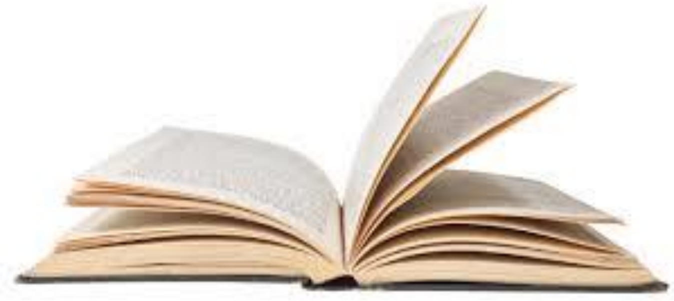
Data Communications and Networking

Lecture 4



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Outlines

- Bandwidth Utilization: Multiplexing and Spectrum Spreading

  - Multiplexing

  - Spread Spectrum

- Transmission Media

  - Guided Media

  - Unguided Media: Wireless

- Switching

  - Introduction

  - Circuit-Switched Networks

  - Packet Switching

Lecture Objectives

- To introduce
  - Multiplexing
  - Spread Spectrum
  - Transmission Media
  - Switching
- To understand the concepts of multiplexing, demultiplexing and spread spectrum
- To describe the physical characteristics of coaxial cable, STP, UTP, and fiber-optic media
- To describe radio waves, microwaves, and infrared waves of their characteristics and applications
- To describe switching methods: packet switching and circuit switching

Topic 1: Bandwidth Utilization: Multiplexing and Spectrum Spreading

Multiplexing

- Multiplexing is the set of techniques that allow the simultaneous transmission of multiple signals across a single data link.
- In a multiplexed system, n lines share the bandwidth of one link.
- Figure 1 shows the basic format of a multiplexed system.
- The lines on the left direct their transmission streams to a multiplexer (MUX), which combines them into a single stream (many-to-one).
- At the receiving end, that stream is fed into a demultiplexer (DEMUX), which separates the stream back into its component transmissions (one-to-many) and directs them to their corresponding lines.
- In the figure, the word link refers to the physical path.
- The word channel refers to the portion of a link that carries a transmission between a given pair of lines.
- One link can have many (n) channels.

Multiplexing (Continue)

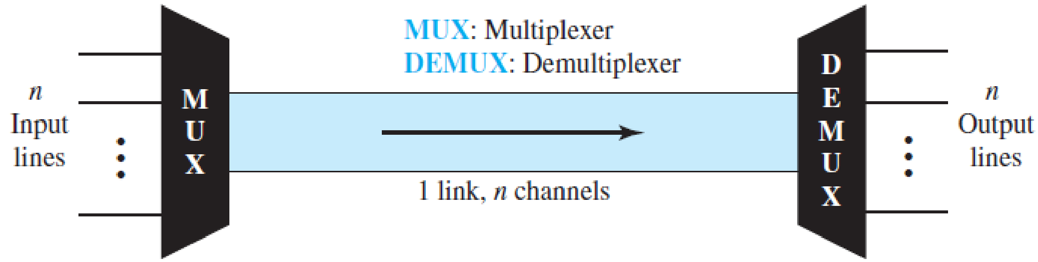

Figure 1. Dividing a link into channels

- There are three basic multiplexing techniques: frequency-division multiplexing, wavelength-division multiplexing, and time-division multiplexing.
- The first two are techniques designed for analog signals, the third, for digital signals.

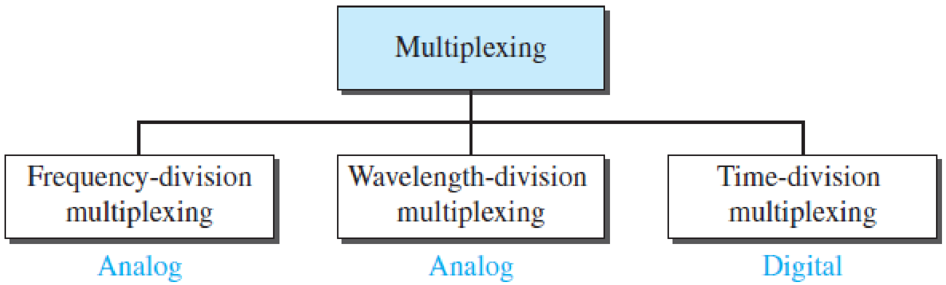

Figure 2. Categories of multiplexing

Multiplexing (Continue)

Frequency-Division Multiplexing

- Frequency-division multiplexing (FDM) is an analog multiplexing technique that combines analog signals.
- In FDM, signals generated by each sending device modulate different carrier frequencies.
- These modulated signals are then combined into a single composite signal that can be transported by the link.
- Carrier frequencies are separated by sufficient bandwidth to accommodate the modulated signal.
- These bandwidth ranges are the channels through which the various signals travel.
- Channels can be separated by strips of unused bandwidth—guard bands—to prevent signals from overlapping.

Multiplexing (Continue)

- In addition, carrier frequencies must not interfere with the original data frequencies.
- Figure 3 gives a conceptual view of FDM.
- In this illustration, the transmission path is divided into three parts, each representing a channel that carries one transmission.

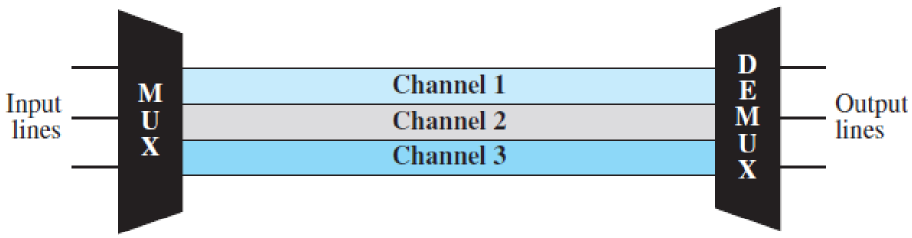

Figure 3. Frequency-division multiplexing

Multiplexing Process

- Figure 4 is a conceptual illustration of the multiplexing process.
- Each source generates a signal of a similar frequency range.
- Inside the multiplexer, these similar signals modulate different carrier frequencies (f1, f2, and f3).

Multiplexing (Continue)

- The resulting modulated signals are then combined into a single composite signal that is sent out over a media link that has enough bandwidth to accommodate it.

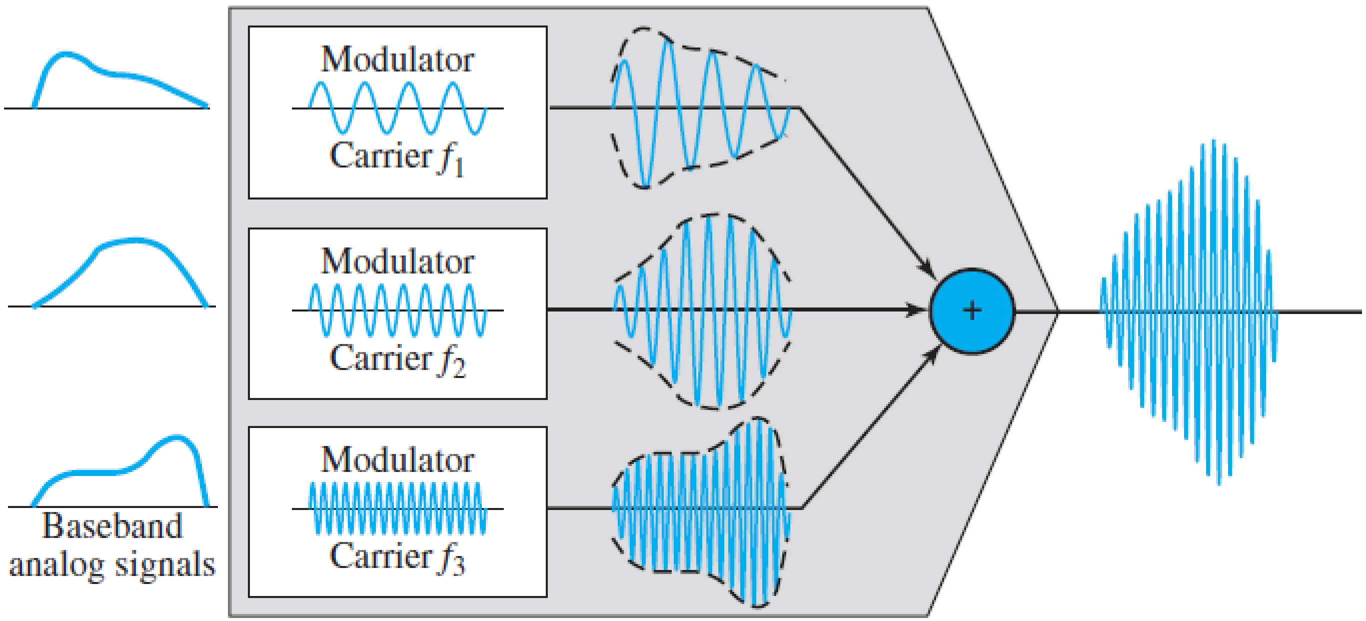

Figure 4. FDM process

Multiplexing (Continue)

Demultiplexing Process

- The demultiplexer uses a series of filters to decompose the multiplexed signal into its constituent component signals.
- The individual signals are then passed to a demodulator that separates them from their carriers and passes them to the output lines.
- Figure 5 is a conceptual illustration of demultiplexing process.

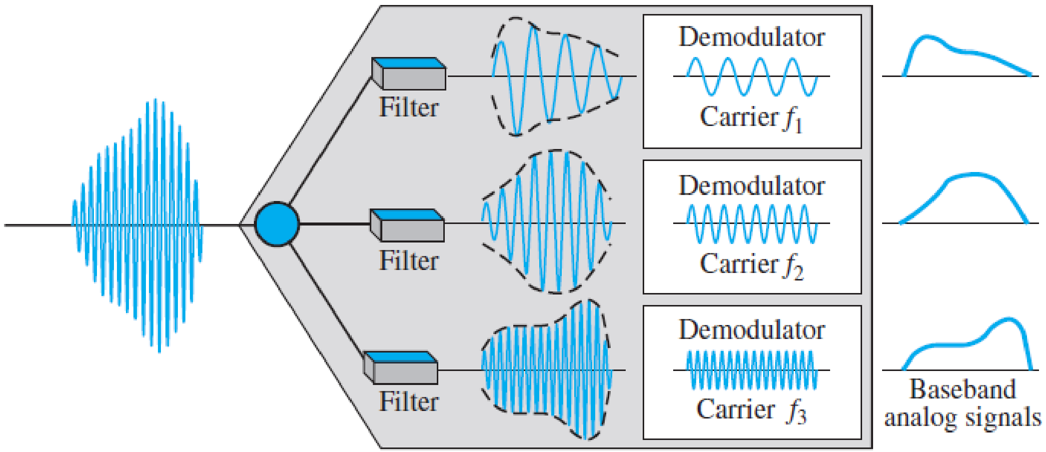

Figure 5. FDM demultiplexing

Multiplexing (Continue)

The Analog Carrier System

- To maximize the efficiency of their infrastructure, telephone companies have traditionally multiplexed signals from lower-bandwidth lines onto higher-bandwidth lines.
- In this way, many switched or leased lines can be combined into fewer but bigger channels.
- For analog lines, FDM is used.
- One of these hierarchical systems used by telephone companies is made up of groups, supergroups, master groups, and jumbo groups as shown in figure 6.

Multiplexing (Continue)

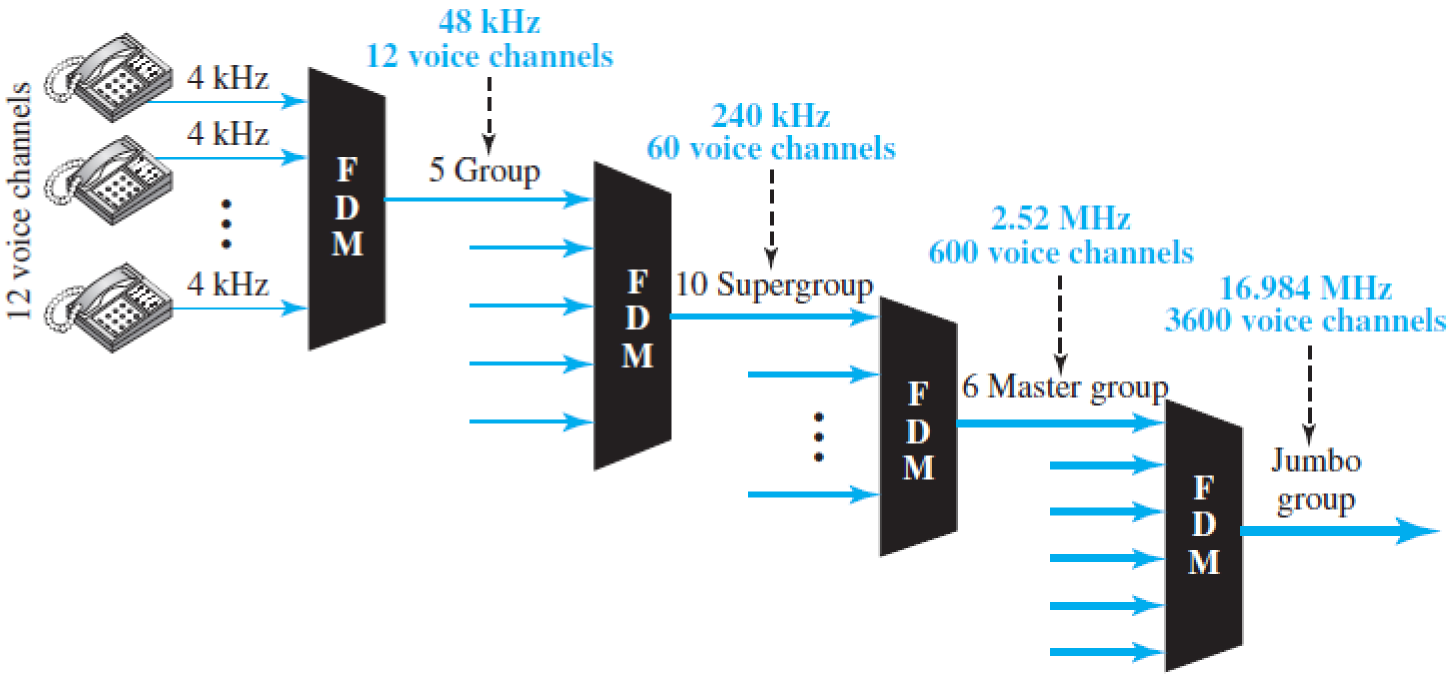

Figure 6. Analog hierarchy

Multiplexing (Continue)

Wavelength-Division Multiplexing

- Wavelength-division multiplexing (WDM) is designed to use the high-data-rate capability of fiber-optic cable.
- The optical fiber data rate is higher than the data rate of metallic transmission cabe , but using a fiber-optic cable for a single line wastes the available bandwidth.
- Multiplexing allows to combine several lines into one.
- Figure 7 gives a conceptual view of a WDM multiplexer and demultiplexer.
- Very narrow bands of light from different sources are combined to make a wider band of light.
- At the receiver, the signals are separated by the demultiplexer.

