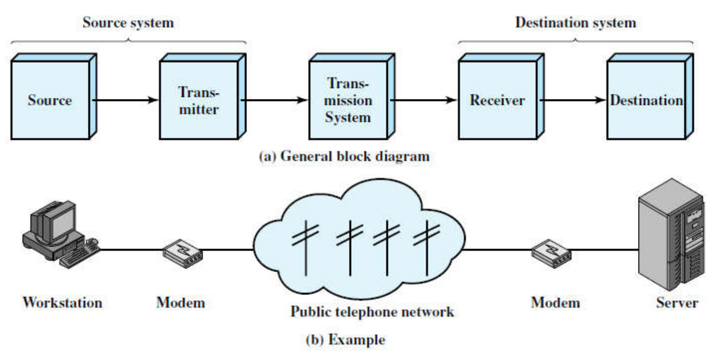

Figure 1.3: Simplified Communications Model

1.2 A Data Communications Model

Fig. 1.4 provides a new perspective on the communications model of Fig. 1.3a.We trace the details of this figure using electronic mail as an example. Suppose that the input device and transmitter are components of a personal computer.The user of the PC wishes to send a message m to another user.The user activates the electronic mail package on the PC and enters the message via the keyboard (input device). The character string is briefly buffered in main memory.We can view it as a sequence of bits (g) in memory.The personal computer is connected to some transmission medium, such as a local network or a telephone line, by an I/O device (transmitter), such as a local network transceiver or a modem.The input data are transferred to the transmitter as a sequence of voltage shifts [$g(t)$] representing bits on some communications bus or cable. The transmitter is connected directly to the medium and converts the incoming stream [$g(t)$] into a signal [$s(t)$] suitable for transmission.

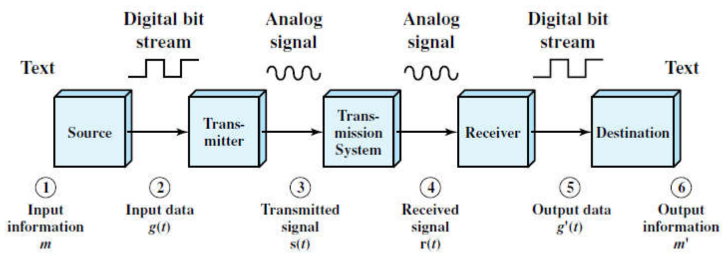

Figure 1.4: Simplified Data Communications Model

The transmitted signal $s(t)$ presented to the medium is subject to a number of impairments, before it reaches the receiver. Thus, the received signal $r(t)$ may differ from $s(t)$. The receiver will attempt to estimate the original $s(t)$, based on $r(t)$ and its knowledge of the medium, producing a sequence of bits $g'(t)$ These bits are sent to the output personal computer, where they are briefly buffered in memory as a block of bits (g'). In many cases, the destination system will attempt to determine if an error has occurred and, if so, it will cooperate with the source system to eventually obtain a complete, error-free block of data. These data are then presented to the user via an output device, such as a printer or screen. The message as viewed by the user will usually be an exact copy of the original message (m).

Now consider a telephone conversation. In this case the input to the telephone is a message (m) in the form of sound waves. The sound waves are converted by the telephone into electrical signals of the same frequency.These signals are transmitted without modification over the telephone line. Hence the input signal $g(t)$ and the transmitted signal $s(t)$ are identical. The signals (t) will suffer some distortion over the medium, so that $r(t)$ will not be identical to $s(t)$. Nevertheless, the signal $r(t)$ is converted back into a sound wave with no attempt at correction or improvement of signal quality. Thus, is not an exact replica of m. However, the received sound message is generally comprehensible to the listener.

The basic building block of any communications facility is the transmission line. The transmission line can carry the information signal in different directions as discussed in Section 1.3. One of the basic choices associated with the transmission line is choosing the transmission medium. For use within the business premises, this choice is generally completely up to the business. For long-distance communications, the choice is generally but not always made by the long-distance carrier. In either case, changes in technology are rapidly changing the mix of media used. Of particular note are fiber optic transmission and wireless transmission (e.g., satellite and radio). These two media are now driving the evolution of data communications transmission.

