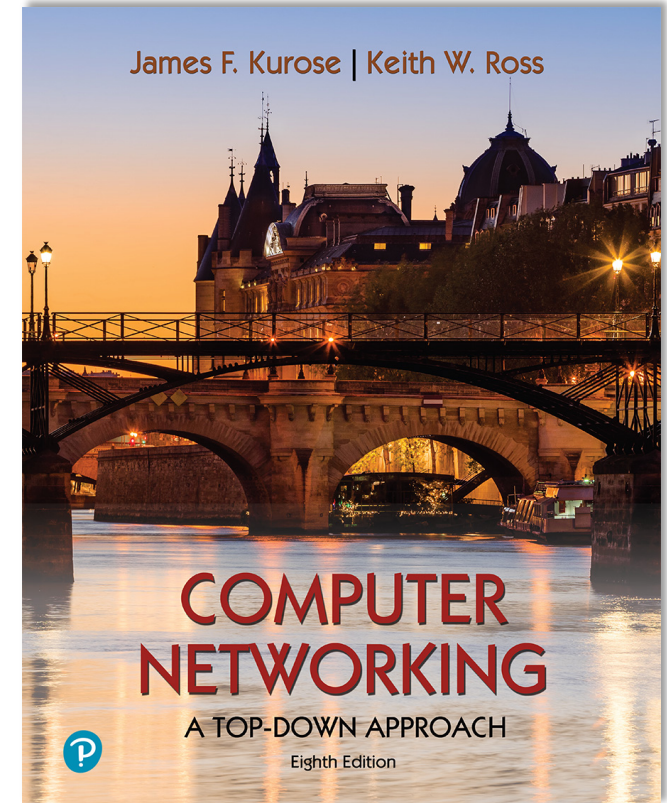


Chapter 7

Wireless and Mobile Networks



Computer Networking: A Top-Down Approach

8th edition

Jim Kurose, Keith Ross
Pearson, 2020

Acknowledgement: Based on the textbook's website:
https://gaia.cs.umass.edu/kurose_ross/index.php

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 (5-1 in 2019)!
 - 4G/5G cellular networks now embracing Internet protocol stack, including SDN
- two important (but different) challenges
 - **wireless**: communication over wireless link
 - **mobility**: handling the mobile user who changes point of attachment to network

Chapter 7 outline

■ Introduction

Wireless

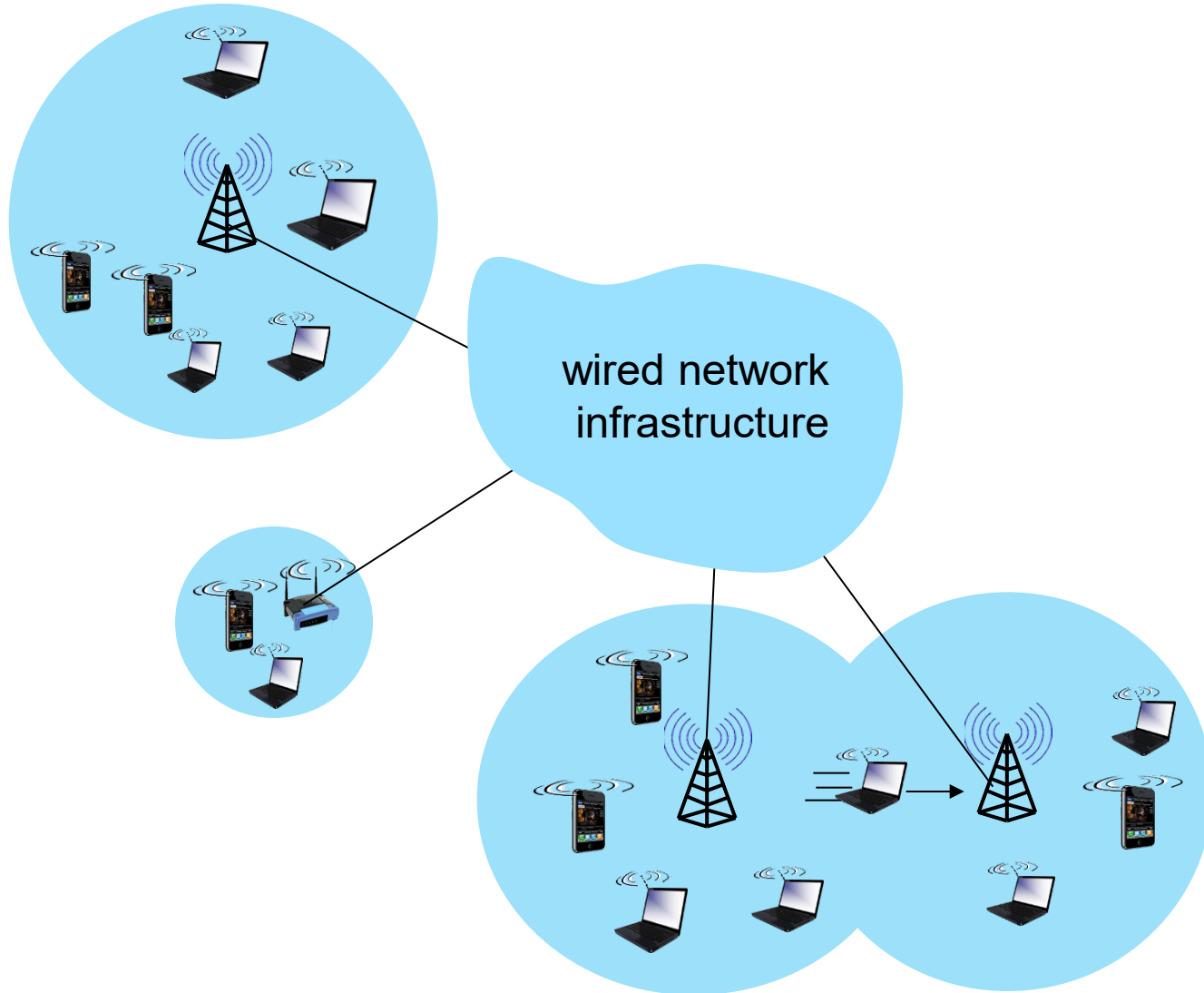
- Wireless Links and network characteristics
- WiFi: 802.11 wireless LANs
- Cellular networks: 4G and 5G

Mobility

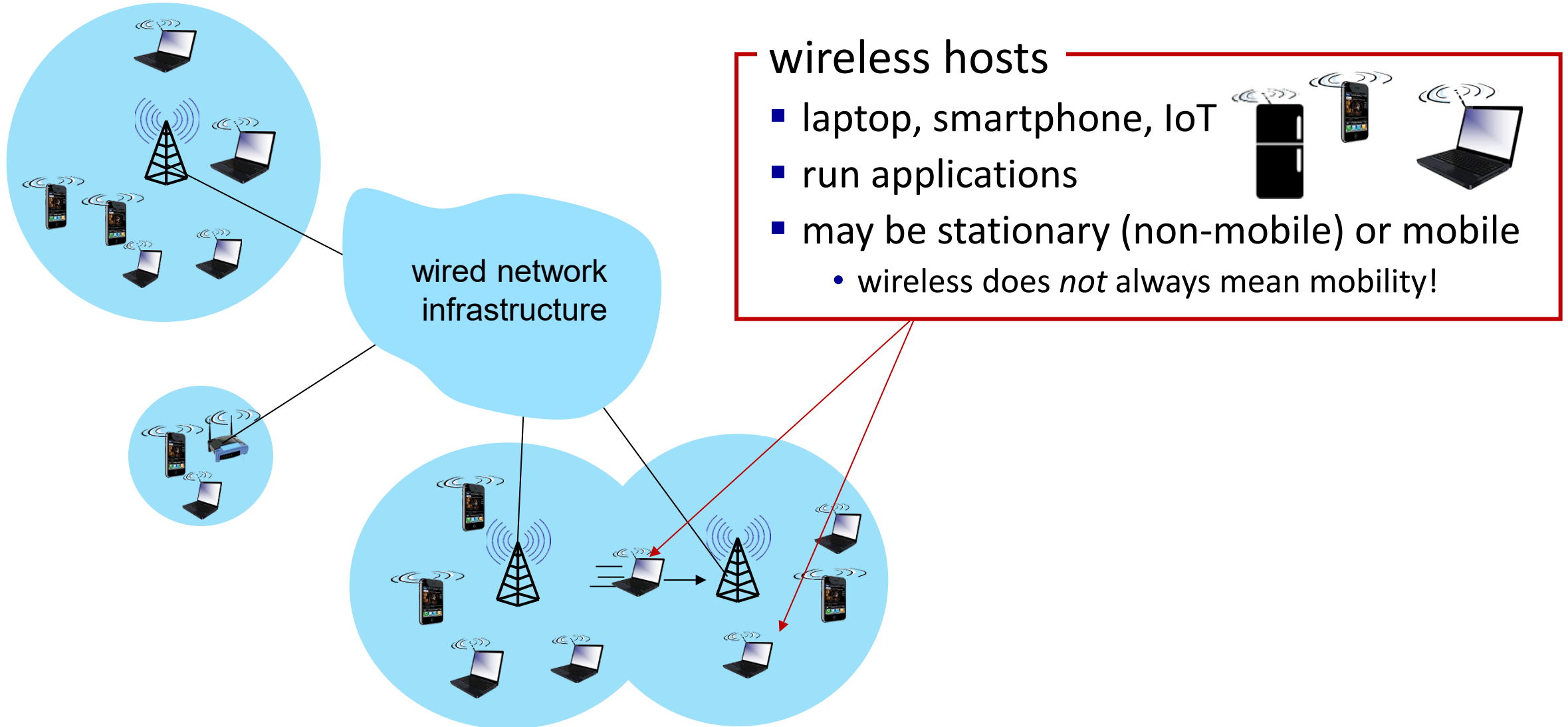
- Mobility management: principles
- Mobility management: practice
 - 4G/5G networks
 - Mobile IP
- Mobility: impact on higher-layer protocols



