Computer Networks

From **Andrew S. Tanenbaum**

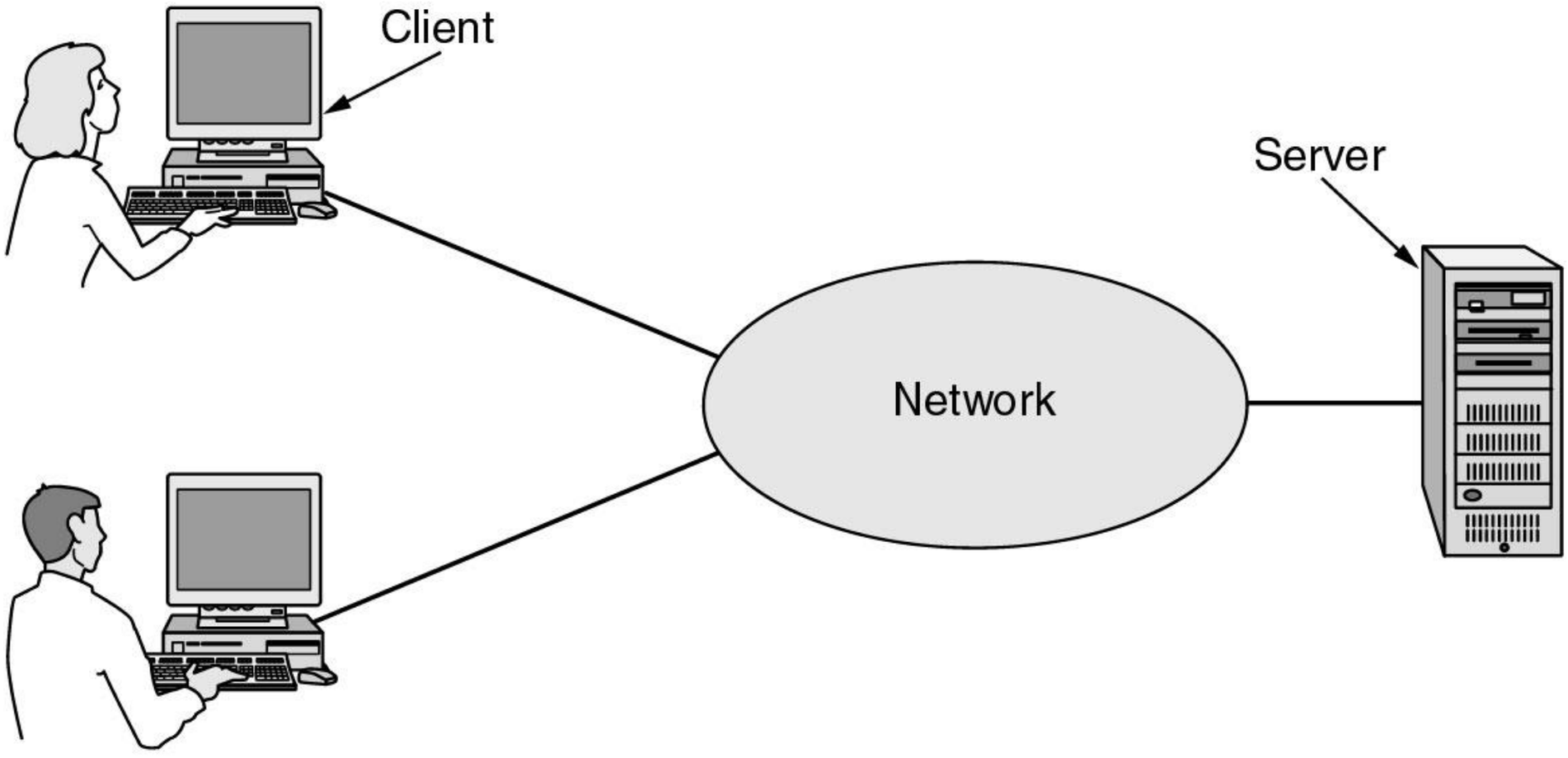
Computer Networks

Latest Edition

Uses of Computer Networks

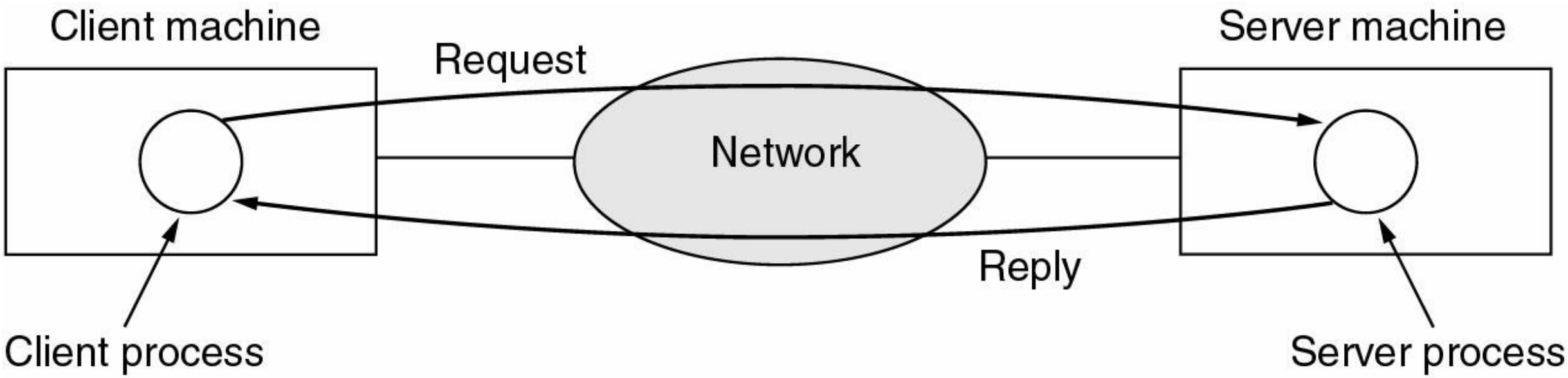
- Business Applications
- Home Applications
- Mobile Users
- Social Issues

Business Applications of Networks



A network with two clients and one server.

Business Applications of Networks (2)

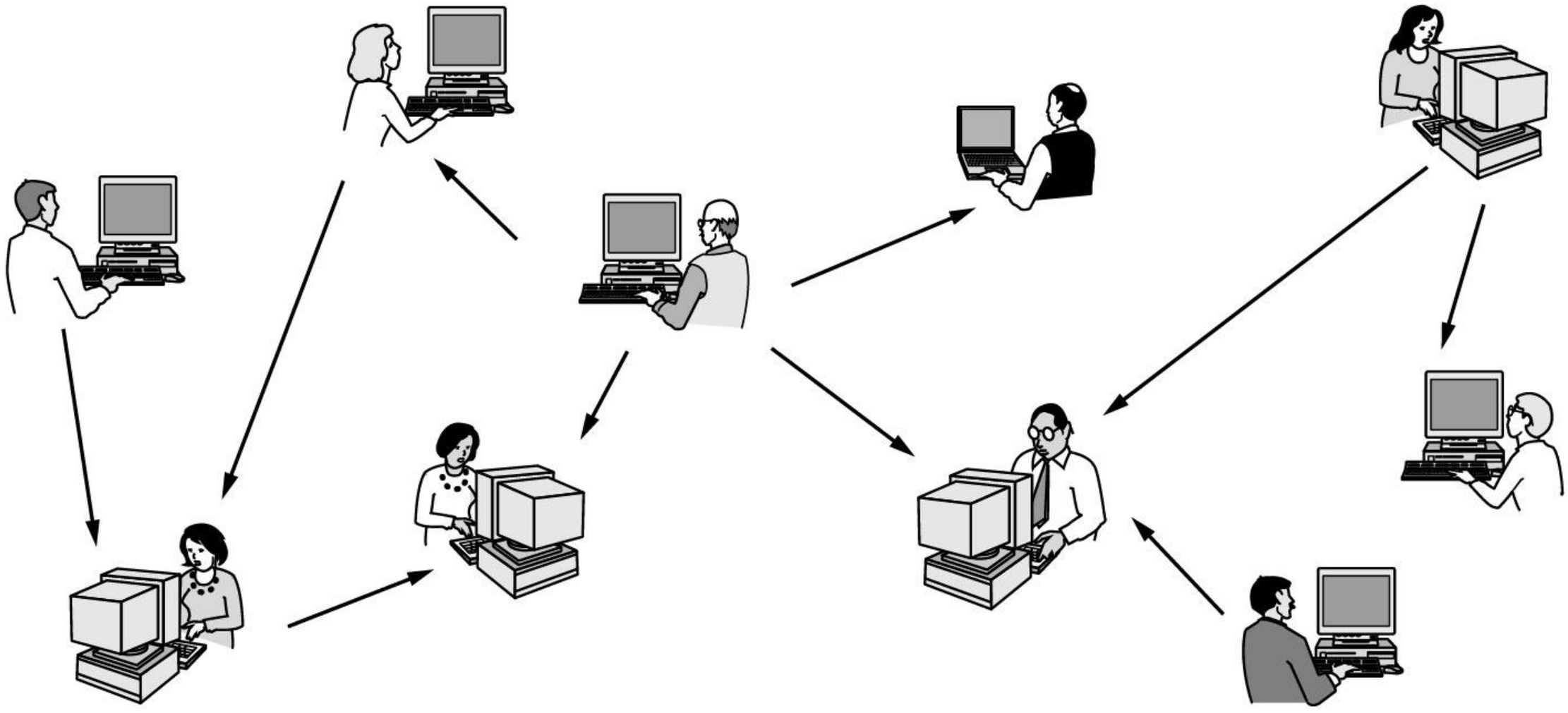


The client-server model involves requests and replies.

Home Network Applications

- Access to remote information
- Person-to-person communication
- Interactive entertainment
- Electronic commerce

Home Network Applications (2)



In peer-to-peer system there are no fixed clients and servers.

Home Network Applications (3)

Tag	Full name	Example
B2C	Business-to-consumer	Ordering books on-line
B2B	Business-to-business	Car manufacturer ordering tires from supplier
G2C	Government-to-consumer	Government distributing tax forms electronically
C2C	Consumer-to-consumer	Auctioning second-hand products on-line
P2P	Peer-to-peer	File sharing

Some forms of e-commerce.

Mobile Network Users

Wireless	Mobile	Applications
No	No	Desktop computers in offices
No	Yes	A notebook computer used in a hotel room
Yes	No	Networks in older, unwired buildings
Yes	Yes	Portable office; PDA for store inventory

Combinations of wireless networks and mobile computing.

Network Hardware

- Local Area Networks
- Metropolitan Area Networks
- Wide Area Networks
- Wireless Networks
- Home Networks

Interconnected processors by scale

Interprocessor distance	Processors located in same	Example
1 m	Square meter	Personal area network
10 m	Room	Local area network
100 m	Building	
1 km	Campus	
10 km	City	Metropolitan area network
100 km	Country	Wide area network
1000 km	Continent	
10,000 km	Planet	The Internet

Classification of interconnected processors by scale.