The ever-increasing capacity of fiber optic channels is making channel capacity a virtually free resource. The growth of the market for optical fiber transmission systems since the beginning of the 1980s is without precedent. During the past 10 years, the cost of fiber optic transmission has dropped by more than an order of magnitude, and the capacity of such systems has grown at almost as rapid a rate. Long-distance telephone communications trunks within the United States will soon consist almost completely of fiber optic cable. Because of its high capacity and because of its security characteristics-fiber is almost impossible to tap-it is becoming increasingly used within office buildings to carry the growing load of business information. However, switching is now becoming the bottleneck.This problem is causing radical changes in communications architecture, including asynchronous transfer mode (ATM) switching, highly parallel processing in switches, and integrated network management schemes.

The second medium-wireless transmission-is a result of the trend toward universal personal telecommunications and universal access to communications. The first concept refers to the ability of a person to identify himself or herself easily and to use conveniently any communication system in a large area (e.g., globally, over a continent, or in an entire country) in terms of a single account. The second refers to the capability of using one's terminal in a wide variety of environments to connect to information services (e.g., to have a portable terminal that will work in the office, on the street, and on airplanes equally well). This revolution in personal computing obviously involves wireless communication in a fundamental way.

Despite the growth in the capacity and the drop in cost of transmission facilities, transmission services remain the most costly component of a communications budget for most businesses. Thus, we need to be aware of techniques that increase the efficiency of the use of these facilities. The two major approaches to greater efficiency are:

- Multiplexing: *Multiplexing* refers to the ability of a number of devices to share a transmission facility. If each device needs the facility only a fraction of the time, then a sharing arrangement allows the cost of the facility to be spread over many users.
- Compression: *Compression*, as the name indicates, involves squeezing the data down so that a lower-capacity, cheaper transmission facility can be used to meet a given demand.

These two techniques show up separately and in combination in a number of types of communications equipment. We need to understand these technologies to be able to assess the appropriateness and cost-effectiveness of the various products on the market.

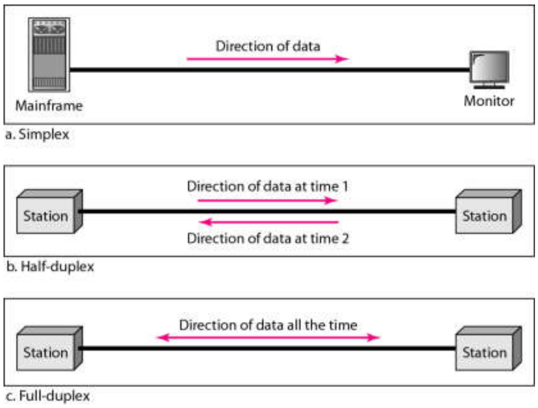

Figure 1.5: (a) Simplex, (b) Half-Duplex and (c) Full Duplex or Duplex

1.3 Direction of data flow

Transmission of signals between 2 computers or nodes (one station being the transmitter and the other being receiver) may be:

1. ***Simplex:*** In simplex transmission, the communication is unidirectional, i.e., signals are transmitted in only one direction. Only one of the two devices on a link can transmit while the other can only receive. Example, keyboards and traditional monitors are examples of simplex devices. The keyboard can only introduce input while the monitor can only accept output. The simplex mode can use the entire capacity of the channel to send data in one direction.

2. ***Half Duplex:*** In half-duplex operation, both devices may transmit, but only one at a time. When one device is sending, the other can only receive, and vice versa. The half-duplex mode is like a one-lane road with traffic allowed in both directions. When cars are traveling in one direction, cars going the other way must wait. In a half-duplex transmission, the entire capacity of a channel is taken over by whichever of the two devices is transmitting at the time. Walkie-talkies and CB (citizens band) radios are both half-duplex systems. The half-duplex mode is used in cases where there is no need for communication in both directions at the same time.

3. ***Full Duplex:*** In full-duplex mode (also called duplex), both stations can transmit and receive simultaneously. Here, the link is carrying signals in both directions at the same time. The full-duplex mode is like a two-way street with traffic flowing in both directions at the same time. One common example of full-duplex communication is the telephone network. When two people are communicating by a telephone line, both can talk and listen at the same time. In full-duplex mode, signals going in one direction share the capacity of the link with signals going in the other direction. The sharing can occur in either of the following 2 ways:
   - the link may contain two physically separate transmission paths, one for sending and the other for receiving.
   - the capacity of the channel is divided between signals traveling in both directions. In such a case, a technique called *echo cancellation* has to be used.

