Hands-on Networking Fundamentals, 2nd ed.

Chapter 2: How LAN and WAN Communications Work

Objectives

- Explain the OSI reference model, which sets standards for LAN and WAN communications
- Discuss communication between OSI stacks when two computers are linked through a network
- Apply the OSI model to realistic networking situations
- Describe major LAN transmission methods

Objectives (continued)

- Explain the basic WAN network communications topologies and transmission methods, including telecommunications, cable TV, satellite and wireless technologies
- Explain the advantages of using Ethernet in network designs

The OSI Reference Model

- Networks work because standards have been implemented to ensure devices from different vendors will work together
- Open Systems Interconnection (OSI) reference model
  - Fundamental network communications model
- Understanding the OSI model enable you to:
  - Choose the best equipment for the job
  - Create the most effective network designs
  - Design networks that will communicate with other networks
  - Troubleshoot network problems more effectively

The OSI Reference Model

- OSI model product of two standards organizations
  - International Organization for Standardization (ISO)
  - American National Standards Institute (ANSI)
- The OSI model was developed in the 1970s
- Represents an effort to standardize network software and hardware implementation

The OSI Reference Model

- Accomplishments of the OSI model
  - Enabled communications among LANs, MANs, WANs
  - Provided standardization of network equipment
  - Enabled older equipment to communicate with newer equipment
  - Enabled development of software and hardware with common interfaces
  - Made worldwide networks possible; e.g., the Internet
- OSI has set the stage for cooperative networking and is constantly evolving to accommodate new networking developments

The OSI Reference Model

- The OSI model is a theoretical model and not a specific hardware device or software routine
- It is a set of guidelines for vendors to consider and follow when they design communications hardware of software
- OSI guidelines specify:
  – How network devices contact each other and how devices using different protocols communicate
  – How a network device knows when to transmit or not transmit data

The OSI Reference Model

- OSI guidelines specify (continued):
  - How the physical network devices are arranged and connected
  - Methods to ensure that network transmissions are received correctly
  - How network devices maintain a consistent rate of data flow
  - How electronic data is represented on the network media
- There are 7 layers in the OSI Model: Physical, Data Link, Network, Transport, Session, Presentation, and Application

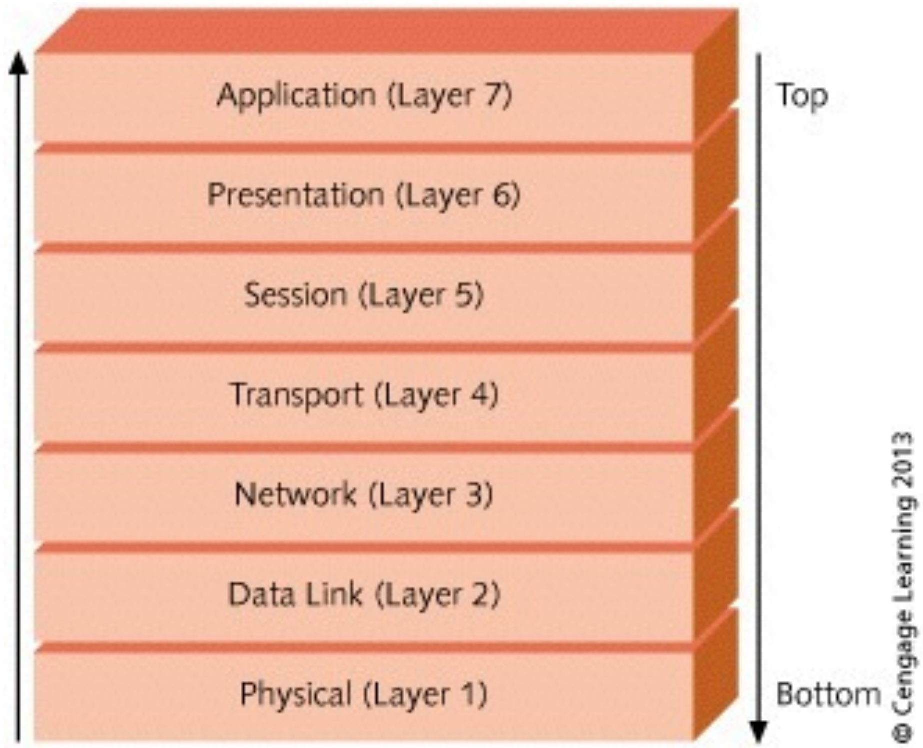

Figure 2-1 The OSI layers

The OSI Reference Model

- Set of layers in OSI model is called a stack
- Communications between two network devices go up and down the layered stack at each device
- Contact between a workstation and server
  - Communications begin at the Application layer of the workstation
  - Specific information is formatted at each layer of the stack until reaching the Physical layer where it is sent out to the communication medium
  - The server picks up the data at the Physical layer and sends it up each layer for interpretation until reaching the Application layer

The OSI Reference Model

- Each layer is called by its actual name or by its placement in the stack
  - Example: Layer 1 or Physical Layer
- Bottom layers perform functions like constructing frames and transmitting packets/frames/signals
- Middle layers coordinate network communication between nodes, ensuring sessions without interruptions or errors
- Top layers perform work that directly affects software applications and data presentation

Physical Layer

- Layer purpose: transmit and receive signals with data
- Responsibilities of the Physical layer (Layer 1)
  - All data transfer mediums
    - wire cable, fiber optics, radio waves, and microwaves
  - Network connectors
  - The network topology
  - Signaling and encoding methods
  - Data transmission devices
  - Network interfaces
  - Detection of signaling errors

