Networks, Security, and Privacy

158.235

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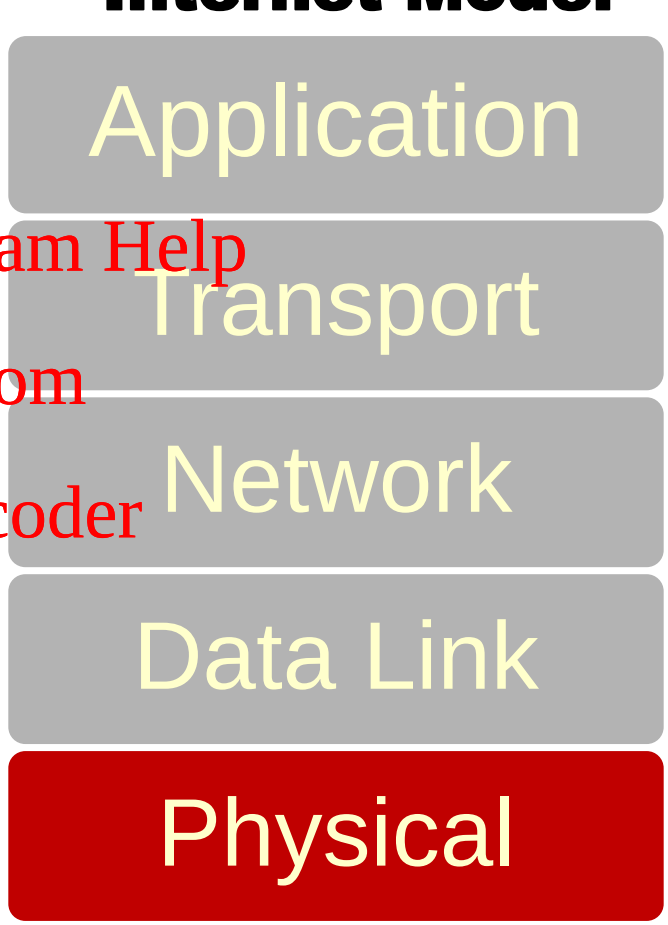
Physical Layer

Reading: Chapter 3 in the prescribed textbook

Physical Layer

- Layer 1 in the Internet model
- Focus on transmission over circuits
- Types of Circuits
  - **Physical circuits** connect devices & include wires
  - **Logical circuits** refer to the transmission characteristics of the circuit
  - Physical and logical circuits may be the same or different. For example, in multiplexing, one physical wire may carry several logical circuits.



Outline

- Media
- Digital Transmission of Digital Data
- Analog Transmission of Digital Data
- Digital Transmission of Analog Data

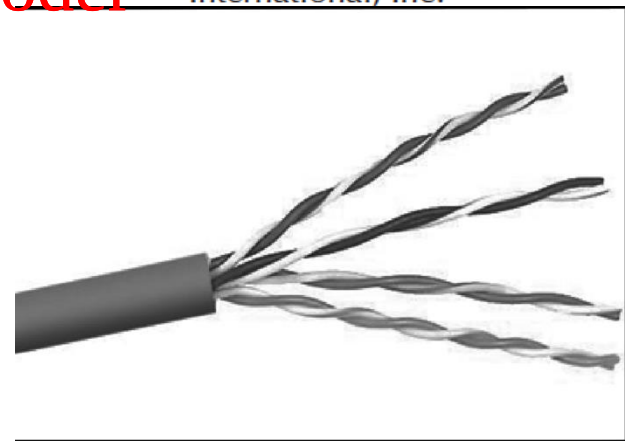
Media

- **Physical matter that carries (the voice or data) transmission**
- **Guided media:**
  - Transmission flows along a *physical guide*
  - e.g. twisted pair, coaxial cable and fiber optic cable
- **Wireless media (radiated media)**
  - the transmission flows through the air or space
  - e.g. Examples radio such as microwave and satellite

Guided Media

- **Twisted-pair (TP) cable**
  - Insulated pairs of wires bundled together
  - Wires twisted to reduce electromagnetic interference
  - Some times use additional shielding (STP)
  - Commonly used for telephones, LANs
  - Characteristics
    - Price – inexpensive
    - Distance – typically up to 100m
    - Use - Telephones, LANs

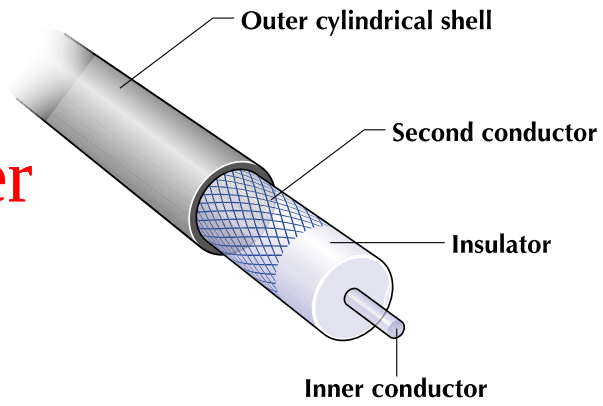
FIGURE 3-5
Category 5e twisted pair wire
Source: Courtesy of Belkin International, Inc.



Guided Media

- **Coaxial cable**
  - Has a single copper core, plus outer insulation, shielding, and inner insulation
  - Less prone to interference
  - Characteristics
    - Price - inexpensive (but more costly than TP)
    - Distance - up to 2 km (1.2 miles)
    - Use: Cable TV / Internet

Source: Courtesy of Tim Kloske



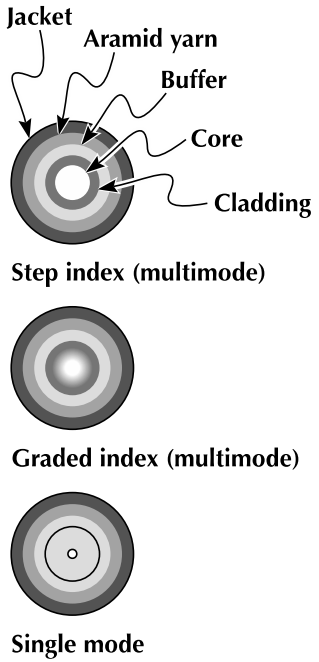
Guided Media

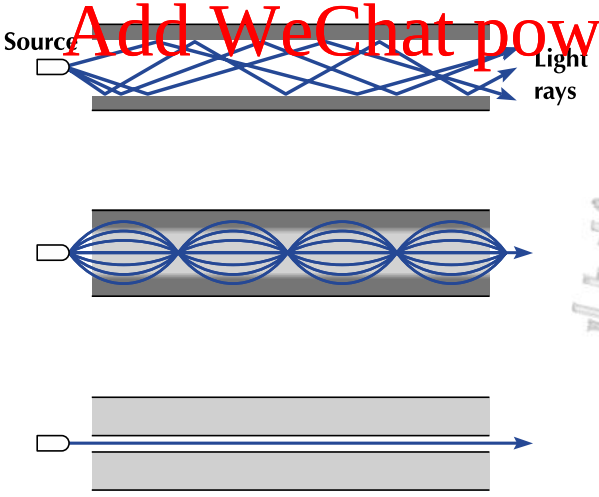
- **Fiber optic cable**
  - Optical core made of glass or plastic
  - Data transmitted using light from lasers or LEDs
  - Resistant to interference and corrosion
  - Extremely fast data rates
  - Characteristics:
    - Price: Expensive
    - Distance: 500m – 100km
    - Use: Trunk line / Backbone, long distance circuits (e.g., undersea cables)

Source: © Hugh Threlfall/Alamy

Guided Media

- **Fiber optics**
  - Multimode (about 50 micron core)
  - Graded index multimode
  - Single mode (about 5 micron core)





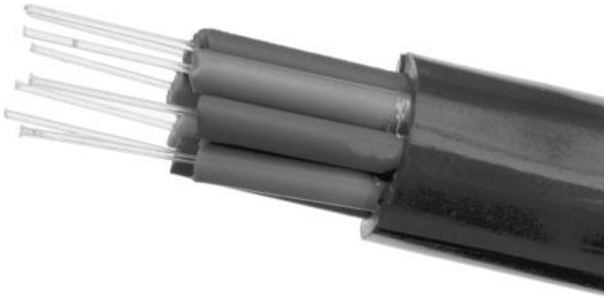


FIGURE 3-7 Fiber-optic cable

Source: © Hugh Threlfall/Alamy

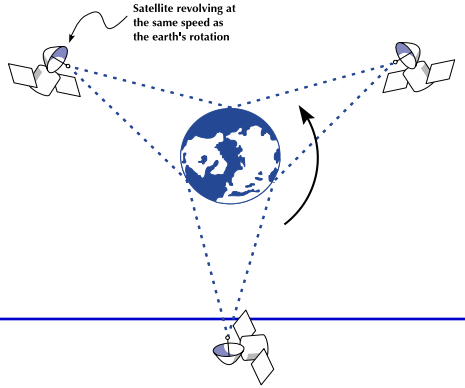
Wireless Media

- **Radio**
  - Wireless transmission of electrical waves through air
  - Each device on network has a radio transceiver operating at a specific frequency range
  - Enables mobile network communication
  - Characteristics
    - Distance: depends on frequency and power
    - Use: Wireless LANs, cellular and cordless phones, baby monitors

Wireless Media

- **Microwave**
  - High-frequency radio communication
  - Requires line of sight which may require large antennas and towers
  - Affected by weather
  - Characteristics
    - Distance: ~60 km (due to curvature of earth)
    - Use: Trunk line / Backbone, long distance

- **Satellite**
  - Special form of microwave communication
  - Long distance leads to propagation delays



Factors Used in Media Selection

- **Type of network**
  - LAN, WAN, or Backbone
- **Cost**
  - Always changing; depends on the distance
- **Transmission distance**
  - Short: up to 300 m; medium: up to 500 m
- **Security**
  - Wireless media is less secure
- **Error rates**
  - Wireless media has the highest error rate (interference)
- **Transmission speeds**
  - Constantly improving; Fiber has the highest

Media Summary

Guided Media						
Media	**Network Type**	**Cost**	**Transmission Distance**	**Security**	**Error Rates**	**Speed**
Twisted Pair	LAN	Low	Short	Good	Low	Low-high
Coaxial Cable	LAN	Moderate	Short	Good	Low	Low-high
Fiber Optics	Any	High	Moderate-long	Very good	Very low	High-very high

