Computer Networks
Chap 7 Wireless and Mobile Networks
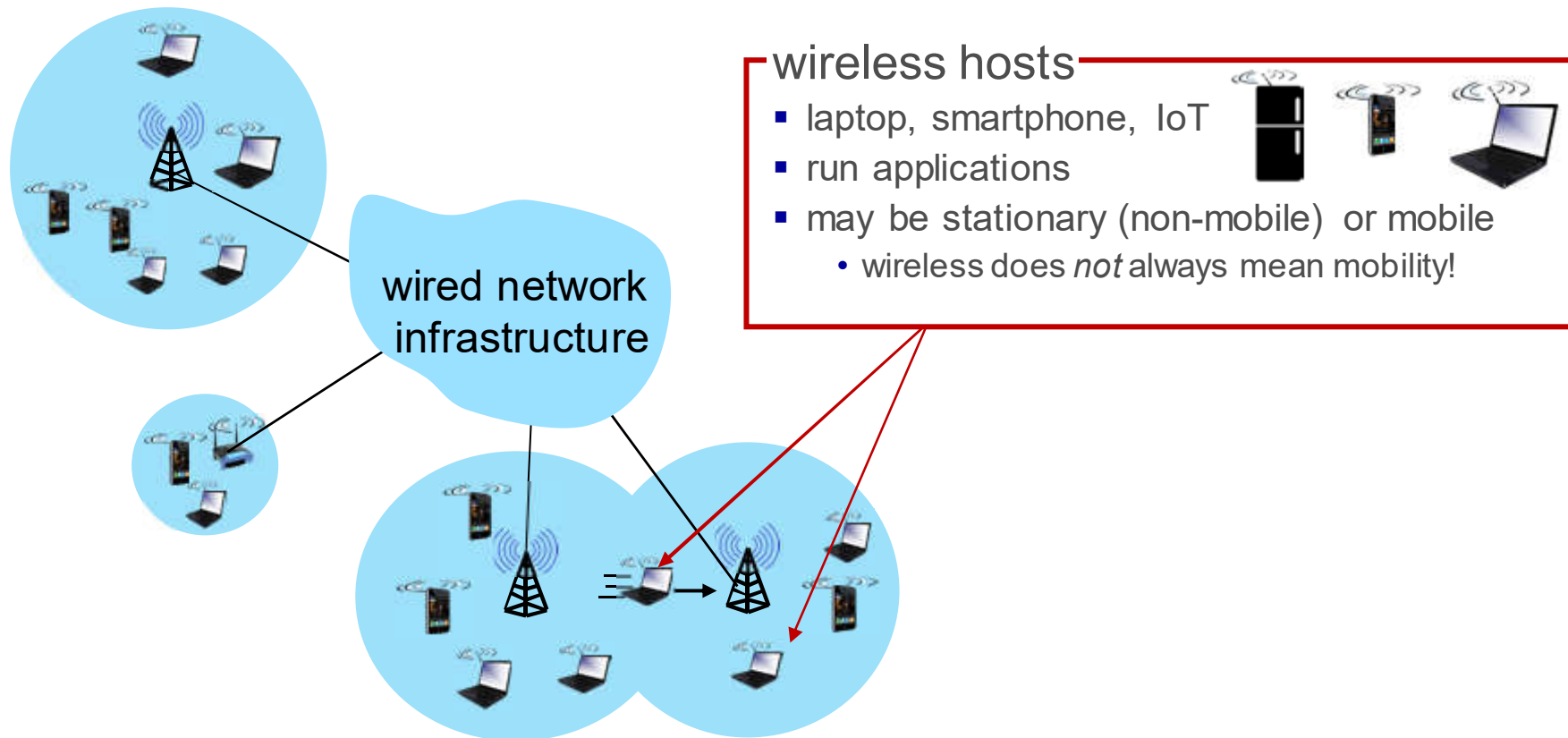
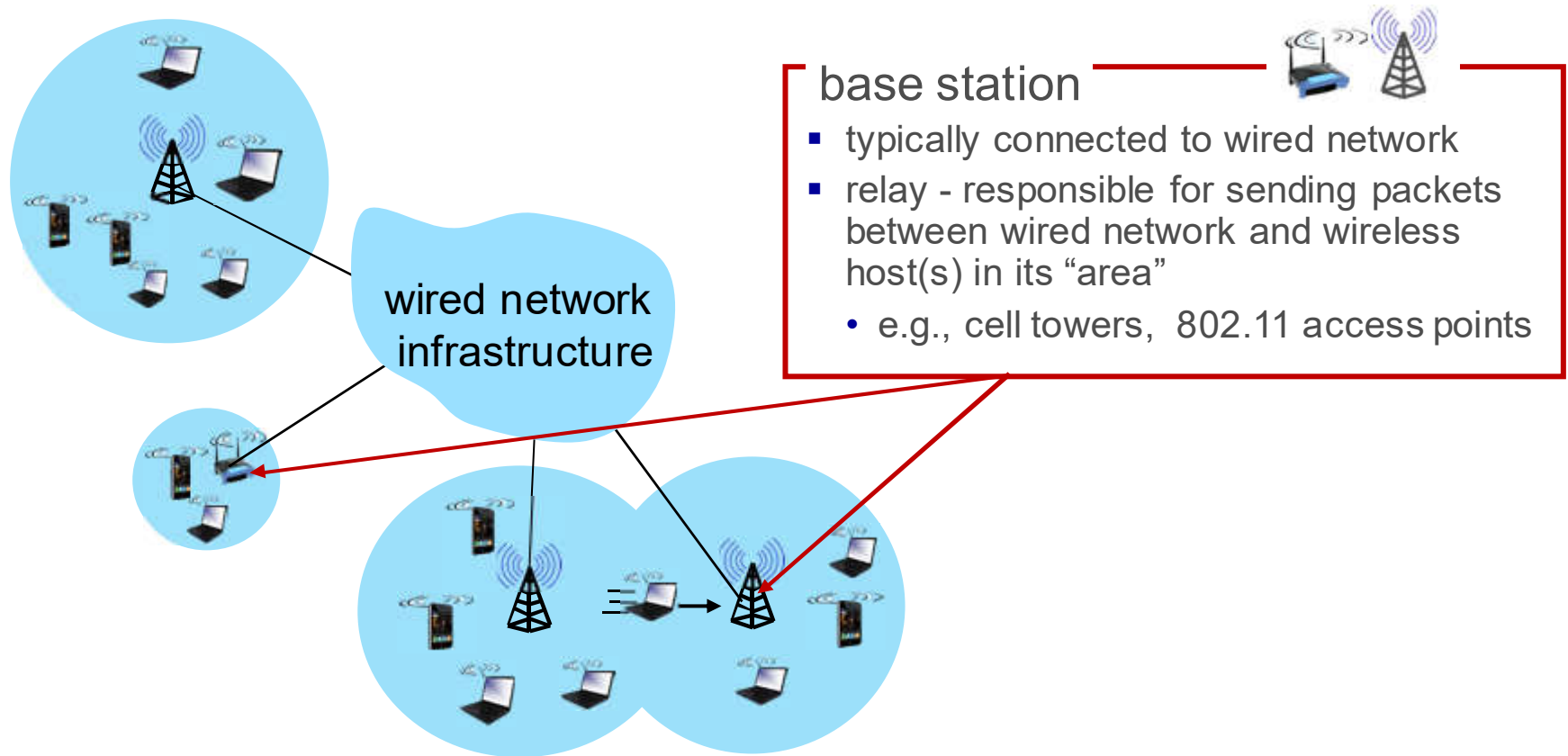# PART-1

