Welcome!

ELEC 8560 – Computer Networks

Local Area Networks

Outline

- Ethernet
- Wi-Fi
- Bluetooth

- Recommended reading: Forouzan – Chapter 4

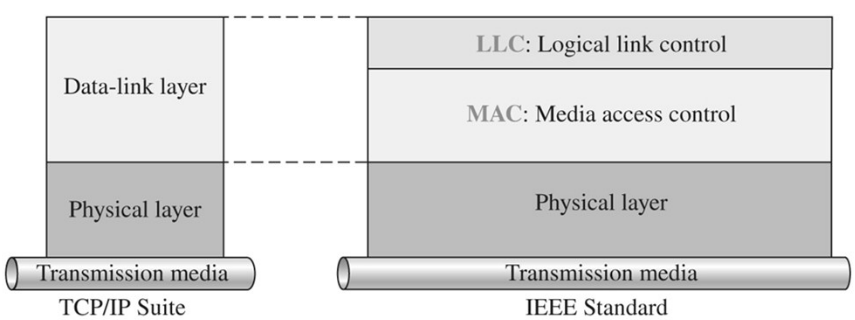
Outline

- Ethernet
- Wi-Fi
- Bluetooth

- Recommended reading: Forouzan – Chapter 4

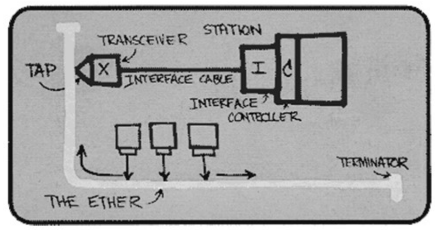
IEEE Standard for LANs

- LAN is a computer network that is designed for a limited geographic area such as a building or a campus
- IEEE 802 standard specify functions of the physical layer and data link layer of major LAN protocols
  - It is not meant to replace TCP/IP or OSI protocol suites



Ethernet

- Dominant wired LAN technology
- Kept up with speed race: 10 Mbps – 400 Gbps
- Four generations so far:
  - Standard Ethernet (10 Mbps)
  - Fast Ethernet (100 Mbps)
  - Gigabit Ethernet (1 Gbps)
  - 10 Gigabit Ethernet (10 Gbps)



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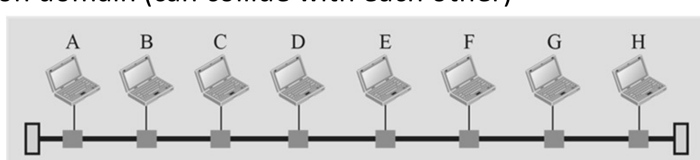
Metcalfe's Ethernet sketch

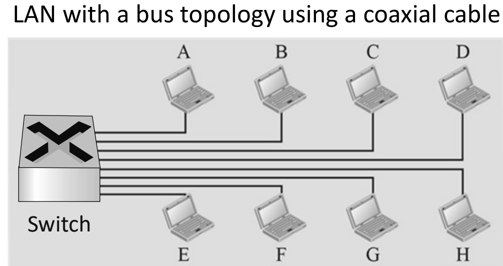
Physical Topology

- Bus: popular through mid 90s
  - All nodes in same collision domain (can collide with each other)



LAN with a bus topology using a coaxial cable

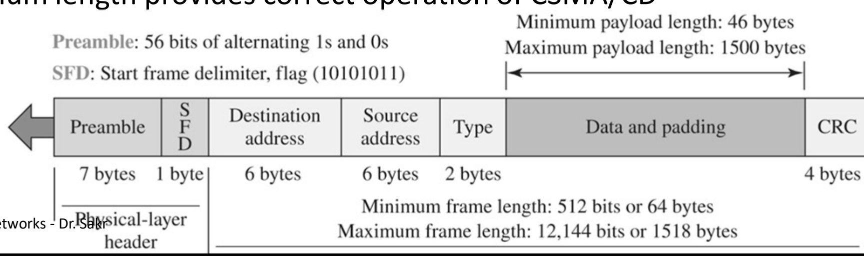
- Switched: prevails today
  - Active Layer 2 switch in center
  - Nodes are not necessarily in same collision domain (no collisions)



LAN with a switched topology using a switch

Ethernet Frame Structure

- Ethernet frame contains seven fields
  - Preamble: synchronize receiver and sender clocks, added at the physical layer
  - SFD: flag to signal the beginning of the frame due to variable-length frames
  - Addresses: source and destination MAC addresses
    - if NIC receives frame with its own destination address, a multicast address for its group, or a broadcast address, it passes data in frame to network layer protocol; otherwise, discard
  - Type: indicates higher layer protocol (e.g., ARP)
  - Data: encapsulated data from upper layers (fragment if long, pad 0s if short)
  - CRC: cyclic redundancy check at receiver for error detection
- Minimum length provides correct operation of CSMA/CD



