Data Communication and Computer Network

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Introduction to Data Communication

- Data communications refers to the exchange of data between two devices via some form of transmission medium such as a wire cable.
- For data communications to occur, the communicating devices must be part of a communication system made up of a combination of hardware (physical equipment) and software (programs).
- The effectiveness of a data communications system depends on four fundamental characteristics: delivery, accuracy, timeliness, and jitter.

1. **Delivery**: The system must deliver data to the correct destination. Data must be received by the intended device or user and only by that device or user.
2. **Accuracy**: The system must deliver the data accurately. Data that have been altered in transmission and left uncorrected are unusable.
3. **Timeliness**: The system must deliver data in a timely manner. Data delivered late are useless. In the case of video and audio, timely delivery means delivering data as they are produced, in the same order that they are produced, and without significant delay. This kind of delivery is called real-time transmission.
4. **Jitter**: Jitter refers to the variation in the packet arrival time. It is the uneven delay in the delivery of audio or video packets. For example, let us assume that video packets are sent every 30 ms . If some of the packets arrive with 30ms delay and others with40ms delay, an uneven quality in the video is the result.

Components of data communications system

A data communications system has five components as shown in the diagram below:

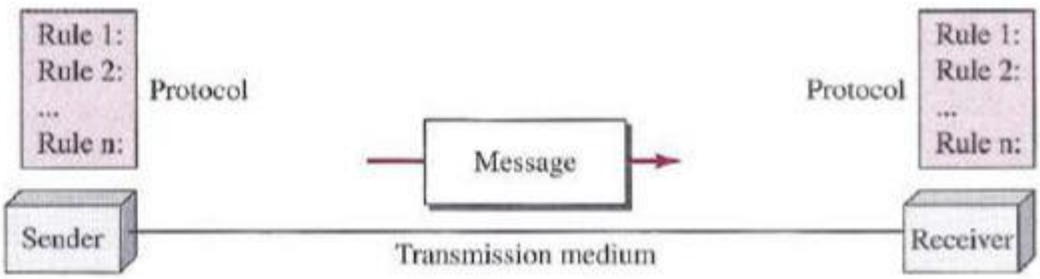

Figure (1) five components of data communication

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1. **Message**: The message is the information (data) to be communicated. Popular forms of information include text, numbers, pictures, audio, and video.
2. **Sender**: The sender is the device that sends the data message. It can be a computer, workstation, telephone handset, video camera, and so on.
3. **Receiver**: The receiver is the device that receives the message. It can be a computer, workstation, telephone handset, television, and so on.
4. **Transmission medium**: The transmission medium is the physical path by which a message travels from sender to receiver. Some examples of transmission media include twisted-pair wire, coaxial cable, fiber-optic cable, and radio waves.
5. **Protocol**: A protocol is a set of rules that govern data communications. It represents an agreement between the communicating devices. Without a protocol, two devices may be connected but not communicating, just as a person speaking French cannot be understood by a person who speaks only Japanese.

Data Representation

Information today comes in different forms such as text, numbers, images, audio, and video.

1. **Text**: In data communications, text is represented as a bit pattern, a sequence of bits (0s or 1s). Different sets of bit patterns have been designed to represent text symbols. Each set is called a code, and the process of representing symbols is called coding. Today, the prevalent coding system is called Unicode.
2. **Numbers**: Numbers are also represented by bit patterns. However, a code such as ASCII is not used to represent numbers; the number is directly converted to a binary number to simplify mathematical operations.
3. **Images**: Images are also represented by bit patterns. In its simplest form, an image is composed of a matrix of pixels (picture elements), where each pixel is a small dot. The size of the pixel depends on the resolution. For example, an image can be divided into 1000 pixels or 10,000 pixels. In the second case, there is a better representation of the image (better resolution), but more memory is needed to store the image. After an image is divided into pixels, each pixel is assigned a bit pattern. The size and the value of the pattern depend on the image. For an image made of only black-

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and-white dots (e.g., a chessboard), a I-bit pattern is enough to represent a pixel. If an image is not made of pure white and pure black pixels, we can increase the size of the bit pattern to include gray scale. For example, to show four levels of grayscale, we can use 2-bit patterns. A black pixel can be represented by 00, a dark gray pixel by 01, a light gray pixel by 10, and a white pixel by 11.

There are several methods to represent color images. One method is called RGB, so called because each color is made of a combination of three primary colors: red, green, and blue. The intensity of each color is measured, and a bit pattern is assigned to it. Another method is called YCM, in which a color is made of a combination of three other primary colors: yellow, cyan, and magenta.

4. **Audio**: Audio refers to the recording or broadcasting of sound or music. Audio is by nature different from text, numbers, or images. It is continuous, not discrete. Even when we use a microphone to change voice or music to an electric signal, we create a continuous signal.

5. **Video**: Video refers to the recording or broadcasting of a picture or movie. Video can either be produced as a continuous entity (e.g., by a TV camera), or it can be a combination of images, each a discrete entity, arranged to convey the idea of motion.