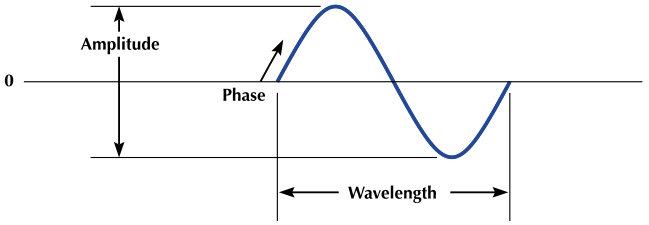
Radiated Media						
Media	**Network Type**	**Cost**	**Transmission Distance**	**Security**	**Error Rates**	**Speed**
Radio	LAN	Low	Short	Poor	Moderate	Moderate
Microwave	WAN	Moderate	Long	Poor	Low-moderate	Moderate
Satellite	WAN	Moderate	Long	Poor	Low-moderate	Moderate

Outline

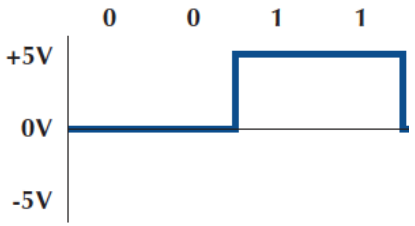
- Media
- Digital Transmission of Digital Data
- Analog Transmission of Digital Data
- Digital Transmission of Analog Data

Types of Data Transmitted

- **Analog data**
  - Produced by telephones
  - Sound waves, which vary continuously over time, *analog*ous to one's voice
  - Can take on any value in a wide range of possibilities



- **Digital data**
  - Produced by computers, in binary form
  - Information is represented as code in a series of ones and zeros
  - All digital data is either on or off, 0 or 1



Types of Transmission

- **Analog-Analog transmissions**
  - Analog data transmitted in analog form
  - Examples of analog data being sent using analog transmissions are broadcast TV and radio
- **Digital-Digital transmissions**
  - Computer networks send digital data using digital transmissions
- **Analog ←→ Digital Transmissions**
  - Modem (modulator/demodulator): used when digital data is sent as an analog transmission
  - Codec (coder/decoder): used when analog data is sent via digital transmission

Data Type vs. Transmission Type

	Analog Transmission	Digital Transmission
Analog Data	AM and FM Radio, Broadcast TV	Pulse code modulation. MP3, CDs, iPOD, VoIP
Digital Data	Modems - sending email from your house using telephone line	Data transmitted as ASCII/EBCDIC over Ethernet LANs, printer

Digital Data-Digital Transmission

- Coding scheme needed to ensure sender and receiver understand messages (e.g., ASCII, Unicode, etc.)
- A character is represented by a group of bits

Character	ASCII
A	01000001
B	01000010
C	01000011
D	01000100
E	01000101
a	01100001
b	01100010
c	01100011
d	01100100
e	01100101
1	00110001
2	00110010
3	00110011
4	00110100
!	00100001
$	00100100

FIGURE 3-10
Binary numbers used to represent different characters using ASCII

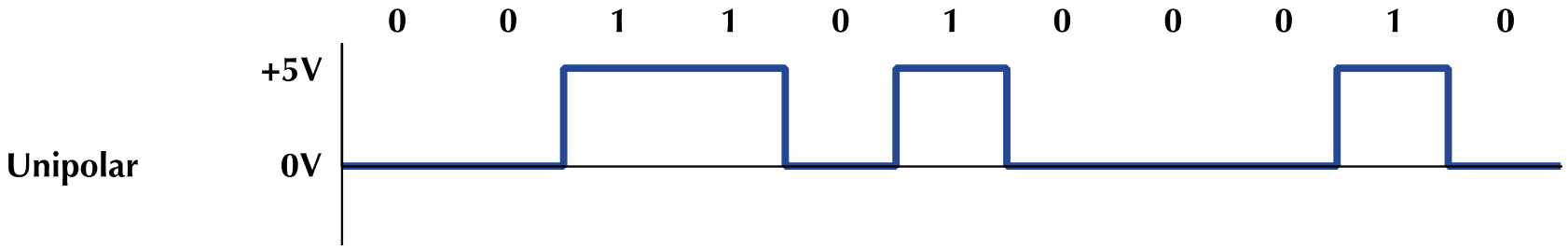
Digital Transmission of Digital Data

- **Sender and receiver must agree upon:**
  - **Set of symbols**
    - How bits are encoded as voltages or light pulses
    - e.g., +5V might be encodes as a “1”
  - **Symbol rate**
    - How many symbols are sent per second
    - e.g., with a symbol sent at every clock cycle. 64 kilohertz (kHz) = 64,000 symbols/sec

Digital Transmission of Digital Data

- **Five types of signaling techniques**
  1. **Unipolar -** voltage is 0 or positive representing binary bits (in some circuits, 0 and negative voltage could be used)

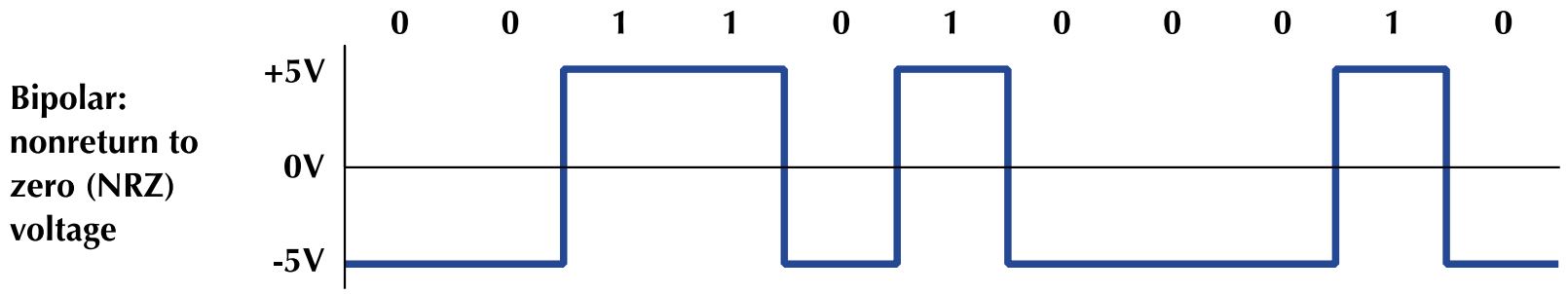
FIGURE 3-13
Unipolar, bipolar, and Manchester signals (digital)



Digital Transmission of Digital Data

- **Five types of signaling techniques**
  2. **Bipolar NRZ -** voltage is positive or negative, but not zero
     - Fewer errors than unipolar because signals are more distinct

FIGURE 3-13
Unipolar, bipolar, and Manchester signals (digital)



Digital Transmission of Digital Data

- **Five types of signaling techniques**
  3. **Bipolar RZ -** voltage is positive or negative, returning to zero between each bit
     - Fewer synchronization errors than bipolar NRZ

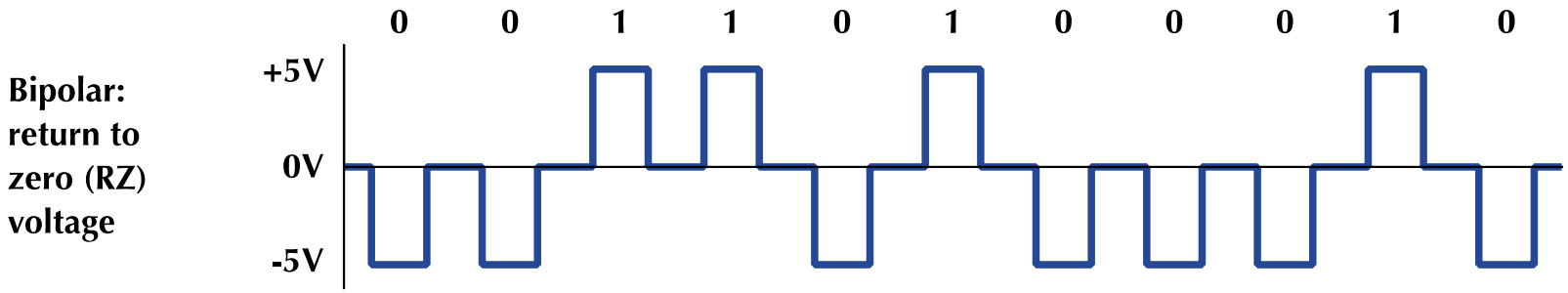


FIGURE 3-13
Unipolar, bipolar, and Manchester signals (digital)

Digital Transmission of Digital Data

- **Five types of signaling techniques**
  4. **Bipolar AMI -** voltage is 0, positive, or negative, returns to zero between each bit, and alternates between positive and negative voltage

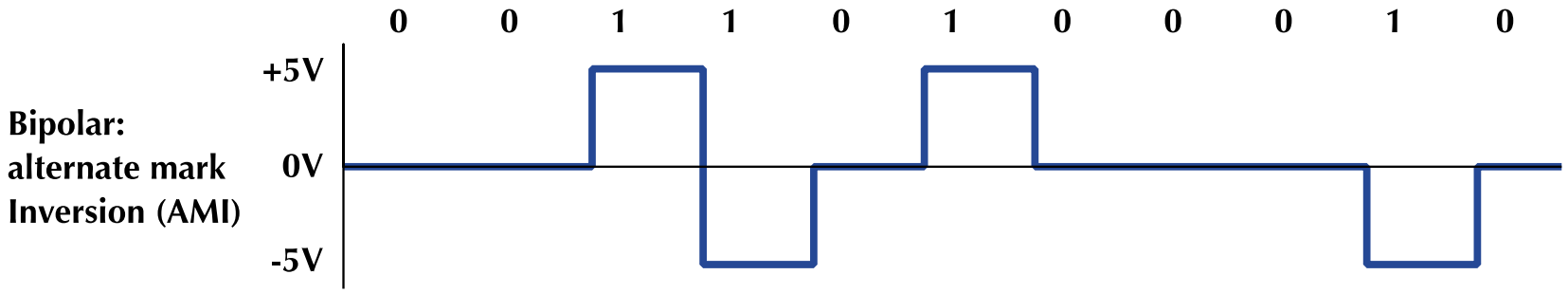


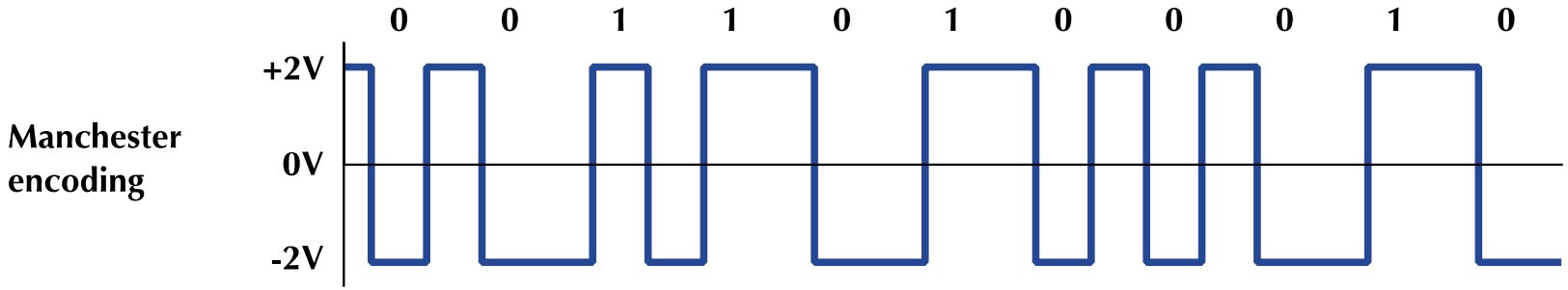
FIGURE 3-13
Unipolar, bipolar, and Manchester signals (digital)

