Chapter 4

Internet Connectivity: Network Technologies

Backbone Technologies

- The backbone is the core infrastructure of a computer network
  - Includes connecting media, hubs, concentrators, internetworking devices, etc
- Backbone technologies rapidly improving along with demands of new applications
- New backbone devices can detect data traffic patterns, or *flows*, and/or the type of traffic
  - Can also monitor the session traffic
  - Devices use this capability to adjust how they handle the traffic

Quality of Service (QoS)

- Quality of Service refers to “how well” a device handles a particular flow or type of traffic
- Examples
  - QoS for a video multicast requires allocation of a fixed capacity
  - QoS for critical data would require high-priority transportation
    - May use highest priority queue in a router
- Various network technologies handle QoS issues differently

Ethernet

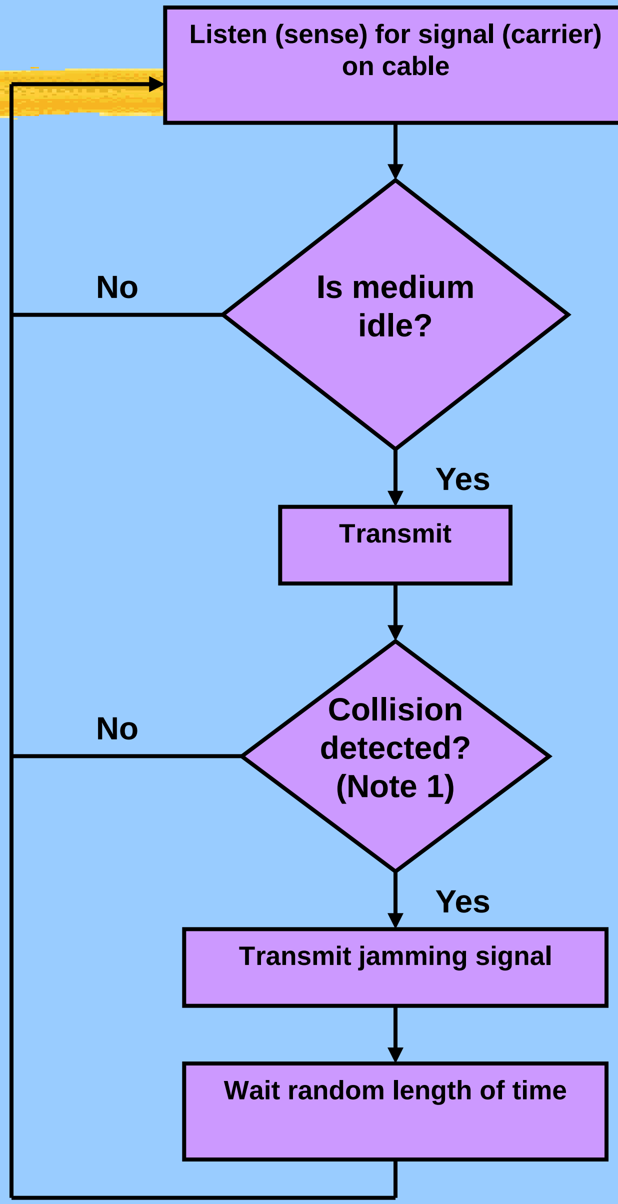
- Most popular LAN technology
- Based on a logical bus topology
  - Hosts attached to the bus contend for available capacity
    - Capacity per host
      - $C_h = C / n$

        Where C_h is the capacity per host, C is the network capacity within that *collision domain* and n is the number of hosts
      - Example: 10 hosts on one segment of a 100BaseTX (100Mbps) Ethernet that connects to a router has C_h = 10 Mbps
  - Bus access is controlled by the CSMA/CD algorithm
    - Carrier Sense Multiple Access / Collision Detect

CSMA/CD Overview

- When a system wants to transmit, it listens to the bus to see if a frame is present (carrier sense)
- If channel is idle, system transmits the frame
- If two or more systems transmit at the same time, a *collision* occurs
- One of the transmitting systems detects the collision and sends out a jamming signal
- Retransmission is determined by the Truncated Binary Exponential Backoff (BEB) algorithm

CSMA/CD Overview



- Note 1: Ethernet frames are a minimum of 64 bytes long. This is long enough for a station to detect a collision while it is transmitting assuming the maximum station separation.

Truncated BEB

- **Ethernet uses the BEB to determine how long to wait before attempting a re-transmit**
- **Once a collision is detected and the jamming signal is sent, stations wishing to transmit wait *x* time slots, where *x* is a random number depending on which transmit retry it is**
  - **The Ethernet card in each computer calculates its own *x***
  - **Each time slot is 51.2μs long**
  - **x is between 0 and 2^n-1, where n is which retry attempt it is**

Truncated BEB

- For example, let *n* = 1 (first retry)
  - Computers attempting to transmit can wait 0 or 1 time slot
  - If a computer picks *x* = 0, it attempts to transmit immediately
  - If it chooses *x* = 1 it waits one time slot, or 51.2μs before attempting to transmit
  - When attempting, ***a computer senses for a carrier first***
  - If a computer got through without a collision, the BEB algorithm ends
  - If a collision occurs during first retry, computers attempt a second retry

Truncated BEB

- For example, let *n* = 2 (second retry, first retry failed)
  - Computers attempting to transmit can wait 0, 1, 2, or 3 time slots
- If the second retry fails, there are 2^3 or 8 time slots to choose from

Ethernet Frame

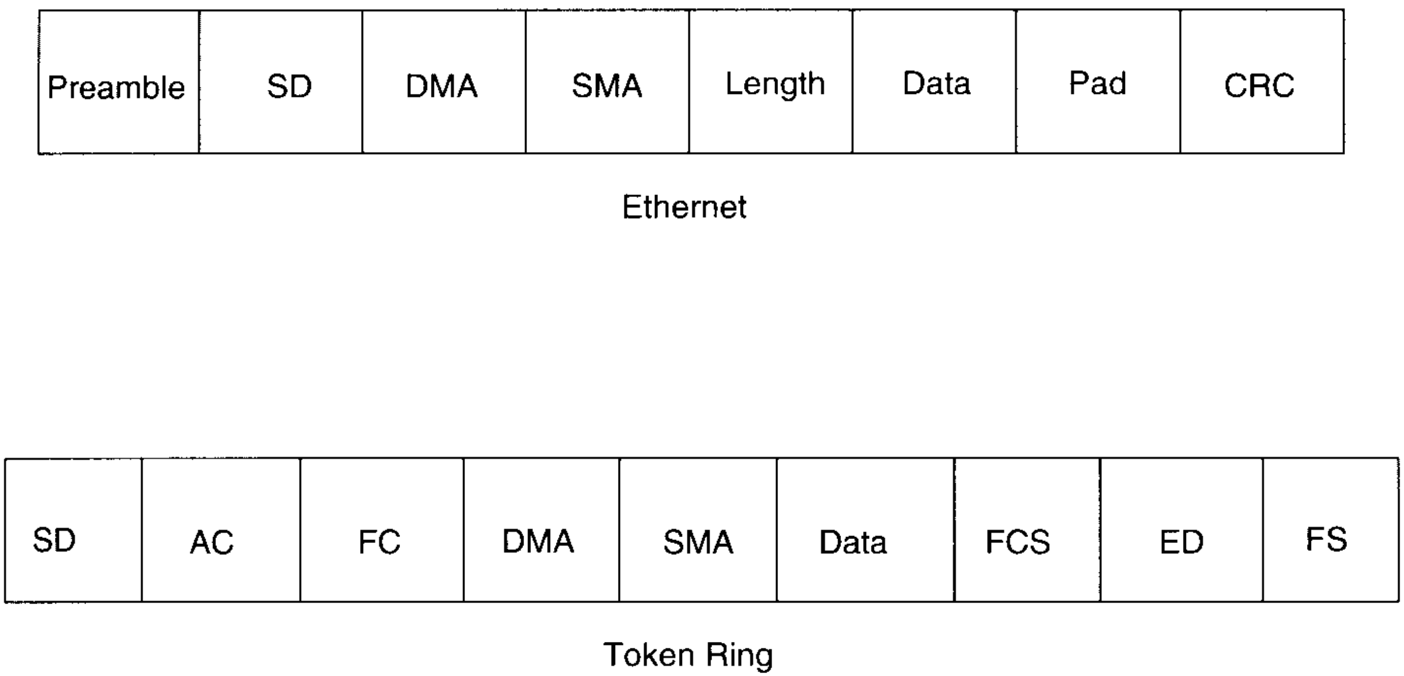


FIGURE 4.1
Ethernet and Token Ring frames.

Ethernet Frame

- Preamble
  - 7-byte square wave (each byte is 10101010) used to synchronize receiver clock to transmitter clock
- Starting Delimiter (SD)
  - Used to indicate beginning of frame (10101011)
- Destination MAC Address (DMA)
  - 6-byte address
- Source MAC Address (SMA)
  - 6-byte address

Ethernet Frame

- Length
  - 2-byte field used to indicate frame length
- Data
  - Variable length field containing layer 3-7 data
- Pad
  - Variable length field used to ensure Ethernet frame is a minimum of 64 bytes long
  - Ethernet frames appearing on network that are less than 64 bytes are *runts*
    - Runts are illegal and are discarded
  - Frames larger than 1518 bytes are *giants*, and are also illegal

Ethernet Frame

- Cyclical Redundancy Check (CRC)
  - 4-byte field containing an error checking code

Types of Ethernet

- IEEE 802.3 standard governs Ethernet
- Ethernet systems have bit rates of 10 Mbps, 100 Mbps, or 1 Gbps

10 Mbps Ethernet

Table 14.1 IEEE 802.3 10-Mbps Physical Layer Medium Alternatives

	10BASE5	10BASE2	10BASE-T	10BASE-FP
Transmission medium	Coaxial cable (50 ohm)	Coaxial cable (50 ohm)	Unshielded twisted pair	850-nm optical fiber pair
Signaling technique	Baseband (Manchester)	Baseband (Manchester)	Baseband (Manchester)	Manchester/ on–off
Topology	Bus	Bus	Star	Star
Maximum segment length (m)	500	185	100	500
Nodes per segment	100	30	—	33
Cable diameter (mm)	10	5	0.4 to 0.6	62.5/125 µm

- W. Stallings, Data and Computer Communications, 6th ed., Upper Saddle River, NJ, Prentice-Hall, 2000

100 Mbps Ethernet

Table 14.2 IEEE 802.3 100BASE-T Physical Layer Medium Alternatives

	100BASE-TX		**100BASE-FX**	**100BASE-T4**
Transmission medium	2 pair, STP	2 pair, Category 5 UTP	2 optical fibers	4 pair, Category 3, 4, or 5 UTP
Signaling technique	MLT-3	MLT-3	4B5B, NRZI	8B6T, NRZ
Data rate	100 Mbps	100 Mbps	100 Mbps	100 Mbps
Maximum segment length	100 m	100 m	100 m	100 m
Network span	200 m	200 m	400 m	200 m

- W. Stallings, Data and Computer Communications, 6th ed., Upper Saddle River, NJ, Prentice-Hall, 2000

Gigabit Ethernet - 802.3z

- Basic specs
  - Allows half- and full-duplex operation at 1000Mbps
  - Uses the 802.3 Ethernet frame format
  - Uses CSMA/CD access method with support for one repeater per collision domain
  - Addresses backward compatibility with 10BASE-T and 100BASE-T

Gigabit Ethernet - Fiber Based (802.3z)

- 1000BASE-LX
  - Long wavelength fiber-based (1300nm)
  - 5km over single-mode fiber (SMF)
  - 550m over multi-mode fiber (MMF)
  - Based on Fibre Channel physical layer
- 1000BASE-SX
  - Short wavelength fiber-based (850nm)
  - 275m over 62.5micron MMF
  - 550m over 50micron MMF
  - Based on Fibre Channel physical layer

Gigabit Ethernet - Copper Based (802.3z)

- 1000BASE-CX
  - Shielded twisted pair cable
  - 25m

Gigabit Ethernet - Copper Based (802.3ab)

- 1000BASE-T
  - Category 5, 5e, 6, or 7 unshielded twisted pair cable
  - 100m
  - Uses all 4 wire pairs (100BASE-TX uses 2 pairs)
  - Increase capacity by using 2 more wire pairs as well as converting to a 5-level bit encoding scheme
    - Each signal pulse transmits one octet

Gigabit Ethernet

- Uses CSMA/CD
- Used in Ethernet backbones

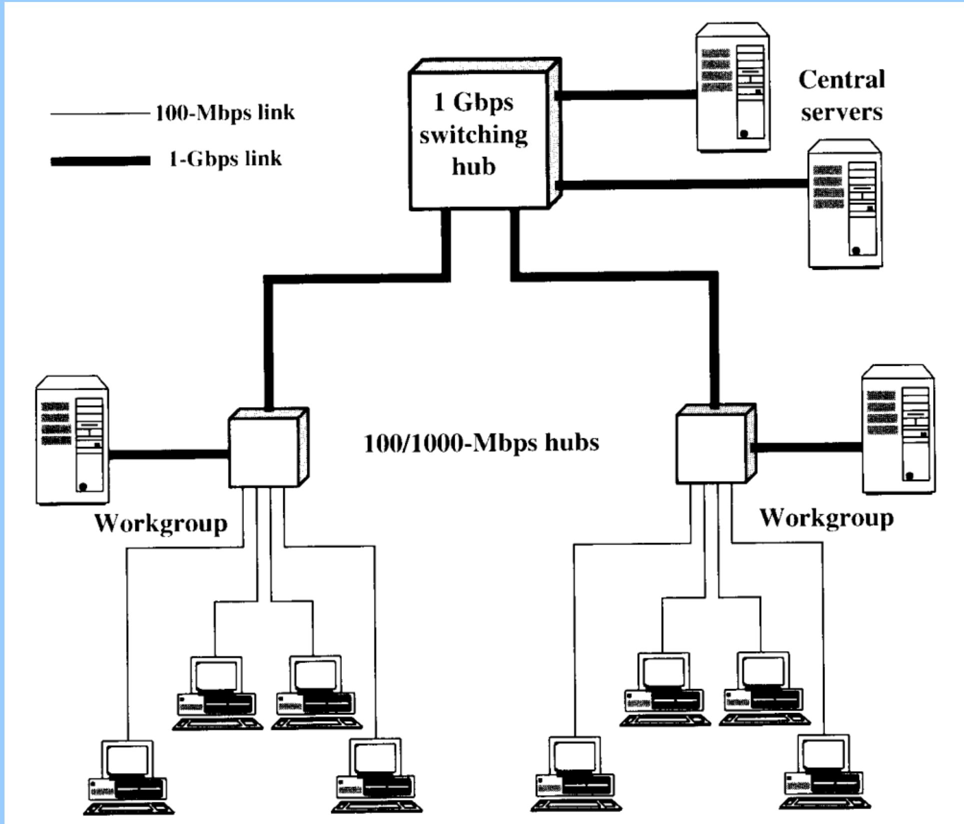


Figure 14.4 Example Gigabit Ethernet Configuration

- W. Stallings, Data and Computer Communications, 6th ed., Upper Saddle River, NJ, Prentice-Hall, 2000

