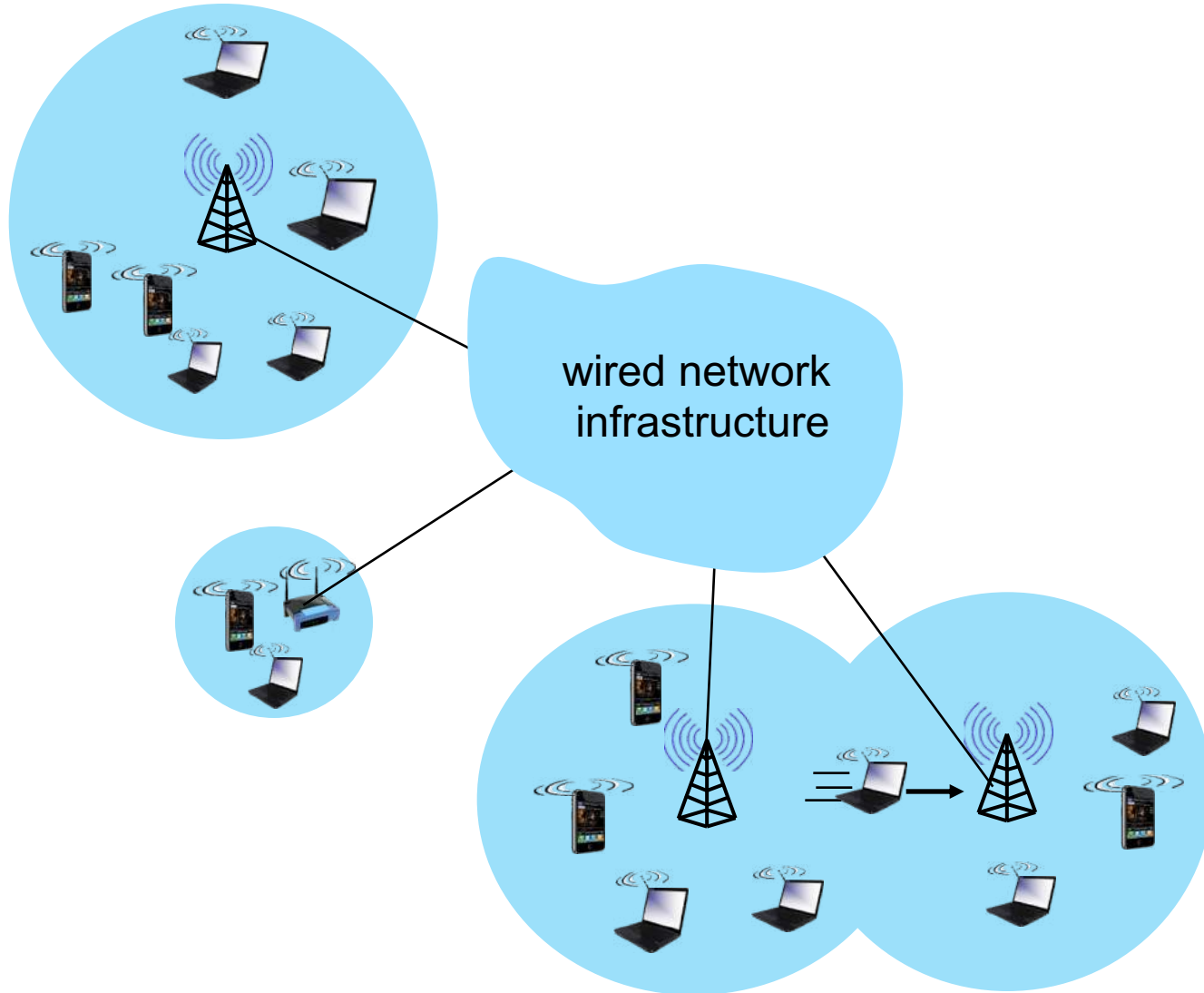


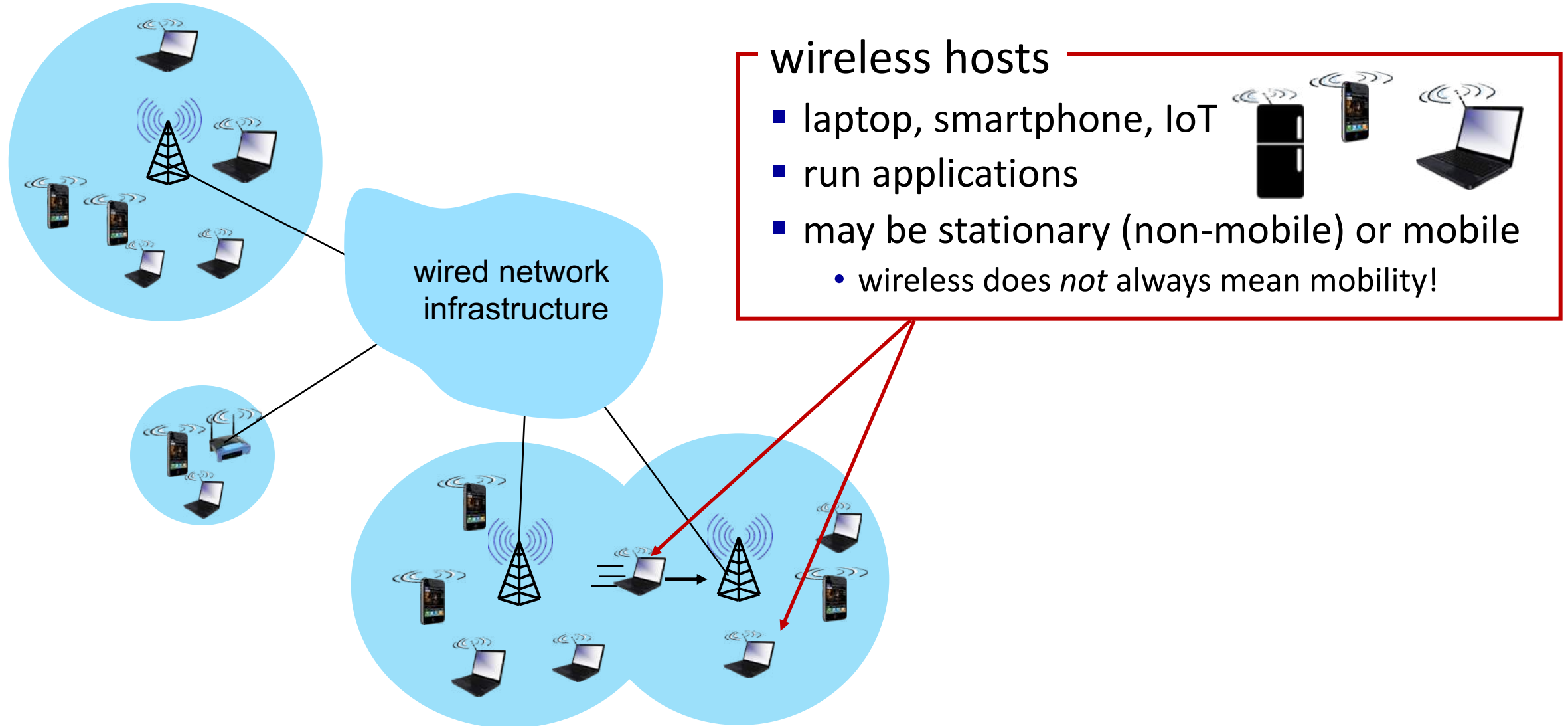
Wireless and Mobile Networks: context

- 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

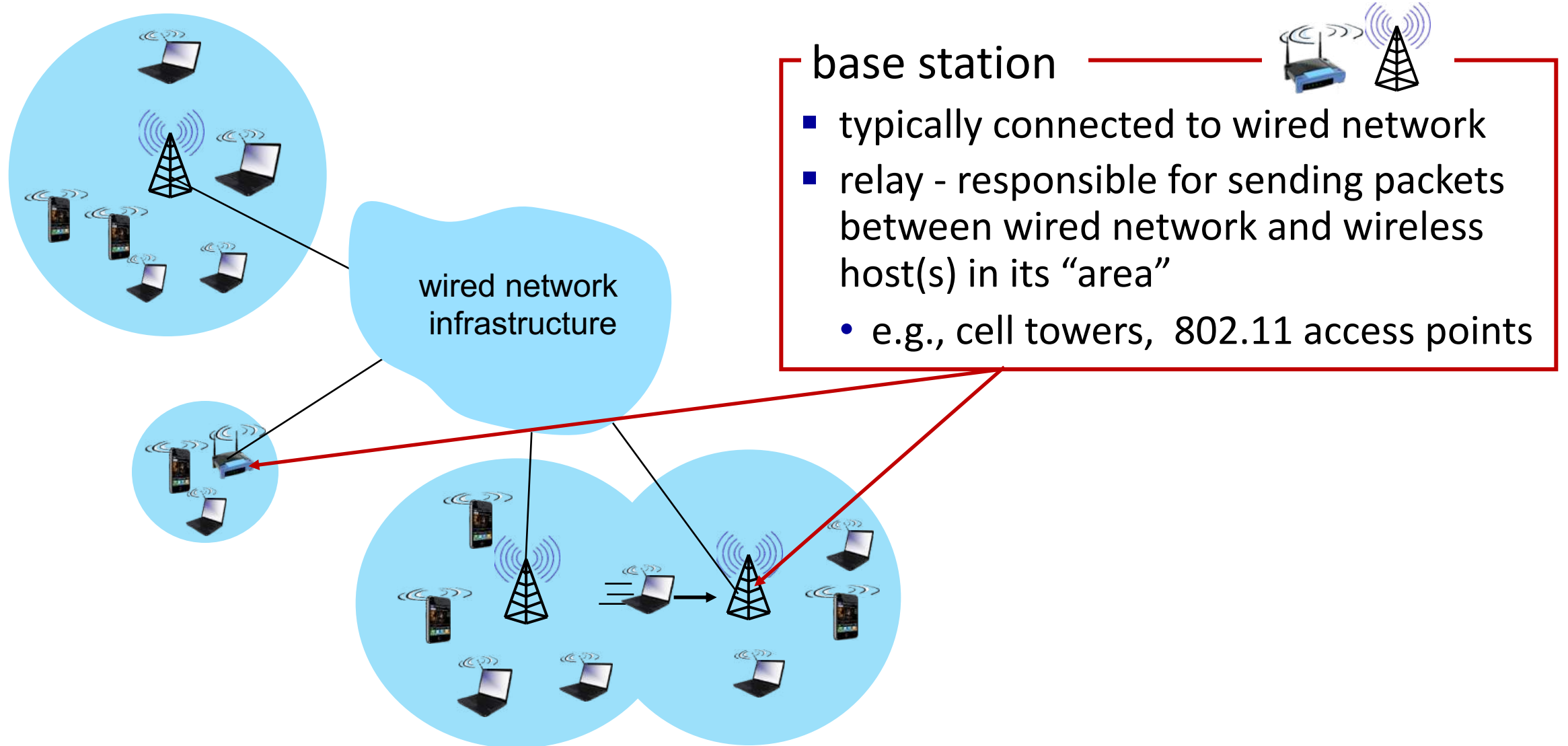