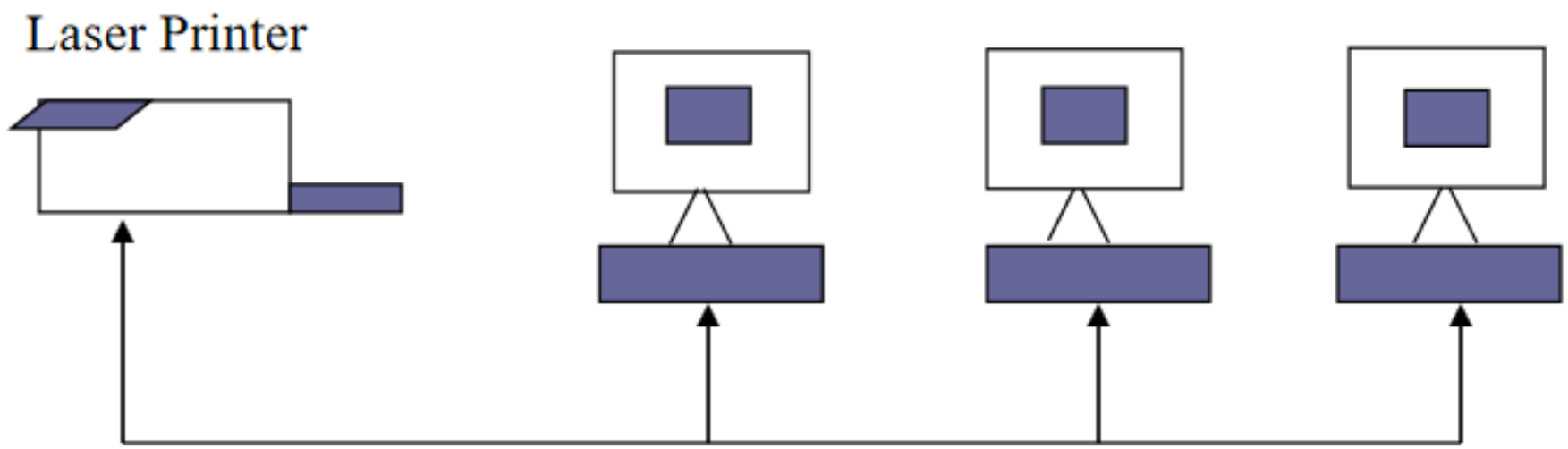
Computer Networks - Introduction

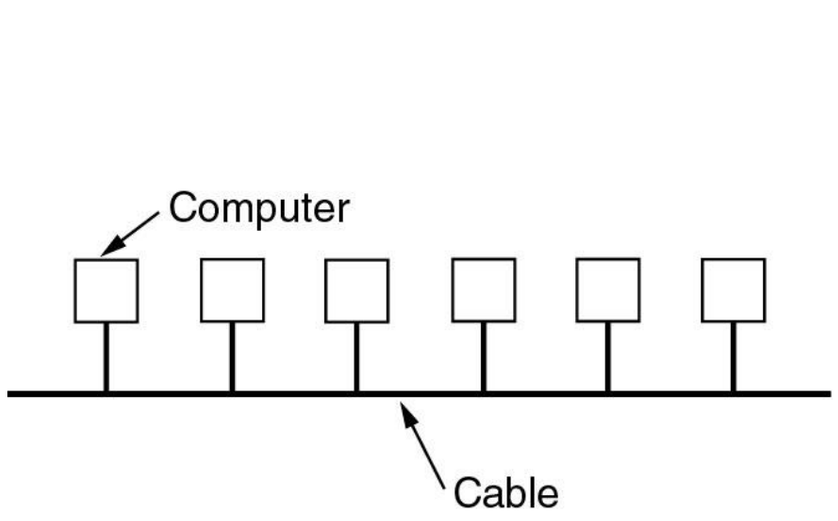
- A network is a number of computers linked together to share resources.
- Or a group of computers and other devices connected together is called a network. The computer can also share resources, such as printers, fax modem and hard disks etc.
- The concept of connected computers sharing resources is called networking.
- There are three types of networking:

LAN, MAN, WAN

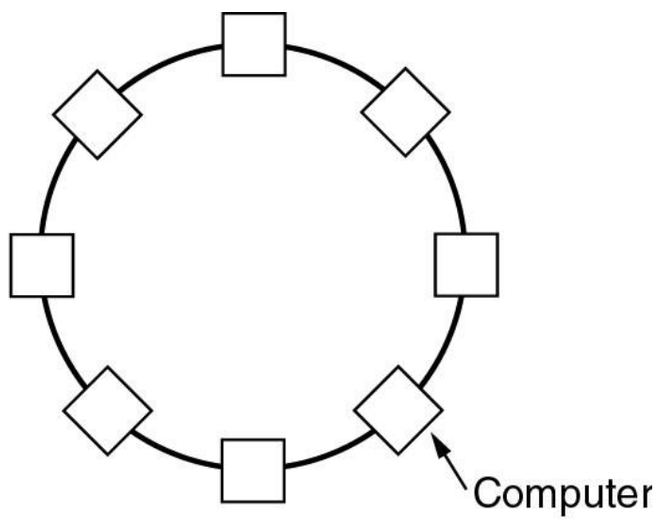
Computer Networks - Introduction

- *Local Area Networks (LAN)*





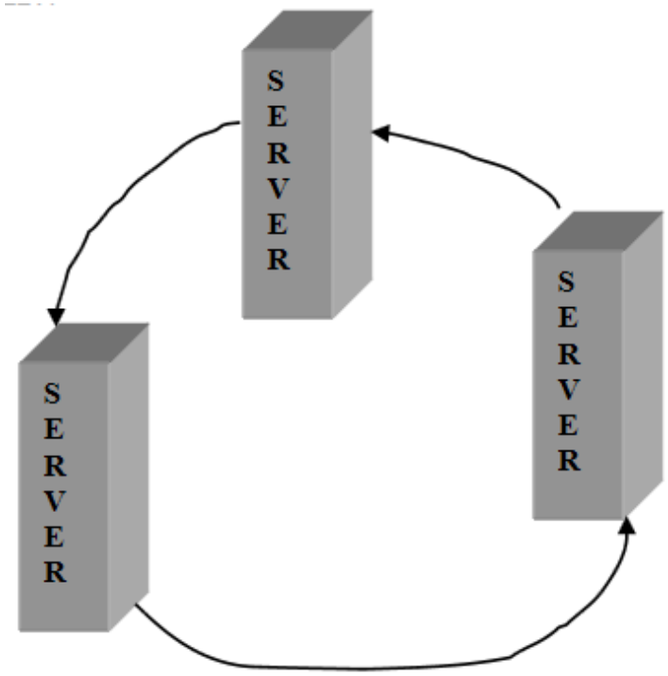
(a)

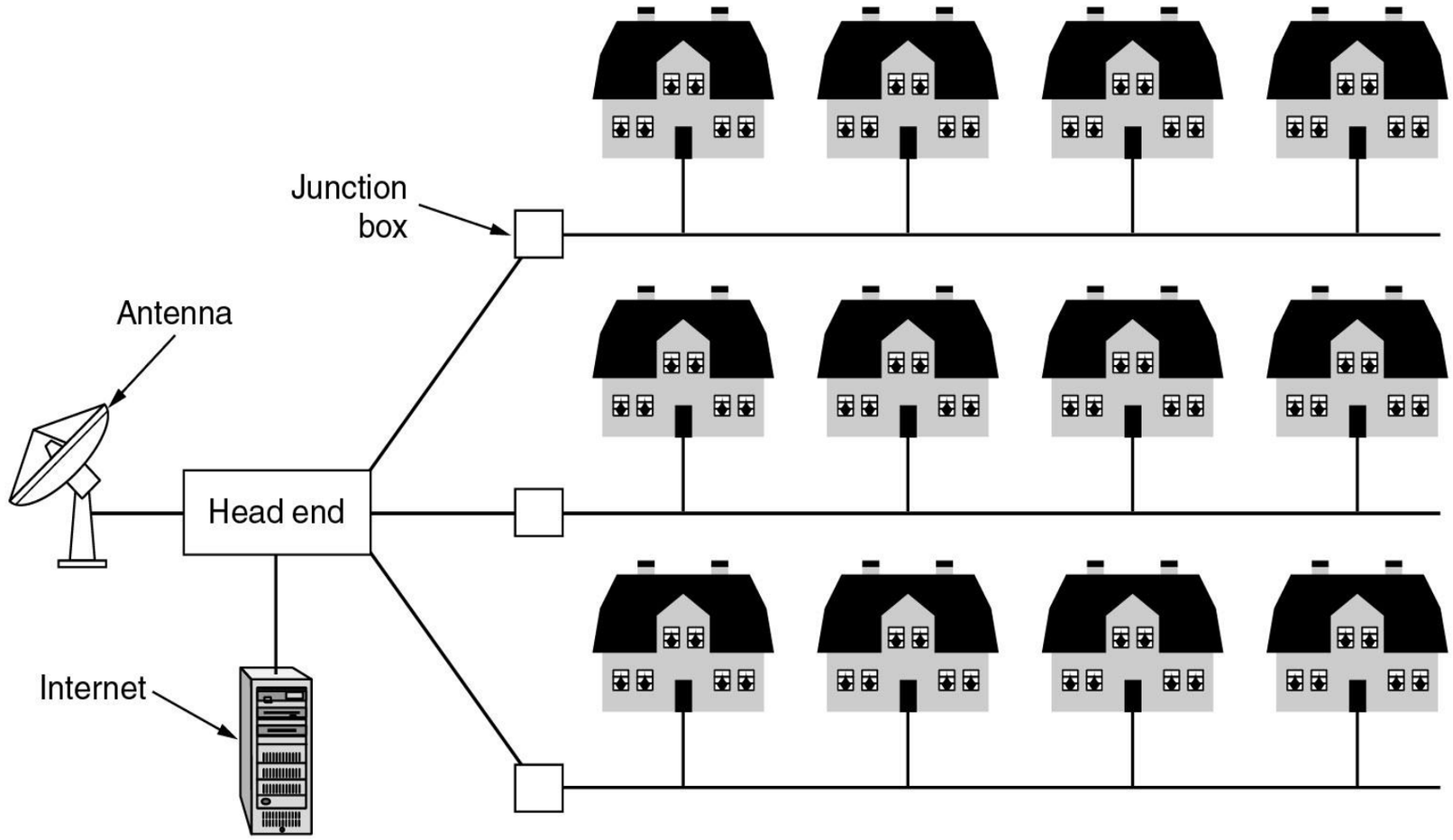


(b)