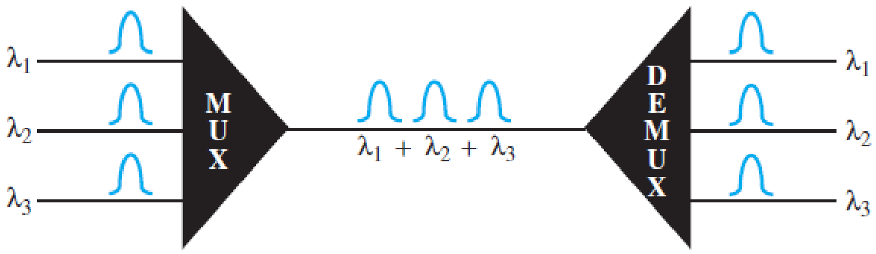

Figure 7. Wavelength-division multiplexing

Multiplexing (Continue)

Time-Division Multiplexing

- Time-division multiplexing (TDM) is a digital process that allows several connections to share the high bandwidth of a link.
- Instead of sharing a portion of the bandwidth as in FDM, time is shared.
- Each connection occupies a portion of time in the link.
- In figure 8, portions of signals 1, 2, 3, and 4 occupy the link sequentially.
-TDM can be divided into two different schemes: synchronous and statistical.
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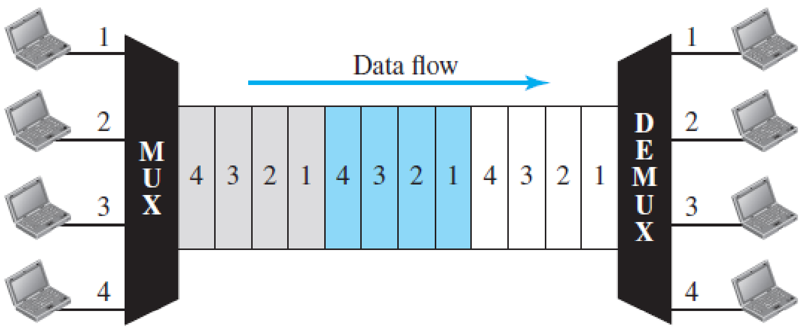

Figure 8. Time division multiplexing

Multiplexing (Continue)

Synchronous TDM

- In synchronous TDM, the data rate of the link is n times faster, and the unit duration is n times shorter.
- In synchronous TDM, the data flow of each input connection is divided into units, where each input occupies one input time slot.
- A unit can be 1 bit, one character, or one block of data.
- Each input unit becomes one output unit and occupies one output time slot.
- However, the duration of an output time slot is *n* times shorter than the duration of an input time slot.

Multiplexing (Continue)

- If an input time slot is T s, the output time slot is T/n s, where *n* is the number of connections. In other words, a unit in the output connection has a shorter duration; it travels faster.
- Figure 9 shows an example of synchronous TDM where n is 3.

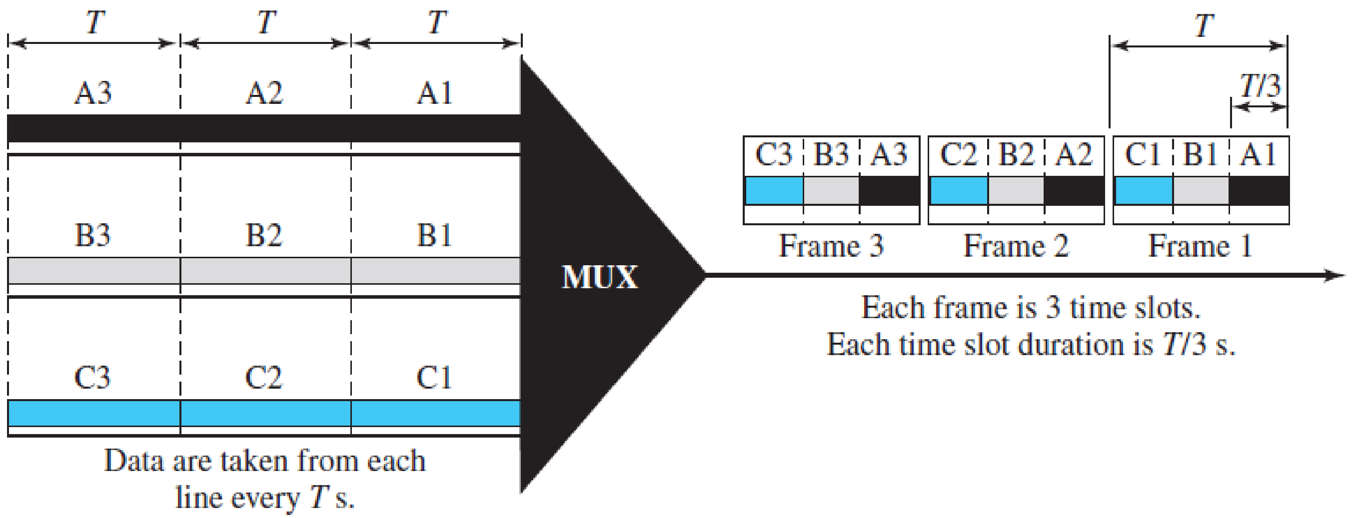

Figure 9. Synchronous time-division multiplexing

Multiplexing (Continue)

Example 1

In figure 9, the data rate for each input connection is 1kbps. If 1 bit at a time is multiplexed (a unit is 1 bit), what is the duration of

1. each input slot,
2. each output slot, and
3. each frame ?

Solution: 1. The data rate of each input connection is 1 kbps. This means that the bit duration is 1/1000 s or 1 ms. The duration of the input time slot is 1 ms (same as bit duration).

2. The duration of the output time slot is 1/3 ms.

3. Each frame carries three output time slots. So the duration of a frame is $3 \times 1/3$ ms, or 1 ms.

Multiplexing (Continue)

Empty Slots

- Synchronous TDM is not as efficient as it could be.
- If a source does not have data to send, the corresponding slot in the output frame is empty as shown in figure 10.

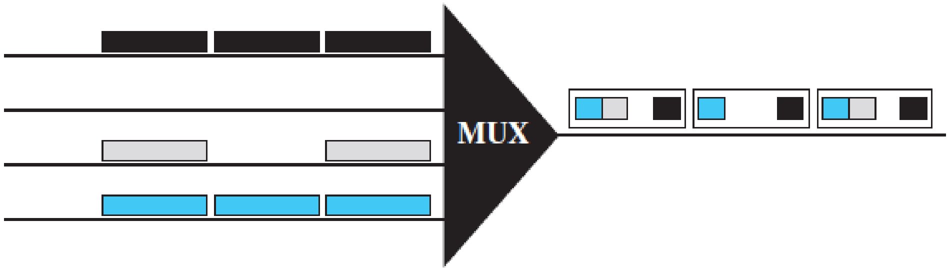

Figure 10. Empty Slots

Data Rate Management

- One problem with TDM is how to handle a disparity in the input data rates.
- If data rates are not the same, three strategies: multilevel multiplexing, multiple-slot allocation, and pulse stuffing, or a combination of them, can be used

Multiplexing (Continue)

Multilevel Multiplexing

- Multilevel multiplexing is a technique used when the data rate of an input line is a multiple of others as depicted in figure 11.

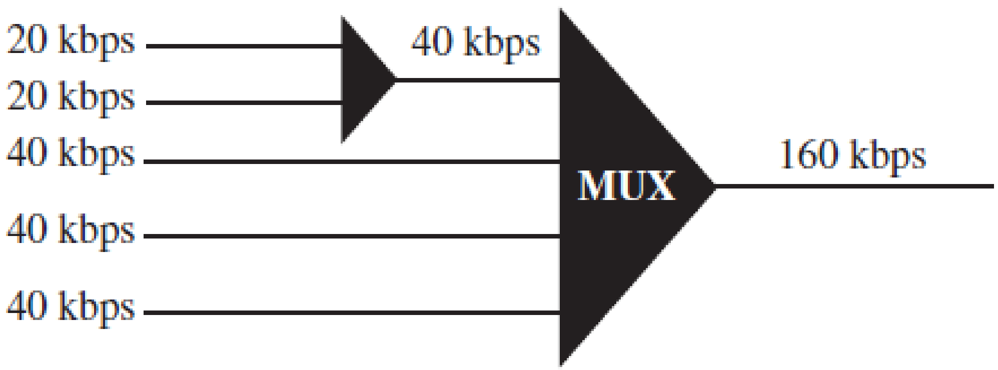

Figure 11. Multilevel Multiplexing

Multiple-Slot Allocation

- It is more efficient to allot more than one slot in a frame to a single input line as shown in figure 12.

Multiplexing (Continue)

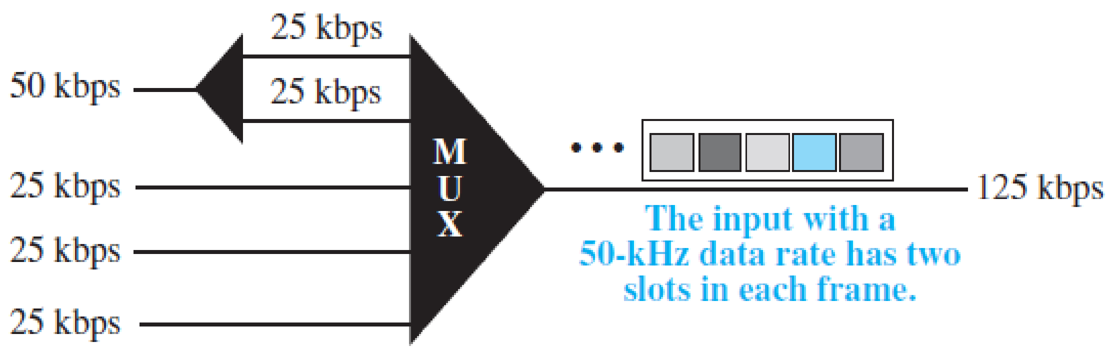

Figure 12. Multiple-slot multiplexing

Pulse Stuffing

- Sometimes the bit rates of sources are not multiple integers of each other.
- Therefore, neither of the above two techniques can be applied.
- One solution is to make the highest input data rate the dominant data rate and then add dummy bits to the input lines with lower rates.
- This will increase their rates.
- This technique is called pulse stuffing, bit padding, or bit stuffing.

Multiplexing (Continue)

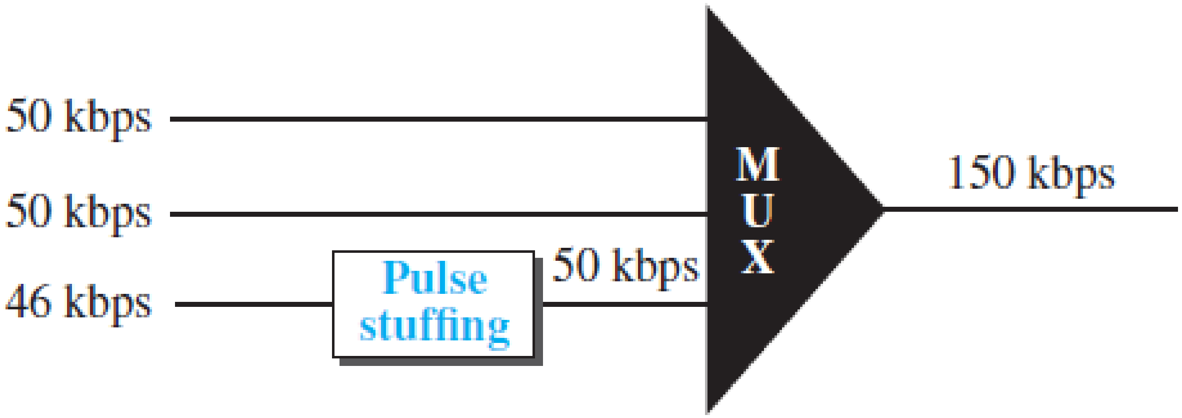

Figure 13. Pulse stuffing

Digital Signal Service

- Telephone companies implement TDM through a hierarchy of digital signals, called digital signal (DS) service or digital hierarchy.
- Figure 14 shows the data rates supported by each level.