Elements of a wireless network



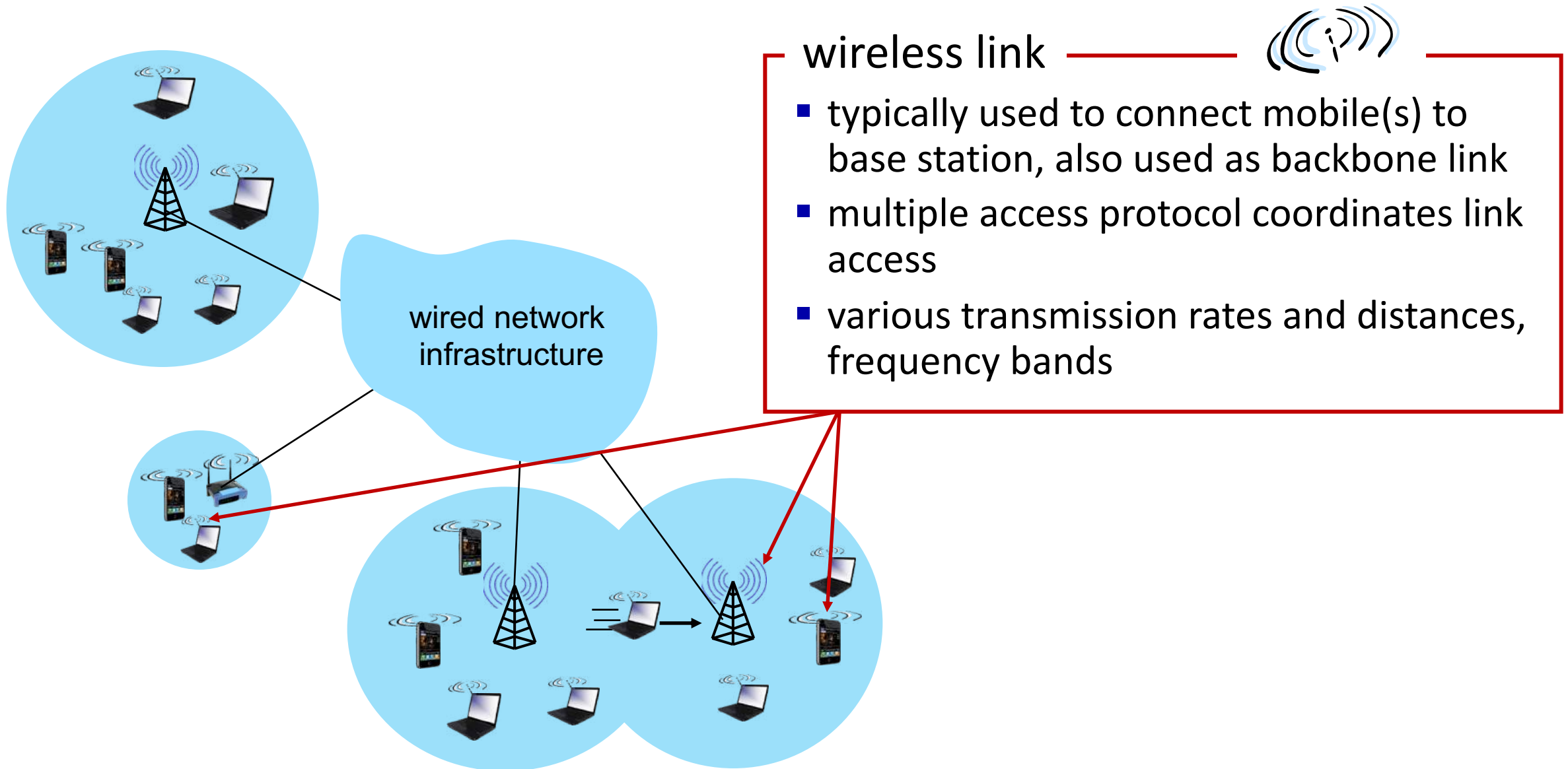
Elements of a wireless network



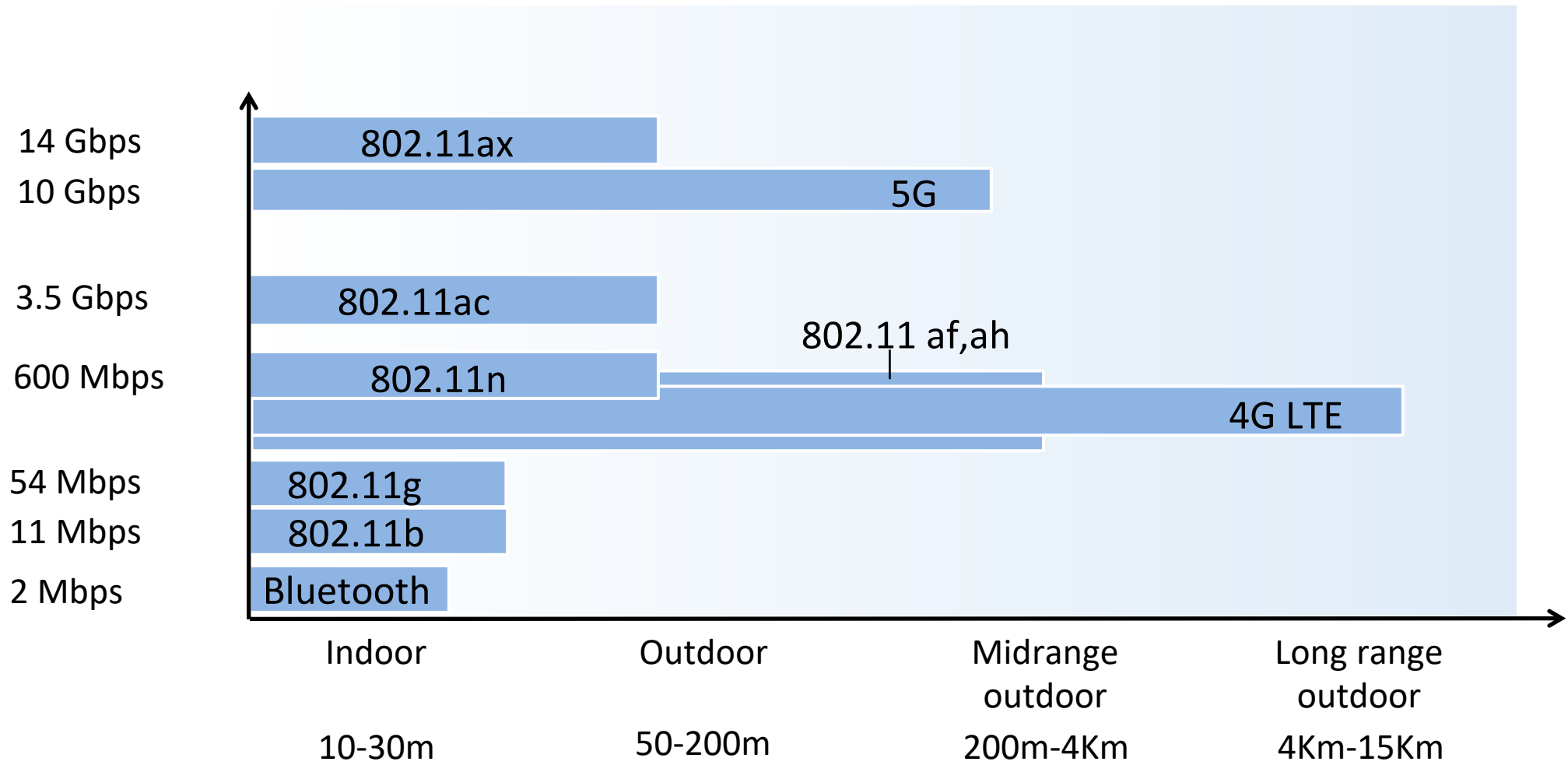
Elements of a wireless network



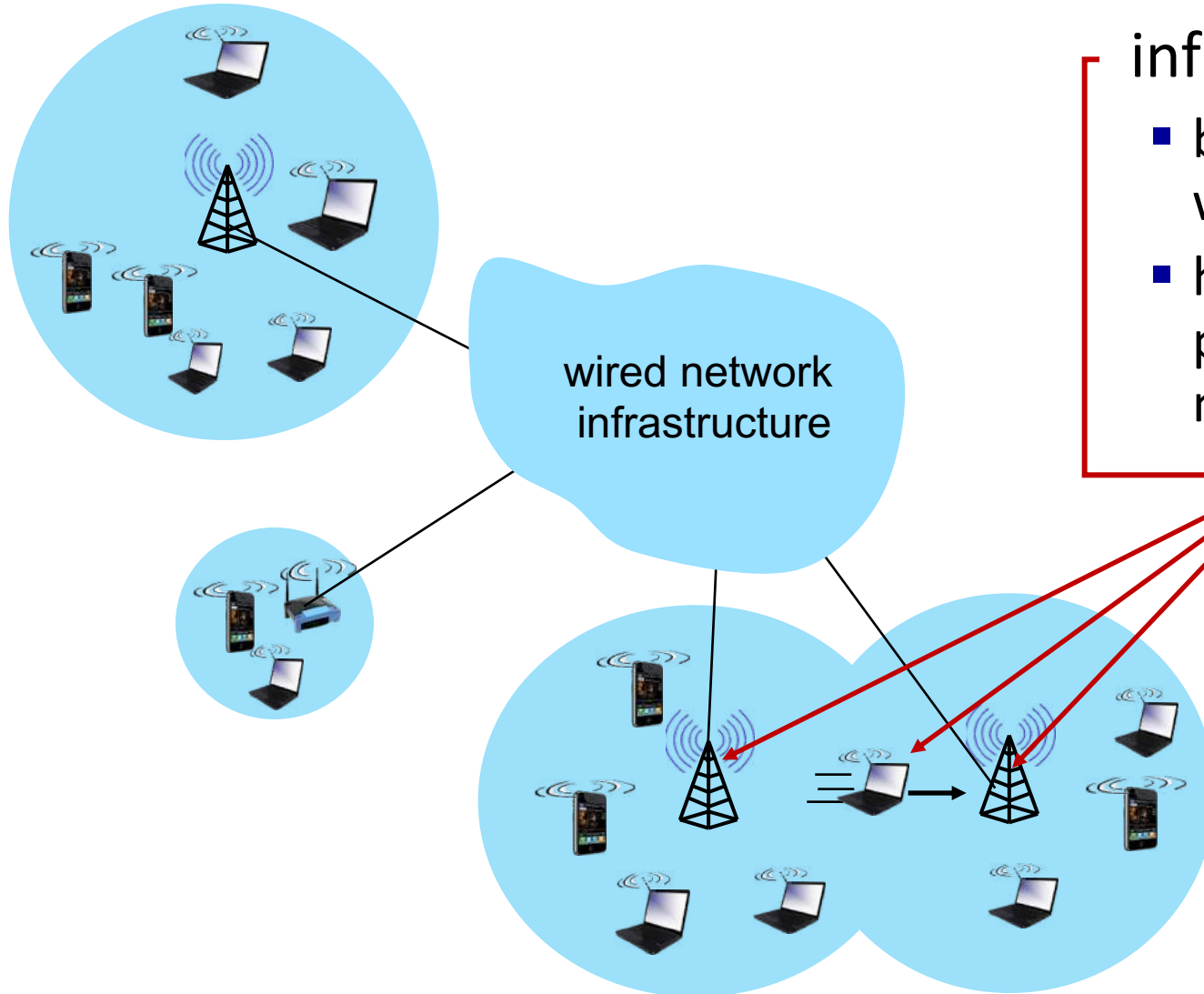
