Chapter 7 Wireless and Mobile Networks

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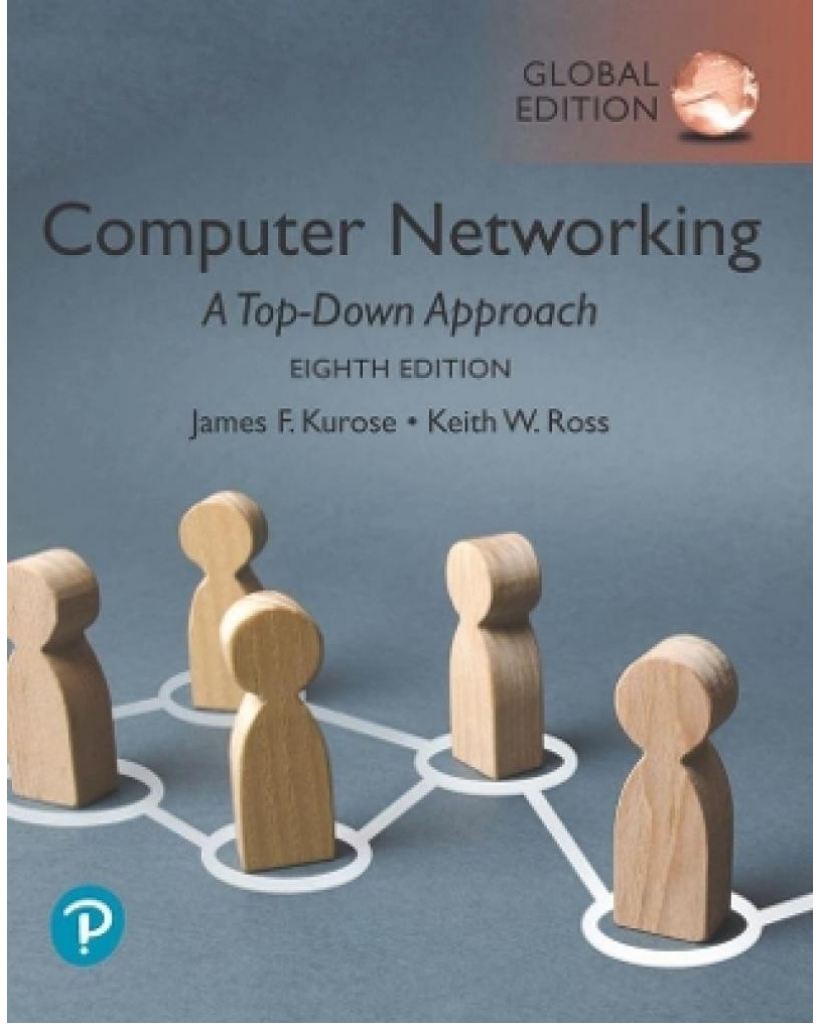


Computer Networking: A Top-Down Approach

8th edition
Jim Kurose, Keith Ross
Pearson, 2020

Chapter 7 outline

7.1 Introduction

7.2 Wireless links and network characteristics

7.3 WiFi: 802.11 wireless LANs

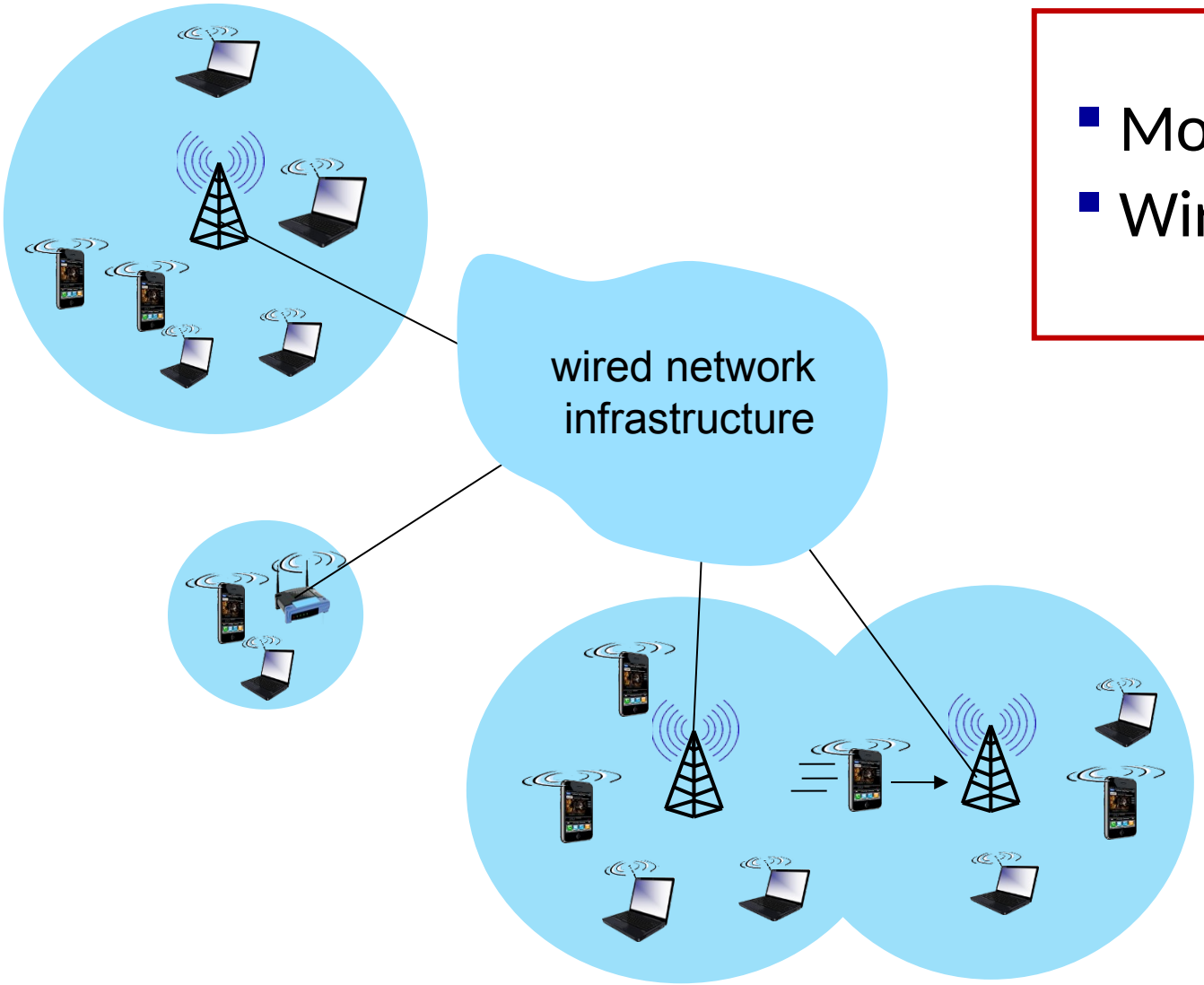
~~7.4 Cellular networks: 4G and 5G~~

~~7.5 Mobility management: principles~~

~~7.6 Mobility management: practice~~

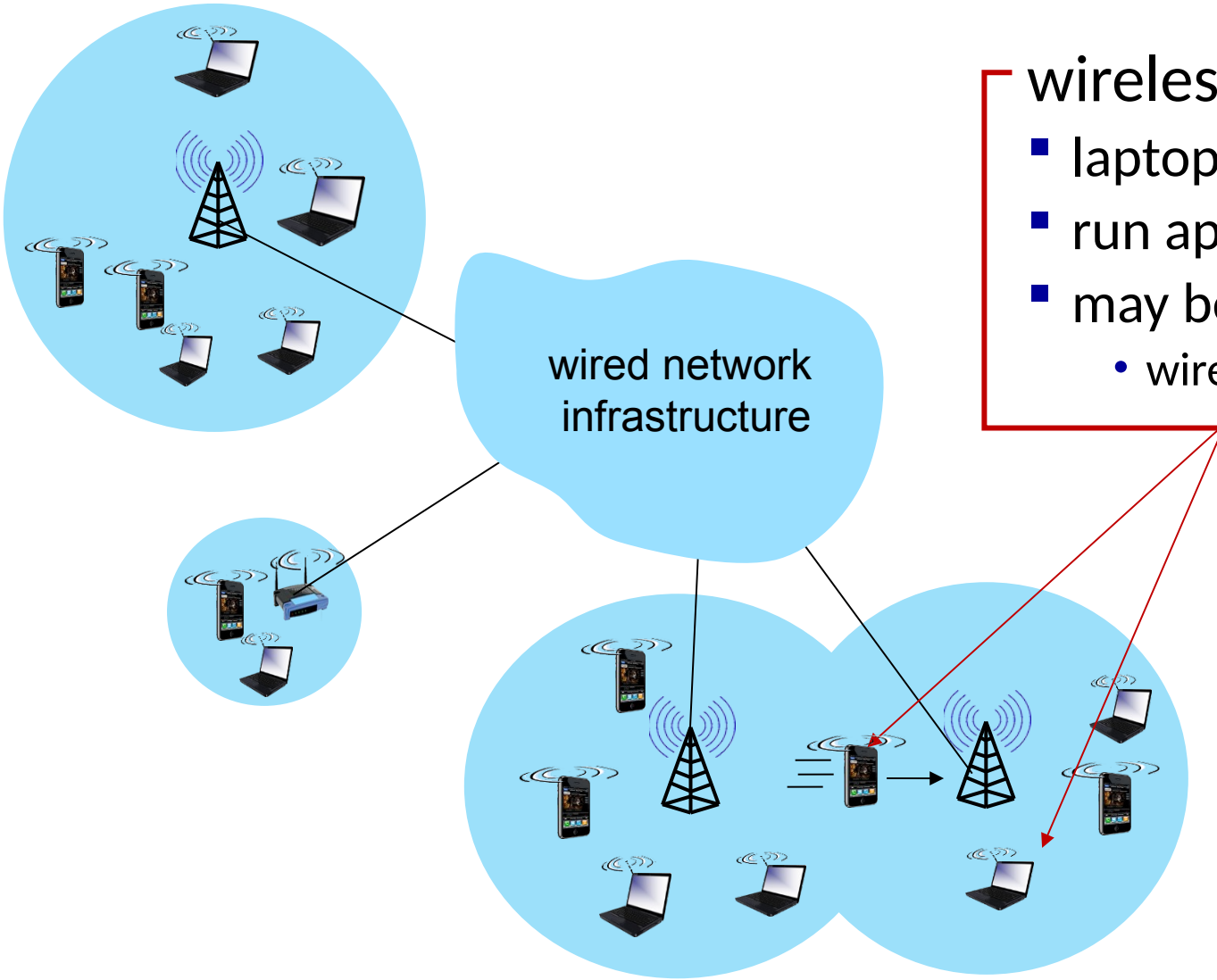
~~7.7 Mobility: impact on higher-layer protocols~~