1.4 Network Topology

There is no generally accepted taxonomy into which all computer networks fit, but two dimensions stand out as important: *Transmission Technology* and *Scale*. Based on the transmission technology, computer networks can be broadly categorized into two types based on transmission technologies:

- Broadcast networks: Broadcast network have a single communication channel that is shared by all the machines on the network as shown in Figs. 1.6 and 1.7. All the machines on the network receive short messages, called packets in certain contexts, sent by any machine. An address field within the packet specifies the intended recipient. Upon receiving a packet, machine checks the address field. If packet is intended for itself, it processes the packet; if packet is not intended for itself it is simply ignored.

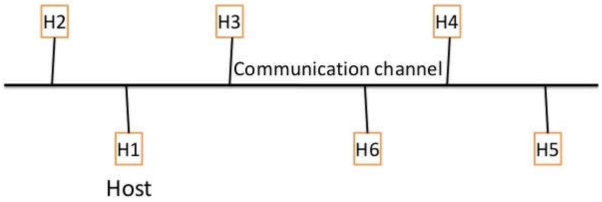

Figure 1.6: Example of a broadcast network based on shared bus

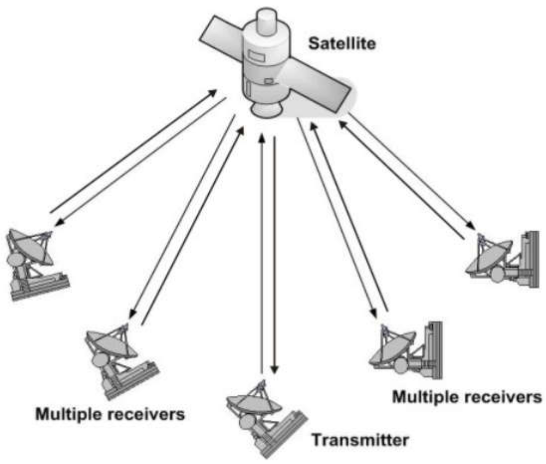

Figure 1.7: Example of a broadcast network based on satellite communication

- Point-to-point networks: A point-to-point connection provides a dedicated link between two devices. The entire capacity of the link is reserved for transmission between those two devices. To go from the source to the destination on a network made up of point-to-point links, short messages, called packets in certain contexts, may have to first visit one or more intermediate machines. Often multiple routes, of different lengths, are possible, so finding good ones is important in point-to-point networks. Point-to-point transmission with exactly one sender and exactly one receiver is sometimes called *unicasting*. Most point-to-point connections use an actual length of wire or cable to connect the two ends, but other options, such as microwave or satellite links, are also possible. When you change television channels by infrared remote control, you are establishing a point-to-point connection between the remote control and the television's control system. Fig. 1.8 illustrates the point-to-point network connection vs. point-to-multipoint connection.

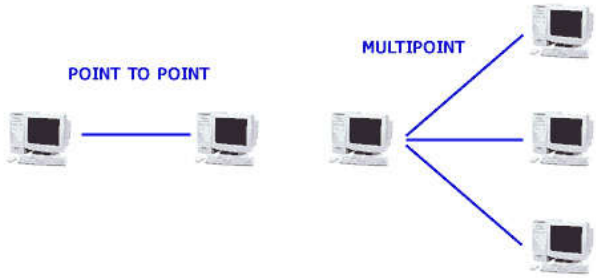

Figure 1.8: Point-to-Point vs. Point-to-Multipoint

Alternative criteria for classifying networks are their *scale*. Based on the span, networks are divided into

- Local Area Network (LAN): LAN is usually privately owned and links the devices in a single office, building or campus of up to few kilometers in size. These are used to share resources (may be hardware or software resources) and to exchange information. LANs are distinguished from other kinds of networks by three categories: their size, transmission technology and topology. LANs are restricted in size, which means that their worst-case transmission time is bounded and known in advance. Hence this is more reliable as compared to MAN and WAN. Knowing this bound makes it possible to use certain kinds of design that would not otherwise be possible. It also simplifies network management. LAN typically used transmission technology consisting of single cable to which all machines are connected. Traditional LANs run at speeds of 10 to 100 Mbps (but now much higher speeds can be achieved). A typical LAN is shown in Fig. 1.9.