Elements of a wireless network



Characteristics of selected wireless links



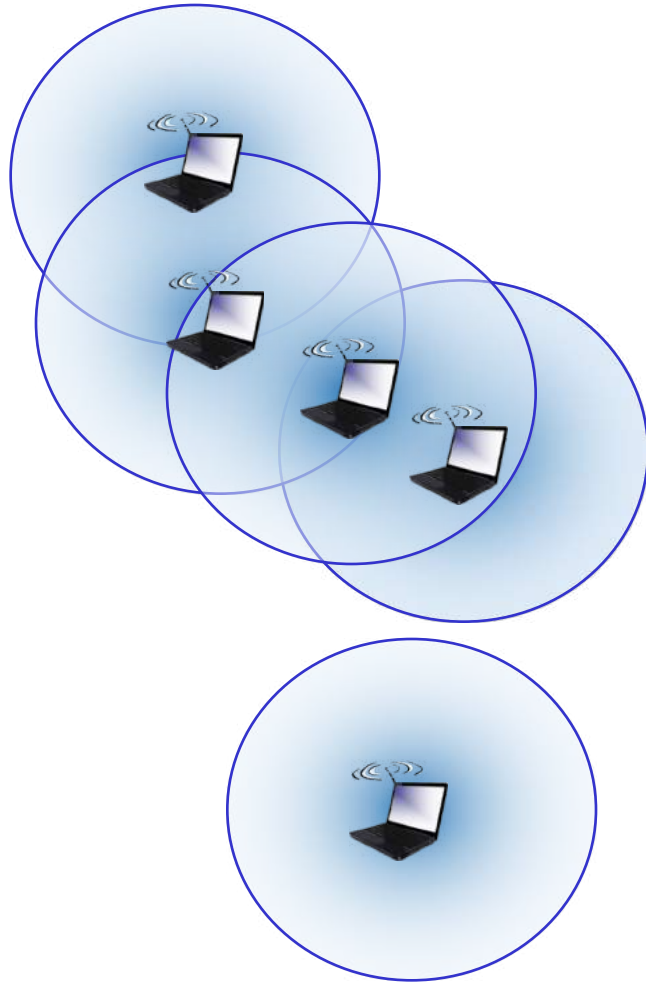
Elements of a wireless network



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

Wireless link characteristics (1)