Etherswitch

- Multi-port bridge
- Uses matrix switching
- Hosts attached to switch experience full media capacity
- Many hosts can transmit concurrently
- Ports can be grouped together into separate broadcast domains
  - Called VLANs (Virtual LANs)
  - Hosts on separate VLANs can only communicate with each other through routers

Broadcast Domain

- LAN segment or segments over which a broadcast will propagate

Collision Domain

- An Ethernet segment or segments over which collisions can occur
- Capacity per host is approximately the collision domain capacity divided by the number of hosts in the collision domain

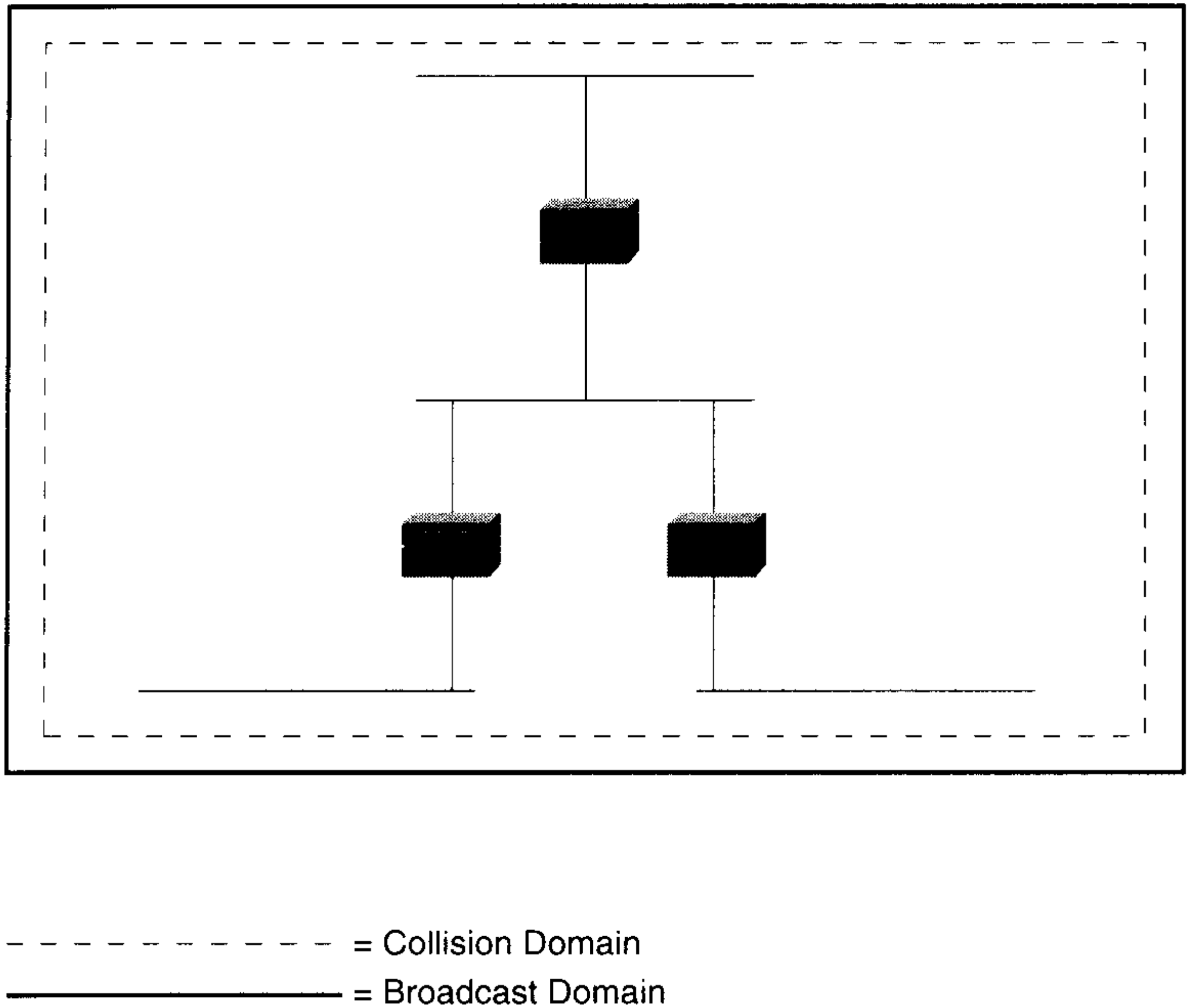
Collision and Broadcast Domains

Table 2-1 *A Comparison of Collision and Broadcast Domain*

Device	Collision Domains	Broadcast Domains
Repeater	One	One
Bridge	Many	One
Router	Many	Many
Switch	Many	Configurable

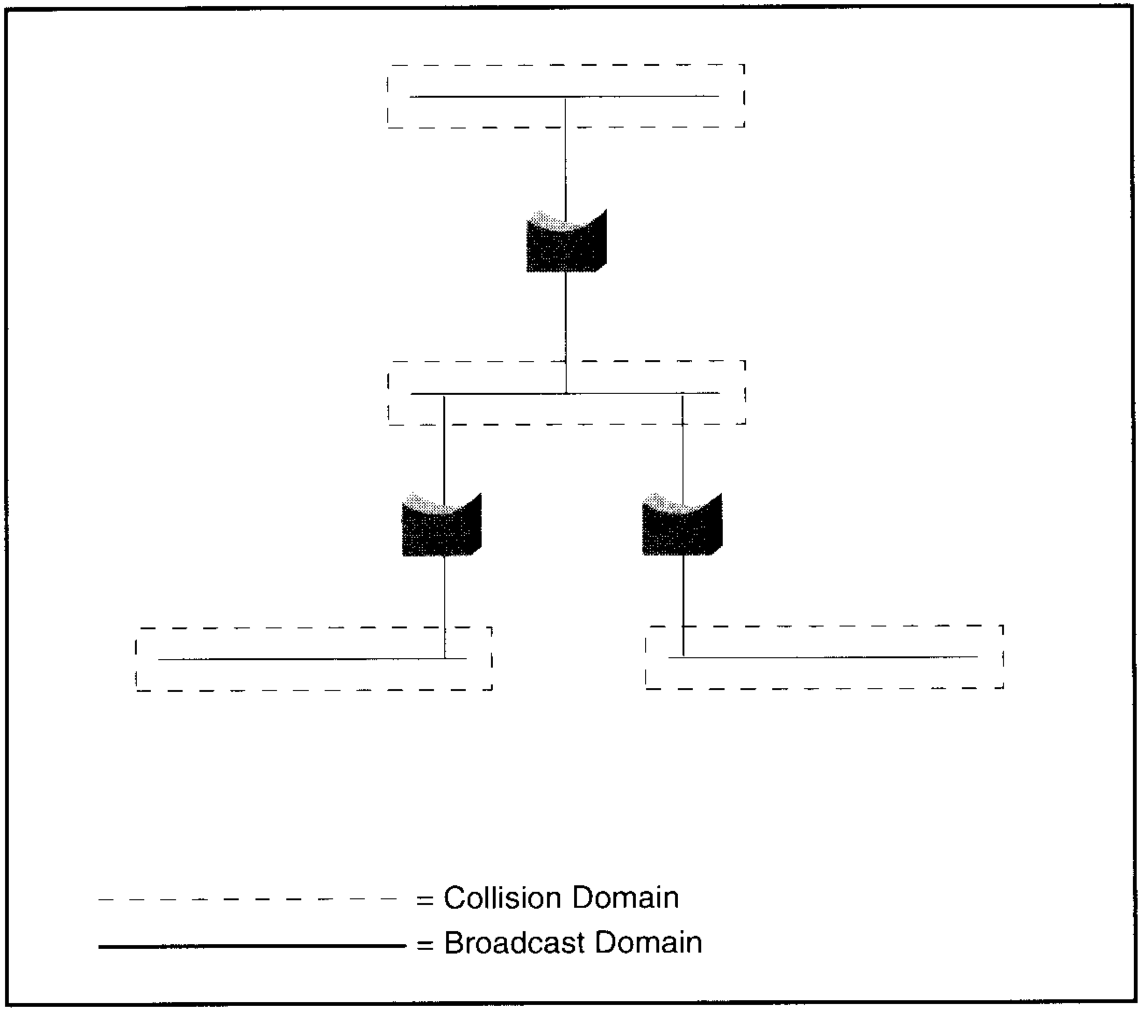
Repeater Broadcast and Collision Domains

Figure 2-5 *Broadcast and Collision Domains in a Repeater Network*



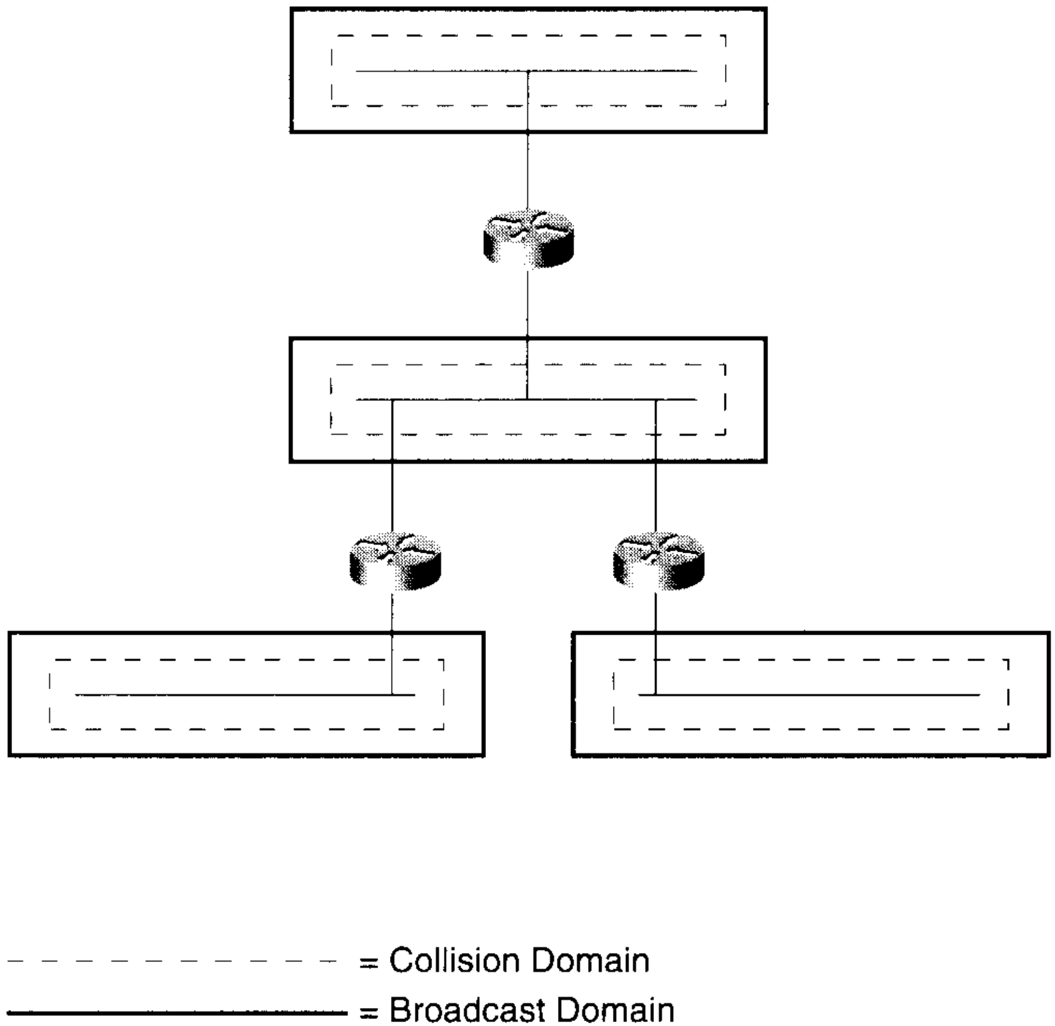
Bridge Broadcast and Collision Domains

Figure 2-8 *Bridges Create Multiple Collision Domains and One Broadcast Domain*



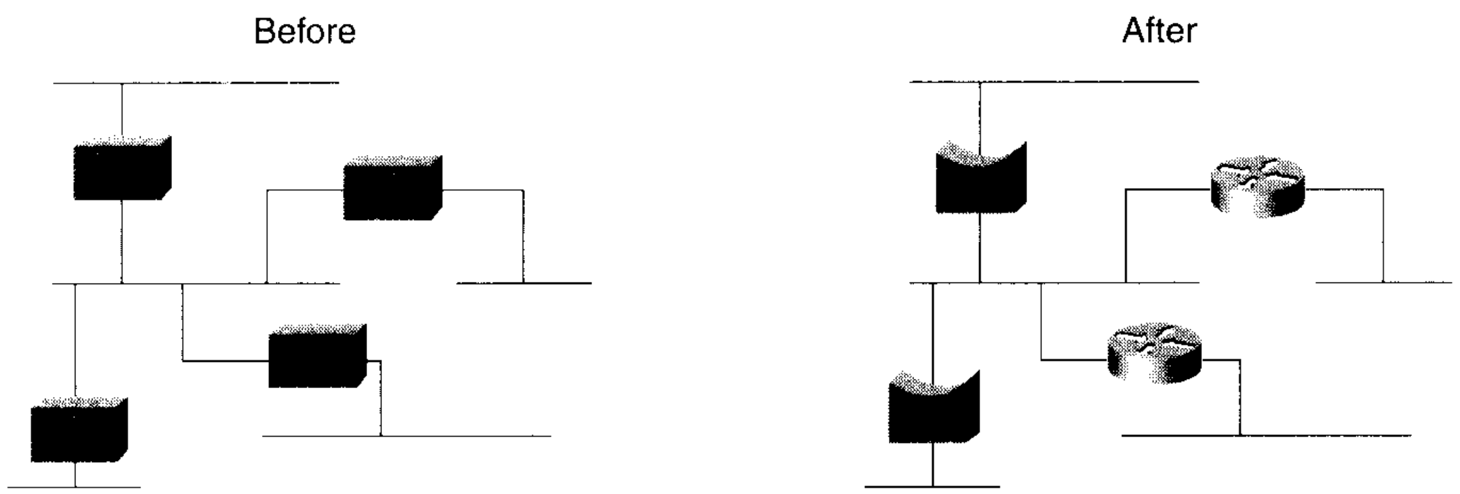
Router Broadcast and Collision Domains

Figure 2-10 *Broadcast and Collision Domains in a Routed Network*



Advantage of Network Segmentation

Figure 2-1 *A Network Before and After Segmentation*



- 100 Users per segment
- 10 Mbps system capacity
- 20 Kbps per user

100 users per segment
10 Mbps system bandwidth
50 Mbps total system bandwidth
(5 collision domains)
100 Kbps per user

Advantage of Network Segmentation

- How many broadcast domains are in the “After” network?