Computer Networks - Introduction

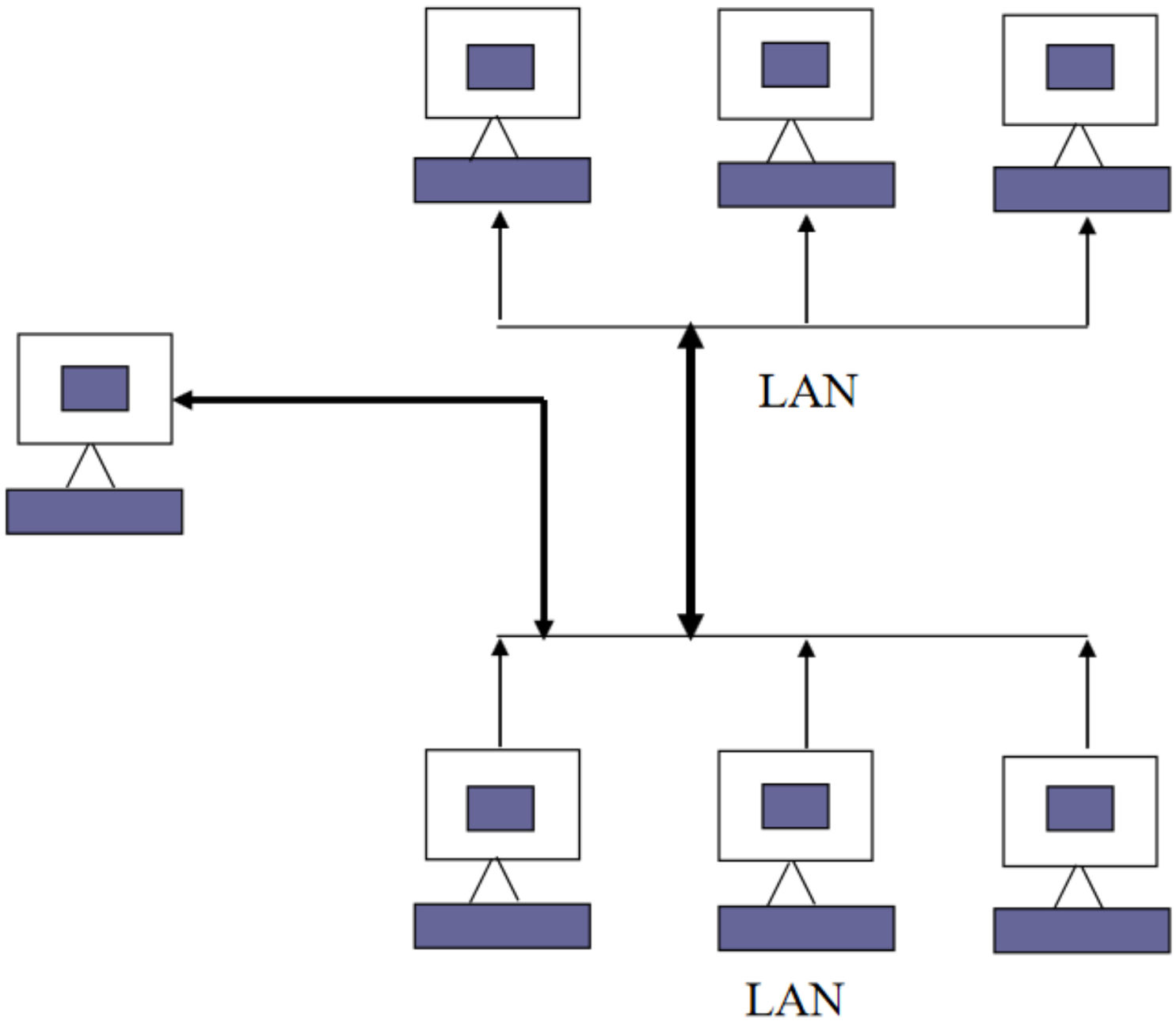
- *Metropolitan Area Networks (MAN)*





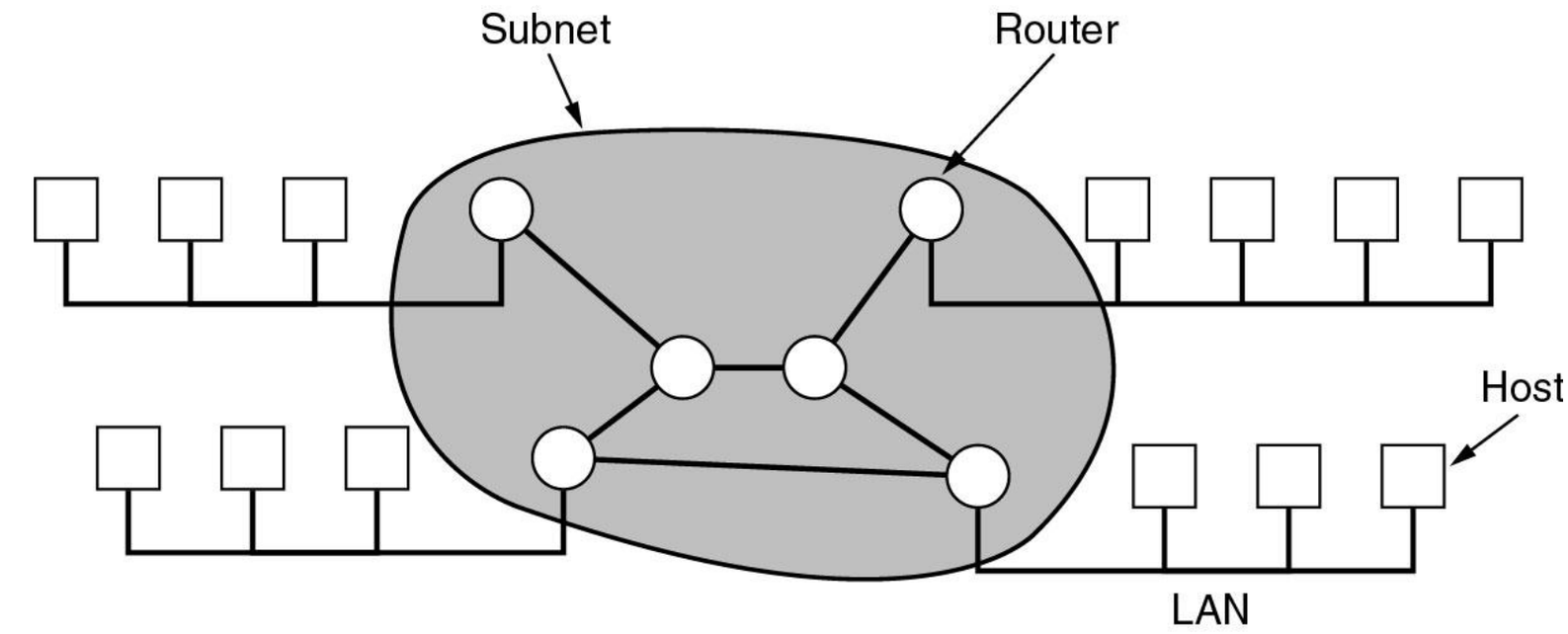
Computer Networks - Introduction

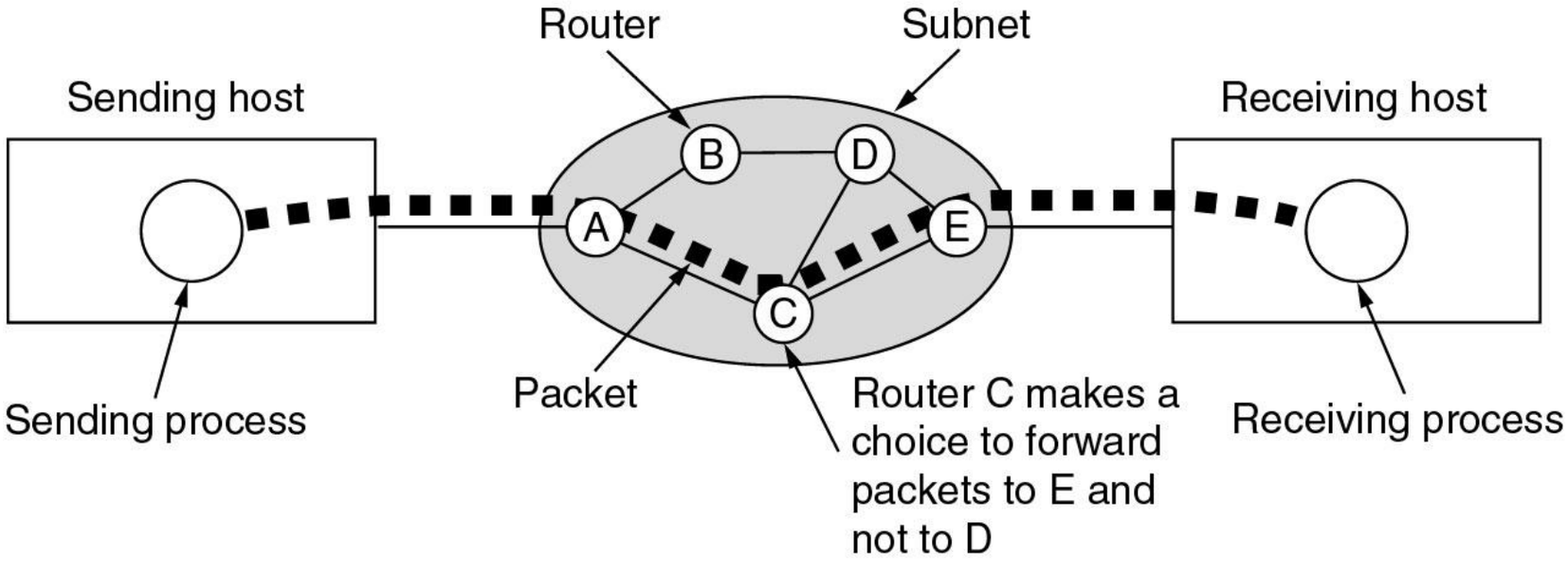
- *Wide Area Networks (WAN)*



Computer Networks - Introduction

- *Wide Area Networks (WAN)*





Types of networks

Figure 1: Network performance

	Example	*Range*	*Bandwidth (Mbps)*	*Latency (ms)*
Wired:				
LAN	Ethernet	1–2 kms	10–10,000	1–10
WAN	IP routing	worldwide	0.010–600	100–500
MAN	ATM	2–50 kms	1–600	10
Internetwork	Internet	worldwide	0.5–600	100–500
Wireless:				
WPAN	Bluetooth (IEEE 802.15.1)	10–30m	0.5–2	5–20
WLAN	WiFi (IEEE 802.11)	0.15–1.5 km	11–108	5–20
WMAN	WiMAX (IEEE 802.16)	5–50 km	1.5–20	5–20
WWAN	3G phone	cell: 1–-5	348–14.4	100–500

km

Data Communication - Introduction

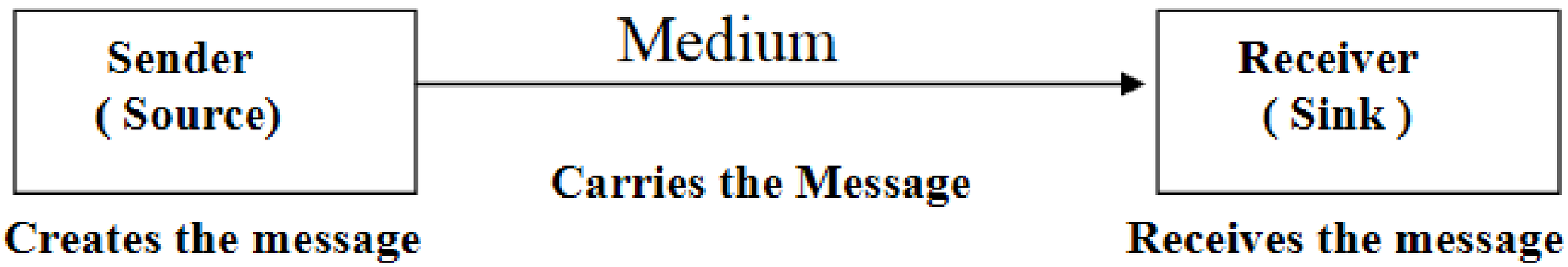
- *Communication* is the process of transferring messages from one point to another point. Three basic elements of any communication process are:

(1) A sender (Source), which creates the message to be transmitted.

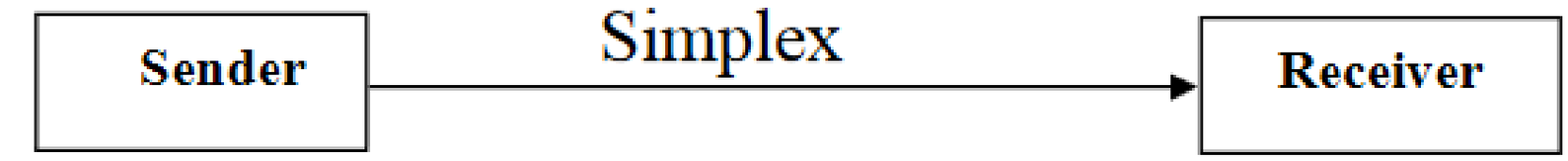
(2) A medium which carries the message.

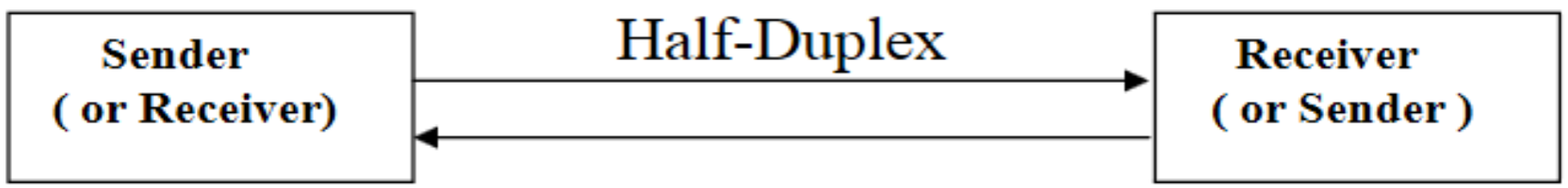
(3) A receiver (Sink), which receives the message.

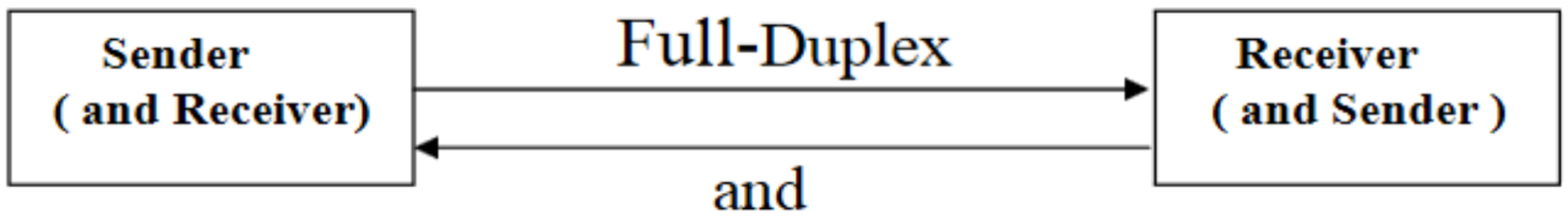
- *Transmission media -* The physical pathway on which the computers are connected. Cable and wireless can connect the computers in a network. For Example.



- *Data Transfer Mode* - There are three ways or modes for transmitting data from one point to another. These are (i) Simplex (ii) Half-Duplex (iii) Full-Duplex

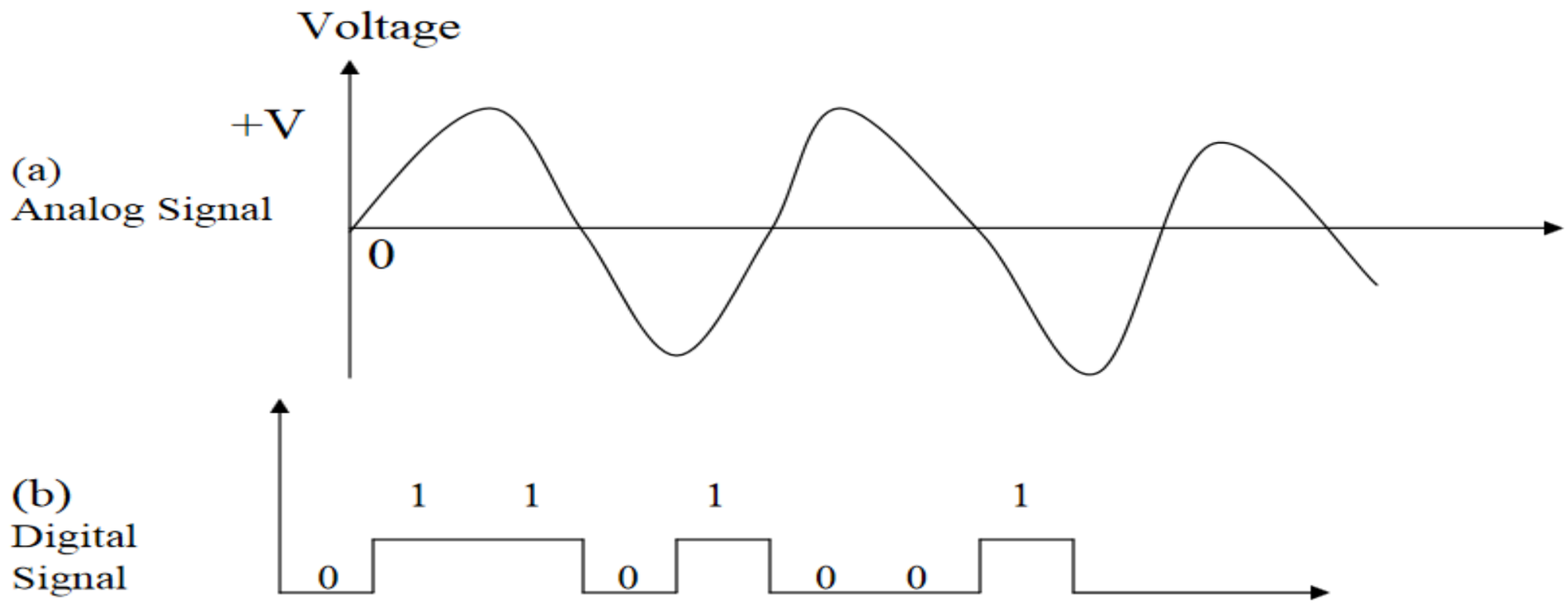






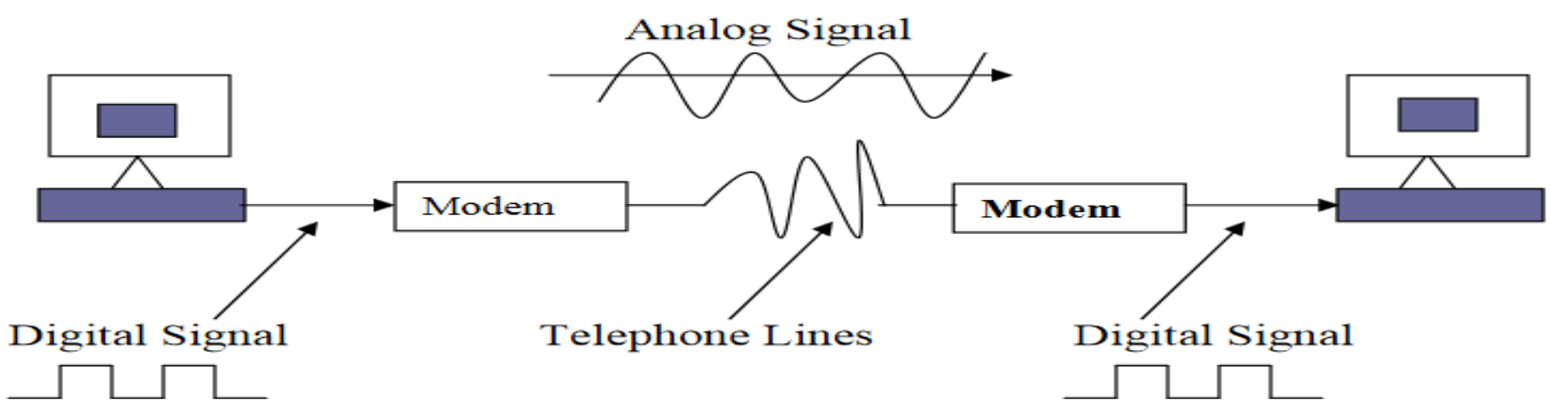
Analog and Digital Transmission

- Data is transferred from one point to another point by means of electrical signals, which may be in digital or analog form.
- In an analog signal the transmitted signals (Power) varies over a continuous range, for example sound, light and radio waves.
- In a digital signal, the signal is a sequence of voltage pulses represented in binary form, ON or OFF (1 or 0).