Elements of a wireless network



- Mobile networks, cellular networks
- Wireless LANs, Wi-Fi

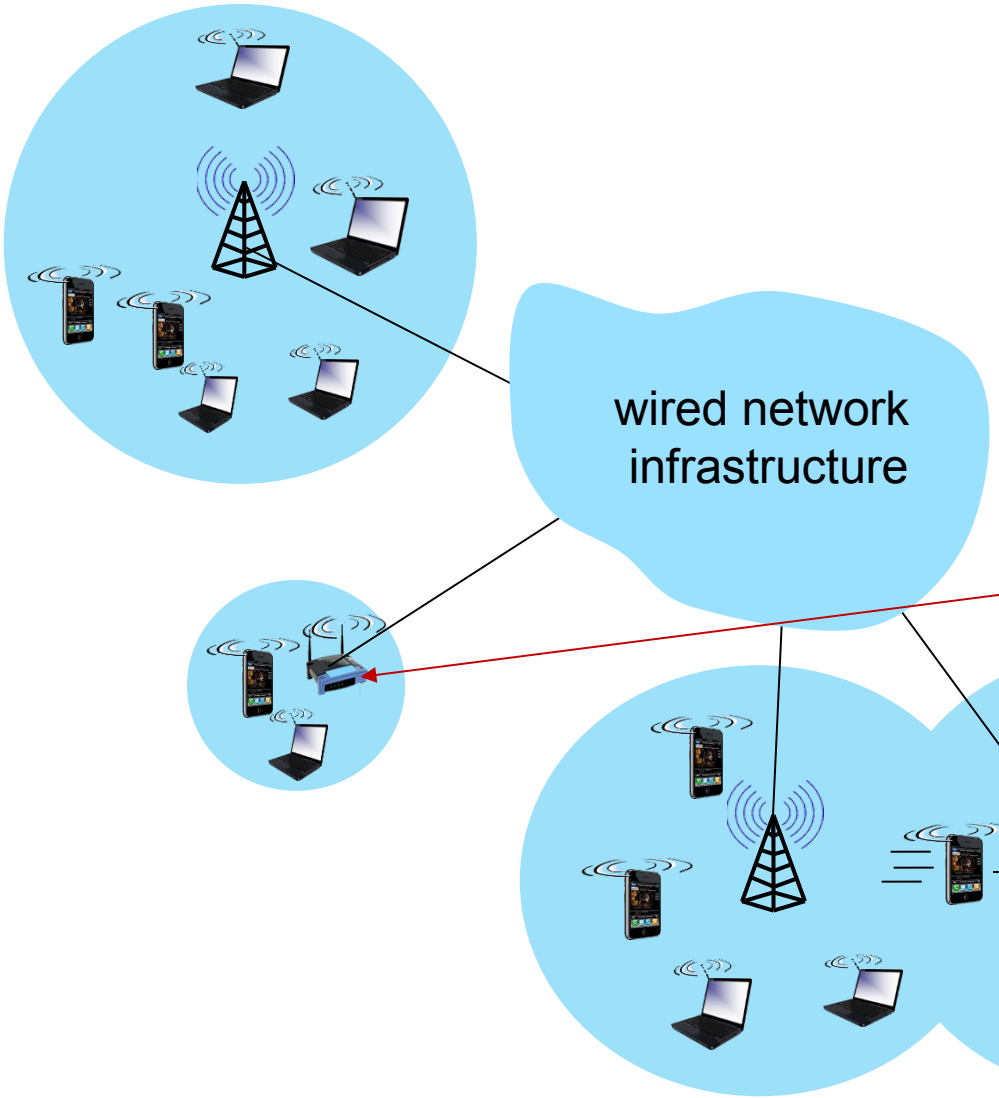
Elements of a wireless network



wireless hosts

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

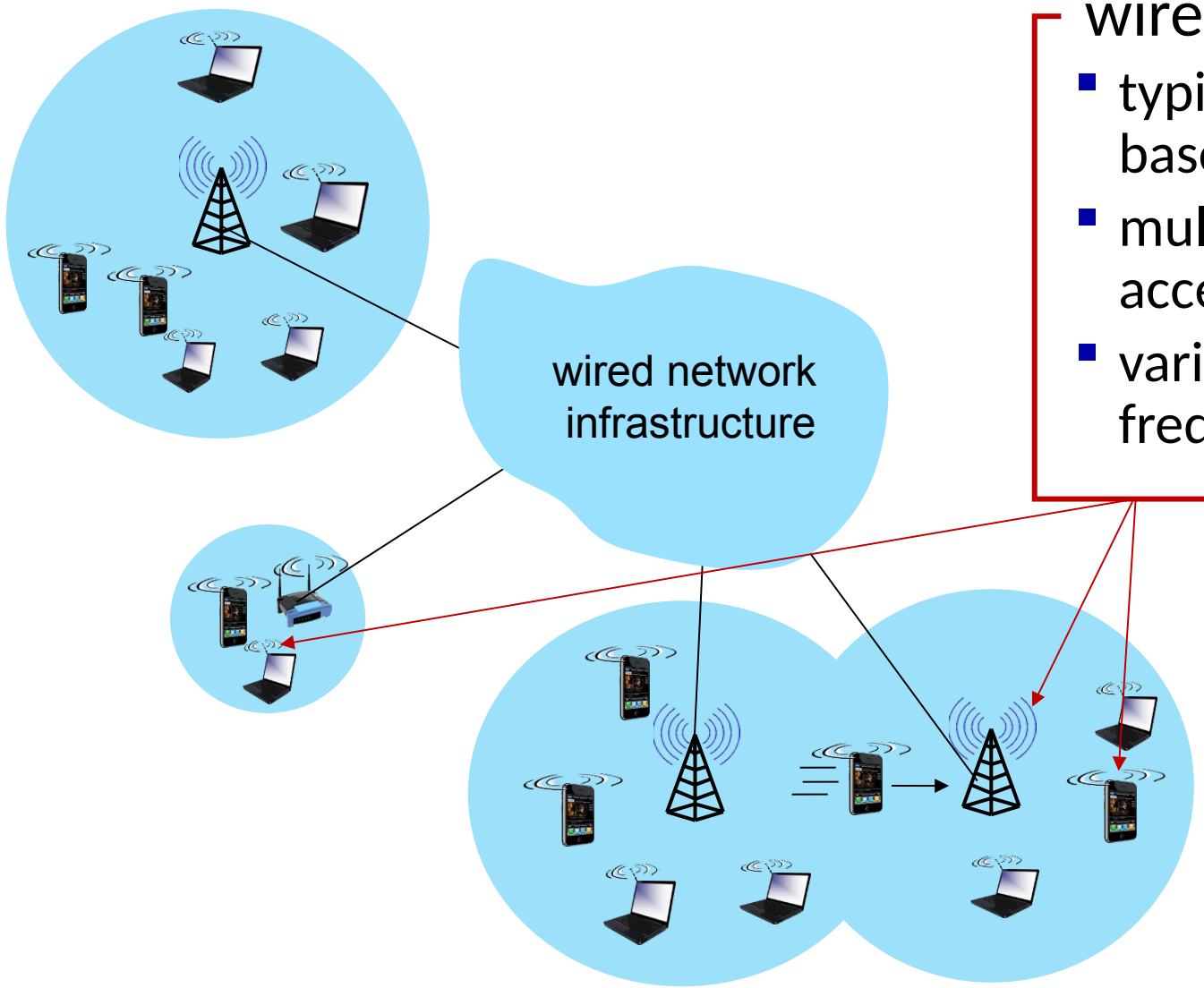
Elements of a wireless network



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

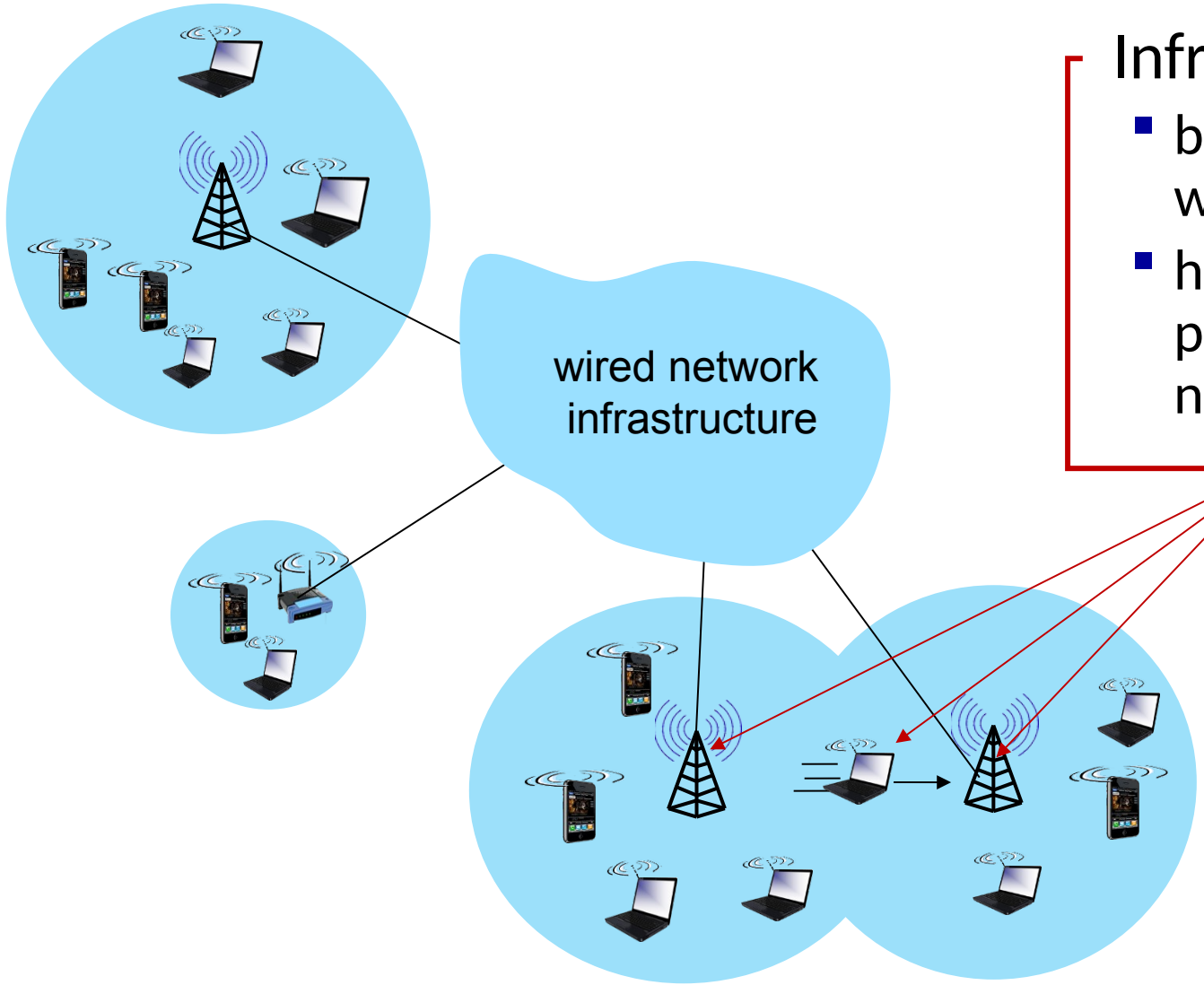
Elements of a wireless network



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

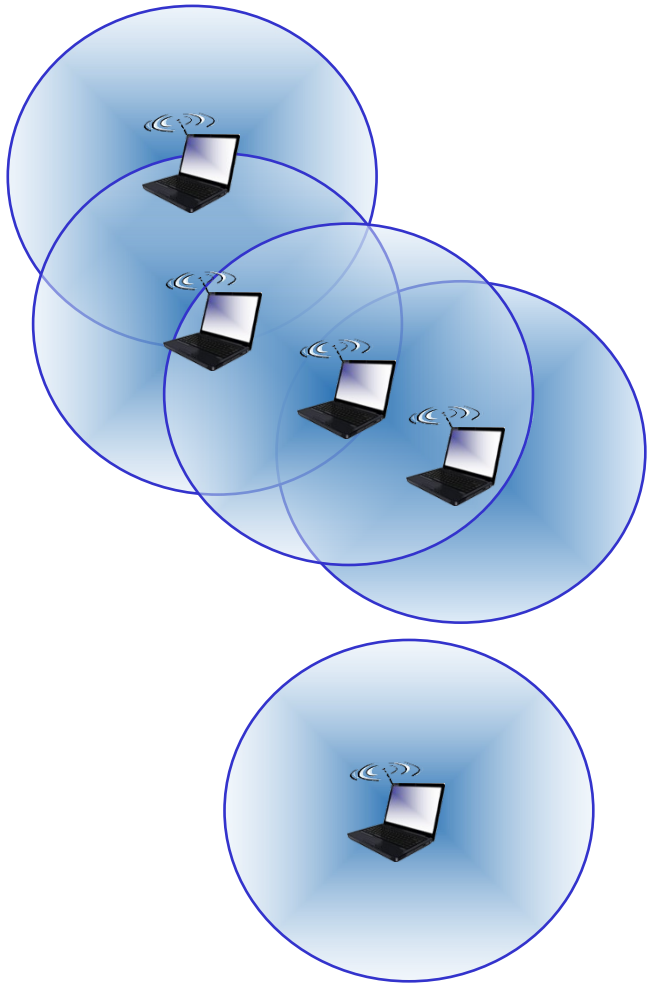
Infrastructure networks



Infrastructure mode

- base station connects mobiles into wired network
- handoff: mobile changes base station providing connection into wired network

Ad hoc networks



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