Wireless and Mobile Networks: context

- more wireless (mobile) phone subscribers than fixed (wired) phone subscribers (10-to-1 in 2019)!

- more mobile-broadband-connected devices than fixed-broadband-connected devices devices (5-1 in 2019)!

- two important (but different) challenges
  - wireless: communication over wireless link
  - mobility: handling the mobile user who changes point of attachment to network

為保護所參考來源之智慧財產權，此教材/視訊音訊資料僅為上課時教學之用。

Elements of a wireless network

Elements of a wireless network

wired network infrastructure

wireless hosts
- laptop, smartphone, IoT
- run applications
- may be stationary (non-mobile) or mobile
  - wireless does *not* always mean mobility!

Elements of a wireless network

wired network infrastructure

base station
- typically connected to wired network
- relay - responsible for sending packets between wired network and wireless host(s) in its "area"
  - e.g., cell towers, 802.11 access points

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Elements of a wireless network

wired network infrastructure

wireless link

- typically used to connect mobile(s) to base station, also used as backbone link
- multiple access protocol coordinates link access
- various transmission rates and distances, frequency bands

Characteristics of selected wireless links

14 Gbps — 802.11ax
10 Gbps — 5G
3.5 Gbps — 802.11ac
802.11 af,ah
600 Mbps — 802.11n
4G LTE
54 Mbps — 802.11g
11 Mbps — 802.11b
2 Mbps — Bluetooth

Indoor	Outdoor	Midrange outdoor	Long range outdoor
10-30m	50-200m	200m-4Km	4Km-15Km