Physical Layer

- Network signals are either analog or digital
- Analog signal
  - Wave pattern with positive and negative voltages
  - Examples: ordinary telephone or radio signal
  - Used in WANs that employ analog modems
- Digital signal generates binary 1s or 0s
  - Most common signaling method on LANs and high-speed WANs
  - Example 1: +5 volts produces 1, 0 volts produce 0
  - Example 2: +5 volts produces 1, -5 volts produce 0
  - Example 3 (Fiber-optics): presence of light is 1, else 0

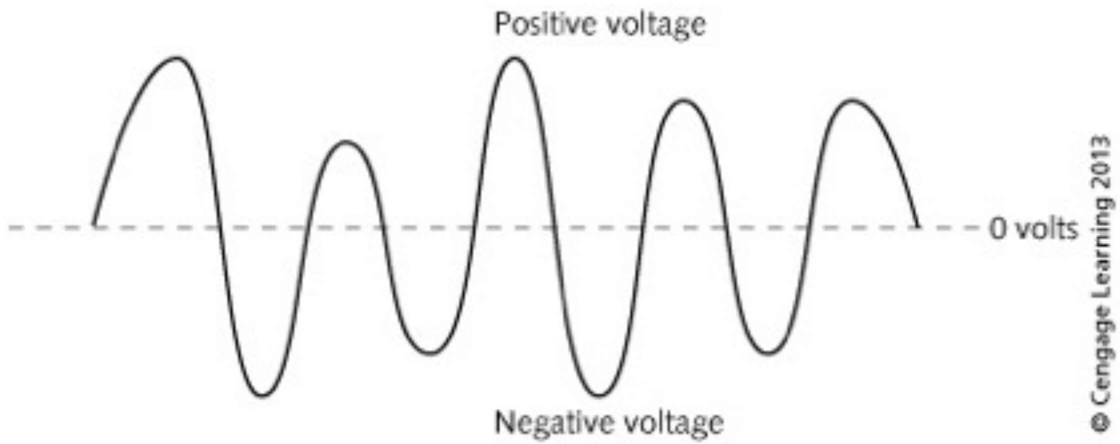

Figure 2-2 An analog signal

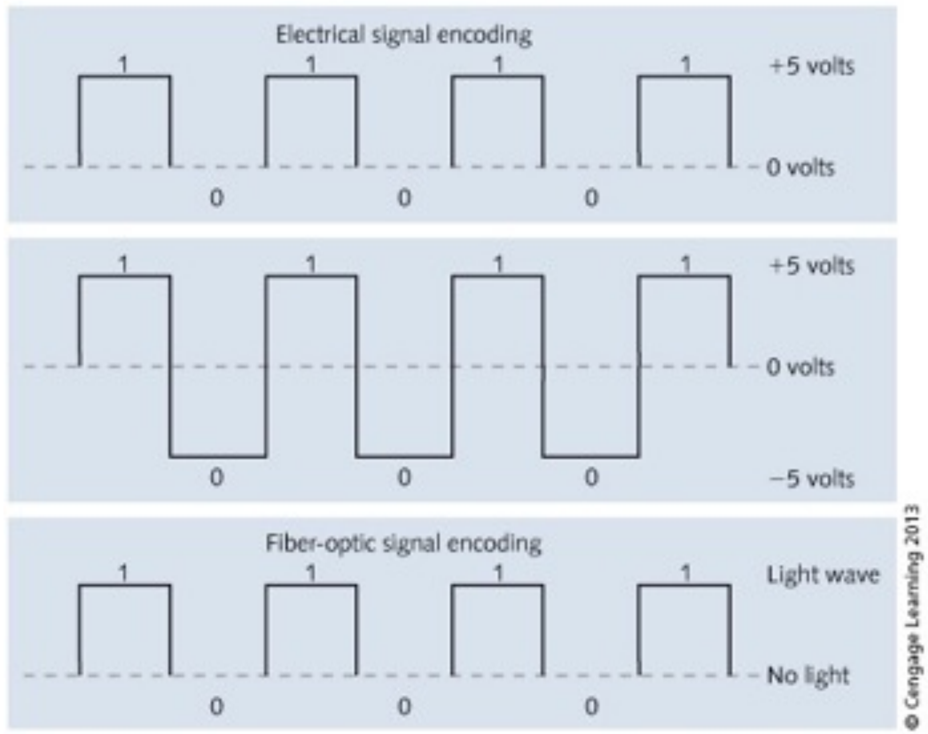

Figure 2-3 Examples of digital signals

Physical Layer

- The Physical layer:
  - Converts bits into voltage for transmission
  - Handles data transmission rate
  - Monitors data error rates
  - Handles voltage levels for signal transmissions
- Electromagnetic interference (EMI)
  - Generated by certain electrical devices
    - Fans, electric motors, portable heaters, air-conditioners
- Radio frequency interference (RFI)
  - Caused by electrical devices emitting radio waves
    - Radio and television stations, radio operators, cable TV
  - Problem when frequency matches network signal

Data Link Layer

- Layer purpose: organize bits and format into frames
- Frame: unit of data transmitted on a network
  – Contains control and address information
  – Does not contain routing information
- How Data Link layer works:
  – Data Link layer formats the frame into an electrical signal and transfers it to the Physical layer to be placed on the communications medium
  – Receiving node then picks up the frame via the Physical layer, decodes the signal, organizes the bits into a frame, and checks the frame for errors

Data Link Layer

- Data Link layer checks incoming signals for duplicate, incorrect, or partial data
- If an error is detected, it requests a retransmission of the data
- Error detection is handled by cyclic redundancy check (CRC)
  - Calculates size of information fields in frame
  - Data Link layer at sender inserts value at end of frame
  - Receiving Data Link layer checks value in frame

Data Link Layer

- Data Link layer contains two important sublayers
- Logical link control sublayer (LLC)
  - Initiates communication link between two nodes
  - Guards against interruptions to link
  - Link to Network layer may be connection-oriented
- Media access control sublayer (MAC)
  - Examines physical (device or MAC) address in frame
  - Frame discarded if address does not match workstation
  - Regulates communication sharing
- MAC address burned into chip on network interface
  - Coded as a hexadecimal number; e.g., 0004AC8428DE
    - First half refers to vendor, second half unique to device