important differences from wired link

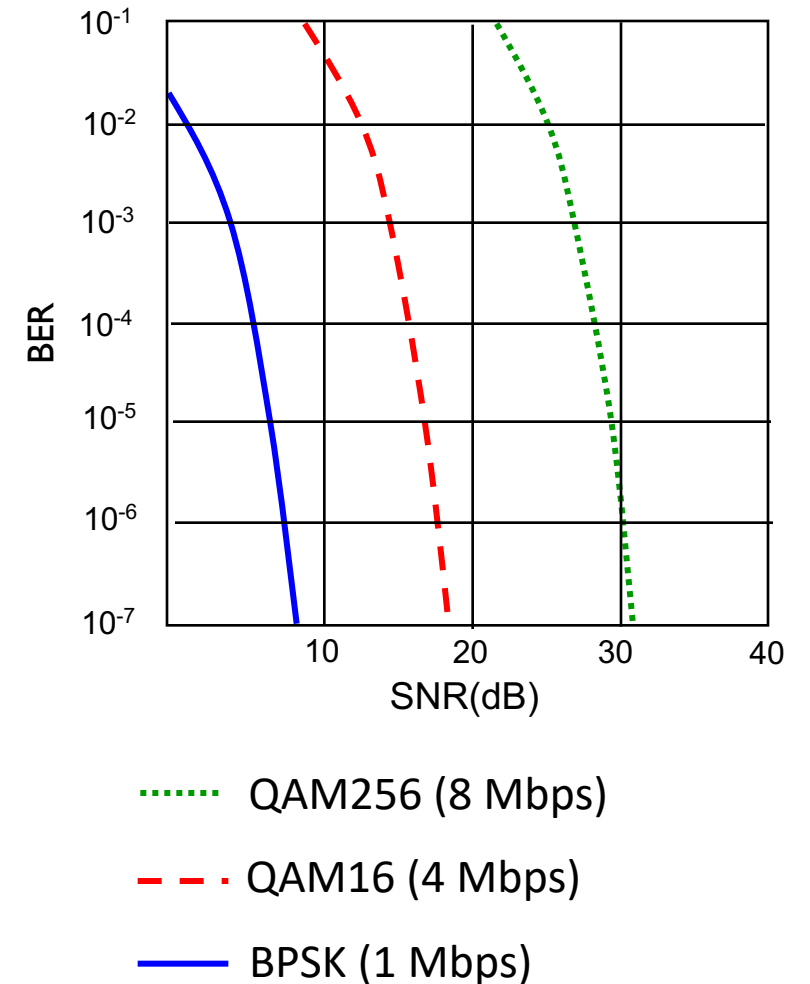
- **decreased signal strength:** radio signal attenuates as it propagates through matter (path loss)
- **interference from other sources:** wireless network frequencies (e.g., 2.4 GHz) shared by many devices (e.g., WiFi, cellular, motors): interference
- **multipath propagation:** radio signal reflects off objects ground, arriving at destination at slightly different times

.... make communication across (even a point to point) wireless link much more “difficult”



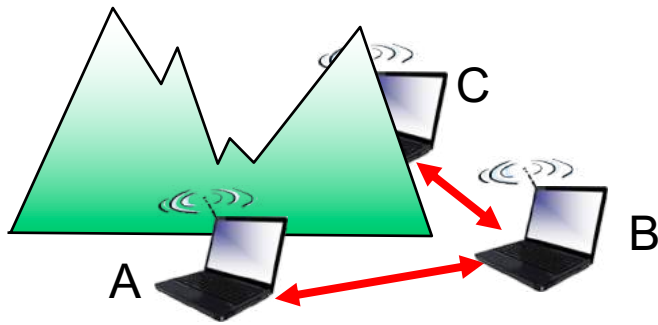
Wireless link characteristics (2)

- 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)



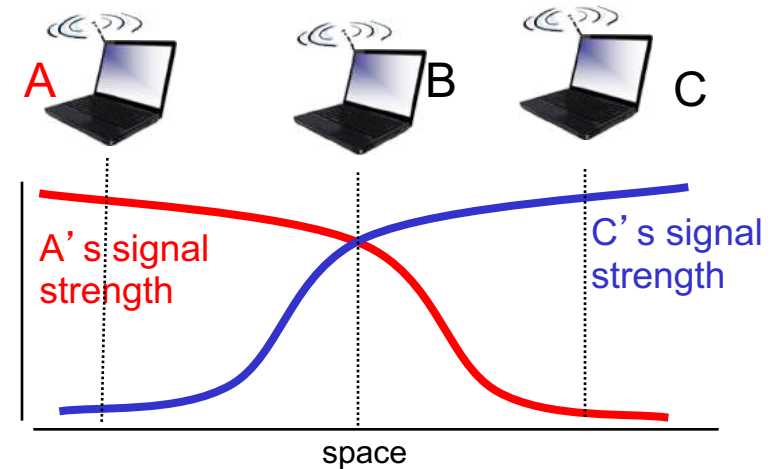
Wireless link characteristics (3)

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



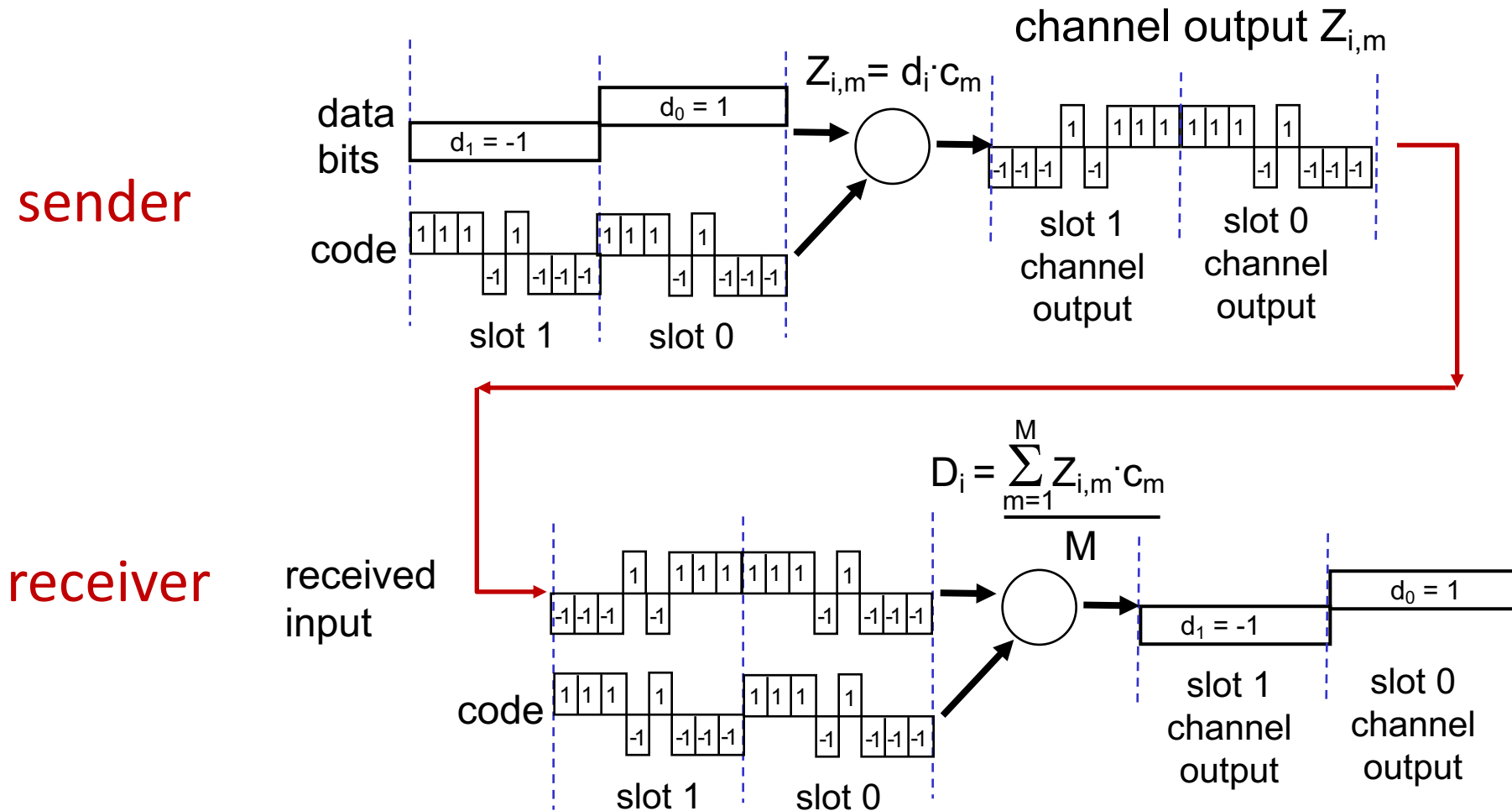
Signal attenuation:

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

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

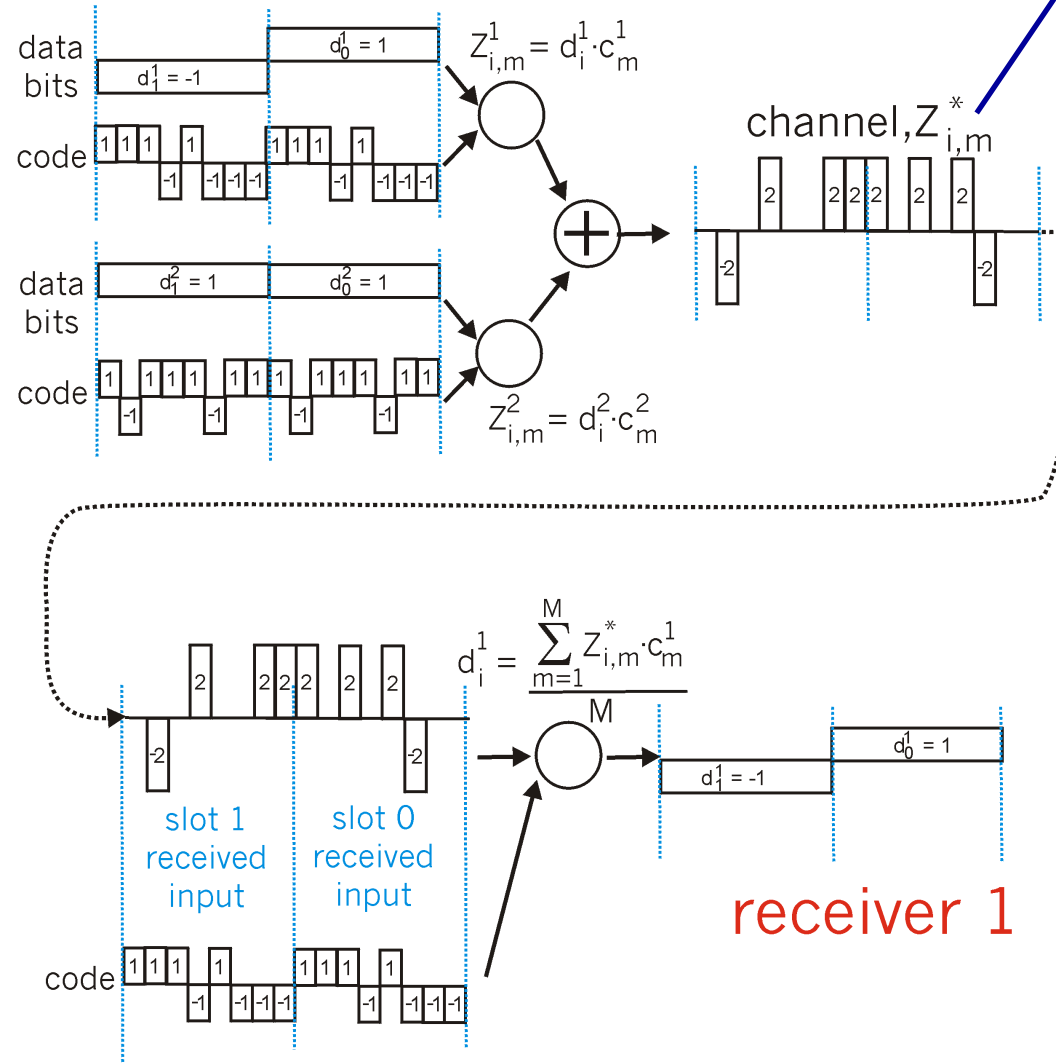


... but this isn't really useful yet!

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!

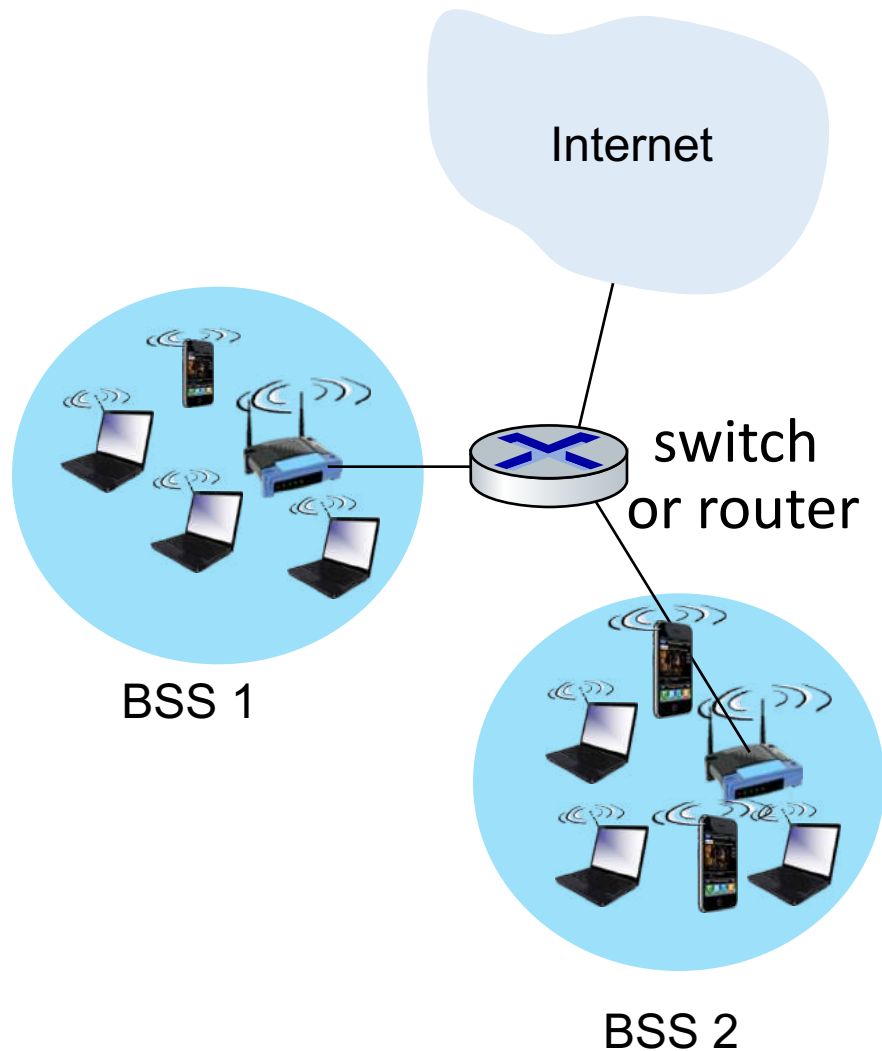
... now *that's* useful!

