Introduction to Computer Networks (SWE3022)

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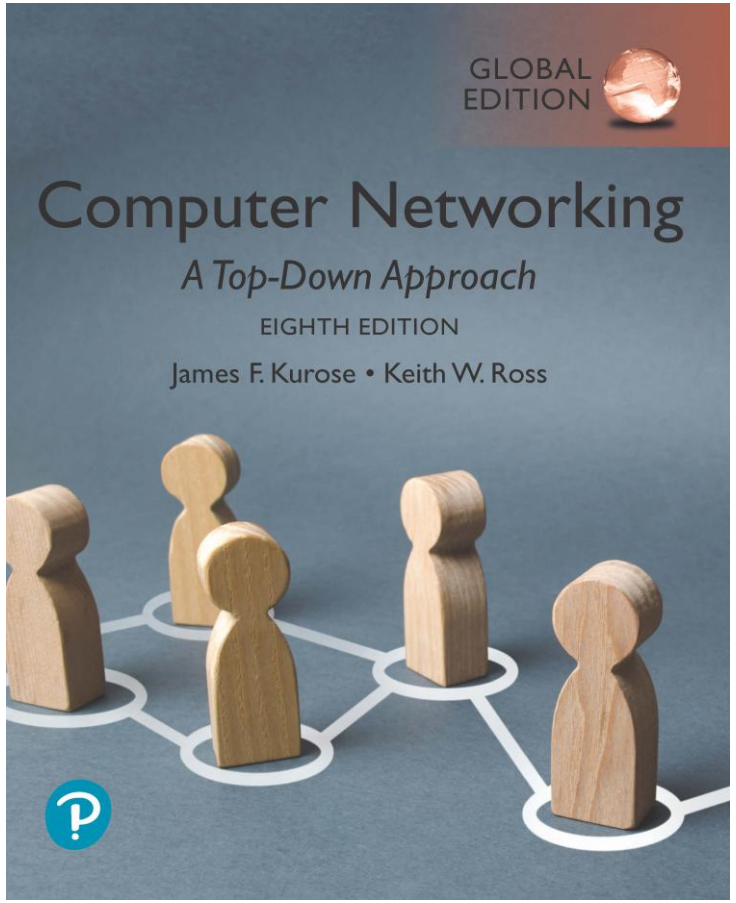
Note: The slides are adapted from the slides of Pearson Education Ltd.

Chapter 7. Wireless and Mobile Networks: Part 1



Computer Networking: A Top-Down Approach

8th Edition, Global Edition
Jim Kurose, Keith Ross

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 Software-Defined Networking (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