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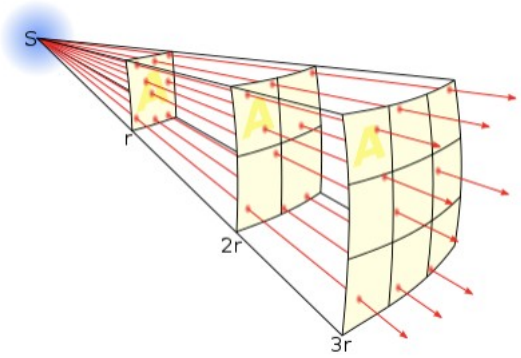
Wireless link characteristics: fading (attenuation)

Wireless radio signal attenuates (loses power) as it propagates (free space "path loss")

Free space path loss ~ $(fd)^2$

f: frequency
d: distance



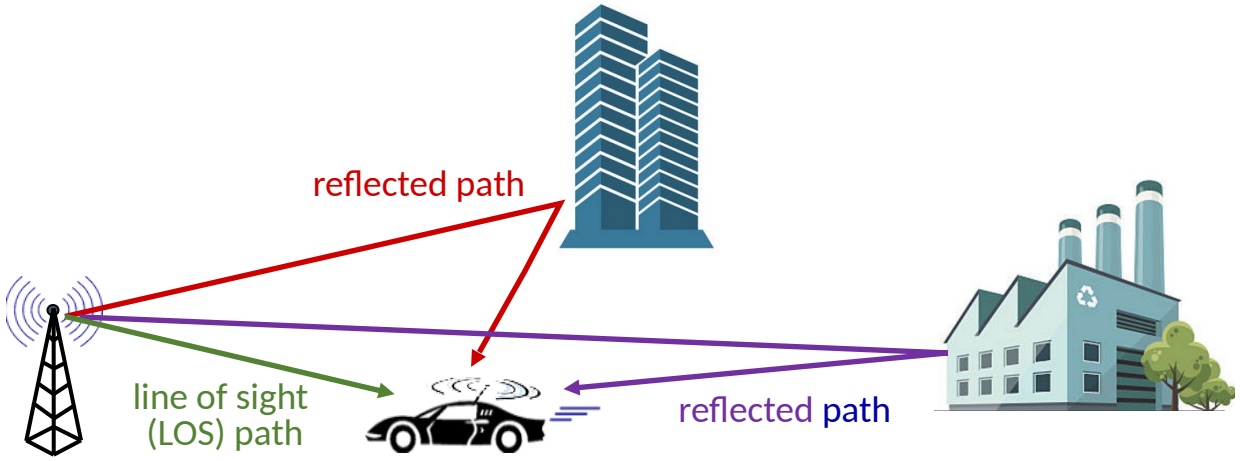
higher frequency or longer distance → larger free space path loss

Wireless link characteristics: interference

- interference from other sources: wireless network frequencies (e.g., 2.4 GHz) shared by many devices (e.g., WiFi, cellular, motors): interference

Wireless link characteristics: multipath

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



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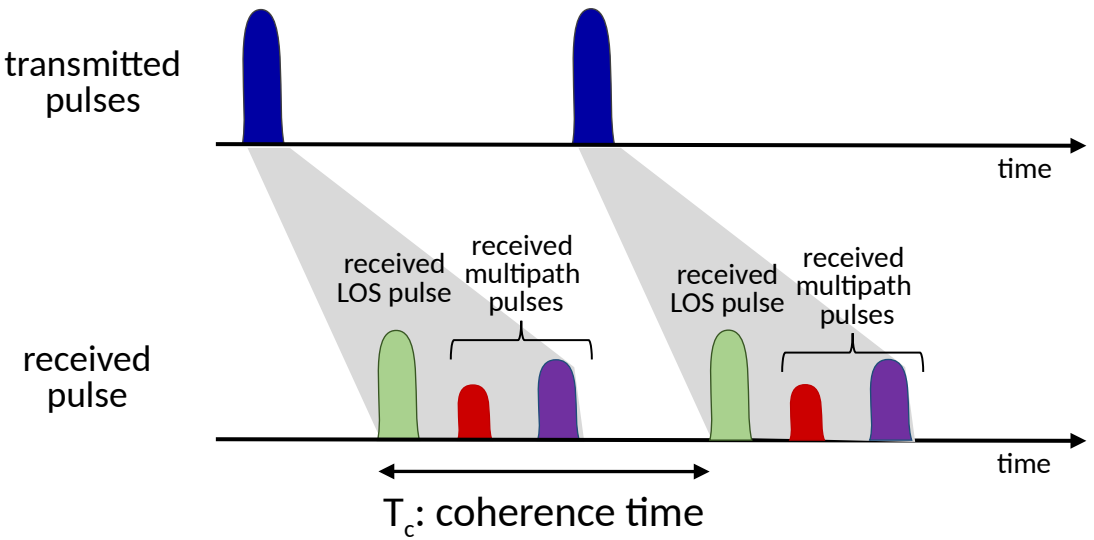
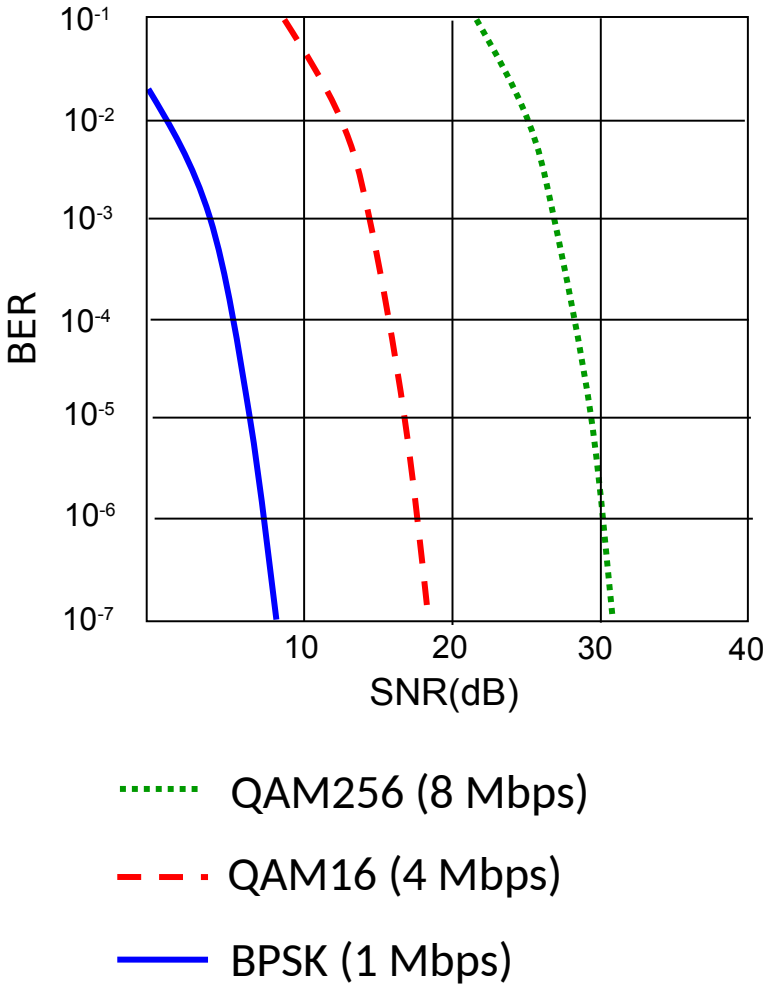


