DATA COMMUNICATIONS

- Data communication is defined as exchange of data between 2 devices over a transmission-medium.
- A communication-system is made up of
  → hardware (physical equipment) and
  → software (programs)

Components of Communication System

- Five components of a communication-system (Figure 1.1):
  1) Message
  2) Sender
  3) Receiver
  4) Transmission-Medium
  5) Protocol

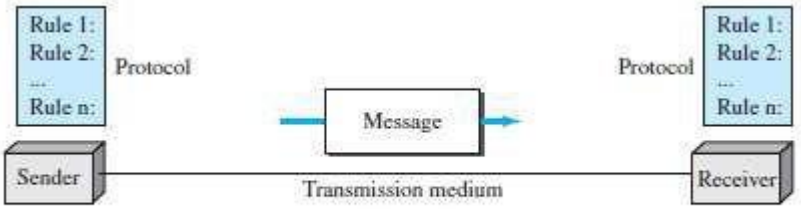

Figure 1.1 *Five components of data communication*

1) Message

- Message is the information (or data) to be communicated.
- Message may consist of
  → number/text
  → picture or
  → audio/video

2) Sender

- Sender is the device that sends the data-message.
- Sender can be
  → computer and
  → mobile phone

3) Receiver

- Receiver is the device that receives the message.
- Receiver can be
  → computer and
  → mobile phone

4) Transmission Medium

- Transmission-medium is physical-path by which a message travels from sender to receiver.
- Transmission-medium can be wired or wireless.
- Examples of wired medium:
  → twisted-pair wire (used in landline telephone)
  → coaxial cable (used in cable TV network)
  → fiber-optic cable
- Examples of wireless medium:
  → radio waves
  → microwaves
  → infrared waves (ex: operating TV using remote control)

5) Protocol

- A protocol is a set of rules that govern data-communications.
- In other words, a protocol represents an agreement between the communicating-devices.
- Without a protocol, 2 devices may be connected but not communicating.

Data Representation

- Five different forms of information:

Text

- Text is represented as a bit-pattern. (Bit-pattern → sequence of bits: 0s or 1s).
- Different sets of bit-patterns are used to represent symbols (or characters).
- Each set is called a code.
- The process of representing symbols is called encoding.
- Popular encoding system: ASCII, Unicode.

Number

- Number is also represented as a bit-pattern.
- ASCII is not used to represent number. Instead, number is directly converted to binary-form.

Image

- Image is also represented as a bit-pattern.
- An image is divided into a matrix of pixels (picture-elements).
- A pixel is the smallest element of an image. (Pixel → Small dot)
- The size of an image depends upon number of pixels (also called resolution). For example: An image can be divided into 1000 pixels or 10,000 pixels.
- Two types of images:

i) Black & White Image

¤ If an image is black & white, each pixel can be represented by a value either 0 or 1.

¤ For example: Chessboard

ii) Color Image

¤ There are many methods to represent color images.

¤ RGB is one of the methods to represent color images.

¤ RGB is called so called '.' each color is combination of 3 colors: red, green & blue.

Audio

- Audio is a representation of sound.
- By nature, audio is different from text, numbers, or images. Audio is continuous, not discrete.

Video

- Video is a representation of movie.
- Video can either

→ be produced as a continuous entity (e.g., by a TV camera), or

→ be a combination of images arranged to convey the idea of motion.

Direction of Data Flow

- Three ways of data-flow between 2 devices (Figure 1.2):

Simplex

Half-duplex

Full-duplex

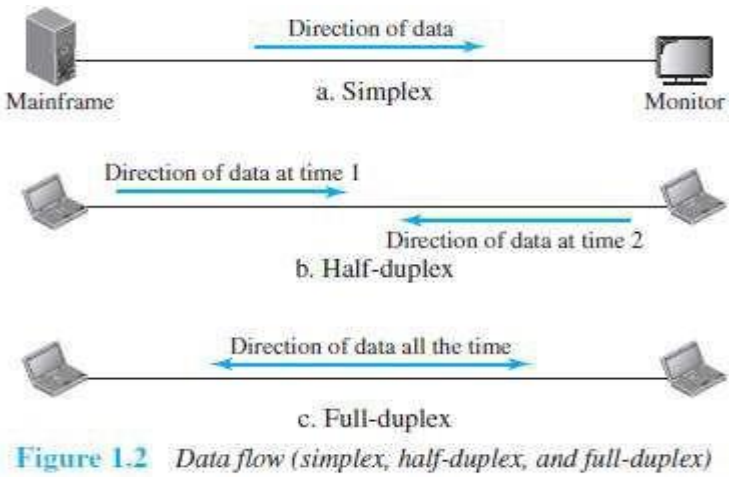

Figure 1.2 *Data flow (simplex, half-duplex, and full-duplex)*

1) Simplex

- The communication is unidirectional
  (For ex: The simplex mode is like a one-way street).
- On a link, out of 2 devices:
  i) Only one device can transmit.
  ii) Another device can only receive.
- For example (Figure 1.2a):
  The monitor can only accept output.
- Entire-capacity of channel is used to send the data in one direction.