Elements of a
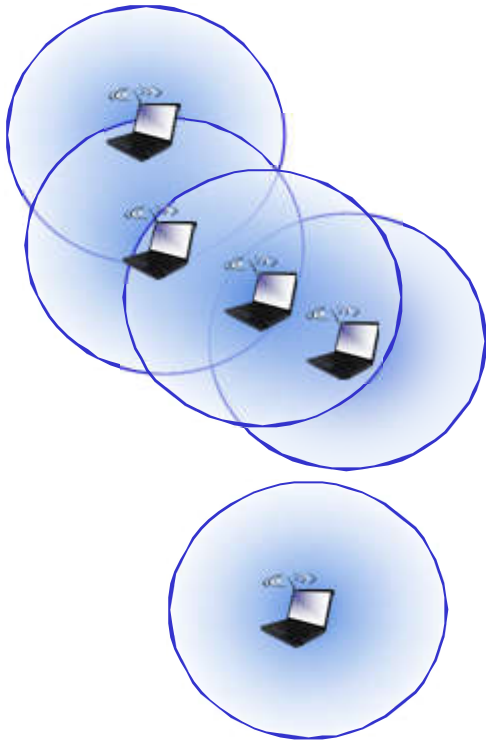# wireless network
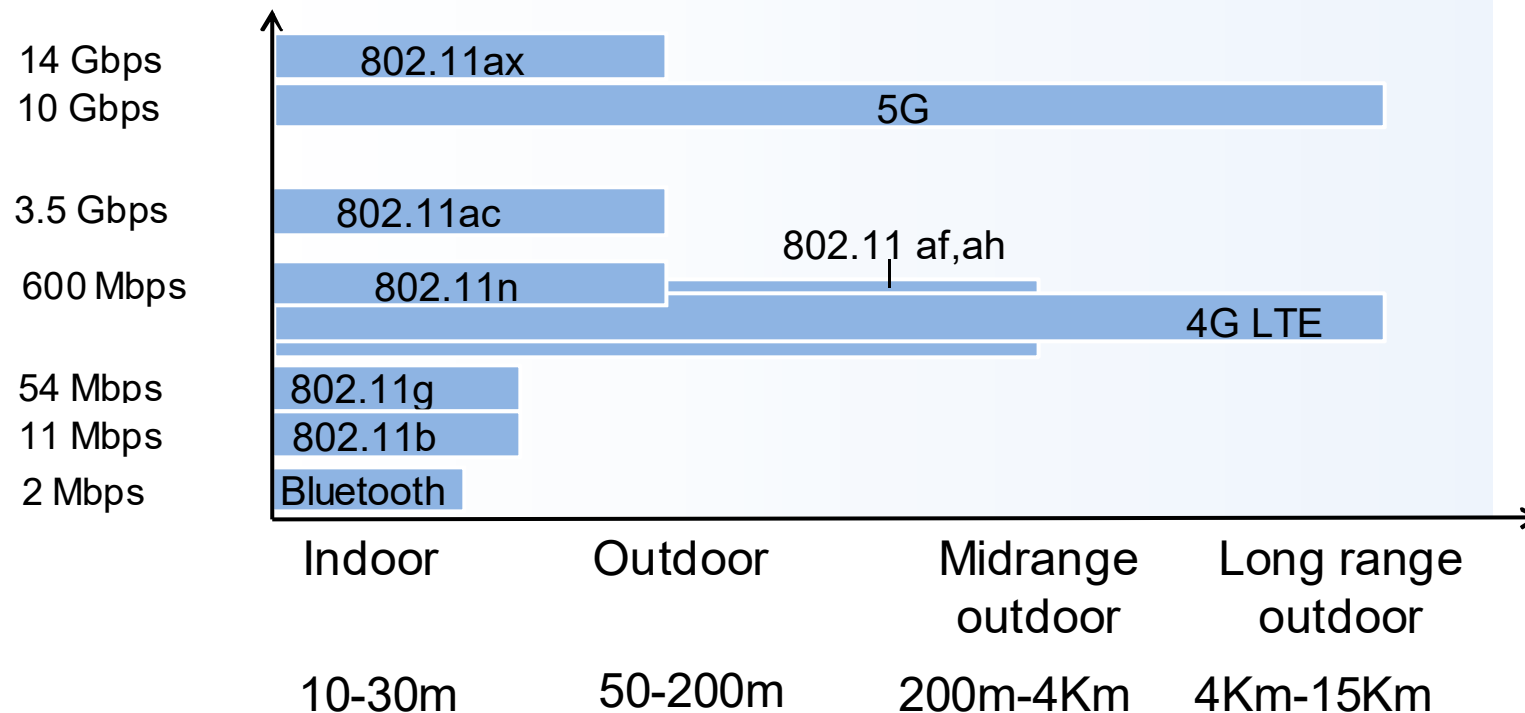
wired network
infrastructure
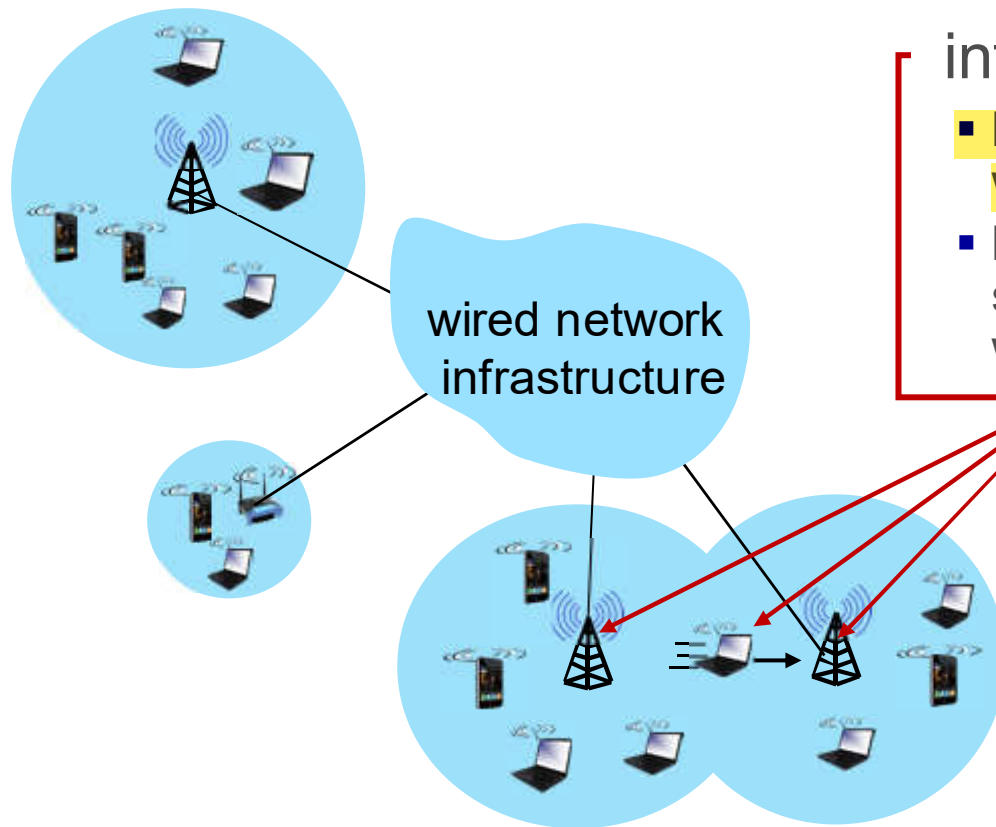
infrastructure mode
- **base station** connects mobiles into wired network
- handoff: mobile changes base station providing connection into wired network

Elements of a wireless network

ad hoc mode
- no base stations
- nodes can only transmit to other nodes within link coverage
- nodes organize themselves into a network: route among themselves

Wireless network taxonomy

	single hop	multiple hops
infrastructure (e.g., APs)	host connects to base station (WiFi, cellular) which connects to larger Internet	host may have to relay through several wireless nodes to connect to larger Internet: *mesh net*
no infrastructure	no base station, no connection to larger Internet (Bluetooth, ad hoc nets)	no base station, no connection to larger Internet. May have to relay to reach other a given wireless node MANET, VANET

outline

Wireless

- Wireless links and
  network characteristics

Wireless link characteristics: fading (attenuation)

Wireless radio signal attenuates (loses power) as it propagates (free space "path loss")
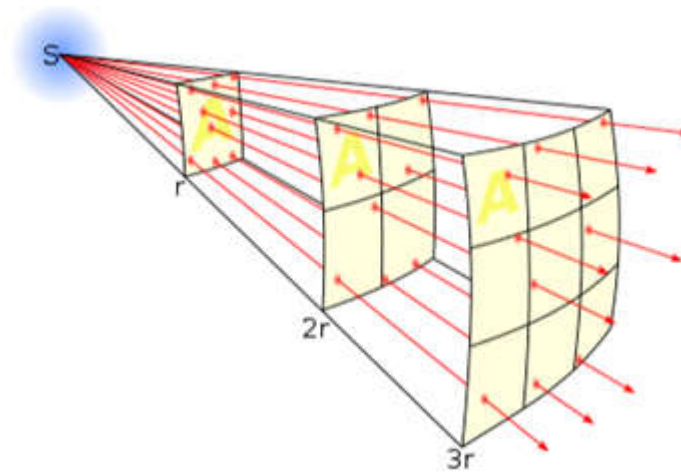
Free space path loss $\sim (fd)^2$