Multiplexing (Continue)

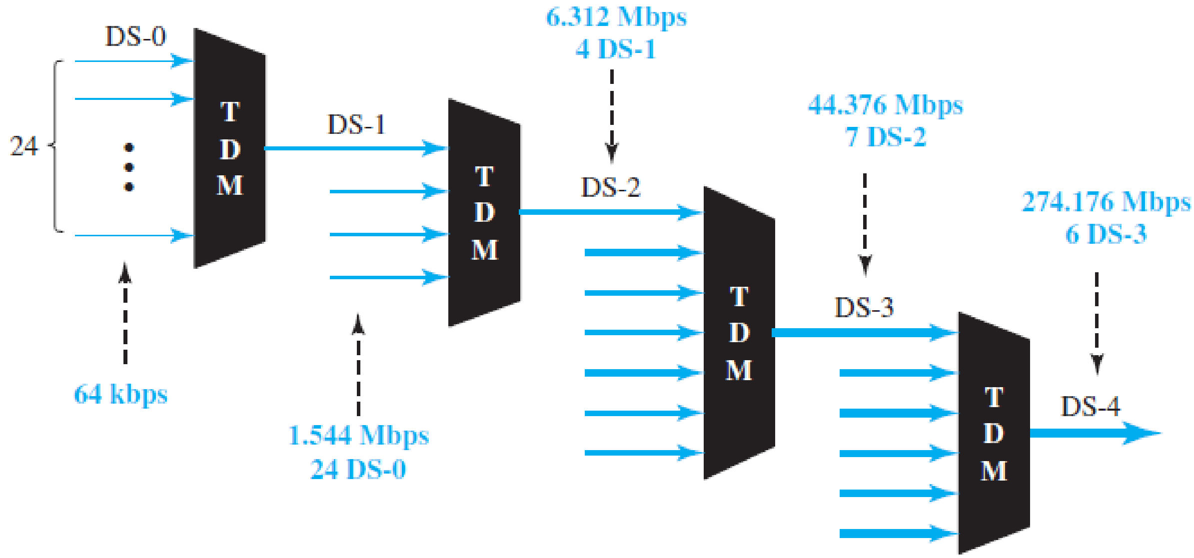

Figure 14. Digital hierarchy

Table 1: DS and T line rates

Service	*Line*	*Rate (Mbps)*	*Voice Channels*
DS-1	T-1	1.544	24
DS-2	T-2	6.312	96
DS-3	T-3	44.736	672
DS-4	T-4	274.176	4032

Multiplexing (Continue)

T Lines for Analog Transmission

- T lines are digital lines designed for the transmission of digital data, audio, or video.
- However, they also can be used for analog transmission (regular telephone connections), provided the analog signals are first sampled, then time-division multiplexed.

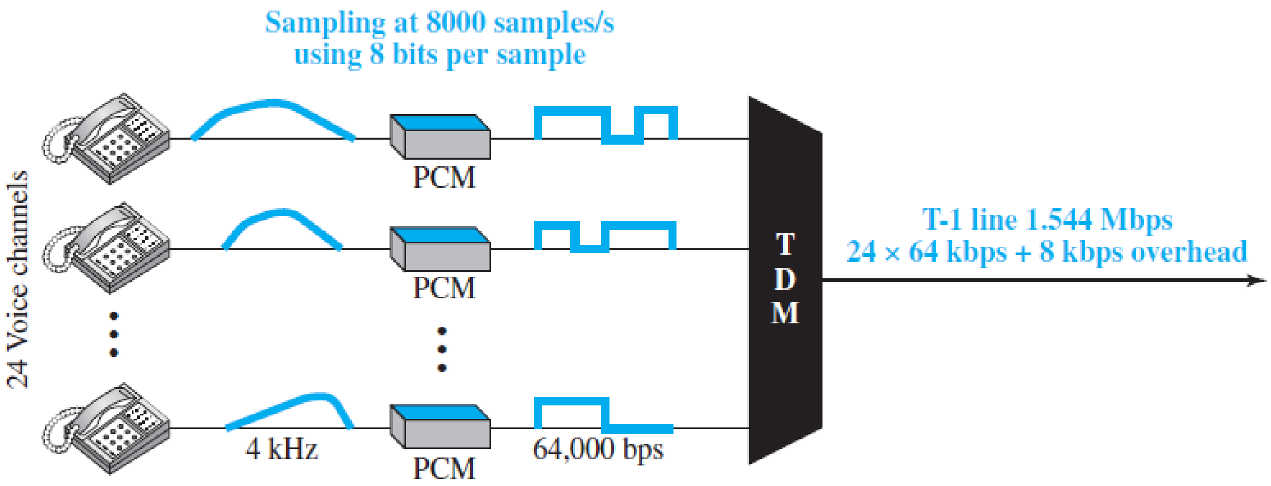

Figure 15. T-1 line for multiplexing telephone lines

Multiplexing (Continue)

E Lines

- Europeans use a version of T lines called E lines.
- The two systems are conceptually identical, but their capacities differ.
- Table 2 shows the E lines and their capacities.

Table 2: E line rates

Line	*Rate (Mbps)*	*Voice Channels*
E-1	2.048	30
E-2	8.448	120
E-3	34.368	480
E-4	139.264	1920

Multiplexing (Continue)

Statistical Time-Division Multiplexing

- In statistical time-division multiplexing, slots are dynamically allocated to improve bandwidth efficiency.
- Only when an input line has a slot’s worth of data to send is it given a slot in the output frame.
- In statistical multiplexing, the number of slots in each frame is less than the number of input lines.

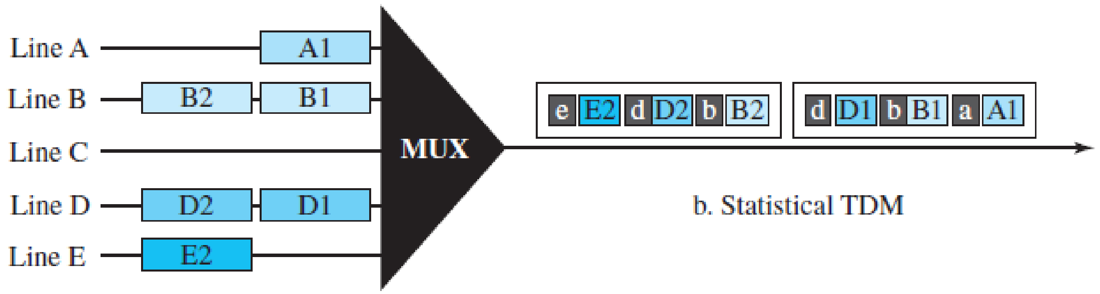

Figure 16. Statistical TDM

Spread Spectrum

- Spread spectrum achieves its goals through two principles:
  1. The bandwidth allocated to each station needs to be, by far, larger than what is needed.
  2. The expanding of the original bandwidth B to the bandwidth B_{SS} must be done by a process that is independent of the original signal.
- After the signal is created by the source, the spreading process uses a spreading code and spreads the bandwidth.
- Figure 17 shows the original bandwidth B and the spread bandwidth B_{SS}.
- The spreading code is a series of numbers that look random, but are actually a pattern.
- There are two techniques to spread the bandwidth: frequency hopping spread spectrum (FHSS) and direct sequence spread spectrum (DSSS).

Spread Spectrum (Continue)

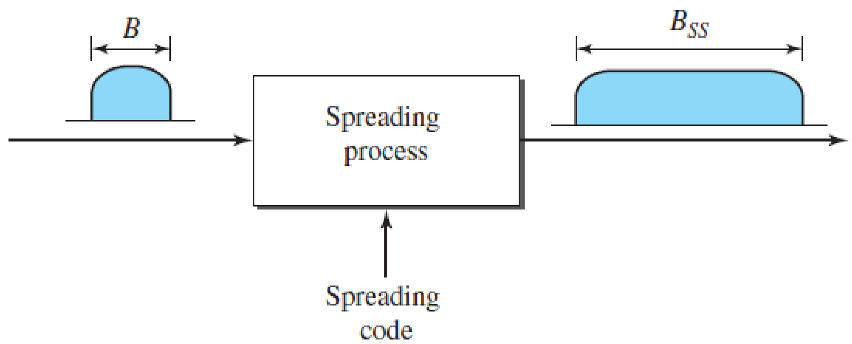

Figure 17. Spread Spectrum

Frequency Hopping Spread Spectrum

- The frequency hopping spread spectrum (FHSS) technique uses M different carrier frequencies that are modulated by the source signal.
- At one moment, the signal modulates one carrier frequency; at the next moment, the signal modulates another carrier frequency.
- Figure 18 shows the general layout for FHSS.
- A pseudorandom code generator, called pseudorandom noise (PN), create a k-bit pattern for every hopping period T_h.

Spread Spectrum (Continue)

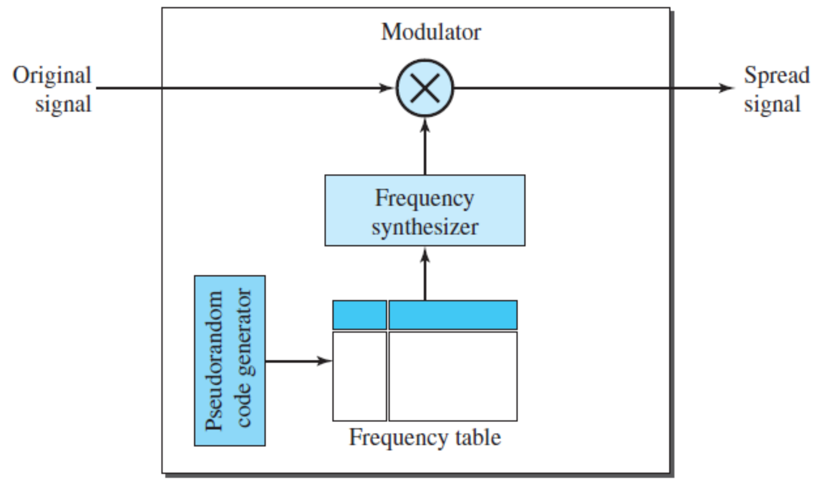

Figure 18. Frequency Hopping Spread Spectrum (FHSS)

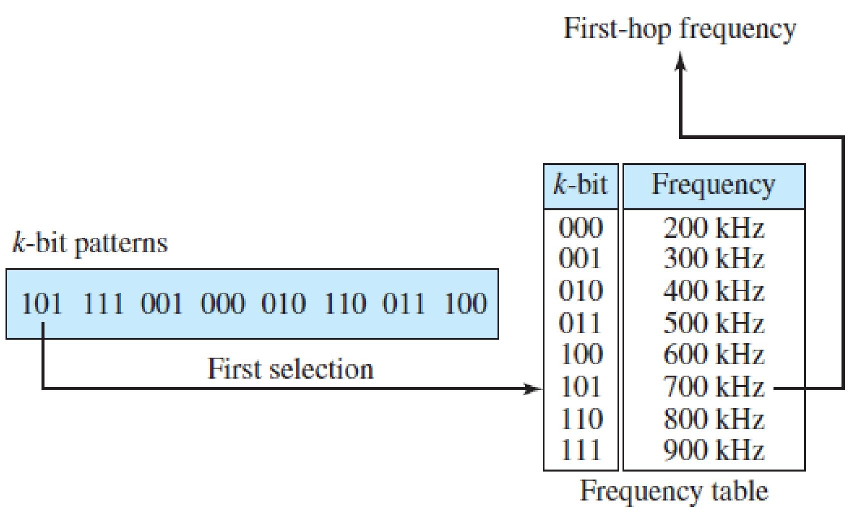

Figure 19. Frequency selection in FHSS

Spread Spectrum (Continue)

Direct Sequence Spread Spectrum

- The direct sequence spread spectrum (DSSS) technique also expands the bandwidth of the original signal, but the process is different.
- In DSSS, each data bit is replaced with n bits using a spreading code.
- In other words, each bit is assigned a code of n bits, called chips, where the chip rate is n times that of the data bit.
- Figure 20 shows the concept of DSSS.

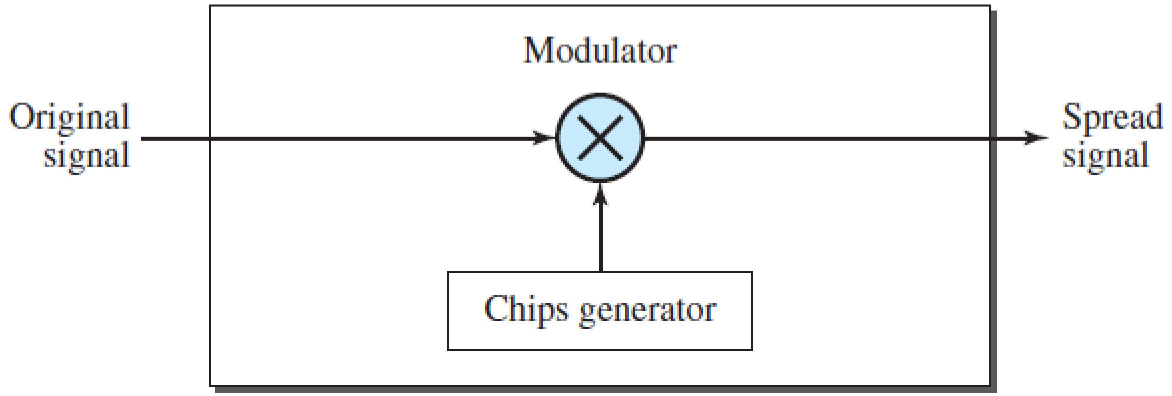

Figure 20. Direct sequence spread spectrum (DSS)

Spread Spectrum (Continue)

- It is assumed that the original signal and the chips in the chip generator use polar NRZ encoding.
- Figure 21 shows the chips and the result of multiplying the original data by the chips to get the spread signal.
- In this figure, the spreading code is 11 chips having the pattern 10110111000 (in this case).
- If the original signal rate is *N*, the rate of the spread signal is 11*N*.
- This means that the required bandwidth for the spread signal is 11 times larger than the bandwidth of the original signal.
- The spread signal can provide privacy if the intruder does not know the code.
- It can also provide immunity against interference if each station uses a different code.