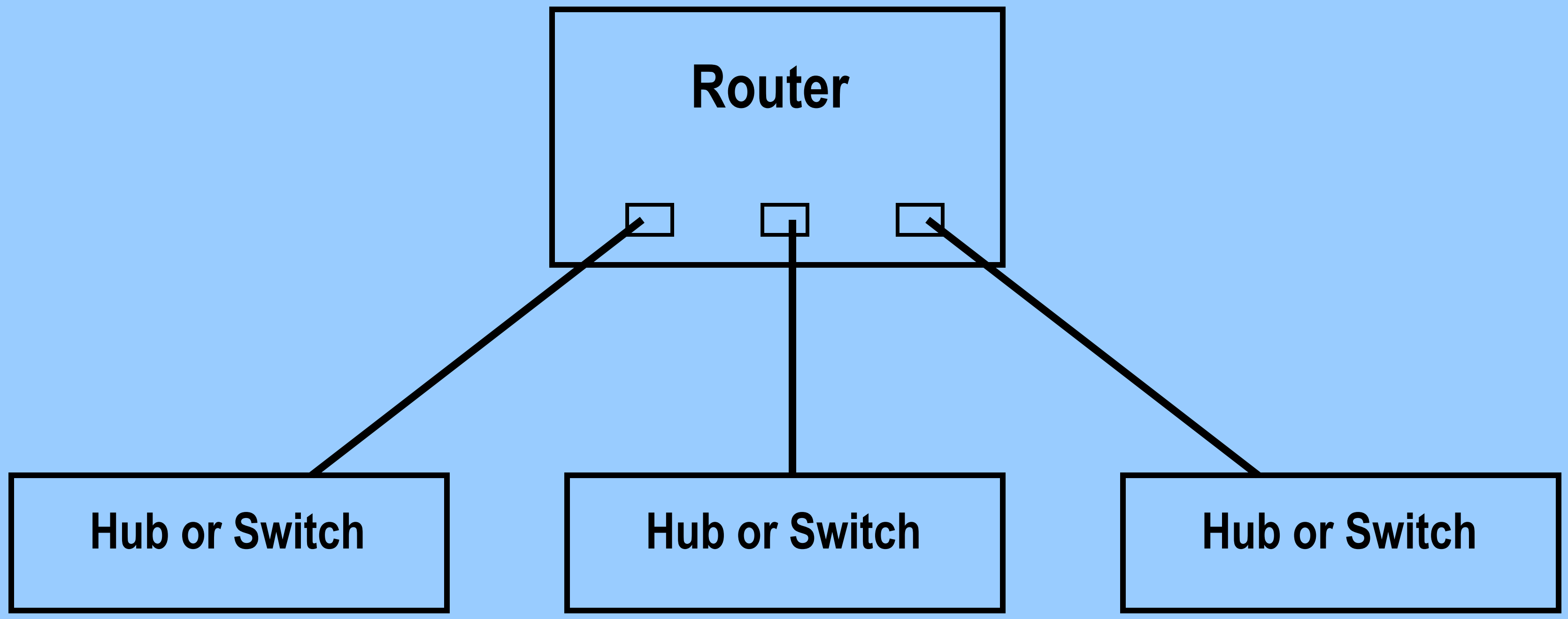
Ethernet Virtual LANs

- Ethernet switches can have their ports configured into groups, or virtual LANs (VLANs)
  - The switch will forward traffic between hosts on the same VLAN
  - The switch will not forward traffic from hosts on one VLAN to hosts on another
  - Traffic between VLANs on a switch must be routed through a router
- Advantage of VLANs
  - Allows more flexibility in segmenting networks
  - Saves router ports by connecting several VLANs to the same router port

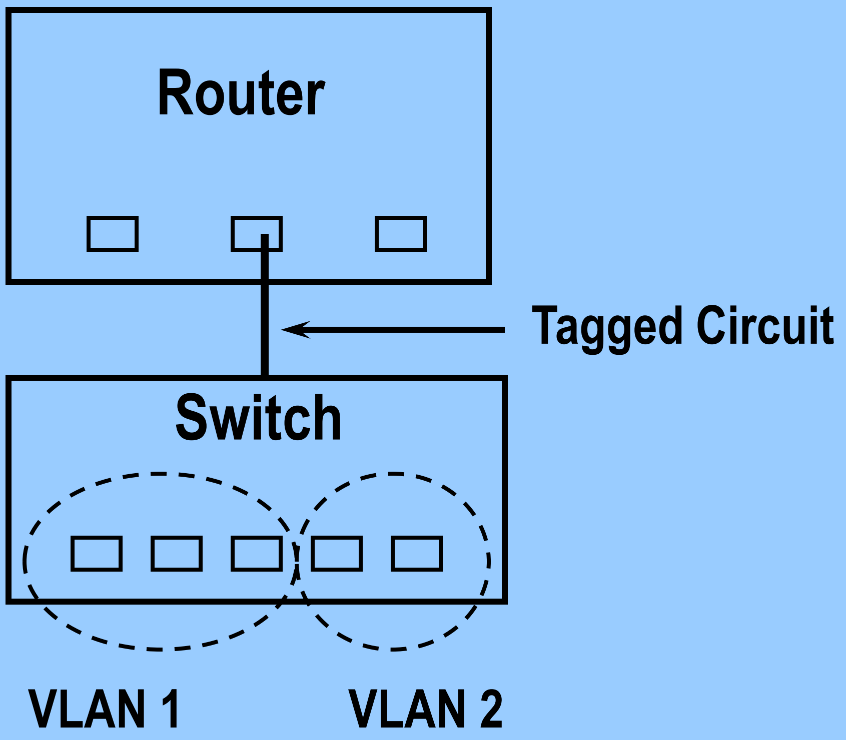
IEEE 802.1Q Tagging

- IEEE 802.1Q standard specifies a way that traffic from different VLANs can travel over a single connection
- A single connection from the switch to the router allows traffic from all VLANs to be sent to the router and routed as necessary
  - The router is configured to understand the tagging and configures the tagged interface as virtual interfaces, one for each VLAN connected through the interface

Routing LANs – Classic Way



Routing VLANs



Token Ring

- IEEE 802.5 standard governs token ring
- Uses ring topologies
- Hosts do not contend for capacity

Token Ring Operation

- Workstations on the ring can gain access to the medium using a round-robin approach
- Round-robin access controlled by passing a token around the ring in *one direction*
  - When the ring is idle, a 3-byte token is passed from one workstation to another
  - When a system is ready to transmit:
    - It seizes the token
    - Adds its data to the the token
    - Changes a bit within the modified token to indicate “busy”
    - Places the resulting frame back on the ring

Token Ring Operation

- Each system, in turn, receives the frame and checks its destination MAC address
  - If the destination address does not match, the system places the frame back on the ring
  - If there is a match,
    - The system copies the frame to a buffer for further processing and
    - Changes some status bits
    - Places the frame back on the bus
- When the frame returns to the originating system
  - The status bits are checked to see that the destination received the frame
  - The frame is removed from the ring
  - A new token is placed back on the ring

Token Ring Operation

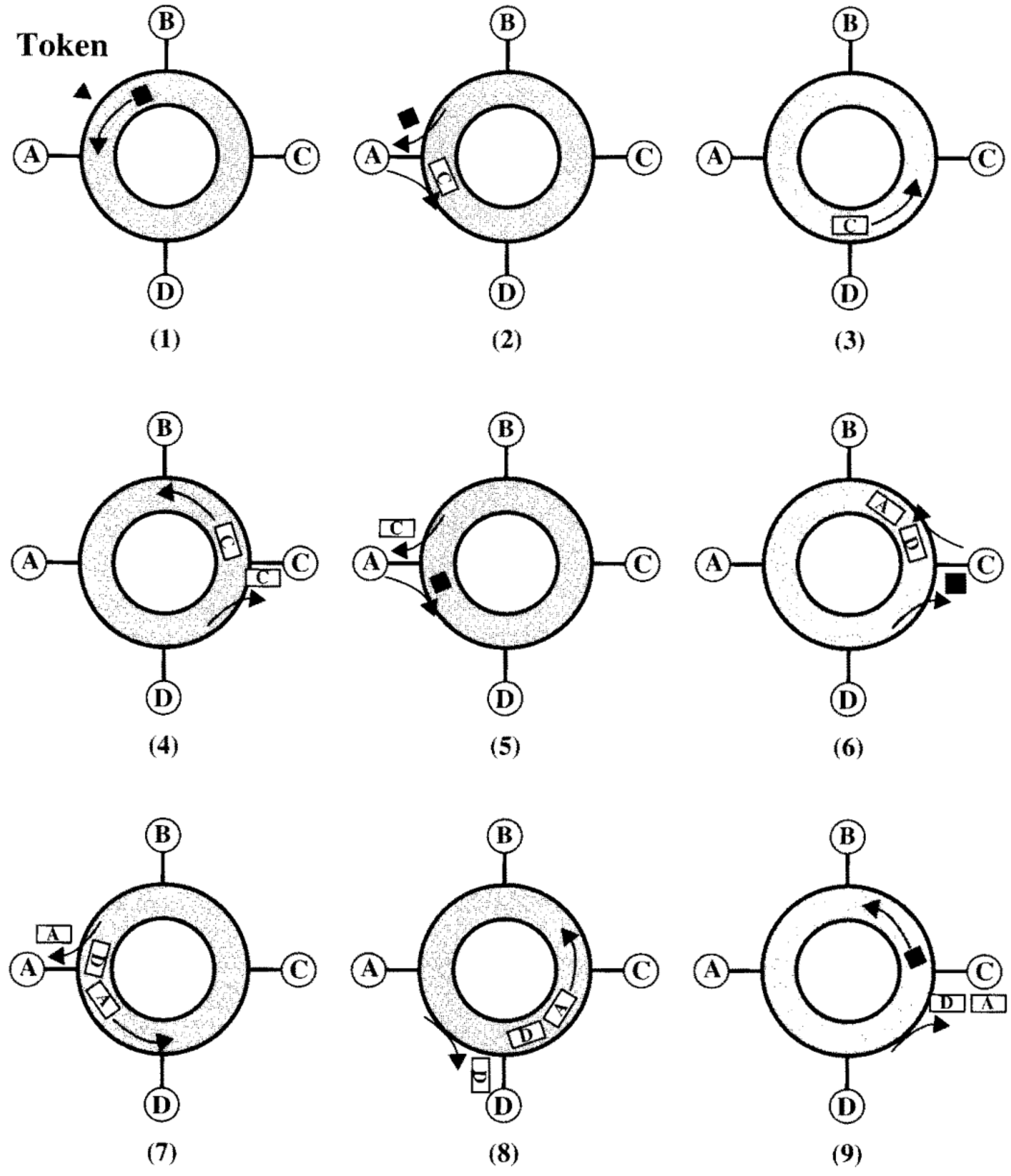


Figure 14.5 Token Ring Operation

Token Ring Frame

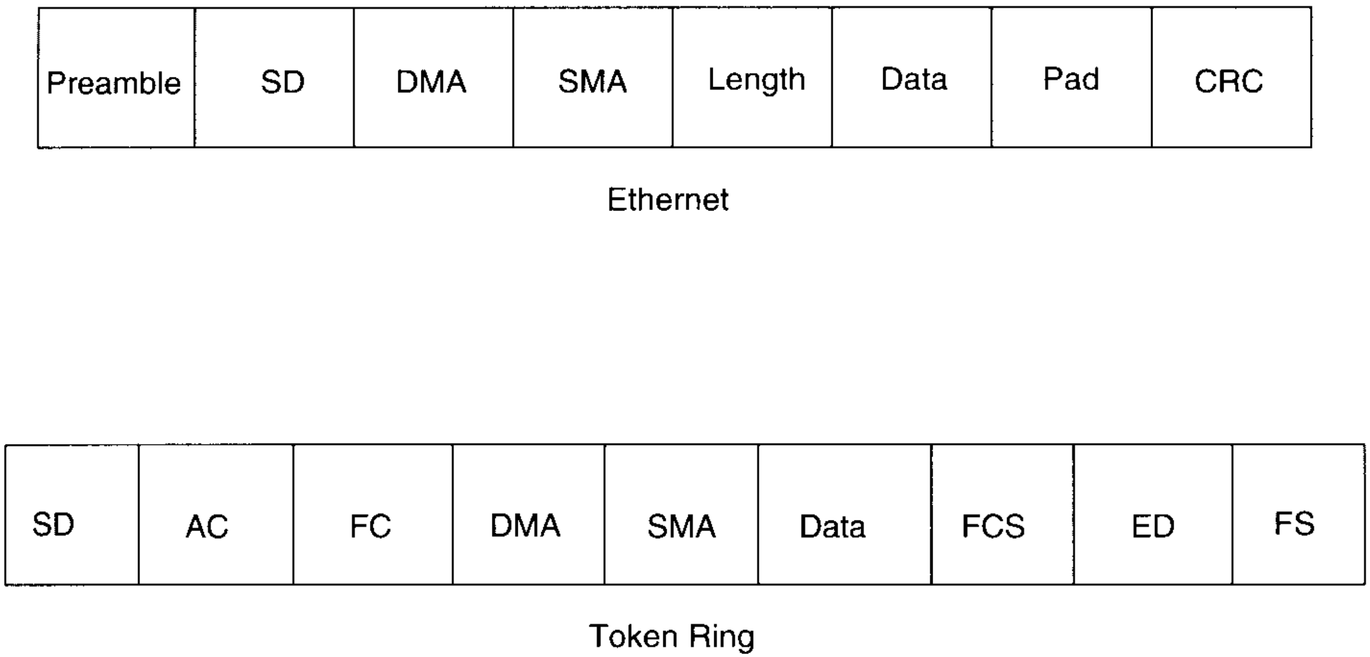


FIGURE 4.1
Ethernet and Token Ring frames.

Token Ring Frame

- Starting Delimiter (SD)
  - Unique 8-bit pattern indicating start of frame
  - *Is also the first byte of the original token*
- Access Control (AC)
  - 1-byte field used to control access to ring and handle prioritization
  - *Is also the second byte of the original token*
- Frame Control (FC)
  - 1-byte field to indicate whether frame has user data or maintenance data

Token Ring Frame

- Destination MAC Address (DMA)
  - 6-byte address
- Source MAC Address (SMA)
  - 6-byte address
- Data
  - Variable-length payload
- Frame Check Sequence (FCS)
  - 4-byte field used to check for frame errors

Token Ring Frame

- Ending Delimiter (ED)
  - Special 8-bit pattern indicating the end of frame
  - Used to indicate whether other frames will be sent as part of the message
  - One bit is used to indicate whether a station on the ring detected a frame error
  - *Also is the third byte of the original token*
- Frame Status (FS)
  - 1-byte field used to show whether destination system received frame and copied it to its buffer

Token Ring Varieties

- 4 Mbps, 16 Mbps, and 100 Mbps are most common
- Workstations in 4 and 16 Mbps systems attach to a Multi-station Access Unit (MAU)
  - Creates a physical star configuration, much like Ethernet hub
  - Logical connection is still a ring
  - MAUs can be connected together to extend the ring size
  - MAU typically has 8 ports
  - Maximum number of stations that can be in a ring is 260

Token Ring Frame Sizes

- For 4 Mbps
  - 4,500 bytes (octets)
- For 16 Mbps
  - 18,000 bytes
- What happens when a router receives a 14,000 byte frame on a token ring network and has to send it to a host on an Ethernet network?