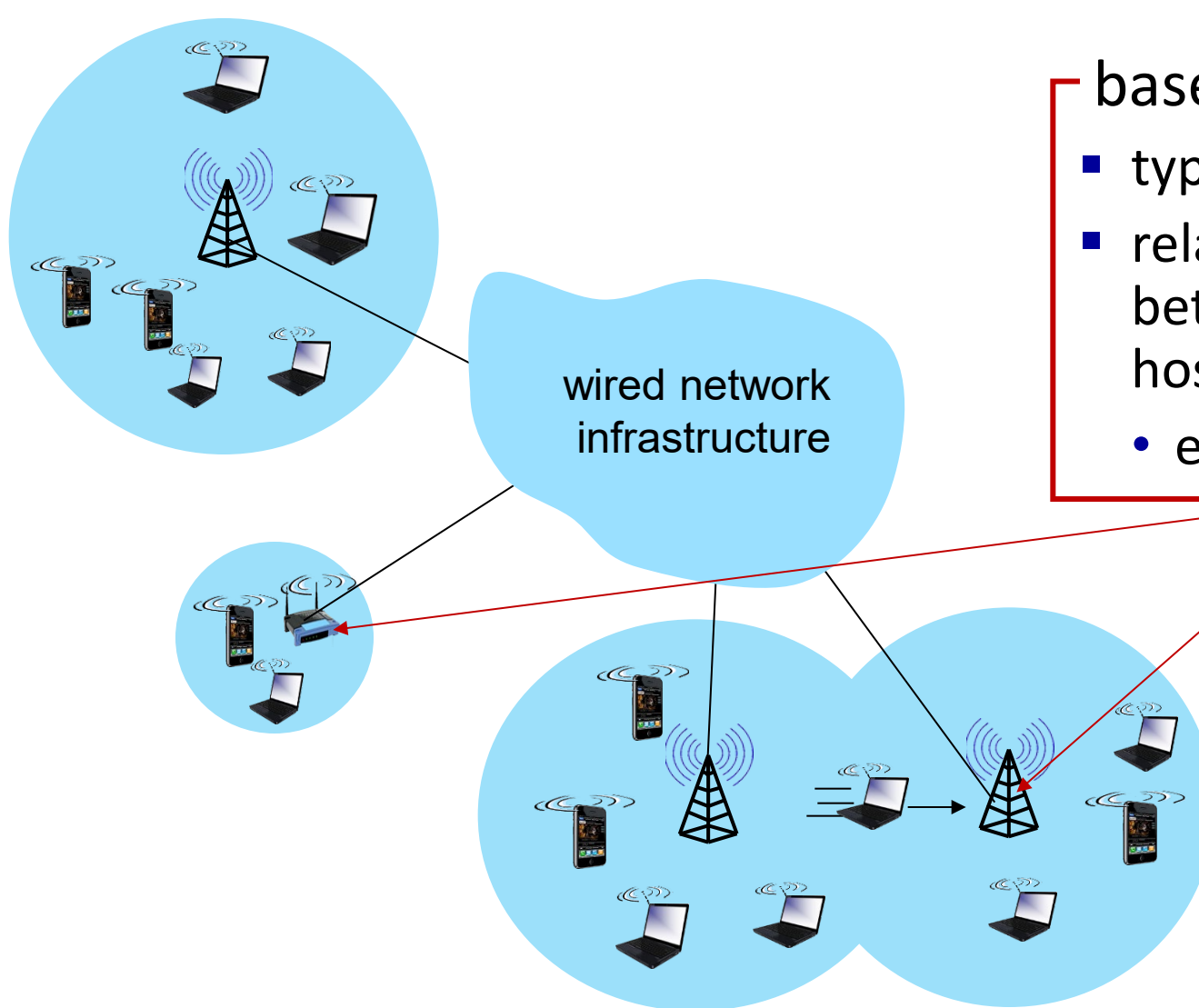
Elements of a wireless network



Elements of a wireless network



Elements of a wireless network

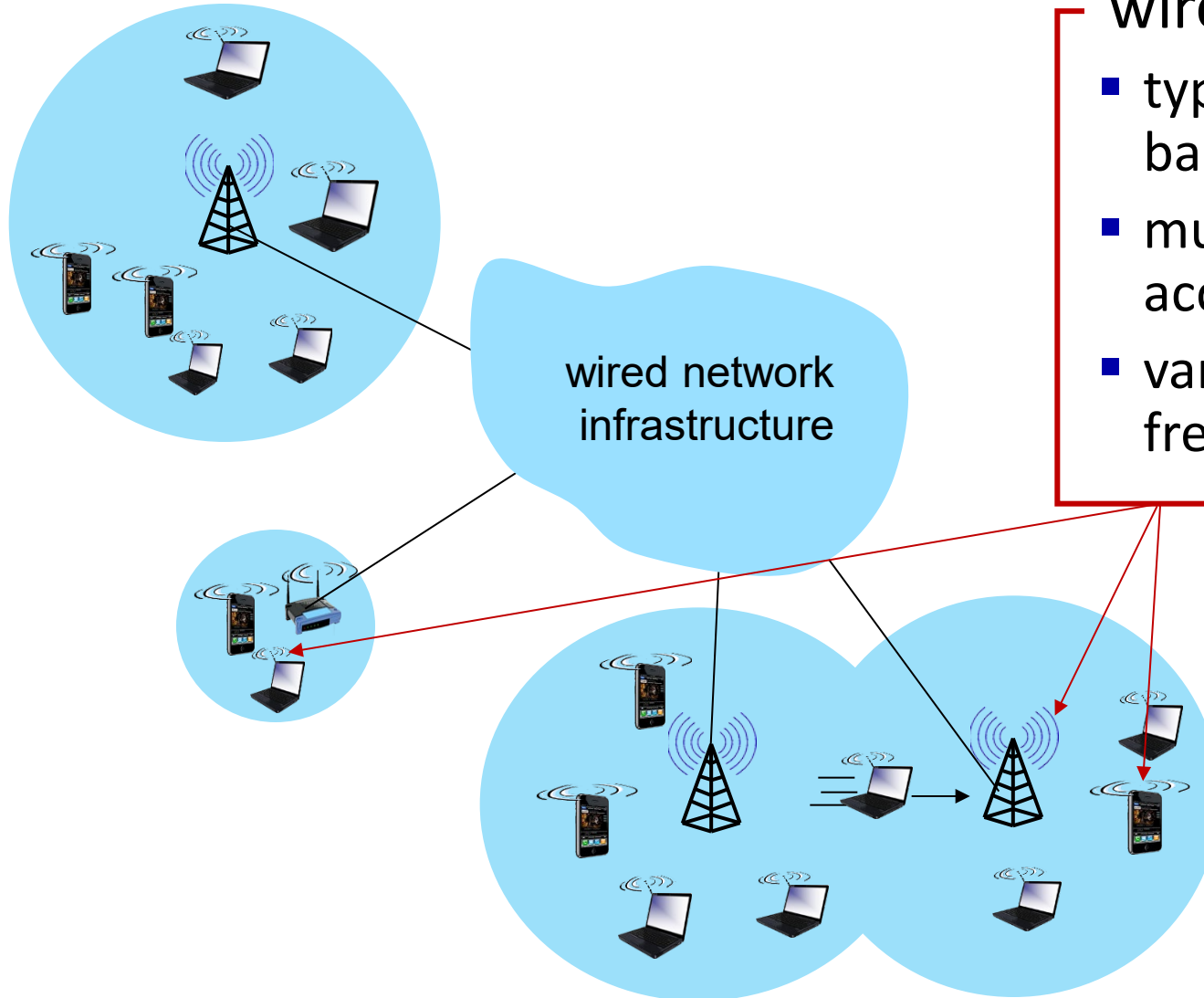


base station



- 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

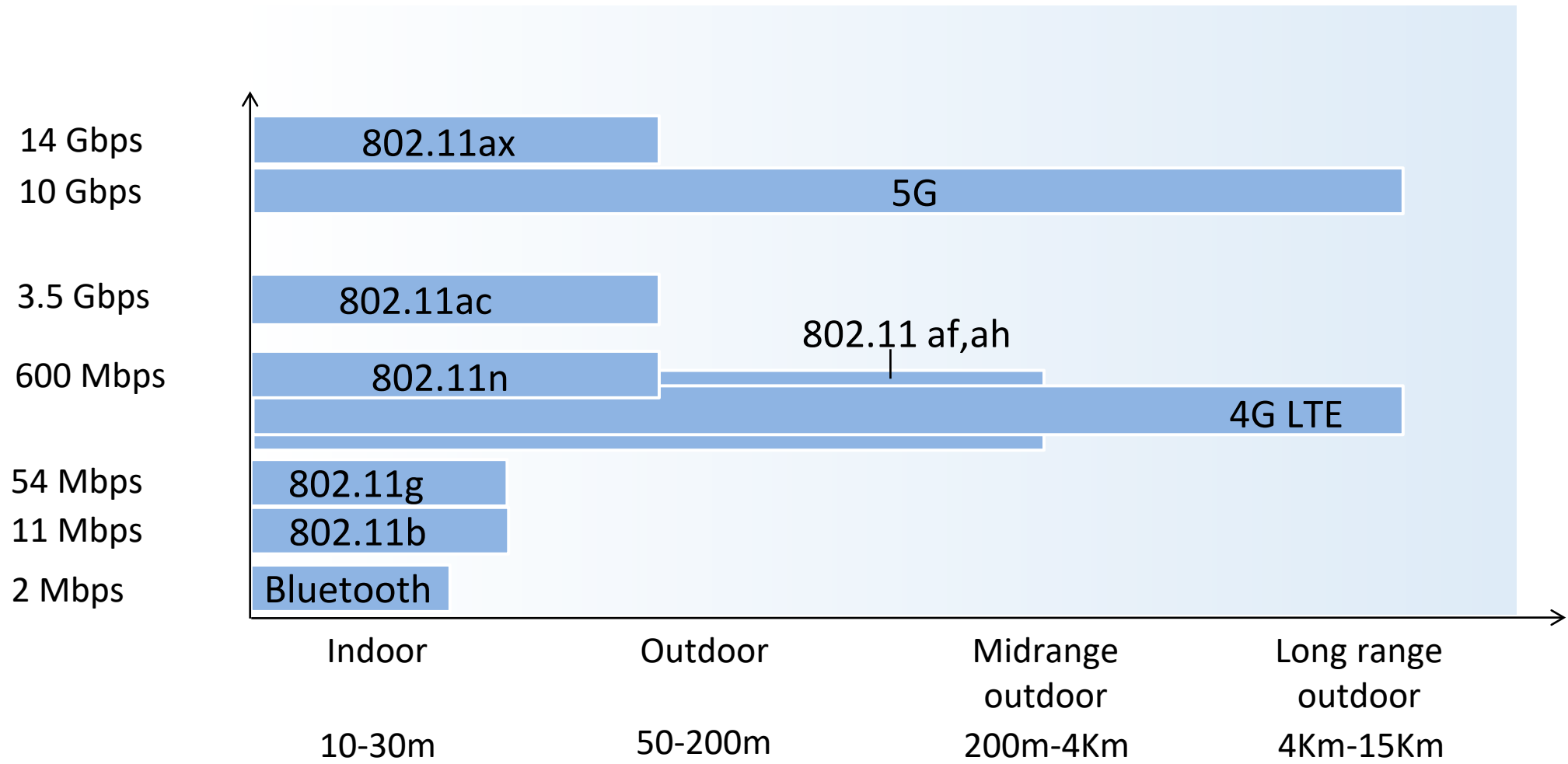


wireless link

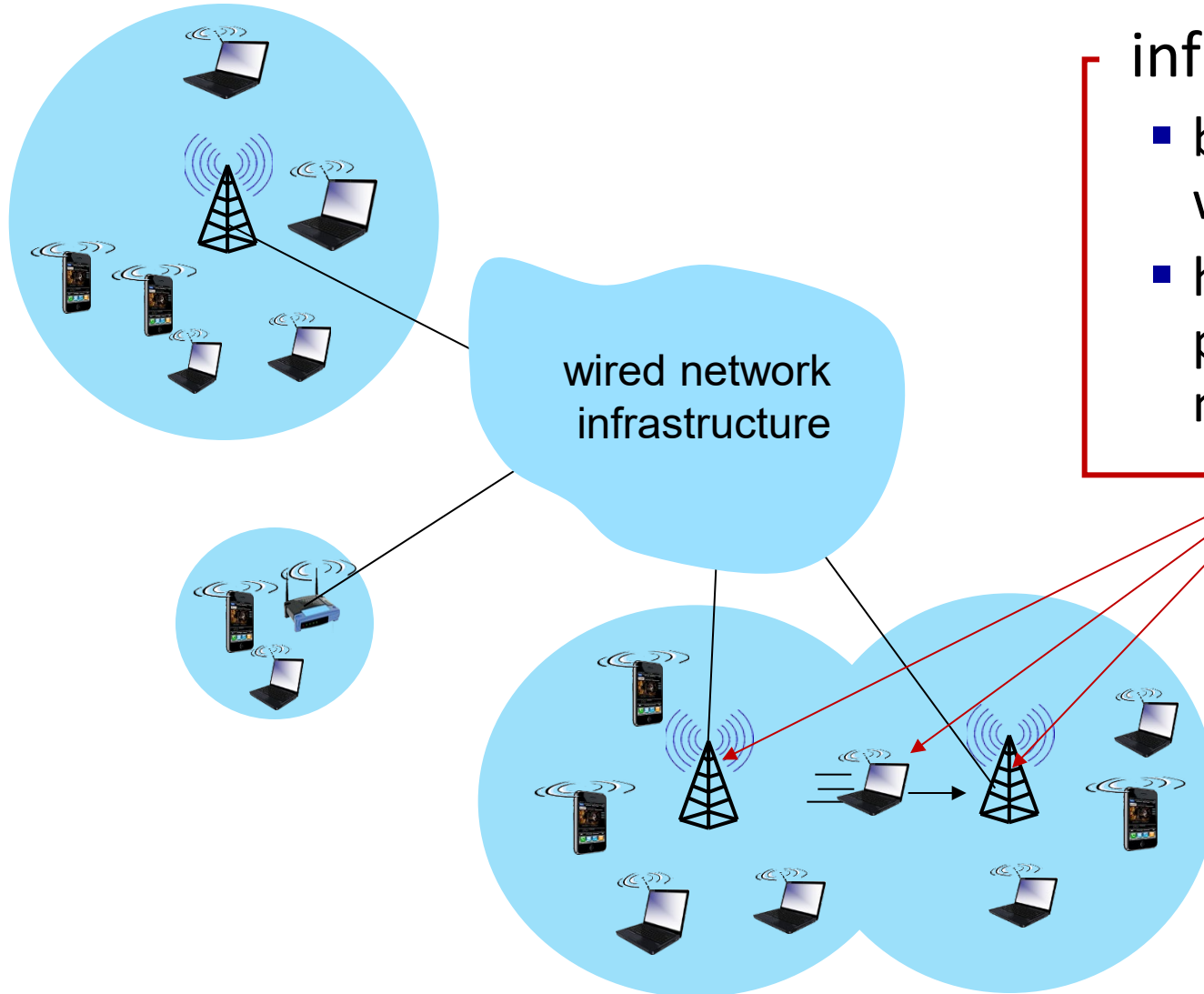


- typically used to connect mobile(s) to base station, also used as backbone link
- multiple access protocol coordinates link access
- various transmission rates and distances, frequency bands

Characteristics of selected wireless links