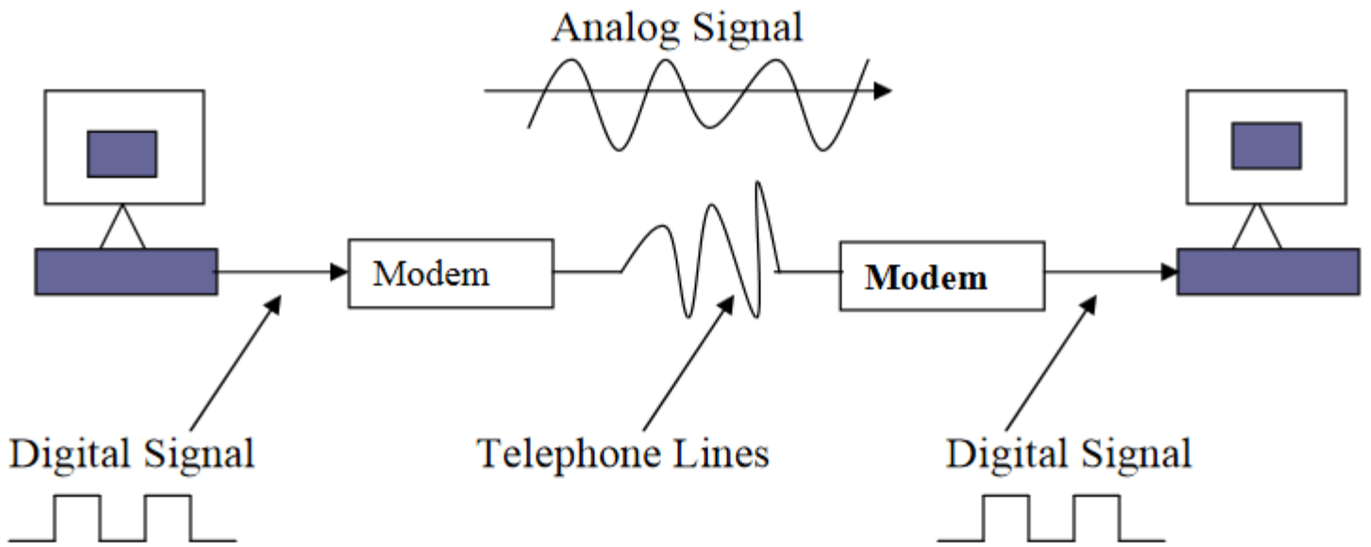


Analog and Digital Transmission

- Computer generated data is digital whereas the telephone lines used for data communication in computer networks are usually meant for carrying analog signals.
- When a digital data are to be sent over an analog facility, the digital signals must be converted to analog form.
- The technique by which a digital signal is converted to its analog form is known as modulation. The reverse process, i.e., conversion of analog signal to its digital form, at a destination device, is called a de-modulation.
- Because, today we do not have all-digital or all-analog networks; we have a mix of the two. Therefore, at various points in a network, it is necessary to convert between the two signal types.



Analog and Digital Transmission



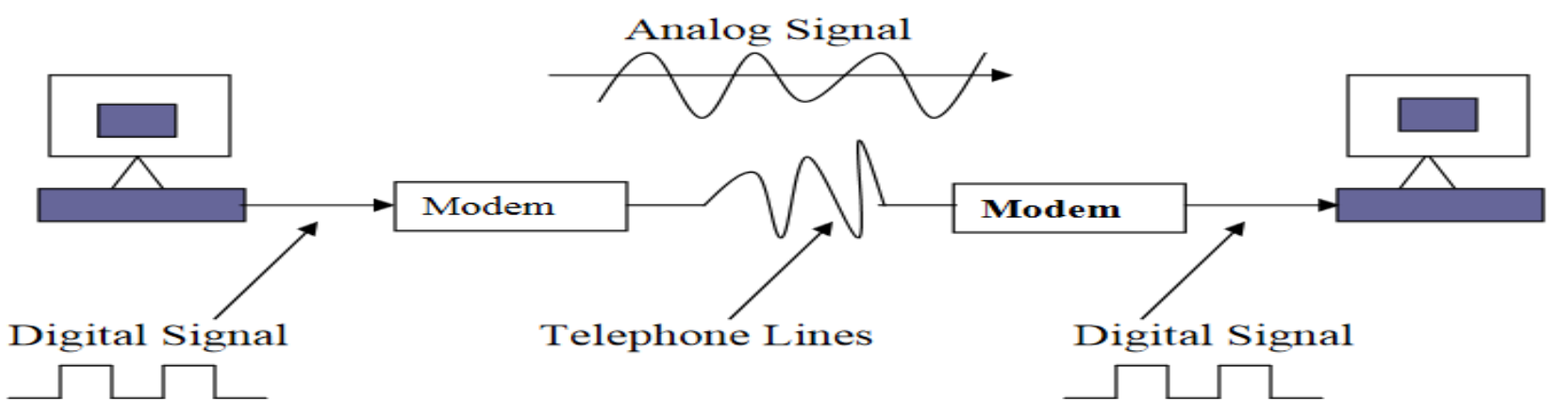
Analog and Digital Transmission

Table 1.1 Characteristics of Analog and Digital Networks

Feature	Analog Characteristics	Digital Characteristics
Signal	Continuously variable, in both amplitude and frequency	Discrete signal, represented as either changes in voltage or changes in light levels
Capacity measurement	Hz (e.g., a telephone channel is 4KHz)	Bits per second (e.g., a T-1 line carries 1.544Mbps, and an E-1 line transports 2.048Mbps)
Bandwidth	Low bandwidth (4KHz), which means low data transmission rates (up to 33.6Kbps) because of limited channel bandwidth	High bandwidth that can support high-speed data applications that involve video and multimedia
Network capacity	Low; one conversation per telephone channel	High; multiplexers enable multiple conversations to share a communications channel and hence to achieve greater transmission efficiencies
Network manageability	Poor; a lot of labor is needed for network maintenance and control because dumb analog devices do not provide management information streams that allow the device to be remotely managed	Good; smart devices produce alerts, alarms, traffic statistics, and performance measurements, and technicians at a network control center (NCC) or network operations center (NOC) can remotely monitor and manage the various network elements
Signal structure	High; the signal contains a wide range of frequencies and amplitudes	Low; only two discrete signals—the one and the zero—need to be transmitted
Security	Poor; when you tap into an analog circuit, you hear the voice stream in its native form, and it is difficult to detect an intrusion	Good; encryption can be used
Error rates	High; 10^{-5} bits (i.e., 1 in 100,000 bits) is guaranteed to have an error	Low; with twisted-pair, 10^{-7} bits (i.e., 1 in 10 million bits) has an error; with satellite, 10^{-9} bits (i.e., 1 in 1 billion bits) has an error; and with fiber, 10^{-11} bits (i.e., 1 in 100 billion bits) to 10^{-13} bits (i.e., 1 in 10 trillion bits) has an error

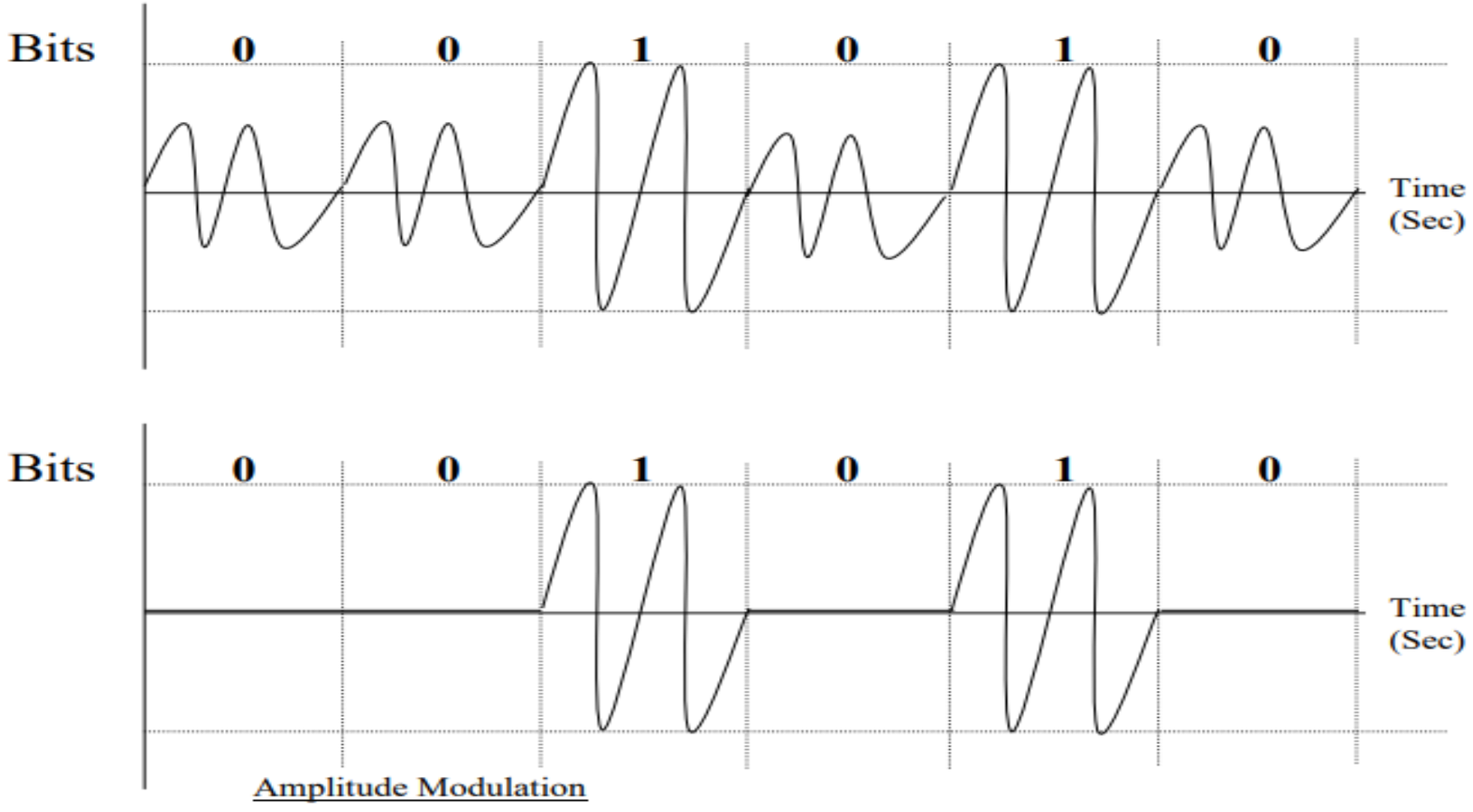
Modulation

- Why is the conversion of the signals necessary? Typically modems are used when the host computer and terminal are in different locations.
- The terminals transmit data using 1’s and 0’s , which form square waves. The square waves used in digital transmission cannot be sent over standard telephone lines without first converting them to analog form, because the public telephone network as designed to carry analog signals like speech as shown above. Typically modems convert the square waves that represent ones and zeroes to sine waves for analog transmission.
- There are many different methods for performing this conversion, each with its own advantages and disadvantages..