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



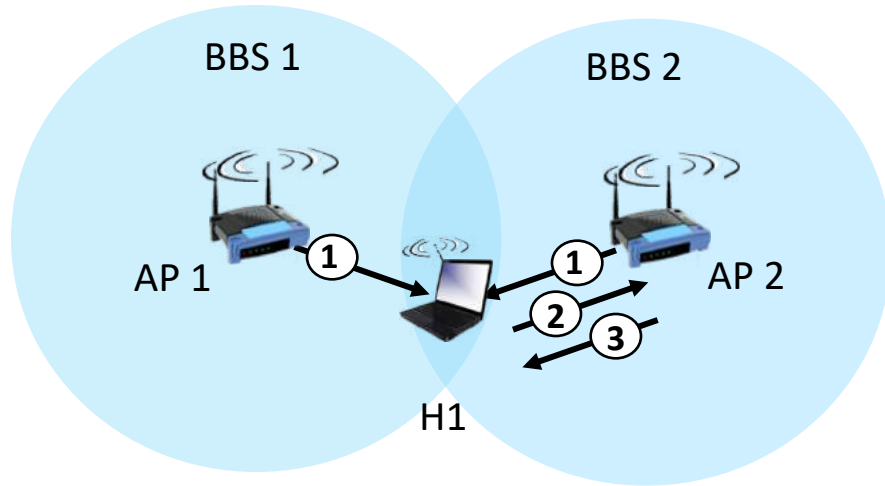
- wireless host communicates with base station
 - base station = access point (AP)
- Basic Service Set (BSS) (aka “cell”) in infrastructure mode contains:
 - wireless hosts
 - access point (AP): base station
 - ad hoc mode: hosts only

802.11: Channels, association

- 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!
- 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

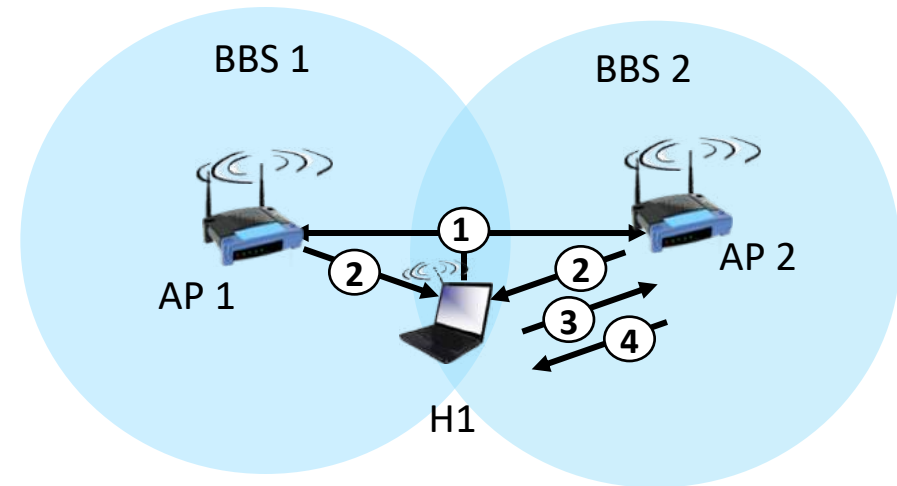


802.11: passive/active scanning



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

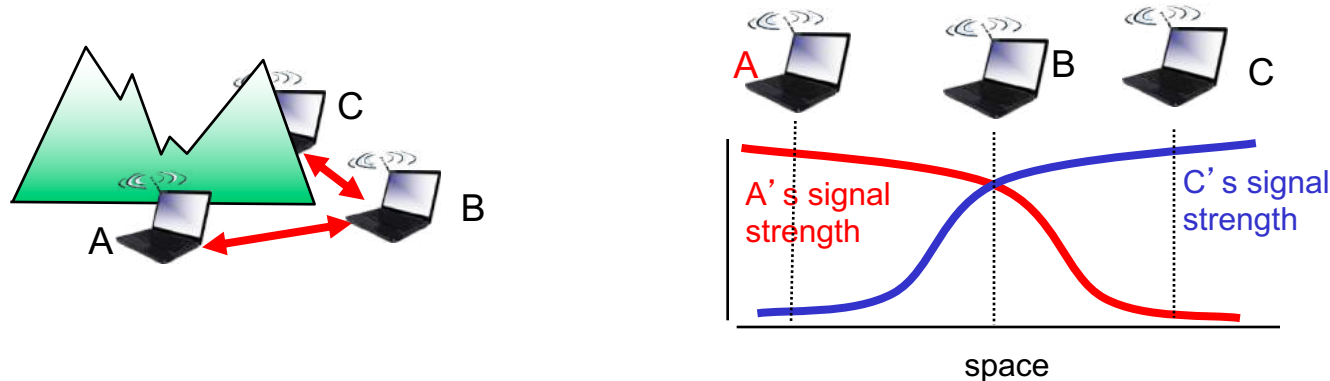


active scanning:

- (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



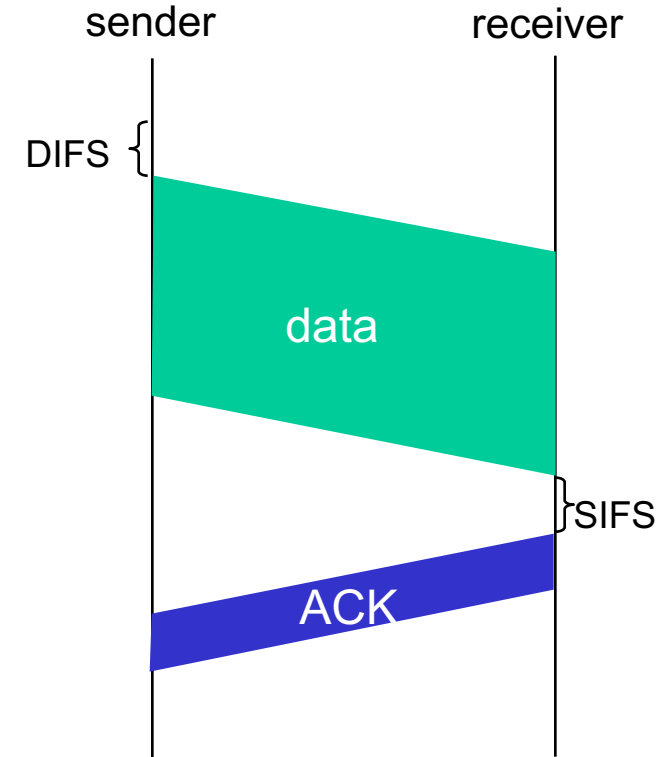
IEEE 802.11 MAC Protocol: CSMA/CA

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)