Dedicated Token Ring (DTR)

- DTR is a new 802.5 standard that supports token passing protocol and a switched protocol
  - Switched protocol does not use token passing
- Stations connected to a central hub or concentrator
  - Performs as logical ring, physical star in token passing mode
  - Performs as logical star, physical star in switched mode
    - Each station gets a full-duplex point-to-point link

Dedicated Token Ring (DTR)

- Speeds supported are 4, 16, and 100 Mbps
  - 100 Mbps must use switched mode without token passing
  - 4 and 16 Mbps can use token passing or switched mode

Fiber-Distributed Data Interface (FDDI)

- Similar to token ring
- 100 Mbps capacity
- Uses a concentrator to connect workstations or a module within a router
- Can span 2 km per segment
- Uses 2 pair of fiber
  - Each pair is a full-duplex connection

Fiber-Distributed Data Interface (FDDI)

- Data normally travels on one pair of fiber
  - If a fault occurs, ring switches to second pair of fiber
  - If fault breaks both pair, ring loops back on itself on each side of the fault to complete the ring

Wireless Communications

- Many varieties of wireless communication exist
- We will look at wireless LANs, analog and digital cellular, and PCS
  - These three can all interface to the Internet

Typical Wireless Modulation Schemes

- Time Division Multiple Access (TDMA)
  - Multiple sources transmit information on a common channel (single carrier frequency) within a unique, predetermined time slot
- Frequency Division Multiple Access (FDMA)
  - Multiple sources transmit information on separate channels (each has a different carrier frequency)

Typical Wireless Modulation Schemes

- Frequency Hopping Spread Spectrum (FHSS)
  - Information is transmitted across a number of channels in a random fashion
  - Carrier frequency is switched at random during transmission
  - Effect is a “noise-like” signal spectrum
  - Improved security since only source and destination know the hopping pattern

Typical Wireless Modulation Schemes

- Direct Sequence Spread Spectrum (DSSS)
  - Transmitted signal is modulated on to a carrier frequency
  - Modulated carrier is modulated with a pseudo-random (PSR) bit pattern
  - Spreads the spectrum of transmitted signal
  - Good security since only source and destination know the pseudo-random bit pattern

Typical Wireless Modulation Schemes

- Code Division Multiple Access (CDMA)
  - Similar to DSSS except
    - Information is modulated with pseudo-random sequence first, then modulated onto carrier
  - Can send multiple signals on same channel
    - Must use different codes if on same channel
  - Good security since only source and destination know the PSR code

Wireless LAN

- Governed by IEEE 802.11 standard
  - Latest speed is 11 Mbps (802.11b)
  - Speed may be less depending on S/N
- Access Point (AP) is the interface device between the wireless and wired LAN
  - Access Point also called Control Module
  - Designed for Token Ring and Ethernet
  - Accesses medium at MAC sublayer

Wireless LAN

- Uses Distributed Foundation Wireless MAC (DFWMAC) media access protocol
  - Two ways it can operate
    - Distributed access using Carrier Sense Multiple Access / Collision Avoidance (CSMA/CA)
    - Polling scheme with centralized control
      - Request-to-send / clear-to-send handshake

Wireless LAN

- Physical medium specs
  - Infrared
  - DSSS at 2.4 GHz
    - Instrumentation, scientific, and medical (ISM) band
  - FHSS at 2.4 GHz

Wireless LAN

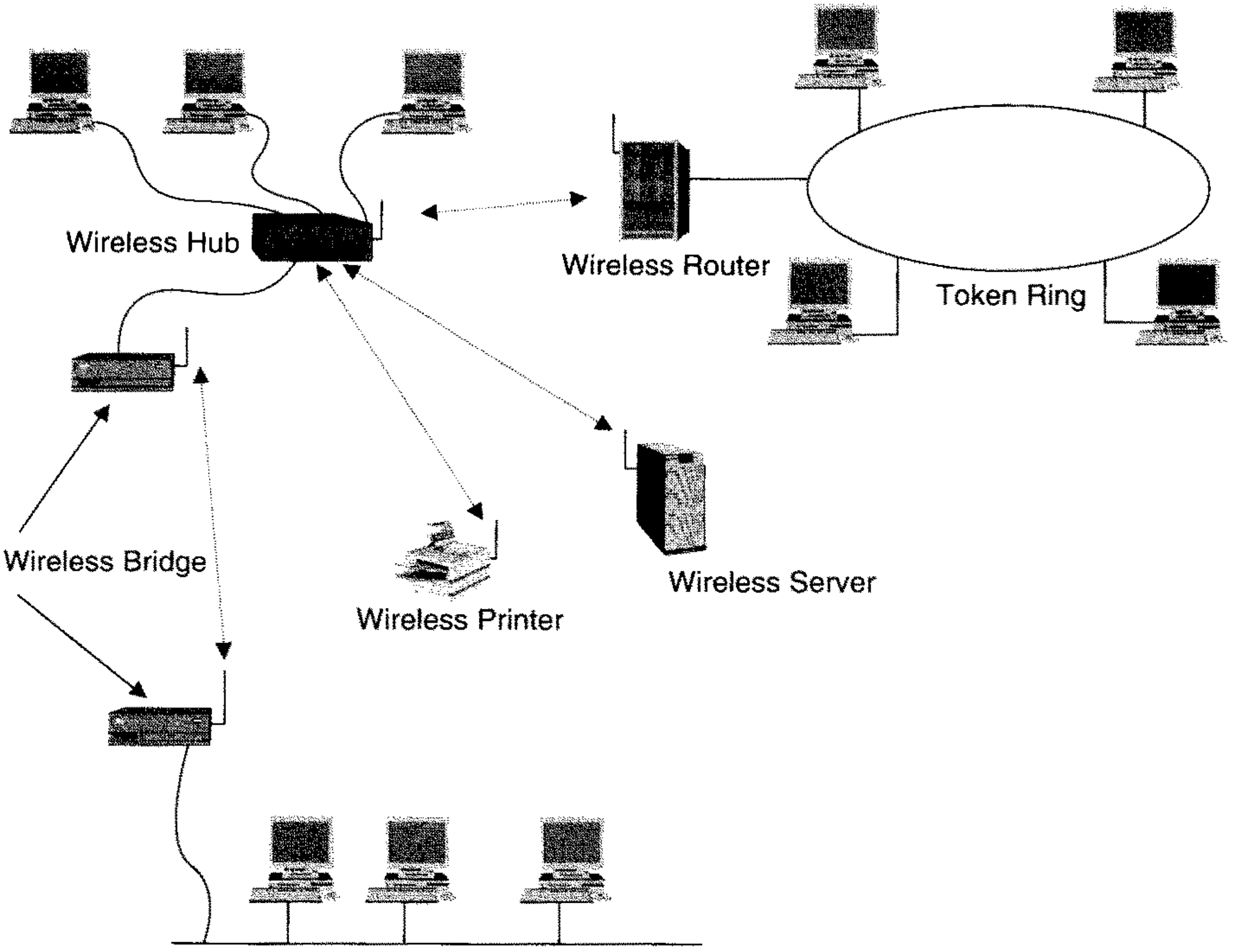


FIGURE 4.2
Wireless LAN (WLAN).

WLAN Applications

- LAN extension
  - Saves cabling costs
  - Useful on manufacturing floors
    - Large open areas
    - Difficult to install wiring
    - Often need mobile workstations
- Cross-building interconnect
  - Used to connect LANs in nearby buildings
  - Usually point-to-point (not mobile)

WLAN Applications

- Nomadic access
  - May be necessary to move laptop computer frequently
- Ad hoc networking
  - Temporary peer-to-peer network
  - Example: several employees meet in a conference room and set up a temporary network to share information

Cellular vs. PCS

- PCS and cellular (analog and digital) are based on cellular coverage areas
  - Roughly hexagonal shaped
  - Total coverage area consists of multiple adjacent cells
  - Mobile Telephone Switching Office (MTSO) links many cell sites
    - Works like CO
    - Interfaces to land lines

MTSO Operation

- When cellular subscriber dials out, MTSO assigns channel to user
  - If destination is another mobile number, call is handled MTSO to MTSO
  - If destination is a wire-line number, call is handled MTSO to CO
- If user moves between cells, MTSO assigns a different channel to user in the new cell site

Cellular Standards

Standard	Region	Format	Access
AMPS (Advanced Mobile Phone Service)	North America	Analog	FDMA
NAMPS (Narrowband AMPS)	North America	Analog	FDMA
NADC (North American Digital Cellular)	North America	Digital	TDMA, CDMA
ETACS (Extended Total Access Communication System)	United Kingdom	Analog	FDMA
GSM (Global System Mobile)	Europe, US	Digital	TDMA, FDMA

Part of the Electromagnetic Spectrum

Table 4.1 Electromagnetic Spectrum (Partial)

Service	*Spectrum Allocation (MHz)*
AMPS (Advanced Mobile Phone System) transmit—N.A. analog cellular	825–845
NAMPS (Narrowband AMPS) transmit—N.A. analog cellular	825–845
NADC (North American Digital Cellular)	825–845
AMPS (Advanced Mobile Phone System) receive—N.A. analog cellular	870–890
NAMPS (Narrowband AMPS) receive—N.A. analog cellular	870–890
NADC (North American Digital Cellular)	870–890
ETACS (Extended Total Access Communications System) receive—U.K. analog cellular	872–905
GSM (Global System for Mobile) transmit—U.S., Europe digital cellular	890–915
ISM (Industrial, Scientific, and Medical) industrial band—WLAN Spread Spectrum	902–928
ETACS (Extended Total Access Communications System) transmit—U.K. analog cellular	917–950
PCS (Personal Communications Services)	920–928
GSM (Global System for Mobile) receive—Europe,U.S. digital cellular	935–960
PCS (Personal Communications Services)	1,800–2,200
PCS (Personal Communications Services)—1997 FCC auctions	1,850–1,990
ISM (Industrial, Scientific, and Medical) scientific band—WLAN Spread Spectrum	2,400–2,483
C-band—satellite downlink	3,700-4,200
ISM (Industrial, Scientific, and Medical) medical band—WLAN Spread Spectrum	5,725-5,850
C-band—satellite uplink	5,900-6,400
Ku-band—satellite downlink	11,700–12,200
Ku-band—satellite uplink	14,000–14,500
Ka-band—satellite downlink	20,000
Ka-band—satellite uplink	30,000
IR (Infrared)—WLAN	333,000,000–375,000,000

Personal Communications Services

- Combines multiple services
  - Paging, fax, voice mail, e-mail, telephony, web browsing

Leased Line

- Used for point-to-point communication for business and government
- Common uses
  - Connect 2 or more customer sites
  - Connect customer to ISP
  - Connect customer to another type of technology such as Frame Relay

Leased Line

- Originally used for voice only
  - Adapted later for data
- Based on TDM
- Voice and data equipment interface to line using DSU/CSU
  - Router interfaces to DSU/CSU using synchronous serial line

Leased Line

- WANs based on leased lines can become complicated (may not scale well)
  - A business interconnecting all sites in a fully-connected mesh find that the number of lines needed increases dramatically as more sites are added
    - Could use a partially-connected mesh to relieve the problem
  - Connecting sites in a star results in fewer lines necessary, but has a single point of failure

Leased Line Connectivity

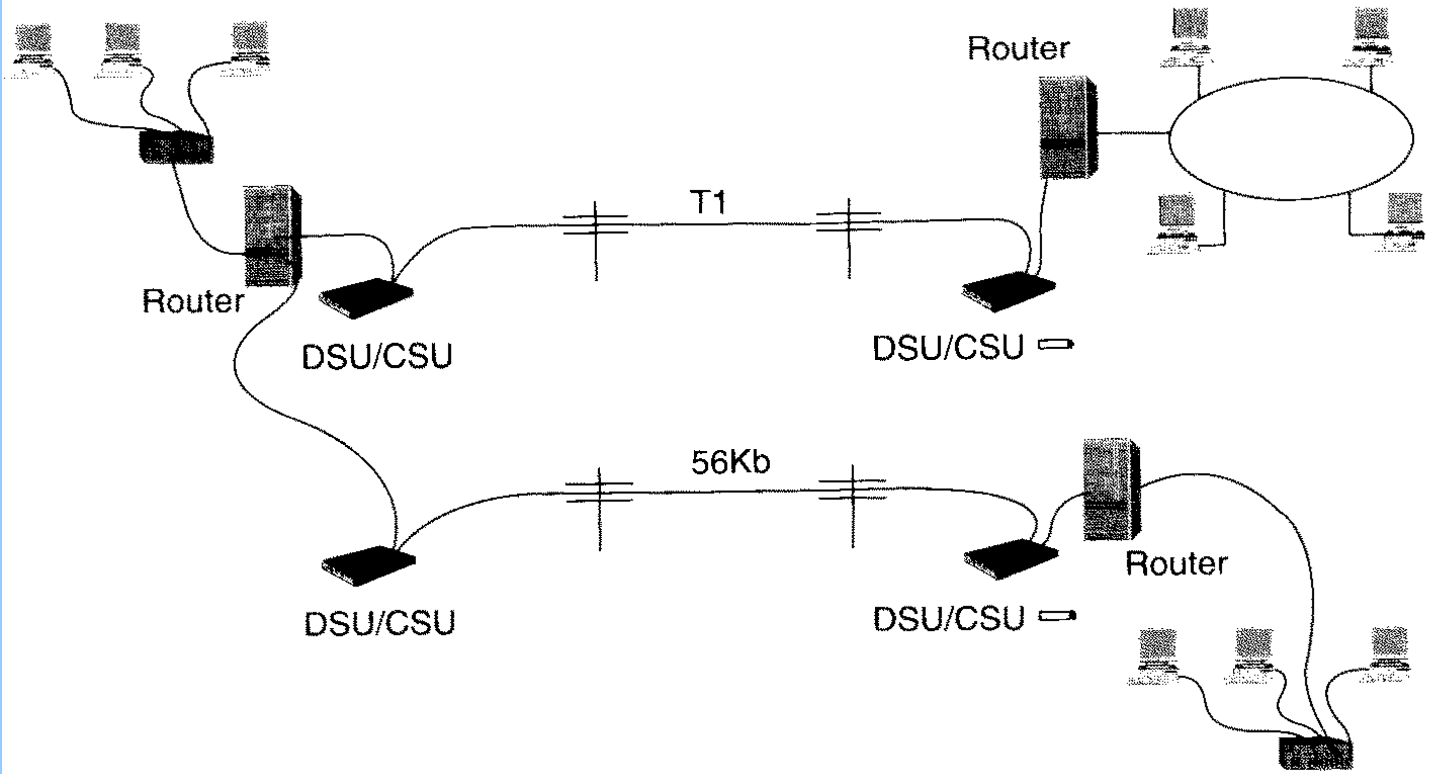


FIGURE 4.4
Point-to-point connectivity (leased line).