Amplitude Modulation

- Two binary values (0 and 1) of digital data are represented by two different amplitudes of the carrier signal keeping the frequency and phase constant.
- Another name for amplitude modulation is amplitude shift keying, or ASK, since data is transmitted by shifting amplitudes. (e.g) The bit pattern 00101001 is being transmitted using amplitude modulation as shown in fig.



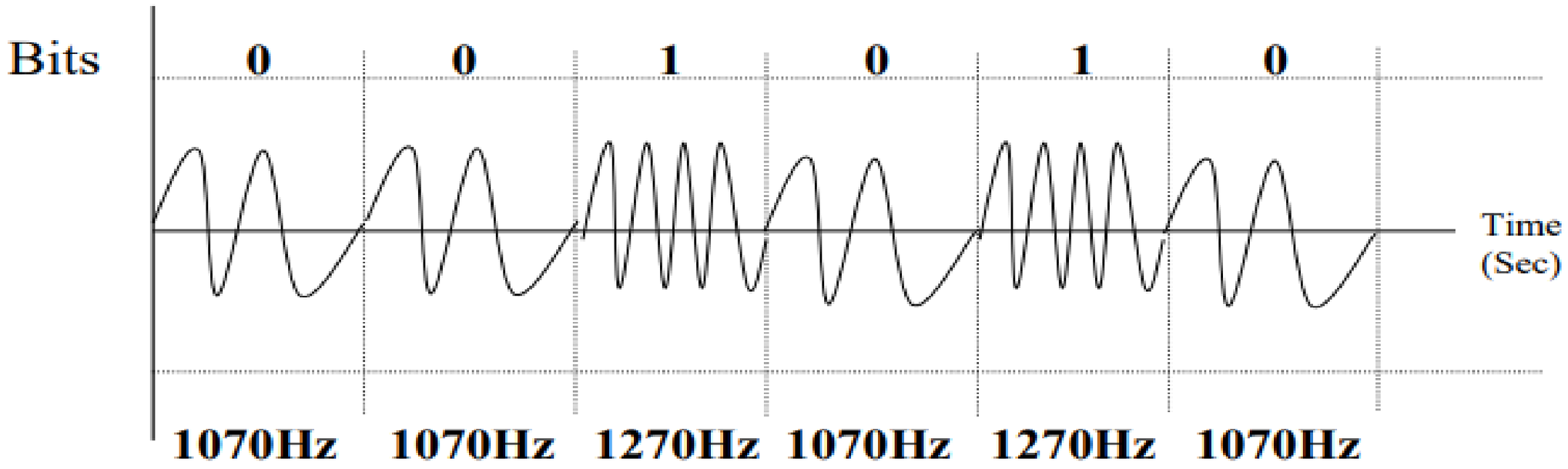
Amplitude Modulation

Amplitude Modulation

- Notice that the sine waves amplitude is high when transmitting a 1, and low when transmitting a 0.
- The duration (or width) of each cycle of the sine wave does not change throughout the transmission; in other words, the frequency does not vary (as shown in fig). There are two completes cycles of sine wave (Two peaks and two valleys) for each bit transmitted.

Frequency Modulation

- Two binary values of digital data are represented by two different frequencies while the amplitude and phase are kept constant.
- Frequency modulation of digital signal is also known as frequency shift keying (FSK), since data is transmitted by shifting frequencies, The same bit pattern 00101001 is being transmitted using frequency modulation as shown in fig.
- Notice that the amplitude of the sine wave does not vary, But the length of each cycle and hence the frequency, varies. A low frequency (1070 HZ) is used to send a 0, and a higher frequency (1270 HZ) is used to send a 1.

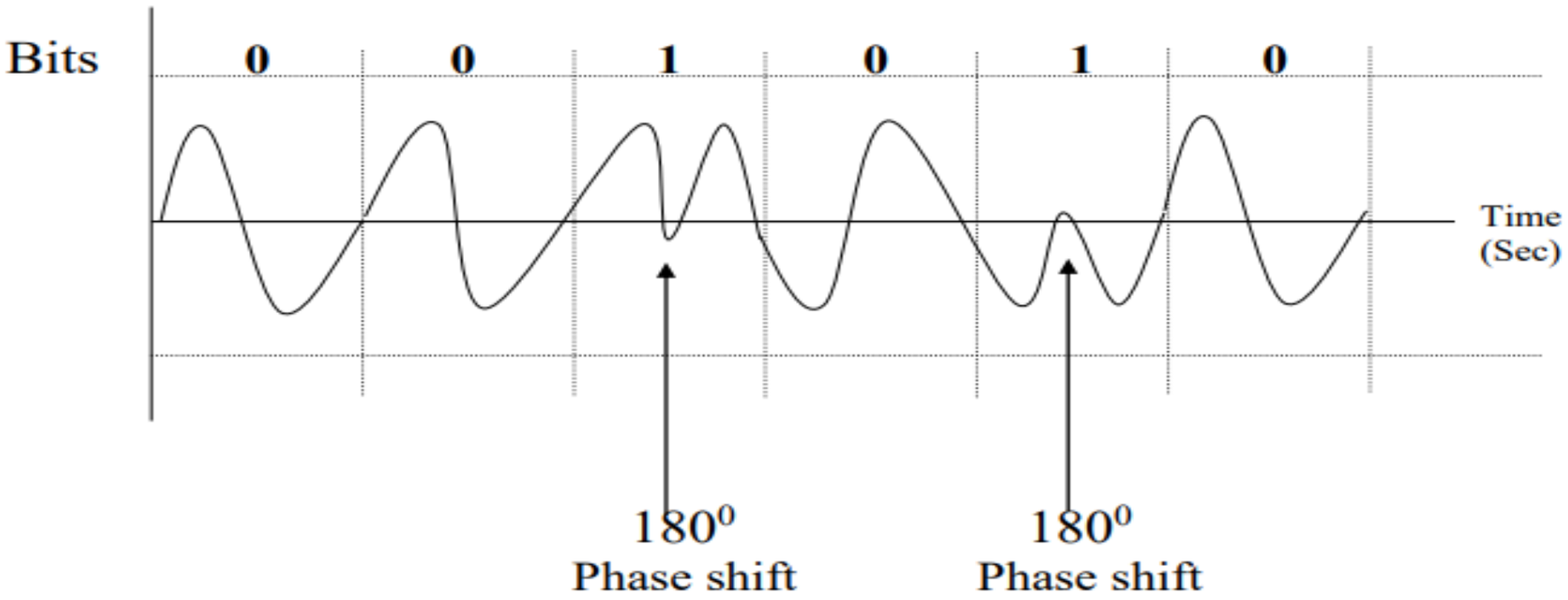


Frequency Modulation

- Since the receiving modem recognizes only differences in frequency and is not concerned with the amplitude of the signal.
- Moreover, frequency modulation devices are easier to design because discrimination between two frequencies is simpler than detecting phase changes.
- Thus for medium speed communication (1200 to 2400 bps) the FSK scheme is preferred.

Phase Modulation

- A more sophisticated technique is known as phase modulation, because data is transmitted by changing the phase of sine wave. Another name for phase modulation is phase shift keying, or PSK.
- Since data is transmitted by shifting phase. A sine wave (A continuous tone or signals in the 1000 to 2000 Hz range called a sine wave carrier) normally repeats itself indefinitely, with one peak and valley after another shifting phase breaks the sine wave abruptly and starts it again a few degree forward or backward.
- In our example, 180 degree phase shift is used to send ones, and a continuous sine wave is used to send zeroes.



Phase Modulation

- This is only one possible way to use phase modulation to transmit data. Notice that the amplitude and frequency of the sine waves stay constant throughout transmission.
- We simply shift phase during a time period to send a one, or continue the sine wave uninterrupted to send a zero. The receiving modem can monitor the incoming sine wave and determine if the phase shifted during a particular time period.
- This technique is more efficient than both amplitude modulation and frequency modulation. The main advantages of the phase modulation are that only a single-frequency sine wave is used to send both 1’s and 0’s in each direction

Asynchronous & Synchronous Transmission

Data transmission on a line is normally carried out in two different methods. Asynchronous & Synchronous Transmission

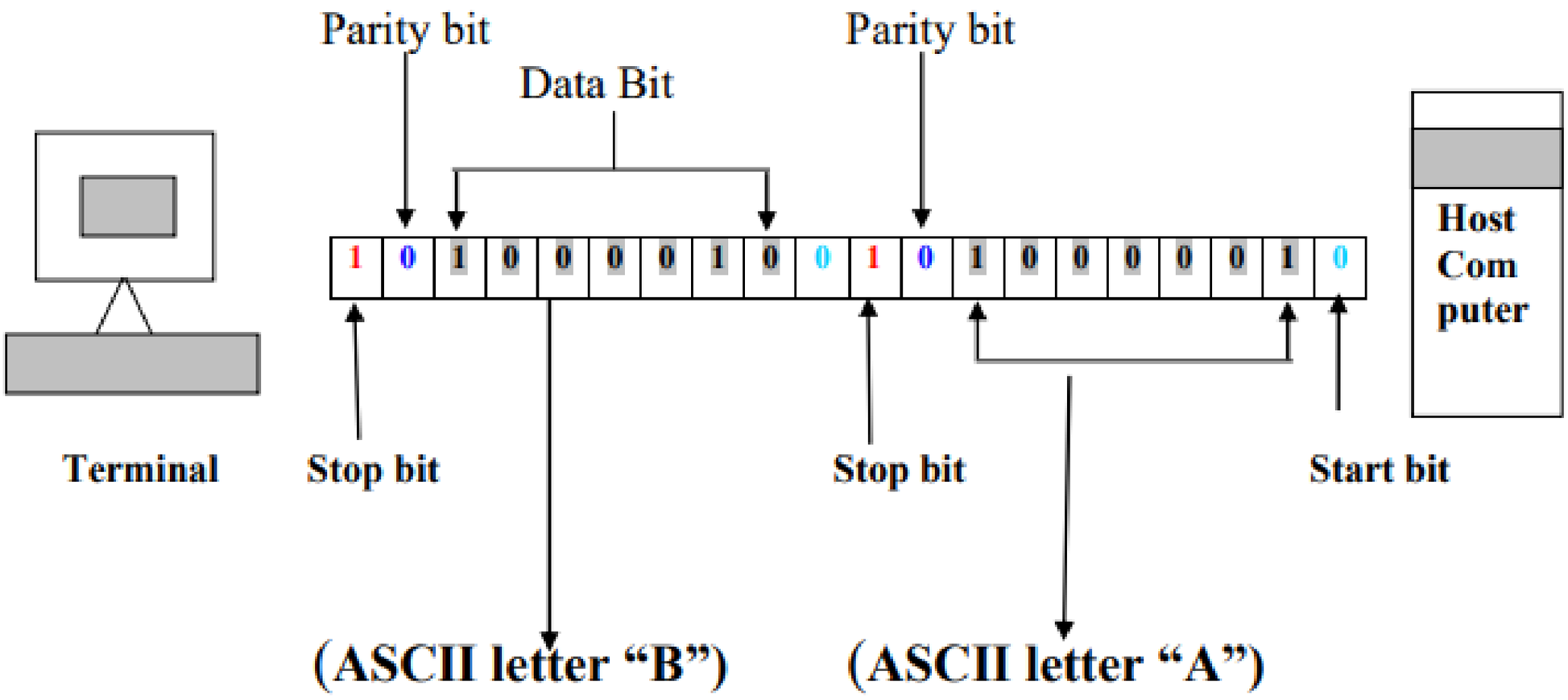
1) Asynchronous Transmission:

- When a terminal is connected to a computer and an operator manually presses keys on the terminal, the time spend between successive keystrokes would vary.
- Thus in asynchronous transmission, data is transmitted character by character at irregular intervals. We assume that our characters are represented by 8-bits, including any parity bit.
- With asynchronous transmission, each device must be set to transmit and receive data at a given speed, known as the data rate (bits per second). When an asynchronous device sends a byte, it begins by sending a start bit, which is always a 0, followed by each of the eight bits in the byte, and then sends a stop bit, which is always a 1.