Data Flow

Communication between two devices can be simplex, half-duplex, or full-duplex as shown in Figure (2)

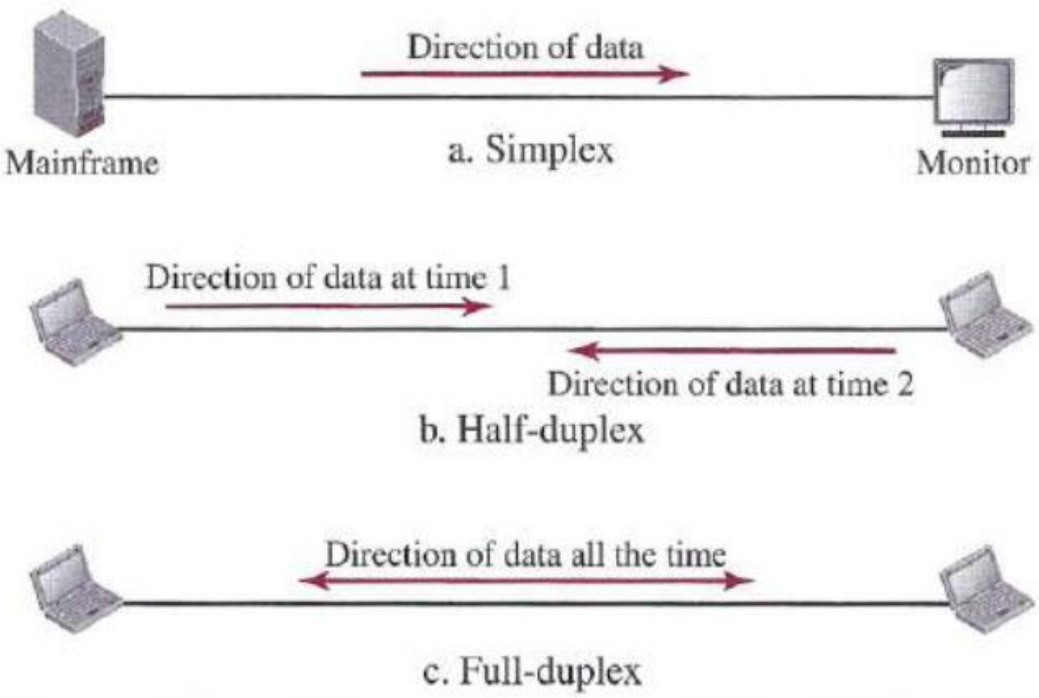

Figure (2) Data flow (simplex, half-duplex, and full-duplex)

<u>Simplex</u>

- In simplex mode, the communication is unidirectional, as on a one-way street. Only one of the two devices on a link can transmit; the other can only receive (see Figure 2a).
- Keyboards and traditional monitors are examples of simplex devices. The key-board can only introduce input; the monitor can only accept output.
- The simplex mode can use the entire capacity of the channel to send data in one direction.

<u>Half-Duplex</u>

- In half-duplex mode, each station can both transmit and receive, but not at the same time. When one device is sending, the other can only receive, and vice versa (see Figure 2b).
- 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. Walkie-talkies and CB (citizens band) radios are both half-duplex systems.

- 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.

Full-Duplex

- In full-duplex mode (also called duplex), both stations can transmit and receive simultaneously (see Figure 2c).
- 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.
- The capacity of the channel, however, must be divided between the two directions.

NETWORKS

A network is the interconnection of a set of devices capable of communication.

In this definition, a device can be a host (or an end system as it is sometimes called) such as a large computer, desktop, laptop, workstation, cellular phone, or security system. A device in this definition can also be a connecting device such as a router, which connects the network to other networks, a switch, which connects devices together, A modem (modulator-demodulator), which changes the form of data, and so on. These devices in a network are connected using wired or wireless transmission media such as cable or air. When we connect two computers at home using a plug-and-play router, we have created a network, although very small.

Network Criteria

A network must be able to meet a certain number of criteria. The most important of these are performance, reliability, and security.

Performance

- Performance can be measured in many ways, including transit time and response time.

- Transit time is the amount of time required for a message to travel from one device to another. Response time is the elapsed time between an inquiry and a response.
- The performance of a network depends on a number of factors, including the number of users, the type of transmission medium, the capabilities of the connected hardware, and the efficiency of the software.
- Performance is often evaluated by two networking metrics: throughput

  and delay. We often need more throughput and less delay.

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Reliability

In addition to accuracy of delivery, network reliability is measured by the frequency of failure, the time it takes a link to recover from a failure, and the network's robustness in a catastrophe.

Security

Network security issues include protecting data from unauthorized access, protecting data from damage and development, and implementing policies and procedures for recovery from breaches and data losses.

Type of Connection

A network is two or more devices connected through links. A link is a communications pathway that transfers data from one device to another. For communication to occur, two devices must be connected in some way to the same link at the same time.

There are two possible types of connections: point-to-point and multipoint.

Point-to-Point

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. 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 (see Figure 3a). When we change television channels by infrared remote control, we are establishing a point-to-point connection between the remote control and the television's control system.

Multipoint

A multipoint (also called multidrop) connection is one in which more than two specific devices share a single link (see Figure 3b). In a multipoint environment, the capacity of the channel is shared, either spatially or temporally. If several devices can use the link simultaneously, it is a spatially shared connection.

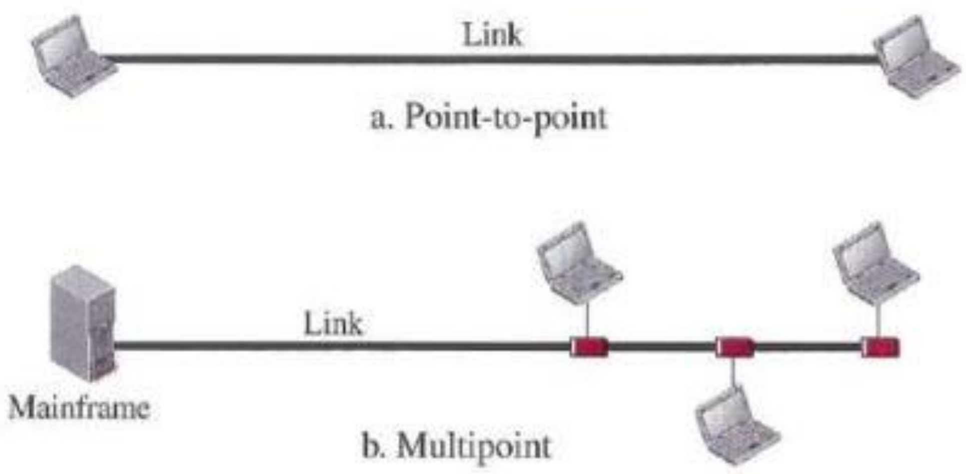

Figure 3 Types of connections: point-to-point and multipoint

Physical Topology

The term physical topology refers to the way in which a network is laid out physically. Two or more devices connect to a link; two or more links form a topology. The topology of a network is the geometric representation of the relationship of all the links and linking devices (usually called nodes) to one another. There are four basic topologies possible: mesh, star, bus, and ring.

