Chapter 3

Internet Connectivity: Fundamental Issues

Computer Networks

- A computer network is the infrastructure necessary for the transportation of information between two or more computer systems

Computer-to-Network Interface

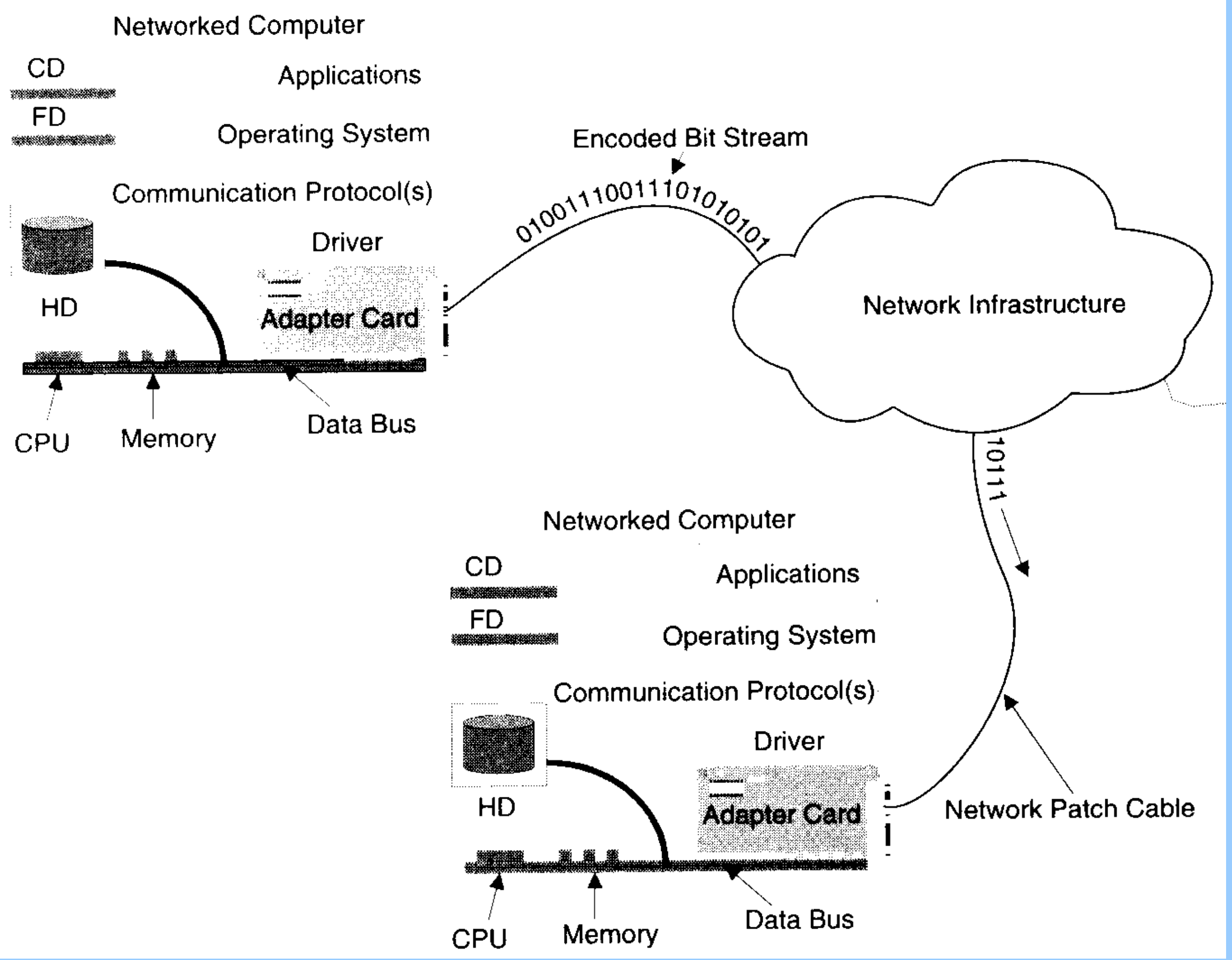
- Host systems connect to the network through an *adapter card,* often called a *network interface card (NIC)*
  - Adapter cards connect to the host's internal data bus that allow it to communicate with the central processing unit (CPU)
  - Adapter cards interact with specific software communication components (communication protocols and operating system) using a *driver*
  - *Binding* interfaces the communication protocol to the adapter card driver

Computer-to-Network Interface

- The host's operating system allocates resources to its devices
  - Device examples: disk drives, NIC, printer
  - Resource examples: memory, processor time
  - Operating system is critical to successful communication
- Operating system interacts with applications
- OSI model (as well as TCP/IP) encompasses all of these components
  - Provides structure to communication process

Conceptual View of Computer Networking

FIGURE 3.1
A conceptual view of computer networking.



Types of Networks - Geographic Area

- Local area network (LAN)
  - Small area: building or campus
  - Owned by single entity
  - Usually large capacity (bandwidth)
  - Technologies include
    - Ethernet
    - Token ring
    - Fiber distributed data interface (FDDI)

Types of Networks - Geographic Area

- Metropolitan area network (MAN)
  - Large area: span all or part of a metropolitan area
  - Owned by a public utility or private company
  - Has medium to large capacity
  - Technologies include
    - Synchronous optical network (SONET)
    - Asynchronous transfer mode (ATM)

Types of Networks - Geographic Area

- Wide area network (WAN)
  - Large area: spans city, state, country, and/or world
    - Interconnect LANs and MANs
  - Owned by communications carriers
  - Has moderate to very large capacity
  - Technologies include:
    - Frame relay
    - Point-to-point T-carrier, OC-carrier
    - ATM
    - Satellite
    - Point-to-point microwave

Digital Telephony

- Original WANs carried voice traffic
  - Telephones are analog devices
  - Original networks were all analog
  - Evolved into digital networks in 1960s
    - Analog phone call converted to digital at telephone company central office (CO) for residential customers
      - Company may have digital connection to CO, so conversion to digital is done on company premesis
    - Digital traffic between telephone company central offices, long distance calls, etc.
    - Converted back to analog for transmission to final destination
      - May happen at CO for residential customers
      - May happen at customer location for large customers

Digitizing Signals

- Analog voice signals are converted to digital using analog-to-digital (A/D) converters
  - Sample the analog signal
  - Samples are quantized into digital numbers