Asynchronous & Synchronous Transmission

- These bits add up to form a 10-bit package for transmission. The asynchronous transmission of the letter “A” followed by the letter “B”, from a terminal to a host computer using ASCII code is shown in fig. The terminal user types the letter “A” on the keyboard, and the terminal converts the letter “A” to the bit sequence 01000001 , with a ‘0’ used as the parity bit (for error detection). This manage the frame, first the start bit , seven data bits, one parity bit and then stop bit have been sent.
- Suppose each of these bits is sent 1 second apart. The start bit actually starts the host computer’s internal stopwatch or clock, and the host then expects to receive the next nine bits 1 second apart.
- The stop bit is used to halt the host computers internal stopwatch. It can later be started again by another start bit, sent with the next character, (i.e) with B. The transmitter will continue to transmit the stop signal until it is ready to send the next character. The advantage of this method is that it does not require any local storage at the terminal or the computer as transmission takes place character by character. Hence it is cheaper to implement.

Asynchronous & Synchronous Transmission



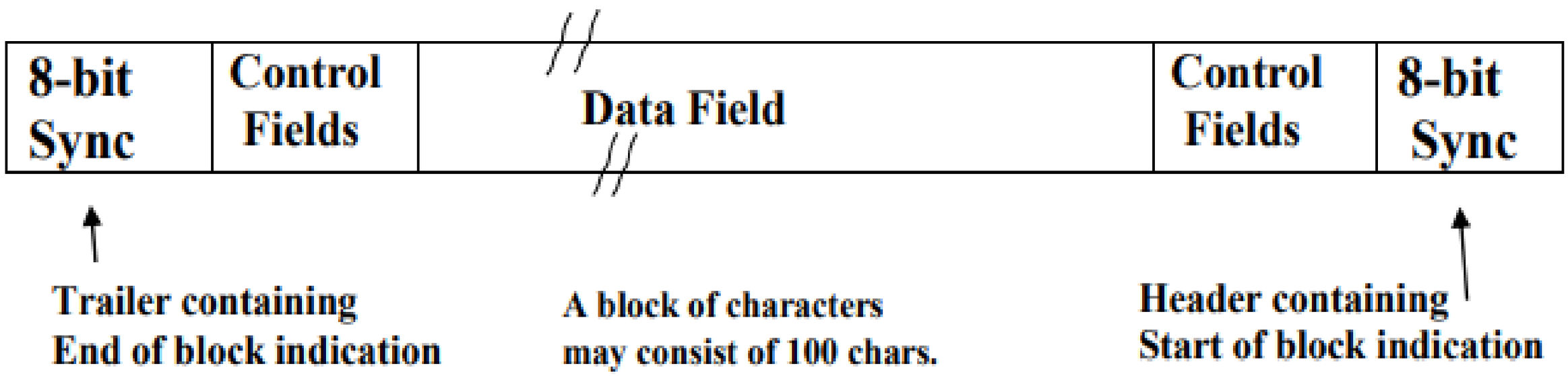
Asynchronous & Synchronous Transmission

2) Asynchronous Transmission:

- Other commonly used form of data transmission is synchronous transmission. Here start & stop bits are not used. There is no pause between characters in synchronous data transmission.
- Synchronous data transmission usually involves large blocks of characters, and special Sync characters can be sent at the beginning of these data blocks. These Sync characters are a special series of bits the receiving device can use to adjust to the transmitters exact rate of speed.
- The header (Sync) also contains information to identify sender and receiver. Following the header is a block of characters that contains the actual message to be transmitted. The number of characters in a block may be variable and may consist of hundreds of characters; the actual data (message) characters in the block are transmitted by a trailer.

Asynchronous & Synchronous Transmission

- The trailer contains an end of message character. Thus, with synchronous transmission entire blocks of characters are framed and transmitted together.



What is a Protocol?

In data communication, a protocol is a set of rules and procedures established to control transmission between two points so that the receiver can properly interpret the bit stream transmitted by the sender. Protocols are the data communications software. An example of a human communications protocol can be found in a classroom and traffic rules etc. In any computer network, protocols perform the following functions for the efficient & error free transmission of data:

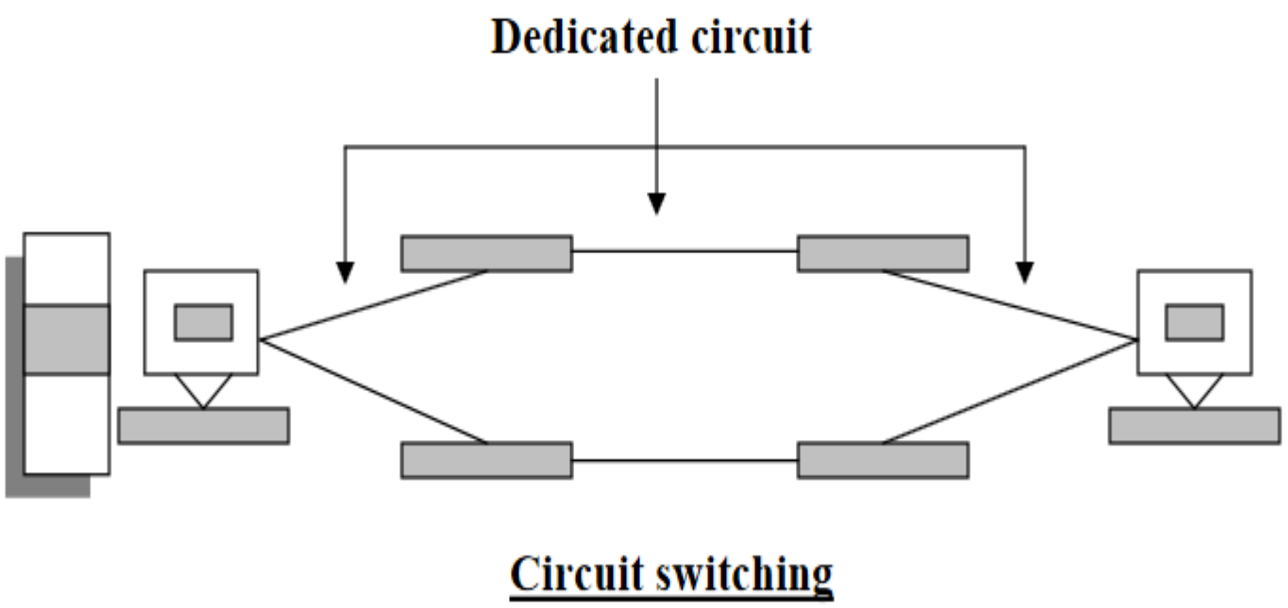
- Data Sequencing.
- Data Routing.
- Flow Control.
- Error Control.
- Precedence and order of Transmission.
- Connection Establishment.
- Data Security.
- Log Information.

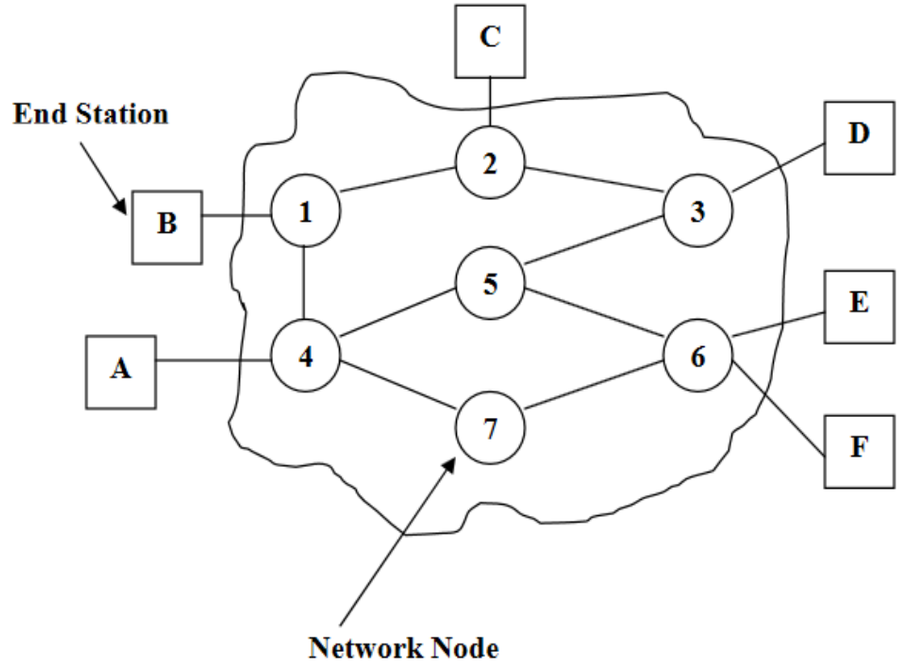
Network Principles – Switching Schemes

- *Switching* is the process of physically moving bits through a network node, from an input port to an output port.
- A network node is any point on the network where communications lines interface (i.e., PBX, a multiplexer, a modem, a host computer, or one of a number of other devices).
- Switching elements are specialized computers used to connect two or more transmission lines. The switching process is based on information gathered through a routing process.
- There are two switching modes: *Circuit Switching* and *Packet Switching*. Both of these switching modes offer forms of bandwidth on demand. Both have different ways of performing path calculations and forwarding functions.

Circuit Switching Network

- In *circuit switching*, a dedicated connection is made b/w the two communicating devices. That path is a connected sequence of links between network nodes.





Communication via circuit switching involves three phases:

Circuit Establishment - Before any signals can be transmitted, an end-to-end circuit must be established.

Data Transfer - Information can now be transmitted from A through network to E.