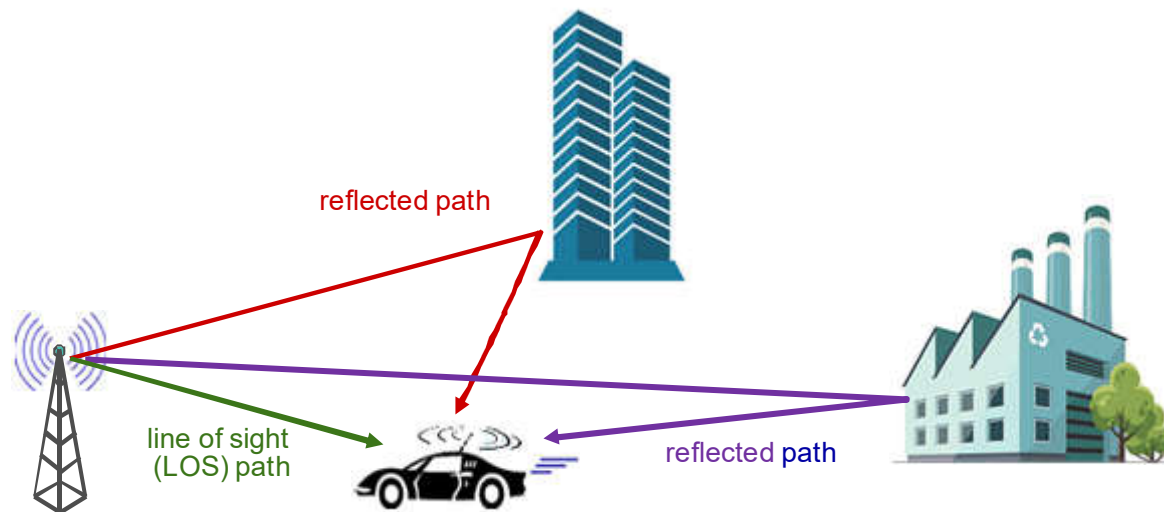f: frequency
d: distance

higher frequency
or longer distance $\longrightarrow$ larger free space
path loss

Wireless link characteristics: multipath

multipath propagation: radio signal reflects off objects ground, built environment, arriving at destination at slightly different times

reflected path

line of sight (LOS) path

reflected path

Wireless link characteristics: noise

- interference from other sources on wireless network frequencies: motors, appliances
- SNR: signal-to-noise ratio
  - larger SNR – easier to extract signal from noise (a "good thing")
- SNR versus BER tradeoff
  - *given physical layer:* increase power -> increase SNR->decrease BER
  - SNR may change with mobility: dynamically adapt physical layer (modulation technique, rate)

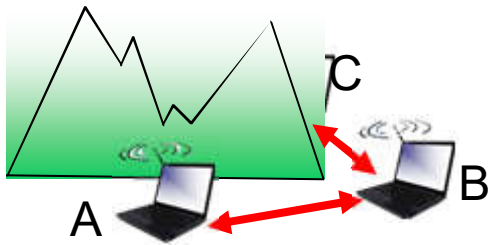

······ QAM256 (8 Mbps)

– – QAM16 (4 Mbps)

—— BPSK (1 Mbps)
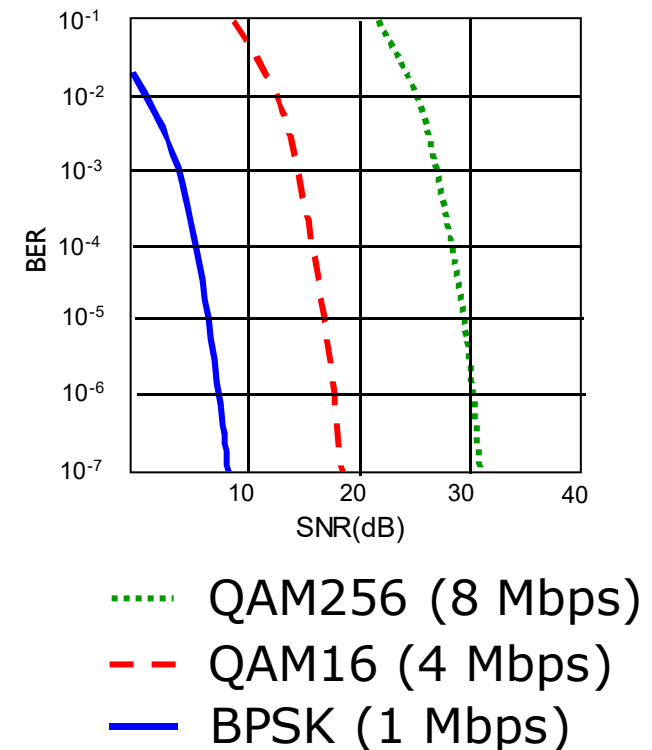
Wireless link characteristics: hidden terminals

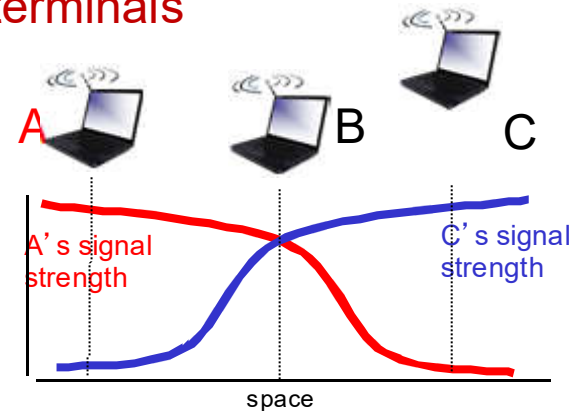**Multiple wireless senders and receivers create additional problems (beyond multiple access):**

Hidden terminal 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

Attenuation also causes "hidden terminals"