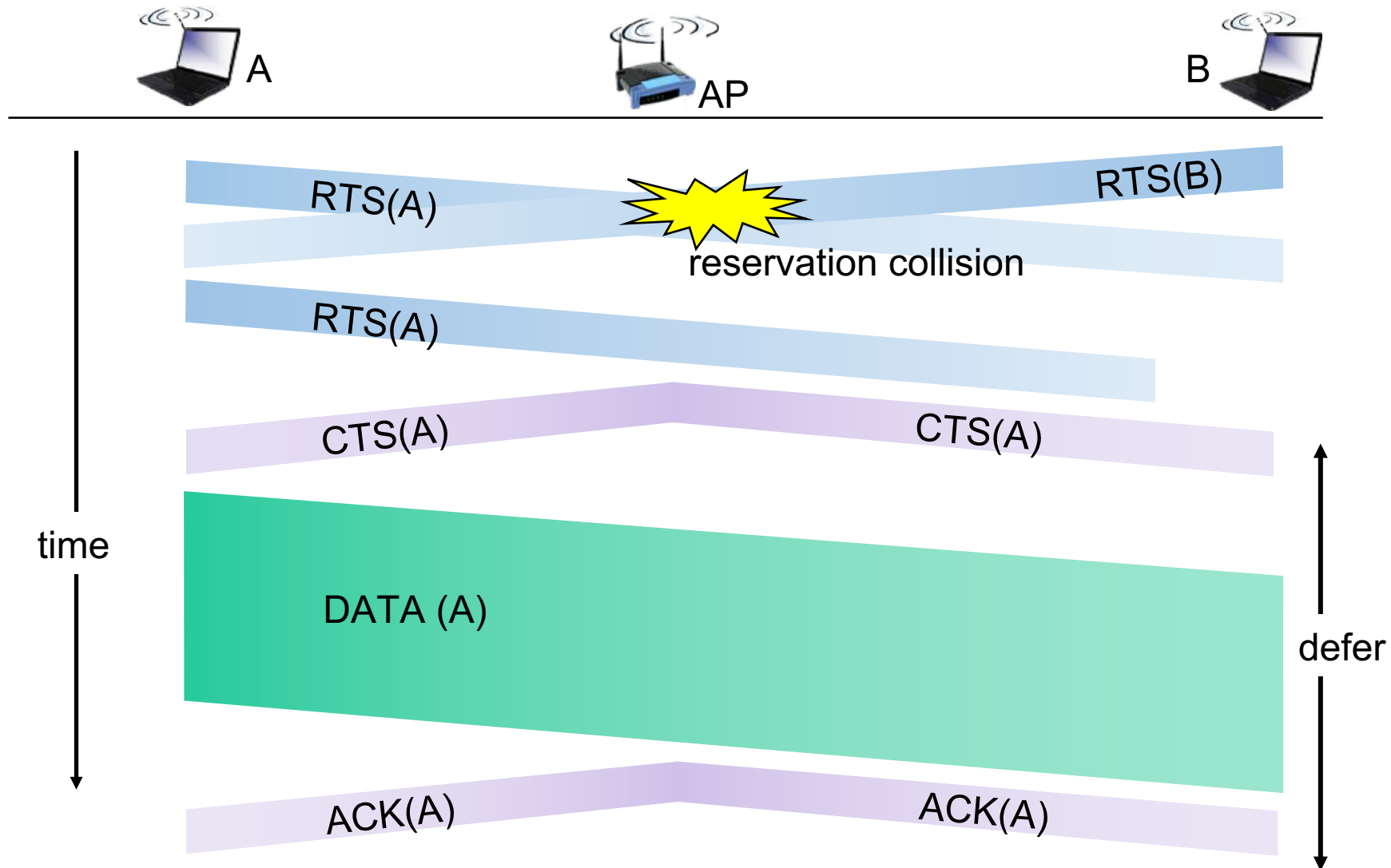


Avoiding collisions (more)

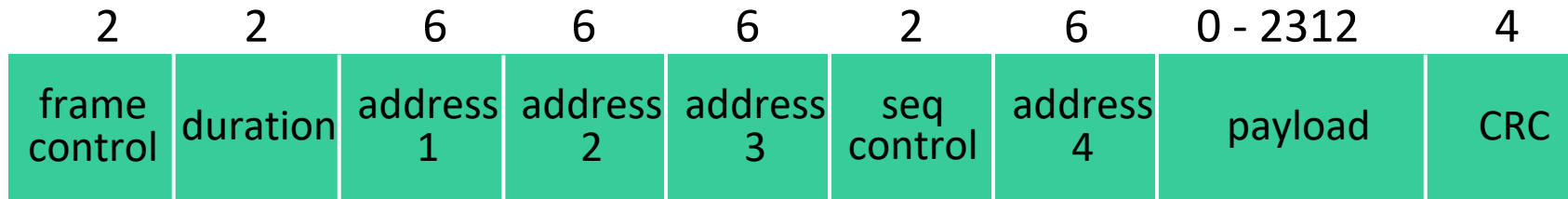
idea: sender “reserves” channel use for data frames using small reservation packets

- 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



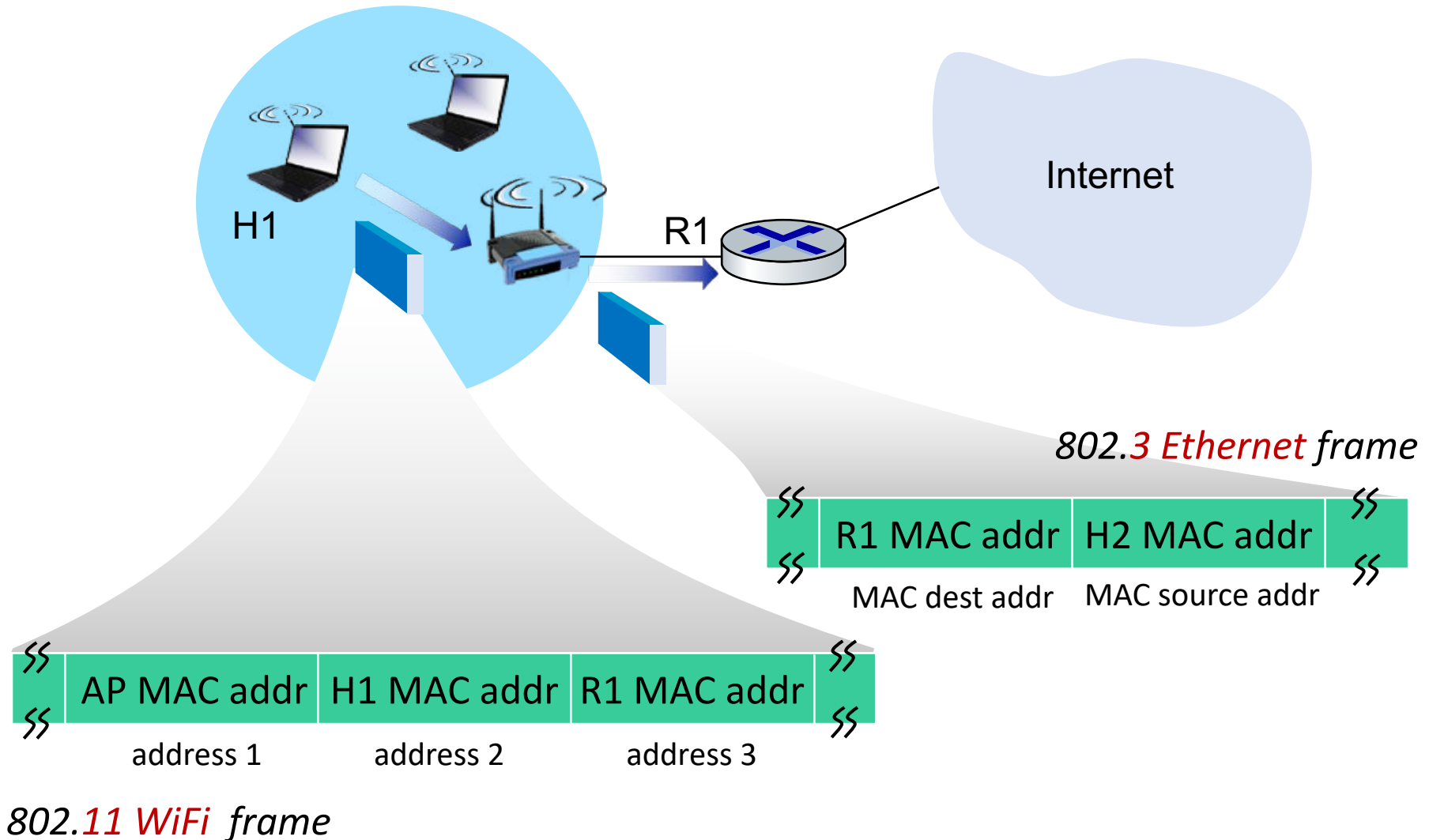
Address 1: MAC address of wireless host or AP to receive this frame