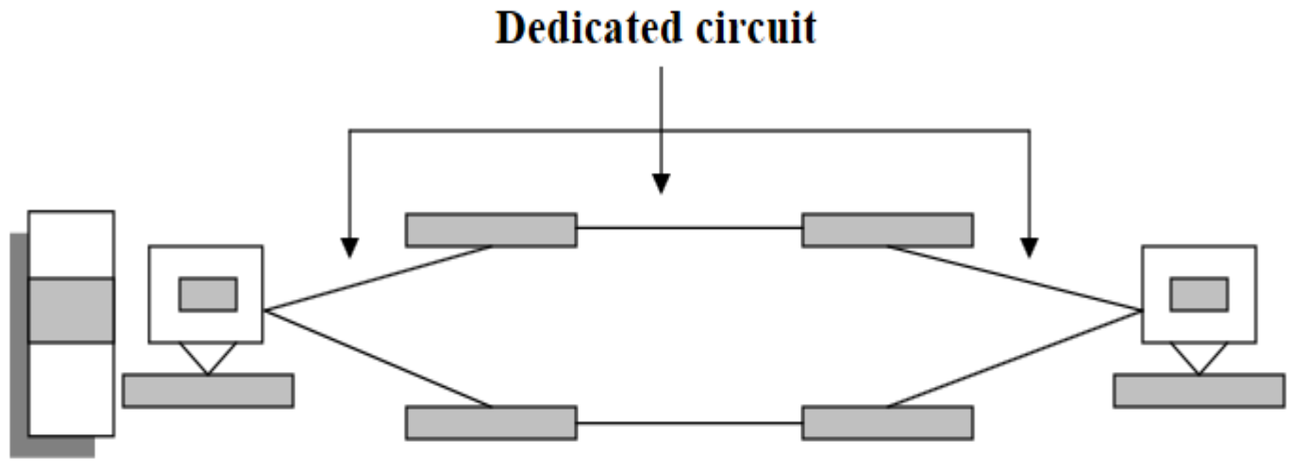
Circuit Disconnect - After some period of data transfer, the connection is terminated to de-allocate the dedicated resources.

Circuit Switching Network

- Connection path is established before data transmission begins.
- Circuit switching can be rather inefficient. Channel capacity is dedicated for the duration of a connection, even if no data are being transferred.
- Information is transmitted

  at a fixed data rate

  with no delay.



Circuit switching

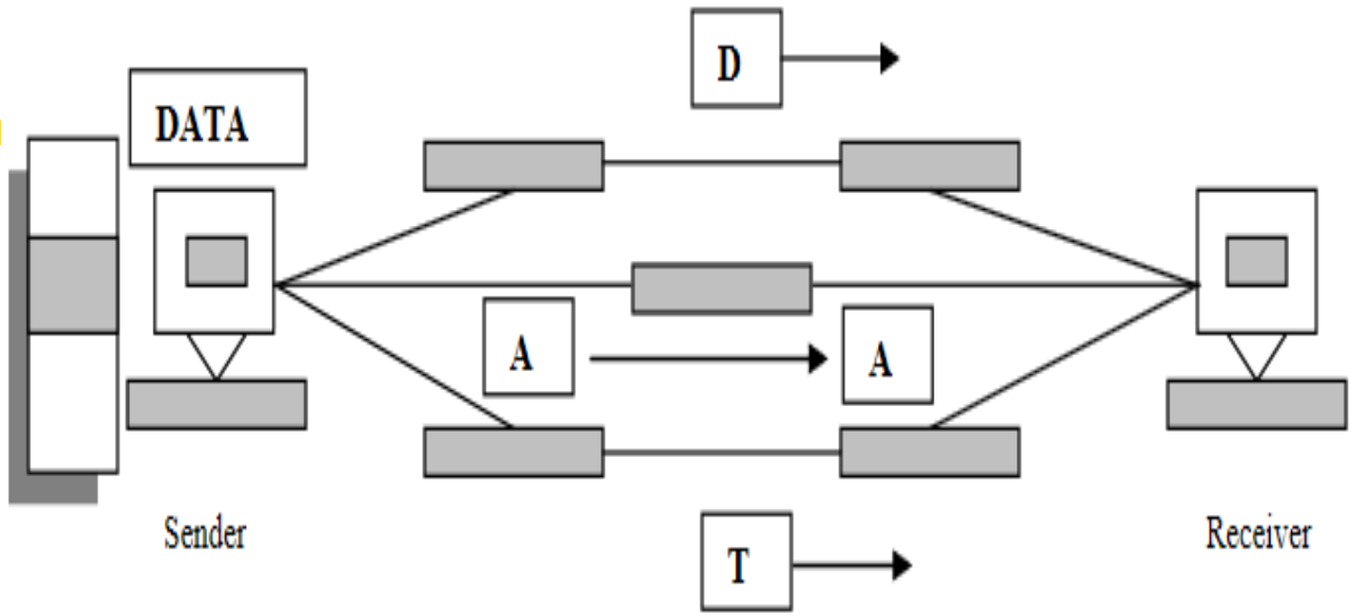
- No congestion.
- A possible long wait to establish a connection. A fixed share of networks resources is reserved for the call, and no other call can use those resources until the original connection is closed.
- The best-known example of a circuit-switching network is the public telephone network.

Packet Switching

With *packet switching* data is sent from device to device in whole across the network. Packets are forwarded through a series of packet-switches, also known as routers that ultimately lead to the destination (also known as store and forward mechanism). Data is broken into small pieces and routed from device to device. A packet header contains - destination address and sequence number.

- packets are queued up and transmitted as rapidly as possible overlink.
- Two stations of different data rates can exchange packets because each connects to its node at its proper data rate.
- When traffic becomes heavy on a circuit-switching network, some calls are blocked. On a packet-switching network, packets are still accepted, but delivery delay increases.
- Priorities can be used. Thus, if a node has a number of packets queued for transmission; it can transmit higher-priority packets first.
- There are two methods of packet switching: *Datagram Packet Switching, Virtual Circuit Packet Switching*

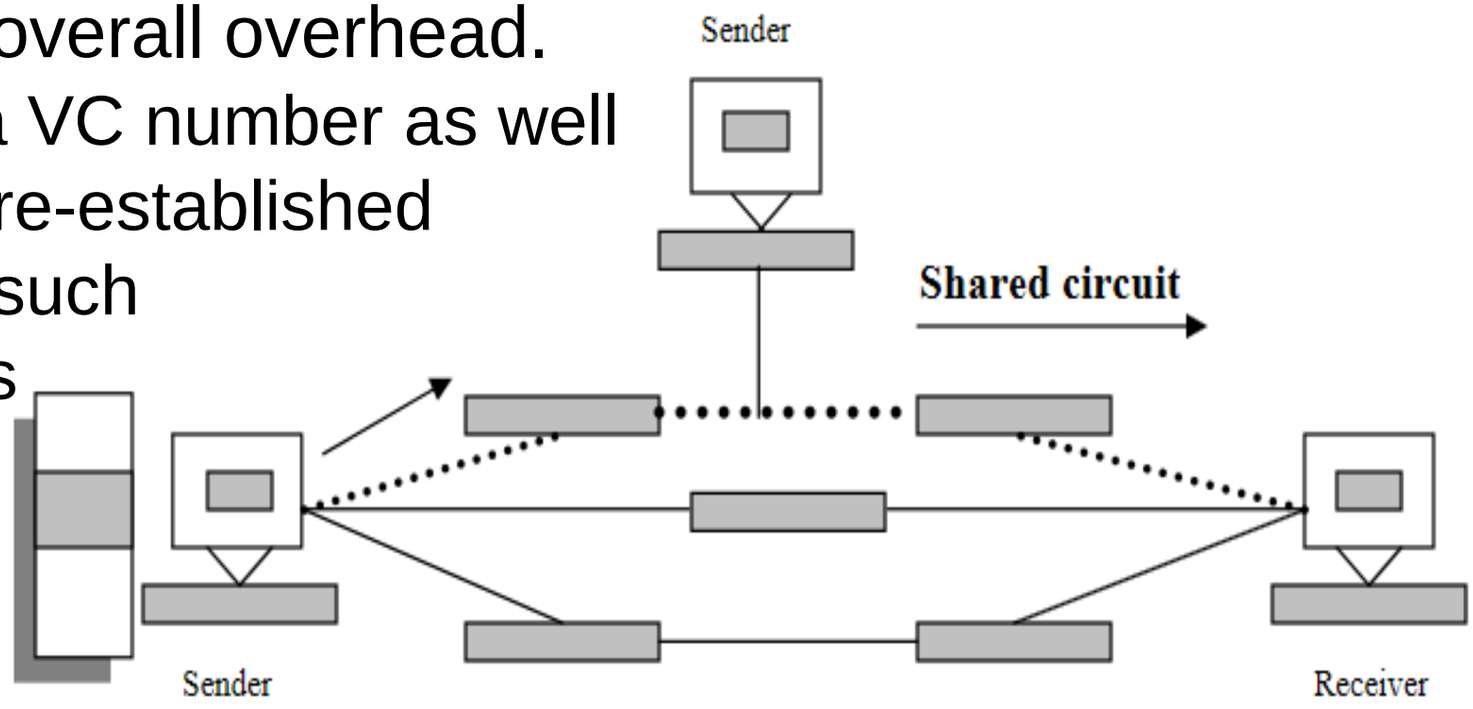
Datagram Packet Switching



- a connectionless method.
- Each piece of information is tagged with destination address so no dedicated connection is needed. Every piece of data is routed individually, and the packets might not all take the same path to the destination point, and hence they may arrive out of sequence.
- Therefore, the sequence number is very important; the terminating point needs it to be able to reassemble the message in its proper order. Thus, at the destination device, the data is pieced back together by using a PAD.
- Each datagram must contain the full destination address. For a large network, these addresses can be quite long. In datagram switching the node need to make a routing decision for each packet. But call setup phase is avoided.

Virtual Circuit Packet Switching

- Similar to dedicated circuit switching, except connections are virtual.
- This way, more than one communication can go over the physical path. This is considered connection-oriented packet switching. Generally, the packets from many different sources are statistically multiplexed and sent on to their destinations over virtual circuits.
- If packets flowing over a given virtual circuit always take same route through network. In a connection-oriented packet-switched network, only one call request packet contains source & destination address. Therefore, subsequent packets don't have to contain address information, which reduces overall overhead.
- Each packet now contains a VC number as well as data. Each node on the pre-established route knows where to direct such packets; no routing decisions are required.



Datagram vs. Virtual Circuit

Issue	Datagram Switching	Virtual Circuit Switching
Circuit setup	Not needed	Required
Addressing	Each packet contains the full source and destination address.	Each packet contains a short VC number.
Routing	Each packet is routed independently.	Route chosen when VC is setup; all packets follow this route.
Effect of router failures	None, except for packets lost during the crash.	All VCs that passed through the failed router are terminated.
Congestion control	Difficult.	Easy if enough buffers can be allocated in advance for each VC.