Digital Transmission of Digital Data

- **Five types of signaling techniques**
  5. **Manchester -** voltage is positive or negative and bits are indicated by a mid-bit transition

Ethernet uses it – less susceptible to bit errors to going unnoticed

FIGURE 3-13
Unipolar, bipolar, and Manchester signals (digital)



Outline

- Media
- Digital Transmission of Digital Data
- **Analog Transmission of Digital Data**
- Digital Transmission of Analog Data

Analog Transmission of Digital Data

- **Telephone system built for analog data**
  - Electrical signals mimic sound waves (i.e., voice)
  - Analog transmissions take on range of values (vs. discrete values of digital transmissions)
  - Need a modem (modulator/demodulator) to convert from analog to digital and vice versa

Analog Transmission of Digital Data

- **Three characteristics of waves**
  1. **Amplitude**: height of wave (decibels)
  2. **Frequency**: waves per second (hertz)
     - Wavelength is the inverse of frequency
  3. **Phase**: wave direction (degrees) or the point at which the wave begins

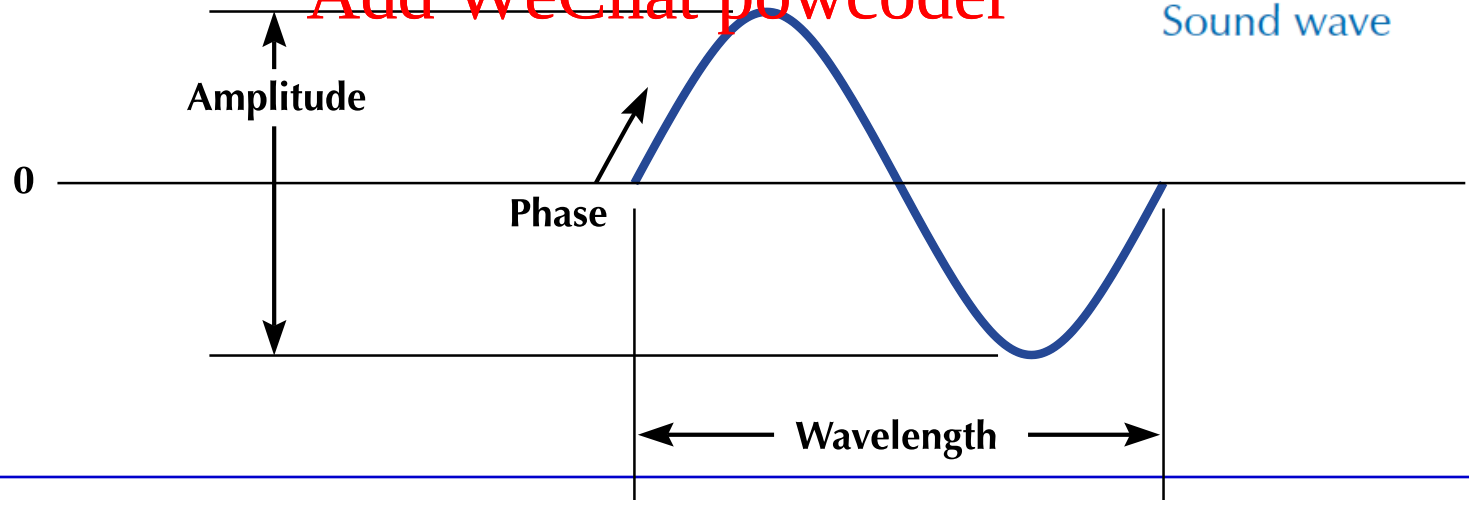


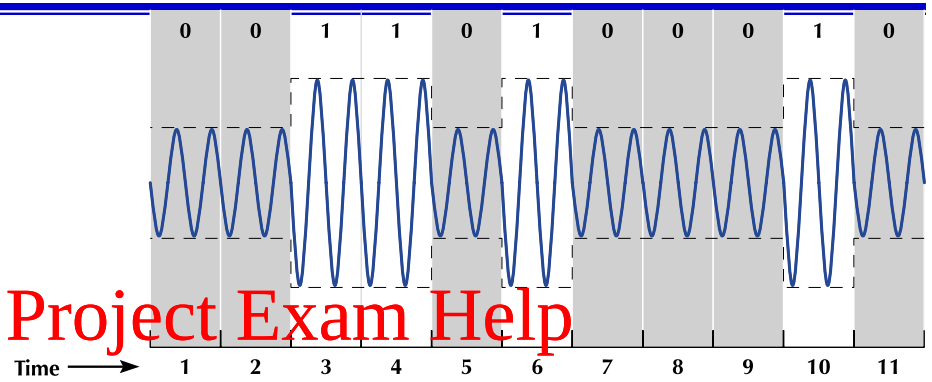
FIGURE 3-14
Sound wave

Analog Transmission of Digital Data

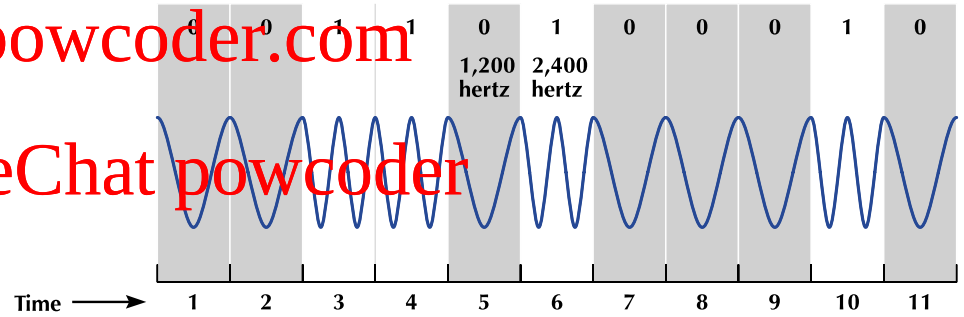
- **Carrier wave** is basic wave transmitted through a circuit
- **Modulation** is the modification of a carrier wave's fundamental characteristics in order to encode information
- **Three ways to modulate a carrier wave:**
  1. **Amplitude Modulation (AM)** or Amplitude Shift Keying (ASK)
  2. **Frequency Modulation (FM)** or Frequency Shift Keying (FSK)
  3. **Phase Modulation (PM)** or Phase Shift Keying (PSK)

Analog Transmission of Digital Data

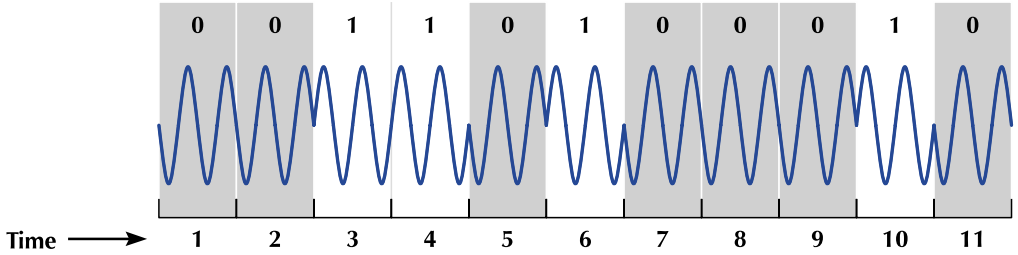
- Amplitude Modulation



- Frequency Modulation



- Phase Modulation



Analog Transmission of Digital Data

- **Symbol:** One or more modifications to a carrier wave used to encode data
- Can send 1 bit by defining two different symbols (e.g., amplitudes, frequencies, etc.)
- Can send multiple bits by defining more than two symbols
  - Need more complicated information coding schemes
  - 1 bit of information → 2 symbols
  - 2 bits of information → 4 symbols
  - 3 bits of information → 8 symbols
  - n bits of information → 2^n symbols

Analog Transmission of Digital Data

- **Two-bit Amplitude Modulation**
  - With 4 levels of amplitude defined as symbols, 2 bits can be transmitted per symbol