Data Link Layer

- Two types of services are used for communication between the LLC sublayer and the Network layer
  - Type 1 – a connectionless service (does not establish a logical connection between nodes)
    - Frames are not checked to ensure that they are in the proper sequence, there is no acknowledgment, and there is no error recovery
  - Type 2 – a connection-oriented service (a logical connection is made before full data transfer begins)
    - Each frame contains a sequence # to ensure they are processed in the proper order, sending node does not transmit data faster than can be received, and if errors are detected the data is retransmitted

Network Layer

- Layer purpose: controls passage of packets along routes on the network
  - Physical routes: cable and wireless paths
  - Logical routes: software paths
- Packet: unit of information (like a frame)
  - Formatted for transmission as signal over network
  - Composed of data bits in fields of information
  - Corresponds to network information sent at Network layer of OSI model
- Specific tasks of Network layer
  - Optimize physical and logical routes
  - Permit routers to move packets between networks

Network Layer

- Discovery: process of information gathering to determine the best path to a destination network
- Virtual circuits: logical communication paths
  - Send and receive data
  - Known only to Network layers between sending and receiving nodes
  - Benefit: manage parallel data paths
- Extra duties using virtual circuits
  - Checks (and corrects) packet sequence
  - Addresses packets
  - Resizes packets to match receiving network protocol
  - Synchronizes flow of data between Network layers

Transport Layer

- Layer purpose: reliable data transmission
  - Ensures data sent and received in same order
  - Receiving node sends acknowledgement ("ack")
- Transport layer is responsible for tracking virtual circuits
  - Tracks unique identification value assigned to circuit
    - Value is called a port or socket
    - Port or socket is assigned by Session layer
  - Establishes level of packet error checking
- There are 5 reliability measures used by Transport layer protocols (Class 0 – Class 4)
- Fragments messages into smaller units

Session Layer

- Multiple goals
  - Establish and maintain the link between two nodes
  - Provide for orderly communication between nodes
    - Establishes which node transmits first
  - Determine how long node can transmit
  - Determine how to recover from transmission errors
  - Link each unique address to a node (like a zip code)
  - Disconnects link after communication session is finished

Session Layer

- Two-way alternate mode (TWA) for dialog control
  - Sets up node to separately send and receive
  - Analogize to use of walkie-talkies
  - Used in half-duplex communications
- Two-way simultaneous (TWS) for dialog control
  - Devices configured to send and receive at same time
  - Increases efficiency two-fold
  - Made possible by buffering at network interface
  - Used in full-duplex communications

Presentation Layer

- Primary purpose: manages data formatting
  - Acts like a syntax checker
  - Ensures data is readable to receiving Presentation layer
- Translates between distinct character codes
  - EBCDIC (Extended Binary Coded Decimal Interchange Code)
    - 8-bit coding method for 256-character set
    - Used mainly by IBM computers
  - ASCII (American Standard Code for Information Interchange)
    - 8-bit character coding method for 128 characters
    - Used by workstations running Windows 7, UNIX/Linux, or Mac OS X

Presentation Layer

- Two additional responsibilities
  - Data encryption: scrambling data so that it cannot be read if intercepted by unauthorized users
    - Example 1: account password encrypted on LAN
    - Example 2: credit card encrypted on a LAN
    - Encryption tool: Secure Sockets Layer (SSL)
  - Data compression: compact data to conserve space
    - Presentation layer at receiving node decompresses data

Application Layer

- Layer purpose: Govern the user's most direct access to applications and network services
- Services managed by Application layer
  - File transfer, file management, remote access to files and printers, message handling for electronic mail, and terminal emulation
- Connecting workstations to network services
  - Link application into electronic mail
  - Providing database access over the network
- Microsoft Windows redirector works through this layer
  - Makes computer visible to another for network access
  - Example: access shared folder using redirector

Communicating Between Stacks

- OSI model enables two computers to communicate
- OSI model provides standards for:
  - Communicating on a LAN
  - Communicating between LANs
  - Internetworking between WANs and LANs (and WANs)
- Constructing a message at the sending node
  - Message created at Application layer
  - Message travels down stack to Physical layer
  - Information at each layer is added to message
    - Layer information is encapsulated
  - Message sent out to the network on the Physical layer