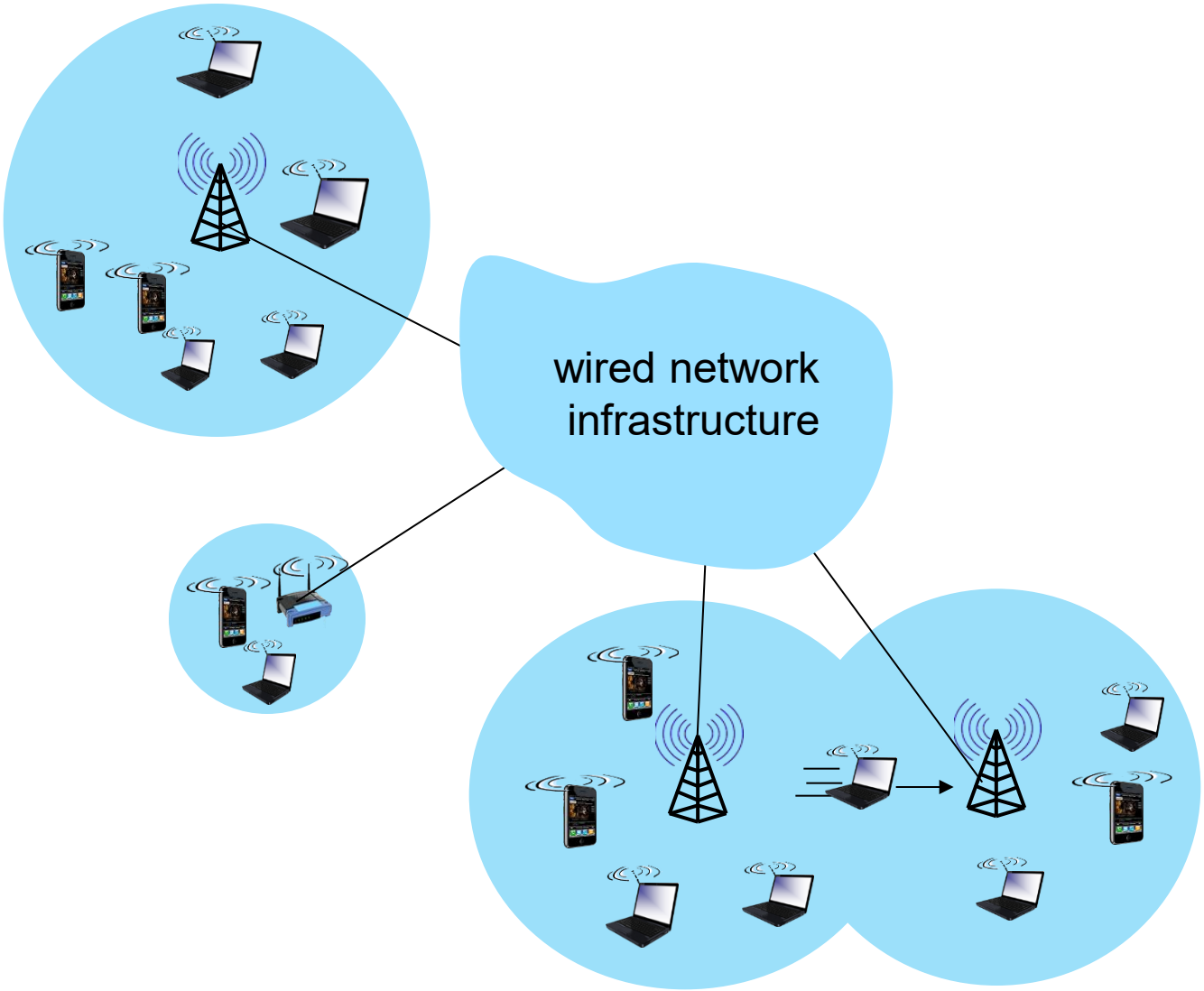
Wireless

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

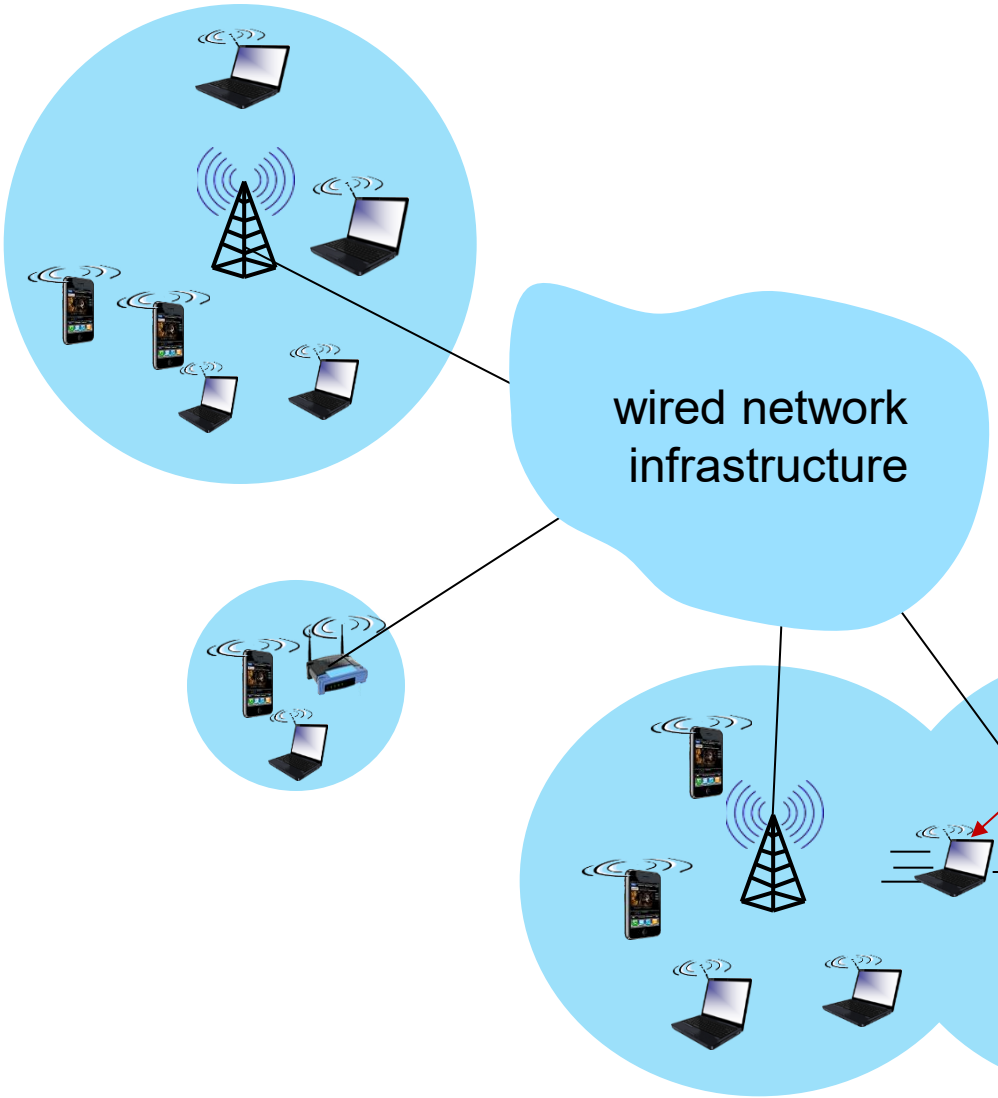
Mobility

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