Mesh Topology

In a mesh topology, every device has a dedicated point-to-point link to every other device. (See Figure 4).

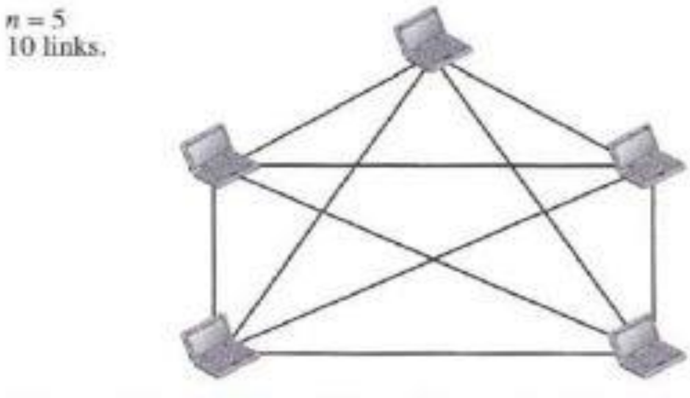

Figure 4 A fully connected mesh topology (five devices)

-To find the number of physical links in a fully connected mesh network with n nodes, we first consider that each node must be connected to every other node. Node 1 must be connected to n - 1 nodes, node 2 must be connected to n – 1 nodes, and finally node n must be connected to n - 1 nodes. We need n (n - 1) physical links.

***** The term **dedicated** means that the link carries traffic only between the two devices it connects.

A mesh offers several **advantages** over other network topologies.

First, 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.

Second, a mesh topology is robust. If one link becomes unusable, it does not incapacitate the entire system.

Third, there is the advantage of privacy or security. When every message travels along a dedicated line, only the intended recipient sees it. Physical boundaries prevent other users from gaining access to messages.

Fourth, finally, point-to-point links make fault identification and fault isolation easy. Traffic can be routed to avoid links with suspected problems. This facility enables the network manager to discover the precise location of the fault and aids in finding its cause and solution.

The main **disadvantages** of a mesh are related to the amount of cabling and the number of I/O ports required.

First, because every device must be connected to every other device, installation and reconnection are difficult.

Second, the sheer bulk of the wiring can be greater than the available space (in walls, ceilings, or floors) can accommodate.

Third, the hardware required to connect each link (I/O ports and cable) can be prohibitively expensive.

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 Topology

In a star topology, each device has a dedicated point-to-point link only to a central controller, usually called a hub. 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 (see Figure 5) .

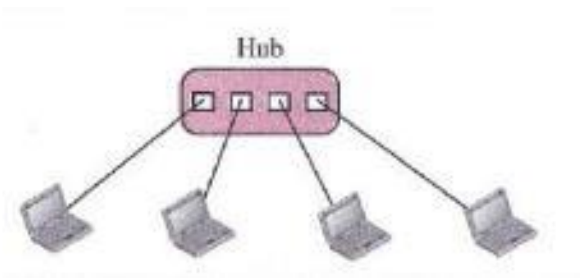

Figure 5 A star topology connecting four stations

Advantages of star topology

First, a star topology is less expensive than a mesh topology. And 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.

Second, Far less cabling needs to be housed, and additions, moves, and deletions involve only one connection: between that device and the hub.

Third, other advantages include robustness. 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.

Disadvantages of star topology

First, the dependency of the whole topology on one single point, the hub. If the hub goes down, the whole system is dead.

Second, 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).

*The star topology is used in local-area networks (LANs),

Bus Topology

The preceding examples all describe point-to-point connections. A bus topology, on the other hand, is multipoint. One long cable acts as a backbone to link all the devices in a network (see Figure 6).

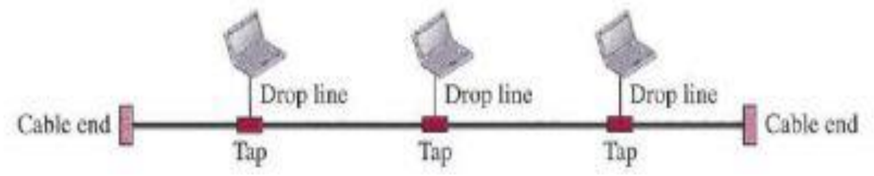

Figure 6 A bus topology connecting three stations

Advantages of a bus topology

First, include ease of installation.

Second, a bus uses less cabling than mesh or star topologies.

Disadvantages of a bus topology

First, include difficult reconnection and fault isolation.

Second, a fault or break in the bus cable stops all transmission, even between devices on the same side of the problem.

* Bus topology was the one of the first topologies used in the design of early local-area networks.

Ring Topology

In a ring topology, 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 (see Figure 7).