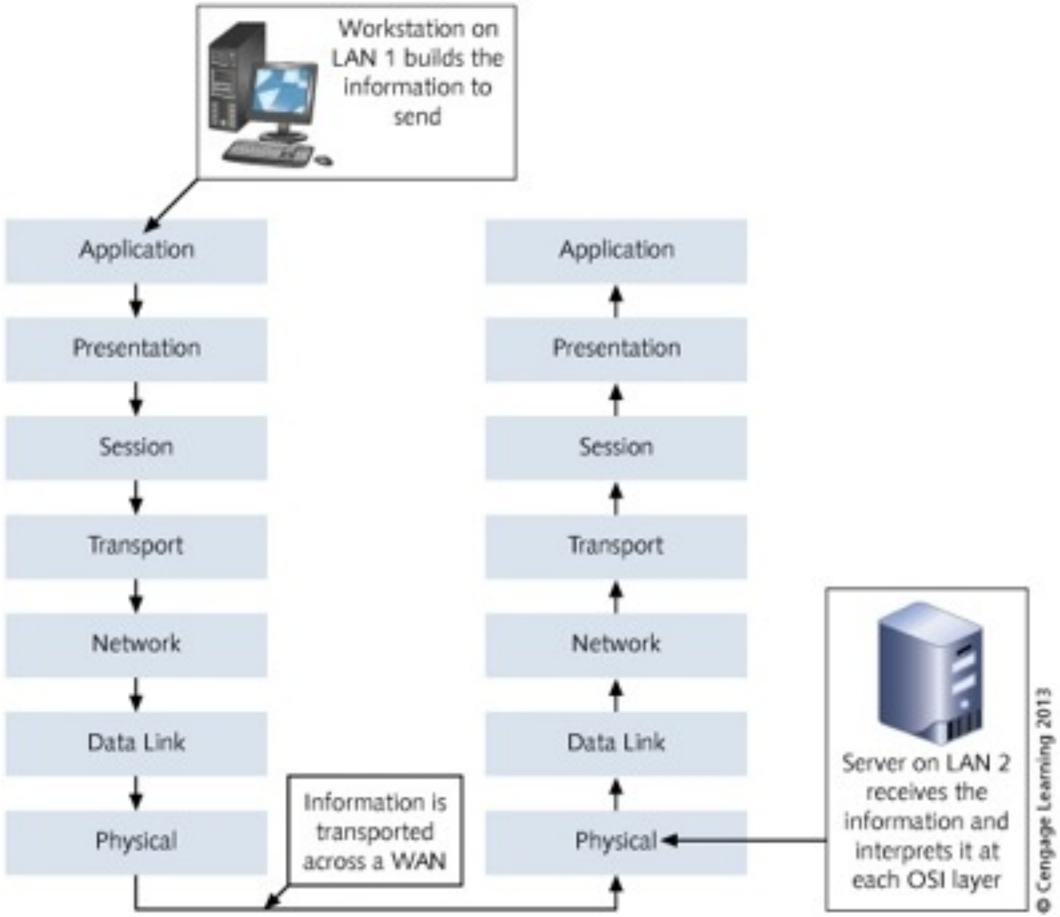

Figure 2-11 Sending information through the OSI reference model

Communicating Between Stacks

- Interpreting the message at the receiving node
  - Message travels up stack from Physical layer
  - Data Link layer checks address of frame
  - Data Link layer uses CRC to check frame integrity
  - Network layer receives valid frame and sends up stack
- Peer protocols: enable the sending layer to communicate with the receiving layer
- Information transferred using primitive commands
  - Protocol data unit (PDU) – as information goes from one layer to the next, new control information is added to the PDU

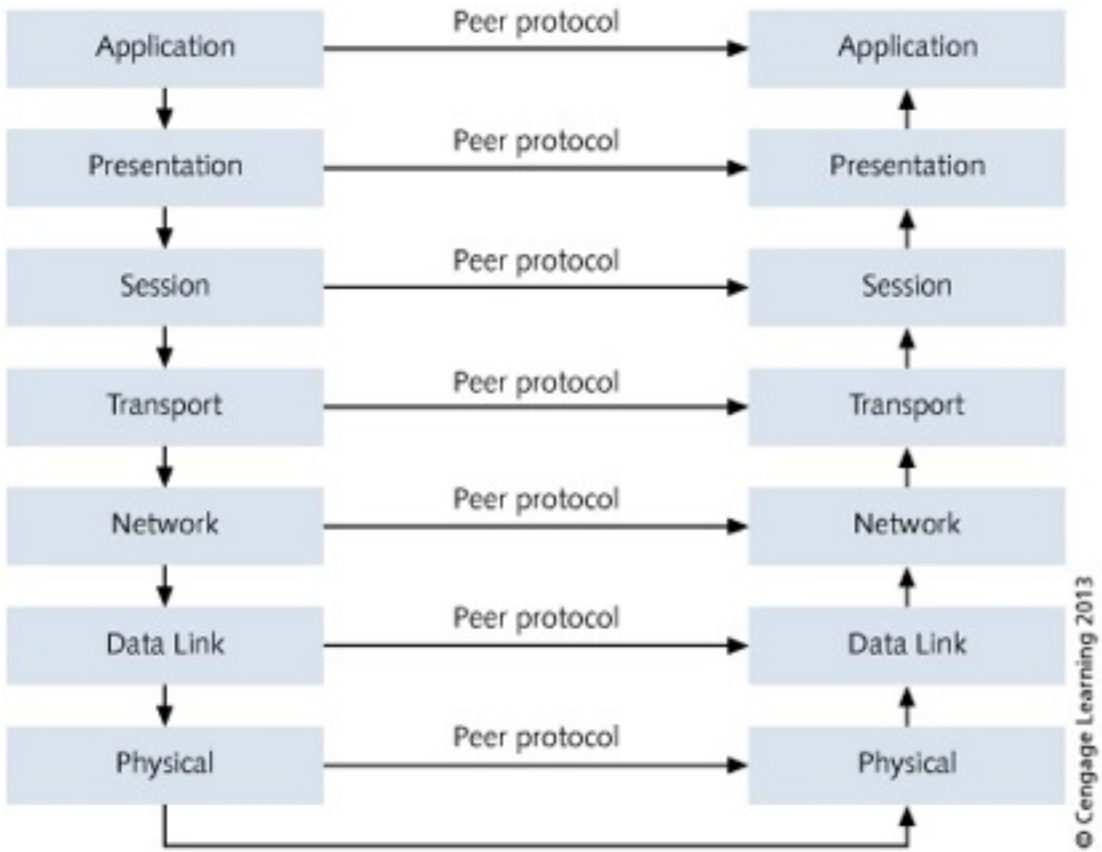

Figure 2-12 Peer protocol communications between the same layers

Communicating Between Stacks

- Control data added to PDU as it traverses stack
  - Next layer gets transfer instructions from previous layer
    - Next layer strips transfer/control information
    - Service data unit (SDU) remains after data stripped
  - Peer protocols used to communicate with companion layer
- Key points
  - Each layer forms a PDU (from an SDU)
  - Each PDU is communicated to counterpart PDU