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

Chapter 7 outline

Wireless

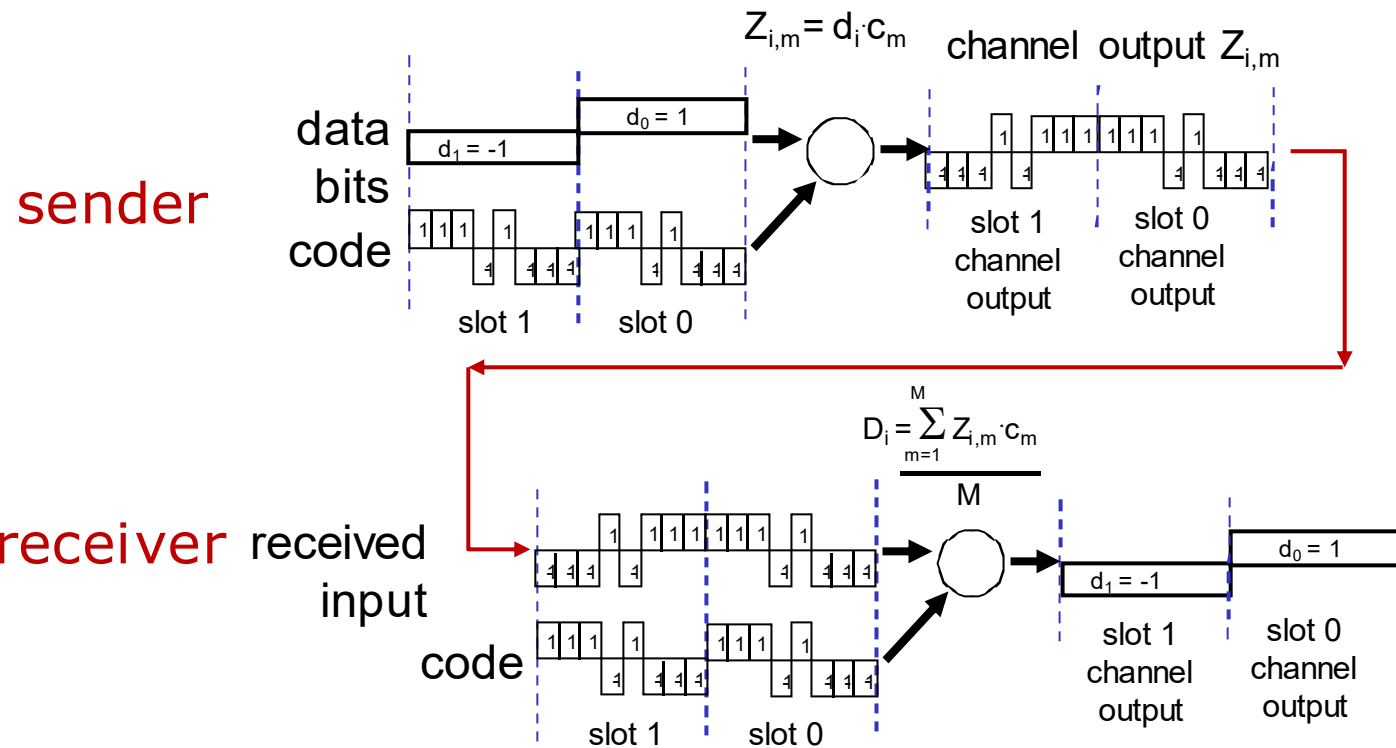- CDMA: code division multiple access

Code Division Multiple Access (CDMA)

- unique "code" assigned to each user; i.e., code set partitioning
  - all users share same frequency, but each user has own "chipping" sequence (i.e., code) to encode data
  - allows multiple users to "coexist" and transmit simultaneously with minimal interference (if codes are "orthogonal")

- encoding: inner product: (original data) X (chipping sequence)

- decoding: summed inner-product: (encoded data) X (chipping sequence)

CDMA encode/decode

$Z_{i,m} = d_i \cdot c_m$

channel output $Z_{i,m}$

sender

data
bits

$d_1 = -1$ $d_0 = 1$

code

slot 1   slot 0

slot 1 channel output   slot 0 channel output

$$D_i = \frac{\sum_{m=1}^{M} Z_{i,m} \cdot c_m}{M}$$

receiver received input

code

slot 1   slot 0

$d_1 = -1$ $d_0 = 1$

slot 1 channel output   slot 0 channel output

… but this isn't really useful yet!

CDMA: two-sender interference

Sender 1

Sender 2

data bits

$d_1^1 = -1$ $d_0^1 = 1$

$Z_{i,m}^1 = d_i^1 \cdot c_m^1$

code

data bits

$d_1^2 = 1$ $d_0^2 = 1$

code

$Z_{i,m}^2 = d_i^2 \cdot c_m^2$

channel, $Z_{i,m}^*$

channel sums together transmissions by sender 1 and 2

$d_i^1 = \dfrac{\sum\limits_{m=1}^{M} Z_{i,m}^* \cdot c_m^1}{M}$

$d_1^1 = -1$ $d_0^1 = 1$

slot 1 received input

slot 0 received input

code

receiver 1

using same code as sender 1, receiver recovers sender 1's original data from summed channel data!

… now *that's* useful!

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Chapter 7 outline

Wireless

- WiFi: 802.11 wireless LANs

IEEE 802.11 Wireless LAN

IEEE 802.11 standard	Year	Max data rate	Range	Frequency
802.11b	1999	11 Mbps	30 m	2.4 Ghz
802.11g	2003	54 Mbps	30m	2.4 Ghz
802.11n (WiFi 4)	2009	600	70m	2.4, 5 Ghz
802.11ac (WiFi 5)	2013	3.47Gpbs	70m	5 Ghz
802.11ax (WiFi 6)	2020	14 Gbps	70m	2.4, 5 Ghz
802.11af	2014	35 – 560 Mbps	1 Km	unused TV bands (54-790 MHz)
802.11ah	2017	347Mbps	1 Km	900 Mhz

- all use CSMA/CA for multiple access, and have base-station and ad-hoc network versions
- 802.11be, WiFi 7 (2024)

802.11 LAN architecture

Internet

switch
or
router

BSS 1

BSS 2
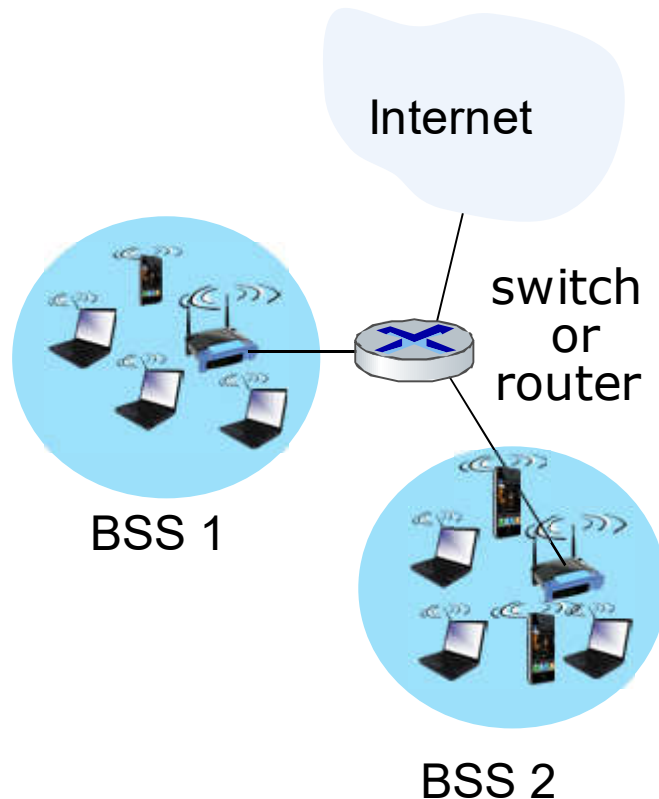
- wireless host communicates with base station
  - base station = access point (AP)
- Basic Service Set (BSS) (aka "cell") in infrastructure mode contains:
  - wireless hosts
  - access point (AP): base station
  - ad hoc mode: hosts only