2) Half Duplex

- Both the stations can transmit as well as receive but not at the same time.
  (For ex: The half-duplex mode is like a one-lane road with 2 directional traffic).
- When one station is sending, the other can only receive and vice-versa.
- For example (Figure 1.2b): Walkie-talkies
- Entire-capacity of a channel is used by one of the 2 stations that are transmitting the data.

3) Full Duplex

- Both stations can transmit and receive at the same time.
  (For ex: The full-duplex is like a 2-way street with traffic flowing in both directions at the same time).
- For example (Figure 1.2c):
  Mobile phones (When 2 people are communicating by a telephone line, both can listen and talk at the same time)
- Entire-capacity of a channel is shared by both the stations that are transmitting the data.

NETWORKS

- A network is defined as a set of devices interconnected by communication-links.
- This interconnection among computers facilitates information sharing among them.
- Computers may connect to each other by either wired or wireless media.
- Often, devices are referred to as nodes.
- A node can be any device capable of sending/receiving data in the network.
- For example: Computer & Printer
- The best-known computer network is the Internet.

Network Criteria

- A network must meet following 3 criteria's:

1) Performance

- Performance can be measured using i) Transit-time or ii) Response-time.
  - **i) Transit Time** is defined as time taken to travel a message from one device to another.
  - **ii) Response Time** is defined as the time elapsed between enquiry and response.
- The network-performance depends on following factors:
  - i) Number of users
  - ii) Type of transmission-medium
  - iii) Efficiency of software
- Often, performance is evaluated by 2 networking-metrics: i) throughput and ii) delay.
- Good performance can be obtained by achieving higher throughput and smaller delay times

2) Reliability

- Reliability is measured by
  - → frequency of network-failure
  - → time taken to recover from a network-failure
  - → network's robustness in a disaster
- More the failures are, less is the network's reliability.

3) Security

- Security refers to the protection of data from the unauthorized access or damage.
- It also involves implementing policies for recovery from data-losses.

Physical Structures

Type of Connection

- Two types of connections (Figure 1.3):

1) Point-to-Point

- Only two devices are connected by a dedicated-link (Figure 1.3a).
- Entire-capacity of the link is reserved for transmission between those two devices.
- For example: Point-to-Point connection b/w remote-control & TV for changing the channels.

2) Multipoint (Multi-Drop)

- Three or more devices share a single link.
- The capacity of the channel is shared, either spatially or temporally (Figure 1.3b).
  - i) If link is used simultaneously by many devices, then it is spatially shared connection.
  - ii) If user takes turns while using the link, then it is time shared (temporal) connection. (spatially→space or temporally→time

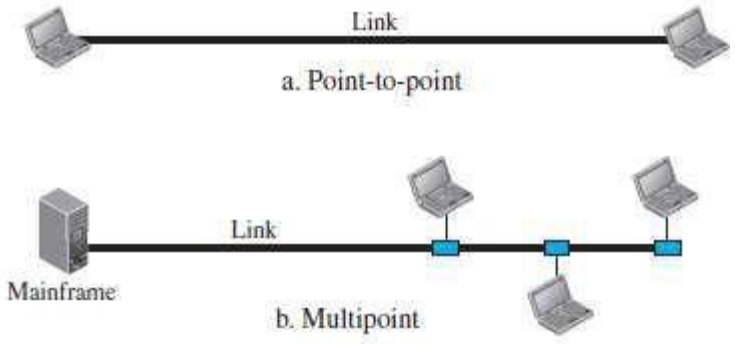

Figure 1.3 *Types of connections: point-to-point and multipoint*

Physical Topology

- The physical-topology defines how devices are connected to make a network.
- Four basic topologies are:
  - Mesh
  - Star
  - Bus
  - Ring

Bus Topology

- All the devices are connected to the single cable called bus (Figure 1.4).
- Every device communicates with the other device through this bus.
- A data from the source is broadcasted to all devices connected to the bus.
- Only the intended-receiver, whose physical-address matches, accepts the data.