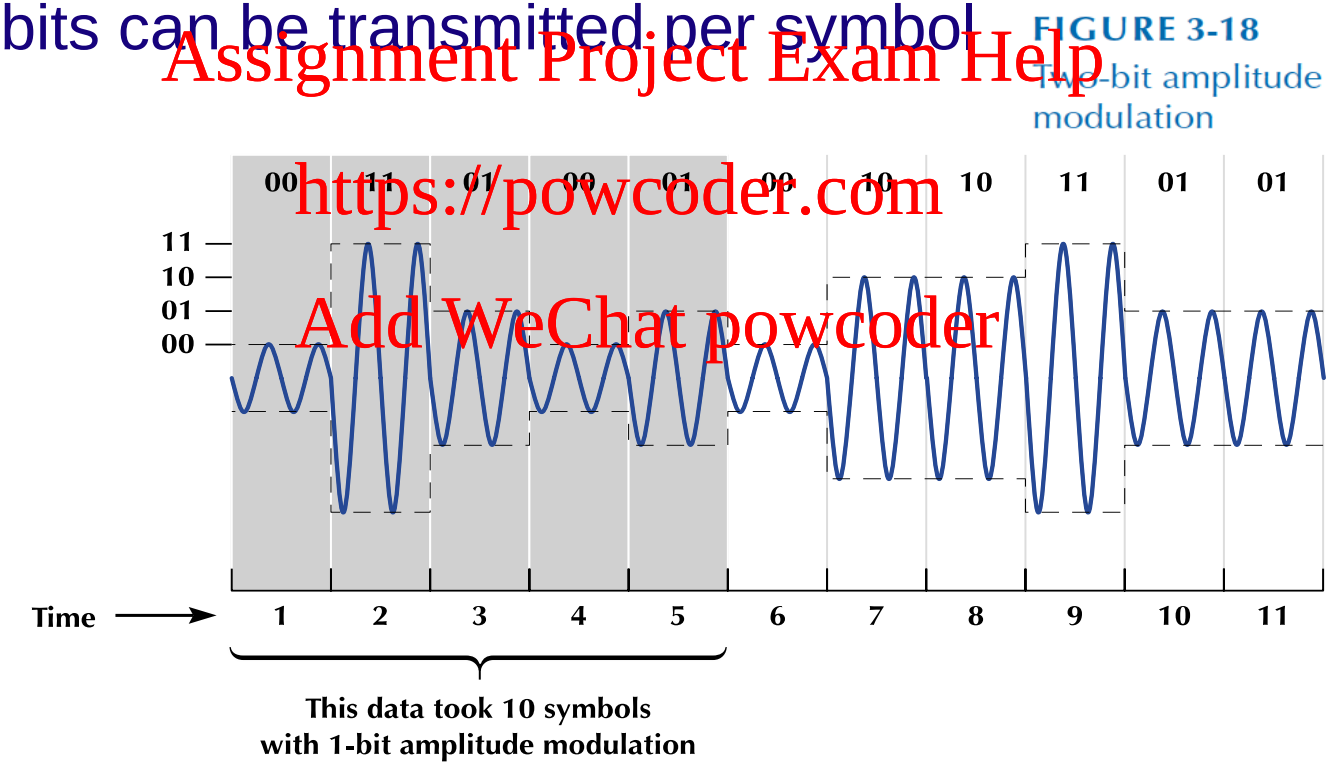


FIGURE 3-18
Two-bit amplitude modulation

Analog Transmission of Digital Data

- **Data rate (or bit rate)** is the number of bits transmitted per second
- **Symbol rate:** number of symbols transmitted per second

Data rate = symbol rate × (# bits/symbol)

- **Example**

Symbol rate = 16,000 symbols/sec

#bits/symbol = 4 bits/symbol

Data rate = 16,000 symbols/sec × 4 bits/symbol

= 64,000 bits/sec = 64Kbps

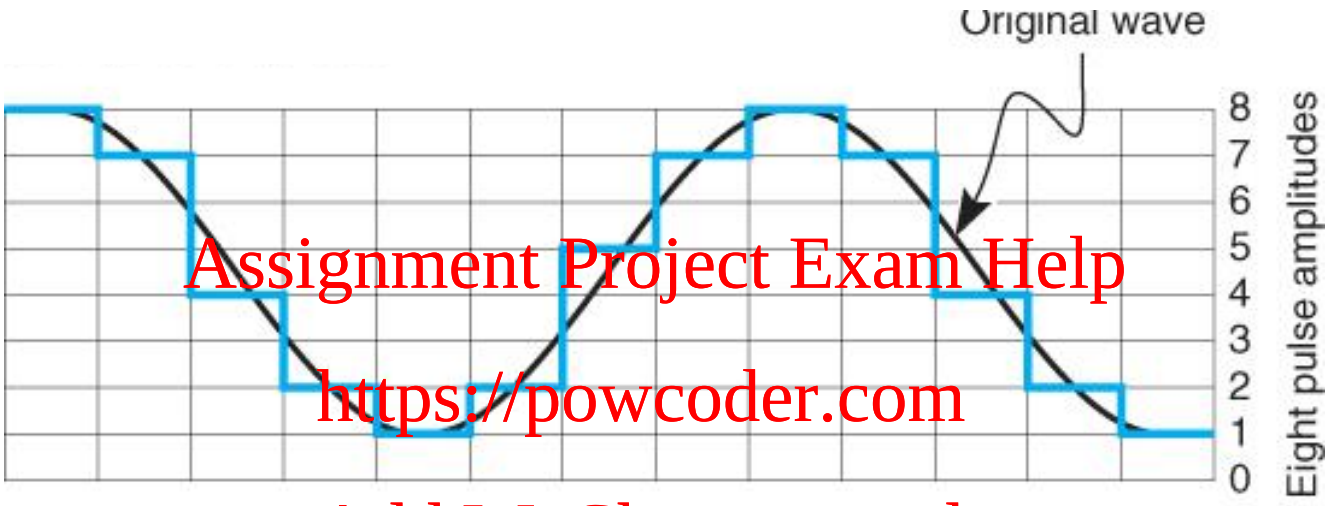
Outline

- Circuits and Data Flow
- Multiplexing
- Media
- Digital Transmission of Digital Data
- Analog Transmission of Digital Data
- Digital Transmission of Analog Data

Digital Transmission of Analog Data

- **Codecs (COde, DECode)** is a device or software that converts an analog signal (e.g., voice) into digital form and the reverse
- **Pulse-Code Modulation (PCM)** converts analog to digital by:
  1. Sampling the analog signal at regular intervals
  2. Measuring the amplitude of each sample
  3. Encoding (quantizing) the amplitude as binary data
- **Quantizing Error** is the difference between the original analog signal and the approximated, digital signal

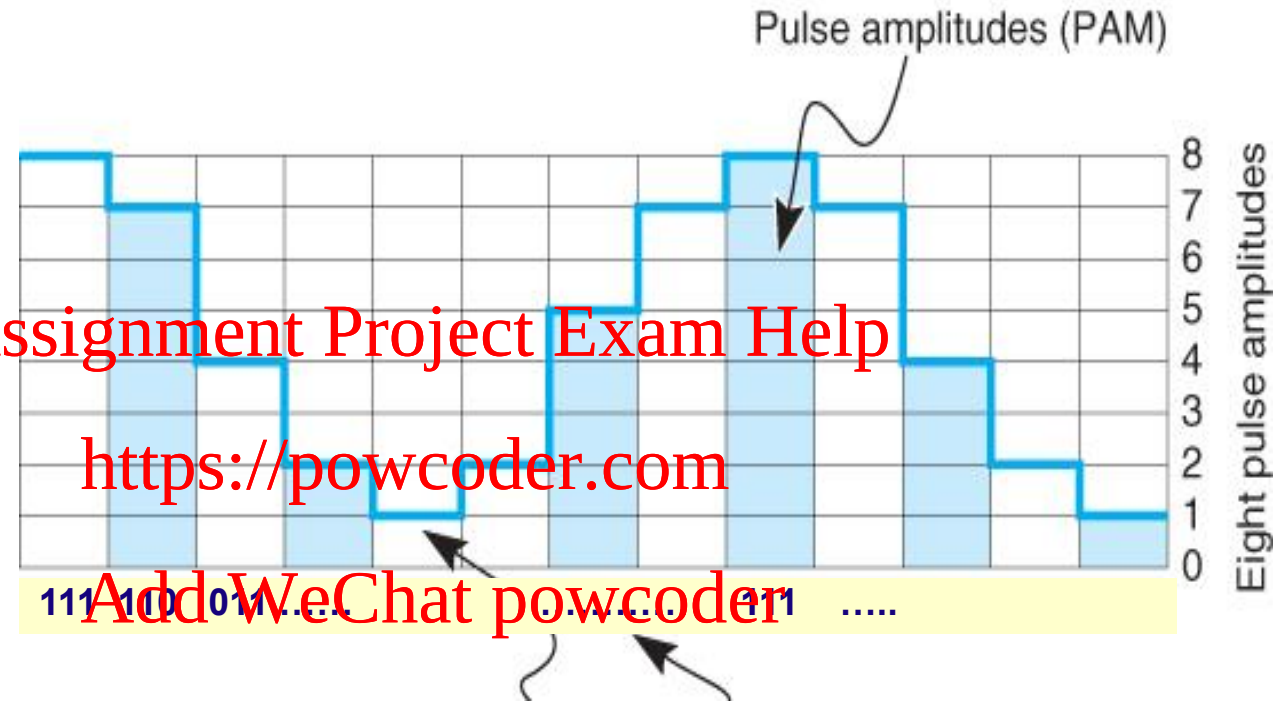
PAM – Measuring Signal



- Sample analog waveform across time and measure amplitude of signal
- In this example, quantize the samples using only 8 pulse amplitudes or levels for simplicity
- Our 8 levels or amplitudes can be depicted digitally by using 0's and 1's in a 3-bit code, yielding 2^3 possible amplitudes

PAM – Encoding and Sampling

000 – PAM Level 1
001 – PAM Level 2
010 – PAM Level 3
011 – PAM Level 4
100 – PAM Level 5
101 – PAM Level 6
110 – PAM Level 7
111 – PAM Level 8