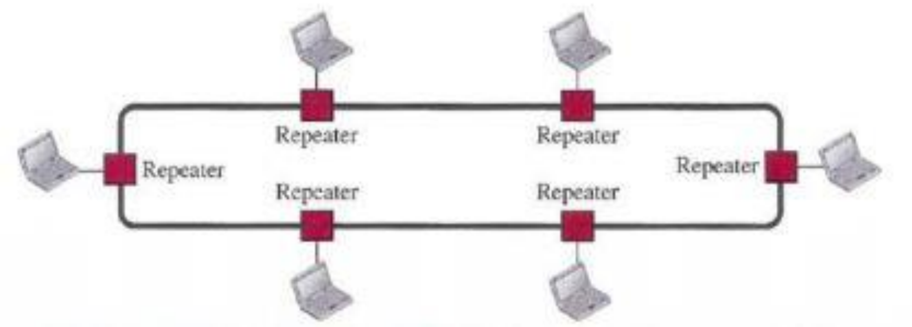

Figure 7 A ring topology connecting six stations

Advantages of a ring topology

First, a ring is relatively easy to install and reconfigure. Each device is linked to only its immediate neighbors (either physically or logically).

Second, fault isolation is simplified.

Disadvantages of a ring topology

First, unidirectional traffic.

Second, in a simple ring, a break in the ring (such as a disabled station) can disable the entire network.

Hybrid Topology A network can be hybrid. For example, we can have a main star topology with each branch connecting several stations in a bus topology as shown in Figure 8

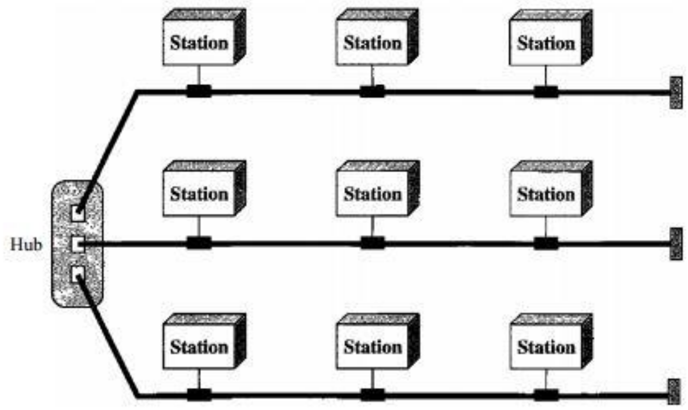

Figure 8 A hybrid topology: a star backbone with three bus networks

NETWORK TYPES

Local Area Network

A local area network (LAN) is usually privately owned and connects some hosts in a single office, building, or campus. Depending on the needs of an organization, a LAN can be as simple as two PCs and a printer in someone's home office, or it can extend throughout a company and include audio and video devices. Each host in a LAN has an identifier, an address, that uniquely defines the host in the LAN. A packet sent by a host to another host carries both the source host's and the destination host's addresses (see Figure 9).

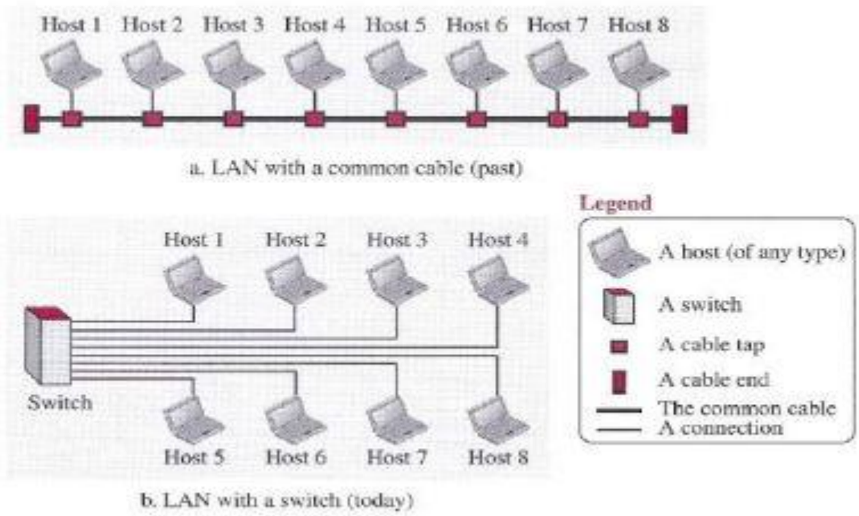

Figure 9 an isolated LAN in the past and today

Wide Area Network

A wide area network (WAN) is also an interconnection of devices capable of communication, has a wider geographical span, spanning a town, a state, a country, or even the world, WAN is normally created and run by communication companies and leased by an organization that uses it. We see two distinct examples of WANs today: point-to-point WANs and switched WANs.

Point-to-Point WAN

A point-to-point WAN is a network that connects two communicating devices through a transmission media (cable or air). We will see examples of these WANs when we discuss how to connect the networks to one another. Figure 10 shows an example of a point-to-point WAN

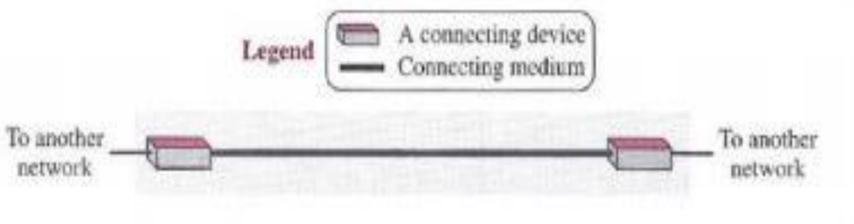

Figure 10 A point-to-point WAN

Switched WAN

A switched WAN is a network with more than two ends. A switched WAN, as we will see shortly, is used in the backbone of global communication today. We can say that a switched WAN is a combination of several point-to-point WANs that are connected by switches. Figure 11 shows an example of a switched WAN.