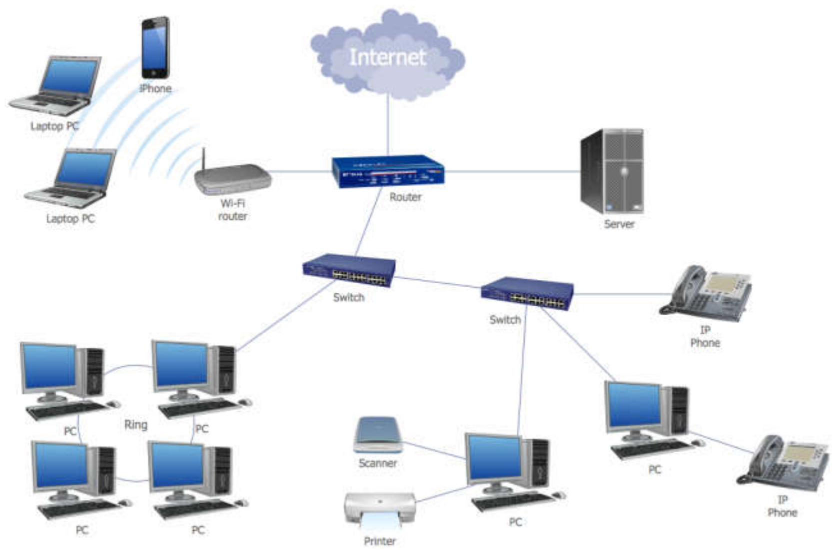

Figure 1.9: Local Area Network

The most common LAN topologies are:

- Mesh: In a mesh topology, every device has a dedicated point-to-point link to every other device. The term *dedicated* means that the link carries traffic only between the two devices it connects. To find the number of physical links in a fully connected mesh network with n nodes, each node must be connected to every other node, i.e., each of the n nodes has to be connected to $n-1$ other nodes for which $n(n-1)$ physical links are required. However, if each physical link allows communication in both directions (duplex mode), we can divide the number of links by 2. In other words, we can say that in a mesh topology, we need $n(n-1)/2$ duplex-mode links. To accommodate the links, every device on the network must have $n-1$ input/output ports to be connected to the other $n-1$ stations. Fig. 1.10 illustrates the fully connected mesh comprising of 5 nodes (i.e., $n=5$).

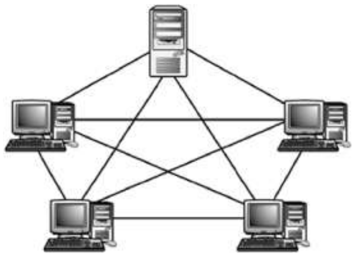

Figure 1.10: Mesh Topology

  * Advantages:
    - The use of dedicated links guarantees that each connection can carry its own data load, thus eliminating the traffic problems that can occur when links must be shared by multiple devices.
    - Mesh topology is robust. If one link becomes unusable, it does not incapacitate the entire system.
    - Mesh topology is secured. When every message travels along a dedicated line, only the intended recipient sees it. Physical boundaries prevent other users from gaining access to messages.
    - Point-to-Point links make fault identification and fault isolation easy. Traffic can be routed to avoid links with suspected problems.

  * Disadvantages:
    - Large amount of cabling and huge number of I/O ports required.
    - Since, every device must be connected to every other device, installation and reconnection are difficult.
    - The sheer bulk of the wiring can be greater than the available space (in walls, ceilings, or floors) can accommodate.
    - The hardware required to connect each link (I/O ports and cable) can be prohibitively expensive.

  * Usage: For the aforementioned reasons a mesh topology is usually implemented in a limited fashion, for example, as a backbone connecting the main computers of

a hybrid network that can include several other topologies. One practical example of a mesh topology is the connection of telephone regional offices in which each regional office needs to be connected to every other regional office.

- Star: In a star topology, each device has a dedicated point-to-point link only to a *central controller*, usually called a *hub* as shown in Fig. 1.11. The devices are not directly linked to one another. Unlike a mesh topology, a star topology does not allow direct traffic between devices. 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 the data to the other connected device.