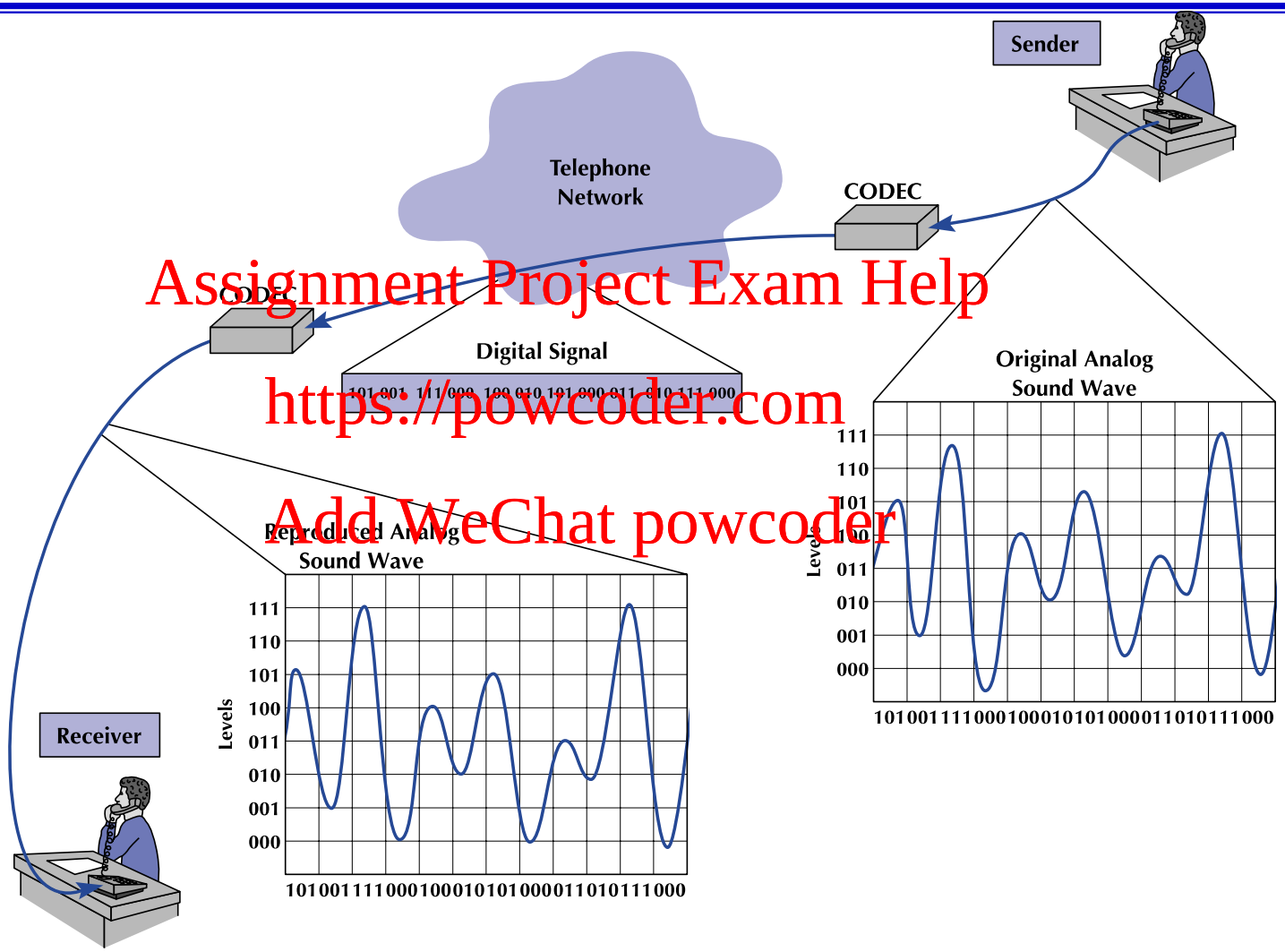


- For digitizing a voice signal, it is typically 8,000 samples per second and 8 bits per sample
- 8,000 samples x 8 bits per sample → 64,000 bps transmission rate needed
- 8,000 samples then transmitted as a serial stream of 0s and 1s

Minimize Quantizing Errors

- **Increase number of amplitude levels**
  - Difference between levels minimized → smoother signal
  - Requires more bits to represent levels → more data to transmit
  - Adequate human voice: 7 bits → 128 levels
  - Music: at least 16 bits → 65,536 levels
- **Sample more frequently**
  - Will reduce the length of each step → smoother signal
  - Adequate Voice signal: twice the highest possible frequency (4Khz x 2 = 8000 samples / second)
  - RealNetworks: 48,000 samples / second

Digital Transmission of Analog Data



Wired and Wireless Local Area Networks

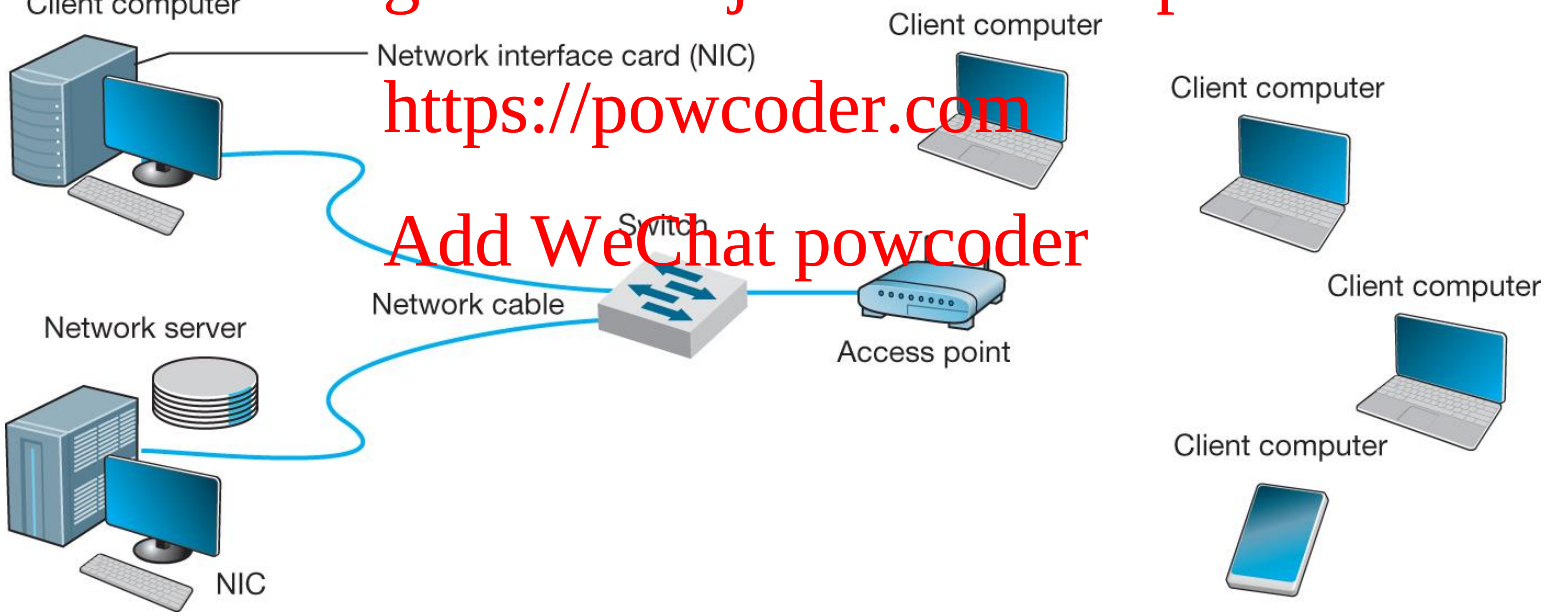
Reading: Chapter 6 in the prescribed textbook

Why Use a LAN?

- Information sharing
  - Improved decision making
  - May reduce data duplication and inconsistency
- Resource sharing
  - Devices such as printers can be shared by many clients
- Software sharing
  - Some software can be purchased on a per-seat basis and resides on server
  - Reduces costs, simplifies maintenance and upgrades
- Device Management
  - Software updates and configuration are easier

LAN Components

1. Clients
2. Servers
3. Network interface cards (NICs)
4. Network cables
5. Hubs / switches / access points
6. Software



LAN Components

1. Clients
   - Devices on the network that request information from servers
2. Servers
   - Devices on the network that deliver information or provide services to clients
3. Network interface cards (NIC)
   - Also called network cards and network adapters
   - Operate at layers 1 and 2
   - Commonly built into motherboards
   - Ethernet NICs contain unique MAC address

LAN Components

4. Network Cables

Name	Type	Maximum Data Rate	Used by
Category 3	UTP	10 Mbps	10BASE-T
Category 5	UTP/STP	100 Mbps	100BASE-T
Category 5e	UTP/STP	1 Gbps	1000BASE-T
Category 6/6a	UTP/STP	10Gbps	10GBASE-T
OM1 (62.5/125 μm)	Fiber	1-10 Gbps*	1000BASE-SX
OM3 (50/125 μm)	Fiber	10-100 Gbps*	10GBASE-SR

* Speed depends on circuit length

LAN Components

5. Hubs and switches
   - Link cables from different devices, sometimes more than one type of cabling
   - Act as repeaters, reconstructing and strengthening incoming signals

(a) Small-Office, Home-Office (SOHO) switch with five 10/100/1000 Mbps ports

http://homestore.cisco.com/en-us/Switches/linksys-EZXS55W_stcVVproductId53934575VVcatId543809VVviewprod.htm

(b) Data center chassis switch with 512 10 Gbps ports

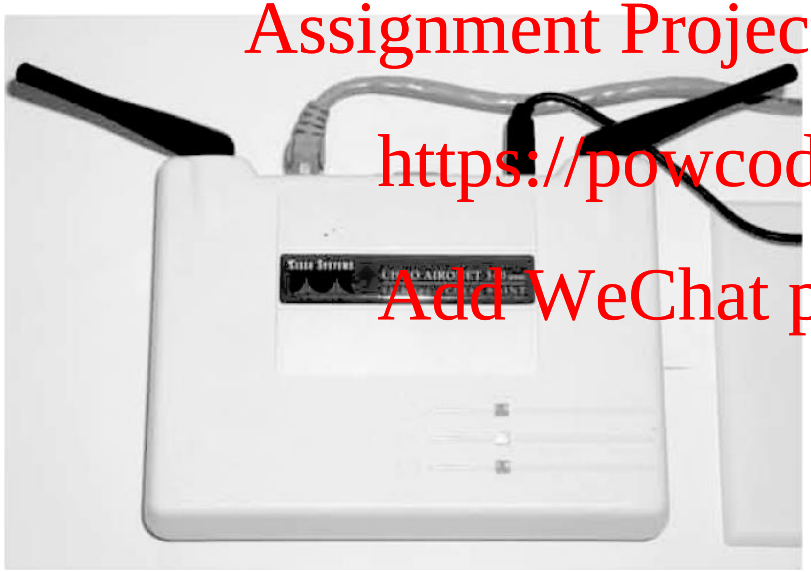
Source: newsroom.cisco.com/dlls/2008/prod_012808b.html

LAN Components

5. **Access points (APs)** use radio waves to connect wireless clients to the wired network (instead of connecting using hubs/switches)
   - Many APs use power over Ethernet (PoE) for electricity
   - No external power is needed
   - Power flows over unused twisted pair wires
   - Also used by some IP cameras and phones

LAN Components

FIGURE 7-3
Wireless access points
Source: Courtesy of the author, Alan Dennis



(a) AP for SOHO use

(b) A power-over-Ethernet AP for enterprise use

LAN Components

6. Software

- Network Operating System (NOS)
  - Runs on devices and manage networking functions
  - E.g., Novel NetWare, Microsoft Windows Server, Linux
  - E.g., Cisco IOS or JUNOS on routers
- Clients devices typically have network software components included with OS installation
  - E.g., TCP/IP included in Windows, OS X, and Linux
  - Allows clients to view and access available network resources
- Provides **directory services** about LAN resources
- **Network profiles** specify resources that devices and users can access