Spread Spectrum (Continue)

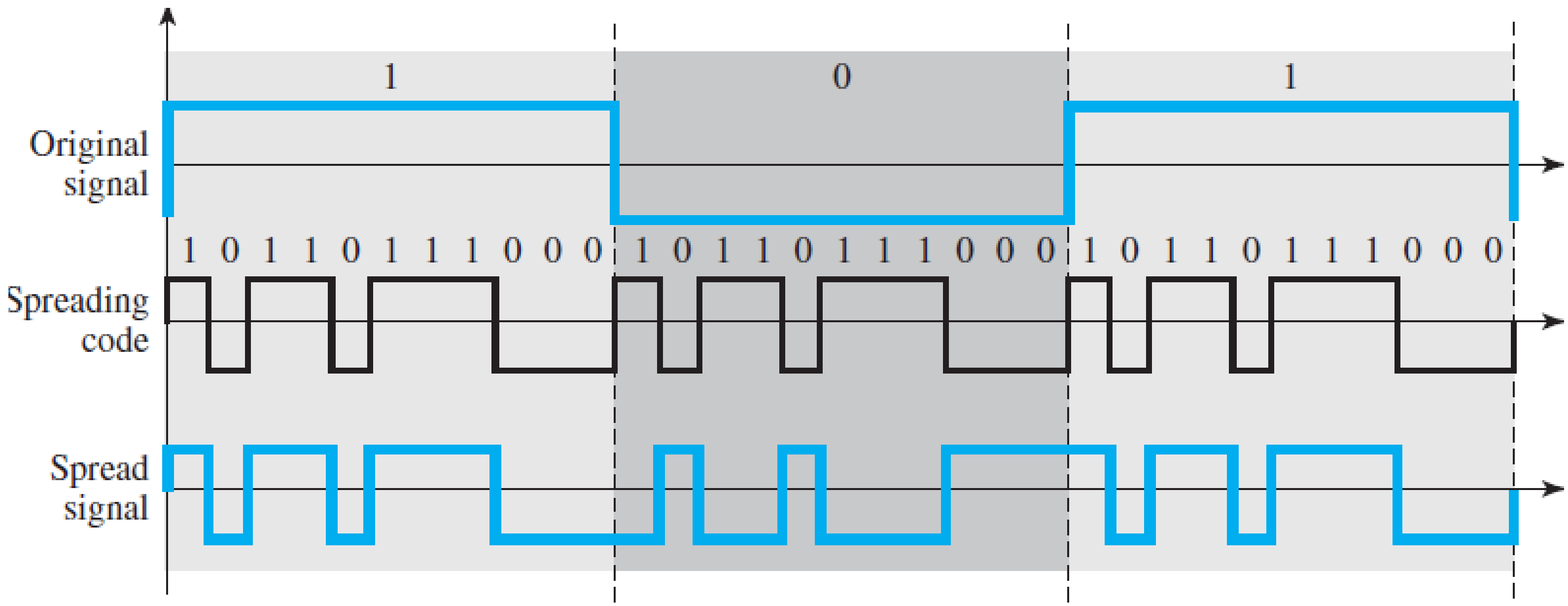

Figure 21. DSSS example

Topic 2: Transmission Media

Transmission Media: Guided Media

- Transmission media are actually located below the physical layer and are directly controlled by the physical layer.
- Figure 22 shows the position of transmission media in relation to the physical layer.
- A transmission medium can be broadly defined as anything that can carry information from a source to a destination.

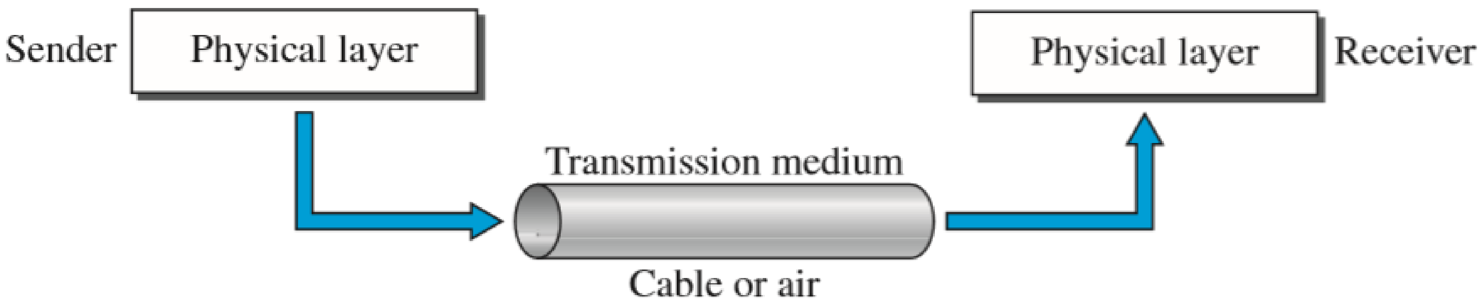

Figure 22. Transmission medium and physical layer

Transmission Media: Guided Media (Continue)

- In telecommunications, transmission media can be divided into two broad categories: guided and unguided.
- Guided media include twisted-pair cable, coaxial cable, and fiber-optic cable.
- Unguided medium is free space.
- Figure 23 shows this taxonomy.

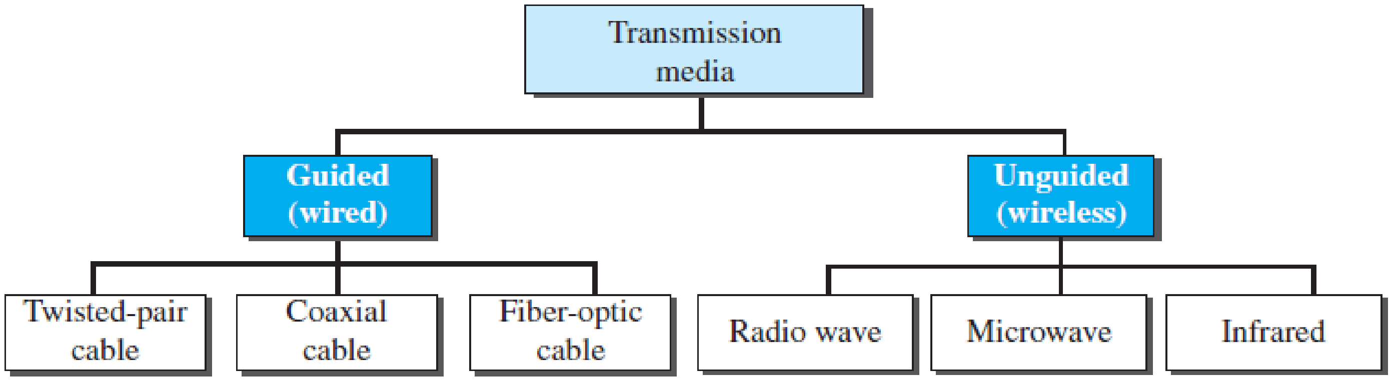

Figure 23. Classes of transmission media

Transmission Media: Guided Media (Continue)

Guided Media

- Guided media, which are those that provide a conduit from one device to another, include twisted-pair cable, coaxial cable, and fiber-optic cable.

Twisted-Pair Cable

- A twisted pair consists of two conductors (normally copper), each with its own plastic insulation, twisted together, as shown in figure 24.
- One of the wires is used to carry signals to the receiver, and the other is used only as a ground reference.

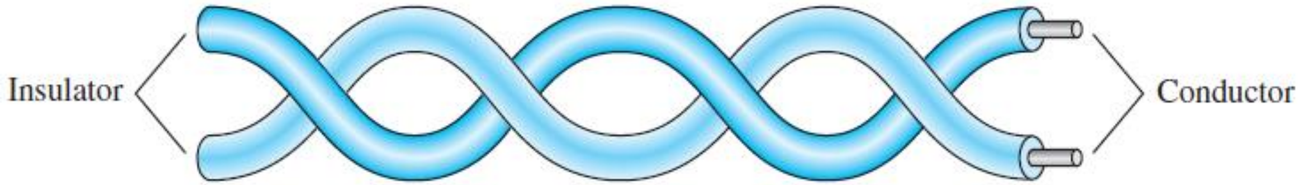

Figure 24. Twisted-pair cable

Transmission Media: Guided Media (Continue)

Unshielded Versus Shielded Twisted-Pair Cable

- The most common twisted-pair cable used in communications is referred to as unshielded twisted-pair (UTP).

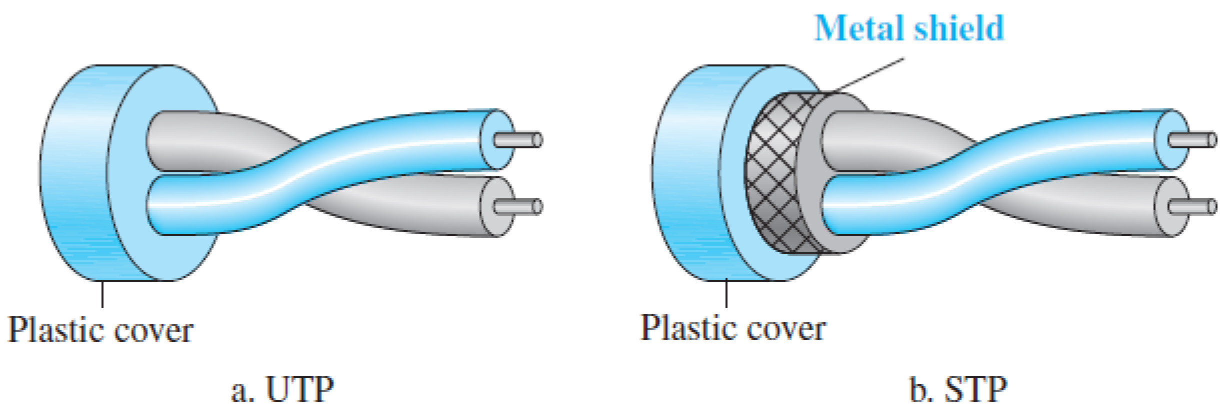

Figure 25. UTP and STP Cables

Transmission Media: Guided Media (Continue)

Table 3: Categories of Unshielded Twisted-Pair Cables

Category	Specification	Data Rate (Mbps)	Use
1	Unshielded twisted-pair used in telephone	< 0.1	Telephone
2	Unshielded twisted-pair originally used in T lines	2	T-1 lines
3	Improved CAT 2 used in LANs	10	LANs
4	Improved CAT 3 used in Token Ring networks	20	LANs
5	Cable wire is normally 24 AWG with a jacket and outside sheath	100	LANs
5E	An extension to category 5 that includes extra features to minimize the crosstalk and electromagnetic interference	125	LANs
6	A new category with matched components coming from the same manufacturer. The cable must be tested at a 200-Mbps data rate.	200	LANs
7	Sometimes called SSTP (shielded screen twisted-pair). Each pair is individually wrapped in a helical metallic foil followed by a metallic foil shield in addition to the outside sheath. The shield decreases the effect of crosstalk and increases the data rate.	600	LANs

Transmission Media: Guided Media (Continue)

Connector

- The most common UTP connector is RJ45 , as shown in figure 26.

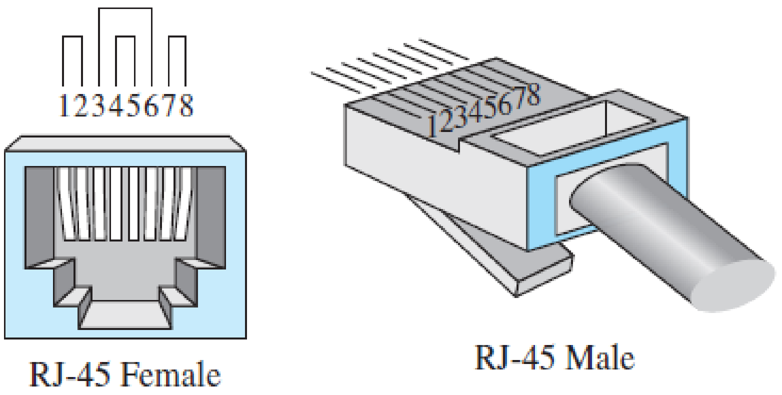

Figure 26. UTP Connector

Performance

- One way to measure the performance of twisted-pair cable is to compare attenuation versus frequency and distance.
- A twisted-pair cable can pass a wide range of frequencies.

Transmission Media: Guided Media (Continue)

- Figure 27 shows that with increasing frequency, the attenuation, measured in decibels per kilometer (dB/km), sharply increases with frequencies above 100 kHz.
- Gauge is a measure of the thickness of the wire.