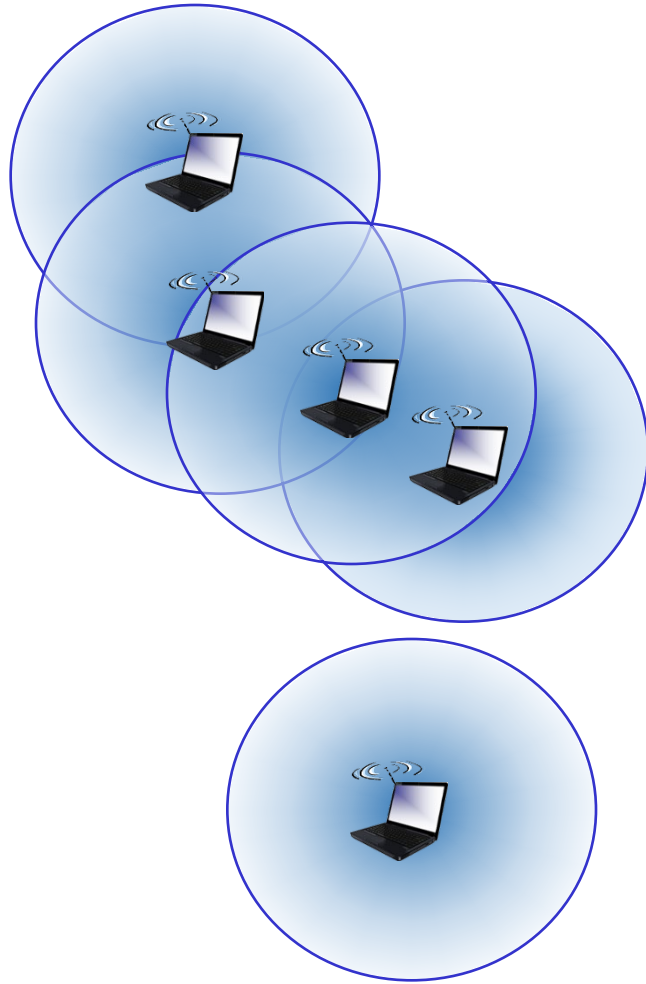
Elements of a wireless network



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: <i>mesh net</i>
<i>no infrastructure</i>	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

Chapter 7 outline

- Introduction

Wireless

- Wireless links and network characteristics
- WiFi: 802.11 wireless LANs
- Cellular networks: 4G and 5G



Mobility

- Mobility management: principles
- Mobility management: practice
 - 4G/5G networks
 - Mobile IP
- Mobility: impact on higher-layer protocols

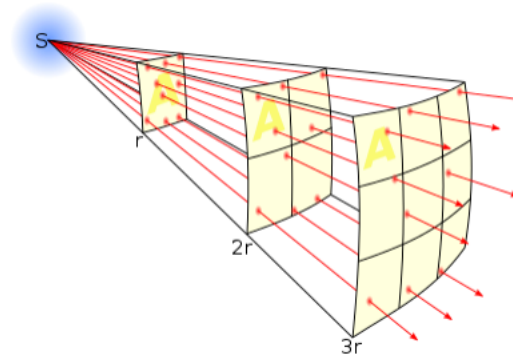
Wireless link characteristics: fading (attenuation)