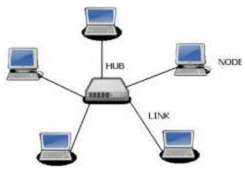

Figure 1.11: Star Topology

  * Advantage:
    - star topology is less expensive than a mesh topology.
    - In a star, each device needs only one link and one I/O port to connect it to any number of others. This factor also makes it easy to install and reconfigure.
    - Far less cabling needs to be housed, and additions, moves, and deletions involve only one connection: between that device and the hub.
    - Star topology is robust. If one link fails, only that link is affected. All other links remain active. This factor also lends itself to easy fault identification and fault isolation. As long as the hub is working, it can be used to monitor link problems and bypass defective links.

  * Disadvantage:
    - The whole topology is dependent on one single point, the hub. If the hub goes down, the whole system is dead.
    - Although a star requires far less cable than a mesh, each node must be linked to a central hub. For this reason, often more cabling is required in a star than in some other topologies (such as ring or bus).

  * Usage: High-speed LANs often use a star topology with a central hub.

- Bus: The preceding examples all describe point-to-point connections. A bus topology, on the other hand, as shown in Fig. 1.12 is point-to-multipoint technology. One long cable acts as a backbone to link all the devices in a network. Nodes are connected to the bus cable by drop lines and taps. A drop line is a connection running between the device and the main cable. A tap is a connector that either splices into the main cable or punctures the sheathing of a cable to create a contact with the metallic core. As a signal travels along the backbone, some of its energy is transformed into heat. Therefore, it becomes weaker and weaker as it travels farther and farther. For this reason there is a limit on the number of taps a bus can support and on the distance between those taps.

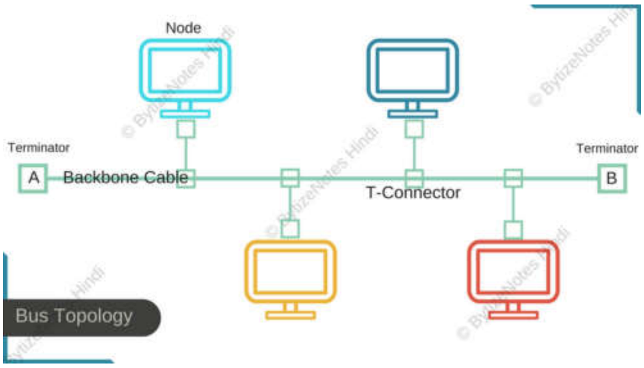

Figure 1.12: Bus Topology

* Advantages:
  - Ease of installation.
  - Backbone cable can be laid along the most efficient path, then connected to the nodes by drop lines of various lengths. In this way, a bus uses less cabling than mesh or star topologies. In a star, for example, four network devices in the same room require four lengths of cable reaching all the way to the hub. In a bus, this redundancy is eliminated. Only the backbone cable stretches through the entire facility. Each drop line has to reach only as far as the nearest point on the backbone.

* Disadvantages:
  - Difficult reconnection and fault isolation. A bus is usually designed to be optimally efficient at installation. It can therefore be difficult to add new devices. Signal reflection at the taps can cause degradation in quality. This degradation can be controlled by limiting the number and spacing of devices connected to a given length of cable. Adding new devices may therefore require modification or replacement of the backbone.
  - In addition, a fault or break in the bus cable stops all transmission, even between devices on the same side of the problem. The damaged area reflects signals back in the direction of origin, creating noise in both directions.

* Usage: Bus topology was the one of the first topologies used in the design of early localarea networks. Ethernet LANs can use a bus topology, but they are less popular now.

- Ring: In a ring topology as shown in Fig. 1.13, each device has a dedicated point-to-point connection with only the two devices on either side of it. A signal is passed along the ring in one direction, from device to device, until it reaches its destination. Each device in the ring incorporates a repeater. When a device receives a signal intended for another device, its repeater regenerates the bits and passes them along.