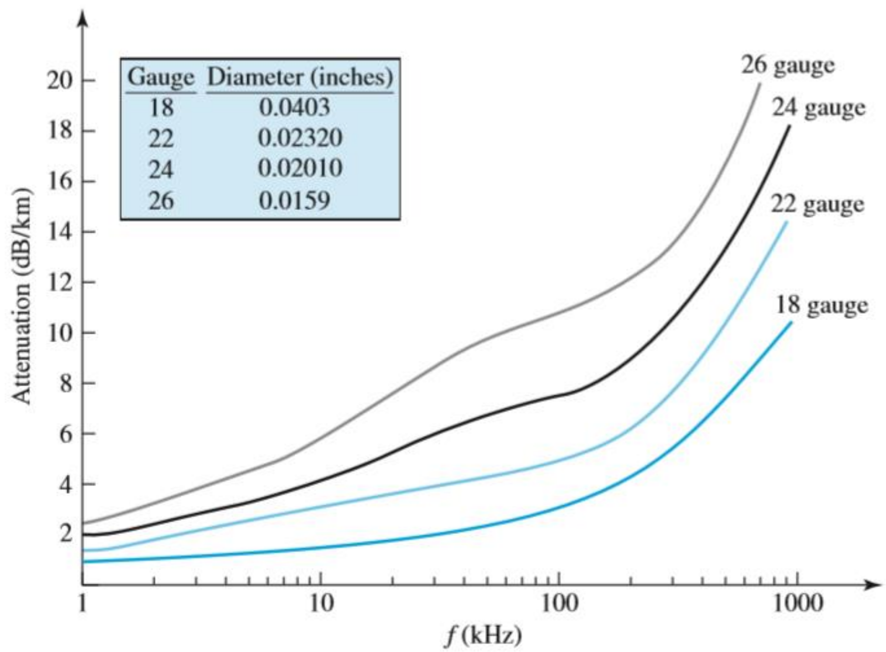

Figure 27. UTP performance

Transmission Media: Guided Media (Continue)

Applications

- Twisted-pair cables are used in telephone lines to provide voice and data channels.

Coaxial Cable

- Coaxial cable (or coax) carries signals of higher frequency ranges than those in twisted-pair cable, in part because the two media are constructed quite differently.

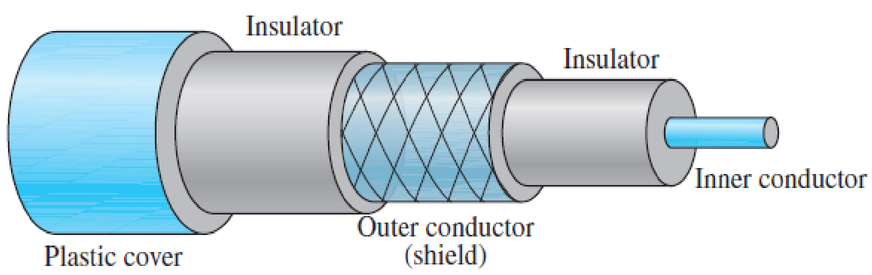

Figure 28. Coaxial cable

Transmission Media: Guided Media (Continue)

Coaxial Cable Connectors

- The most common type of connector used today is the Bayonet Neill-Concelman (BNC) connector as shown in figure 29.

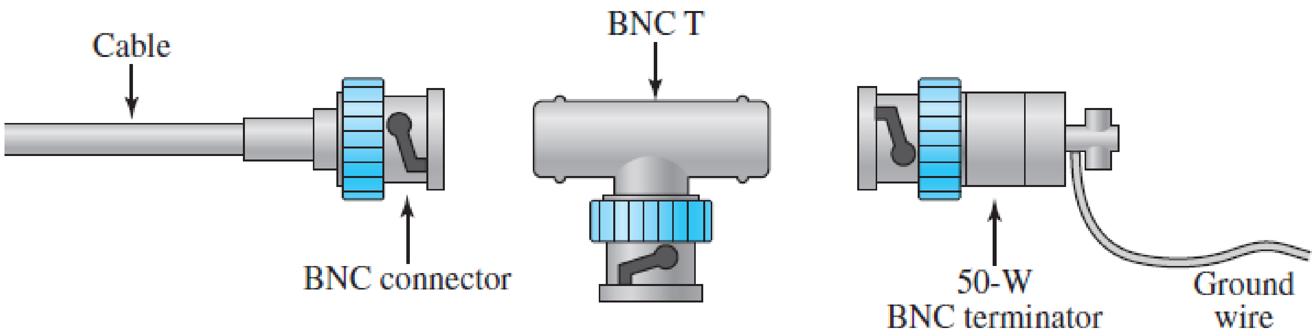

Figure 29. BNC connectors

Applications

- Coaxial cable was widely used in analog telephone networks where a single coaxial network could carry 10,000 voice signals.

Transmission Media: Guided Media (Continue)

Performance

- It can measure the performance of a coaxial cable.
- The attenuation is much higher in coaxial cable than in twisted-pair cable.
- In other words, although coaxial cable has a much higher bandwidth, the signal weakens rapidly and requires the frequent use of repeaters.

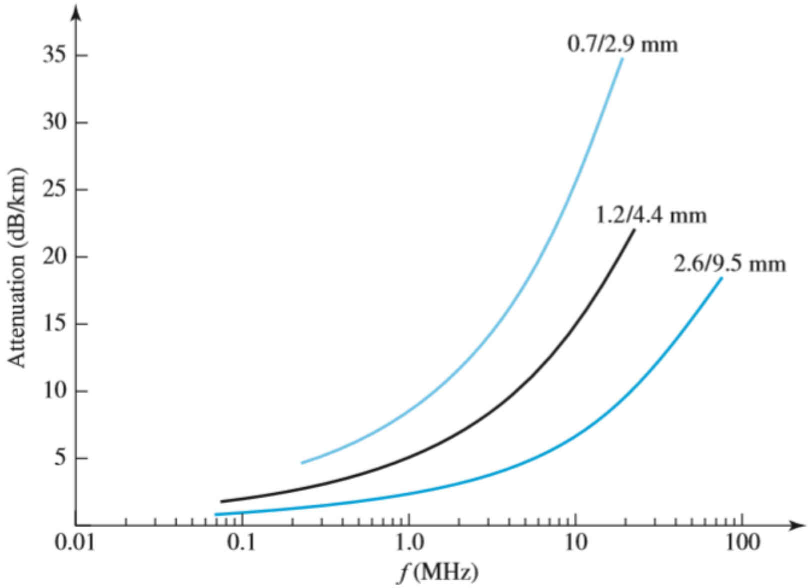

Figure 30. Coaxial cable performance

Transmission Media: Guided Media (Continue)

Fiber-Optic Cable

- A fiber-optic cable is made of glass or plastic and transmits signals in the form of light.
- Light travels in a straight line as long as it is moving through a single uniform substance.
- If a ray of light traveling through one substance suddenly enters another substance (of a different density), the ray changes direction.
- Optical fibers use reflection to guide light through a channel.
- A glass or plastic core is surrounded by a cladding of less dense glass or plastic.
- The difference in density of the two materials must be such that a beam of light moving through the core is reflected off the cladding instead of being refracted into it as shown in figure 31.

Transmission Media: Guided Media (Continue)

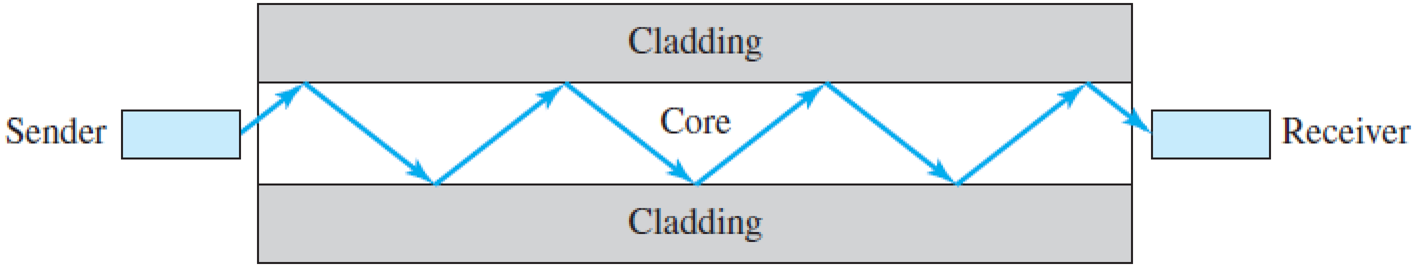

Figure 31. Optical fiber

Propagation Modes

- Current technology supports two modes (multimode and single mode) for propagating light along optical channels, each requiring fiber with different physical characteristics.
- Multimode can be implemented in two forms: step-index or graded-index as shown in figure 32.

Transmission Media: Guided Media (Continue)

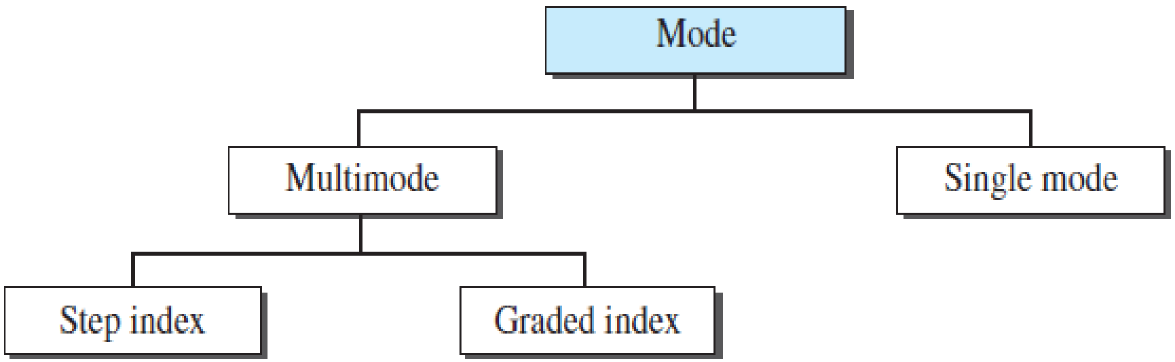

Figure 32. Propagation modes

Multimode

- Multimode is so named because multiple beams from a light source move through the core in different paths.
- How these beams move within the cable depends on the structure of the core, as shown in figure 33.

Transmission Media: Guided Media (Continue)

- In multimode step-index fiber, the density of the core remains constant from the center to the edges.
- The term step-index refers to the suddenness of this change, which contributes to the distortion of the signal as it passes through the fiber.
- A second type of fiber, called multimode graded-index fiber, decreases this distortion of the signal through the cable.

Single -Mode

- Single-mode uses step-index fiber and a highly focused source of light that limits beams to a small range of angles, all close to the horizontal.

Transmission Media: Guided Media (Continue)

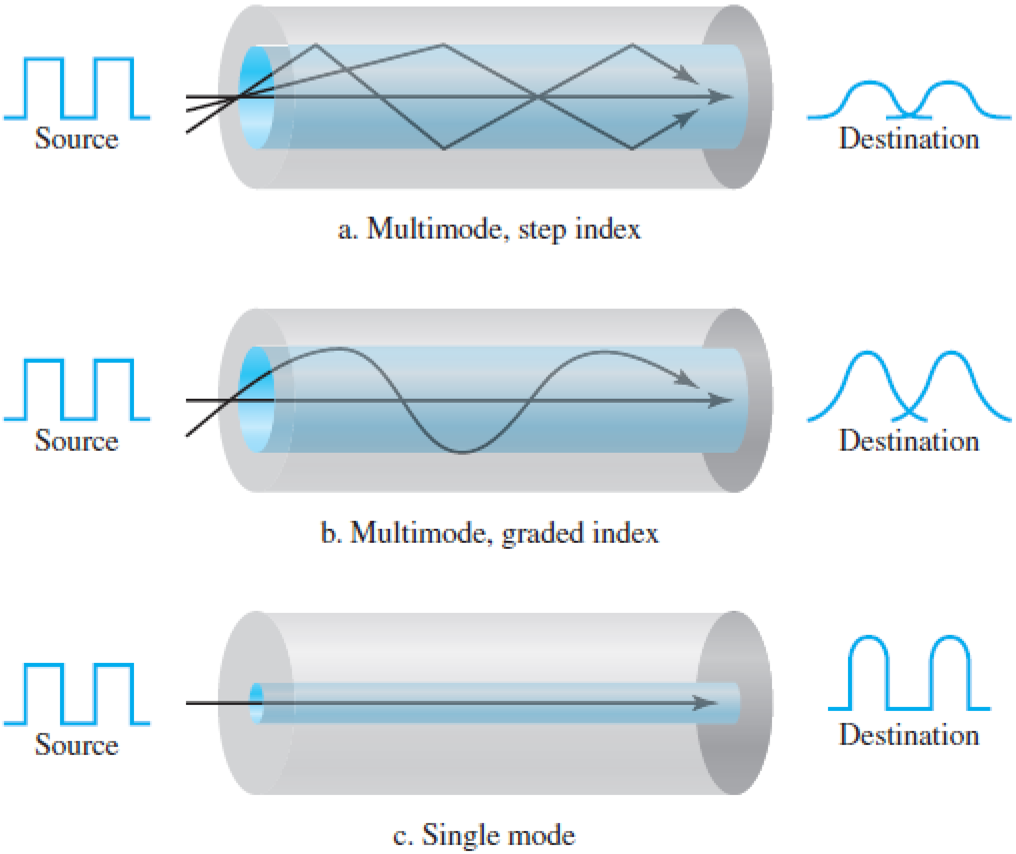

Figure 33.Modes

Transmission Media: Guided Media (Continue)

Fiber-optic Cable Connectors

- There are three types of connectors for fiber-optic cables as shown in figure 34.
- The subscriber channel (SC) connector is used for cable TV.
- The straight-tip (ST) connector is used for connecting cable to networking devices.
- MT-RJ is a connector that is the same size as RJ45.