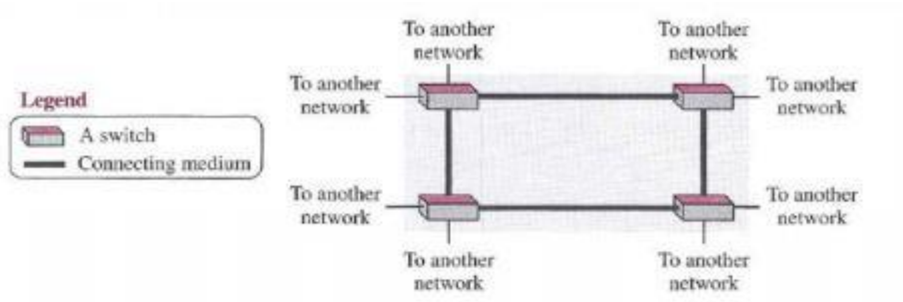

Figure 11 A switched WAN

Internetwork

Today, it is very rare to see a LAN or a WAN in isolation; they are connected to one another. When two or more networks are connected, they make an internetwork, or internet. As an example, assume that an organization has two offices, one on the east coast and the other on the west coast. Each office has a LAN that allows all employees in the office to communicate with each other. To make the communication between employees at different offices possible, the management leases a point-to-point dedicated WAN from a service provider, such as a telephone company, and connects the two LANs. Now the company has an internetwork, or a private internet (with lowercase i). Communication between offices is now possible. Figure 12 shows this internet.

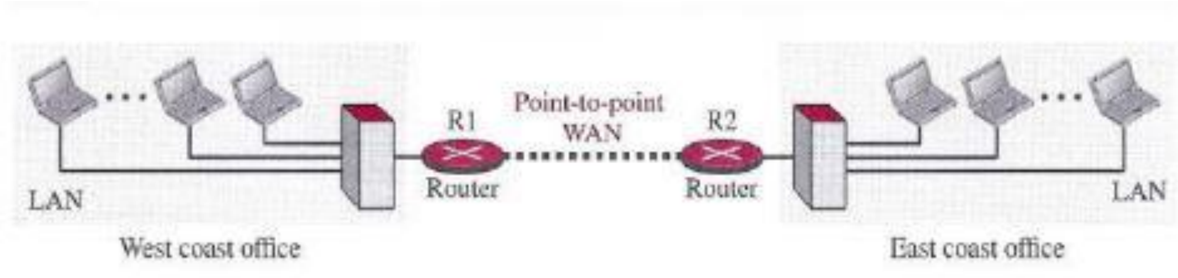

Figure 12 an internetwork made of two LANs and one point-to-point WAN

Analog and Digital Data

Data can be analog or digital. The term **analog data** refers to information that is continuous; **digital data** refers to information that has discrete states. For **example**, an analog clock that has hour, minute, and second hands gives information in a continuous form; the movements of the hands are continuous. On the other hand, a digital clock that reports the hours and the minutes will change suddenly from 8:05 to 8:06. Analog data, such as the sounds made by a human voice, take on continuous values. When someone speaks, an analog wave is created in the air. This can be captured by a microphone and converted to an analog signal or sampled and converted to a digital signal. Digital data take on discrete values. For **example**, data are stored in computer memory in the form of 0s and 1s. They can be converted to a digital signal or modulated into an analog signal for transmission across a medium. Figure 13 illustrates an analog signal and a digital signal.

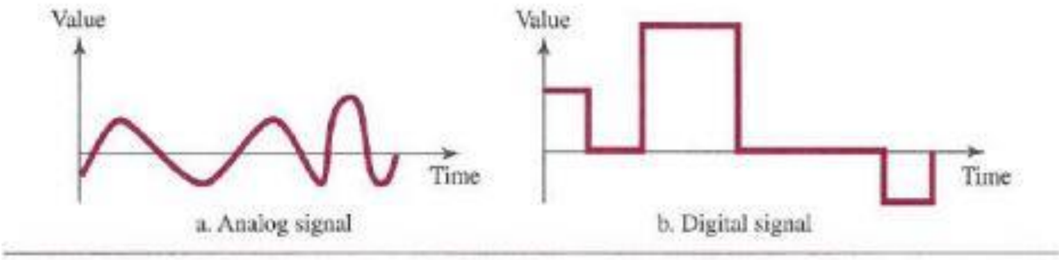

Figure 13 Comparison of analog and digital signals

Periodic and Nonperiodic

Both analog and digital signals can take one of two forms: periodic or nonperiodic

A periodic signal completes a pattern within a measurable time frame, called a period, and repeats that pattern over subsequent identical periods. The completion of one full pattern is called a cycle

A nonperiodic signal changes without exhibiting a pattern or cycle that repeats over time.

* Both analog and digital signals can be periodic or nonperiodic. In data communications, we commonly use periodic analog signals and nonperiodic digital signals.

Analog – to – Analog Conversion

Analog-to-analog conversion, or analog modulation, is the representation of analog information by an analog signal.