Digitizing Signals

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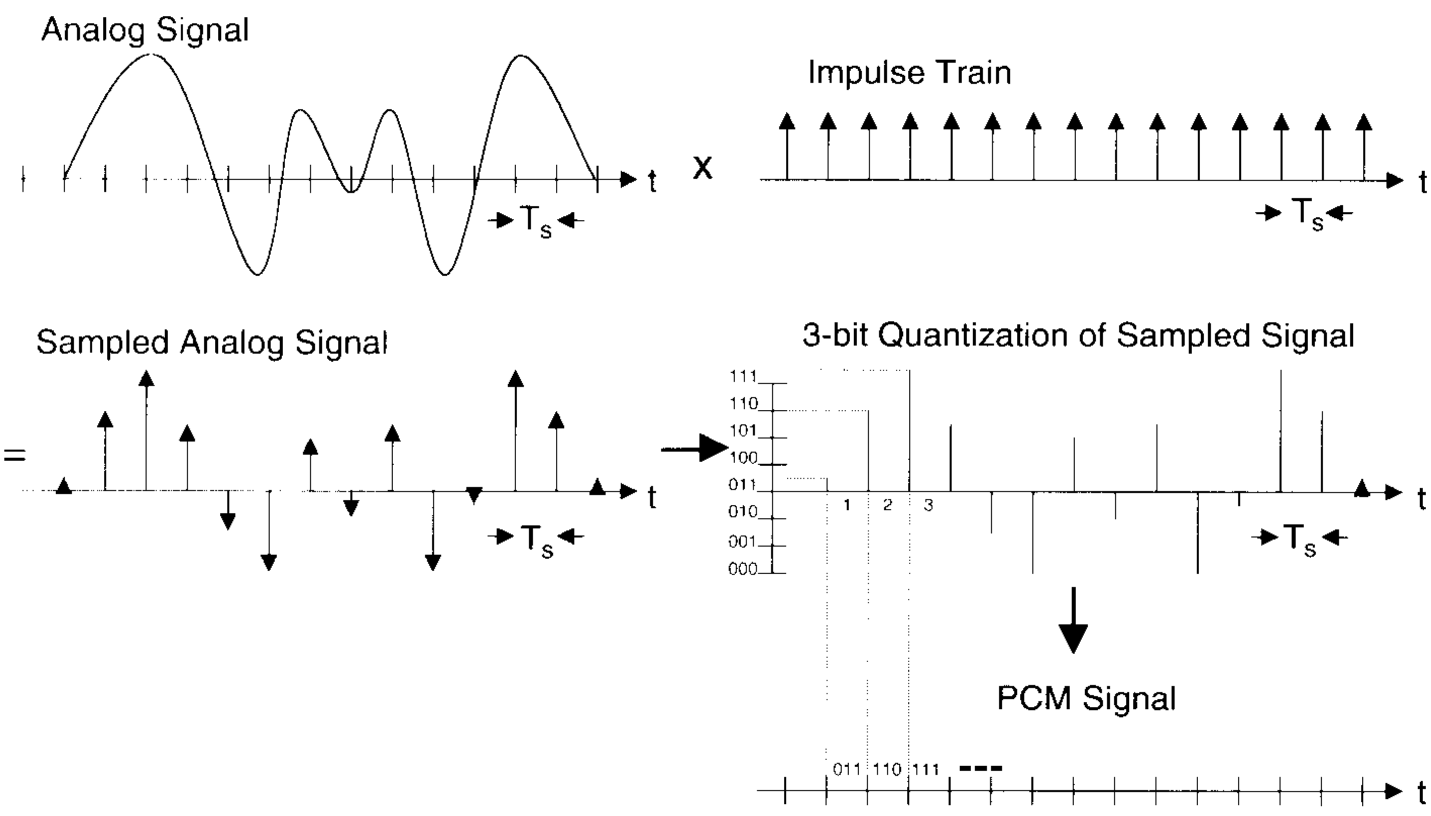
  - Sample the analog signal
  - Samples are quantized and encoded into digital numbers

Digitizing Signals

FIGURE 3.2
Analog-to-digital conversion and PCM.



Digitizing Signals

- Analog signal sampled at predetermined rate
  - Sample rate must be at least twice the highest frequency in the analog signal
    - Nyquist rate = 2 x f_{max}

      where f_{max} is the highest frequency in the signal
  - Sampling is like multiplying an impulse train by the analog signal
    - Result is amplitude-modulated impulses (weighted impulses)

Digitizing Signals

- Modulated impulses are *quantized*
  - Impulse height is rounded to nearest discrete level
    - Levels determined by resolution of quantizer
    - Number of bits determines resolution of quantizer
    - Example: 8-bit quantizer has 256 different codes, so a 4 V peak-to-peak signal will have 4V/256 = 15.625mV per bit resolution
- Quantized impulses are converted to digital codes by the *encoder*
- PCM is a particular A/D conversion process (digitizing, quantizing, and encoding)
  - Used in telephone voice circuits
- CODEC - device that performs PCM A/D and D/A conversion

Telephone Voice Channel

- Telco allocates a 0 Hz to 4000 Hz channel for each call
  - Signal is filtered to occupy 280 Hz to 3400 Hz
- Sampled at 8 kHz
  - What is Nyquist rate for voice channel?
- 8-bit quantization is used
- 8 bits/sample x 8000 samples/sec = 64 kbps

Asynchronous Transmission

- With asynchronous communication, bit timing information is not sent with the data
  - Rely on start and stop bits to indicate where blocks of data begin and end
  - Usually consists of sending single characters encoded using schemes such as ASCII (American Standard Code for Information Exchange)
  - Example: dialup modems use asynchronous communication
    - Receiver has an internal clock that is used for decoding
    - Clock is "as close as possible" to encoding clock frequency
      - Works well for short data blocks
      - Long data blocks can cause errors due to difference in clock frequencies