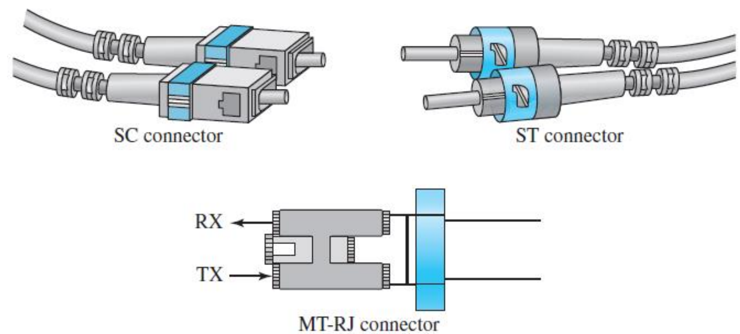

Figure 34. Fiber-optic cable connectors

Applications

- Fiber-optic cable is often found in backbone networks because its wide bandwidth is cost-effective.

Transmission Media: Guided Media (Continue)

Performance

- The plot of attenuation versus wavelength in Figure 35 shows a very interesting phenomenon in fiber-optic cable.
- Attenuation is flatter than in the case of twisted-pair cable and coaxial cable.
- The performance is such that we need fewer (actually onetenth as many) repeaters when we use fiber-optic cable.

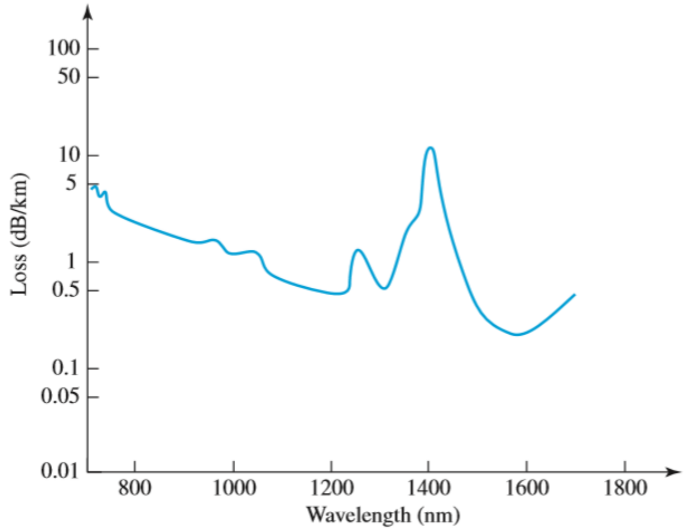

Figure 35. Optical fiber performance

Unguided Media: Wireless

- Unguided medium transport electromagnetic waves without using a physical conductor.
- This type of communication is often referred to as wireless communication.

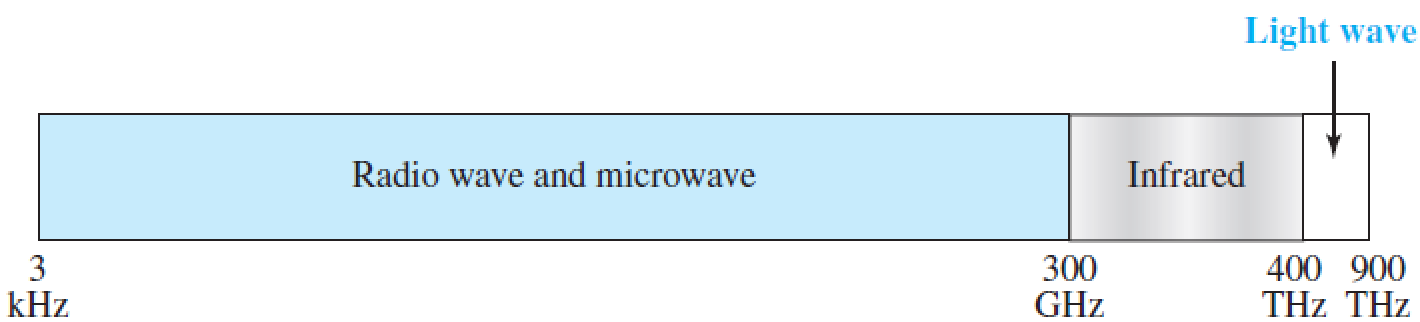

Figure 36. Electromagnetic spectrum for wireless communication

Unguided Media: Wireless (Continue)

- Unguided signals can travel from the source to the destination in several ways: ground propagation, sky propagation, and line-of-sight propagation, as shown in figure 37.

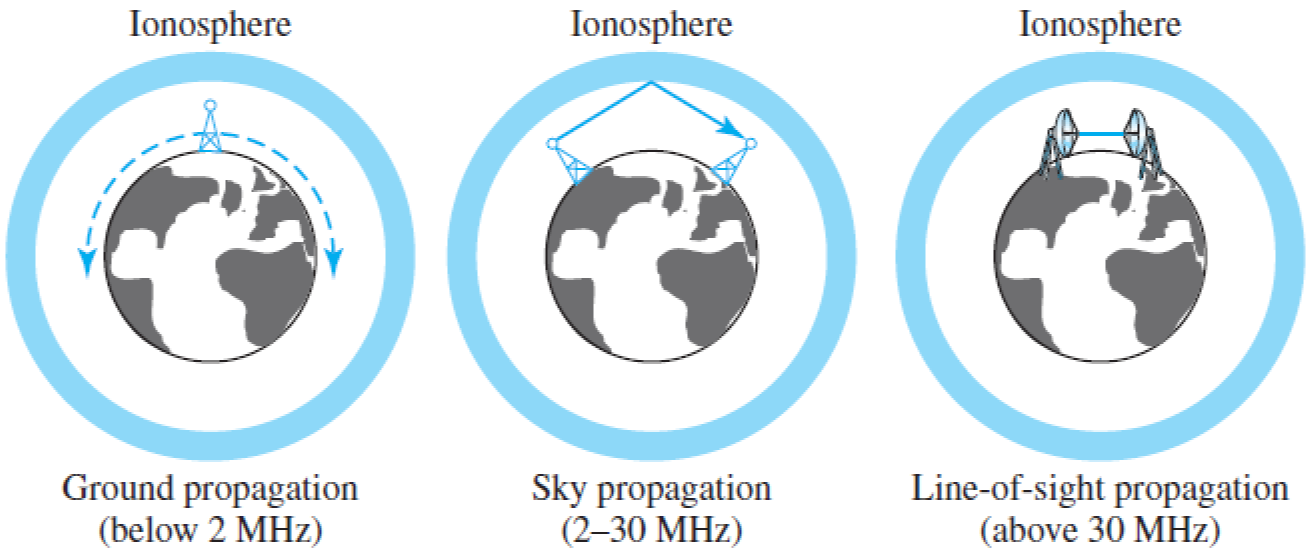

Figure 37. Propagation methods

Unguided Media: Wireless (Continue)

- In ground propagation, radio waves travel through the lowest portion of the atmosphere, hugging the earth.
- In sky propagation, higher-frequency radio waves radiate upward into the ionosphere (the layer of atmosphere where particles exist as ions) where they are reflected back to earth.
- In line-of-sight propagation, very high-frequency signals are transmitted in straight lines directly from antenna to antenna.

Radio Waves

- Electromagnetic waves ranging in frequencies between 3 kHz and 1 GHz are normally called radio waves.

Unguided Media: Wireless (Continue)

Omnidirectional Antenna

- Radio waves use omnidirectional antennas that send out signals in all directions as shown in figure 38.
- Radio waves are used for multicast communications, such as radio and television, and paging systems.

Figure 38. Omnidirectional Antenna

Unguided Media: Wireless (Continue)

Microwaves

- Electromagnetic waves having frequencies between 1 and 300 GHz are called microwaves.
- Microwaves are unidirectional.
- The characteristics of microwave propagation:
  1. Microwave propagation is line-of-sight.
  2. Very high-frequency microwaves cannot penetrate walls.
  3. The microwave band is relatively wide, almost 299 GHz.
  4. Use of certain portions of the band requires permission from authorities.

Unguided Media: Wireless (Continue)

Unidirectional Antenna

- Microwaves need unidirectional antennas that send out signals in one direction.
- Two types of antennas are used for microwave communications: the parabolic dish and the horn as shown in figure 39.

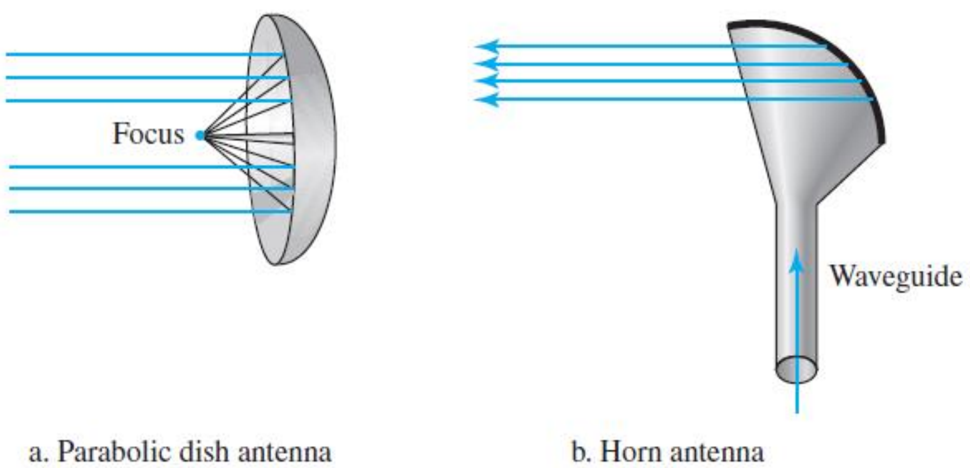

Figure 39. Unidirectional antennas

Unguided Media: Wireless (Continue)

Applications

- Microwaves are used for unicast communication such as cellular telephones, satellite networks, and wireless LANs.

Infrared

- Infrared waves, with frequencies from 300 GHz to 400 THz (wavelengths from 1 mm to 770 nm), can be used for short-range communication. Infrared waves, having high frequencies, cannot penetrate walls.

Topic 3: Switching

Switching: Introduction

- A switched network consists of a series of interlinked nodes, called switches.
- Switches are devices capable of creating temporary connections between two or more devices linked to the switch.
- In a switched network, some of these nodes are connected to the end systems (computers or telephones, for example).
- Others are used only for routing.
- Figure 40 shows a switched network.
- The end systems (communicating devices) are labeled A, B, C, D, and so on, and the switches are labeled I, II, III, IV, and V.
- Each switch is connected to multiple links.

Switching: Introduction (Continue)

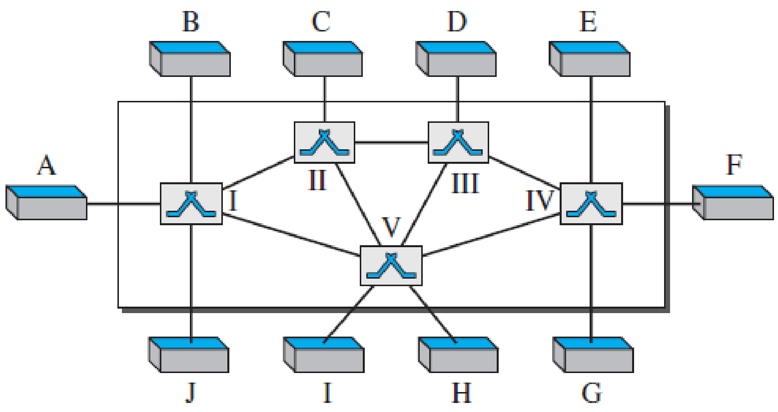

Figure 40. Switched Network

- Three methods of switching are circuit switching, packet switching, and message switching as shown in figure 41.

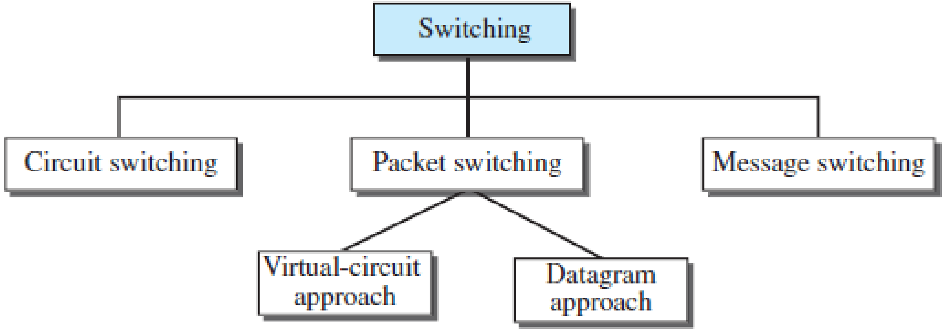

Figure 41. Taxonomy of switched networks

Circuit-Switched Networks

- A circuit-switched network is made of a set of switches connected by physical links, in which each link is divided into n channels.

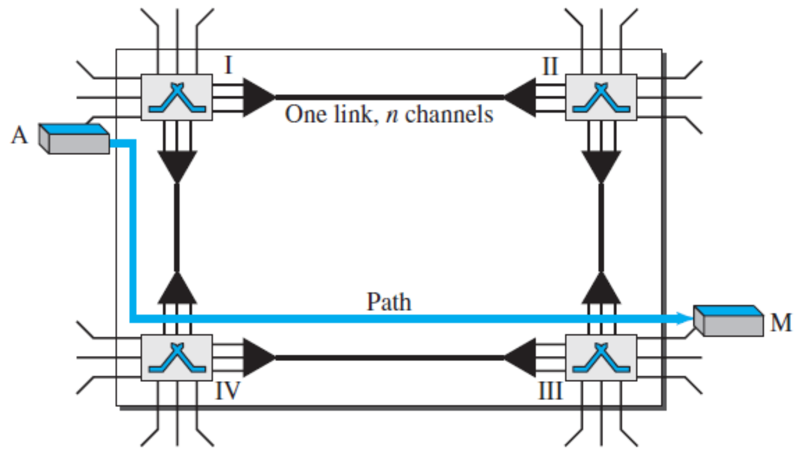

Figure 42. A trivial circuit-switched network

- The end systems, such as computers or telephones, are directly connected to a switch.
- When end system A needs to communicate with end system M, system A needs to request a connection to M that must be accepted by all switches as well as by M itself.