Addressing

- Each station on an Ethernet network has its own NIC
- NIC fits provides the link layer address (i.e., MAC address)
- Ethernet (or MAC) address is 6 bytes (48 bits), normally written in hexadecimal notation
- Example:

2C-6D-B2-65-18-8C

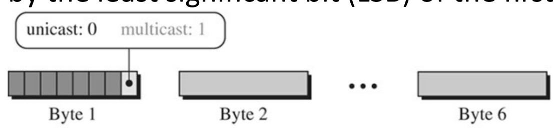
```
C:\Users\admin>ipconfig /all

Wireless LAN adapter Local Area Connection* 1:

   Media State . . . . . . . . . . . : Media disconnected
   Connection-specific DNS Suffix  . :
   Description . . . . . . . . . . . : Microsoft Wi-Fi Direct Virtual Adapter
   Physical Address. . . . . . . . . : 2C-6D-B2-65-18-8C
   DHCP Enabled. . . . . . . . . . . : Yes
   Autoconfiguration Enabled . . . . : Yes
```

Example: Unicast, Multicast, and Broadcast Addresses

Define the type of the following destination addresses: (a) 4A-30-10-21-10-1A (b) 47-20-1B-2E-08-EE (c) FF-FF-FF-FF-FF-FF

Solution:

- This is determined by the least significant bit (LSB) of the first byte



- Therefore,
  a) $4A_{16} = 01001010_2 \rightarrow$ unicast
  b) $47_{16} = 01000111_2 \rightarrow$ multicast
  c) All 1s is broadcast
- Notes:
  - Source address is always a unicast address, frame comes from only one station
  - Destination address can be unicast, multicast, or broadcast

Bit-reversed Transmission of Address Bits

- Transmission of MAC addresses is left to right, byte by byte; however, for each byte, the least significant bit that defines the address type is sent first

Show how the address 47-20-1B-2E-08-EE is sent out online.

Solution:

Hexadecimal	**47**	**20**	**1B**	**2E**	**08**	**EE**
Binary	01000111	00100000	00011011	00101110	00001000	11101110
Transmitted ←	11100010	00000100	11011000	01110100	00010000	01110111

IEEE 802.3

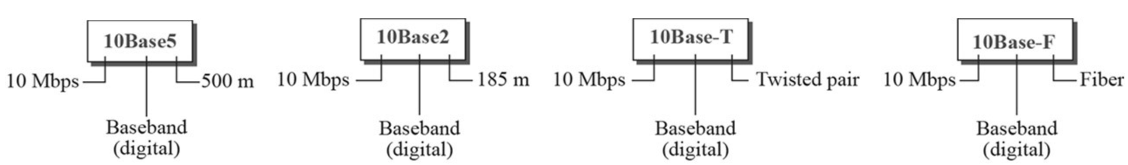
Standard Ethernet

- Original Ethernet technology with the data rate of 10 Mbps
- Connectionless:
  - No handshaking between sending and receiving NICs
    - Sender sends frame whenever it has, receiver may or may not be ready for it
  - Frames are sent independent of each other
- Unreliable:
  - Receiving NIC does not send ACKs or NAKs to sending NIC
    - Receiver drops corrupted frames silently, sender does not know
- Access method: CSMA/CD with 1-persistent method

Physical Layer of Standard Ethernet

- The standard Ethernet defines several implementation, but only four of them became popular

Implementation	*Medium*	*Medium Length(m)*	*Encoding*
10Base5	thick coax	500 m	Manchester
10Base2	thin coax	185 m	Manchester
10Base-T	2 UTP	100 m	Manchester
10Base-F	2 fiber-optic	2000 m	Manchester



IEEE 802.3u

Fast Ethernet

- Transmission rate increased to 100 Mbps
- MAC sublayer was left unchanged for backward compatibility:
  - Keep address length, frame format, maximum and minimum frame length the same, and access method (i.e., CSMA/CD)
- To keep same minimum frame size ($2T_p \times R$) when transmissions are 10 times faster:
  - Maximum length of the network should be 10 times shorter to detect collisions 10 times sooner

Physical Layer of Fast Ethernet

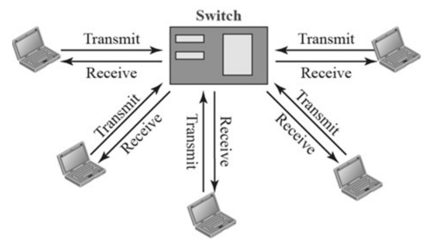
- To be able to handle a 100 Mbps data rate, several changes need to be made at the physical layer related to transmission rate
  - Two-wire implementation: STP which is called 100Base-TX, or fiber-optic cable, which is called 100Base-FX
  - Four-wire implementation: UTP which is called 100Base-T4