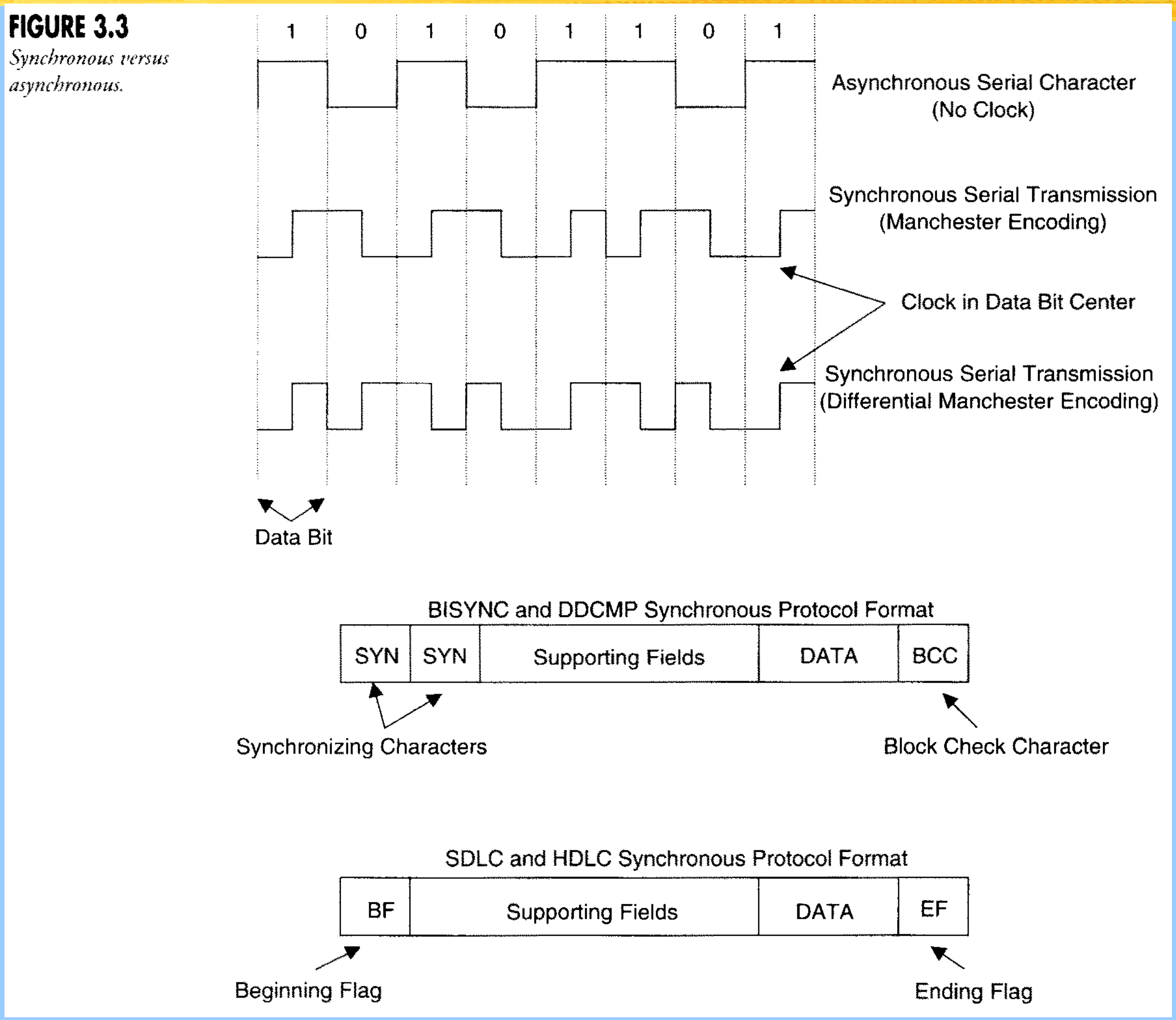
Synchronous Transmission

- With synchronous communication, bit timing information is sent with the data
  - Some schemes use a “preamble” at the beginning of the frame
    - Preamble contains synchronizing characters consisting of alternating 1 and 0 bits that synchronize the receiver’s clock so it is the same frequency as the transmitter’s
    - Thus, same clock is used at receiver that was used to encode data at transmitter
  - Data entering synchronous networks leave at the same rate
    - Good for real-time voice

Synchronous Transmission

- Examples of systems using synchronous communication
  - Telephone network
  - Ethernet
  - Token ring
  - HDLC - High-Level Data Link Control

Synchronous vs. Asynchronous



Multiplexing

- Multiplexing is the process of selectively combining the input from several sources onto a single communication channel

TDM and FDM

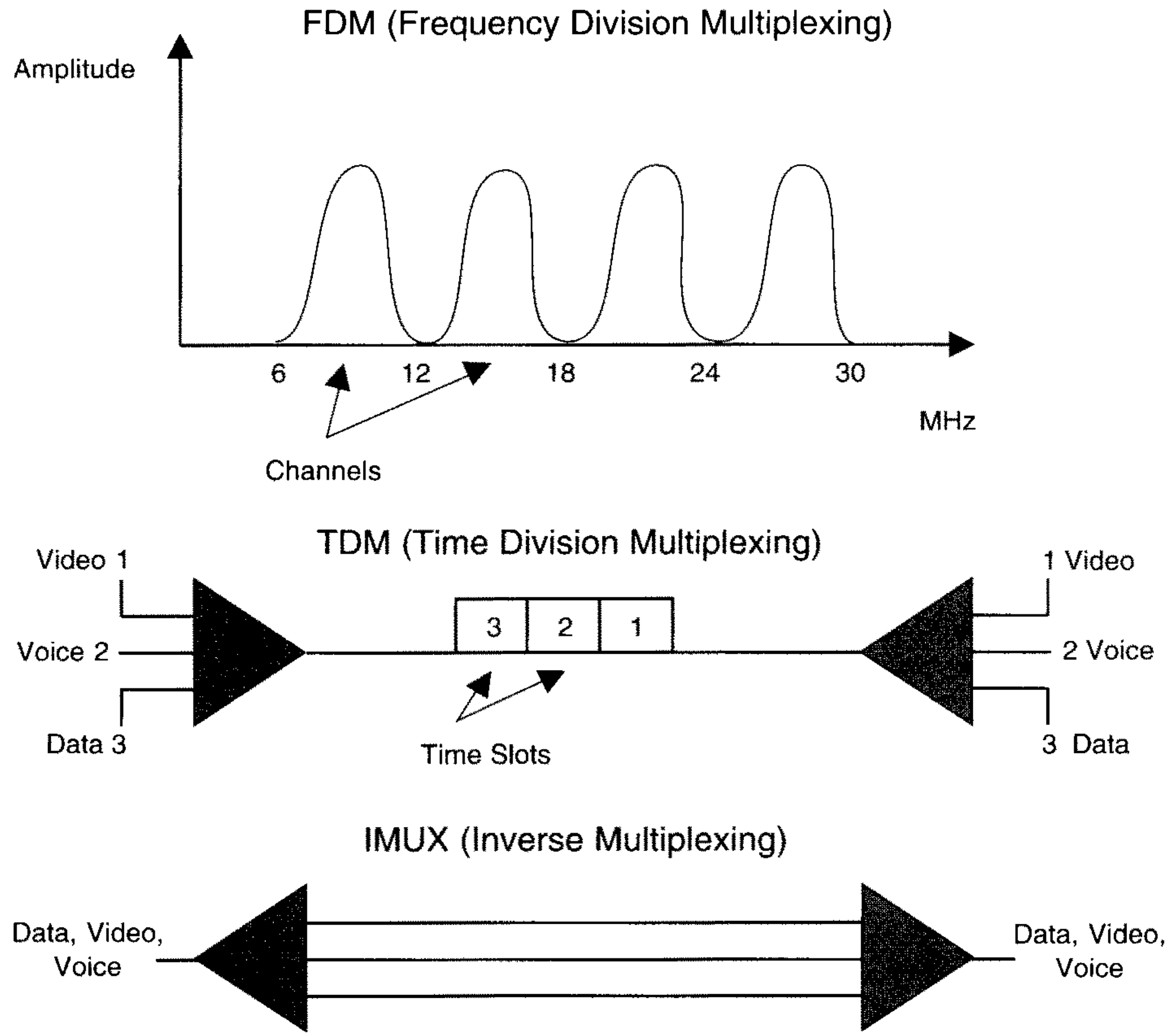


FIGURE 3.4
FDM versus TDM.

Time Division Multiplexing (TDM)

- Multiplexes signal sources into different time slots
- Time slots are organized into frames
- Example: T1 carrier
  - Originally designed to carry telephone call traffic
  - Later adapted to handle data
  - Each T1 frame has 24 time slots
    - Each time slot contains a single 8-bit sample from a telephone call (or data source)
    - Each frame adds 1 synchronizing bit to the end

Statistical Multiplexing

- Similar to TDM
- Differences
  - Each channel does not get a fixed, designated time slot
  - Multiplexer can allocate more than one slot to a single source when needed
- Advantage
  - Channels get adjustable capacity depending on circuit load

Frequency Division Multiplexing (FDM)

- Information from signal sources are allocated channels in a frequency band
- Examples
  - Broadcast TV
  - Cable TV, cable modem
  - Wireless telephone