Coherence time:

- amount of time bit is present in channel to be received
- influences maximum possible transmission rate, since coherence times can not overlap
- inversely proportional to
  - frequency
  - receiver velocity

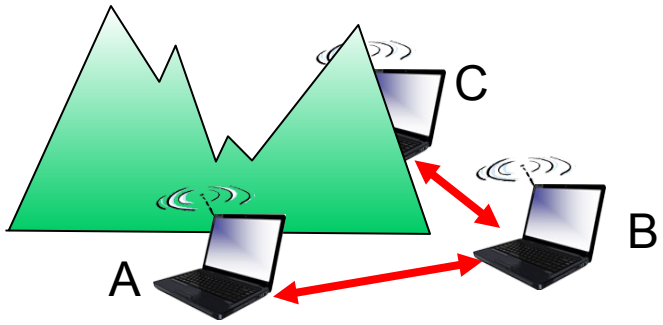
Wireless link characteristics: noise

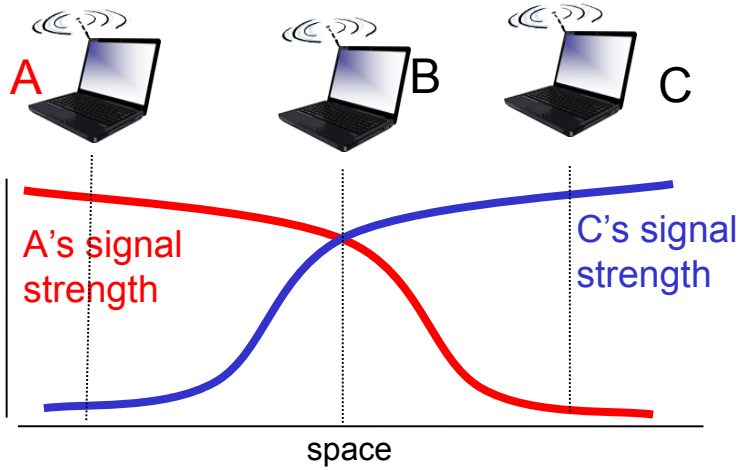
- SNR: signal-to-noise ratio
  - larger SNR – easier to extract signal from noise (a "good thing")
- SNR versus BER tradeoffs
  - *given physical layer:* increase power -> increase SNR->decrease BER
  - *given SNR:* choose physical layer that meets BER requirement, giving highest throughput
    - SNR may change with mobility: dynamically adapt physical layer (modulation technique, rate)



Wireless link characteristics (3)

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





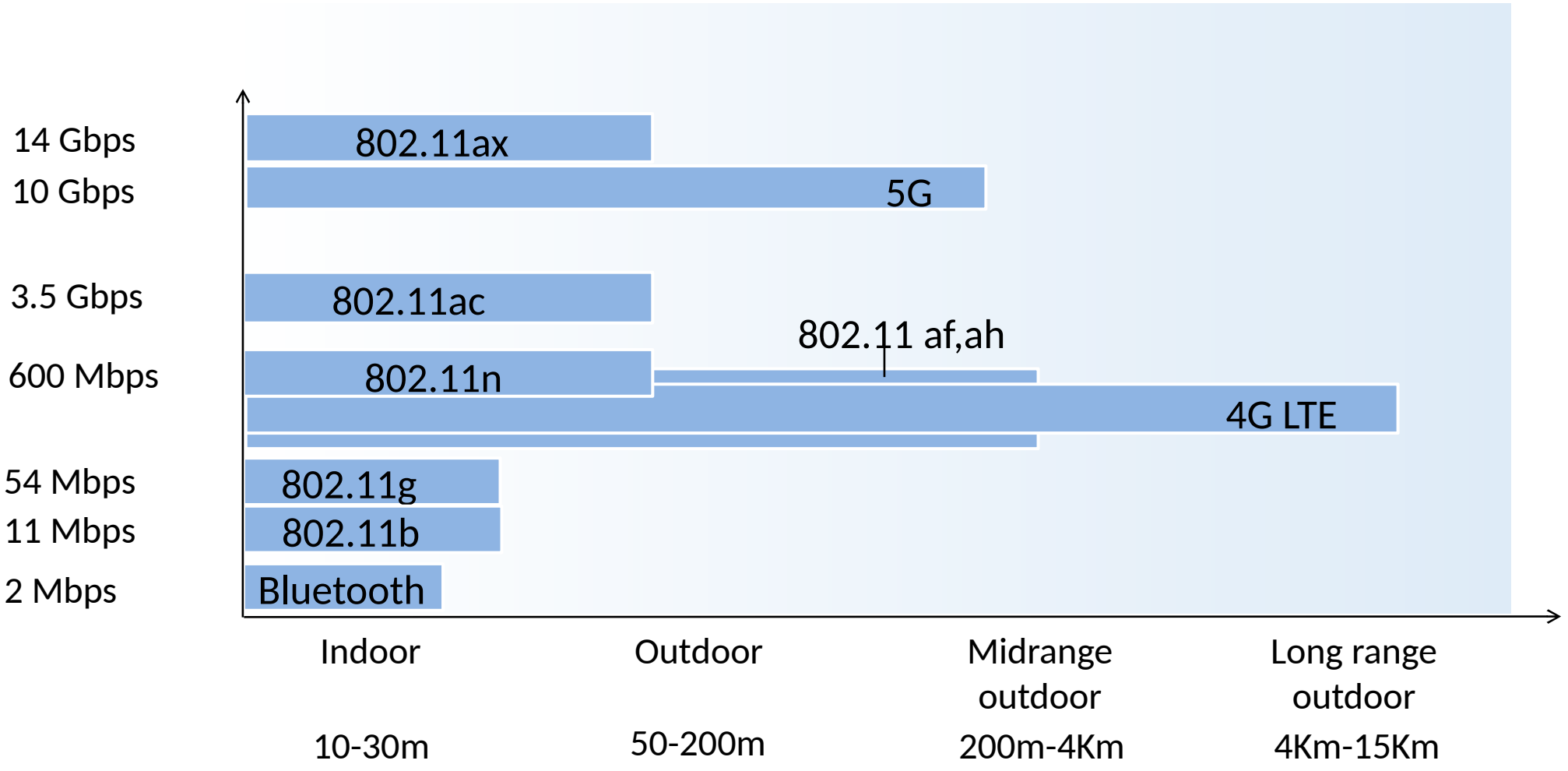
Hidden terminal problem

- 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

Signal attenuation:

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

Characteristics of selected wireless links



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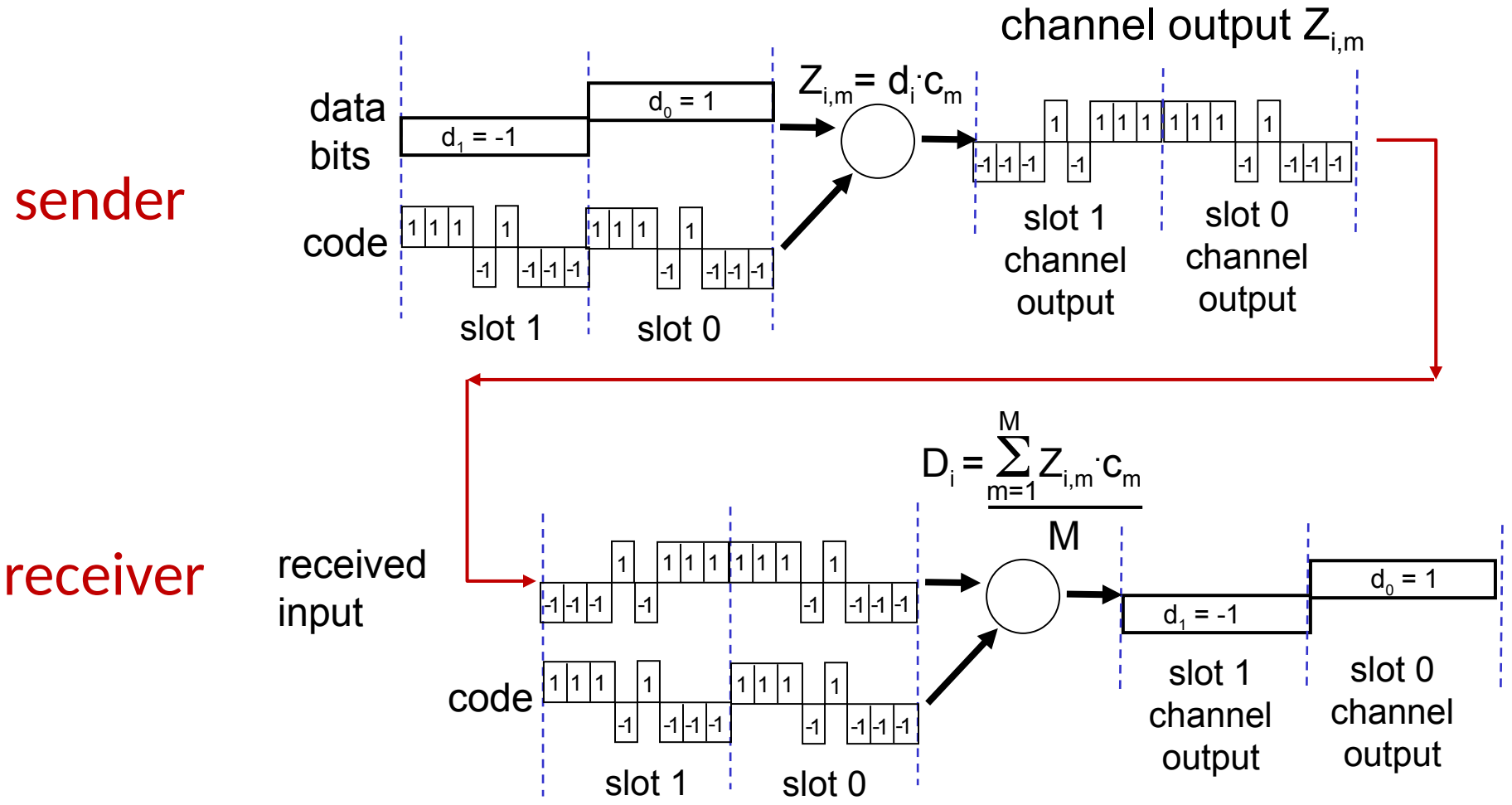
Code Division Multiple Access (CDMA)