Analog-to-analog conversion can be accomplished in three ways: amplitude modulation (AM), frequency modulation (FM), and phase modulation (PM). FM and PM are usually categorized together. See Figure (36)

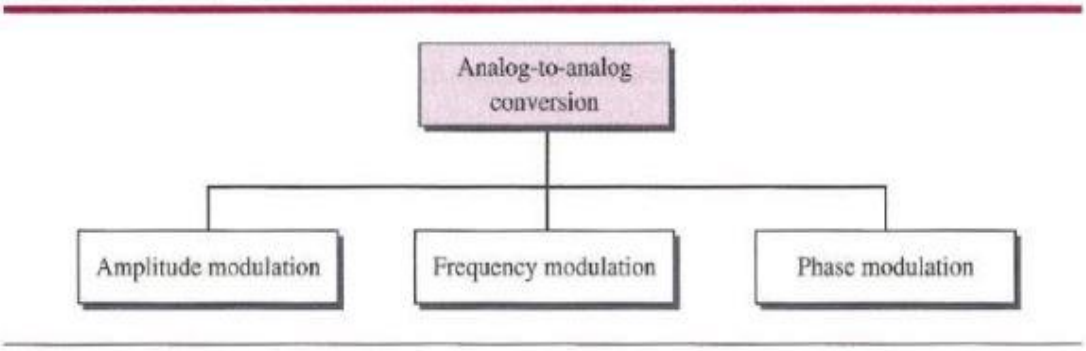

Figure 36 Types of analog-to-analog modulation

Amplitude Modulation (AM)

In AM transmission, the carrier signal is modulated so that its amplitude varies with the changing amplitudes of the modulating signal. The frequency and phase of the carrier remain the same; only the amplitude changes to follow variations in the information. Figure 37 shows how this concept works. The modulating signal is the envelope of the carrier. As Figure 37 shows, AM is normally implemented by using a simple multiplier because the amplitude of the carrier signal needs to be changed according to the amplitude of the modulating signal.

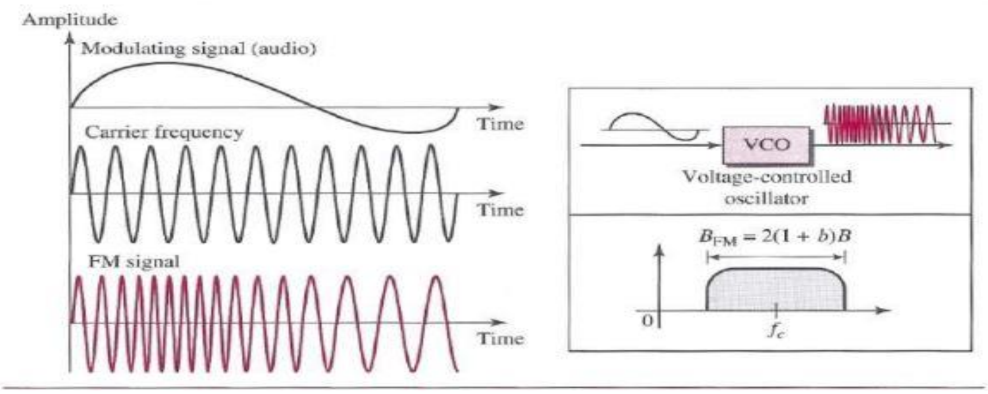

Figure 37 Amplitude modulation

Frequency Modulation (FM)

In FM transmission, the frequency of the carrier signal is modulated to follow the changing voltage level (amplitude) of the modulating signal. The peak amplitude and phase of the carrier signal remain constant, but as the amplitude of the information signal changes, the frequency of the carrier changes correspondingly. Figure (38) shows the relationships of the modulating signal, the carrier signal, and the resultant FM signal.

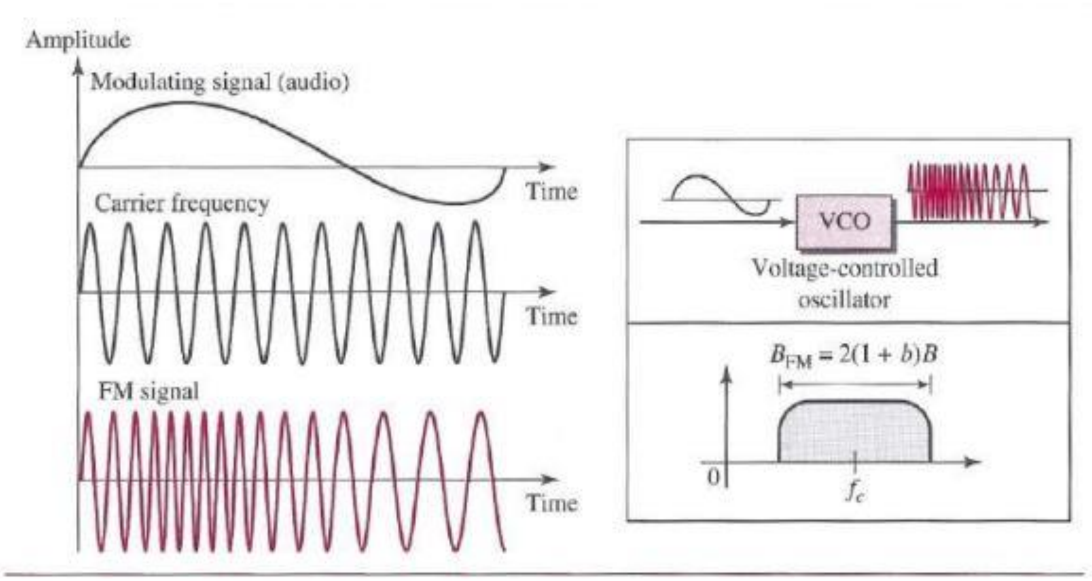

Figure 38 Frequency modulation

Phase Modulation (PM)

In PM transmission, the phase of the carrier signal is modulated to follow the changing voltage level (amplitude) of the modulating signal. The peak amplitude and frequency of the carrier signal remain constant, but as the amplitude of the information signal changes, the phase of the carrier changes correspondingly. In FM, the instantaneous change in the carrier frequency is proportional to the amplitude of the modulating signal; in PM the instantaneous change in the carrier frequency is proportional to the derivative of the amplitude of the modulating signal. Figure (39) shows the relationships of the modulating signal, the carrier signal, and the resultant PM signal.