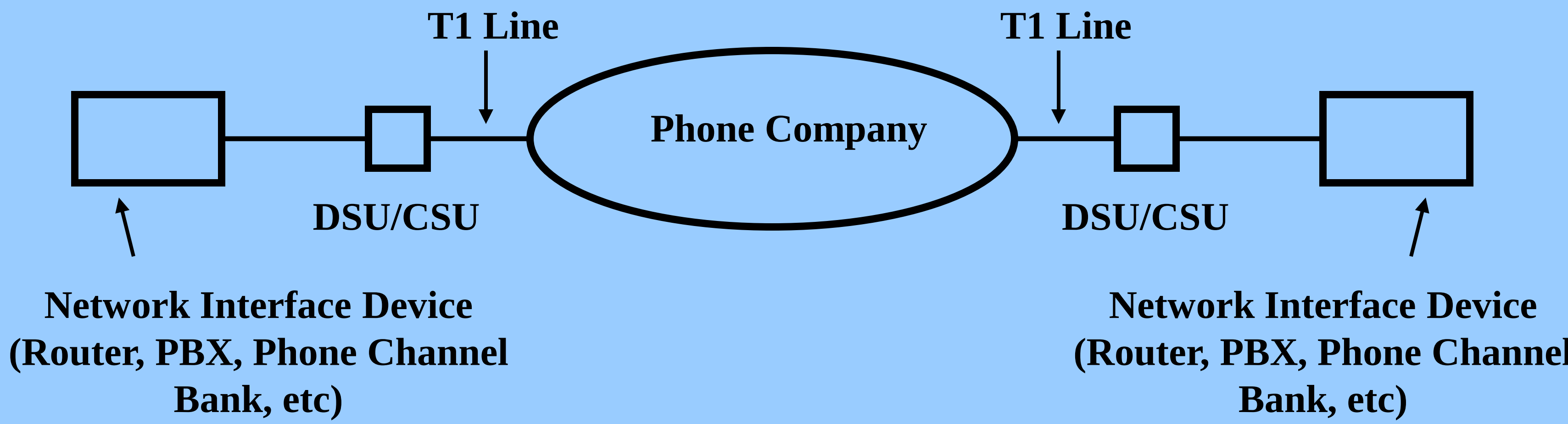
Wavelength Division Multiplexing (WDM)

- Used for fiber optic transmission
- Same as FDM except fiber optic terminology refers to wavelength instead of frequency

T1 Line

- Special leased point-to-point line between business and telephone company central office
- Interface device needed to convert from LAN data format to TDM format
  - Data Service Unit / Channel Service Unit (DSU/CSU)
    - CSU manages control functions
    - DSU converts data
- T1 line is expensive
  - >$1000 per month
  - Always connected
  - Requires telco to set up expensive equipment on line

T1 Line



T1 Line
T1 Line
Phone Company
DSU/CSU
DSU/CSU
Network Interface Device
(Router, PBX, Phone Channel
Bank, etc)
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T-Carrier Standards

- Telco has hierarchy of digital TDM “carriers”
  - Digital signals travel on the digital carrier
    - DS-0, DS-1, . . . , DS-5

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  - Digital signals travel on the digital carrier
    - DS-0, DS-1, . . . , DS-5
  - T-carrier refers to the “physical” line standard
  - DS signal refers to the “data link” standard

T-Carrier Designations

Line Type	Digital Signal	TDM Voice Channels	Transmission Rate	Medium
	DS-0	1	64 kbps	1 wire pair
T1	DS-1	24	1.544 Mbps	2 wire pairs
T2	DS-2	96 (4 T1)	6.312 Mbps	Wire pairs, fiber
T3	DS-3	672 (28 T1)	44.736 Mbps	Coax, MW, fiber
T4	DS-4	4032 (168 T1)	274.176 Mbps	Coax, MW, fiber
T5	DS-5	8064 (336 T1)	560.160 Mbps	Coax, fiber

Optical Carrier Circuits

- Optical carriers (OC-carriers) are high capacity and are used in fiber optic links
  - Synchronous Transport Signal (STS)
    - STS-1, STS-2, . . .
  - OC-carrier refers to the “physical” line standard
  - STS signal refers to the “data link” standard

Optical Carrier Designations

Carrier	STS	TDM Voice Channels	Transmission Rate
OC-1	STS-1	810	51.840 Mbps
OC-3	STS-3	2430	155.520 Mbps
OC-12	STS-12	9720	622.080 Mbps
OC-24	STS-24	19,440	1.244 Gbps
OC-48	STS-48	38,880	2.488 Gbps
OC-96	STS-96	77,760	5.976 Gbps

Data Compression

- Reduces the number of bits to be transmitted on a link
  - Compression algorithm used on sending host
  - Decompression algorithm used on receiving host
- Algorithms exploits bit patterns and/or byte patterns in files
  - Inserts a fewer number of bits to represent the original bits in the file
  - File sizes are reduced prior to transmission

Network Topologies

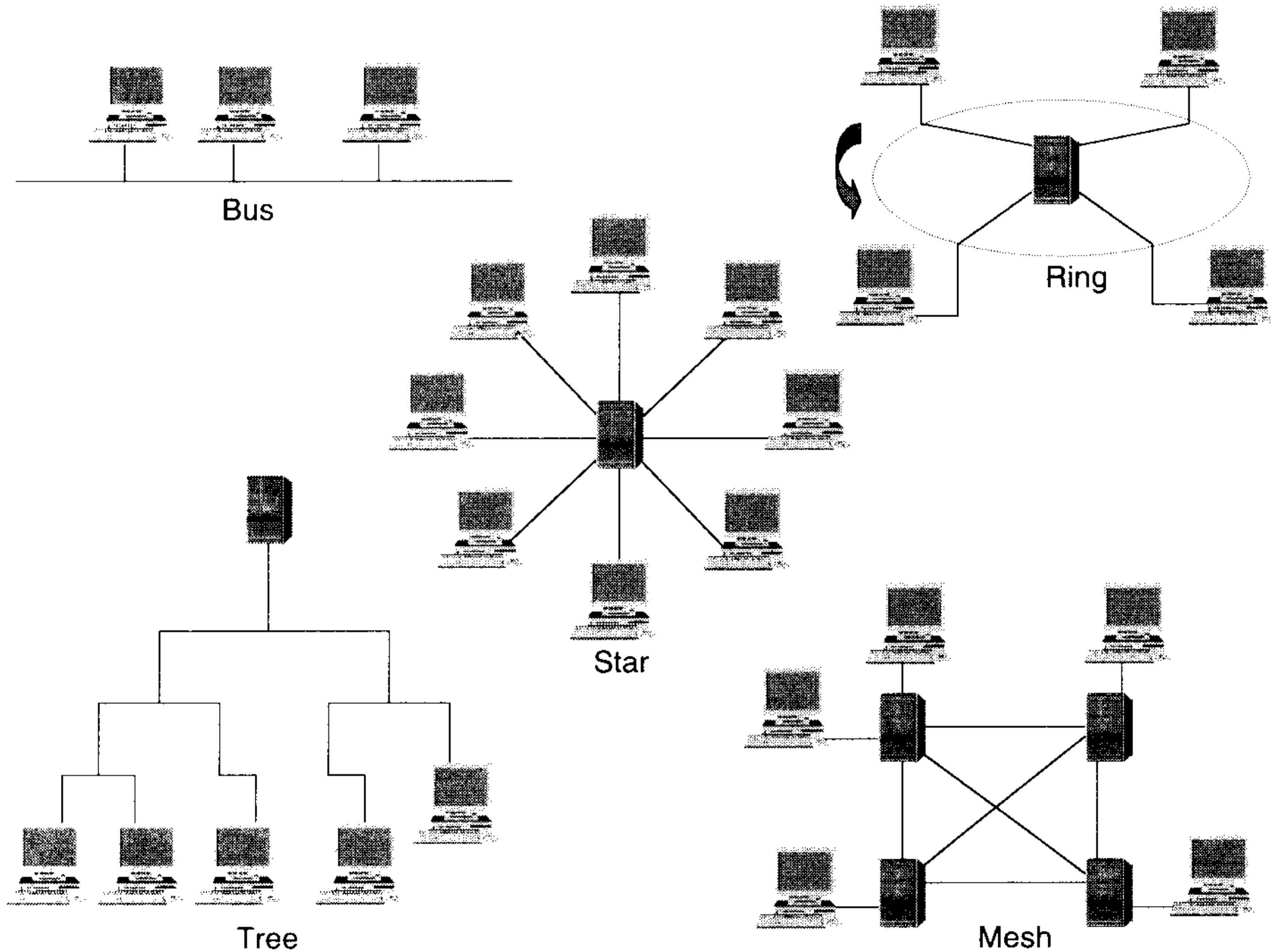
- Topology refers to the way network entities are connected together
  - Physical topology
    - How devices are physically connected
  - Logical topology
    - How devices logically interact with each other
  - Example
    - A logical bus is often connected as a physical star