WIRED ETHERNET

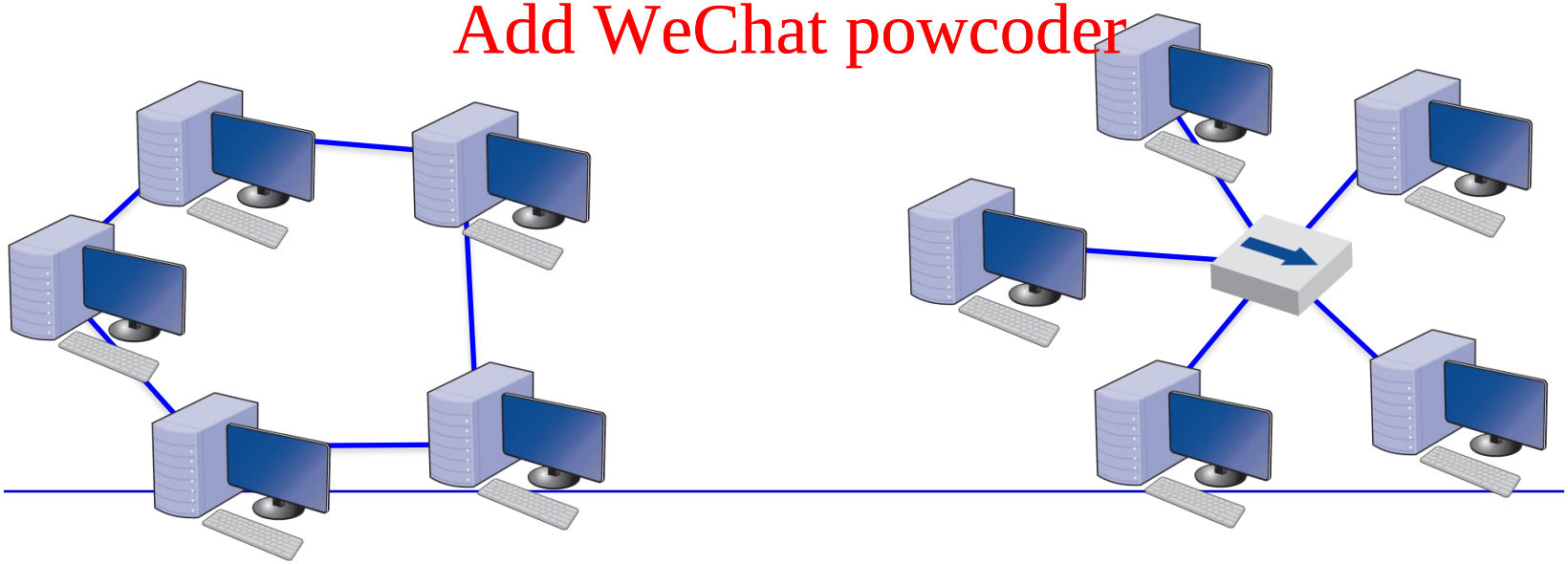
Wired Ethernet

- Used by almost all LANs today
- Originally developed by a consortium of Digital Equipment Corp., Intel and Xerox
- Standardized as IEEE 802.3
- Layer 2 protocol, but physical layer must meet protocol requirements

Topology

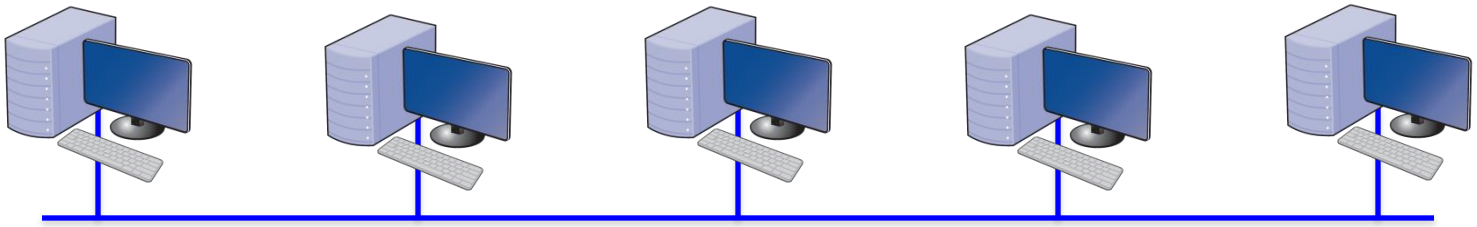
- **Topology: Basic geographic layout of a network**
- **Types**
  - **Logical**: How the network works conceptually

  - **Physical**: How the network is physically installed



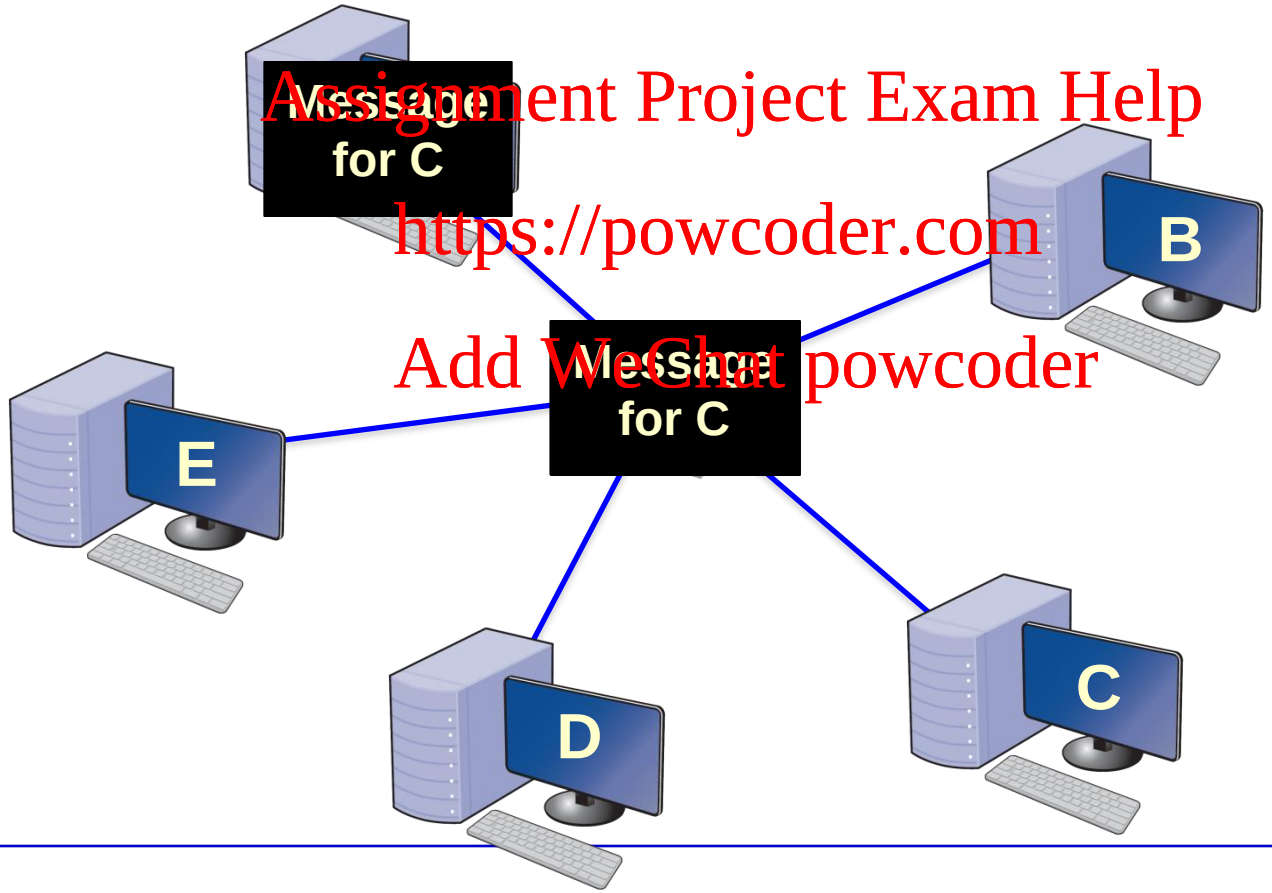
Hub-based (Shared) Ethernet

- Hub-based Ethernet
  - Also called shared or traditional Ethernet
  - Logical bus topology – means that all devices receive every frame as if they were connected to the same circuit
  - The hub is a multiport repeater



Hub-based (Shared) Ethernet

- Hub-based Ethernet uses physical star topology

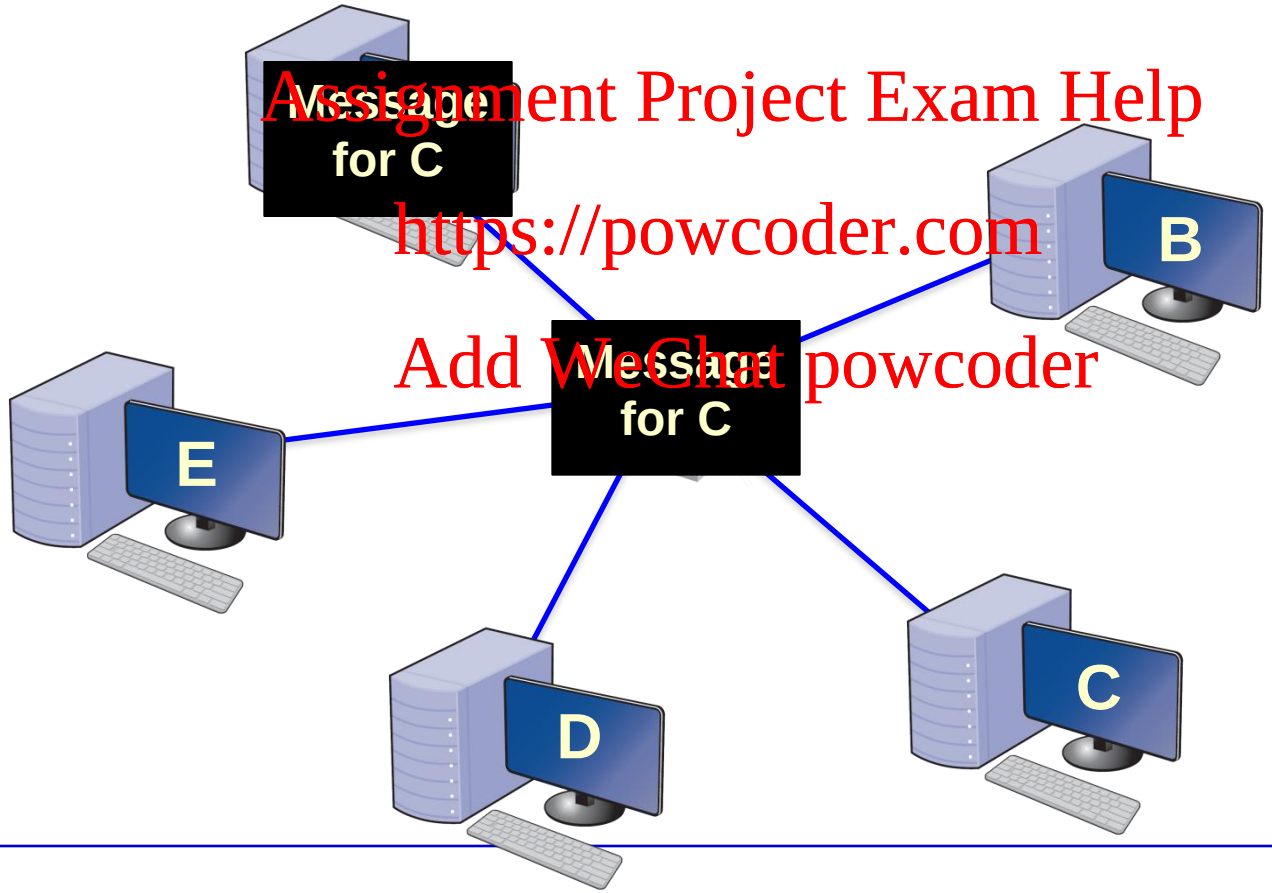


Swtich-based Ethernet

- Logical **star topology** means that only the destination receives the frame
  - Switch reads destination address of the frame and only sends it to the interface (physical port) connected to as/r port
  - Uses forwarding tables (also called MAC or CAM tables), which are similar to routing tables
  - Breaks up the **collision domain**
- Physical **star topology**