802.11: Channels

- spectrum divided into channels at different frequencies
  - AP admin chooses frequency for AP
  - interference possible: channel can be same as that chosen by neighboring AP!
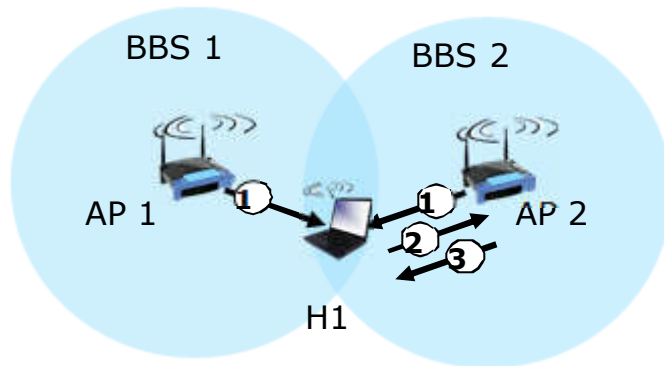
Example: 2.4 GHz
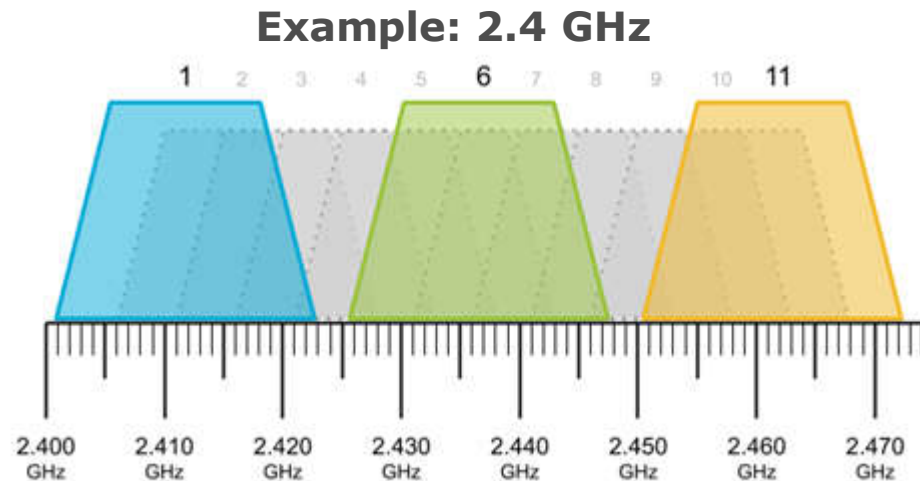
802.11: Association

- arriving host: must **associate** with an AP
  - scans channels, listening for *beacon frames* containing AP's name ((Service Set Identifier) ,SSID) and MAC address
  - selects AP to associate with
  - then may perform authentication [Chapter 8]
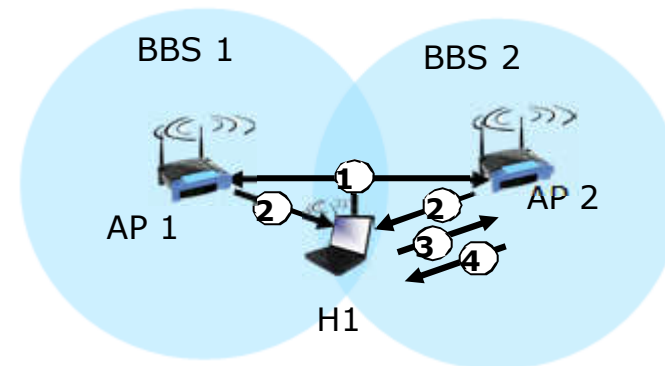 - then typically run DHCP to get IP address in AP's subnet

BSS

802.11: passive/active scanning

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

IEEE 802.11: multiple access

- avoid collisions: 2$^+$ nodes transmitting at same time
- 802.11: CSMA - sense before transmitting
  - don't collide with detected ongoing transmission by another node
- 802.11: *no* collision detection!
  - difficult to sense collisions: high transmitting signal, weak received signal due to fading
  - can't sense all collisions in any case: hidden terminal, fading
  - goal: *avoid collisions:* CSMA/CollisionAvoidance
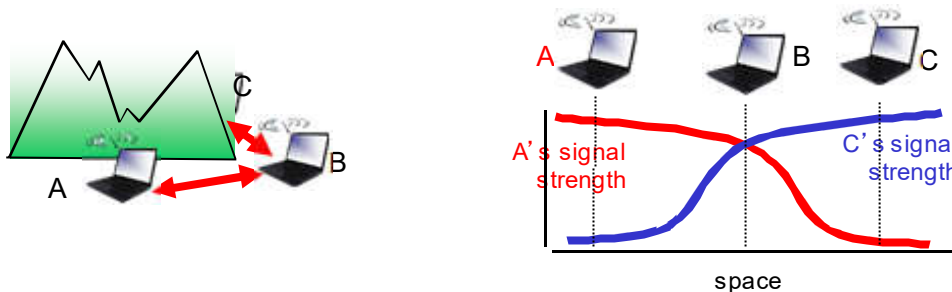
IEEE 802.11 MAC Protocol: CSMA/CA

802.11 sender

1 if sense channel idle for Distributed Interframe Space (DIFS) then

transmit entire frame (no CD)