Circuit-Switched Networks (Continue)

- This is called the setup phase; circuit (channel) is reserved on each link, and the combination of circuits or channels defines the dedicated path.
- After the dedicated path made of connected circuits (channels) is established, the data-transfer phase can take place.
- After all data have been transferred, the circuits are torn down.

Three Phases

- The actual communication in a circuit-switched network requires three phases: connection setup, data transfer, and connection teardown.

Setup Phase

- Before the two parties (or multiple parties in a conference call) can communicate, a dedicated circuit (combination of channels in links) needs to be established.

Circuit-Switched Networks (Continue)

- The end systems are normally connected through dedicated lines to the switches, so connection setup means creating dedicated channels between the switches.

Data-Transfer Phase

- After the establishment of the dedicated circuit (channels), the two parties can transfer data.

Teardown Phase

- When one of the parties needs to disconnect, a signal is sent to each switch to release the resources.

Circuit-Switched Networks (Continue)

Delay

- Although a circuit-switched network normally has low efficiency, the delay in this type of network is minimal.
- During data transfer the data are not delayed at each switch; the resources are allocated for the duration of the connection.
- Figure 43 shows the idea of delay in a circuit-switched network when only two switches are involved.

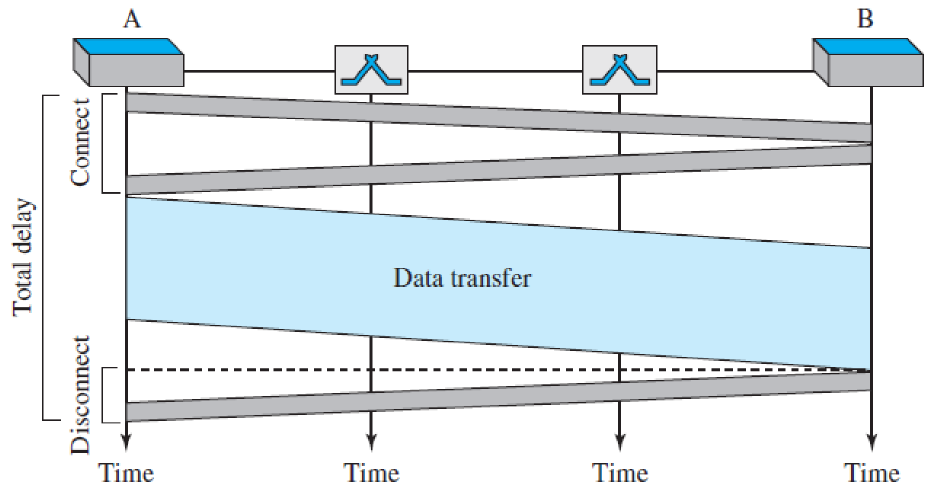

Figure 43. Delay in a Circuit-Switched Network

Packet Switching

- In data communications, it is needed to send messages from one end system to another.
- If the message is going to pass through a packet-switched network, it needs to be divided into packets of fixed or variable size.
- Two types of packet-switched networks are datagram networks and virtual-circuit networks.

Packet Switching (Continue)

Datagram Network

- In a datagram network, each packet is treated independently of all others.
- Packets in this approach are referred to as datagrams.
- Datagram switching is normally done at the network layer.
- Figure 44 shows how the datagram approach is used to deliver four packets from station A to station X.
- The switches in a datagram network are traditionally referred to as routers.
- The datagram networks are sometimes referred to as connectionless networks.

Packet Switching (Continue)

- The term connectionless here means that the switch (packet switch) does not keep information about the connection state.
- There are no setup or teardown phases.

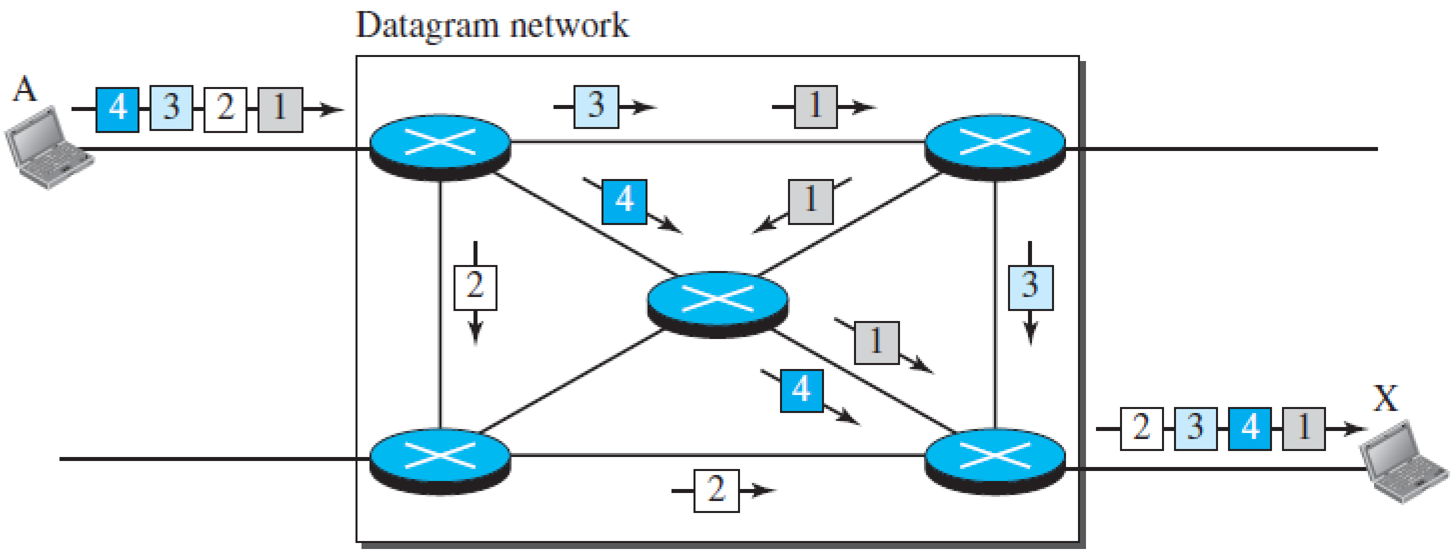

Figure 44. A datagram network with four switches (routers)

Packet Switching (Continue)

Routing Table

- A switch in a datagram network uses a routing table that is based on the destination address.

Destination address	Output port
1232	1
4150	2
⋮	⋮
9130	3

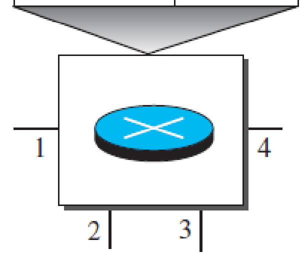

Figure 45. Routing table in a datagram network

Destination Address

- The destination address in the header of a packet in a datagram network remains the same during the entire journey of the packet.

Packet Switching (Continue)

Delay

- There may be greater delay in a datagram network than in a virtual-circuit network.
- Although there are no setup and teardown phases, each packet may experience a wait at a switch before it is forwarded.
- In addition, since not all packets in a message necessarily travel through the same switches, the delay is not uniform for the packets of a message.
- Fig.46 gives an example of delay in a datagram network for one packet.

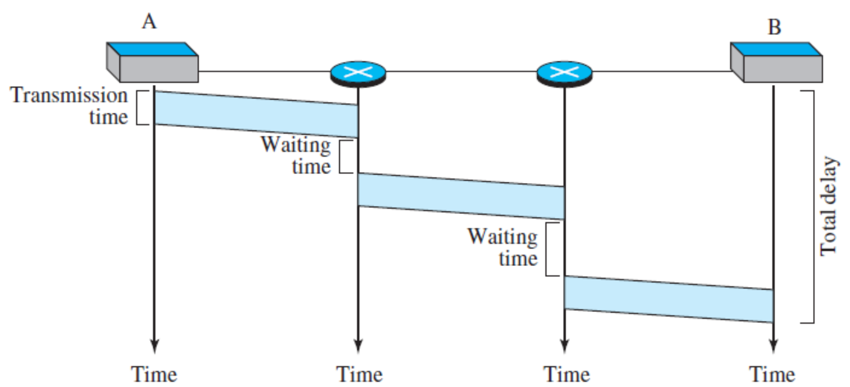

Figure 46. Delay in a Datagram Network

Packet Switching (Continue)

- The packet travels through two switches.
- There are three transmission times (3*T*), three propagation delays (slopes 3τ of the lines), and two waiting times (w1 + w2).
- The processing time is ignored in each switch.
- The total delay is

$$\text{Total delay} = 3T + 3\tau + W_1 + W_2$$

Virtual-Circuit Networks

- A virtual circuit (VC) is a means of transporting data over a packet switched computer network in such a way that it appears as though there is a dedicated physical layer link between the source and destination end systems of this data.

Packet Switching (Continue)

- First packet goes and reserves resources for the subsequent packets which as a result follow the same path for the whole connection time.
- A virtual-circuit network is normally implemented in the data-link layer.

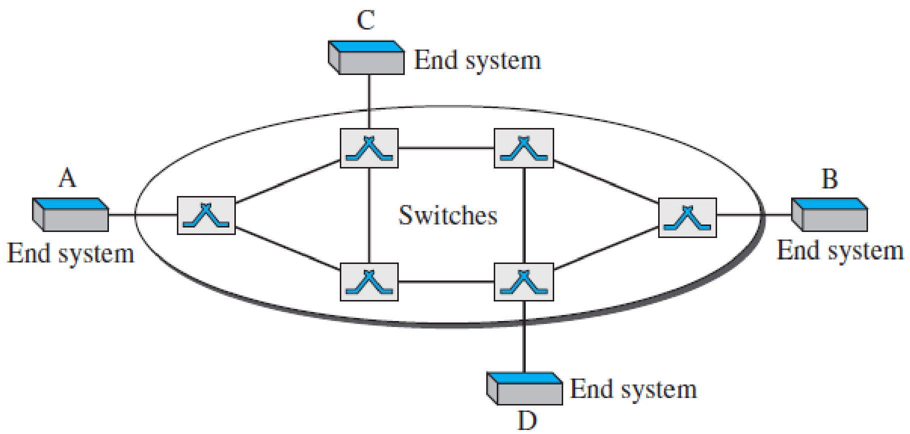

Figure 47. Virtual-Circuit Network

Addressing

- In a virtual-circuit network, two types of addressing are involved: global and local (virtual-circuit identifier).

Packet Switching (Continue)

Global Addressing

- A source or a destination needs to have a global address—an address that can be unique in the scope of the network or internationally if the network is part of an international network.

Virtual-Circuit Identifier

- The identifier that is actually used for data transfer is called the virtual-circuit identifier (VCI) or the label.

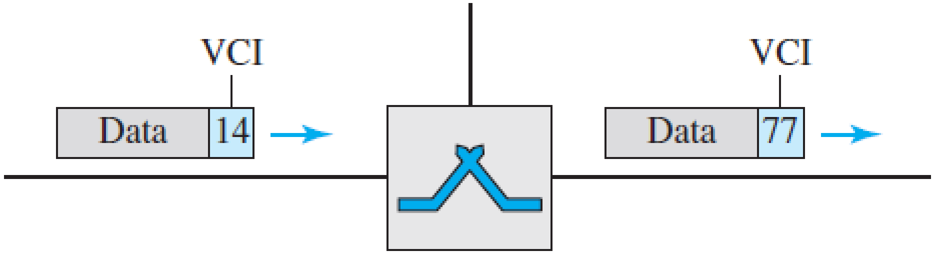

Figure 48. Virtual-Circuit Identifier

Packet Switching (Continue)

Three Phases

- As in a circuit-switched network, a source and destination need to go through three phases in a virtual-circuit network: setup, data transfer, and teardown.

Data-Transfer Phase

- To transfer a frame from a source to its destination, all switches need to have a table entry for this virtual circuit.
- Figure 49 shows a frame arriving at port 1 with a VCI of 14.
- When the frame arrives, the switch looks in its table to find port 1 and a VCI of 14.

Packet Switching (Continue)

- When it is found, the switch knows to change the VCI to 22 and send out the frame from port 3.
- Figure 50 shows how a frame from source A reaches destination B and how its VCI changes during the trip.
- Each switch changes the VCI and routes the frame.