Switch-based Ethernet

- Switch-based Ethernet



Switch Operation

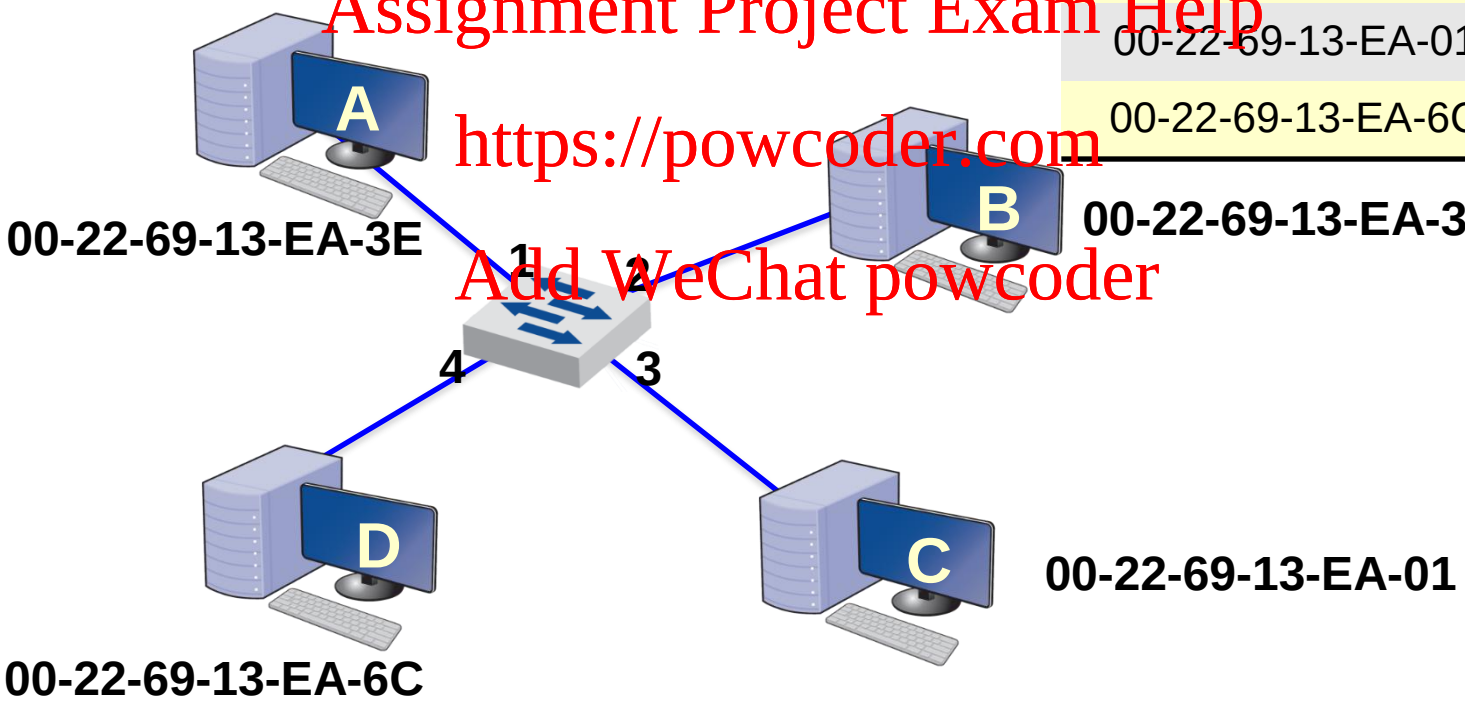
- Switches learn which MAC address is associated with an interface (physical port) by reading the source address on a frame
- When a new frame is received, the switch reads the destination MAC address
- Looks up destination address in the forwarding table
  - If found, forwards frame to the corresponding interface
  - If not found, broadcasts frame to all devices (like a hub)

Forwarding table

- Switch-based Ethernet

Switch Forwarding Table

MAC	Port
00-22-69-13-EA-3E	1
00-22-69-13-EA-3A	2
00-22-69-13-EA-01	3
00-22-69-13-EA-6C	4



Learning Switch Operation

- Switch starts by working like a simple hub
  - With an empty forwarding table
- It gradually fills its forwarding table by learning about the nodes
  - Reads the source MAC address of the incoming frame and records it to the corresponding port number
  - Reads the destination MAC address. If not in the Table then it broadcasts the frame to all ports
  - Waits for the destination computers to respond, and repeats the first step

Media Access Control (MAC)

- Uses a contention-based protocol called CSMA/CD (Carrier Sense Multiple Access / Collision Detect)
- Frames can be sent by two computers on the same network at the same time
  - They will collide and destroy each other
  - Can be termed as “ordered chaos”
  - Tolerates, rather than avoids, collisions

CSMA/CD

- **Carrier Sense (CS):**
  - **A computer listens to the bus to determine if another computer is transmitting before sending anything**
  - **Transmit when no other computer is transmitting**
- **Multiple Access (MA):**
  - **All computers have access to the network medium**
- **Collision Detect (CD):**
  - **Declared when any signal other than its own detected**
    - **Normally occurs before the transmission of 512th bits**
  - **If a collision is detected**
    - **To avoid a collision, both wait a random amount of time and then resend message**

WIRELESS ETHERNET

Wireless Ethernet

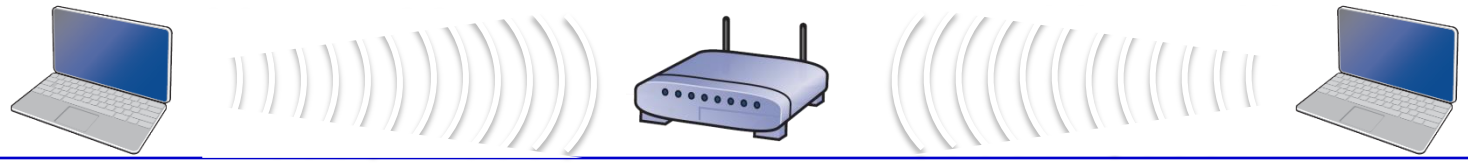
- Commonly called Wi-Fi
- A family of standards developed by IEEE formally called 802.11
- Uses radio frequencies to transmit signals through the air (instead of cables)
- Wi-Fi has many benefits
  - Provides network connections where cabling is impossible or undesirable
  - Allows device and user mobility
  - Potentially more economical than wired networks

Wireless Ethernet

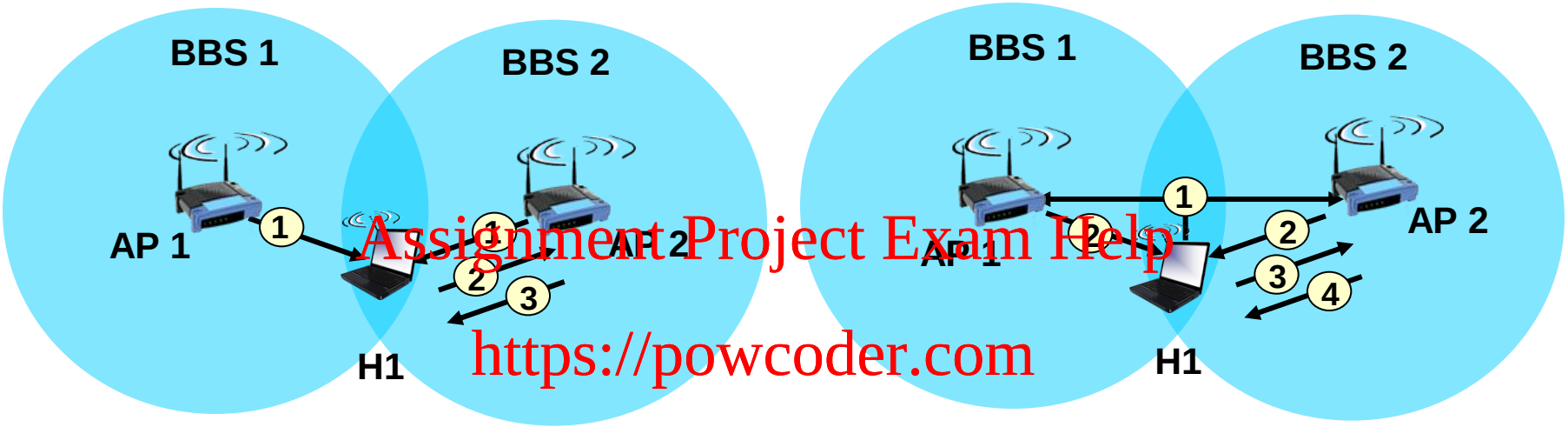
- **Components**
  - **Access points (APs)**
    - **Antenna type**
      - Omnidirectional
      - Directional
    - **Association with AP**
      - Active vs. passive scanning
  - **Wireless NICs**
- **Topology**

Physical star

Logical bus



Association with AP



passive scanning:

(1) beacon frames sent from APs
(2) association Request frame sent: H1 to selected AP
(3) association Response frame sent from selected AP to H1

active scanning:

(1) Probe Request frame broadcast from H1
(2) Probe Response frames sent from APs
(3) Association Request frame sent: H1 to selected AP
(4) Association Response frame sent from selected AP to H1