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

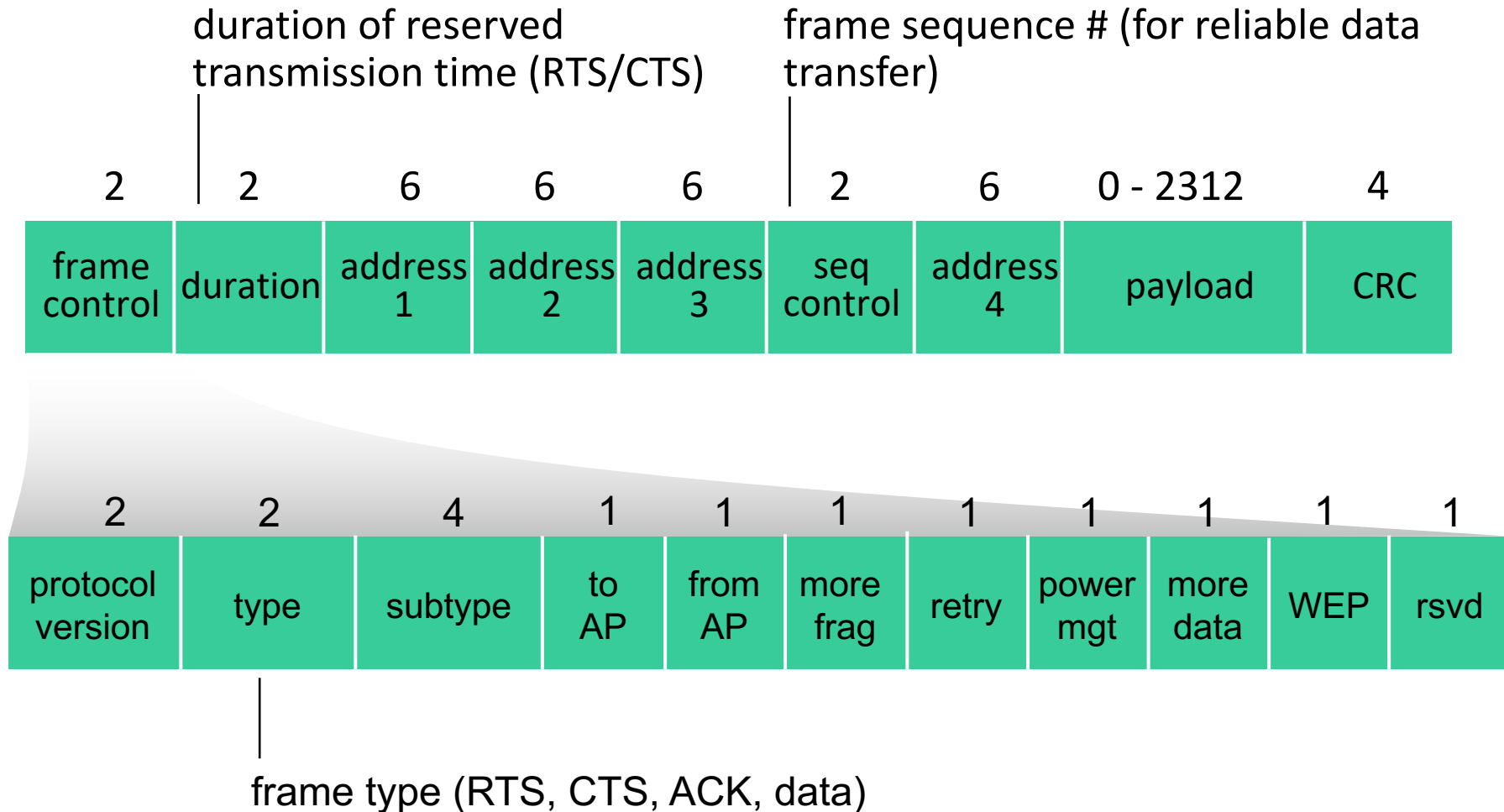
Address 3: MAC address of router interface to which AP is attached

Address 4: used only in ad hoc mode

802.11 frame: addressing

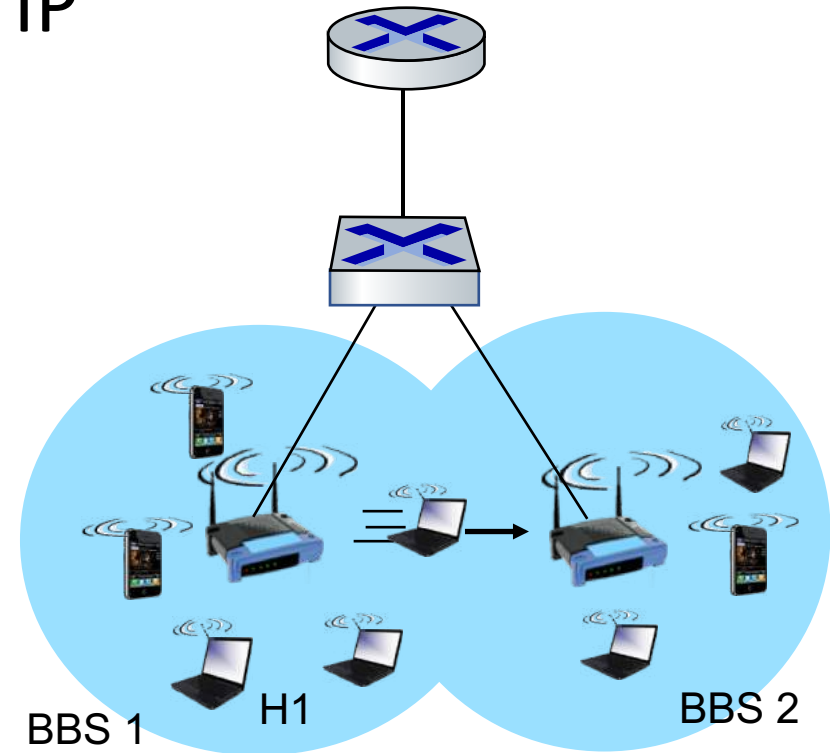


802.11 frame: addressing



802.11: mobility within same subnet

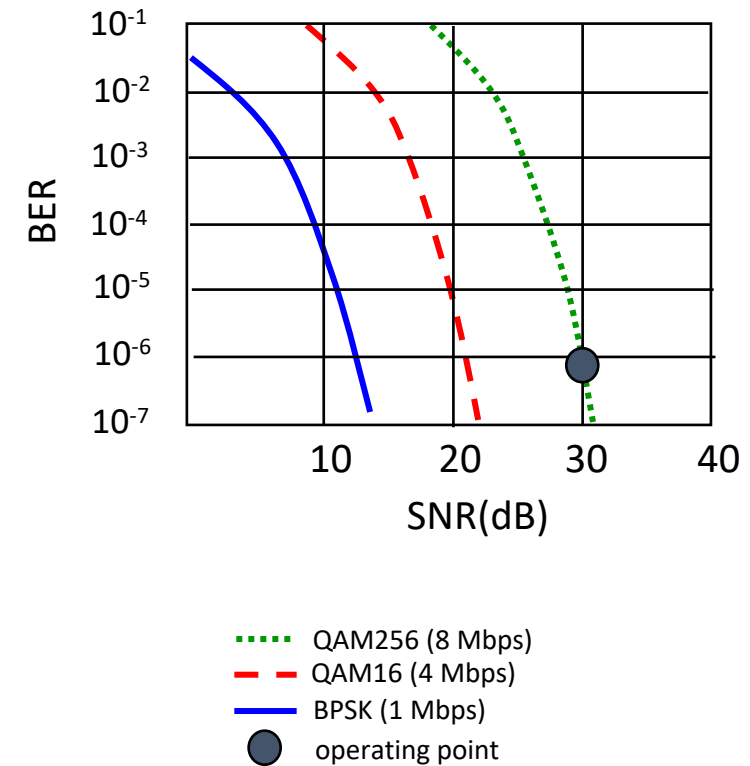
- H1 remains in same IP subnet: IP address can remain same
- switch: which AP is associated with H1?
 - self-learning (Ch. 6): switch will see frame from H1 and “remember” which switch port can be used to reach H1



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