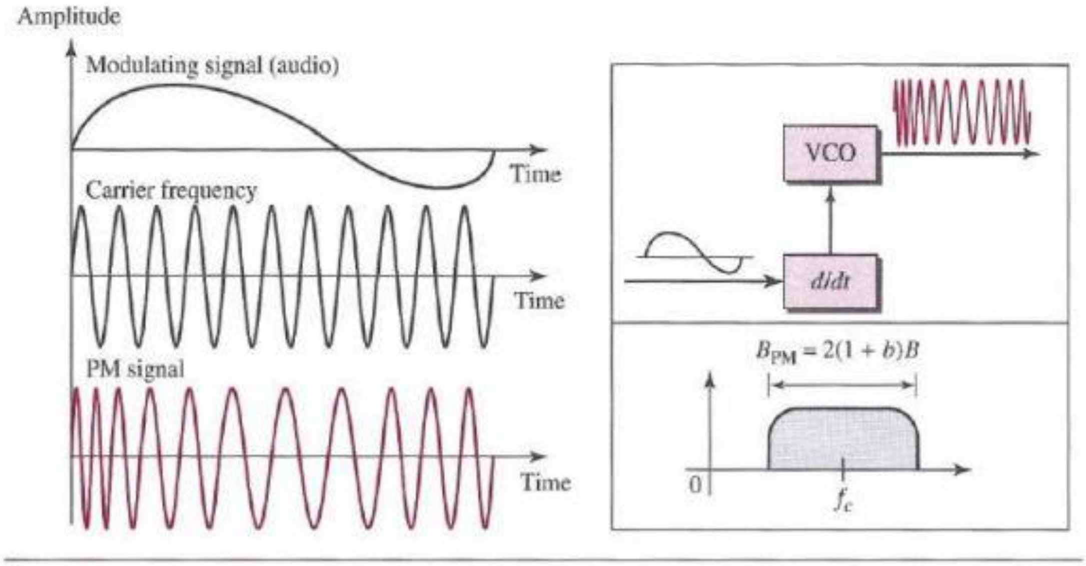

Figure 39 Phase modulation

Analog – to – Digital Conversion

Analog-to-digital conversion is the representation of analog information by a digital signal. In analog-to-digital conversion, a continuous quantity is converted to a discrete time digital representation.

Analog-to-digital conversion can be accomplished in two ways, namely, **pulse code modulation, and delta modulation**. After the digital data are created, it can be stored in digital format like CD, DVD, or hard drive.

Pulse Code Modulation (PCM)

The most common technique to change an analog signal to digital data (digitization) is called pulse code modulation (PCM). A PCM encoder has three processes, as shown in Figure 40.

1. The analog signal is sampled.

2. The sampled signal is quantized.

3. The quantized values are encoded as streams of bits.

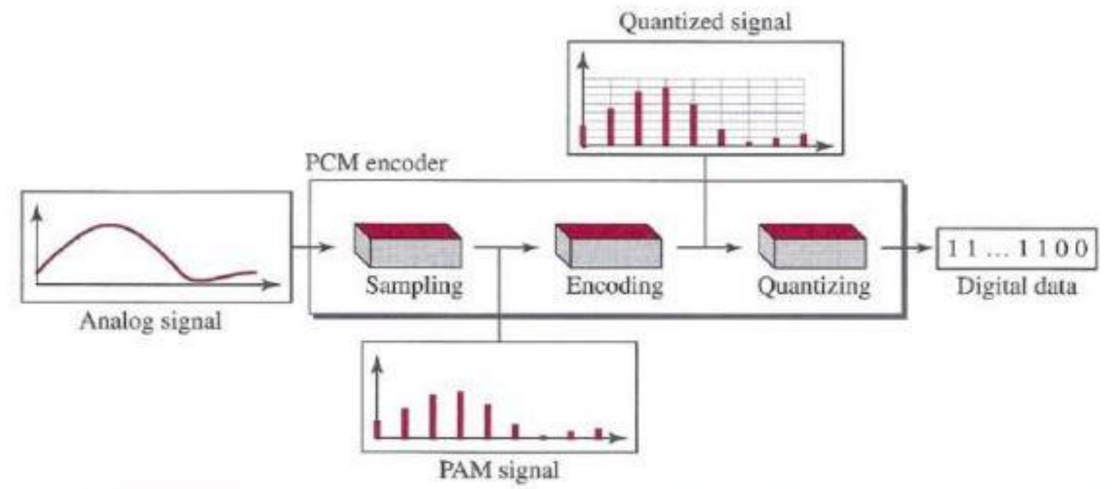

Figure 40 Components of PCM encoder

Sampling

The first step in PCM is sampling. The analog signal is sampled every T_S s, where T_S, is the sample interval or period. The inverse of the sampling interval is called the sampling rate or sampling frequency and denoted by f_S, where is $f_S = 1/T_S$. There are three sampling methods-ideal, natural, and flat-top-as shown in Figure (41). In ideal sampling, pulses from the analog signal are sampled. This is an ideal sampling method and cannot be easily implemented. In natural sampling, a high-speed switch is turned on for only the small period of time when the sampling occurs. The result is a sequence of samples that retains the shape of the analog signal. The most common sampling method, called sample and hold, however, creates flat-top samples by using a circuit. The sampling process is sometimes referred to as pulse amplitude modulation (PAM).