2 if sense channel busy then

start random backoff time
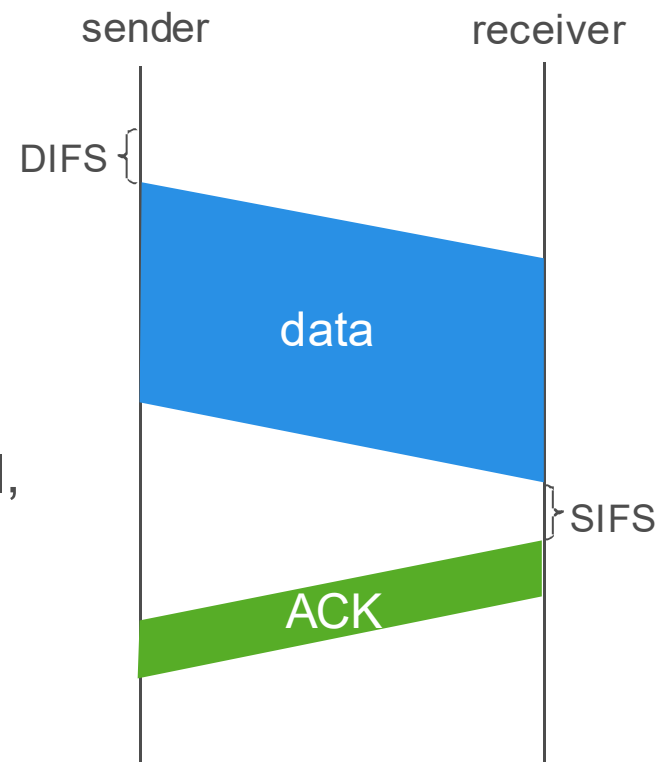
timer counts down while channel idle

transmit when timer expires

if no ACK, increase random backoff interval, repeat 2

802.11 receiver

- if frame received OK

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

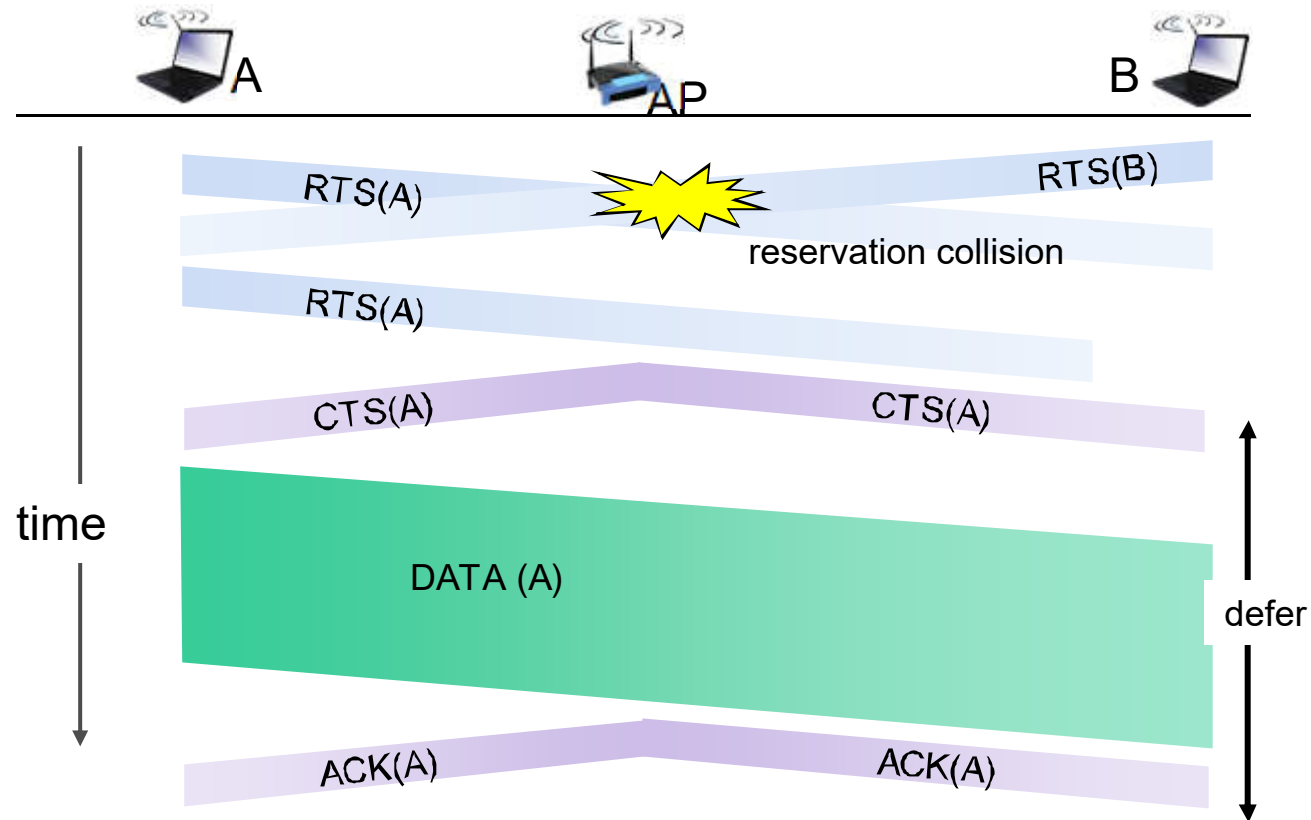sender   receiver
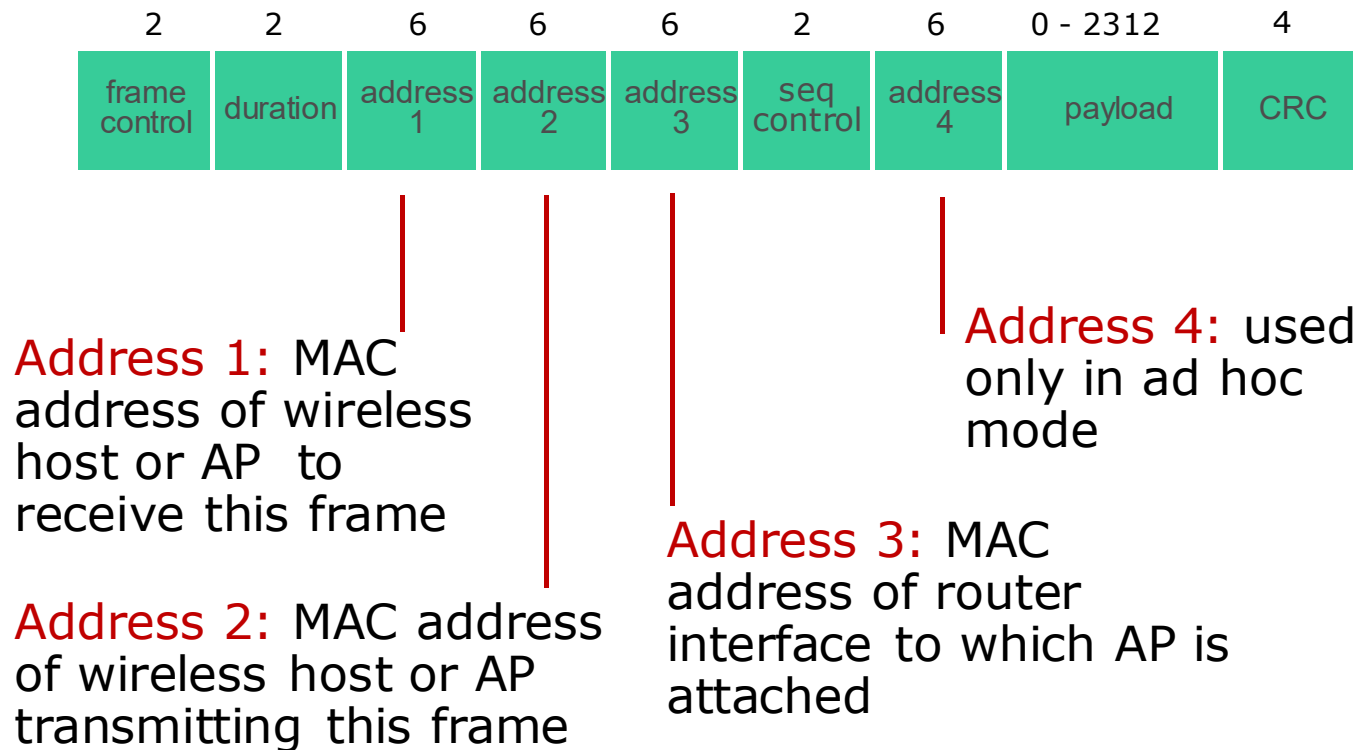
DIFS {