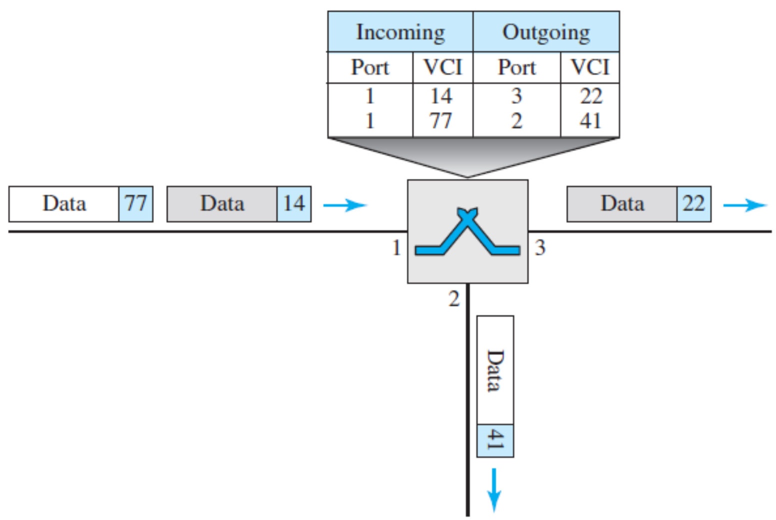

Figure 49. Switch and tables in a virtual-circuit network

Packet Switching (Continue)

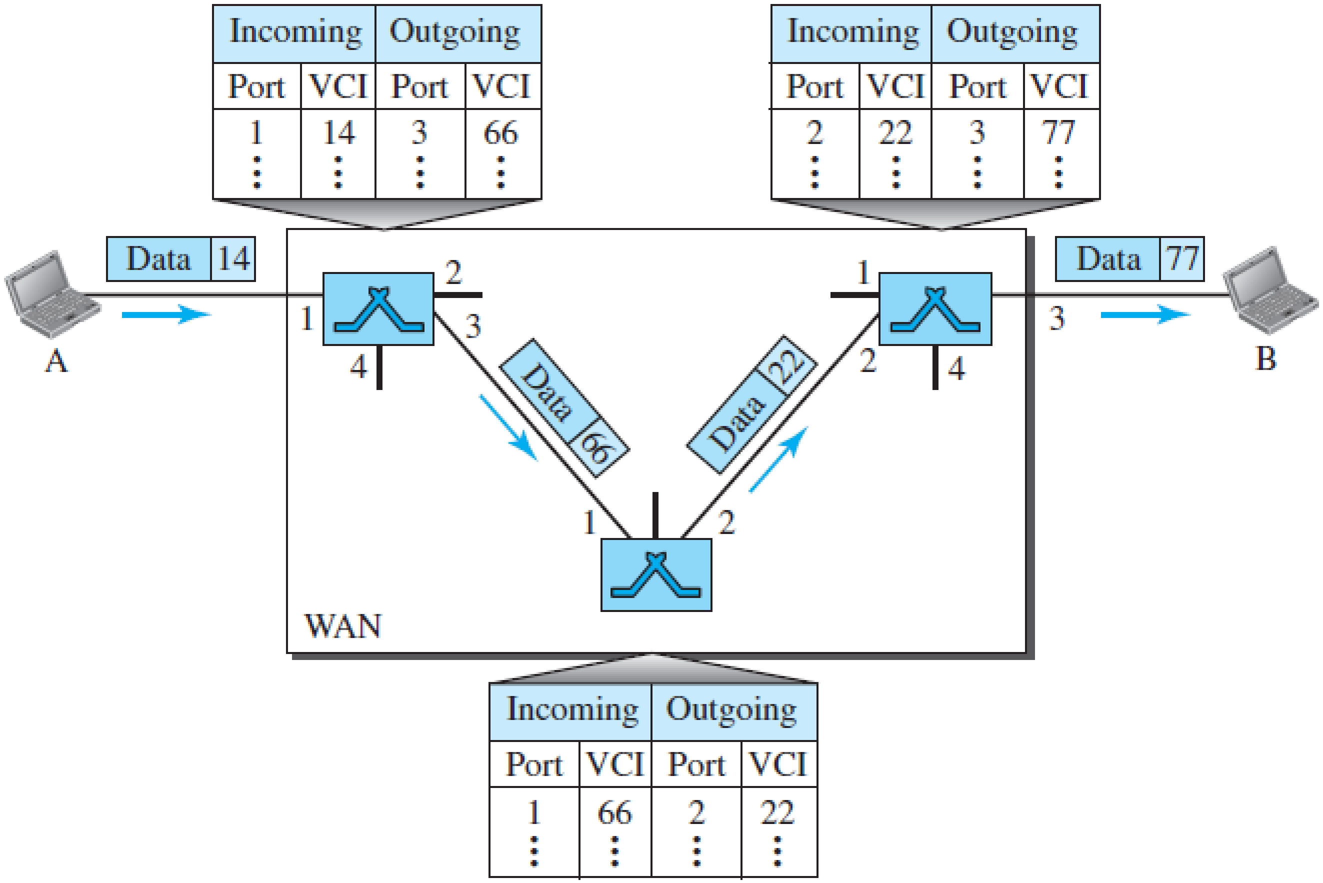

Figure 50. Source-to-destination data transfer in a virtual-circuit network

Packet Switching (Continue)

Setup Phase

- In the setup phase, a switch creates an entry for a virtual circuit. For example, suppose source A needs to create a virtual circuit to B.
- Two steps are required: the setup request and the acknowledgment.

Setup Request

- A setup request frame is sent from the source to the destination.
- Figure 51 shows the process.

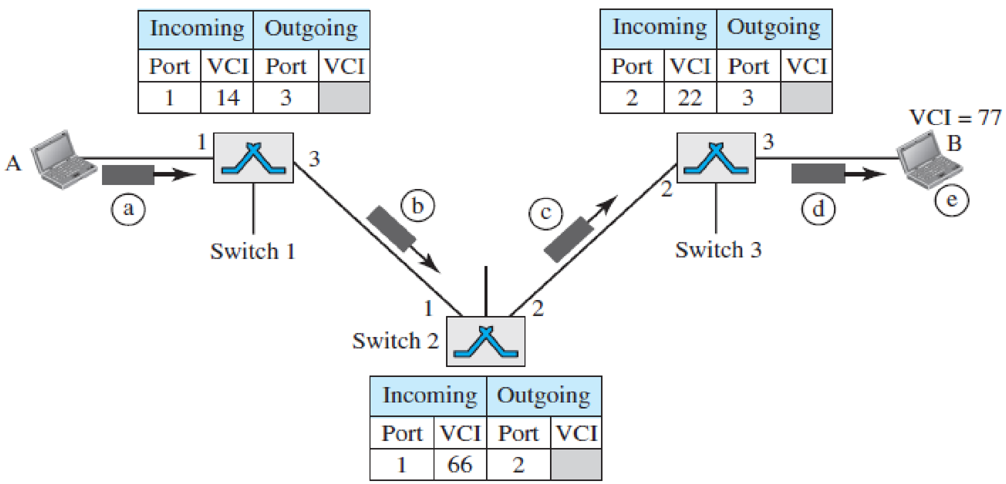

Figure 51. Setup request in a virtual-circuit network

Packet Switching (Continue)

Acknowledgment

- A special frame, called the acknowledgment frame, completes the entries in the switching tables.
- Figure 52 shows the process.

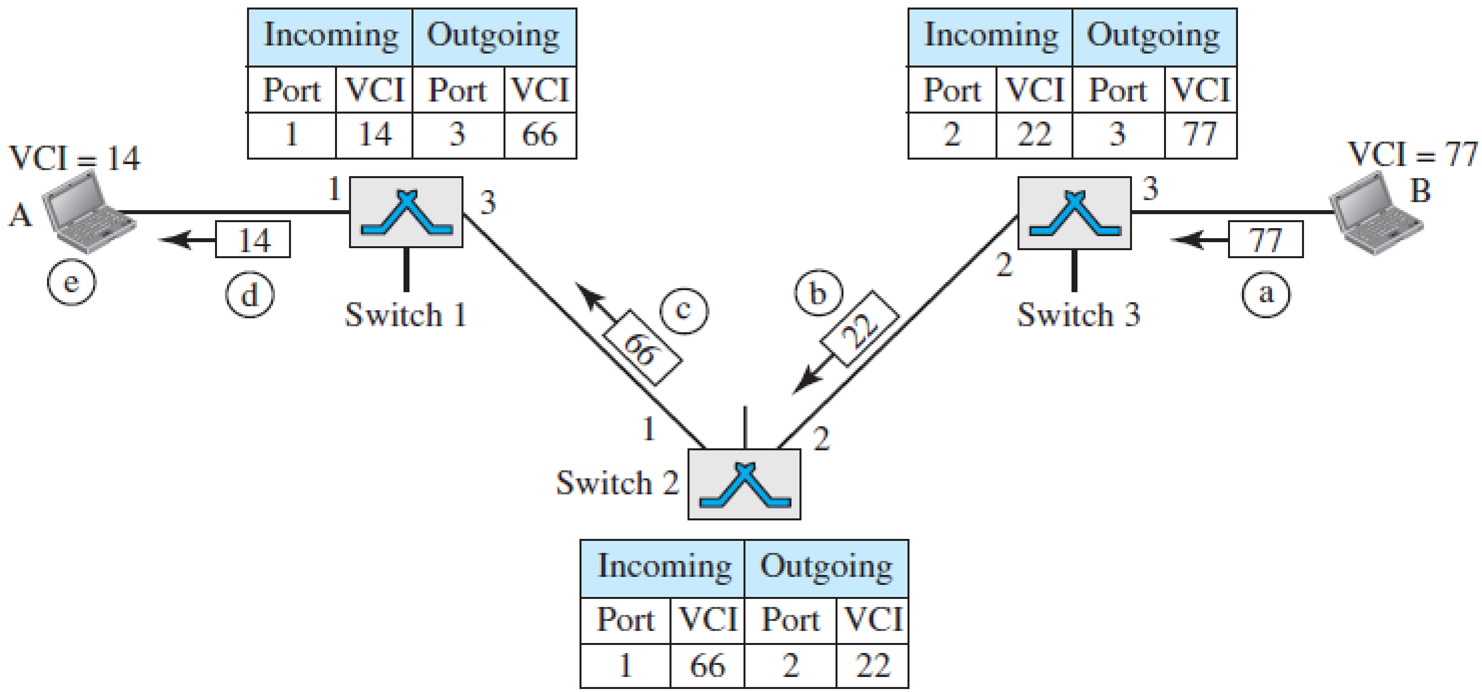

Figure 52. Setup Acknowledgment in a Virtual-Circuit Network

Packet Switching (Continue)

Teardown Phase

- In this phase, source A, after sending all frames to B, sends a special frame called a teardown request.
- Destination B responds with a teardown confirmation frame.
- All switches delete the corresponding entry from their tables.

Delay in Virtual-Circuit Networks

- In a virtual-circuit network, there is a one-time delay for setup and a one-time delay for teardown.
- If resources are allocated during the setup phase, there is no wait time for individual packets.
- Figure 53 shows the delay for a packet traveling through two switches in a virtual-circuit network.

Packet Switching (Continue)

- The packet is traveling through two switches (routers).
- There are three transmission times ($3T$), three propagation times (3τ), data transfer depicted by the sloping lines, a setup delay, and a teardown delay.
- The processing time is ignored in each switch.
- The total delay time is

$$\text{Total delay} = 3T + 3\tau + \text{setup delay} + \text{teardown delay}$$

- Switching at the data-link layer in a switched WAN is normally implemented by using virtual-circuit techniques.

Packet Switching (Continue)

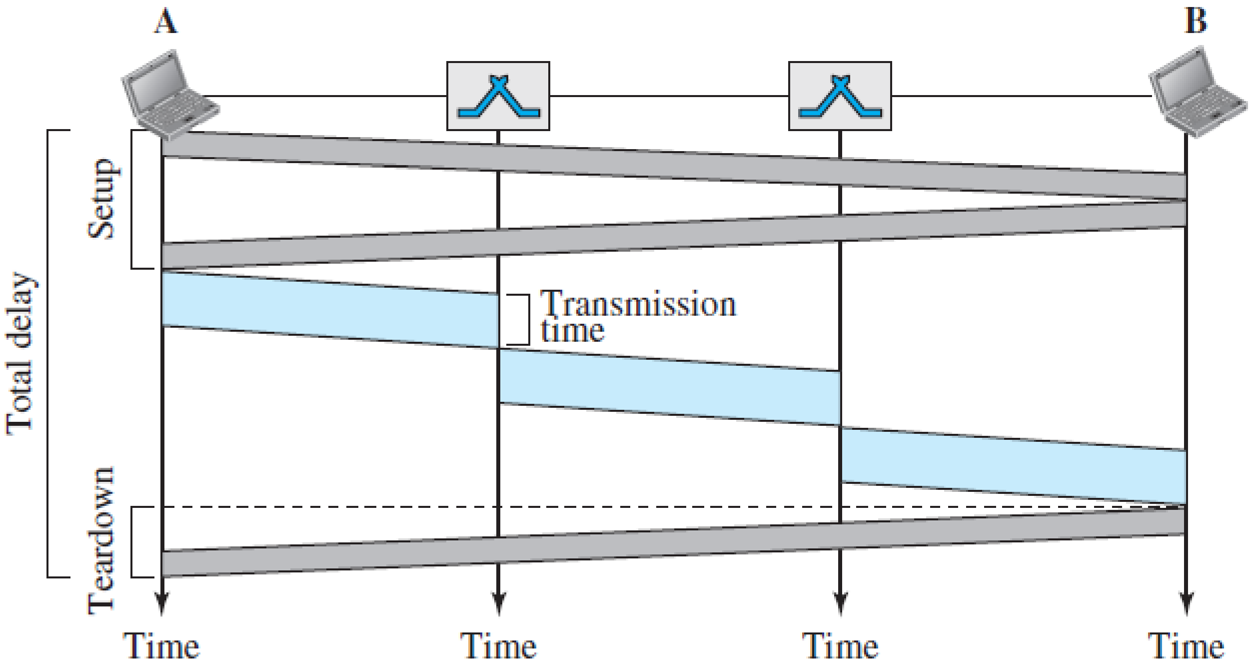

Figure 53. Delay in a Virtual-Circuit Network

Next Week Lecture

- Introduction to Data-Link Layer
- Error Detection and Correction
- Data Link Control (DLC)
- Media Access Control (MAC)

Thank You