Implementation	*Medium*	*Medium Length*	*Wires*	*Encoding*
100Base-TX	STP	100 m	2	4B/5B + MLT-3
100Base-FX	fiber-optic	185 m	2	4B/5B + NRZ-I
100Base-T4	UTP	100 m	4	Two 8B/6T

IEEE 802.3z

Gigabit Ethernet

- Transmission rate increased to 1 Gbps
- MAC sublayer was left unchanged for backward compatibility
- Access methods to achieve a data rate of 1 Gbps:
  - Full-duplex Mode:
    - Almost followed in all implementations of Gigabit Ethernet
    - A central switch connected to all computers (private medium + buffer for each host)
    - No collision in this mode (no need for CSMA/CD)
  - Half-duplex Mode:
    - Less common
    - A switch can be replaced by a hub
    - CSMA/CD



Full-duplex Switched Ethernet

Physical Layer of Gigabit Ethernet

- To be able to handle a 1 Gbps data rate, several changes need to be made at the physical layer related to transmission rate

Implementation	***Medium***	***Medium Length***	***Wires***	***Encoding***
1000Base-SX	fiber-optic Shortwave	550 m	2	8B/10B + NRZ
1000Base-LX	fiber-optic Longwave	5000 m	2	8B/10B + NRZ
1000Base-CX	STP	25 m	2	8B/10B + NRZ
1000Base-T4	UTP	100 m	4	4D-PAM5

IEEE 802.3ae

10-Gigabit Ethernet

- Transmission rate increased to 10 Gbps
- MAC sublayer was left unchanged for backward compatibility
- Operates only in full-duplex mode
- No collision in this mode (no need for CSMA/CD)
- Four implementations are the most common:

Implementation	*Medium*	*Medium Length*	*Wires*	*Encoding*
10GBase-SR	fiber-optic 850 nm	300 m	2	64B66B
10GBase-LR	fiber-optic 1310 nm	10 km	2	64B66B
10GBase-EW	fiber-optic 1350 nm	40 km	2	SONET
10GBase-X4	fiber-optic 1310 nm	300 m to 10 km	2	8B10B

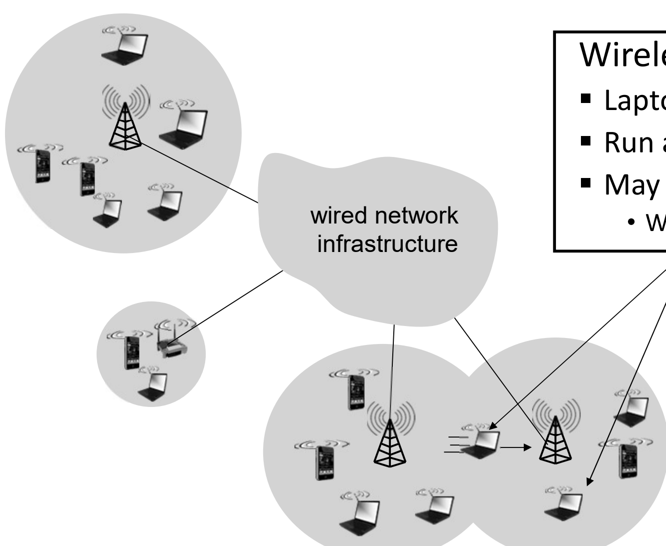
Outline

- Ethernet
- Wi-Fi
- Bluetooth

Wireless Networks

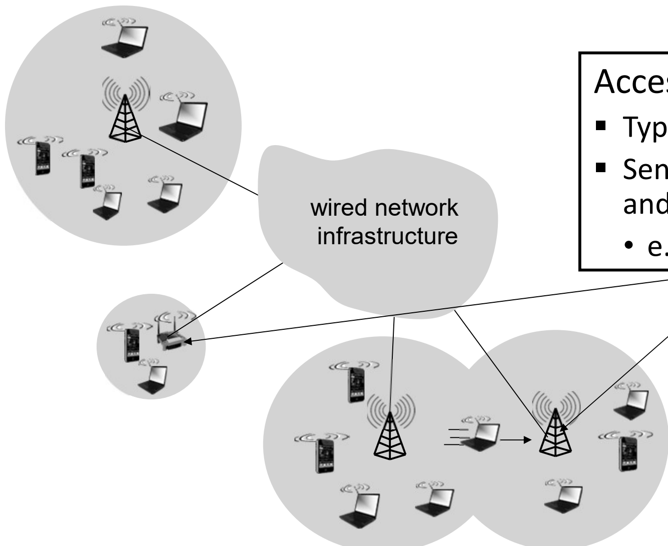
- Wireless communication is one of the fastest-growing technologies
  - More wireless (mobile) phone subscribers than fixed (wired) phone subscribers (10:1 in 2019)
  - More mobile-broadband-connected devices than fixed-broadband-connected devices (5-1 in 2019)
- Compared to wired networks:
  - Wireless: communication over wireless link
  - Mobility: handling mobile user movement between access points