- 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

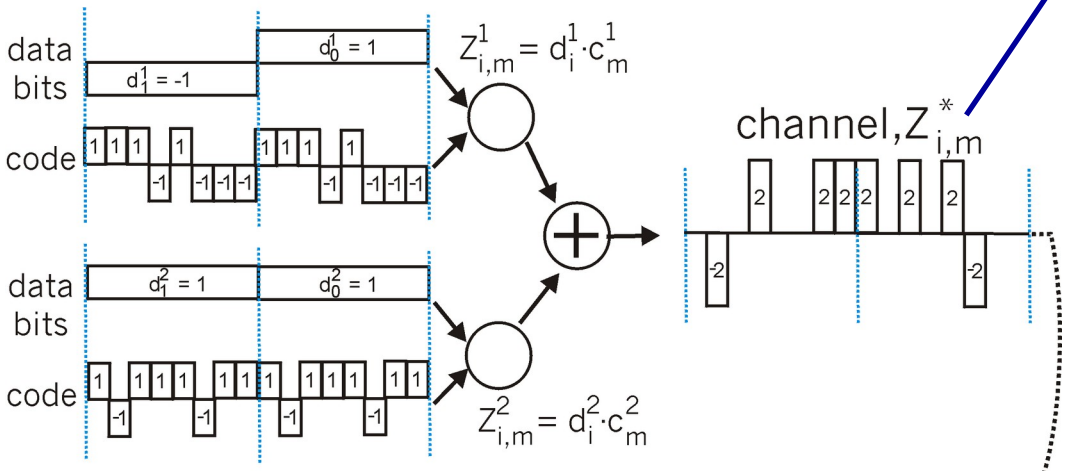


… but this isn't really useful yet!

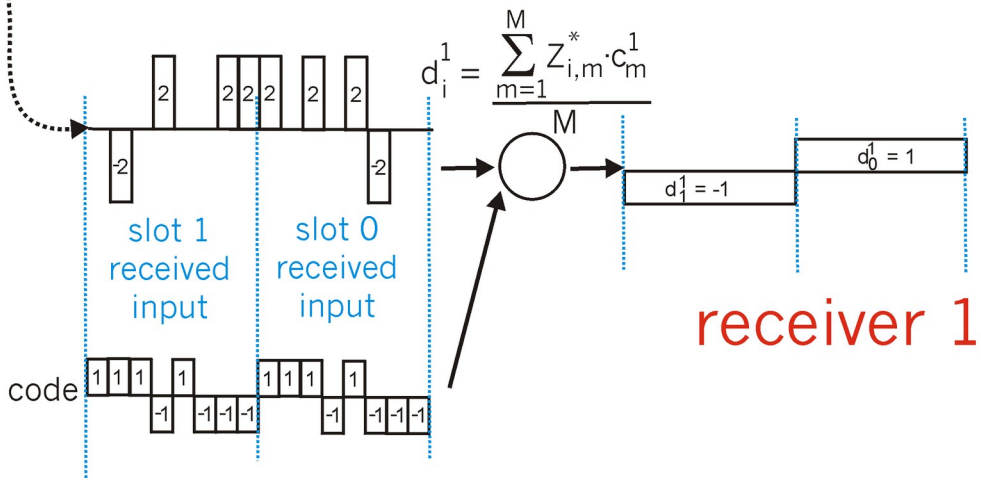
CDMA: two-sender interference

Sender 1

Sender 2



channel sums together transmissions by sender 1 and 2



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

... now *that's* useful!

Orthogonal Frequency Division Multiplexing (OFDM)

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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 Mbps	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

Unlicensed ISM 2.4 GHz frequency band

- ISM radio bands: Reserved for Industrial, Scientific and Medical purposes
- Used without a government license
- Short-range, low-power wireless communications systems
- Used by low-power transmitters not considered to be ISM devices
  - Cordless phones, Bluetooth devices, near-field communication (NFC) devices, garage door openers, baby monitors, and wireless computer networks (Wi-Fi)

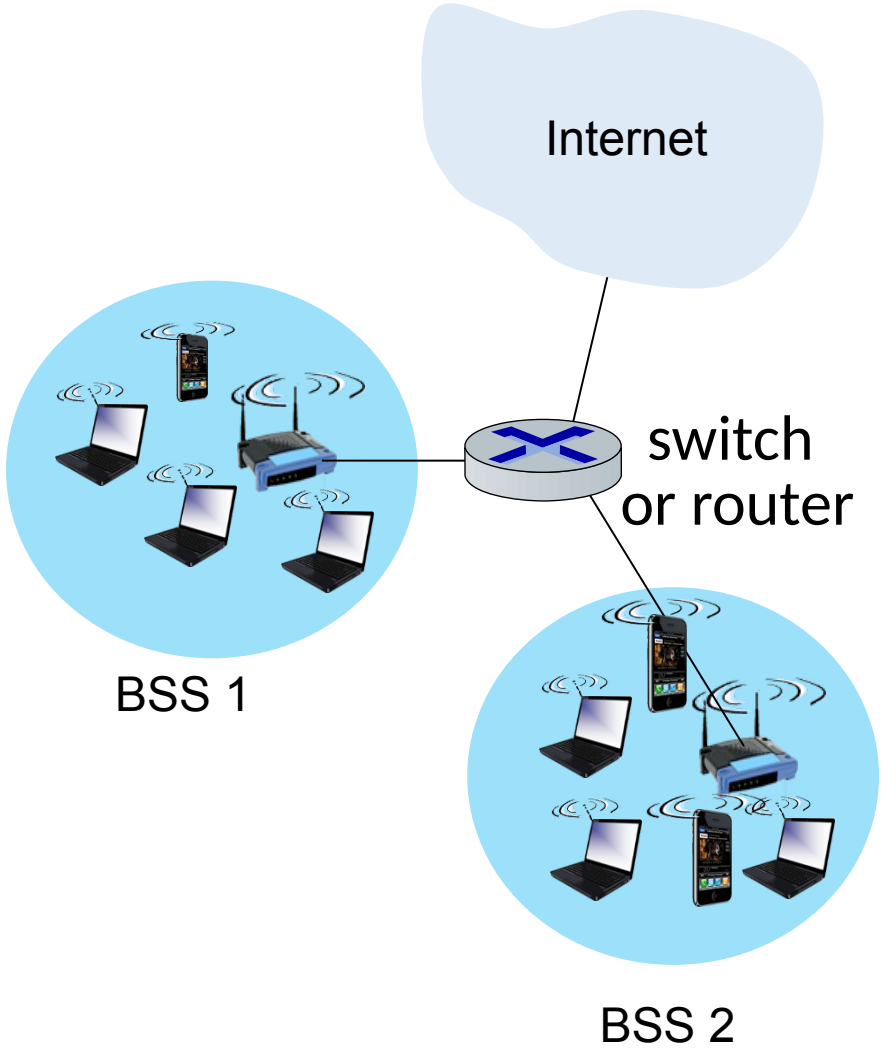
Unlicensed 5 GHz frequency band

As of March 2021, U-NII consists of eight ranges. U-NII 1 through 4 are for 5 GHz WLAN (802.11a and newer), and 5 through 8 are for 6 GHz WLAN (802.11ax) use. U-NII 2 is further divided into three subsections.

U-NII bands and FCC regs

Name	Aliases	Freq. Range (GHz)	Bandwidth (MHz)	Max Power (mW)	Max EIRP (mW)
U-NII-1	U-NII Low / U-NII Indoor	5.150–5.250	100	50	200
U-NII-2A	U-NII Mid	5.250–5.350	100	250	1,000
U-NII-2B		5.350–5.470	120	—	—
U-NII-2C	U-NII Worldwide / U-NII-2-Extended / U-NII-2e	5.470–5.725	255	250	1,000
U-NII-3	U-NII Upper	5.725-5.850	125	1,000	4,000
U-NII-4	DSRC/ITS	5.850–5.925	75	—	—
U-NII-5		5.925–6.425	500	—	—
U-NII-6		6.425–6.525	100	—	—
U-NII-7		6.525–6.875	350	—	—
U-NII-8		6.875–7.125	250	—	—

802.11 LAN architecture



- Basic Service Set (BSS)

  a single access point (AP) interconnecting with wireless hosts

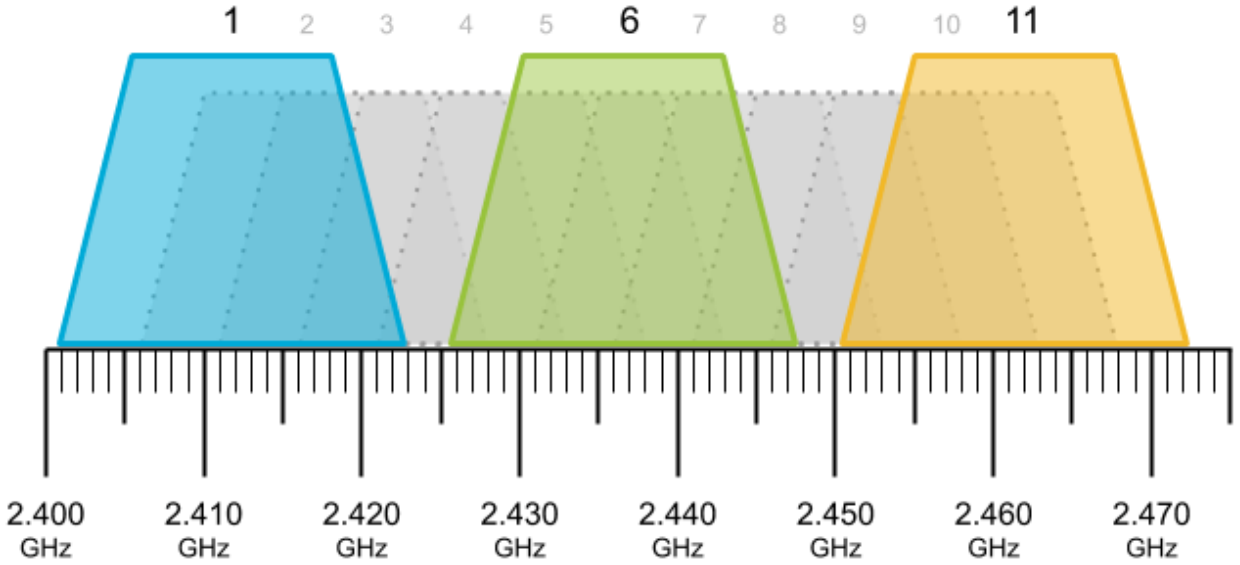
- Basic Service Area (BSA) (aka. cell)

  is the area that is covered by the access point 's signal

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!