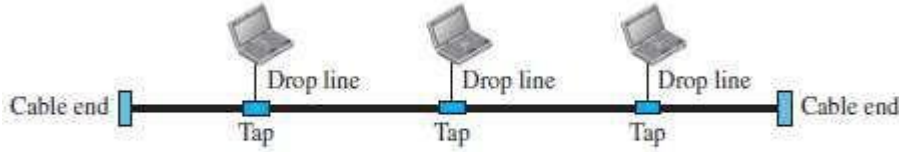

Figure 1.4 *A bus topology connecting three stations*

- Devices are connected to the bus by drop-lines and taps.
- A drop-line is a connection running between the device and the bus.
- A tap is a connector that links to the bus or
- Advantages:
  1) Easy installation.
  2) Cable required is the least compared to mesh/star topologies.
  3) Redundancy is eliminated.
  4) Costs less (Compared to mesh/star topologies).
  5) Mostly used in small networks. Good for LAN.
- Disadvantages:
  1) Difficult to detect and troubleshoot fault.
  2) Signal reflection at the taps can cause degradation in quality.
  3) A fault/break in the cable stops all transmission.
  4) There is a limit on
     i) Cable length
     ii) Number of nodes that can be connected.
  5) Security is very low because all the devices receive the data sent from the source.

Star Topology

- All the devices are connected to a central controller called a hub (Figure 1.5).
- There exists a dedicated point-to-point link between a device & a hub.
- The devices are not directly linked to one another. Thus, there is no direct traffic between devices.
- The hub acts as a junction:
  If device-1 wants to send data to device-2, the device-1 sends the data to the hub,

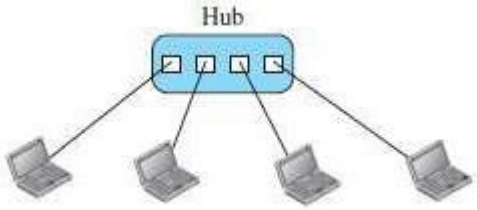

Figure 1.5 *A star topology connecting four stations*

then the hub relays the data to the device-2

Advantages:

1) Less expensive: Each device needs only one link & one I/O port to connect it to any devices. Easy installation & reconfiguration: Nodes can be added/removed w/o affecting the network.
2) Robustness: If one link fails, it does not affect the entire system.
3) Easy to detect and troubleshoot fault.
4) Centralized management: The hub manages and controls the whole network.

Disadvantages:

1) Single point of failure: If the hub goes down, the whole network is dead.
2) Cable length required is the more compared to bus/ring topologies.
3) Number of nodes in network depends on capacity of hub

Ring Topology

- Each device is connected to the next, forming a ring (Figure 1.6).
- There are only two neighbors for each device.
- Data travels around the network in one direction till the destination is reached.
- Sending and receiving of data takes place by the help of token.
- Each device has a repeater.
- A repeater
  → receives a signal on transmission-medium &
  → regenerates & passes the signal to next device.

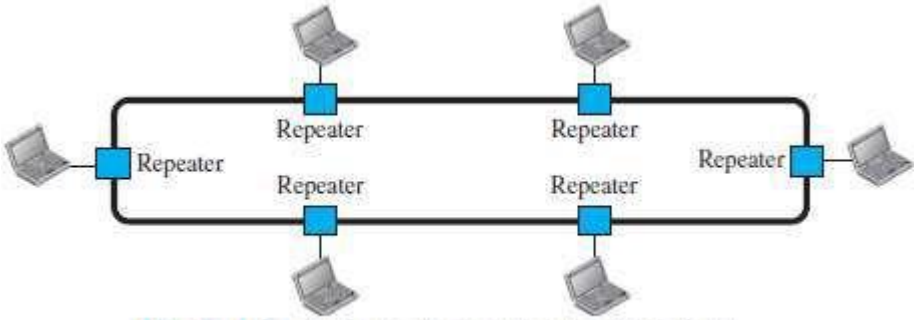

Figure 1.6 *A ring topology connecting six stations*

- Advantages:
  1) Easy installation and reconfiguration.
     To add/delete a device, requires changing only 2 connections.
  3) Fault isolation is simplified.
     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.
  3) Congestion reduced: Because all the traffic flows in only one direction.

- Disadvantages:
    1) Unidirectional traffic.
    2) A fault in the ring/device stops all transmission.
        The above 2 drawbacks can be overcome by using dual ring.
    3) There is a limit on
        i) Cable length &
        ii) Number of nodes that can be connected.
    4) Slower: Each data must pass through all the devices between source and destination.