WLAN Media Access Control

- **Uses CSMA/CA**
  - **CA → collision avoidance (*before* collision happens)**
  - **A station waits until another station is finished transmitting plus an additional random period (i.e. back-off timer) before sending anything**
    - **collisions harder to detect on wireless Ethernet ('over the air'), so more effort is put into avoidance**
- **Contrast with CSMA/CD**
  - **detect collision, stop transmission, wait, and re-transmit**
  - ***after* collision**

MAC Techniques

- May use two MAC techniques simultaneously
  - Distributed Coordination Function (DCF)
    - Also called "Physical Carrier Sense Method"
  - Point Coordination Function (PCF)
    - Also called "Virtual Carrier Sense Method"
    - Optional: (can be set as "always", "never", or "just for certain frame sizes")

Distributed Coordination Function

- **Relies on the ability of computers to physically listen before they transmit**
  - When a node wants to send a message:
    - First listens to make sure that the transmitting node has finished, then
    - Waits a period of time longer
- **Each frame is sent using stop-and-wait ARQ**
  - By waiting, the listening node can detect that the sending node has finished
    - ACK/NAK sent a *short time* after a frame is received, (hence, ensuring no collision occurring) *shorter than the wait time required for other nodes to start transmitting*
- **DCF Suffers from the hidden node problem**

Distributed Coordination Function

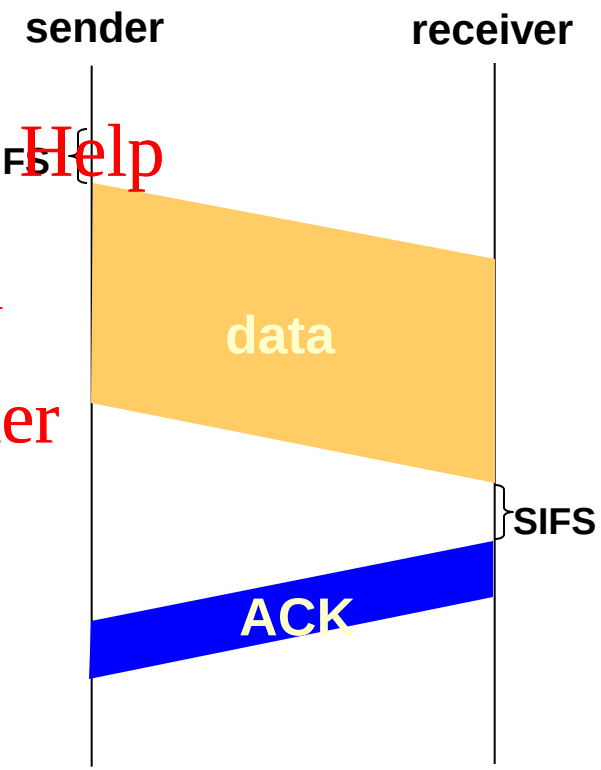
Sender

1 if sense channel idle for DIFS then

transmit entire frame (no CD)

2 if sense channel busy then

start random backoff time
timer counts down while channel idle
transmit when timer expires
if no ACK, increase random backoff interval,
repeat 2

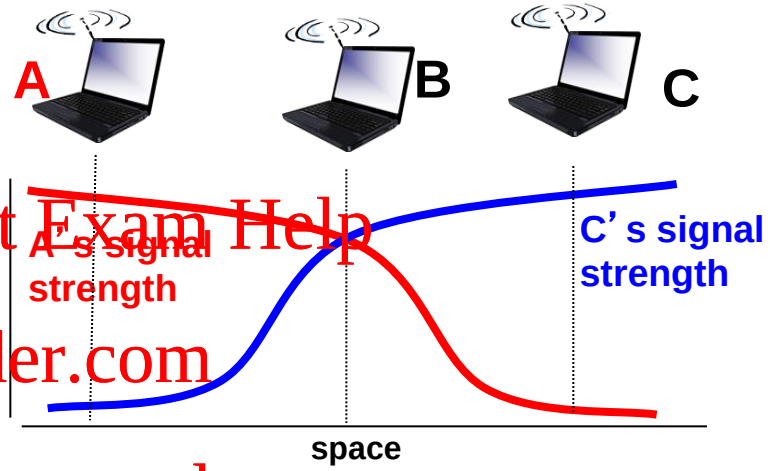


Receiver

- if frame received OK

return ACK after SIFS (ACK needed due to hidden terminal problem)

Hidden Node Problem



Hidden terminal/node problem:

- B, A hear each other
- B, C hear each other
- A, C can not hear each other means A, C unaware of their interference at B

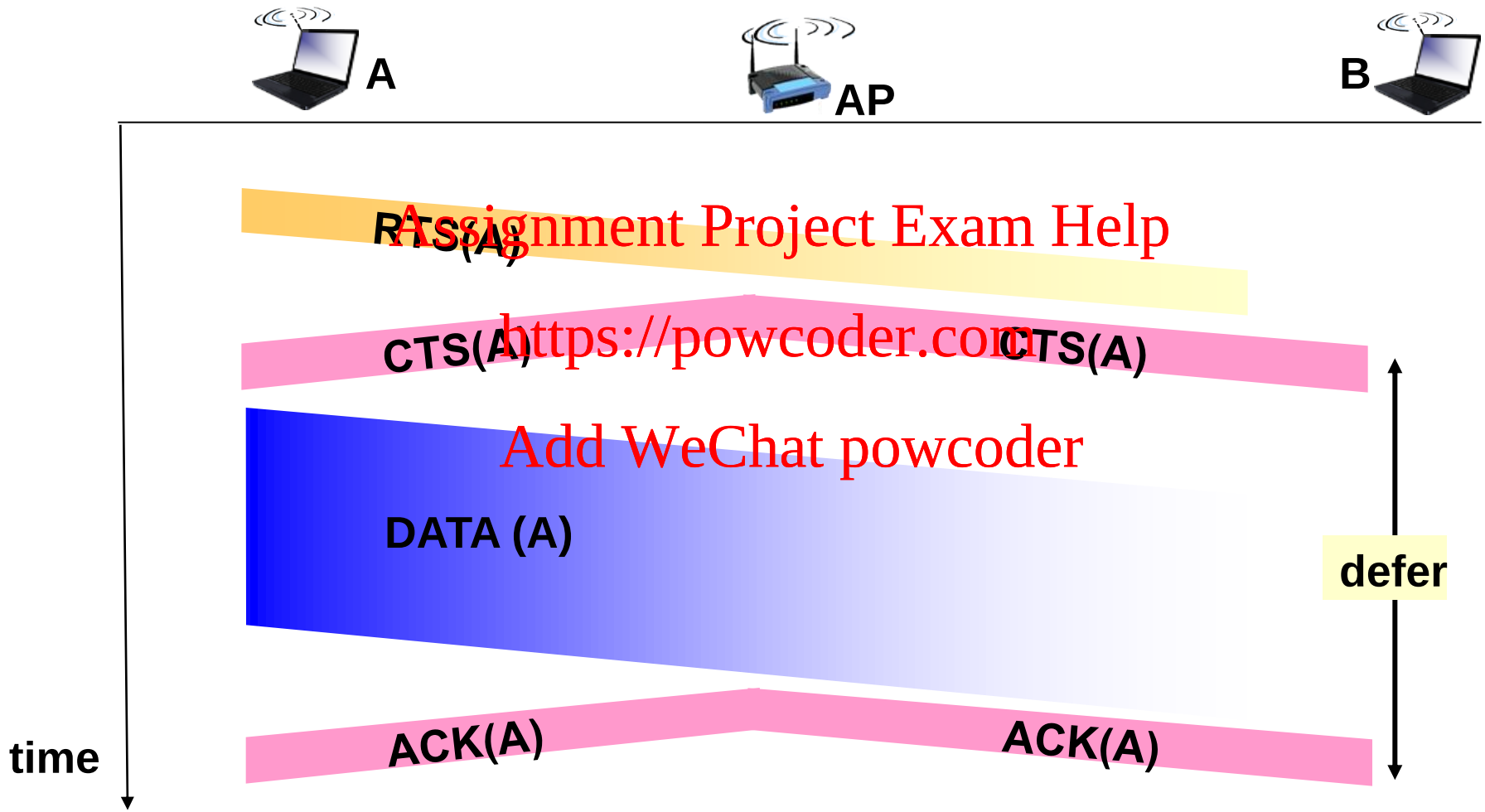
Signal attenuation:

- B, A hear each other
- B, C hear each other
- A, C can not hear each other interfering at B

Point Coordination Function

- Hidden Node problem
  - Two computers can not detect each other's signals
    - A computer is near the transmission limits of the AP at one end and another computer is near the transmission limits at the other end of the AP's range
    - Cannot sense each other's transmission signals
  - DCF method will not work
- Solution: PCF
  - First send a Request To Send (RTS) signal to the AP
    - Request to reserve the circuit and duration
  - AP responds with a Clear To Send (CTS) signal,
    - Also indicates duration that the channel is reserved
  - Computer wishing to send begins transmitting

Point Coordination Function



802.11 Frame

- **Includes four address fields**

  Two addresses have the same meaning as in wired Ethernet, the others are used communicating with APs and other devices

Address 1: AP to receive this frame

Address 2: source MAC address

Address 3: dest. MAC address

Address 4: used only in ad hoc mode

Frequency Ranges

- **WiFi devices transmit and receive within frequency ranges**
  - **These frequency ranges are divided into "channels"**
- **Frequency ranges**
  - 2.4 GHz range
    - 2.412-2.462 Ghz
    - 3 non-overlapping channels
  - 5 GHz range
    - 5.180-5.320 and 5.745-5.825 Ghz
    - 12 non-overlapping channels
- **Larger frequency range → higher potential bandwidth**
- **Higher frequency → greater attenuation (i.e., shorter range)**
- **Overlapping channels should be minimized**

Types of Wi-Fi

Type	Date Published	Max Tx Speed	Frequency (Ghz)	Official Status
802.11a	1999	54 Mbps	5, 3.7	Obsolete (Superseded)
802.11b	1999	11 Mbps	2.4	Obsolete (Superseded)
802.11g	2003	54 Mbps	2.4	Obsolete (Superseded)
802.11n	2009	600 Mbps	2.4/5	Obsolete (Superseded)*
802.11ac	2013	6.77 Gbps	2.4,5	Current
802.11ad	2012	~7 Gbps	2.4, 5	Current
802.11ax	Est. 2019	?	2.4, 5	In-Progress

*Still widely used in 2014

END