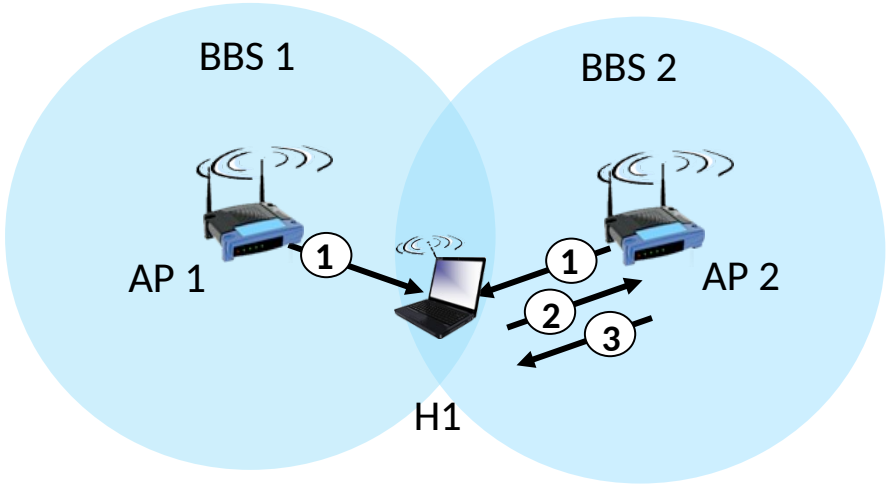
Example: 2.4 GHz

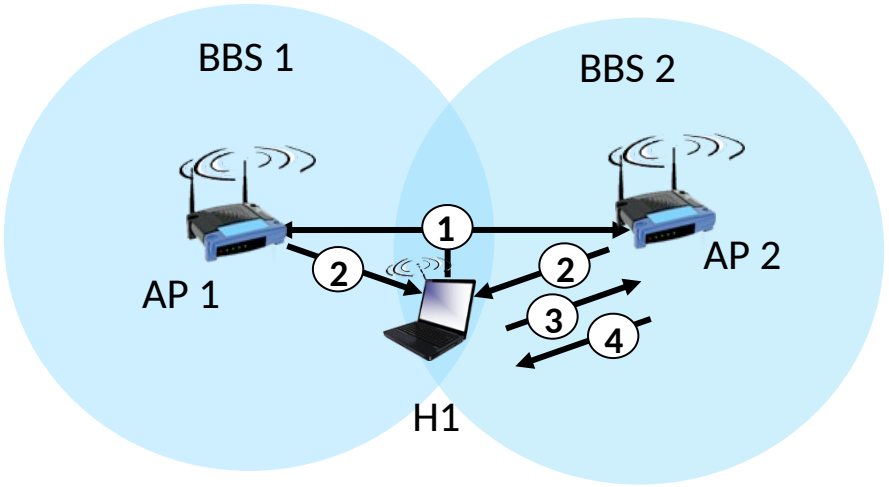


802.11: Channels, association

- arriving host: must associate with an AP
  - scans channels, listening for *beacon frames* containing AP's name (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

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

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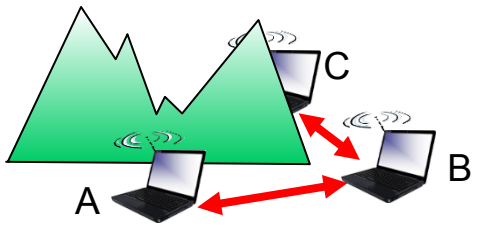
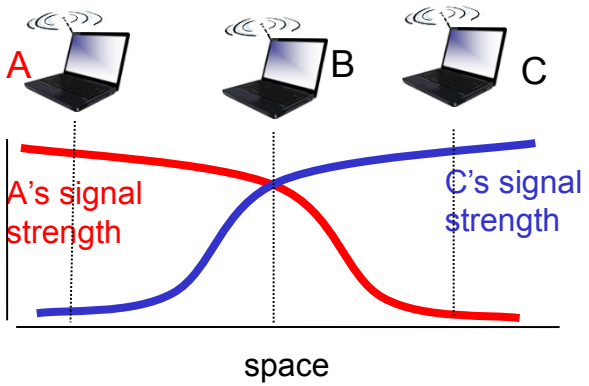
IEEE 802.11: multiple access

- 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

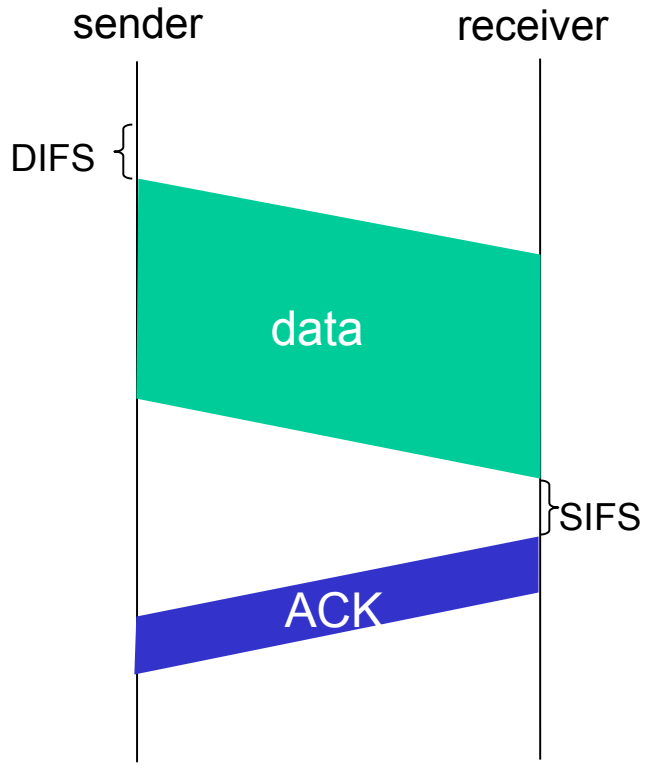
1 if sense channel idle for **DIFS** then
transmit entire frame (no CD)

2 if sense channel busy then
start random backoff time
timer counts down while channel idle

3 transmit when timer expires
if no ACK, increase random backoff interval, repeat 2

802.11 receiver

if frame received OK
return ACK after **SIFS** (ACK needed due to hidden terminal problem)