Mesh Topology

- All the devices are connected to each other (Figure 1.7).
- There exists a dedicated point-to-point link between all devices.
- There are n(n-1) physical channels to link n devices.
- Every device not only sends its own data but also relays data from other nodes.
- For 'n' nodes,
    → there are n(n-1) physical-links
    → there are n(n-1)/2 duplex-mode links
- Every device must have (n–1) I/O ports to be connected to the other (n-1) devices.

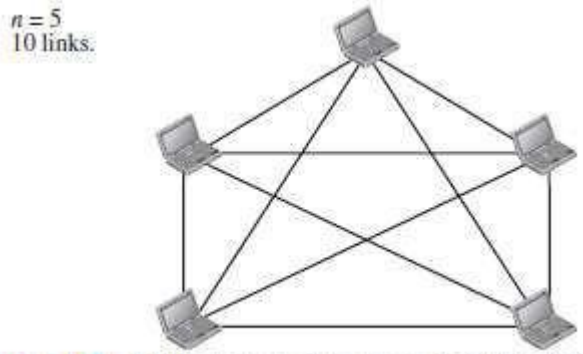

Figure 1.7 *A fully connected mesh topology (five devices)*

- Advantages:
    1) Congestion reduced: Each connection can carry its own data load.
    2) Robustness: If one link fails, it does not affect the entire system.
    3) Security: When a data travels on a dedicated-line, only intended-receiver can see the data.
    4) Easy fault identification & fault isolation: Traffic can be re-routed to avoid problematic links.
- Disadvantages:
    1) Difficult installation and reconfiguration.
    2) Bulk of wiring occupies more space than available space.
    3) Very expensive: as there are many redundant connections.
    4) Not mostly used in computer networks. It is commonly used in wireless networks.
    5) High redundancy of the network-connections.

Network Types

- Two popular types of networks:
    1) LAN (Local Area Network)
    2) WAN (Wide Area Network)

LAN

- LAN is used to connect computers in a single office, building or campus (Figure 1.8).
- LAN is usually privately owned network.
- A LAN can be simple or complex.
  - **1)** Simple: LAN may contain 2 PCs and a printer.
  - **2)** Complex: LAN can extend throughout a company.
- Each host in a LAN has an address that uniquely defines the host in the LAN.
- A packet sent by a host to another host carries both source host's and destination host's addresses.
- LANs use a smart connecting switch.
- The switch is able to
  - → recognize the destination address of the packet &
  - → guide the packet to its destination.
- The switch
  - → reduces the traffic in the LAN &
  - → allows more than one pair to communicate with each other at the same time.
- Advantages:
  - **1)** Resource Sharing
    - ➢ Computer resources like printers and hard disks can be shared by all devices on the network.
  - **2)** Expansion
    - ➢ Nowadays, LANs are connected to WANs to create communication at a wider level.

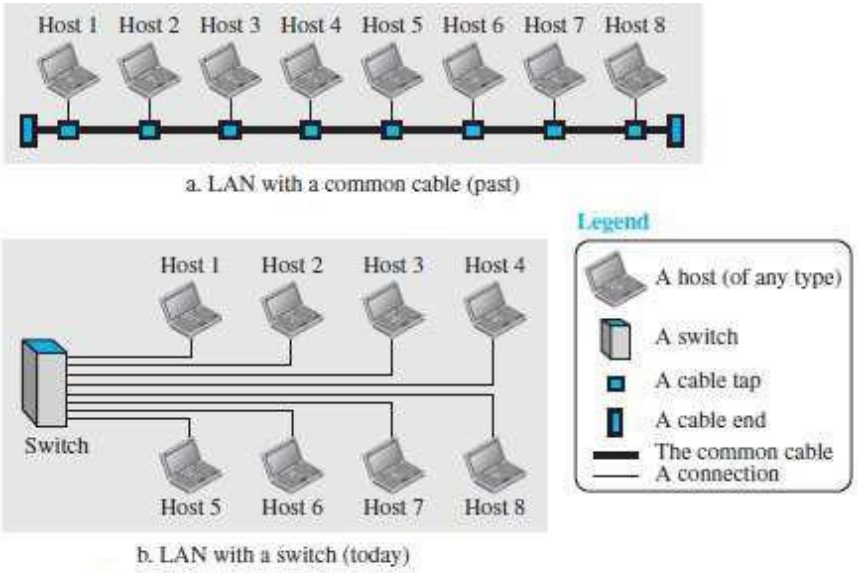

Figure 1.8 *An isolated LAN in the past and today*

WAN

- WAN is used to connect computers anywhere in the world.
- WAN can cover larger geographical area. It can cover cities, countries and even continents.
- WAN interconnects connecting devices such as switches, routers, or modems.
- Normally, WAN is

→ created & run by communication companies (Ex: BSNL, Airtel)
→ leased by an organization that uses it.