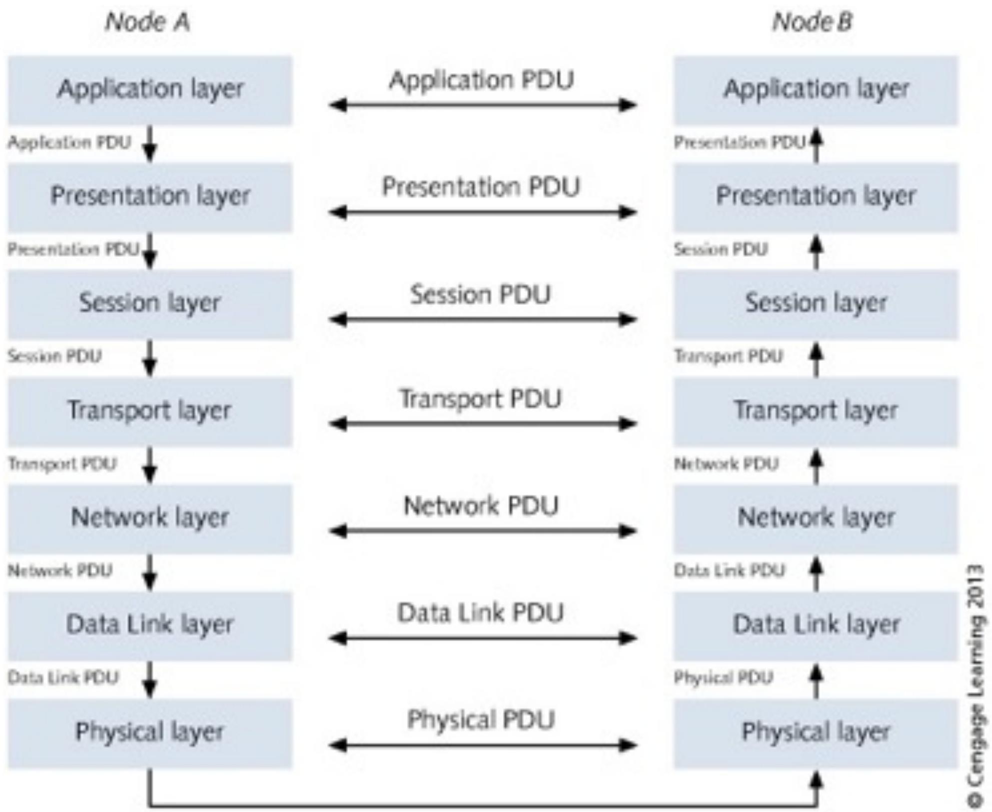

Figure 2-14 Layered communications using PDUs

Applying the OSI Model

- Example: Workstation accessing a shared drive
  - Redirector at Application layer locates shared drive
  - Presentation layer ensures data format is ASCII
  - Session layer establishes and maintains link
  - Transport layer monitors transmission/reception errors
  - Network layer routes packet along shortest path
  - Data Link layer formats frames, verifies address
  - Physical layer converts data to electrical signal
- OSI model is also applied to network hardware and software communications

OSI Layer	Corresponding Network Hardware or Software
Application	Application programming interfaces, Internet browsers, messaging and e-mail software, software to access a computer remotely from another computer, and gateways
Presentation	Data translation software, data encryption software, graphics formatting (.gif and .jpg file formatting), and gateways
Session	Network equipment software drivers, computer name lookup software, half- and full-duplex capabilities, remote procedure call (RPC) capability to run a program on a remote computer, and gateways
Transport	Network equipment software drivers, flow control software and capabilities, Layer 4 switches, and gateways
Network	Gateways, routers, routing protocols, source-route bridges, and Layer 3 switches
Data Link	Network interface cards, intelligent hubs and bridges, Layer 2 switches, and gateways
Physical	Cabling, cable connectors, multiplexers, transmitters, receivers, transceivers, passive and active hubs, repeaters, and gateways

Table 2-2 Network hardware and software associated with the OSI model layers

Understanding the Role of Requests for Comments

- Request for Comment (RFC): basis for standards and conventions
  - Originated in 1969
  - Prepared and distributed as a way to further networking, Internet, and computer communications
  - Help ensure that network standards are provided so one network can talk to another
- RFCs managed by IETF (Internet Engineering Task Force)
  - RFCs evaluated by IESG (Internet Engineering Steering Group) within IETF

Understanding the Role of Requests for Comments

- RFCs are assigned a unique identification number to provided a way to track it
- When an RFC is widely accepted it if often adopted as a standard

LAN Transmission Methods

- Two main LAN transmission methods for wire-based networks
  - Ethernet: defined in IEEE 802.3 specifications
  - Token ring: defined in IEEE 802.5 specifications
- Ethernet is more widespread than token ring
  - Has more high-speed and expansion options
- Fiber Distributed Data Interface (FDDI): high-speed variation of token ring

Ethernet

- Takes advantage of bus and star topologies
- Uses a control method: Carrier Sense Multiple Access with Collision Detection (CSMA/CD)
  - Algorithm that transmits and decodes formatted frames
- Permits only one node to transmit at a time
  - All nodes wishing to transmit frame are in contention
  - No single node has priority over another node
  - Nodes listen for packet traffic on cable
    - Carrier sense: process of detecting signal presence
- Collision occurs if two nodes transmit simultaneously
  - Sending node recovers with collision detection software

Ethernet

- Frames find destination through physical addressing
  - Each node has a unique MAC address associated with NIC
- Each NIC requires network drivers suited for:
  - the network access method, data encapsulation format, and addressing method
- Data transmitted in Ethernet encapsulated in frames
  - composed of six predefined fields
    - Preamble
    - Start of frame delimiter (SFD or SOF):
    - Destination address (DA) and source address (SA):
    - Length (Len)
    - Data and pad
    - Frame check sequence or frame checksum (FCS)