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

Free space path loss $\sim (fd)^2$

f : frequency

d : distance



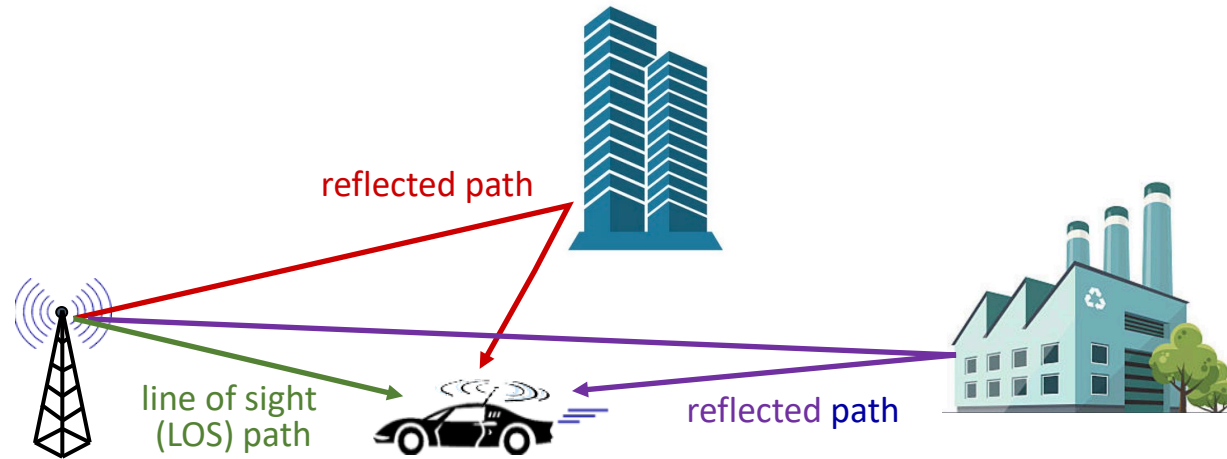
higher frequency or
longer distance



larger free space
path loss

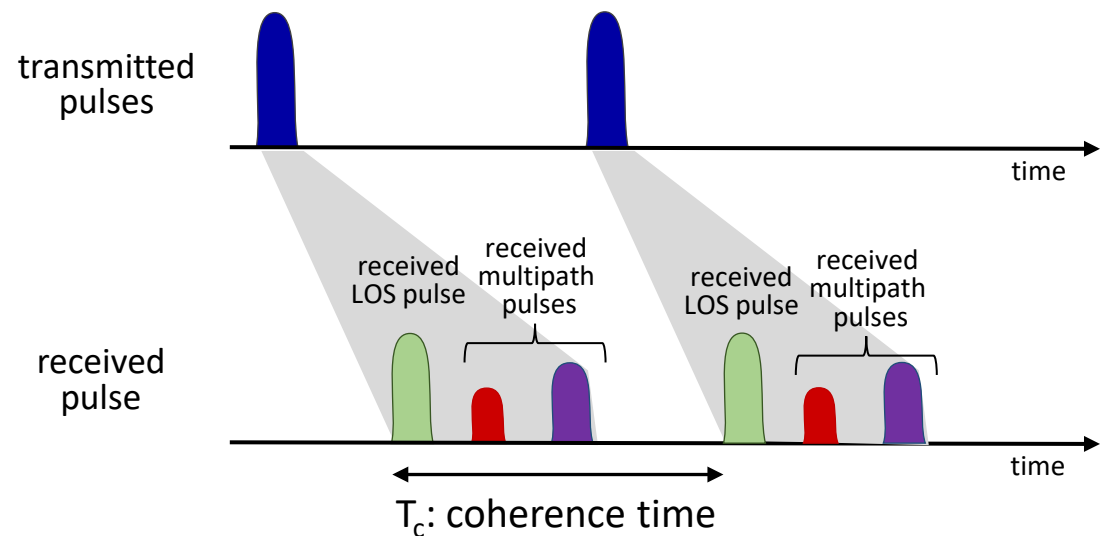
Wireless link characteristics: multipath

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



Wireless link characteristics: multipath

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

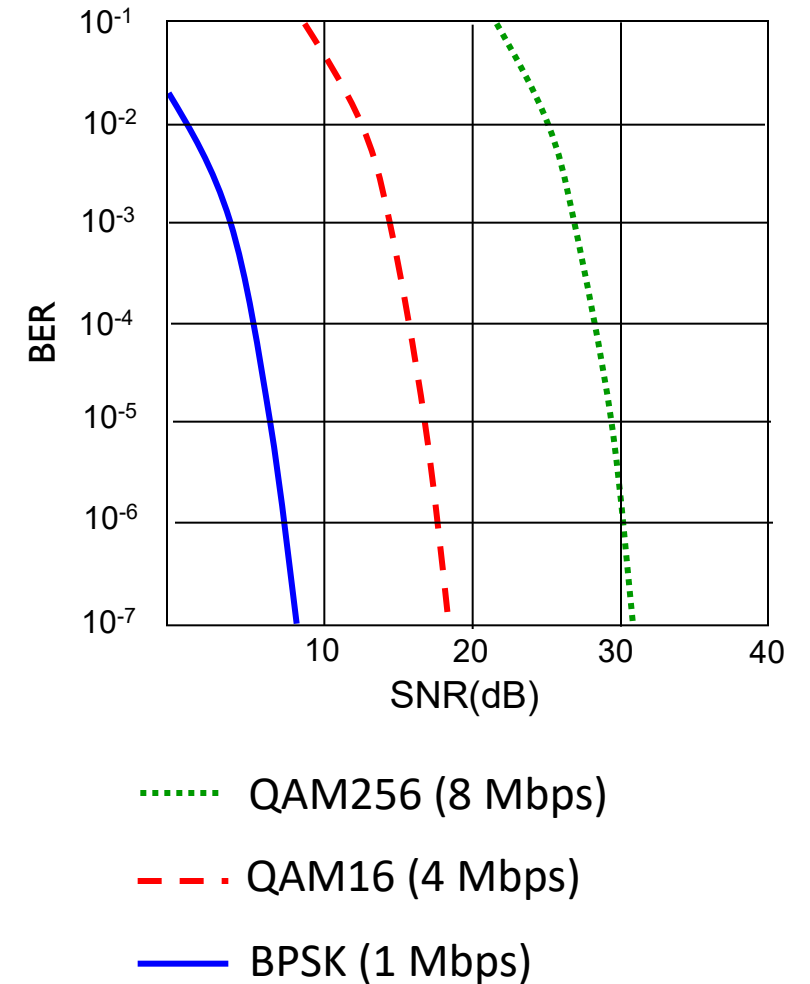


Coherence time:

- 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

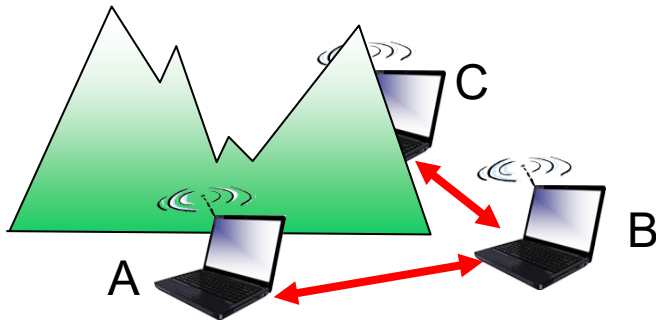
Wireless link characteristics: noise

- **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)



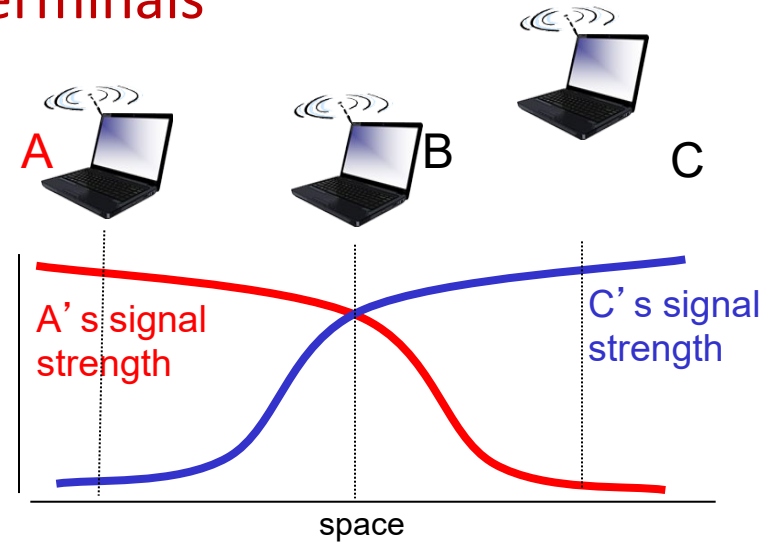
Wireless link characteristics: hidden terminals

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

- Introduction

Wireless

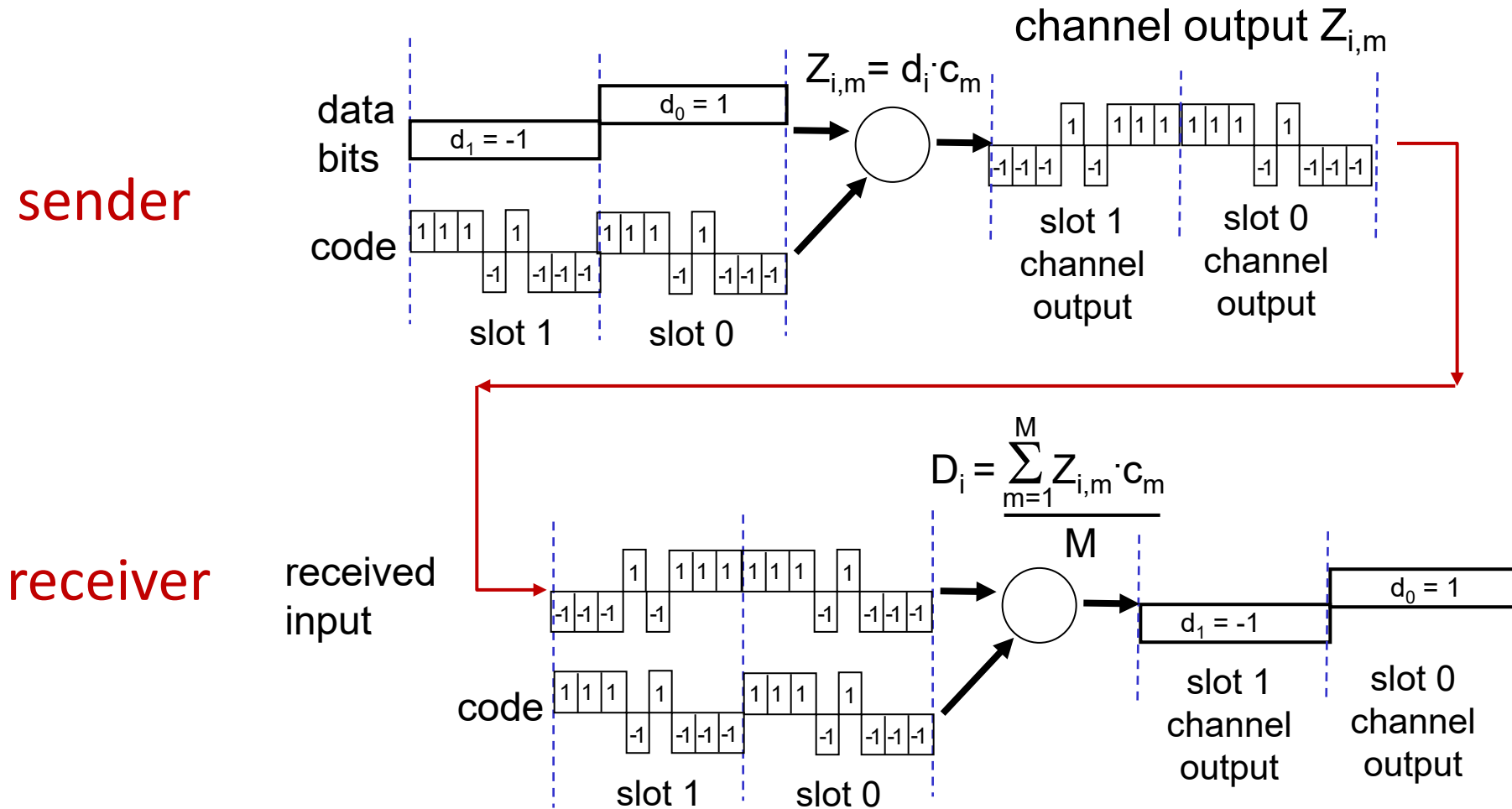
- Wireless links and network characteristics
- **CDMA: code division multiple access**
- WiFi: 802.11 wireless LANs
- Bluetooth