- A WAN can be of 2 types:

Point-to-Point WAN

➢ A point-to-point WAN is a network that connects 2 communicating devices through a transmission media (Figure 1.9).

Figure 1.9 *A point-to-point WAN*

Switched WAN

➢ A switched WAN is a network with more than two ends.
➢ The switched WAN can be the backbones that connect the Internet.
➢ A switched WAN is a combination of several point-to-point WANs that are connected by switches (Figure 1.10).

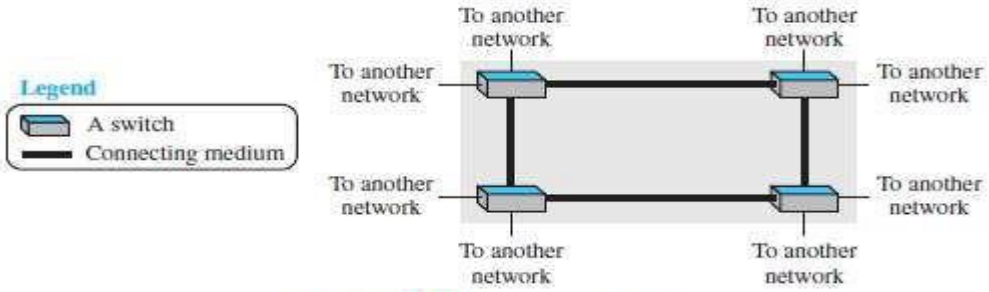

Figure 1.10 *A switched WAN*

Internetwork

- A network of networks is called an internet. (Internet → inter-network) (Figure 1.12).
- For example (Figure 1.11):
  - ➢ Assume that an organization has two offices,
    - i) First office is on the east coast &
    - ii) Second office is on the west coast.
  - ➢ Each office has a LAN that allows all employees in the office to communicate with each other.
  - ➢ To allow communication between employees at different offices, the management leases a point-to-point dedicated WAN from a ISP and connects the two LANs.
    - (ISP → Internet service provider such as a telephone company ex: BSNL).

Figure 1.11 *An internetwork made of two LANs and one point-to-point WAN*

➢ When a host in the west coast office sends a message to another host in the same office, the router blocks the message, but the switch directs the message to the destination.

➢ On the other hand, when a host on the west coast sends a message to a host on the east coast, router R1 routes the packet to router R2, and the packet reaches the destination.

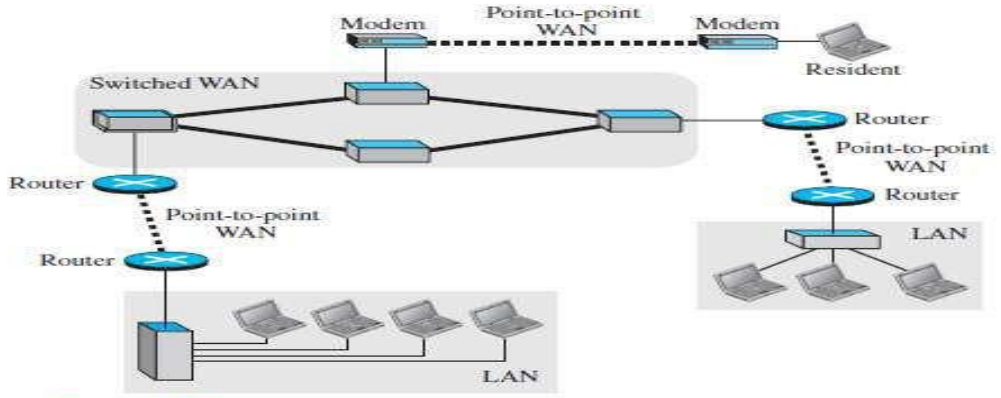

Figure 1.12 *A heterogeneous network made of four WANs and three LANs*

LAN vs. WAN

Parameters	LAN	WAN
Expands to	Local Area Network	Wide Area Network
Meaning	LAN is used to connect computers in a single office, building or campus	WAN is used to connect computers in a large geographical area such as countries
Ownership of network	Private	Private or public
Range	Small: up to 10 km	Large: Beyond 100 km
Speed	High: Typically 10, 100 and 1000 Mbps	Low: Typically 1.5 Mbps
Propagation Delay	Short	Long
Cost	Low	High
Congestion	Less	More
Design & maintenance	Easy	Difficult
Fault Tolerance	More Tolerant	Less Tolerant
Media used	Twisted pair	Optical fiber or radio waves
Used for	College, Hospital	Internet
Interconnects	LAN interconnects hosts	WAN interconnects connecting devices such as switches, routers, or modems

Switching

- An internet is a switched network in which a switch connects at least two links together.
- A switch needs to forward data from a network to another network when required.
- Two types of switched networks are 1) circuit-switched and 2) packet-switched networks.