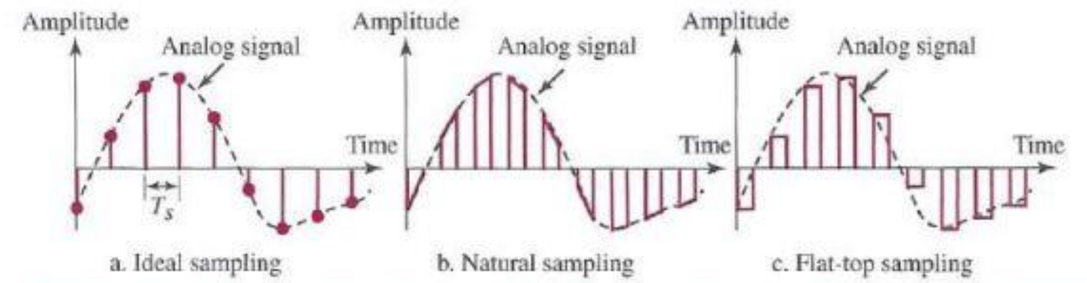

Figure 41 Three different sampling methods for PCM

Quantization

The result of sampling is a series of pulses with amplitude values between the maximum and minimum amplitudes of the signal. The set of amplitudes can be infinite with nonintegral values between the two limits. These values cannot be used in the encoding process. The following are the steps in quantization:

1. We assume that the original analog signal has instantaneous amplitudes between V_{min} and V_{max}:

2. We divide the range into L zones, each of height Δ (delta).

$$\Delta = (V_{max} - V_{min})/L$$

3. We assign quantized values of 0 to L - 1 to the midpoint of each zone.

4. We approximate the value of the sample amplitude to the quantized values.

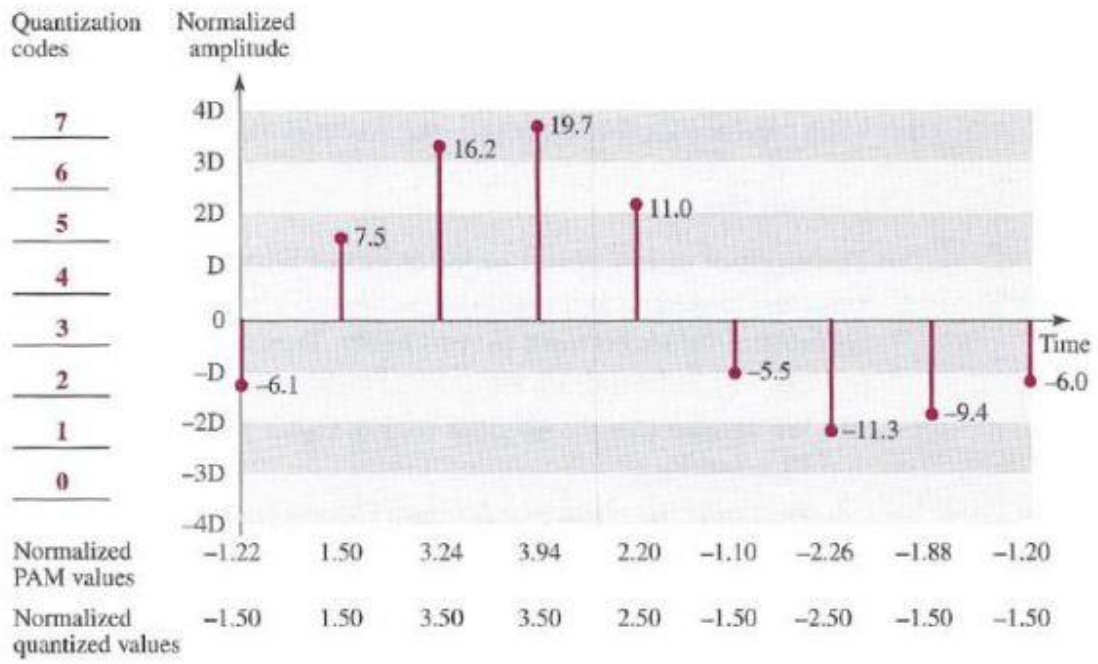

Figure 42 Quantization and encoding of a sampled signal

Encoding

The last step in PCM is encoding. After each sample is quantized and the number of bits per sample is decided, each sample can be changed to an n_b-bit code word. Note that the number of bits for each sample is determined from the number of quantization levels. If the number of quantization levels is L, the number of bits is $n_b = \log_2 L$

Delta Modulation (DM)

PCM is a very complex technique. Other techniques have been developed to reduce the complexity of PCM. The simplest is delta modulation. PCM finds the value of the signal amplitude for each sample; DM finds the change from the previous sample. Figure (43) shows the process. Note that there are no code words here; bits are sent one after another.

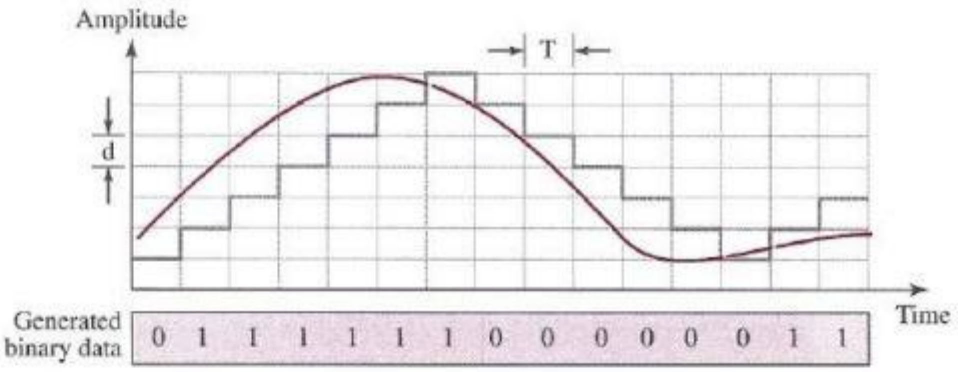

Figure 43 the process of delta modulation