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) \times (chipping sequence)
- **decoding:** summed inner-product: (encoded data) \times (chipping sequence)

CDMA encode/decode

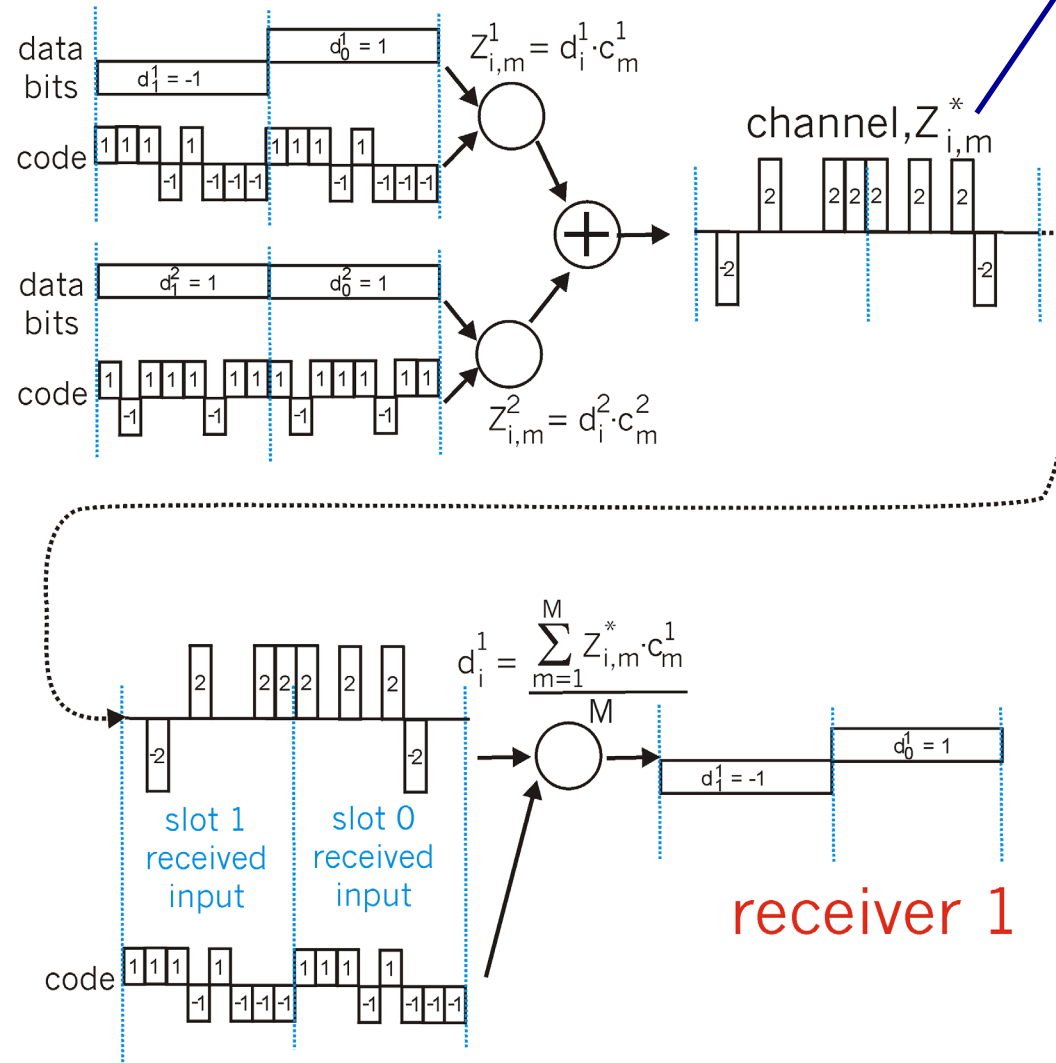


... but this isn't really useful yet!

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!

Chapter 7 outline

- Introduction

Wireless

- Wireless links and network characteristics
- **WiFi: 802.11 wireless LANs**
- Cellular networks: 4G and 5G



Mobility

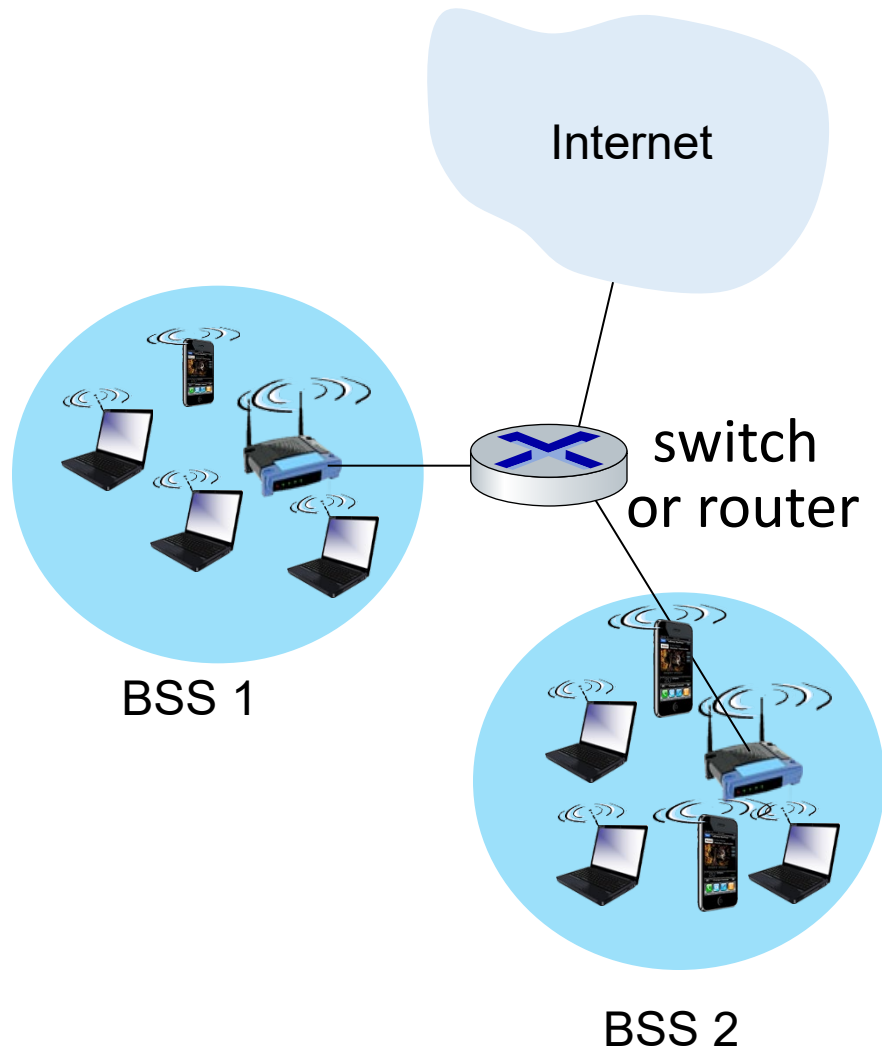
- Mobility management: principles
- Mobility management: practice
 - 4G/5G networks
 - Mobile IP
- Mobility: impact on higher-layer protocols

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 (exp.)	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

802.11 LAN architecture

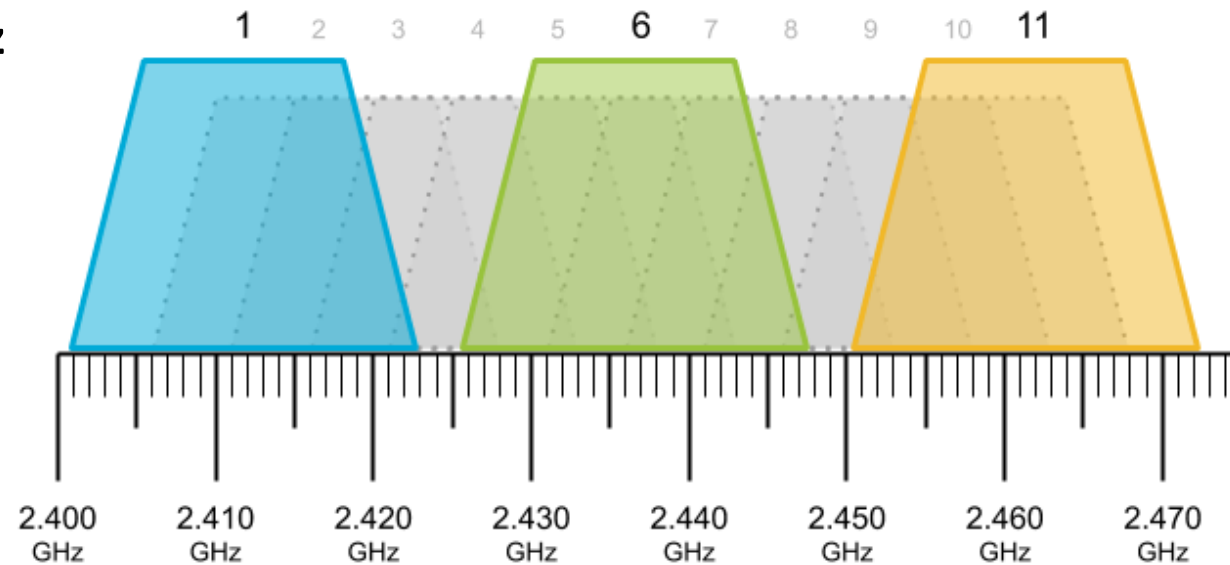


- wireless host communicates with base station
 - base station = access point (AP)
- Basic Service Set (BSS) (aka “cell”) in infrastructure mode contains:
 - wireless hosts
 - access point (AP): base station
 - ad hoc mode: hosts only