Circuit Switched Network

➢ A dedicated connection, called a circuit, is always available between the two end systems.

➢ The switch can only make it active or inactive.

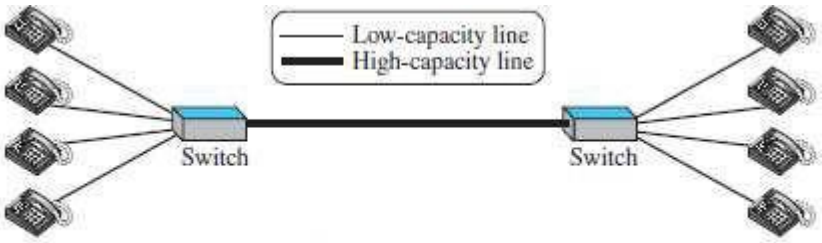

Figure 1.13 *A circuit-switched network*

- ¤ As shown in Figure 1.13, the 4 telephones at each side are connected to a switch.
- ¤ The switch connects a telephone at one side to a telephone at the other side.
- ¤ A high-capacity line can handle 4 voice communications at the same time.
- ¤ The capacity of high line can be shared between all pairs of telephones.
- ¤ The switch is used for only forwarding.

➢ Advantage:

A circuit-switched network is efficient only when it is working at its full capacity.

➢ Disadvantage:

Most of the time, the network is inefficient because it is working at partial capacity.

Packet Switched Network

➢ In a computer network, the communication between the 2 ends is done in blocks of data called packets.

➢ The switch is used for both storing and forwarding because a packet is an independent entity that can be stored and sent later.

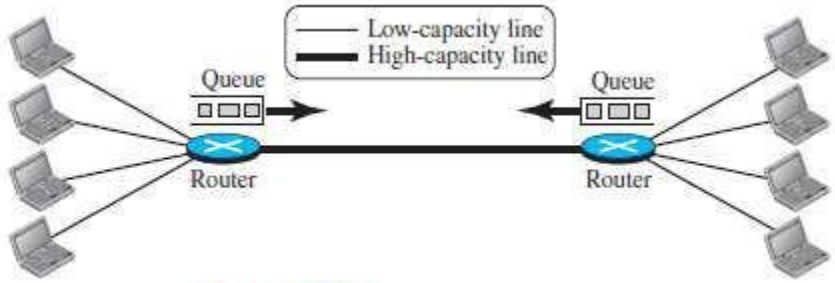

Figure 1.14 *A packet-switched network*

- ¤ As shown in Figure 1.14, the 4 computers at each side are connected to a router.
- ¤ A router has a queue that can store and forward the packet.
- ¤ The high-capacity line has twice the capacity of the low-capacity line.
- ¤ If only 2 computers (one at each site) need to communicate with each other, there is no waiting for the packets.
- ¤ However, if packets arrive at one router when high-capacity line is at its full capacity, the packets should be stored and forwarded.

➢ Advantages:

A packet-switched network is more efficient than a circuit switched network.

➢ Disadvantage:

The packets may encounter some delays.

The Internet Today

- A network of networks is called an internet. (Internet → inter-network)
- Internet is made up of (Figure 1.15)
  - **1)** Backbones
  - **2)** Provider networks &
  - **3)** Customer networks

1) Backbones

- Backbones are large networks owned by communication companies such as BSNL and Airtel.
- The backbone networks are connected through switching systems, called peering points.

2) Provider Networks

- Provider networks use the services of the backbones for a fee.
- Provider networks are connected to backbones and sometimes to other provider networks.

3) Customer Networks

- Customer networks actually use the services provided by the Internet.
- Customer networks pay fees to provider networks for receiving services.

- Backbones and provider networks are also called Internet Service Providers (ISPs).
- The backbones are often referred to as international ISPs.
  The provider networks are often referred to as national or regional ISPs.