Elements of Wireless Networks



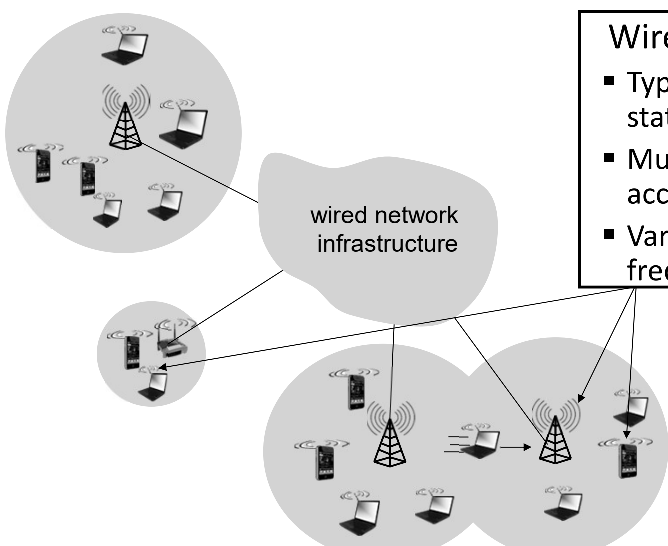
Wireless hosts
- Laptop, smartphone, IoT
- Run applications
- May be stationary (non-mobile) or mobile
  - Wireless does *not* always mean mobility!

Elements of Wireless Networks



Access point (or base station)
- Typically connected to wired network
- Send packets between wired network and wireless host(s) in its coverage area
  - e.g., cell towers, 802.11 access points

Elements of Wireless Networks

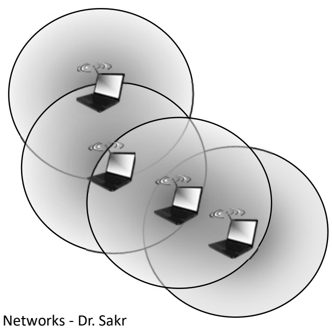


Wireless link
- Typically used to connect host(s) to base station, also used as backbone link
- Multiple access protocol coordinates link access
- Various transmission rates and distances, frequency bands

Ad-Hoc vs. Infrastructure Networks

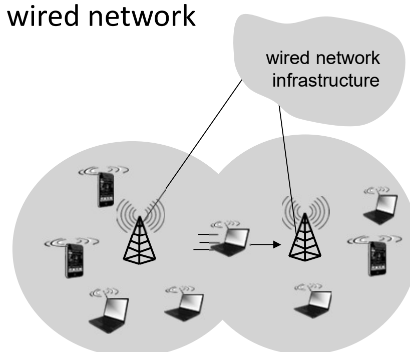
Ad-hoc mode:

- No access points
- Nodes can only transmit to other nodes within link coverage
- Nodes organize themselves into a network: route among themselves



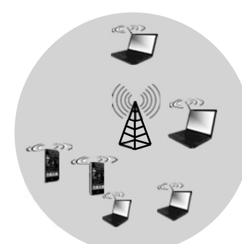
Infrastructure mode:

- Access point connects hosts into wired network
- Handoff: mobile changes base station providing connection into wired network



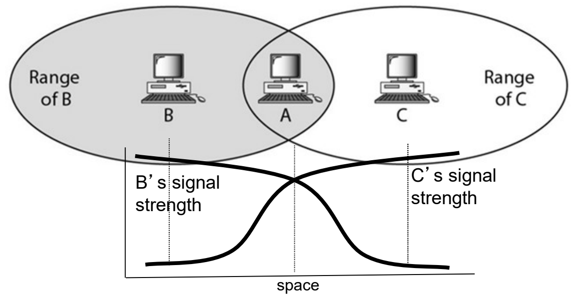
Wireless Link Characteristics

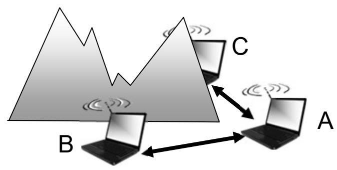
- Compared to wired links:
  - Decreased signal strength: radio signal attenuates as it propagates through matter due to pathloss
  - Interference from other sources: wireless network frequencies (e.g., 2.4 GHz) shared by many devices (e.g., Wi-Fi, cellular, motors)
  - Multipath propagation: radio signal reflects off objects ground, arriving at destination at slightly different times
- Signal-to-interference-plus-noise ratio (SINR):
  - Used to characterize communication links
  - Larger SINR means easier to extract signal from noise