Popular Topologies

- Bus
- Ring
- Star
- Tree
- Mesh

Topologies

FIGURE 3.5
Network topologies.



Bus Topology

- Shared medium
- All nodes receive transmissions from any node on the bus
- Access to transmit on bus controlled by protocol
  - Attempts to ensure that only one node transmits at a time
  - Nodes trying to transmit at same time cause a *collision*
    - Protocol sorts out who gets to transmit after collision occurs
- Example: Ethernet

Ring Topology

- System of repeaters connected in a loop
  - All hosts on ring contain a repeater
  - Repeater reads data frame address
    - If addressed to that host, repeater passes copy of frame to host's upper protocol layers, then passes original frame on to next host
    - If not addressed to that host, repeater just passes original frame on to next host
  - Only one node can transmit and receive at a time
- Examples: SONET ring, token-ring LAN

Star Topology

- Hosts connected to a central node
  - Forms a star
- Hosts communicate with each other through the central node
- Examples: Arcnet, Older mainframe/terminal arrangements
- Special example:
  - Ethernets are logical busses but can be connected in physical star
  - Token-rings are logical rings, but can be connected in physical star

Tree Topology

- Hierarchical arrangement of nodes that appears like a tree
- Root of tree is called *headend*
- Example: one-way downstream cable TV channel delivery
  - CATV changing to allow some upstream communication
    - Cable modem

Mesh Topology

- System of interconnected nodes
  - Creates redundant paths
- Fully-connected mesh is where all nodes are connected to all other nodes
  - Creates a very complicated network
  - Most meshes are not fully-connected
  - Is the example in Fig. 3-5 fully-connected?
- Examples: telephone network, the Internet, Frame Relay

Switching

- WANs have used switching techniques to move data
- Circuit switching traditionally used by telephone company
- Packet switching used in modern data networks

Circuit Switching

- Voice and/or data is transported across the network on a dedicated circuit
- Three phases
  - Connection establishment
    - Relies on a signaling protocol to set up connection
    - Example: dialing a phone number initiates the signaling protocol to set up a voice circuit path
  - Data transfer
  - Connection termination
- Data move across network in constant bit rate

Packet Switching

- Data is segmented into packets, each containing routing information
  - May just be a destination address
  - May include a complete route
- Routing nodes in networks use packet routing information to decide which path to send packet
  - Small delays created at each routing node to process packet routing information
- Data moves across network at a variable bit rate

Connectionless Packet Switching

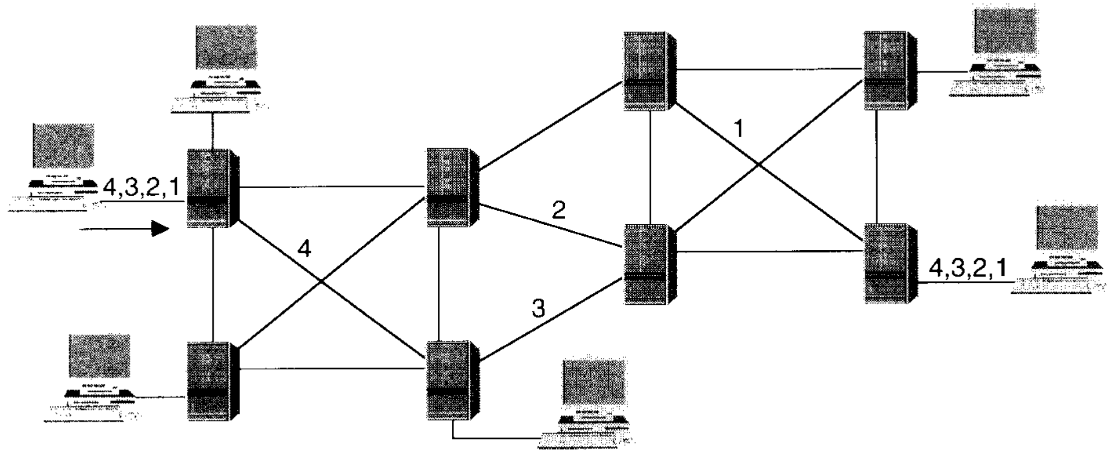
- Packets that are part of a single session may follow different paths to destination
- Independent packets known as *datagrams*

Connection-Oriented Packet Switching

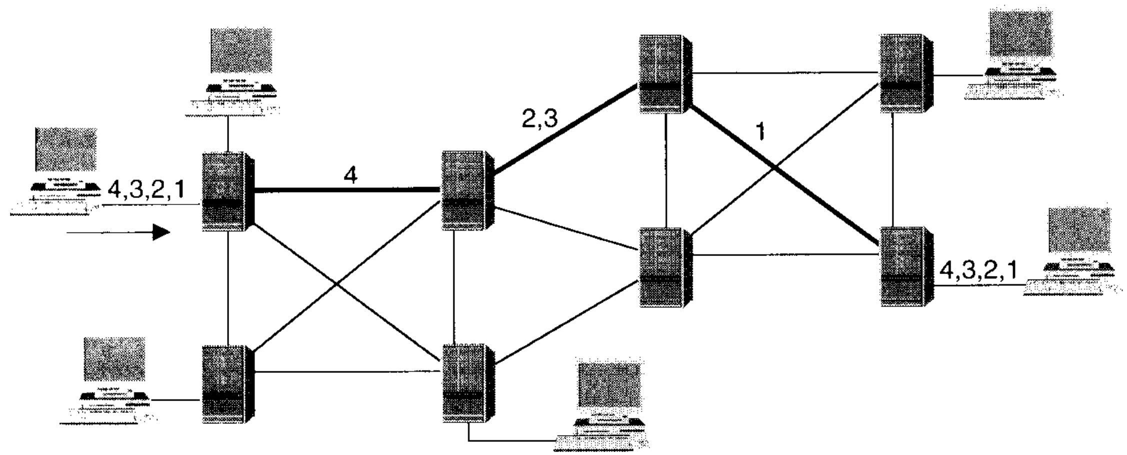
- Also known as virtual circuit
- Packets follow the same path to destination
  - Packets sent from source may contain complete list of intermediate routers (source routing), or
  - Packets may have a connection identifier number
    - Intermediate routers read the connection identifier and send the packet on a pre-determined path
    - Path determined during connection establishment

Packet Switching

FIGURE 3.6
Packet switching.