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

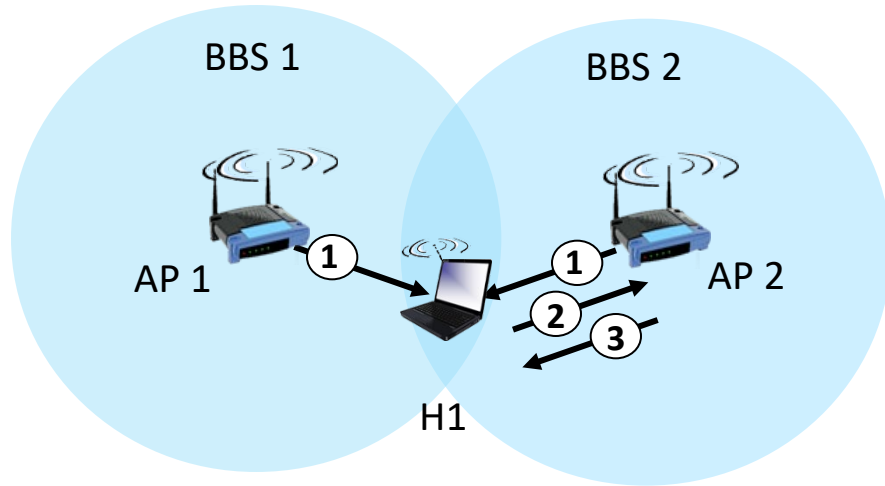


802.11: Association

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

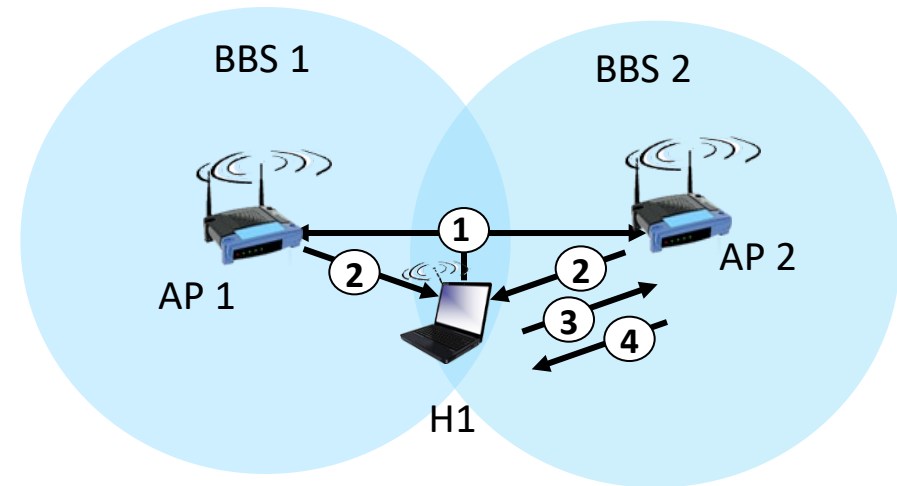


802.11: passive/active scanning



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

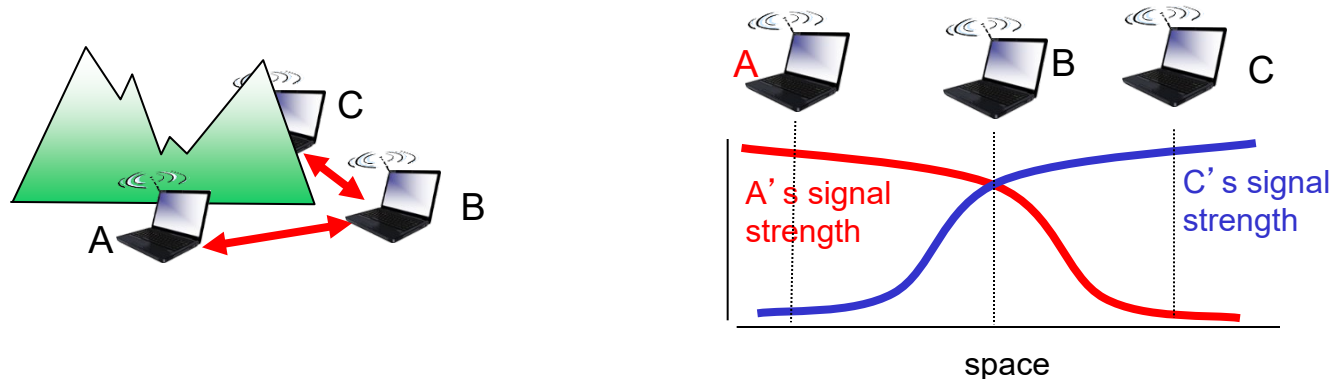


active scanning:

- (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

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



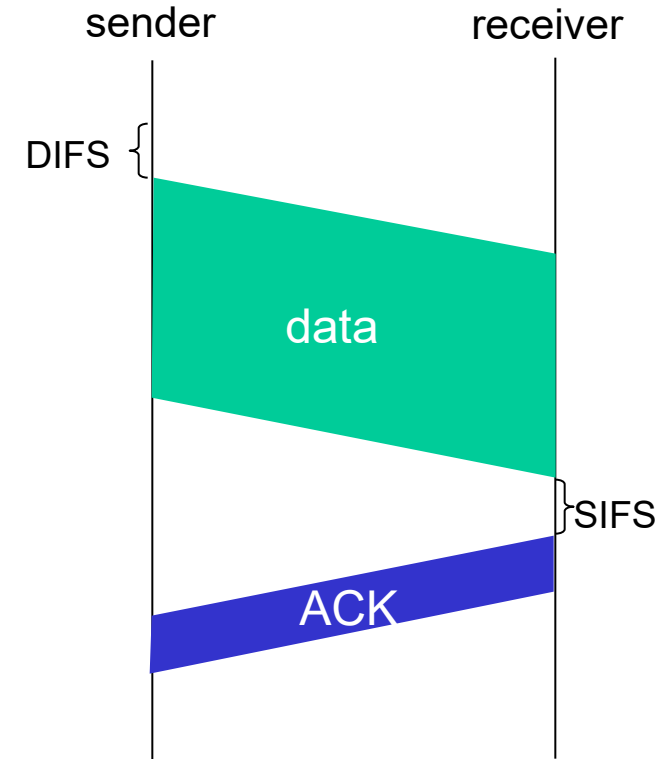
IEEE 802.11 MAC Protocol: CSMA/CA

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
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)

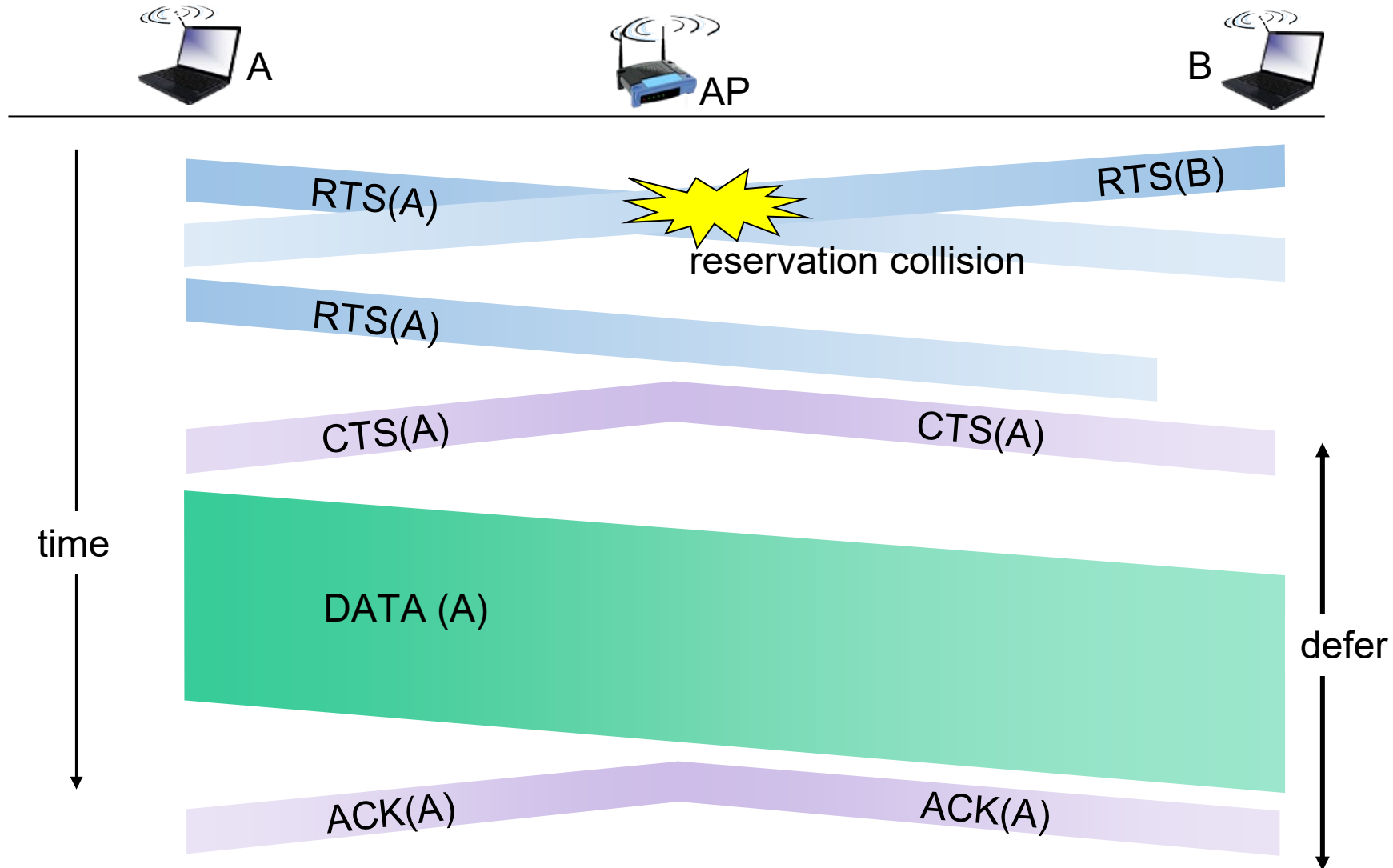


Avoiding collisions (more)