Hidden Station Problem

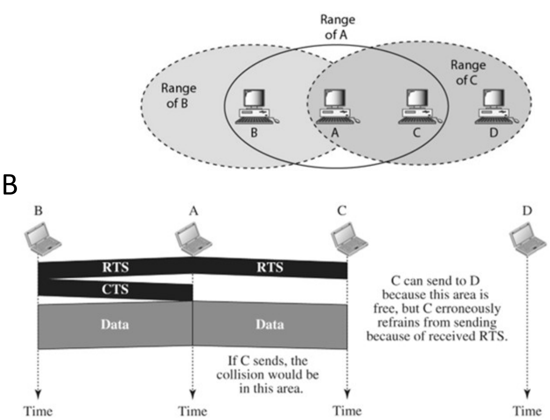
- Sometimes called Hidden Node (or Terminal) Problem
- Causes a station to use a channel when the channel is busy, but the station is unaware
- Example:
  - B, A hear each other
  - C, A hear each other
  - B, C can not hear each other
  - B, C unaware of their interference at A





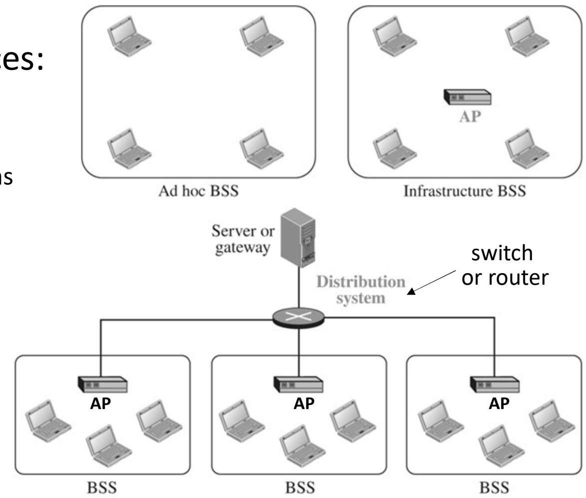
Exposed Station Problem

- Sometimes called Exposed Node (or Terminal) Problem
- Causes a station to refrain from using a channel when the channel is available
- Example:
  - A is sending to B
  - C receives RTS from A
  - C can send to D and cause no collision at B
  - C erroneously refrains from sending



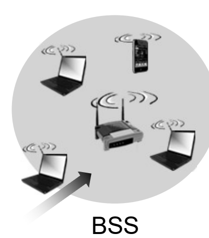
Wi-Fi – IEEE 802.11 Project

- IEEE 802.11 defines specifications of physical and data link layers for wireless LANs
- Standard defines two kind of services:
  - Basic service set (BSS):
    - Cell: Building block of a wireless LAN
    - Defines an optional base station known as the access point (AP)
  - Extended service set (ESS)
    - Two or more BSS with APs that are connected together using a distribution system (DS)
    - DS can be wired (e.g., Ethernet LAN) or wireless



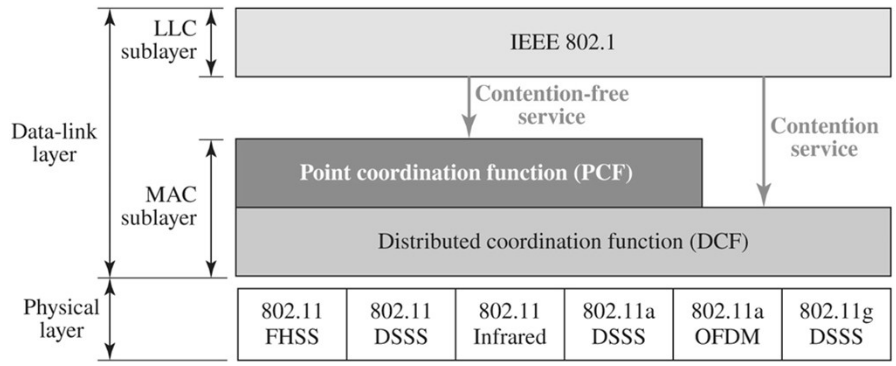
Channels and Association

- Spectrum is divided into channels at different frequencies
  - AP admin chooses frequency for AP
  - Interference: channels can be reused neighboring APs
- Arriving host must associate with an AP
  1. Scans channels, listening for beacon frames containing AP's name (SSID) and MAC address
  2. Selects AP to associate with
  3. Performs authentication if needed
  4. Runs a protocol (e.g., DHCP) to get an IP address



MAC Sublayers

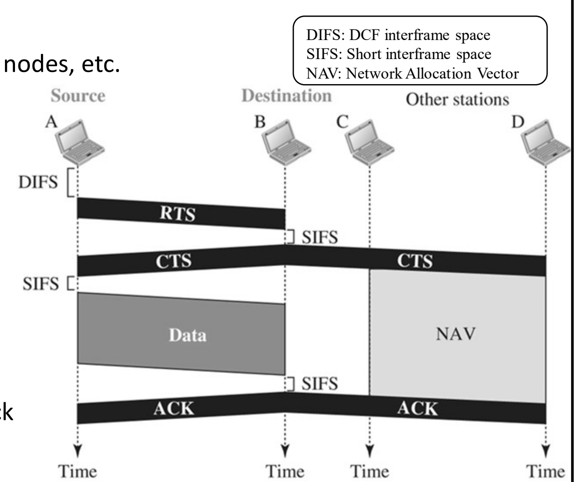
- IEEE 802.11 defines two MAC sublayers:
  - Distributed coordination function (DCF)
  - Point coordination function (PCF)