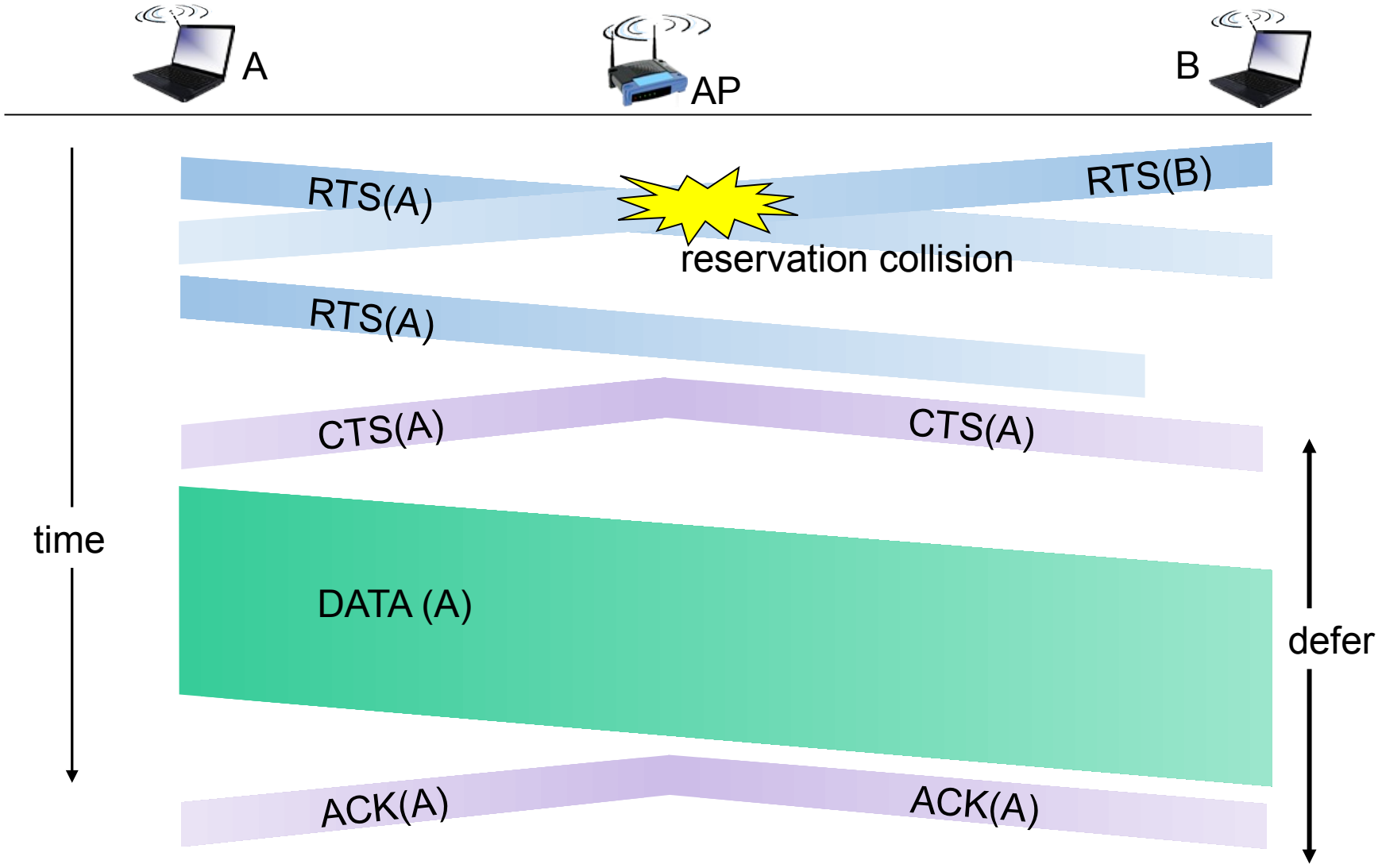


Avoiding collisions: RTS-CTS exchange

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

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

Collision Avoidance: RTS-CTS exchange



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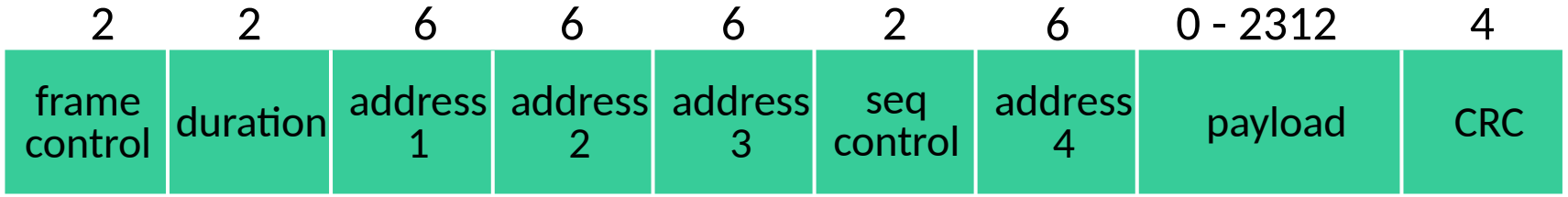
802.11 frame: addressing



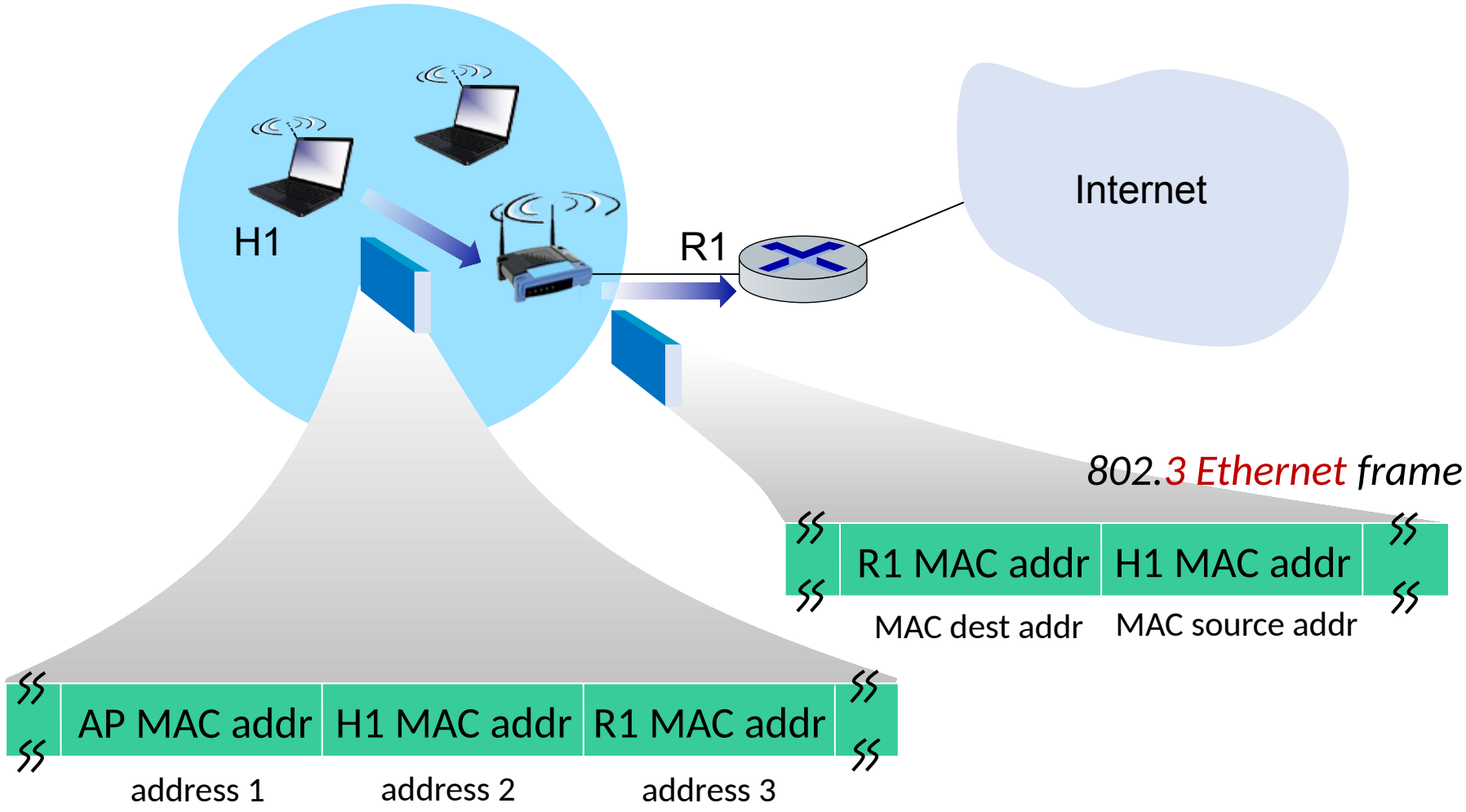
Address 1: MAC address of wireless host or AP to receive this frame

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

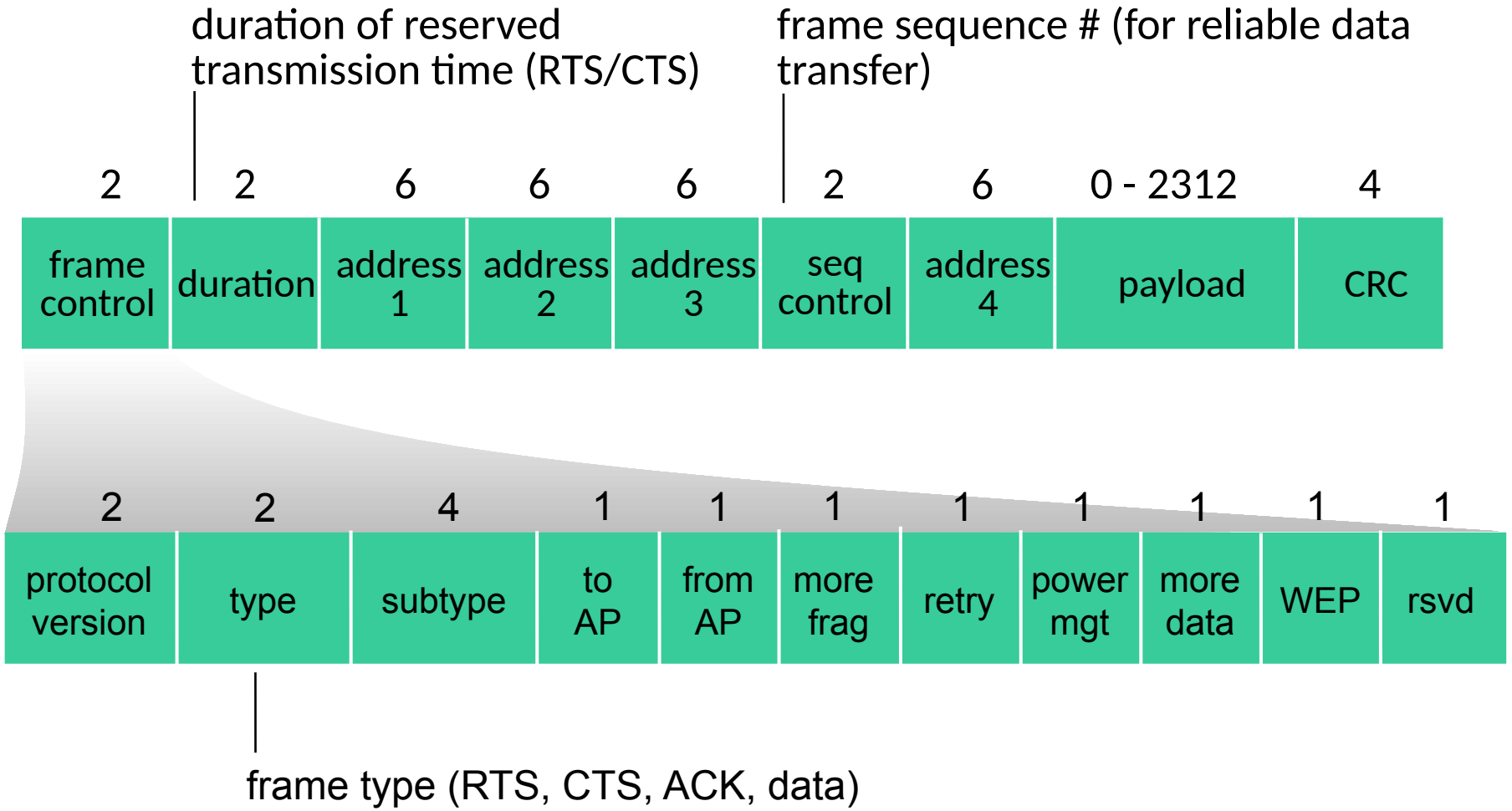
Address 3: MAC address of frame destination or source (in infrastructure mode)