data

} SIFS

ACK

Avoiding collisions (more)

idea: sender "reserves" channel use for data frames using small reservation packets

- sender first transmits *small* request-to-send (RTS) packet to BS using CSMA
  - RTSs may still collide with each other (but they're short)
- BS broadcasts clear-to-send CTS in response to RTS
- CTS heard by all nodes
  - sender transmits data frame
  - other stations defer transmissions

- Although the RTS/CTS exchange can help reduce collisions, it also introduces delay and consumes channel resources. For this reason, the RTS/CTS exchange is only used (if at all) to reserve the channel for the transmission of a long DATA frame.

Collision Avoidance:
RTS-CTS exchange

802.11 frame: addressing

2	2	6	6	6	2	6	0 - 2312	4
frame control	duration	address 1	address 2	address 3	seq control	address 4	payload	CRC

Address 1: MAC address of wireless host or AP to receive this frame

Address 2: MAC address of wireless host or AP transmitting this frame

Address 3: MAC address of router interface to which AP is attached

Address 4: used only in ad hoc mode

802.11 frame: addressing

Internet

H1

R1

802.3 Ethernet frame

R1 MAC addr	H2 MAC addr
MAC dest addr	MAC source addr

AP MAC addr	H1 MAC addr	R1 MAC addr
address 1	address 2	address 3

802.11 WiFi frame

802.11 frame: addressing

duration of reserved
transmission time (RTS/CTS)

frame sequence # (for reliable data
transfer)

2	2	6	6	6	2	6	0 - 2312	4
frame control	duration	address 1	address 2	address 3	seq control	address 4	payload	CRC

| 2	2	4	1	1	1	1	1	1	1	1
protocol version	type	subtype	to AP	from AP	more frag	retry	power mgt	more data	WEP	rsvd

frame type (RTS, CTS, ACK, data)

802.11: mobility within same subnet

- H1 remains in same IP subnet: IP address can remain same

    - switch: which AP is associated with H1?

        • self-learning (Ch. 6): switch will see frame from H1 and "remember" which switch port can be used to reach H1


BBS 1   H1   BBS 2
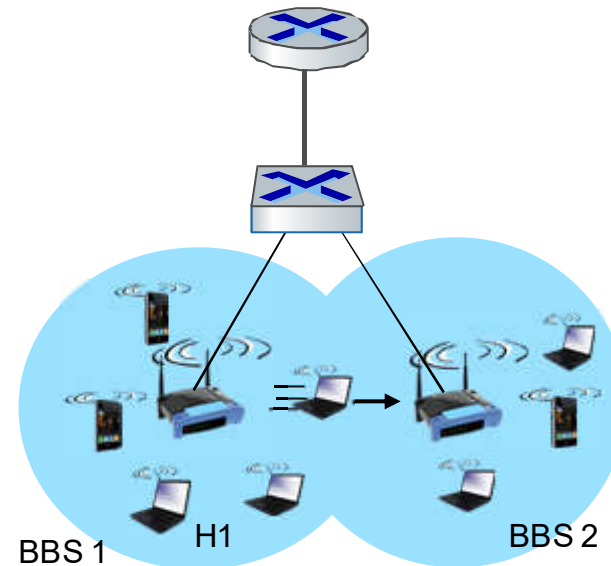
802.11: advanced capabilities

Rate adaptation

- base station, mobile dynamically change transmission rate (physical layer modulation technique) as mobile moves, SNR varies

QAM256 (8 Mbps)
QAM16 (4 Mbps)
BPSK (1 Mbps)
operating point

1. SNR decreases, BER increase as node moves away from base station

2. When BER becomes too high, switch to lower transmission rate but with lower BER
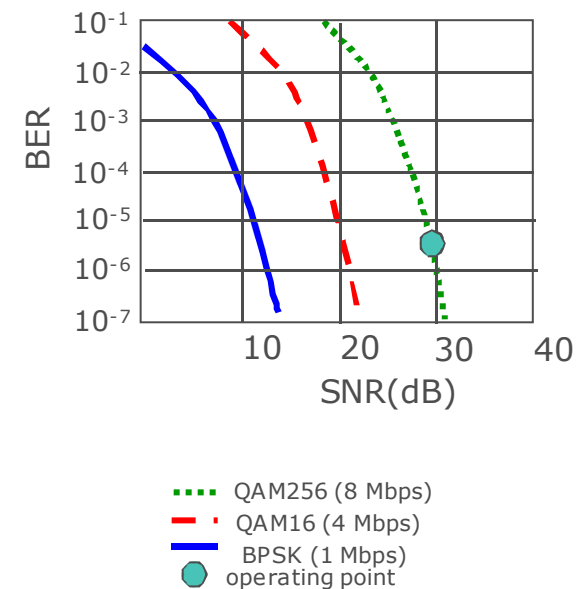
802.11: advanced capabilities

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