Distribution Coordination Function (DCF)

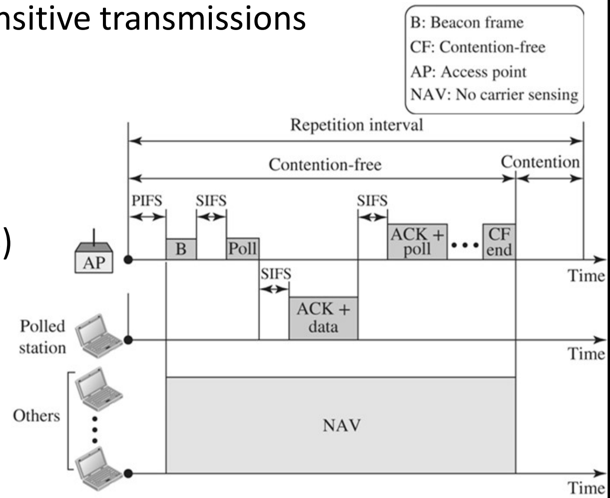
- DCF uses CSMA/CA for access control
  - CSMA/CD does not work well in wireless
    - difficult to detect collisions
    - weak received signal due to pathloss, hidden nodes, etc.
- Operation:
  1. Source senses medium before transmission
     - If busy, backoff until channel is idle
     - If idle, wait for a period of time and send RTS
  2. Received RTS, wait for a period of time and send CTS to source station
  3. Source sends after waiting same period of time
  4. Destination sends an ACK after waiting same period of time

  Other stations start timer (NAV), remain silent, check later (RTS includes time needed for transmission)



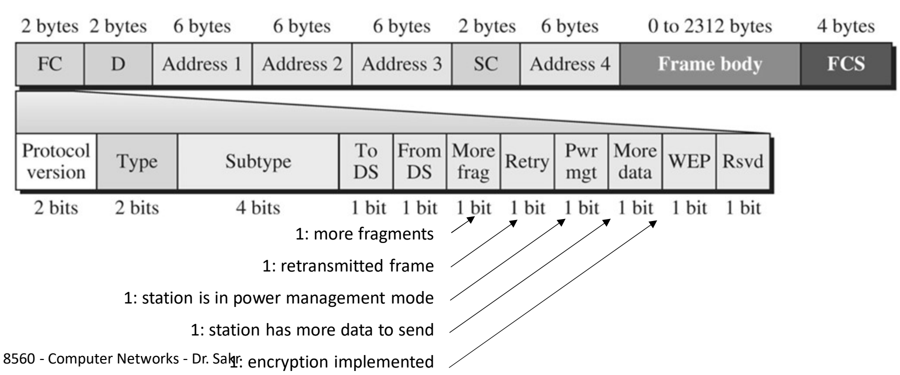
Point Coordination Function (PCF)

- Optional access that can be implemented in an infrastructure network (on top of DCF) for time-sensitive transmissions
- Centralized, contention-free, and use polling access method
  - AP performs polling for stations one after another
- PCF has priority over DCF (PIFS<DIFS)
- To allow DCF frames, repetition interval are added to the network:
  - Allow both PCF and DCF frames
  - Beacon frame to start NAV
  - CF frame to end contention-free



Frame Format

- Wireless environment is very noisy and frames are often corrupted
- Fragmentation is the division of frame into smaller ones to avoid resending large frames
- The MAC layer frame consists of nine fields



FC: frame control

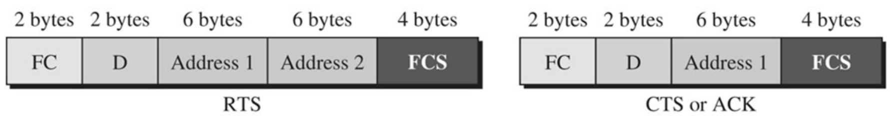
D: duration of reserved transmission time (i.e., NAV)

SC: sequence control

FCS: frame check sequence (CRC-32)

Frame Type and Subtype

- IEEE 802.11 has three types of frames: management (00), control (01), or data (10)
- Example: control frames



- Subtypes:

Subtype	***Meaning***
1011	Request to send (RTS)
1100	Clear to send (CTS)
1101	Acknowledgment (ACK)