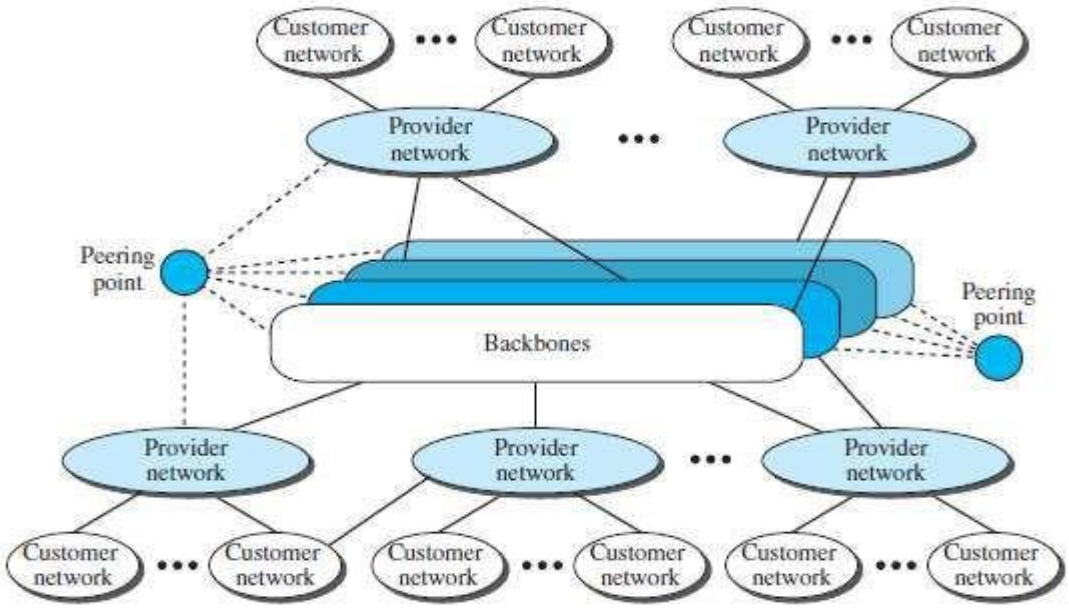

Figure 1.15 *The Internet today*

Accessing the Internet

- The Internet today is an internetwork that allows any user to become part of it.
- However, the user needs to be physically connected to an ISP.
- The physical connection is normally done through a point-to-point WAN.

Using Telephone Networks

- Most residences have telephone service, which means they are connected to a telephone network.

- Most telephone networks have already connected themselves to the Internet.
- Thus, residences can connect to the Internet using a point-to-point WAN.
- This can be done in two ways:

A) Dial-up service

- A modem can be added to the telephone line.
- A modem converts data to voice.
- The software installed on the computer
  → dials the ISP &
  → imitates making a telephone connection.
- Disadvantages:
  i) The dial-up service is very slow.
  ii) When line is used for Internet connection, it cannot be used for voice connection.
  iii) It is only useful for small residences.

B) DSL Service

- DSL service also allows the line to be used simultaneously for voice & data communication.
- Some telephone companies have upgraded their telephone lines to provide higher speed Internet services to residences.

Using Cable Networks

- A residence can be connected to the Internet by using cable service.
- Cable service provides a higher speed connection.
- The speed varies depending on the number of neighbors that use the same cable.

Using Wireless Networks

- A residence can use a combination of wireless and wired connections to access the Internet.
- A residence can be connected to the Internet through a wireless WAN.

Direct Connection to the Internet

- A large organization can itself become a local ISP and be connected to the Internet.
- The organization
  → leases a high-speed WAN from a carrier provider and
  → connects itself to a regional ISP.

STANDARDS AND ADMINISTRATION

Internet Standards

- An Internet standard is a thoroughly tested specification useful to those who work with the Internet.
- The Internet standard is a formalized-regulation that must be followed.
- There is a strict procedure by which a specification attains Internet standard status.
- A specification begins as an Internet draft.
- An Internet draft is a working document with no official status and a 6-month lifetime.
- Upon recommendation from the Internet authorities, a draft may be published as a RFC.
- Each RFC is edited, assigned a number, and made available to all interested parties.
- RFCs go through maturity levels and are categorized according to their requirement level. (working document → a work in progress RFC → Request for Comment)

Maturity Levels

- An RFC, during its lifetime, falls into one of 6 maturity levels (Figure 1.16):