Frame Relay

- Packet switching protocol
  - Replaced older X.25 protocol
  - Actually is a connection-oriented data link technology
- Supports voice, Internet, video, data in digital format

Frame Relay

- Main components
  - Frame Relay Access Devices (FRAD) or router with Frame Relay interface
  - Frame Relay switches
  - Leased lines (Time Division Multiplexed)

Frame Relay

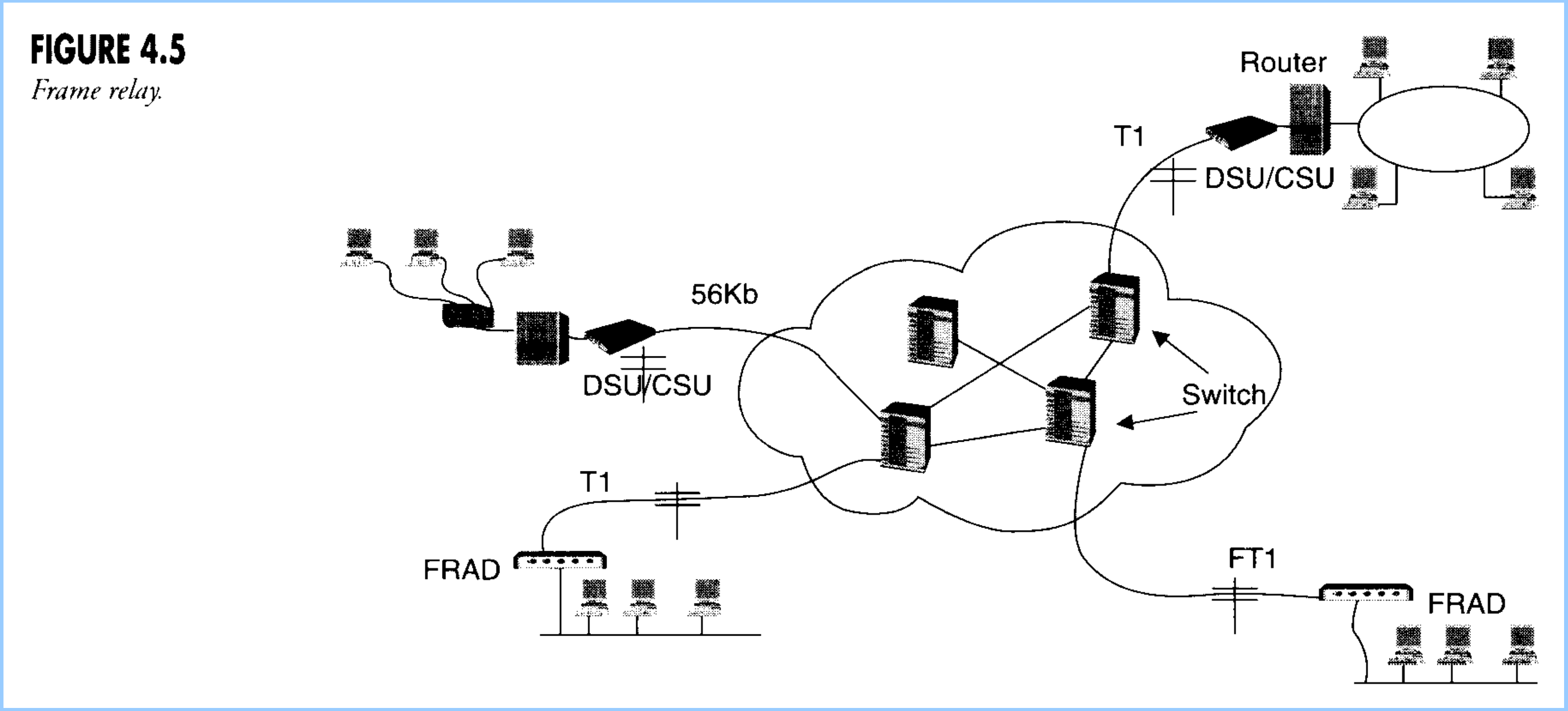


FIGURE 4.5
Frame relay.
Router
T1
DSU/CSU
56Kb
DSU/CSU
Switch
T1
FRAD
FT1
FRAD

Frame Relay Network Terms

- Customer Premise Equipment (CPE)
  - FRAD or router with Frame Relay interface
- Public Data Network (PDN)
  - Name for network itself
  - Owned by communications carriers and is
- Network-to-Network Interfaces (NNI)
  - Connection between Frame Relay switches
- User-to-Network Interface (UNI)
  - Connection between Frame Relay switch and CPE
  - Capacity ranges from DS0 to DS1

Frame Relay Data Transport

- Information is transported over logical links called *virtual circuits*
- Many virtual circuits are statistically multiplexed onto physical transmission links
- Source and destination CPE are assigned the same connection identifier
  - All frames traveling in the network between these devices will contain this number
- Service provider's switching equipment maps the connection identifier to its output ports
- Connection path is set up prior to sending of first frame

Virtual Circuits

- Permanent Virtual Circuit (PVC)
  - Configured by carrier and remain present until customer requests removal
  - Use if frequent communication between two locations is needed
- Switched Virtual Circuit (SVC)
  - Established on-demand by CPE and discontinued at end of session

Virtual Private Network

- A VPN between two or more sites can be established over a Frame Relay network by using PVCs

Frame Relay Frame

- Opening flag
  - 8-bit flag indicating start of frame
- Data Link Connection Identifier
  - 6-bit field used to indicate upper 6 bits of DLCI
- Address extension
  - Normally 0
- Data Link Connection Identifier
  - 4-bit field indicating the lower 4 bits of DLCI

Frame Relay Frame

- Forward Explicit Congestion Notification (FECN)
  - 1-bit field used by Frame Relay switch to inform destination device of network congestion
- Backward Explicit Congestion Notification (BECN)
  - 1-bit field used by Frame Relay switch to inform the source device of network congestion
- Discard Eligibility (DE)
  - 1-bit field used to indicate to FR switches that the present frame may be discarded during times of congestion
- Address Extension (AE)
  - Normally set to 1

Frame Relay Frame

- Data
  - Variable length field containing data from layers 3-7
- Frame Check Sequence
  - 16-bit field used for error detection
- Closing flag
  - 8-bit field indicating end of frame

Frame Efficiency

- Note that only 8 bytes of the 4096 maximum are overhead
  - Efficient protocol - 99.8%
- How does it compare to Ethernet assuming maximum frame size?
  - Ethernet has 26 bytes of overhead (including 7-byte preamble) and a 1525 byte maximum frame
  - Efficiency is 98.3%

Frame Relay Data Transmission

- Range of speeds for UNI leased line is 64 Kbps to 1.544 Kbps
- Customer is promised a minimum guaranteed capacity called the Committed Information Rate (CIR)
  - Higher data rate costs more
- When network is not busy, customer can send/receive at a higher data rate

Frame Relay Data Transmission

- As network becomes congested
  - Frame relay switch sends a Forward Explicit Congestion Notification (FECN) frame to the destination CPE device
  - Frame relay switch sends a Backward Explicit Congestion Notification (BECN) frame to the source CPE
    - Source CPE cuts its transmission rate
  - FR switches discard frames from source CPE devices sending at above their CIR before discarding from CPE devices sending at below their CIR
  - Source CPE will identify some frames as Discard Eligible by setting the frame DE bit
    - FR switch will discard these frames first during congestion
    - DE bit set on oversubscribed traffic

Asynchronous Transmission Mode (ATM)

- During Broadband Integrated Services Digital Network (B-ISDN) development, two technologies chosen
  - SONET/SDH
  - ATM

B-ISDN Model

- Backbone is a SONET network
  - Has repeaters, multiplexers, and fiber
  - Usually configure in a ring
  - Data rates between OC-1 to OC-48
  - Information multiplexed into TDM frames and transported over the network
  - Access to SONET network is through ATM switches

B-ISDN Model

- ATM network
  - Has switches, multiplexers, concentrators, computers and fiber
  - Usually configured in a mesh
  - Supports same data rates as SONET/SDH
    - Typical inter-switch (NNI) rate is OC-12
    - Typical rate to CPE switch (UNI) rate is OC-3
  - Can interface to SONET or can be its own backbone network
  - Used in LAN, MAN, and WAN environment
  - Can emulate Token Ring and Ethernet LANs

ATM Network

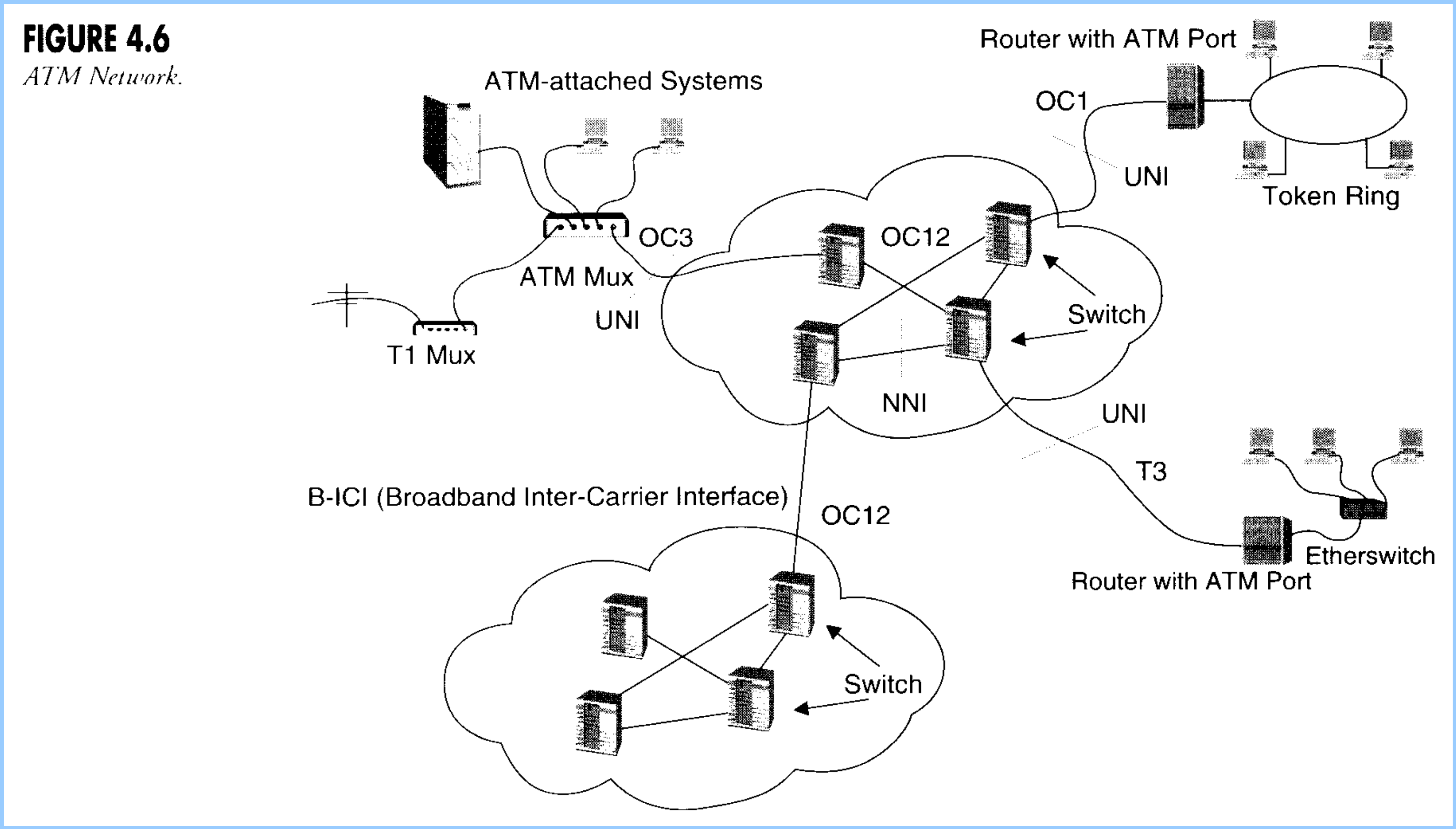


FIGURE 4.6
ATM Network.
ATM-attached Systems
Router with ATM Port
OC1
UNI
Token Ring
OC3
OC12
ATM Mux
UNI
Switch
T1 Mux
NNI
UNI
T3
B-ICI (Broadband Inter-Carrier Interface)
OC12
Etherswitch
Router with ATM Port
Switch

ATM Backbone Examples

- Very High-Speed Backbone Network Services (vBNS)
- Internet2

ATM Services

- Real-Time Services
  - Constant Bit Rate (CBR)
    - Videoconferencing
    - Telephony
    - Streaming audio/video
  - Real-Time Variable Bit Rate (rt-VBR)
    - Time sensitive applications - bursty traffic

ATM Services

- Non-Real-Time Services
  - Non-Real-Time Variable Bit Rate (nrt-VBR)
    - Data rate based on peak rate and an average rate
    - For critical response-time applications like airline reservations
  - Unspecified Bit Rate (UBR)
    - Capacity not used for CBR, rt-VBR and nrt-VBR is available for UBR
    - For non-critical traffic that can experience cell loss like TCP
    - File transfer, messaging, telnet
  - Available Bit Rate (ABR)
    - Similar to UBR but network attempts to share ABR capacity among the ABR applications
    - Example: LAN Emulation (LANE)

ATM Bit Rate Services

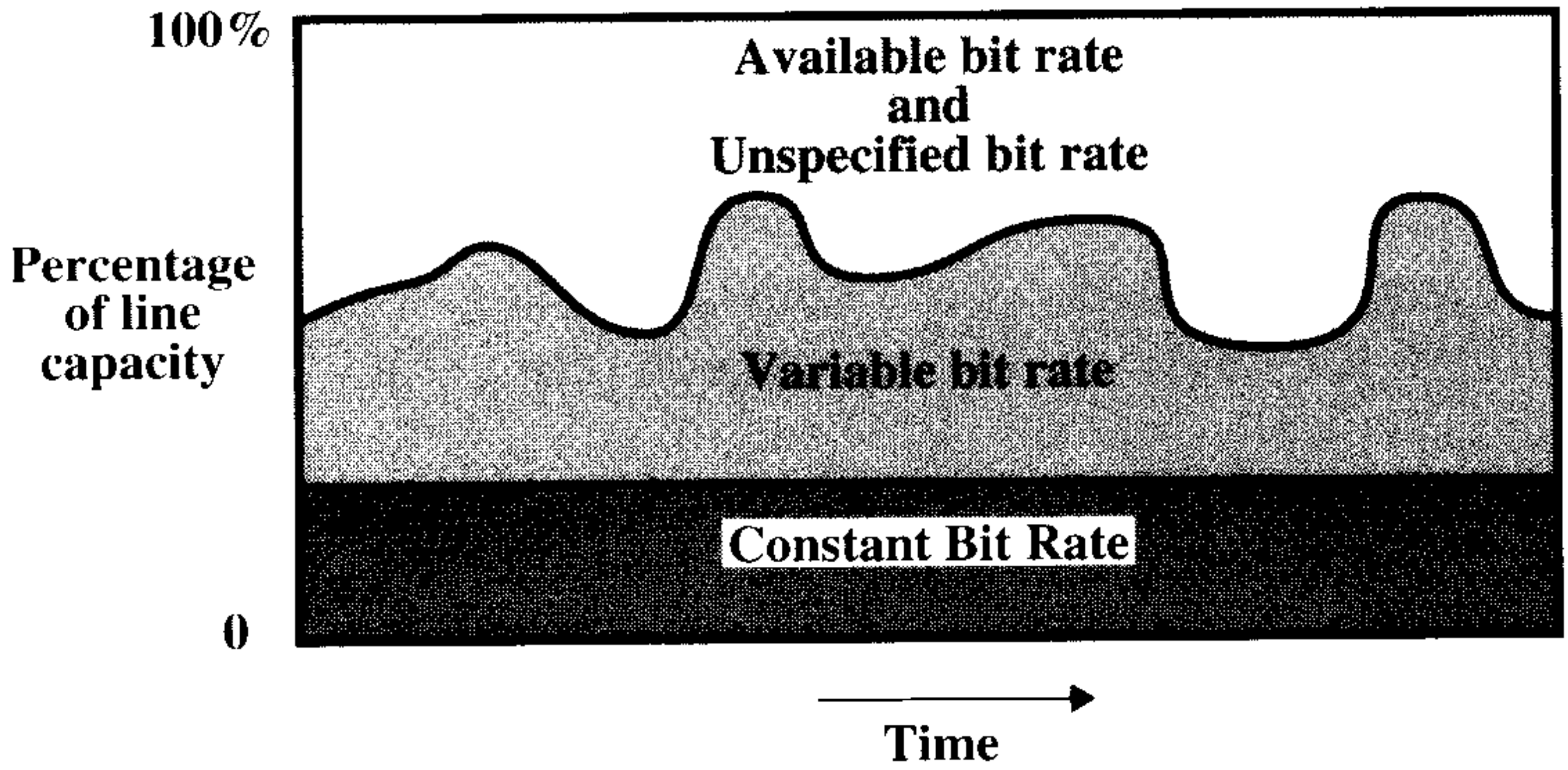


Figure 11.12 ATM Bit Rate Services

- W. Stallings, Data and Computer Communications, 6 ed., Upper Saddle River, NJ, Prentice Hall, 2000