Preamble	SFD	Destination address	Source address	Optional	Length	Data and pad	FCS
56	8	16 or 48	16 or 48	802.1Q tag 32	16	368–12,000	32

Figure 2-15 The 802.3 frame format in bits

Ethernet

- Ethernet II – frame formatting method used on the Internet and other modern networks
  - Makes network transmissions more efficient by having a preamble that is 64 bits long
  - Also combines synchronization information with the start of frame (SOF) delimiter
  - Uses a 16-bit type field instead of a length field
  - Contains a 32-bit FCS field that performs a CRC in the same way as the regular 802.3 standard

Token Ring

- Developed by IBM in the 1970s
  - Uses physical star topology and logic of ring topology
  - Data transmission up to 100 Mbps
- Multistation access unit (MAU): hub ensures packet circulated
- Token: a specialized packet continuously transmitted around the ring to determine when a node can send
  - Size: 24 bits
  - Structure: three 8-bit fields
    - Starting delimiter (SD)
    - Access control (AC)
    - Ending delimiter (ED)
- Frame associated with token has thirteen fields

Token Ring

- Using a token
  - Node must capture token to transmit
  - Node builds frame using token fields
  - Resulting frame sent around ring to target node
  - Target node acknowledges frame received and read
  - Target node sends frame back to transmitting node
  - Transmitting node reuses token or returns it to ring
- Active monitor uses broadcast frame to check nodes
- Beaconing: node sends frame to indicate problem
  - Ring tries to self-correct problem
- Token ring networks are reliable
  - Broadcast storms and interference are rare

Fiber Distributed Data Interface

- Fiber Distributed Data Interface (FDDI)
  - Standard for high-capacity data throughput 100 Mbps
- FDDI uses fiber-optic cable communications medium
- FDDI uses timed token access method
  - Send frames during target token rotation time (TTRT)
  - Allows for parallel frame transmission
- Two types of packets
  - Synchronous communications (time-sensitive traffic)
  - Asynchronous communications (normal traffic)
- Two classes of nodes connect to FDDI network
  - Class A: nodes attached to both rings (hubs)
  - Class B: node (workstation) attached via Class A node

WAN Network Communications

- WANs are built on topologies and network transmission techniques
  - WAN transmission techniques are very complex
  - Providers do not provide detailed specifications
- WAN network service providers
  - Telecommunications companies
    - Especially regional telephone companies (telcos or RBOCs (regional bell operating companies))
  - Cable TV companies
  - Satellite TV companies

Telecommunications WANs

- Plain old telephone service (POTS)
  - Carry most basic WAN communications
  - 56-Kbps dial-up access, Integrated Service Digital Network (ISDN), Digital Subscriber Line (DSL)
- Topology used by regional bell operating companies (RBOCs) is often referred to as a “cloud”
  - RBOC provides the local access and transport area (LATA) lines
  - IXC lines join RBOC and long distance carrier
    - Point of presence (POP) is the term for where LATA lines are connected to IXC lines