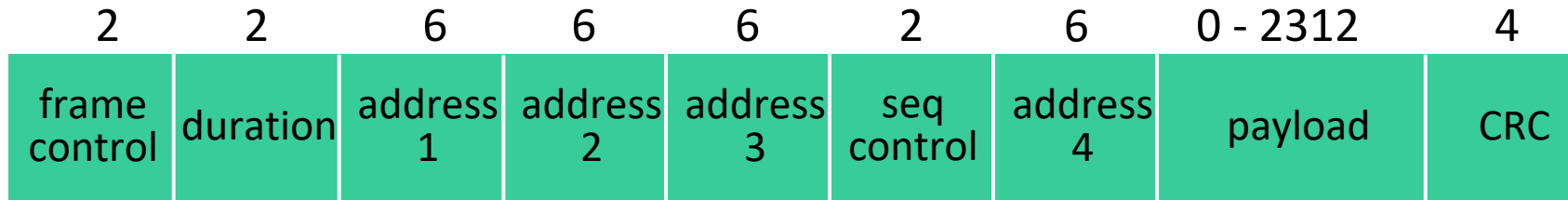
idea: sender “reserves” channel use for data frames using small reservation packets

- 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

Collision Avoidance: RTS-CTS exchange



802.11 frame: addressing



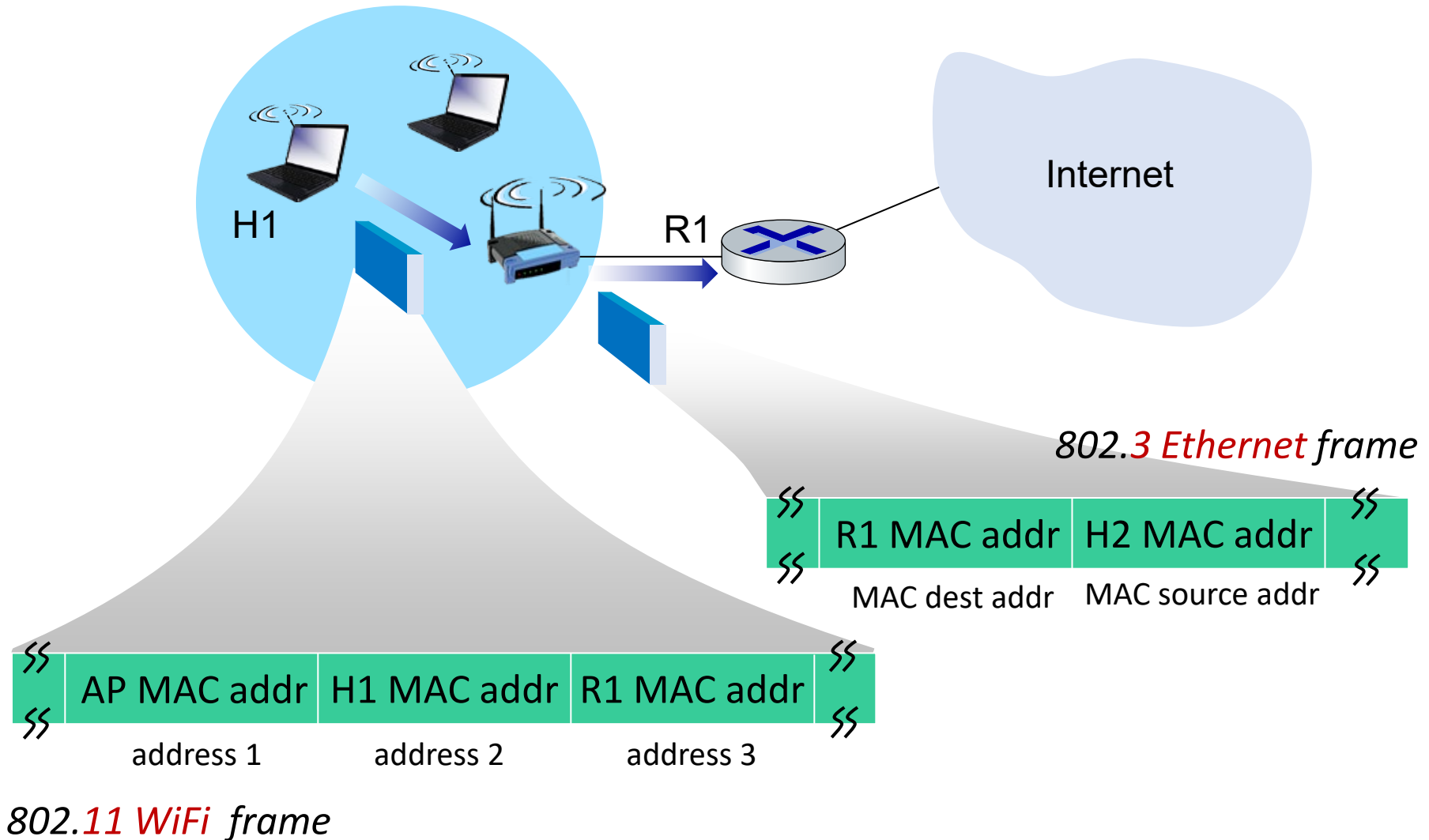
Address 1: MAC address of wireless host or AP to receive this frame

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

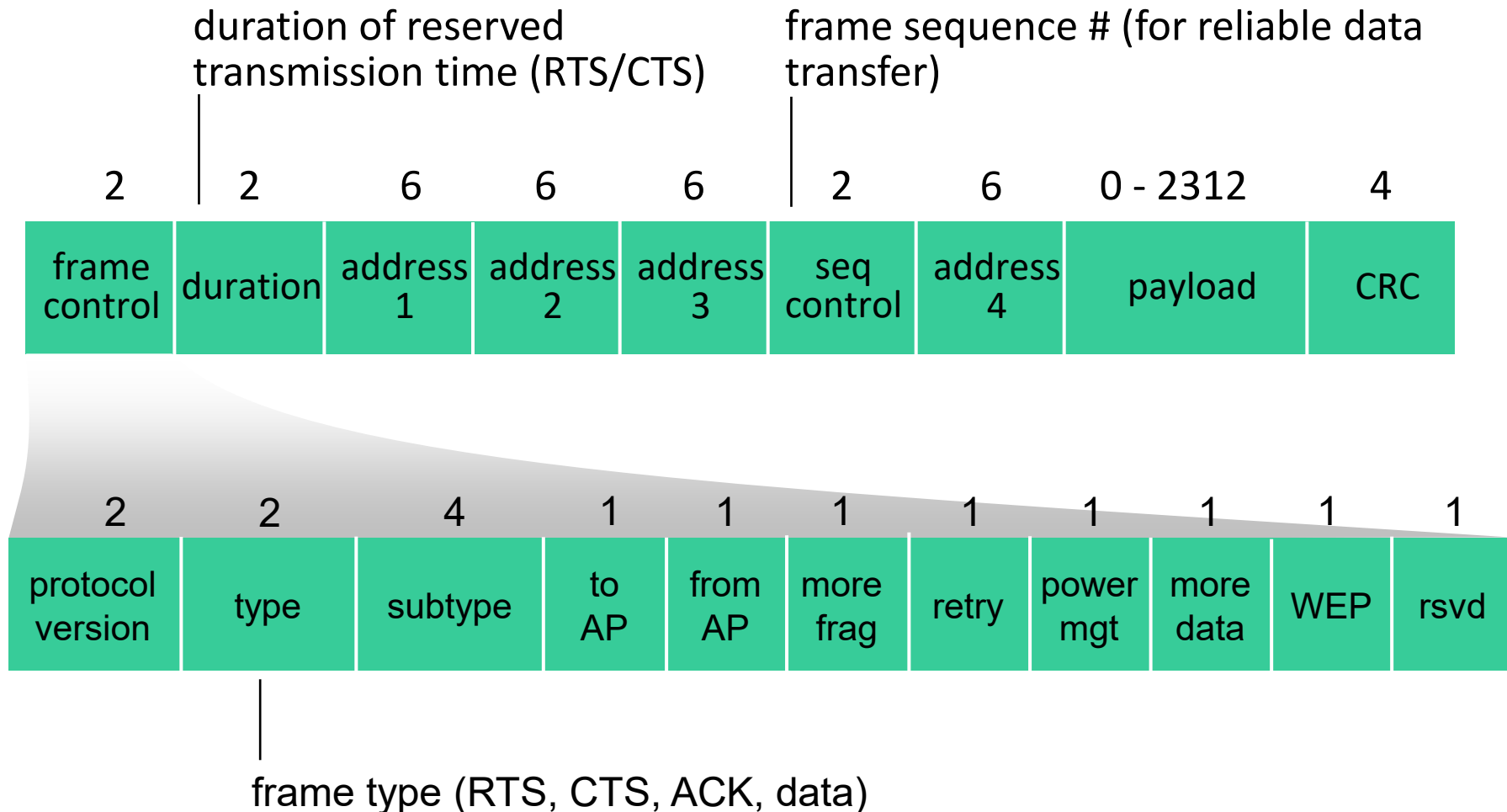
Address 3: MAC address of router interface to which AP is attached