Packet Switching—Datagram



Packet Switching—Virtual Circuit

Connection Oriented Confusion

- Is it the same thing when we call TCP a "connection-oriented" protocol and then talk about connection-oriented routing?
  - With respect to TCP, connection-oriented refers to establishing and maintaining a reliable connection so that all packets will be delivered between hosts and does not mean that the IP packets will follow a fixed route
  - Connection-oriented routing means the packets follow a fixed route
- Similarly, UDP is a connectionless protocol, but this has nothing to do with the way the packets are routed

Matrix Switching

- Commonly used in LANs
- A switch “matrix” is used where all hosts can be directly connected to each other by the switch
  - Can be unicast, multicast, or broadcast (one-to-one, one-to-many, or one-to-all)
- Used in MAC layer of switched Ethernet networks
  - No longer a shared medium
  - Hosts not in destination address of MAC frame do not see the frame!!

Multi-Rate Circuit Switching

- Refers to moving data to (or from) a lower bit rate path from (or to) a higher bit rate path
- This technique is used to multiplex 28 T1 lines on to a single T3 line

Internetworking Devices

- Many different types
- Main ones
  - Repeaters
  - Bridges
  - Routers
  - Gateways
- Functions of these devices may be combined in one

Internetworking Devices

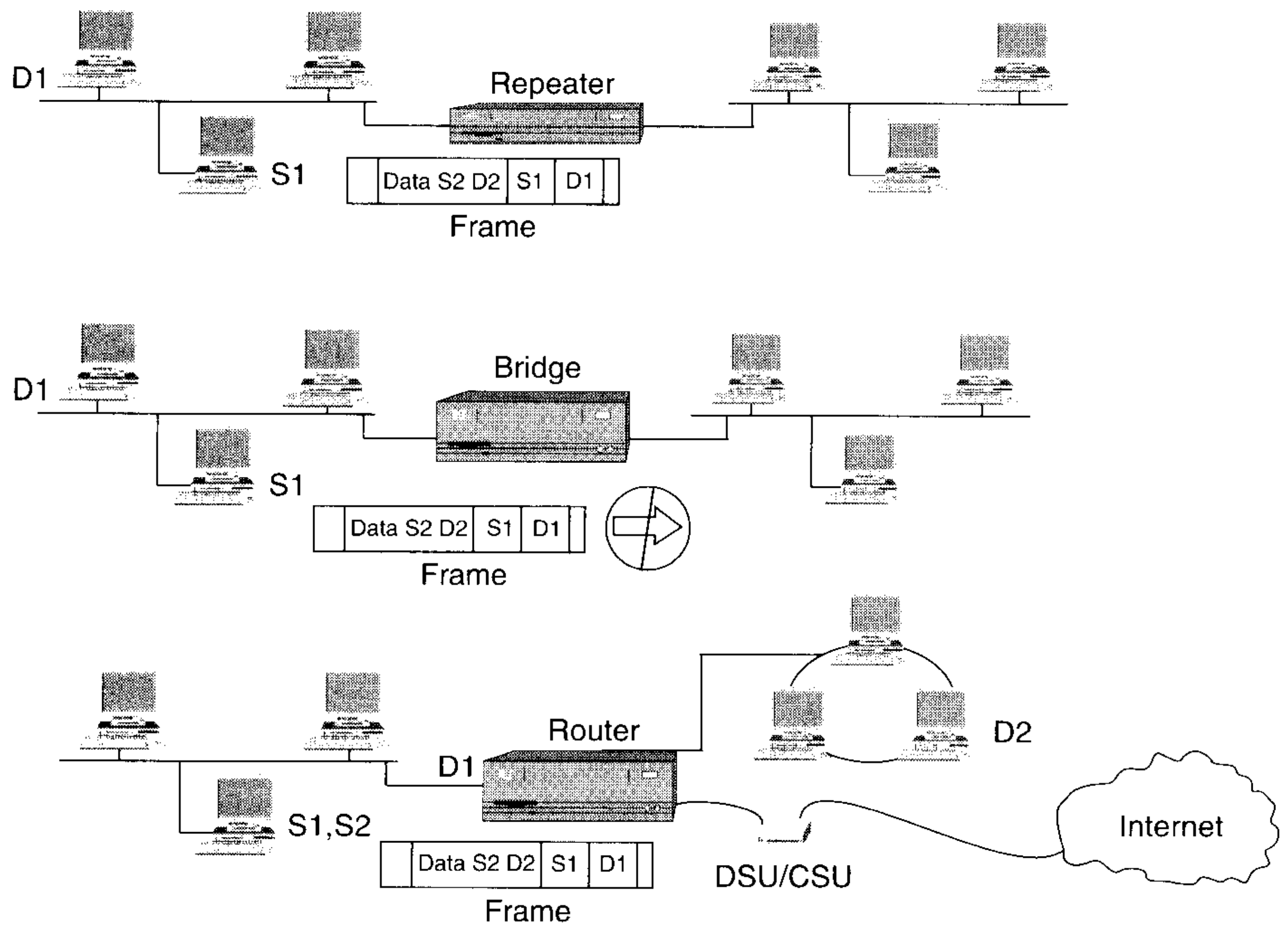


FIGURE 3.7
Internetworking devices.

Repeater

- Extends the size of a LAN by interconnecting multiple segments
- Data received at input port is copied and re-sent to all output ports
- Operates at OSI layer 1
  - Can interconnect different types of media like coax and twisted pair
  - Cannot interconnect different data-link (layer 2 protocols) like token-ring and Ethernet

Bridge

- Expands LAN size by interconnecting segments but can also segregate data traffic between segments
- Bridge "learns" MAC addresses of hosts and which segment the host is on
  - Develops a routing table of MAC addresses
- Traffic between hosts on same segment is not transmitted across the bridge to another segment
- Traffic from a host on one segment having destination address of a host on another segment is transmitted across the bridge

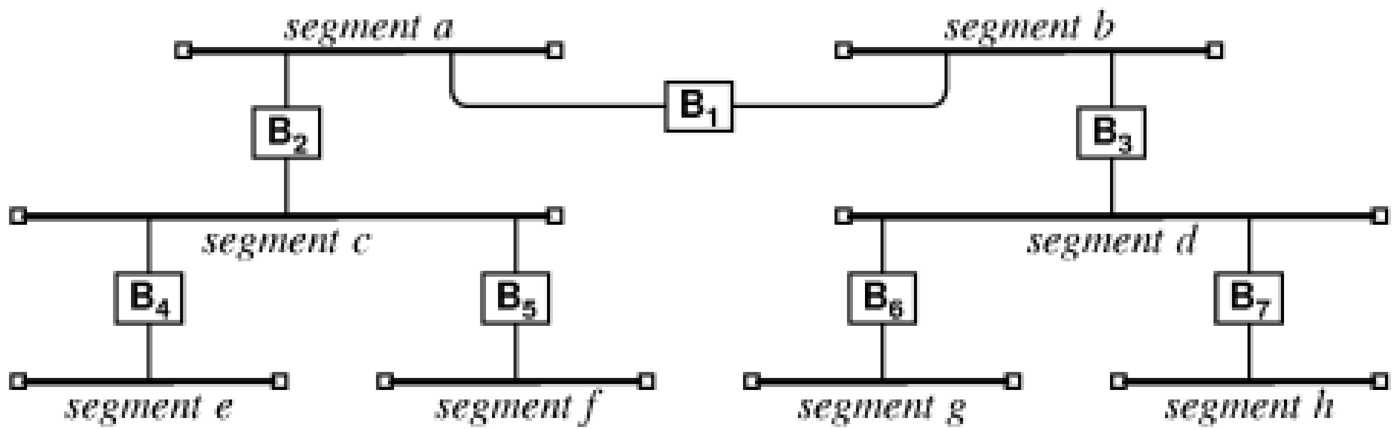
Bridge

- Operates on layers 1 through 2 of the OSI model
  - Can detect errors in frames (checksums that don't match) and will discard them
- What if multiple bridges are used to connect segments?
  - Cannot permit a forwarding loop to occur or frames will continue to circulate the network, eventually overloading it