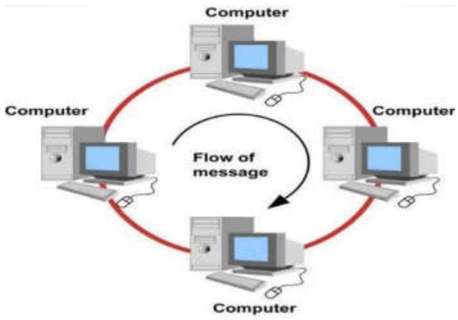

Figure 1.13: Ring Topology

- Advantage
  - A ring is relatively easy to install and reconfigure. Each device is linked to only its immediate neighbors (either physically or logically). To add or delete a device requires changing only two connections. The only constraints are media and traffic considerations (maximum ring length and number of devices).
  - Fault isolation is simplified. Generally in a ring, a signal is circulating at all times. If one device does not receive a signal within a specified period, it can issue an alarm. The alarm alerts the network operator to the problem and its location.

- Disadvantages: Unidirectional traffic can be a disadvantage. In a simple ring, a break in the ring (such as a disabled station) can disable the entire network. This weakness can be solved by using a dual ring or a switch capable of closing off the break.

- Usage: Ring topology was prevalent when IBM introduced its local-area network Token Ring. Today, the need for higher-speed LANs has made this topology less popular.

– Hybrid: A network can be hybrid as well. A hybrid network is formed by combining the aforementioned topologies. For example, we can have a main star topology with a branch connecting several stations in a bus topology and another branch connecting several stations in a ring topology as shown in Fig. 1.14.

- Metropolitan Area Network (MAN): MAN is designed to extend over the entire city. It may be a single network as a cable TV network or it may be means of connecting a number of LANs into a larger network so that resources may be shared as shown in Fig. 1.15. For example, a company can use a MAN to connect the LANs in all its offices in a city. MAN is wholly owned and operated by a private company or may be a service provided by a public company. The main reason for distinguishing MANs as a special category is that a standard has been adopted for them. It is DQDB (Distributed Queue Dual Bus) or IEEE 802.6.

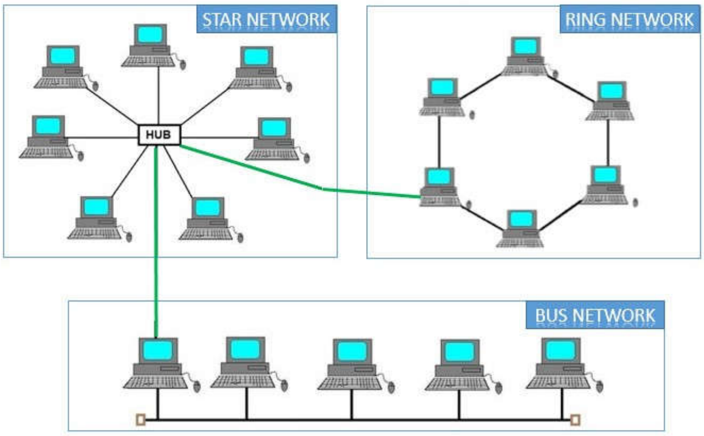

Figure 1.14: Hybrid Topology

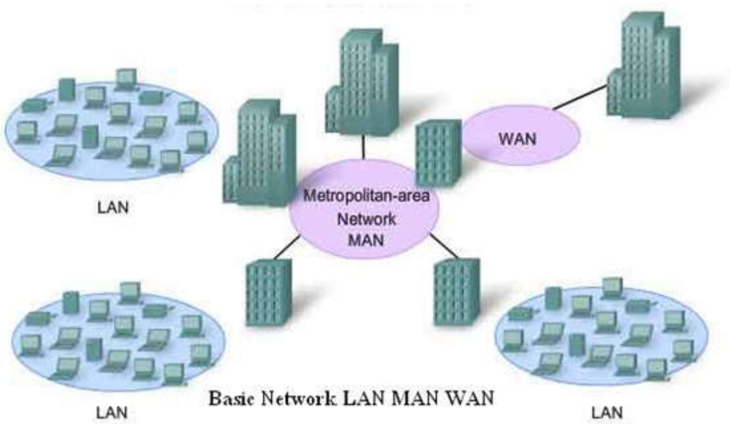

Figure 1.15: Metropolitan Area Network

- Wide Area Networks (WAN): WAN provides long-distance transmission of data, voice, image and information over large geographical areas that may comprise a country, continent or even the whole world. In contrast to LANs, WANs may utilize public, leased or private communication devices, usually in combinations, and can therefore span an unlimited number of miles as shown in Fig. 1.16. A WAN that is wholly owned and used by a single company is often referred to as enterprise network.