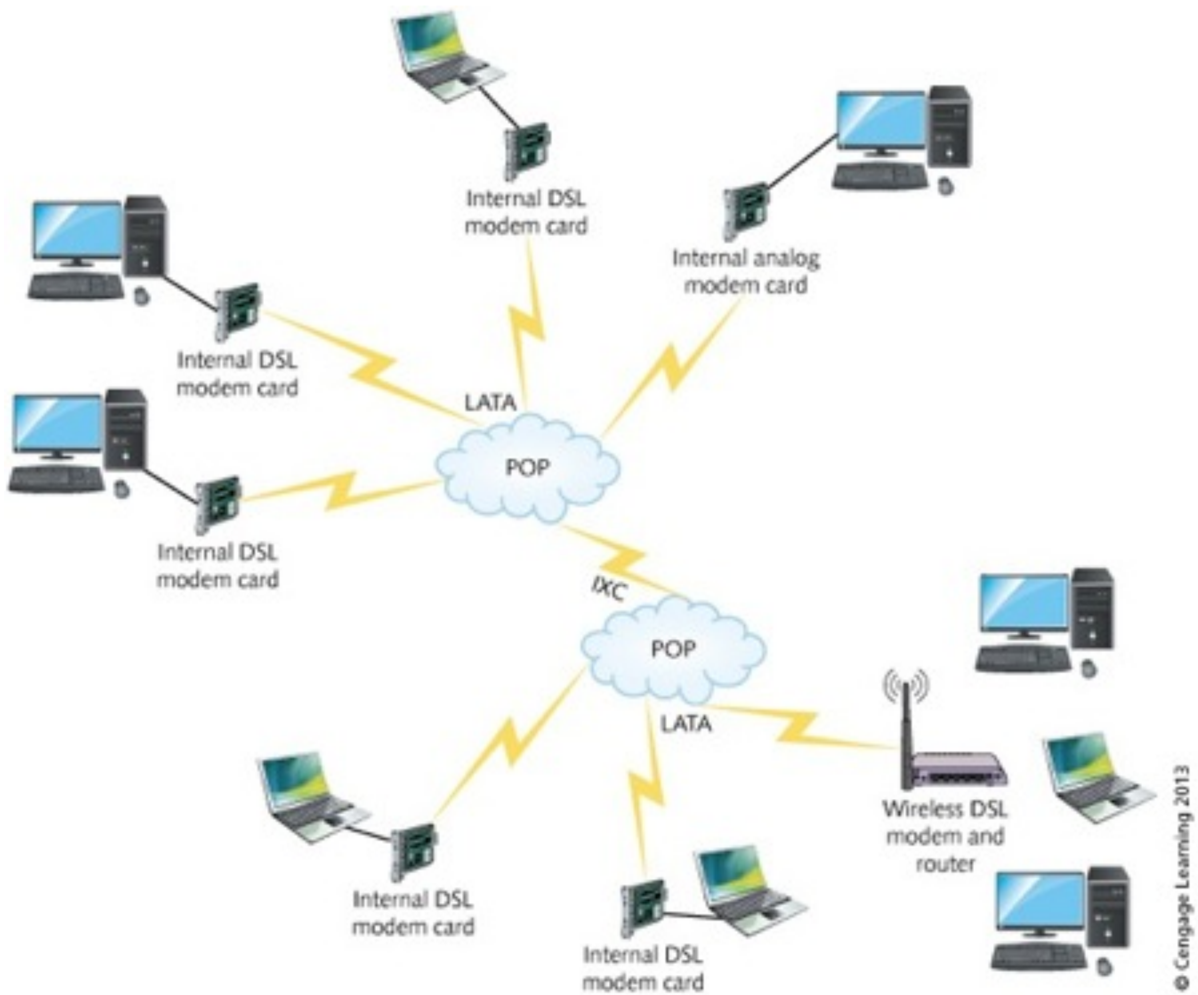

Figure 2-17 POTS topology

Telecommunications WANs

- T-carrier lines: dedicated telephone line for data communications
  – Example: states use T-carrier lines to connect branch offices to government headquarters in the state capitol
- Smallest T-carrier service is a T-1 line, which offers 1.544 Mbps data communication
- Alternative to T-carrier: synchronous 56-Kbps service

Cable TV WANs

- Architecture consists of star-shaped locations
- Headend is the focal point in the star
  - Central receiving point for various signals
    - Grouping of antennas, cable connections, satellite dishes, microwave towers
  - Signals distilled, transferred to distribution centers
- Distribution centers transfer signals to feeder cables
  - Homes use drop cables to tap into feeder cables
- Cable modems convert signals for computer use
  - Upstream frequency differs from downstream
  - Example: 10 Mbps upstream and 50 Mbps downstream

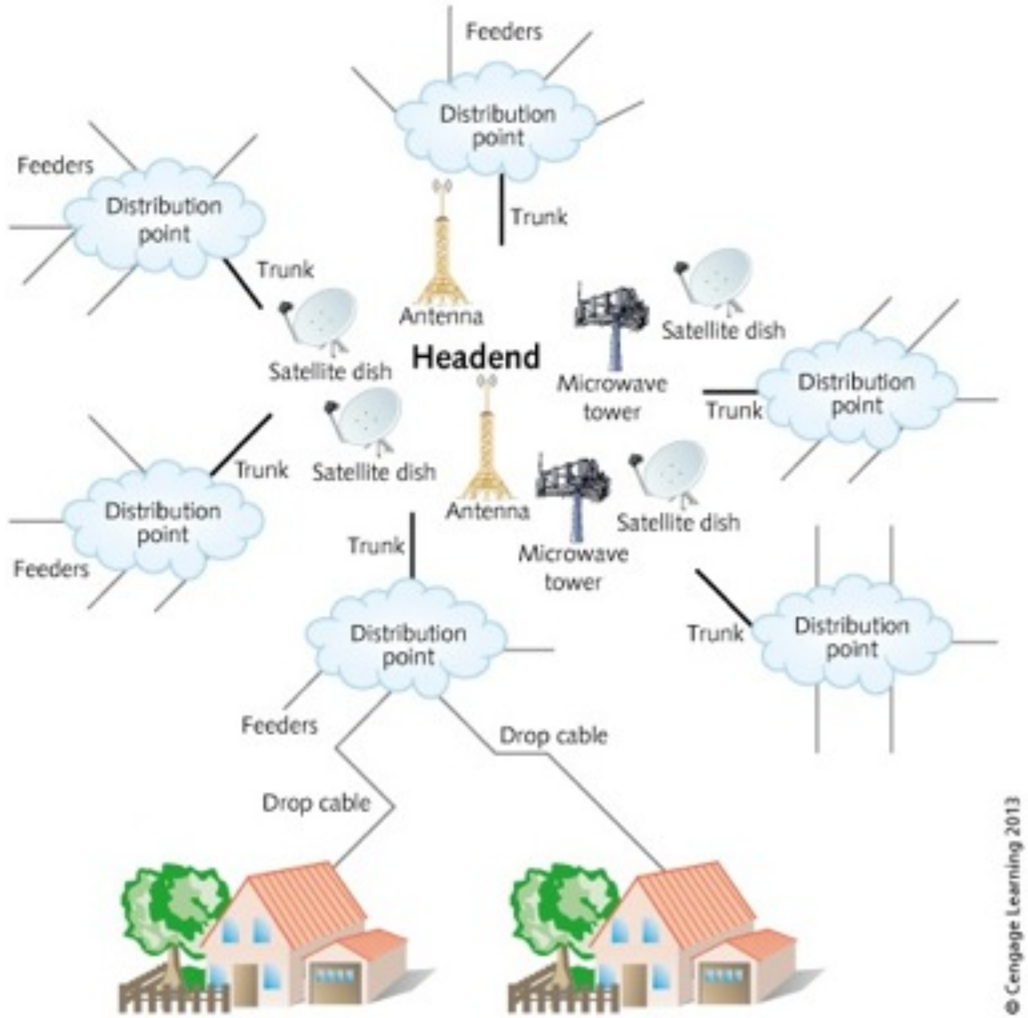

Figure 2-19 Cable TV WAN

Wireless WANs

- Wireless WANS: use of radio, microwaves, satellites
- Topology of radio communications
  - Connect wireless LAN to wireless bridge or switch
  - Connect bridge or switch to antenna
  - Antenna transmits wave to distant antenna
- Topology of microwave communication
  - Connect microwave dish to LAN
  - Dish transmits to microwave dish at remote location
- Topology of satellite communications
  - Satellite dish transmits to satellite in space
  - Satellite relays signal to satellite dish at remote location