Addressing

- The interpretation of the four MAC addresses (address 1 to address 4) in the MAC frame depends on the value of To DS and From DS flags
- IEEE 802.11 addressing mechanism has four cases

To DS	***From DS***	***Address 1***	***Address 2***	***Address 3***	***Address 4***
0	0	Destination	Source	BSS ID	N/A
0	1	Destination	Sending AP	Source	N/A
1	0	Receiving AP	Source	Destination	N/A
1	1	Receiving AP	Sending AP	Destination	Source

Next device frame will visit

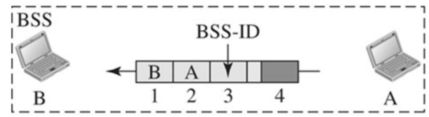
Previous device the frame has left

Final destination if not Address 1 or original source if not Address 2 or BSS ID

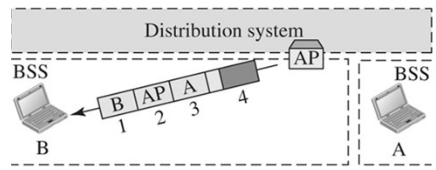
Original source when distribution system is also wireless

Addressing (cont.)

- Case 1:
  - Frame not coming from a DS (*From DS* = 0) and not going to a DS (*To DS* = 0)
  - Frame is going from a station in a BSS to another without passing through the distribution system

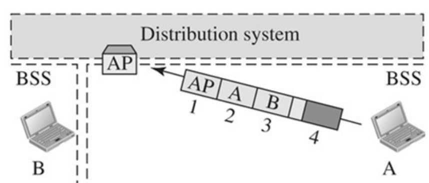


- Case 2:
  - Frame is coming from a DS (*From DS* = 1) but not going to a DS (*To DS* = 0)
  - Frame is coming from an AP and going to a station
  - Address 3 contains the original sender of the frame in another BSS

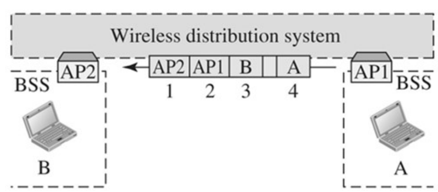


Addressing (cont.)

- Case 3:
  - Frame is going to a DS (*To DS* = 1) but not coming from a DS (*From DS* = 0)
  - Frame is going from a station to an AP
  - Address 3 contains the final destination of the frame in another BSS



- Case 4:
  - Frame is coming from a DS (*From DS* = 1) and not going to a DS (*To DS* = 1)
  - Frame is coming from an AP and going to an AP
  - Address 3 contains the final destination of the frame in another BSS
  - Address 4 contains the original sender of the frame as DS is wireless



Physical Layer

- IEEE 802.11 defines multiple specifications
- All following implementations operate in the ISM band:
  - Industrial, Scientific, and Medical band
  - Three unlicensed bands:
    - 902-928 MHz
    - 2.4-2.4835 GHz
    - 5.725-5.825 GHz

Evolution of Wi-Fi

- Wi-Fi 1 (802.11b - 1999)
  - 2.4 GHz band (Unlicensed)
  - 11 Mbps
  - Direct sequence spread spectrum (DSSS) + complementary code keying (CCK) modulation
- Wi-Fi 2 (802.11a - 1999)
  - 5 GHz band
  - 54 Mbps (adaptive rates: 6, 9, 12, 18, 24, 36 and 48 Mbps)
  - Orthogonal frequency division multiplexing (OFDM) + BPSK, QPSK, 16 QAM or 64 QAM
  - Not widely accepted initially because of high cost, low range, and incompatibility with 802.11b
- Wi-Fi 3 (802.11g - 2003)
  - 2.4 GHz band
  - 54 Mbps (adaptive rates: 6, 9, 12, 18, 24, 36 and 48 Mbps)
  - OFDM + BPSK, QPSK, 16 QAM or 64 QAM
  - Compatible with 802.11b

Evolution of Wi-Fi (cont.)

- Wi-Fi 4 (802.11n - 2009)
  - 2.4/5 GHz band
  - 600 Mbps (adaptive rate)
  - OFDM + MIMO (up to 4 streams) + BPSK, QPSK, 16 QAM or 64 QAM
- Wi-Fi 5 (802.11ac - 2013)
  - 2.4/5 GHz band
  - 6.8 Gbps (adaptive rate)
  - OFDM + MIMO (up to 8 streams) + MU-MIMO (up to 4 users downlink) + high density modulation (up to 256 QAM)
- Wi-Fi 6 (802.11ax - 2021)
  - 2.4/5 GHz band
  - 10 Gbps (adaptive rate)
  - OFDM + MIMO (up to 8 streams) + MU-MIMO (up to 8 users uplink and downlink) + higher density modulation (up to 1024 QAM)

Evolution of Wi-Fi (cont.)