Address 4: used only in ad hoc mode

802.11 frame: addressing - host to router



802.11 frame: addressing



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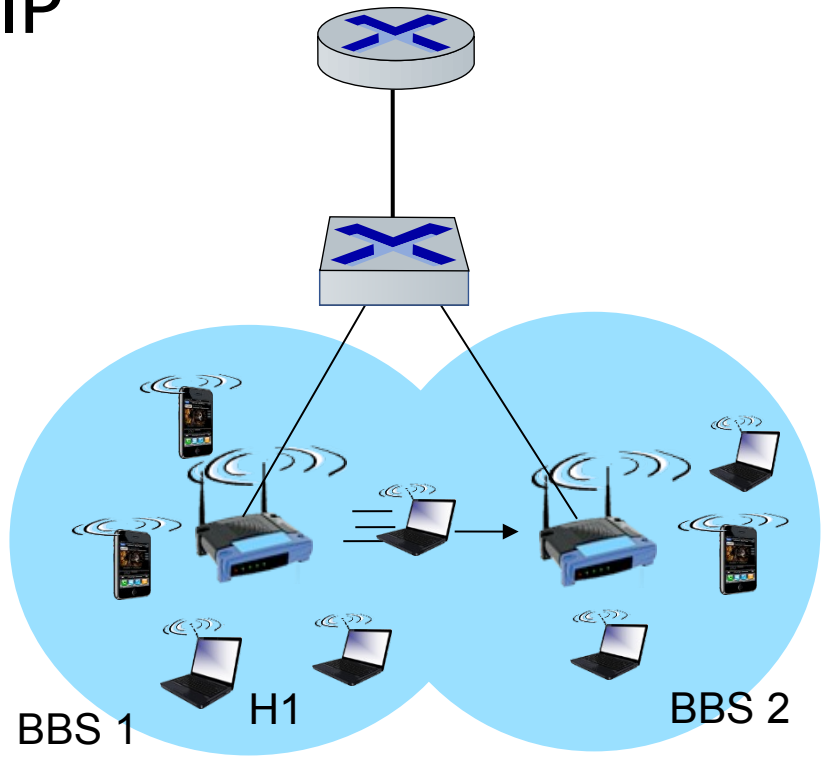
802.11: mobility within same subnet

- 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



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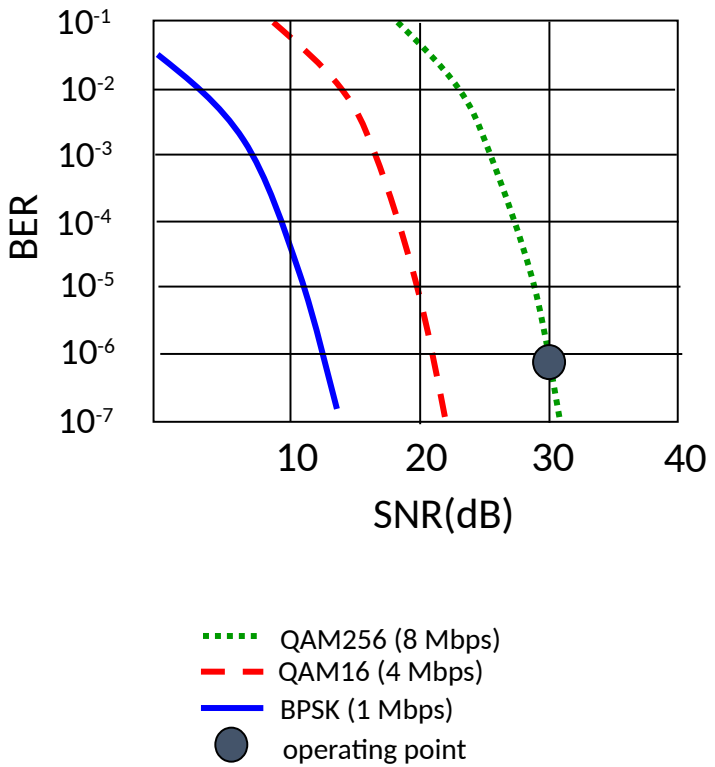
802.11: advanced capabilities

Rate adaptation

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

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

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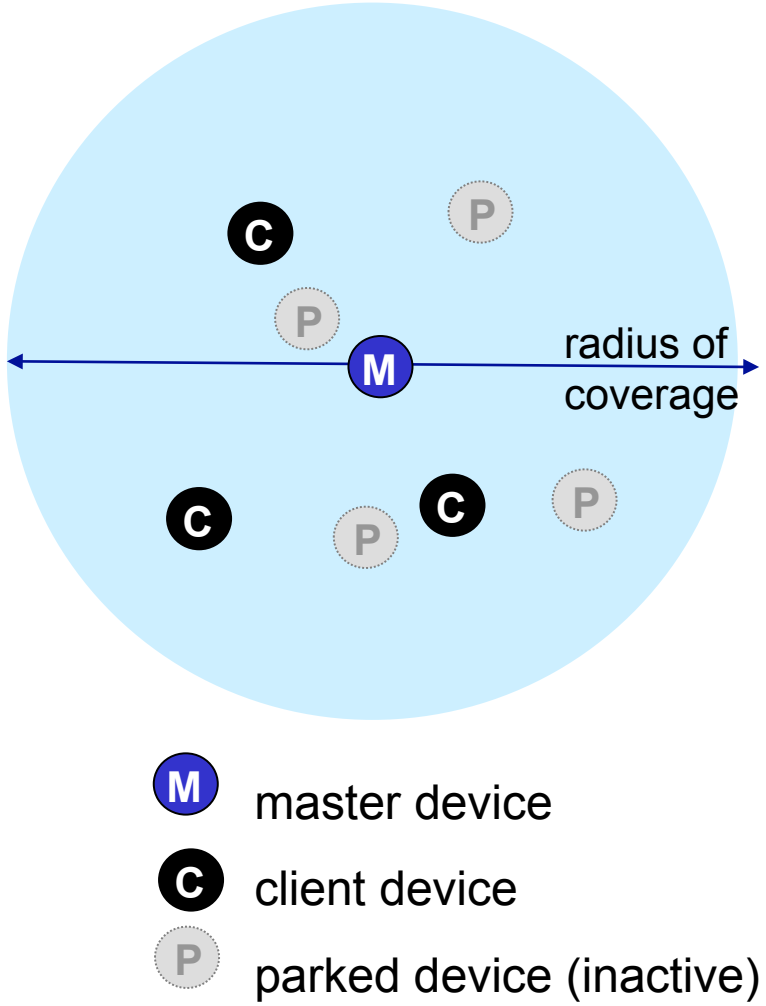
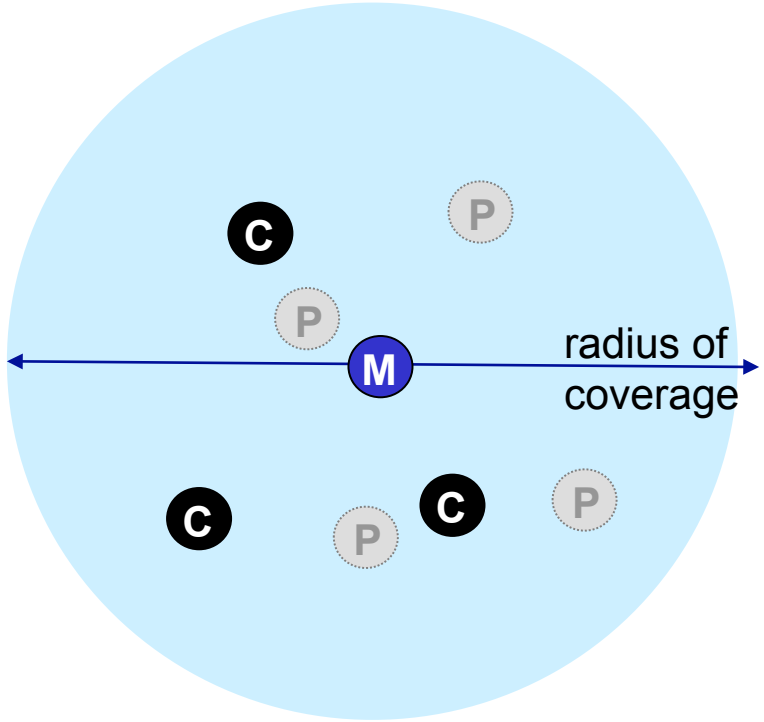
Personal area networks: Bluetooth

- less than 10 m diameter
- replacement for cables (mouse, keyboard, headphones)
- ad hoc: no infrastructure
- master controller / clients devices:
  - master polls clients, grants requests for client transmissions



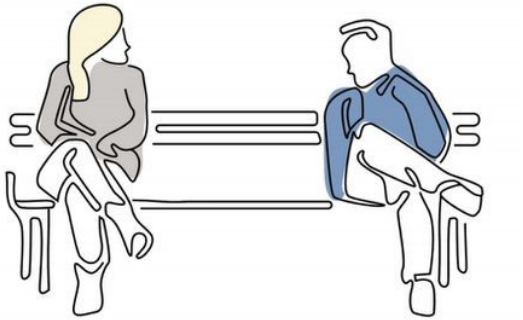
Personal area networks: Bluetooth

- 2.4-2.5 GHz ISM radio band, up to 2 Mbps
- TDM, 625 μsec sec. slot
- FDM: sender uses 79 frequency channels in known, pseudo-random order slot-to-slot (spread spectrum)
  - other devices/equipment not in piconet only interfere in some slots
- parked mode: clients can "go to sleep" (park) and later wakeup (to preserve battery)
- bootstrapping: nodes self-assemble (plug and play) into piconet



Pandemic + Bluetooth

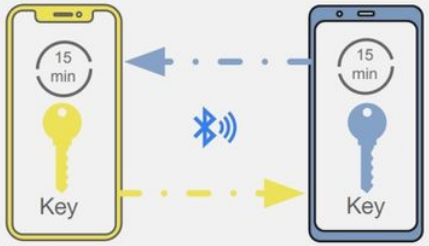
Alice and Bob meet each other for the first time and have a 10-minute conversation.



Bob is positively diagnosed for COVID-19 and enters the test result in an app from a public health authority.

A few days later...

Their phones exchange anonymous identifier beacons (which change frequently).



With Bob's consent, his phone uploads the last 14 days of keys for his broadcast beacons to the cloud.

Apps can only get more information via user consent

Google

Source: https://www.macrumors.com/guide/exposure-notification/

Chapter 7 outline

7.1 Introduction

7.2 Wireless Links and network characteristics

7.3 WiFi: 802.11 wireless LANs

~~7.4 Cellular networks: 4G and 5G~~

~~7.5 Mobility management: principles~~

~~7.6 Mobility management: practice~~

~~7.7 Mobility: impact on higher-layer protocols~~

Chapter 7 summary

Wireless

- Wireless Links and network characteristics
- Wi-Fi: 802.11 wireless LANs

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Wireless

- Wireless Links and network characteristics
- Wi-Fi: 802.11 wireless LANs