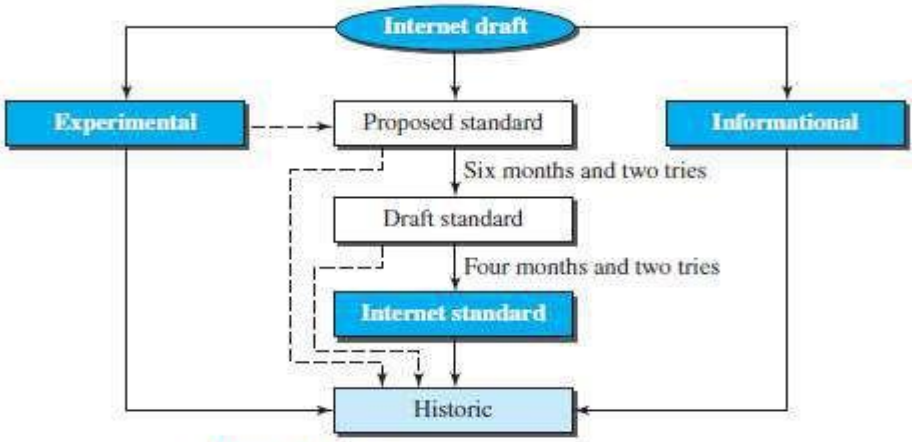

Figure 1.16 *Maturity levels of an RFC*

1) Proposed Standard

- Proposed standard is specification that is stable, well-understood & of interest to Internet community.
- Specification is usually tested and implemented by several different groups.

2) Draft Standard

- A proposed standard is elevated to draft standard status after at least 2 successful independent and interoperable implementations.

3) Internet Standard

- A draft standard reaches Internet standard status after demonstrations of successful implementation.

4) Historic

- The historic RFCs are significant from a historical perspective.
- They either
  → have been superseded by later specifications or
  → have never passed the necessary maturity levels to become an Internet standard.

5) Experimental

- An RFC classified as experimental describes work related to an experimental situation.
- Such an RFC should not be implemented in any functional Internet service.

6) Informational

- An RFC classified as informational contains general, historical, or tutorial information related to the Internet.
- Usually, it is written by a vendor.

(ISOC → Internet Society IAB → Internet Architecture Board) (IETF → Internet Engineering Task Force IRTF → Internet Research Task Force)
(IESG → Internet Engineering Steering Group IRSG → Internet Research Steering Group)

Requirement Levels

- RFCs are classified into 5 requirement levels:

Required

- An RFC labeled required must be implemented by all Internet systems to achieve minimum conformance.
- For example, IP and ICMP are required protocols.

Recommended

- An RFC labeled recommended is not required for minimum conformance.
- It is recommended because of its usefulness.
- For example, FTP and TELNET are recommended protocols.

Elective

- An RFC labeled elective is not required and not recommended.
- However, a system can use it for its own benefit.

Limited Use

- An RFC labeled limited use should be used only in limited situations.
- Most of the experimental RFCs fall under this category.

Not Recommended

- An RFC labeled not recommended is inappropriate for general use.
- Normally a historic RFC may fall under this category.

Internet Administration

1) ISOC

- ISOC is a nonprofit organization formed to provide support for Internet standards process (Fig 1.17).
- ISOC maintains and supports other Internet administrative bodies such as IAB, IETF, IRTF, and IANA.

2) IAB

- IAB is the technical advisor to the ISOC.
- Two main purposes of IAB:
  - i) To oversee the continuing development of the TCP/IP Protocol Suite
  - ii) To serve in a technical advisory capacity to research members of the Internet community.
- Another responsibility of the IAB is the editorial management of the RFCs.
- IAB is also the external liaison between the Internet and other standards organizations and forums.
- IAB has 2 primary components: i) IETF and ii) IRTF.

i) IETF

- IETF is a forum of working groups managed by the IESG.
- IETF is responsible for identifying operational problems & proposing solutions to the problems
- IETF also develops and reviews specifications intended as Internet standards.
- The working groups are collected into areas, and each area concentrates on a specific topic.
- Currently 9 areas have been defined. The areas include applications, protocols, routing, network management next generation (IPng), and security.

ii) IRTF

- IRTF is a forum of working groups managed by the IRSG.
- IRTF focuses on long-term research topics related to Internet protocols, applications, architecture, and technol

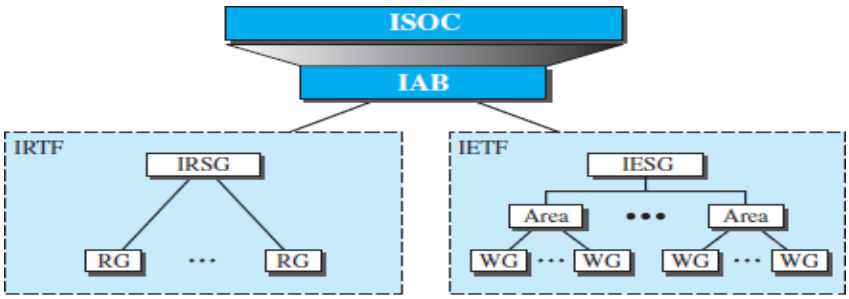

Figure 1.17 *Internet administration*