Bridge

- Spanning Tree Protocol eliminates loops of bridges
  - Contained in IEEE 802.1d specification
  - Bridges communicate with each other and eventually determine that one of them will not forward frames from one segment to another
    - Bridges/switches exchange messages with each other using Bridge Protocol Data Units
    - Elect a root bridge/switch
    - Elect a designated bridge/switch for each LAN segment
    - Remove loops by placing redundant ports in a backup state (path redundancy)
  - Result is a “tree” with no connected loops
  - STP provides path redundancy while eliminating loops

Complex Bridged Network



Switch/Bridge Analogy

- An Ethernet switch matrix works much like multiple bridges
  - Each port on the switch has a “bridge” between itself and every other switch port
  - Only the “bridge” connecting source and destination host ports passes the frame

Router

- Expands the size of a network (LAN or WAN)
- Segregates traffic between network segments based on internetwork addresses (not MAC)
- Interconnects networks that use different MAC protocols
  - Router needs the proper interface for each network
- Operates on OSI layers 1 through 3
- Multiple routers can be used in hierarchical designs for better network segmentation

Router

- Can perform many sophisticated functions related to networking protocols depending on software
  - Support various internetworking protocols (IPX, IP, etc)
  - Perform packet filtering on interfaces
    - Restricts traffic in or out of interface based on criteria such as source IP address or TCP port
  - Implement network address translation (NAT)
  - Establish virtual private networks by using encrypted data paths
  - Support different routing protocols (RIP, OSPF, BGP)
  - Can run firewall software

Gateway

- Computer customized to provide protocol translation for any and all layers of the OSI model
- Example: a gateway could be configured to
  - Connect to different media types (layer 1)
  - Translate between different MAC protocols (layer 2)
  - Translate between different networking and transport protocols such as between TCP/IP and IPX/SPX (layers 3,4)
  - Translate between e-mail programs (layer 7)

Gateway

- "Gateway" is not a clear term
  - Some years ago, routers were called gateways
  - When you configure TCP/IP on your Microsoft NT workstation, you specify the "Default Gateway," or the router interfacing your LAN to a larger network

Bandwidth and Capacity

- In computer networking arena, the term bandwidth is frequently misused
  - The bandwidth of a communication system is the width of a band of frequencies assigned to the system
    - Can also mean the maximum range of frequencies that the system can support
    - Example, telephone voice channel bandwidth is 0-4kHz, with the actual signal filtered to fall within 280Hz to 3400 Hz (3,120 Hz signal bandwidth)
  - Capacity is the data rate that can be supported by the communication channel
    - Measured in bits per second

Shannon's Channel Capacity Theorem

- Relates maximum capacity of a channel to the channel signal-to-noise ratio

$$C = B \log_2(1+S/N)$$

where C is the capacity in bps, B is the channel bandwidth, and S/N is the signal-to-noise ratio (not in dB!!!)

Shannon's Channel Capacity Theorem

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Shannon's Channel Capacity Theorem

Since

$$\log_2 x = \frac{\log_{10} x}{\log_{10} 2}$$

Then

$$C = 3.322 B \log_{10}\left(1 + S/N\right)$$

Example Using Shannon's Theorem

- Assume a telephone line has S/N = 24dB. What is the capacity of the line?

  24 dB represents a S/N ratio of $10^{24/10} = 10^{2.4} = 251$

  The line has bandwidth 3120 Hz, so

  $C = 3120\ (3.322)\ \log_{10}(1+251) = 24{,}893$ bps

Effect of Channel Capacity

- Service time
  - The time it takes for a file of a given size to be transmitted across a link.

Service Time for Different Files on a DS-0 line

FIGURE 3.8
Channel capacity (DS0) versus service time.

- 25 KB Text File = 200,000 bits/64,000 bps = 3.125 seconds
- 3 MB Application = 24,000,00 bits/64,000 bps = 375 seconds
- 1 second of Digital Voice = 64,000 bits/64,000 bps = 1 second
- 1 second of Uncompressed CD Quality Sound = 352,800 bits/64,000 bps = 5.5725 seconds
- Uncompressed 200x200x24 Color Image = 960,000 bits/64,000 bps = 15 seconds
- 1 second of Uncompressed 200x200x24 Color Full-Motion Video at 15 fps = 14,400,000 bits/64,000 bps = 225 seconds
- 1 second of Uncompressed Multimedia = Full-Motion Video + CD-Quality Sound = 230.513 seconds