Address 4: used only in ad hoc mode

802.11 frame: addressing

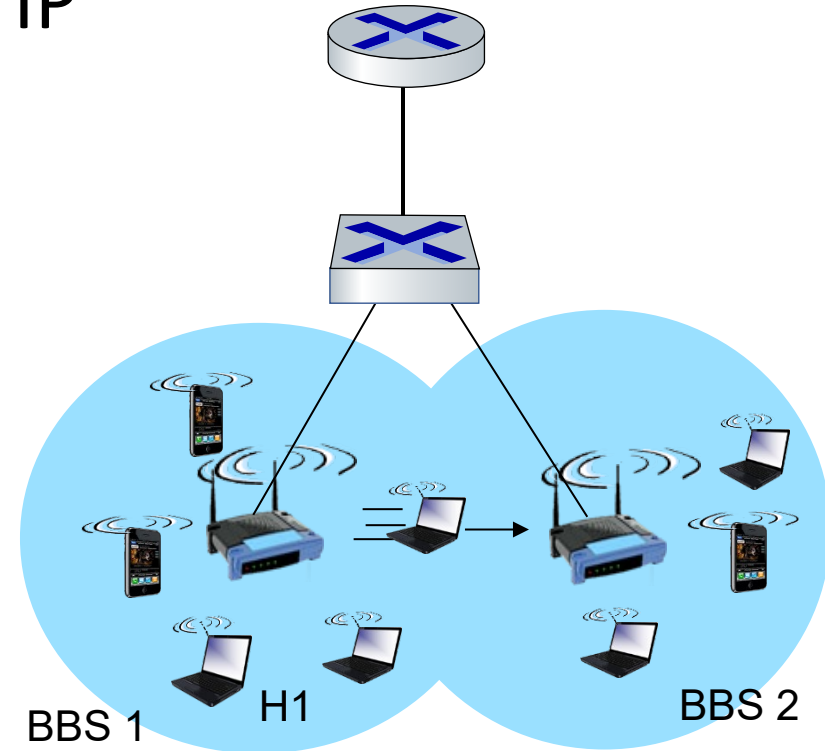


802.11 frame: addressing



802.11: mobility within same subnet

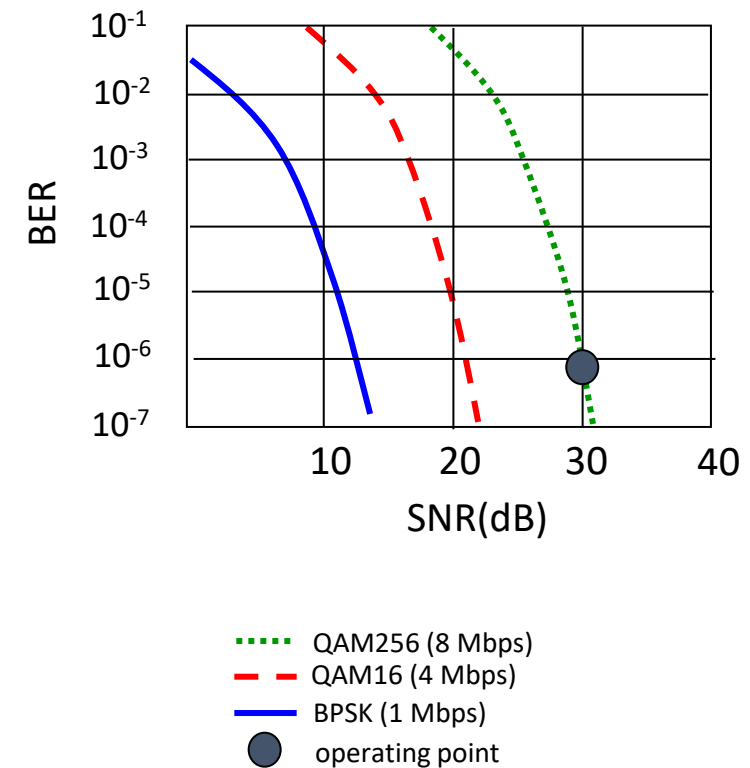
- H1 remains in same IP subnet: IP address can remain same
- switch: which AP is associated with H1?
 - self-learning (Ch. 6): switch will see frame from H1 and “remember” which switch port can be used to reach H1



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

Chapter 7 outline

- Introduction

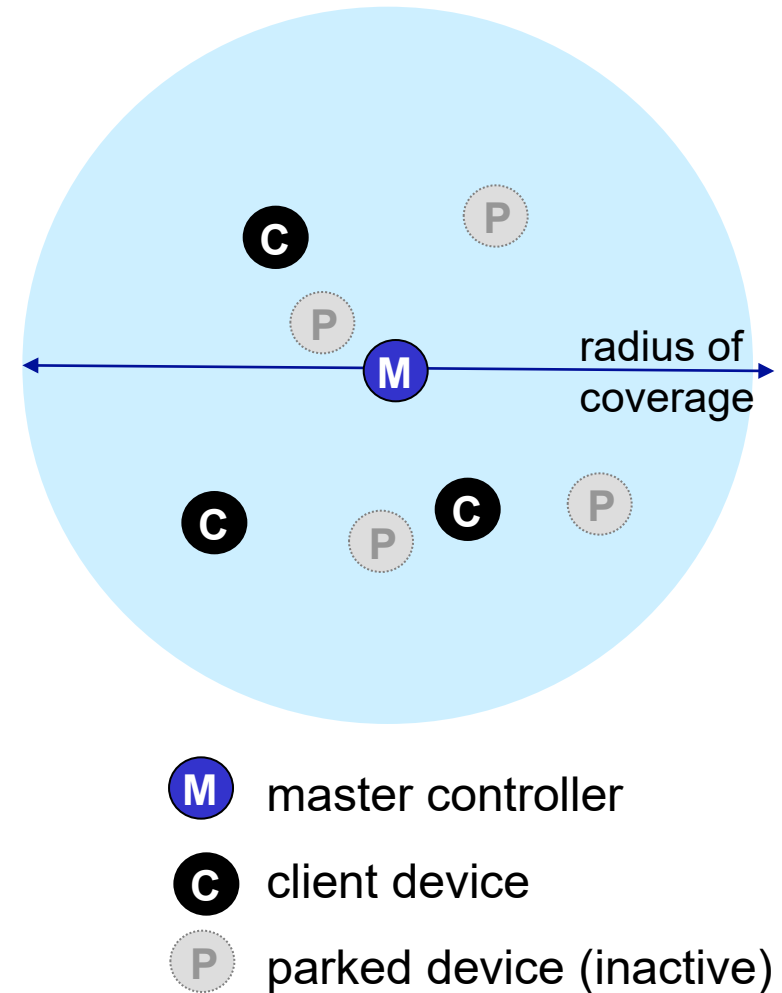
Wireless

- Wireless links and network characteristics
- CDMA: code division multiple access
- WiFi: 802.11 wireless LANs
- Bluetooth



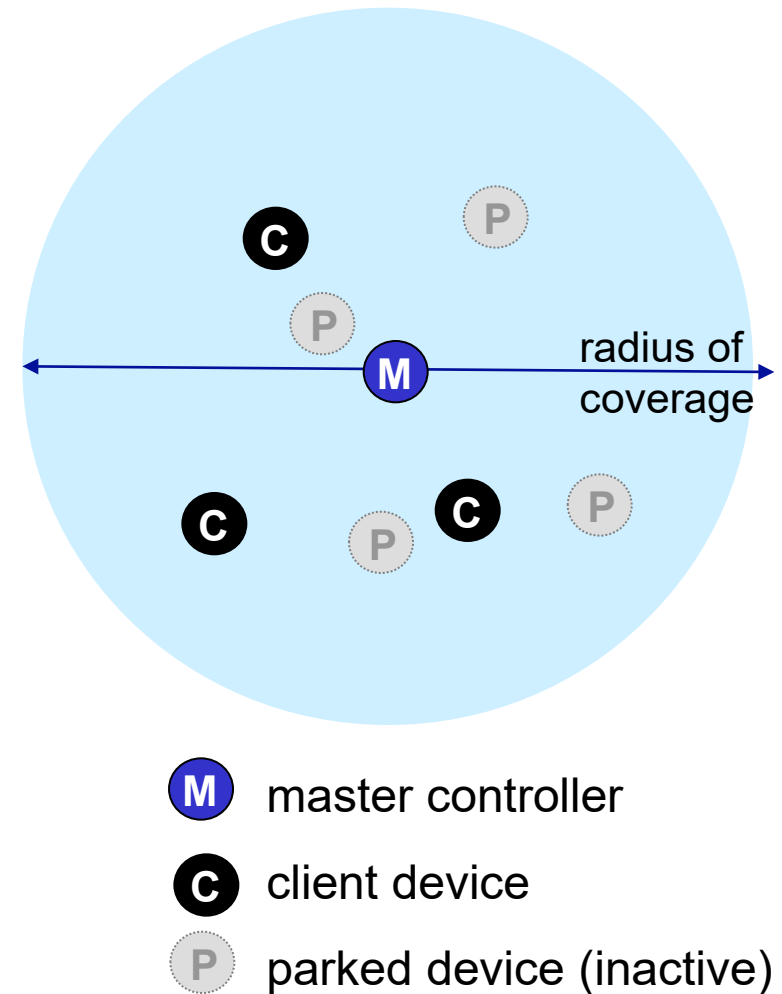
Personal area networks: Bluetooth

- less than 10 m diameter
- replacement for cables (mouse, keyboard, headphones)
- ad hoc: no infrastructure
- 2.4-2.5 GHz ISM radio band, up to 3 Mbps
- master controller / client devices:
 - master polls clients, grants requests for client transmissions



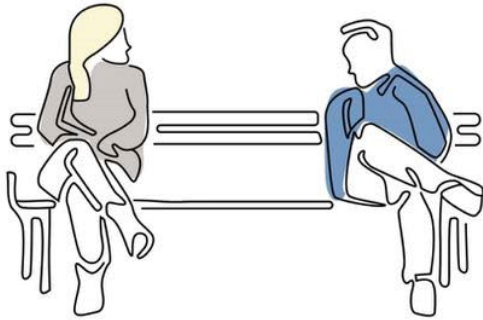
Personal area networks: Bluetooth

- TDM, 625 μ sec 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.

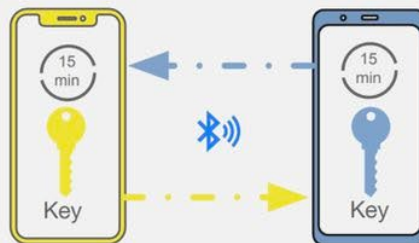


Bob is positively diagnosed for COVID-19 and enters the test result in an app from a public health authority.



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