Cell Format

- Uses 53-byte, fixed-length *Cells*
  - 5-byte header, 48-byte information field
- Header is associated with MAC sublayer of OSI Layer 2
  - Known as *ATM Layer*
- Several bytes of information field are associated with the Logical Link Control (LLC) sublayer of OSI Layer 2
  - Known as *ATM Adaptation Layer* (AAL)

Cell Format

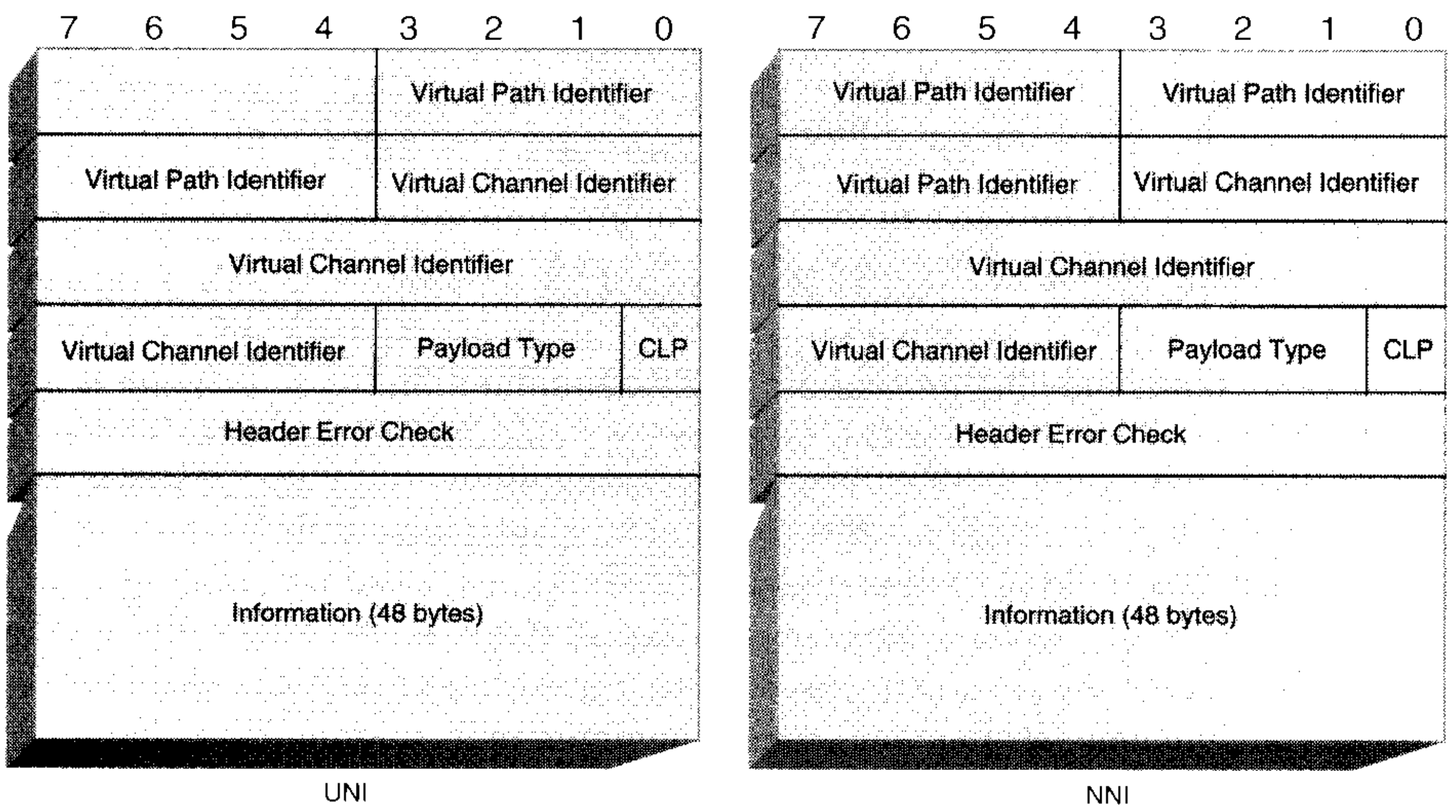


FIGURE 4.7
ATM cell format.

- Note: numbers at top are bit positions

Cell Format

- Generic Flow Control (GFC)
  - 4-bits used to control flow of cells across UNI.
  - Not used in NNI cells
- Virtual Path Identifier (VPI)
  - 8-bits (UNI) or 12 bits (NNI) used to route cells through network vial one or more virtual paths
- Virtual Channel Identifier (VCI)
  - 16-bit field used to route cells through the network via one or more virtual channels

Cell Format

- Payload Type (PT)
  - 3-bit field used to indicate type of information (user or network management) contained in information field
  - Also indicates network congestion
- Cell Loss Priority (CLP)
  - 1-bit field used to indicate to ATM switches whether this cell is discard-eligible
- Header Error Control (HEC)
  - 8-bit field used for detecting errors in header
- Information Field
  - 48-bytes (384-bit) user information

Protocol Architecture

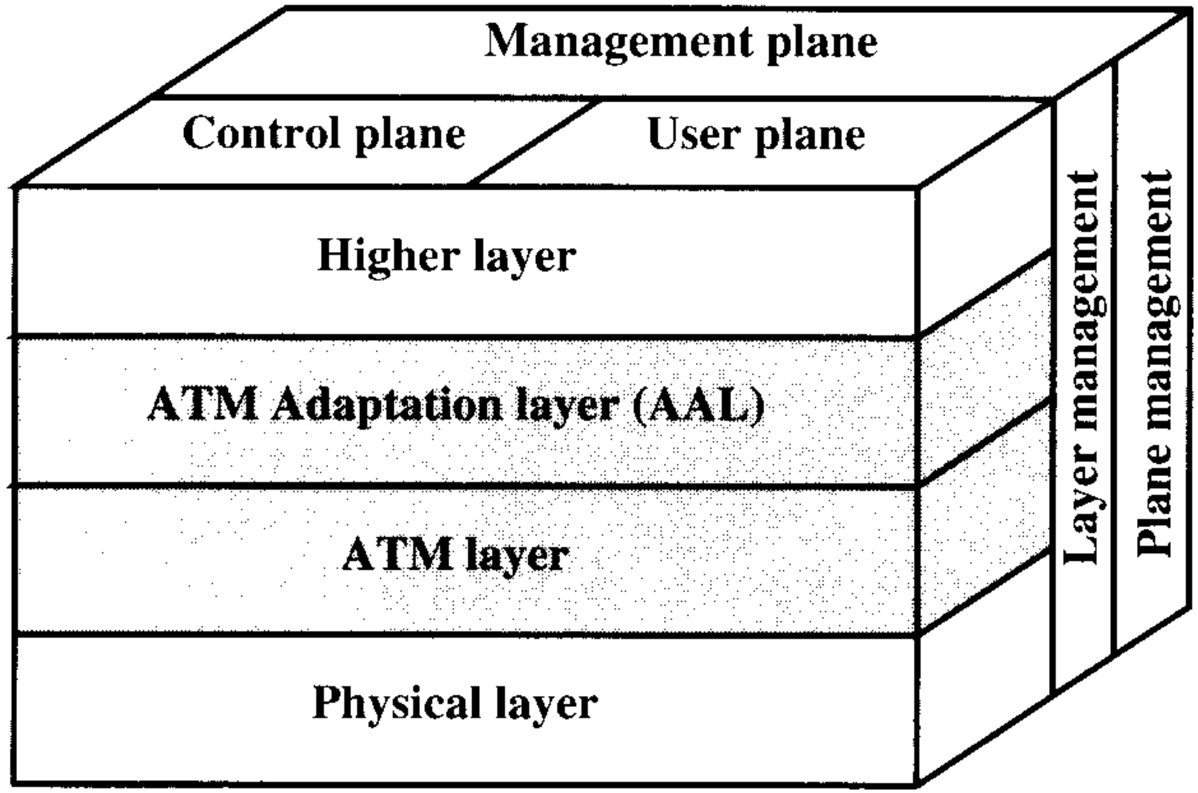


Figure 11.1 ATM Protocol Architecture

- W. Stallings, Data and Computer Communications, 6 ed., Upper Saddle River, NJ, Prentice Hall, 2000

ATM Layer & Virtual Connections

- ATM layer handles the virtual connections
- Virtual Channel Connection (VCC)
  - Previously established path
  - Establishment phase
    - Traffic QoS characteristics negotiated at all UNI and NNI along the way
  - VCC is full duplex
  - Each link in path gets its own Virtual Channel Identifier (VCI)
    - ATM switches know how to move traffic from one VCI to another along the path
  - On-demand VCC is Switched Virtual Channel (SVC)
  - Permanent VCC is Permanent Virtual Channel (PVC)

ATM Layer & Virtual Connections

- Virtual Path Connection (VPC)
  - Group of VCCs with same end points
  - Use Virtual Path Identifier (VPI) to keep track of them

ATM Adaptation Layer and Services

- Five different AAL formats depending on service needed
- Supports transport of protocols not based on ATM
  - Pulse code modulation (PCM) voice bits must be assembled into ATM cells
  - IP packets must be segmented into ATM cells at source and reassembled at destination
- Maps higher-layer information into ATM cells at source and and reverses process at destination

ATM Adaptation Layer and Services

Table 11.4 AAL Protocols and Services

	CBR	rt-VBR	nrt-VBR	ABR	UBR
AAL 1	Circuit emulation, ISDN, voice over ATM				
AAL 2		VBR voice and video			
AAL 3/4			General data services		
AAL 5	LAN emulation	Voice on demand, LANE emulation	Frame relay, ATM, LANE emulation	LANE emulation	IP over ATM

ATM Adaptation Layer and Services

- AAL1 - Constant Bit Rate (CBR)
  - Supports PCM voice such as transporting T1 over ATM
  - Why does this work?
    - ATM bits are clocked much faster than voice PCM (64 Kbps)
- AAL2 - Real-time Variable Bit Rate (rt-VBR) voice and video (timing critical)
  - Transports compressed voice and video
  - Does not need constant bit rate when transported but needs constant bit rate at destination
    - What does this mean?

ATM Adaptation Layer and Services

- AAL3 & 4 - Non-real-time Variable Bit Rate (nrt-VBR)
  - General data services
    - Messaging and transactions not needing real time
- AAL5 - Covers certain CBR, rt-VBR, nrt-VBR, Available Bit Rate (ABR) and Unspecified Bit Rate (UBR) services
  - IP over ATM
  - LAN Emulation
    - Emulate LAN broadcast and multicast
  - Frame Relay over ATM
  - Voice on demand

ATM Cell Transmission

- Transmission Speed
  - Defined by B-ISDN standard I.432
  - 25.6Mbps, 51.84Mbps, 155.52Mbps, or 622.08Mbps
- Two ways to carry the cells on physical layer
  - Cell-based format
  - Synchronous Digital Hierarchy (SDH) based format
    - SDH format does not support the 25.6Mbps speed

Cell-Based Physical Layer

- No framing is used
  - Advantage: results in simplified interface
- This interface has a continuous stream of 53 octet cells
- Needs method of synchronization
  - Receiver HUNTs for several correct header error-correction (HEC) codes in succession
  - Once done, HEC is used only for error detection and correction
    - Note: HEC can correct a 1-bit error and detect a multi-bit error without correction

Cell-Based Physical Layer Format

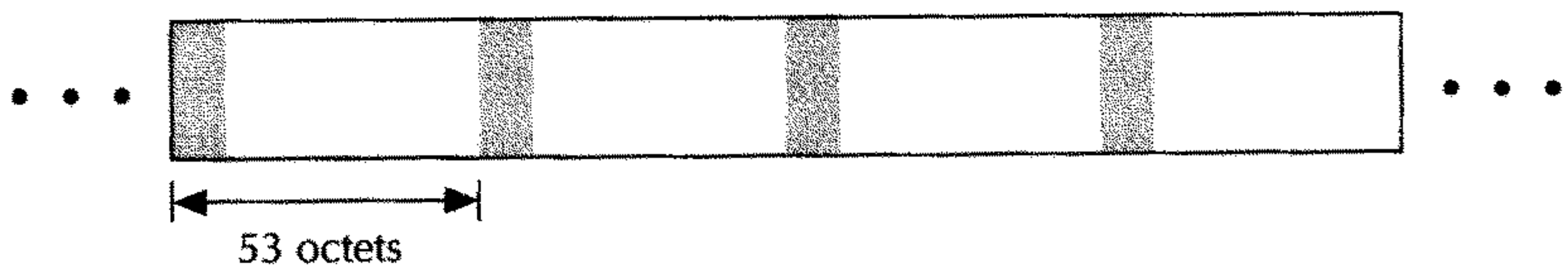


Figure 16.11 Cell-Based Physical Interface for ATM Cell Transmission.

SDH-Based Physical Layer

- SDH is an optical network framing standard similar to SONET
  - SDH standardized in 1996
- Advantages of SDH-based approach
  - Can carry ATM-based or STM-based (synchronous transfer mode) payloads
    - Can deploy a fiber-based circuit-switched network and migrate to support B-ISDN
    - Part of a network can be circuit switched
    - SDH multiplexing schemes can be used to combine ATM streams
      - May be cheaper than one ATM stream at the higher speed

SDH-Based Physical Layer

- SONET does the following
  - Establishes a standard multiplexing format using based on multiples of 51.84Mbps signals
    - Each block can carry a DS3 signal
    - SDH adds a 25.6 Mbps
  - Establishes an optical signal standard for interconnecting equipment from different suppliers
  - Establishes operations, administration, and maintenance (OAM) capabilities Defines synchronous multiplexing format for carrying lower-level digital signals (DS1, DS2, ITU-T standards)
    - Interfaces to digital switches, digital cross-connect switches, etc.
  - Establishes flexible architecture capable of supporting future applications such as B-ISDN

SONET/SDH Signal Hierarchy

Table 15.3 SONET/SDH Signal Hierarchy

SONET Designation	ITU-T Designation	Data Rate (Mbps)	Payload Rate (Mbps)
STS-1/OC-1		51.84	50.112
STS-3/OC-3	STM-1	155.52	150.336
STS-9/OC-9		466.56	451.008
STS-12/OC-12	STM-4	622.08	601.344
STS-18/OC-18		933.12	902.016
STS-24/OC-24		1244.16	1202.688
STS-36/OC-36		1866.24	1804.032
STS-48/OC-48	STM-16	2488.32	2405.376
STS-96/OC-96		4876.64	4810.752
STS-192/OC-192	STM-64	9953.28	9621.504

- W. Stallings, ISDN and Broadband ISDN with Frame Relay and ATM, 4ed, Upper Saddle River, NJ, Prentice Hall, 1999.