* Information is uncompressed
**1KB = 1024 bytes, 1MB = $(1024)^2$ bytes

Designing Network Capacity

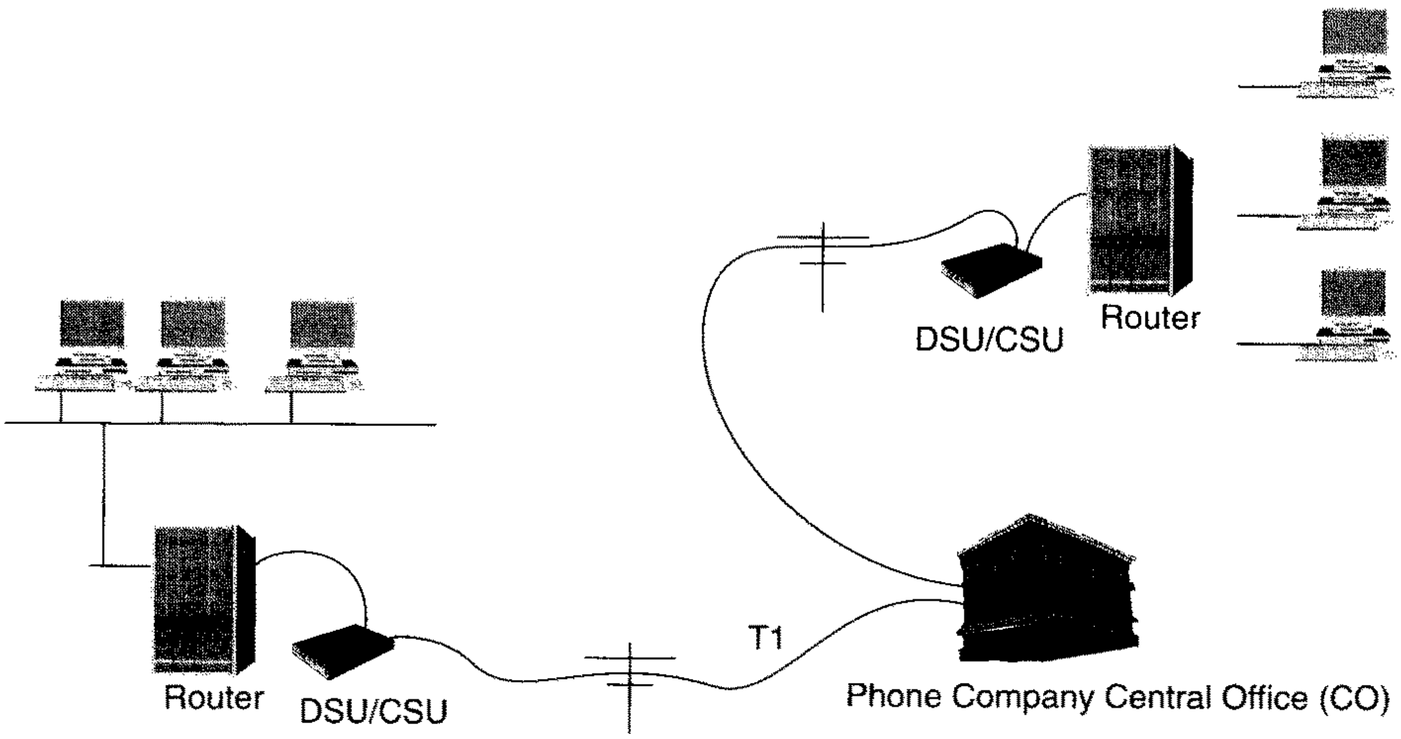

FIGURE 3.9
Queuing theory model.

Designing Network Capacity

- Queuing theory is used to determine if the capacity of a communication channel is sufficient for a given network design
- Example
  - Assume two Ethernet bus networks are connected with a T1 line
  - Assume a 1000-byte frame traverses the T1 line
  - Assume that one Ethernet sends 50 frames/sec to its router, to be sent across the T1 line to the second Ethernet

Designing Network Capacity

- The T1 line operates at 1.544 Mbps, with 8000 bps allocated for timing bits
  - Thus T1 line capacity is 1.536 Mbps of data
- The 1000-bit frame takes

$$t_1 = \frac{1000 \text{ bytes} \times 8 \text{ bits/byte}}{1.536 \times 10^6} = 5.2 \times 10^{-3} \text{ sec}$$

- The number of frames per second on the T1 line is

$$f = \frac{1}{5.2 \times 10^{-3} \text{ sec/frame}} = 192 \text{ frames/sec}$$

Designing Network Capacity

- Now if one Ethernet is delivering 50 frames to its router and the router sends them across the T1 line to the second Ethernet, then the utilization of the T1 line is

$$P_{util} = \frac{50}{192} = 0.26, \quad \text{or} \quad 26\%$$

- Thus, the T1 line is idle 74% of the time and can easily handle the traffic load

Online Service Provider vs. Internet Service Provider

- Online Service Provider
  - Access the Internet indirectly via the service provider's computers which operate as a bulletin board service
  - Proprietary user interface provides customer with all standard Internet services, such as e-mail and web pages
  - Example: America Online (AOL)

Online Service Provider vs. Internet Service Provider

- Internet Service Provider (ISP)
  - Provide direct access to the Internet using TCP/IP
  - Customer's computer becomes a remote node of the ISP's network
  - ISP assigns the customer an IP address using DHCP
  - Provides DNS service, web services, e-commerce services
  - Offer a number of different connectivity options
    - Dial-up modems
    - Frame Relay, Integrated Services Digital Network (ISDN), T1, etc.
    - Customer connects to ISP through telephone company central office (CO)
  - ISP connects to major internet connectivity site, or POP (Point-of-Presence) using high-capacity TDM line like T3

Internet Service Provider

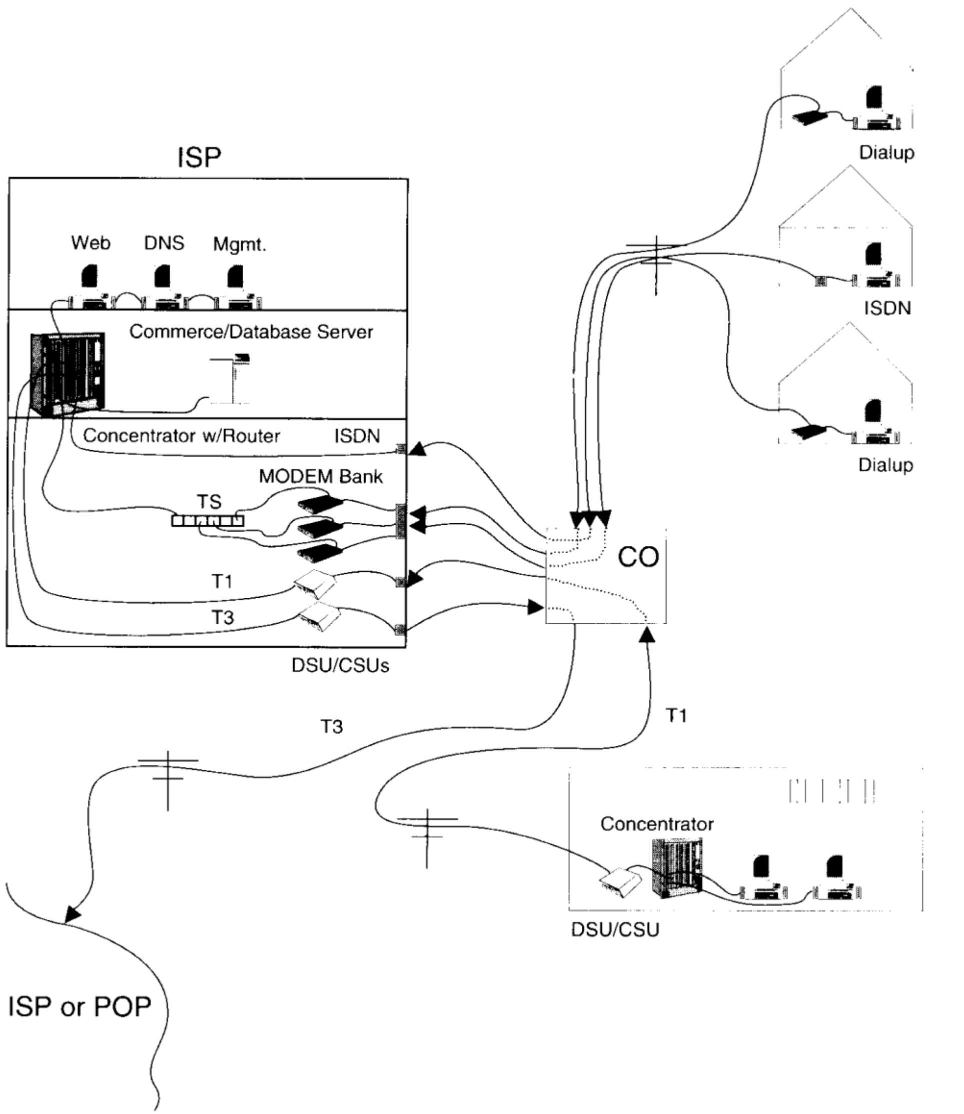

FIGURE 3.10
ISP example.