- To check what Wi-Fi radio types your computer's WLAN adapter supports:
  - In Windows, open the Command Prompt window and enter "**netsh wlan show drivers**".

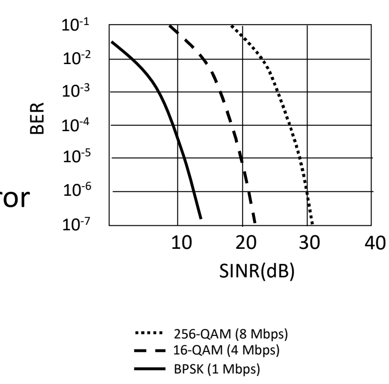
```
C:\Users\admin>netsh wlan show drivers

Interface name: Wi-Fi

    Driver                    : Intel(R) Wireless-AC 9560
    Vendor                    : Intel Corporation
    Provider                  : Intel
    Date                      : 2022-07-21
    Version                   : 21.110.2.1
    INF file                  : oem53.inf
    Type                      : Native Wi-Fi Driver
    Radio types supported     : 802.11b 802.11g 802.11n 802.11a 802.11ac
    FIPS 140-2 mode supported : Yes
    802.11w Management Frame Protection supported : Yes
    Hosted network supported  : No
```

Advanced Capabilities: Power Management

- Node-to-AP: "I am going to sleep until next beacon frame"
  - AP knows not to transmit frames to this node
  - Node wakes up before next beacon frame
- Beacon frame: contains list of mobiles with AP-to-mobile frames waiting to be sent
  - Node will stay awake if AP-to-mobile frames to be sent; otherwise, sleep again until next beacon frame

Advanced Capabilities: Rate adaptation

- SINR varies over time due to node movement, etc.
- Base station and mobile dynamically change transmission rate (physical layer modulation technique) based on SINR level
- Example:
  - Node moves away from AP → SINR decreases → error probability increases
  - When error probability becomes too high → reduce transmission rate → lower error probability



Outline

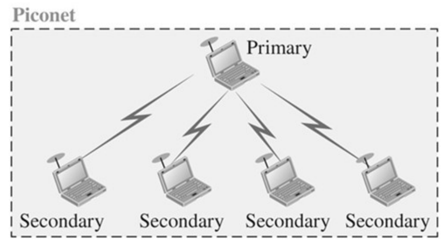
- Ethernet
- Wi-Fi
- Bluetooth

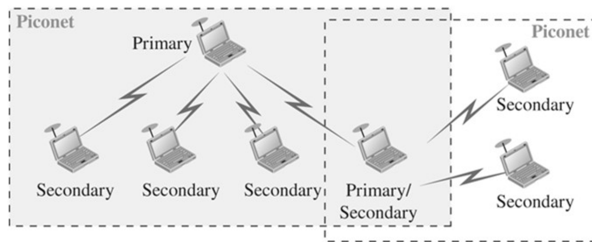
Bluetooth

- Designed to connect devices at a short distance from each other
  - For example, replacement for cables (mouse, keyboard, headphones)
- Devices are low-power with a range of 10 m (at 2.5 mW)
- Operates in ISM band 2.4 GHz to 2.4835 GHz
- Bluetooth LANs are ad-hoc networks:
  - No infrastructure

Piconet

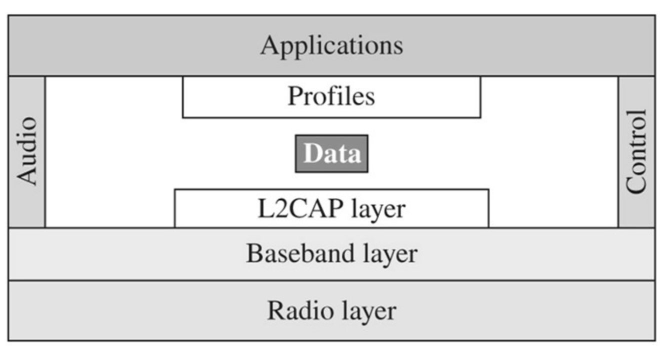
- Piconet (small net):
  - Up to 8 devices find each other and make a network called a piconet
  - One device is called the primary (polls clients, grants requests for client transmissions)
  - Others are called the secondaries
- Scatternet:
  - Multiple piconets can be combined to create a scatternet
  - A secondary station in one piconet can be a primary in another one





Bluetooth Layers

- Bluetooth uses several layers that do not exactly match those of the Internet model we discussed earlier
  - Logical Link Control and Adaption Protocol (L2CAP) layer: roughly equivalent to LLC sublayer in LANs
  - Baseband layer: roughly equivalent to MAC sublayer in LANs
  - Radio layer: roughly equivalent to the physical layer



Summary

- We covered:
  - Wired vs. wireless links
  - Wired LANs: Ethernet
  - Wireless LANs: Wi-Fi and Bluetooth