SONET/SDH Frame Format

- SONET building block is STS-1 frame
  - 810 octets transmitted once every 125μs (51.84Mbps)
  - Frame has 9 rows of 90 octets
  - First 3 columns are overhead (27 octets)
  - Rest is payload
    - One column of payload is path overhead
- Transmitted row-by-row
- All SONET frames, no matter what the speed are transmitted in 125 μs
  - Higher bit rates result from larger frames
  - OC-3 is 3 x 810 octets = 2430 octets

SONET/SDH Frame Formats

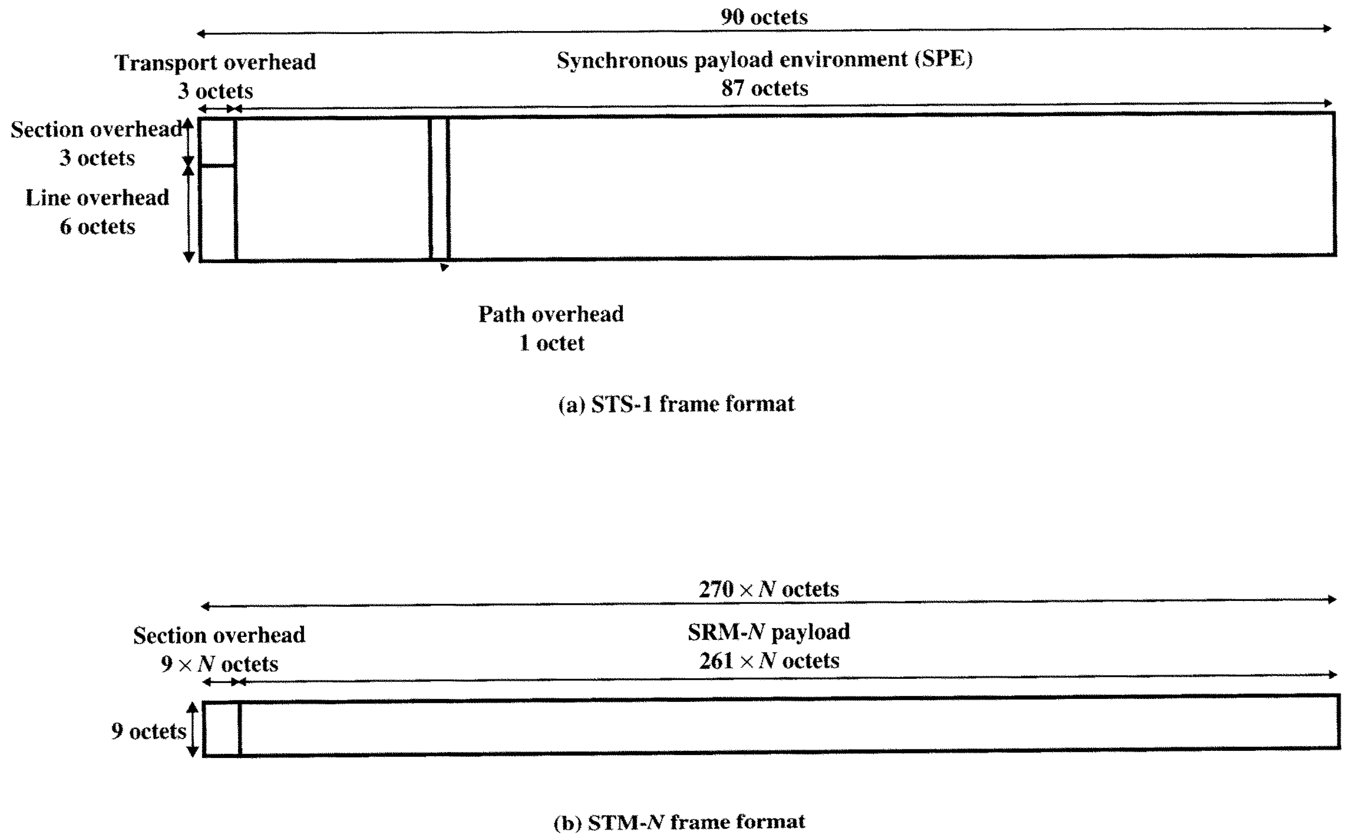


Figure 15.4 SONET/SDH Frame Formats.

- W. Stallings, ISDN and Broadband ISDN with Frame Relay and ATM, 4ed, Upper Saddle River, NJ, Prentice Hall, 1999.

Framing for 155.2 Mbps

- Based on STM-1 (STS-3) frame
- First 3 columns (27 octets) are path head
- Remaining 260 columns (2340 octets) contain ATM cells
- Cells can cross frame boundaries

STM-1 Payload for SDH-Based ATM

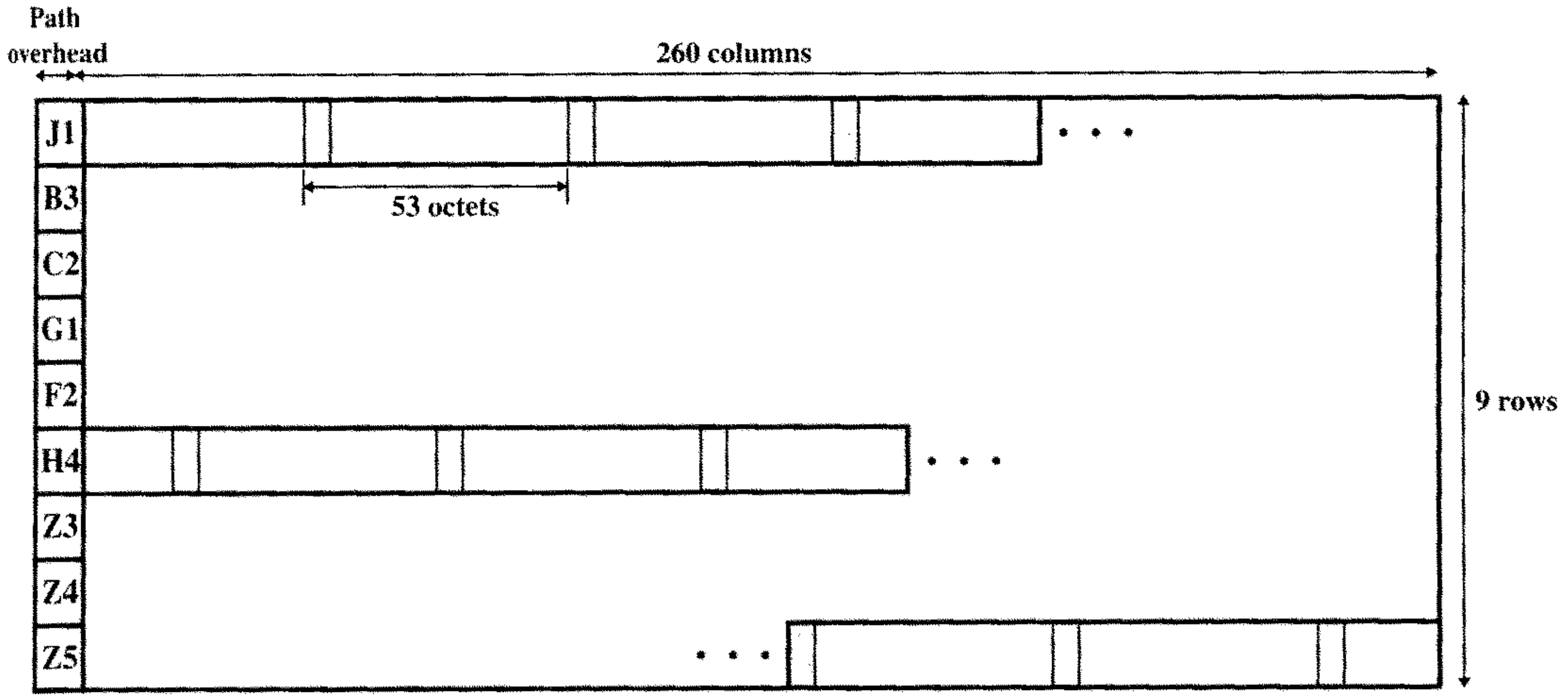


Figure 16.15 STM-1 Payload for SDH-Based ATM Cell Transmission.

Access Technologies

- Dial-up
  - Modem over standard analog phone line
- Digital Subscriber Line (DSL)
- Integrated Services Digital Network (ISDN)
  - (Typo in book)
- Cable Modem

DSL

- Often called xDSL, where x is any one of a number of letters corresponding to the type of DSL service
- Uses twisted-pair copper voice telephone lines
  - Uses additional bandwidth above the voice channel
  - Divide bandwidth into multiple channels in FDM scheme
    - Runs full duplex
    - Communicates in channels much like dial up modem

DSL

- Main categories: Symmetrical and Asymmetrical
  - Symmetrical – same capacity upstream and downstream
  - Asymmetrical – greater capacity downstream to user than upstream to ISP
    - Takes advantage of customer's typical Internet usage pattern
- Requires DSL modem at customer and telephone company CO (or telephone company's remote terminal)
  - ISP modems are rack mounted in a DSLAM (DSL Access Multiplexer)
  - DSLAM connects to service provider's backbone

Key DSL Types

xDSL Type	Distance	Upstream (bps)	Downstream (bps)
ADSL (Asymmetric)	18,000	64,000	1,544,000
ADSL Lite	18,000	100,000	500,000
SDSL (Symmetric)	10,000	1,100,000	1,100,000
HDSL (High bit rate DSL)	12,000	1,544,000	1,544,000
VDSL (Very high speed DSL)	4,500	1,800,000	12,980,000

Integrated Services Digital Network (ISDN)

- Development began in late 1960s, matured in 1980s
- Standardized by International Telecommunication Union Telecommunications Section (ITU-T)
- Uses digital signal over the same connection used for telephone local loop
- Circuit-switched technology
- Data transfer between data devices
- Integrates voice/data in connection to customer
- ISDN standards define hardware and call setup schemes for end-to-end digital connectivity

ISDN Benefits/Disadvantages

- Advantages
  - Handles variety of user traffic
    - Video, voice, packet-switched data, enhanced telephone network services
  - Faster call set up compared to analog modem
    - Less than 1 second
    - Uses D (Delta) channel
  - Faster than analog modem
    - 1 or 2 64 kbps per B (Bearer) channel
- Disadvantages
  - More expensive than dial-up modem
  - DSL and cable modem faster than BRI for data

ISDN Components

- Network consists of various CPE, ISDN routers (sometimes called ISDN modem), ISDN switches at the CO, and ISDN subscriber lines

ISDN Network

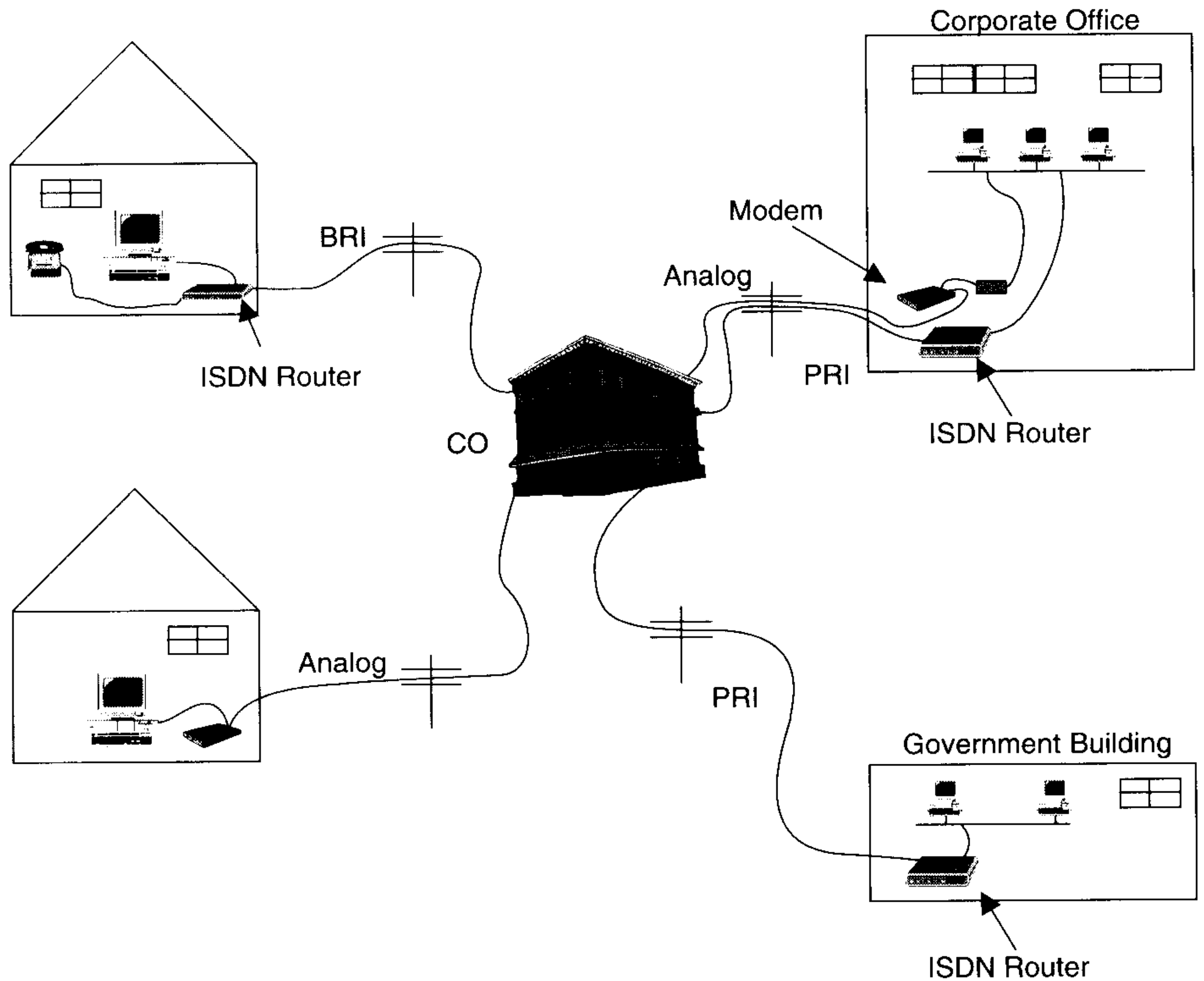
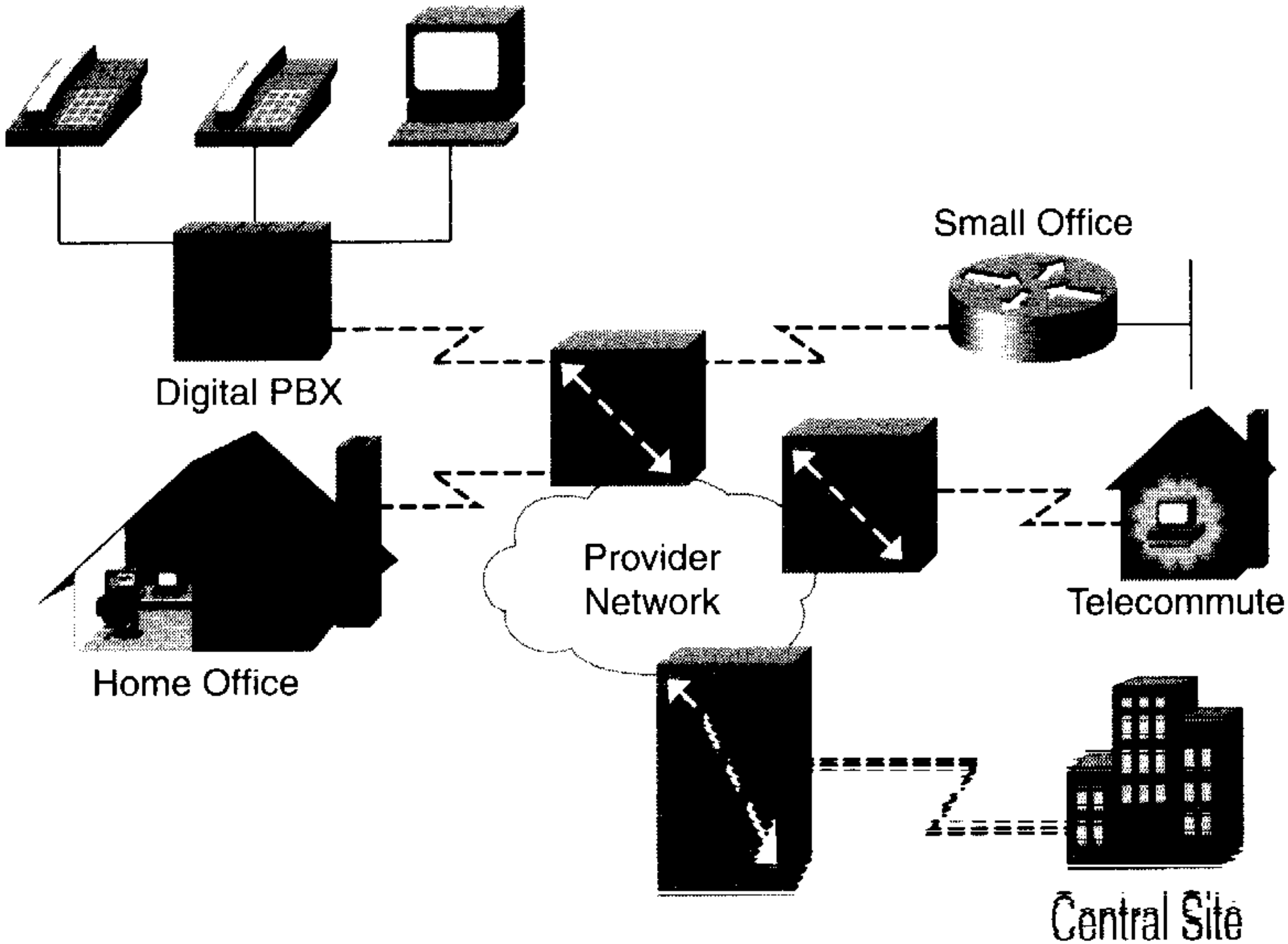