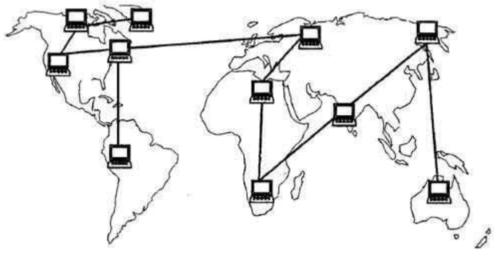

Figure 1.16: Wide Area Network

1.5 The Internet with the capital I

Today, it is very rare to see a LAN, a MAN, or a LAN in isolation; they are connected to one another. When two or more networks are connected, they become an inter-network, or internet. The *Internet* is a collection of networks or network of networks. Various networks such as LAN and WAN connected through suitable hardware and software to work in a seamless manner. Schematic diagram of the Internet is shown in Fig. 1.17. It allows various applications such as e-mail, file transfer, remote log-in, World Wide Web, Multimedia, etc run across the internet. The basic difference between WAN and Internet is that WAN is owned by a single organization while internet is not so. But with the time the line between WAN and Internet is shrinking, and these terms are sometimes used interchangeably.

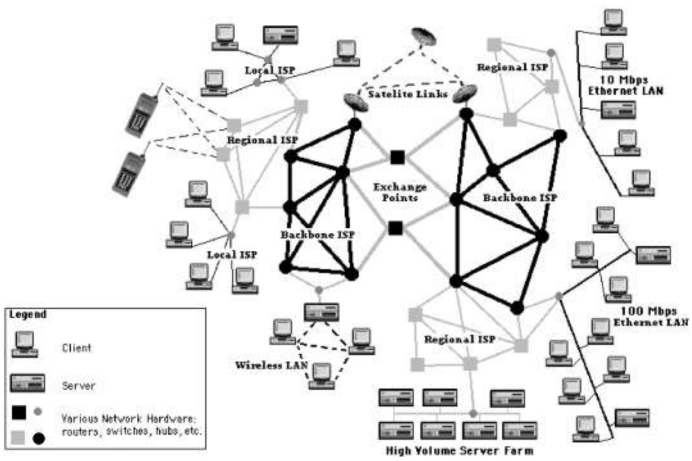

Figure 1.17: The Internet

1.6 Assignments

1. Is an oil pipeline a simplex system, a half-duplex system, a full-duplex system, or none of the above? What about a river or a walkie-talkie-style communication?
2. An alternative to a LAN is simply a big timesharing system with terminals for all users. Give two advantages of a client-server system using a LAN.
3. Identify the five components of a data communications system.
4. What are the advantages of a multipoint connection over a point-to-point connection?
5. What are the two types of line configuration?
6. Categorize the four basic topologies in terms of line configuration.
7. What is the difference between half-duplex and full-duplex transmission modes?
8. Name the four basic network topologies, and cite an advantage of each type.
9. For n devices in a network, what is the number of cable links required for a mesh, ring, bus, and star topology?
10. What are some of the factors that determine whether a communication system is a LAN or WAN?
11. A color image uses 16 bits to represent a pixel. What is the maximum number of different colors that can be represented?
12. Assume six devices are arranged in a mesh topology. How many cables are needed? How many ports are needed for each device?
13. For each of the following four networks, discuss the consequences if a connection fails.
    (a) Five devices arranged in a mesh topology
    (b) Five devices arranged in a star topology (not counting the hub)
    (c) Five devices arranged in a bus topology
    (d) Five devices arranged in a ring topology
14. You have two computers connected by an Ethernet hub at home. Is this a LAN, a MAN, or a WAN? Explain your reason.
15. In the ring topology, what happens if one of the stations is unplugged?
16. In the bus topology, what happens if one of the stations is unplugged?
17. Draw a hybrid topology with a star backbone and three ring networks.
18. Draw a hybrid topology with a ring backbone and two bus networks.
19. Performance is inversely related to delay. When you use the Internet, which of the following applications are more sensitive to delay?
    (a) Sending an e-mail
    (b) Copying a file
    (c) Surfing the Internet
20. When a party makes a local telephone call to another party, is this a point-to-point or multi-point connection? Explain your answer.
21. Compare the telephone network and the Internet. What are the similarities? What are the differences?