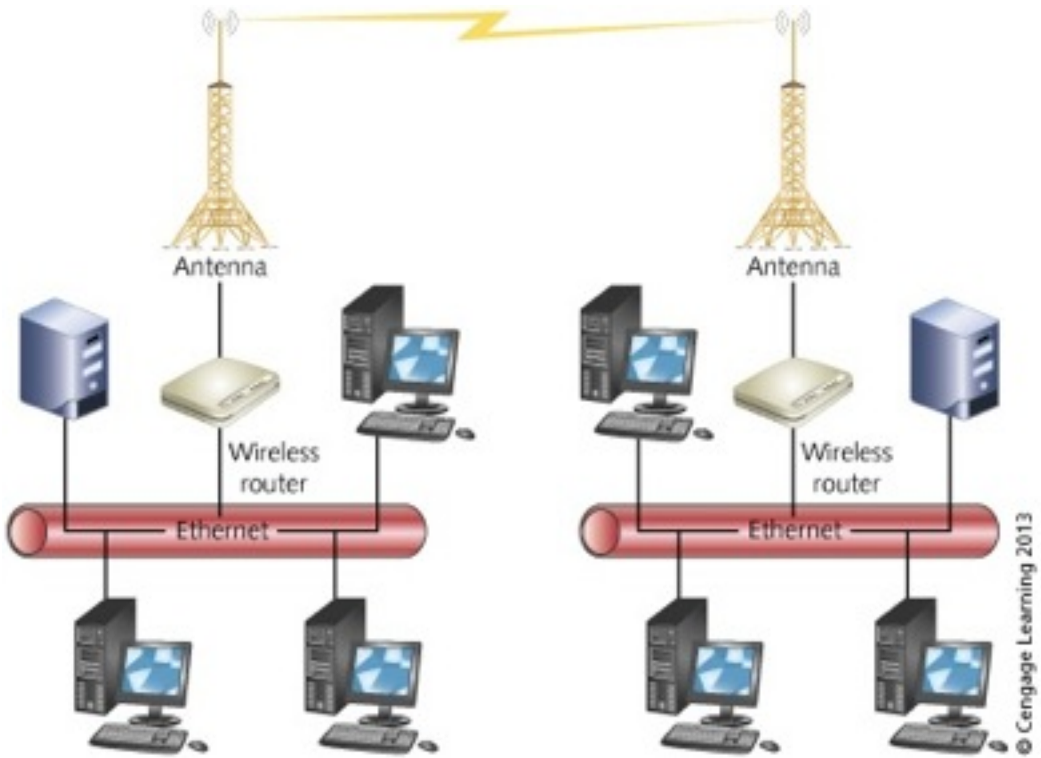

Figure 2-20 Radio wave WAN

Wireless WANs

- 2G Wireless Networks – 2nd generation (2G) mobile telephone network
  - Uses modern digital signals broadcast from radio transmission antennas instead of analog signals
  - Has been upgraded to 2.5G and later to 2.75G capable of up to 236.8 Kbps transmissions
- 3G Wireless Networks – Enable users to access the Internet and transmit data at up to 5.8 Mbps upstream and 14.4 Mbps downstream
  - Supports digital voice, data applications, streaming music, full motion video, Internet access, voice mail, conference calling and other wireless communications

Wireless WANs

- 4G Wireless Networks – 4th generation (4G)
  - Uses the International Mobile Telecommunications-Advanced (IMT-Advanced) standards
  - Can yield up to 100 Mbps for high-mobility devices
  - Besides higher data speeds than 3G, 4G offers:
    - Enhanced sound quality
    - High-definition streaming video
    - Video conferencing
    - Better security
  - Vendors are extending 4G into devices such as refrigerators, vending machines and TV phones

WAN Transmission Methods

- Switching techniques creating data paths (channels)
  - Time Division Multiple Access (TDMA): divides the channels into distinct time slots
  - Frequency Division Multiple Access (FDMA): divides the channels into frequencies instead of time slots
  - Statistical multiple access: bandwidth of cable dynamically allocated based on application need
  - Circuit switching: involves creating a dedicated physical circuit between the sending and receiving nodes
  - Message switching: uses store-and-forward method to transmit data from sending to receiving node
  - Packet switching: establishes a dedicated logical circuit between the two transmitting nodes

Putting It All Together: Designing an Ethernet Network

- Scenario: New campus needs a new network
- Reasons for choosing Ethernet technology
  - Ethernet enjoys widespread vendor/technical support
  - Compatible with star-bus topology popular with LANs
  - Network upgrades easily to higher bandwidths
  - Standards exist for cable and wireless versions
  - Ethernet network scales well, adapts well to WANs
  - Network devices on old campus may be used
  - Many options for Internet connections
- Ethernet appropriate for all areas of new campus

Summary

- The 7-layer OSI model is the foundation of LAN and WAN communications
- Bottom layers: connectivity, frame formation, encoding, signal transmission
- Middle layers: establish and maintain sessions
- Upper layers: presentation of data, data encryption
- Information is transported over LANs by using a LAN transmission or access method. Ethernet is most commonly used method.

Summary

- Ethernet uses bus and star topology
- Ethernet control method: Carrier Sense Multiple Access with Collision Detection (CSMA/CD)
- Token ring combines physical star topology with logical ring topology
- Fiber Distributed Data Interface (FDDI): alternative high-speed LAN transmission method

Summary

- WAN communications provided by telcos, cablecos, and satellite TV companies
- Wireless WANs use radio, microwave, and satellite communications
- WAN transmission methods use six common switching techniques