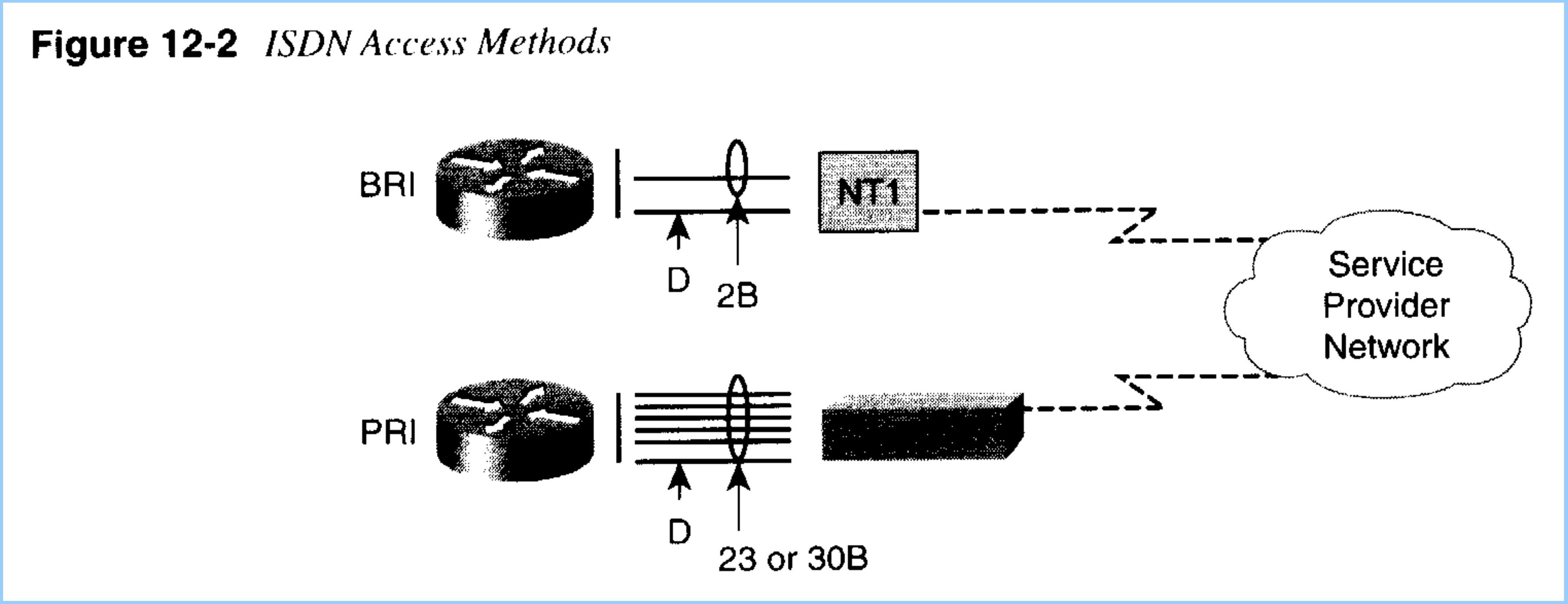
FIGURE 4.8
ISDN (Integrated Services Digital Network).

ISDN Network

Figure 12-1 *What Is ISDN?*



ISDN Components



Basic Rate Interface (BRI)

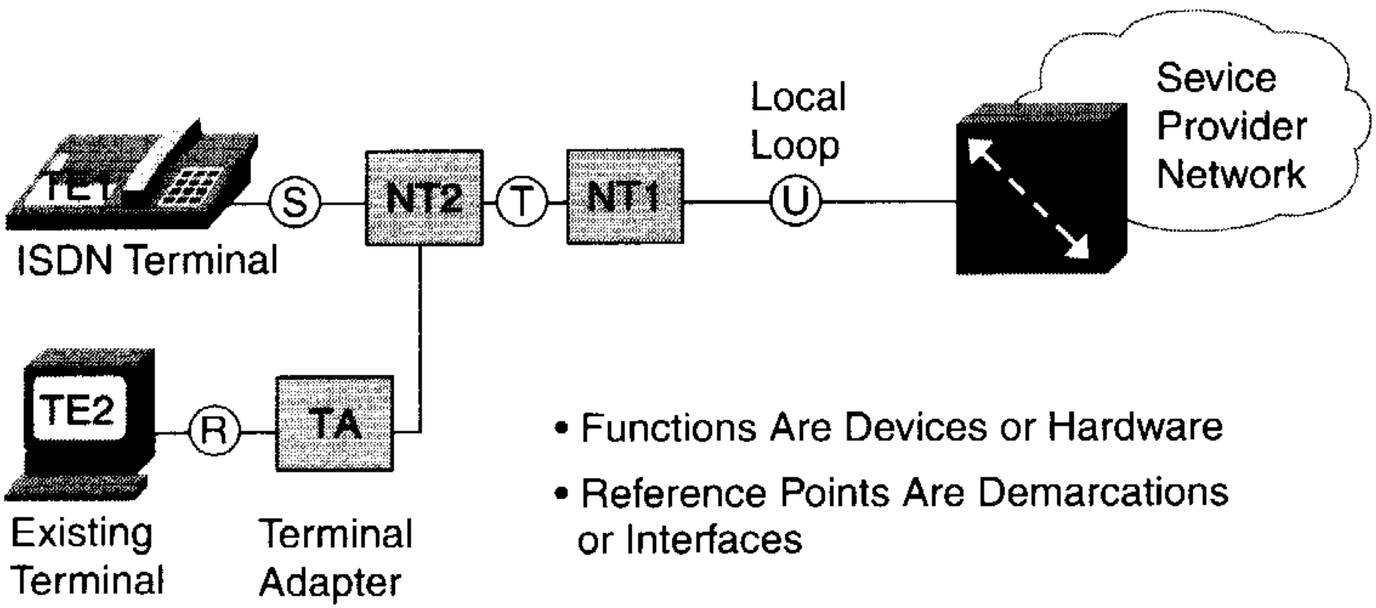
- Also known as 2B+D
- Two 64 Kbps B channels, one 16 Kbps D channel
- B channels can be used for digitized speech or for data
  - Can be combined to form one 128 Kbps channel
- D channel carries signaling information
  - Call set up signaling

Primary Rate Interface (PRI)

- Also known as 23B+D
- 23 64 Kbps B channels, one 64 Kbps D channel
- Uses a DSU/CSU to connect to 4-wire line
- Can interface to PBX or LAN

ISDN CPE Equipment and Reference Points

Figure 12-4 *ISDN Equipment Types and Reference Points*



ISDN CPE Equipment and Reference Points

- CPE must interface properly to ISDN network
- Devices
  - TE1 – Terminal Endpoint 1
    - Router with a native ISDN interface
  - NT2 – Network Termination 2
    - Point at customer site where ISDN lines are aggregated and switched using a customer switching device (like a PBX)
  - NT1 – Network Termination 1
    - Converts BRI signals into form used by ISDN line
  - TE2 – Terminal Endpoint 2
    - Designates a router as a device requiring a TA for its BRI signals
  - TA – Terminal Adapter
    - Converts EIA/TIA-232 and V.35 signals into BRI signals

ISDN CPE Equipment and Reference Points

- Reference Points define a connection between two functions
  - R – References the point between non-ISDN compatible device and a TA
  - S – references the points between the NT2 customer switching device and equipment connected to it
  - T – Outbound connection between NT2 and ISDN network
  - U – References connection between NT1 and the ISDN network owned by the telephone compaby

Cable Modem

- Allows digital information to travel to/from customer to cable TV network head end
- Uses asymmetrical data rates
  - Typical 27 Mbps downstream, 2 Mbps upstream
- Modulates digital data onto available channels in cable TV FDM scheme
- Uses a version of CSMA/CD
  - Subscribers contend for available bandwidth

Cable Modem

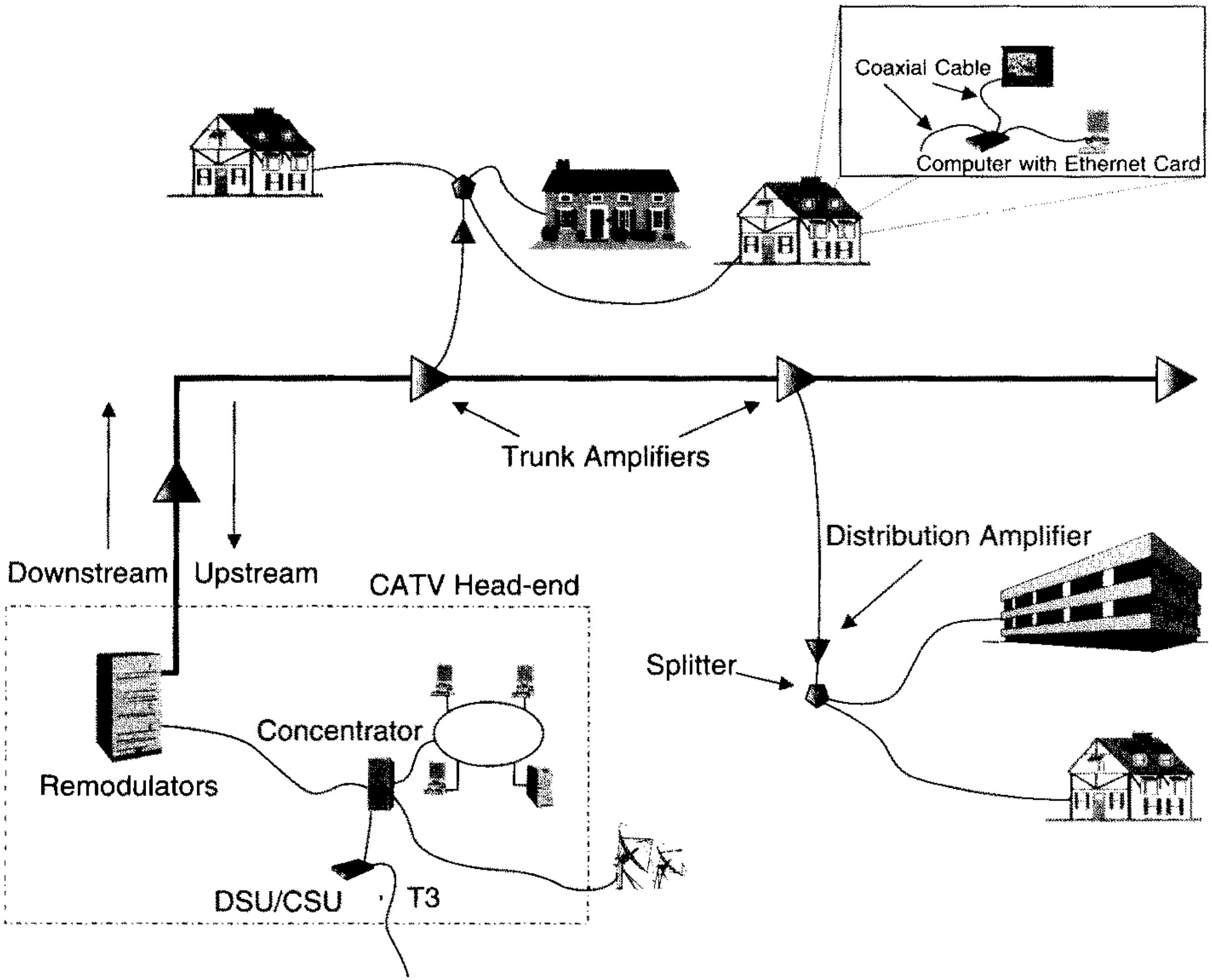


FIGURE 4.9
Cable modem.