Elements of a wireless network



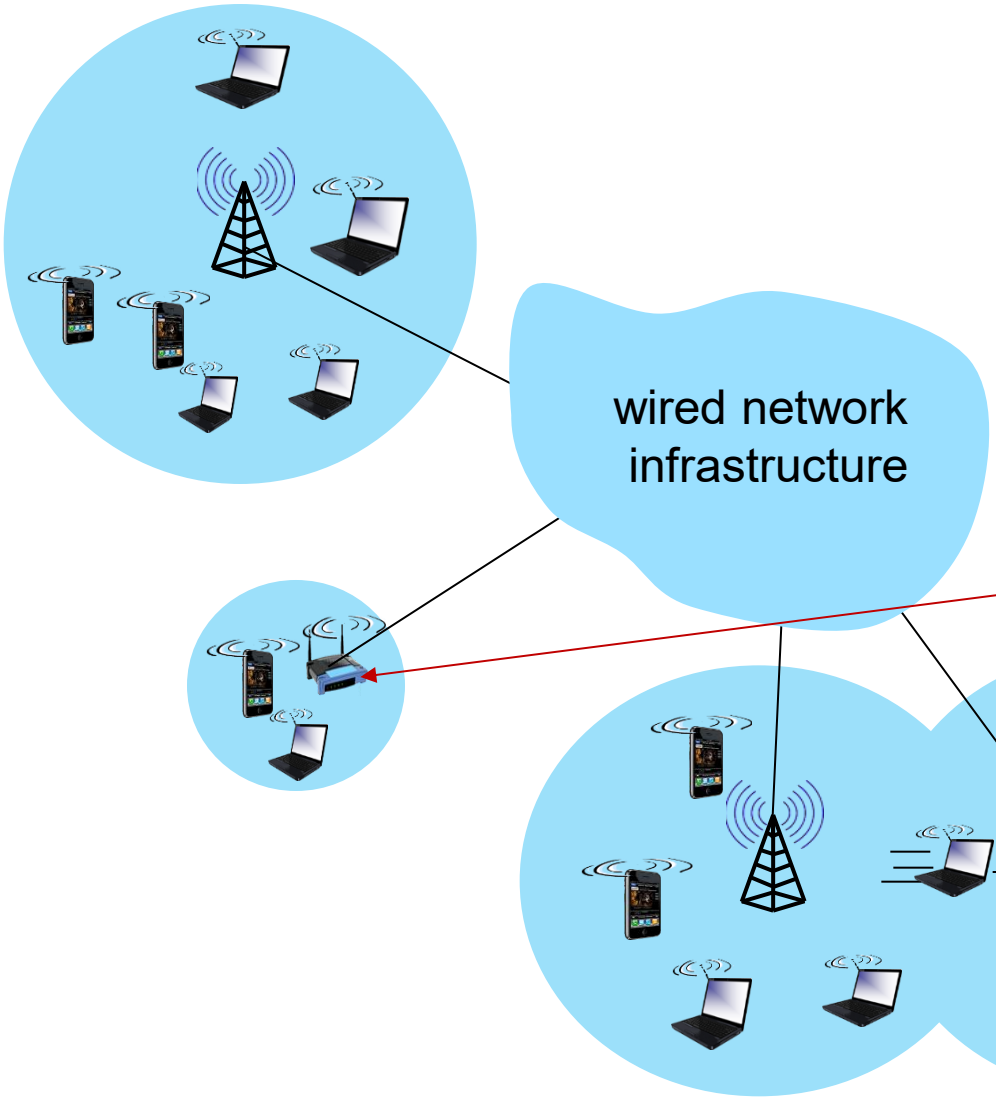
Elements of a wireless network



Wireless Hosts

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

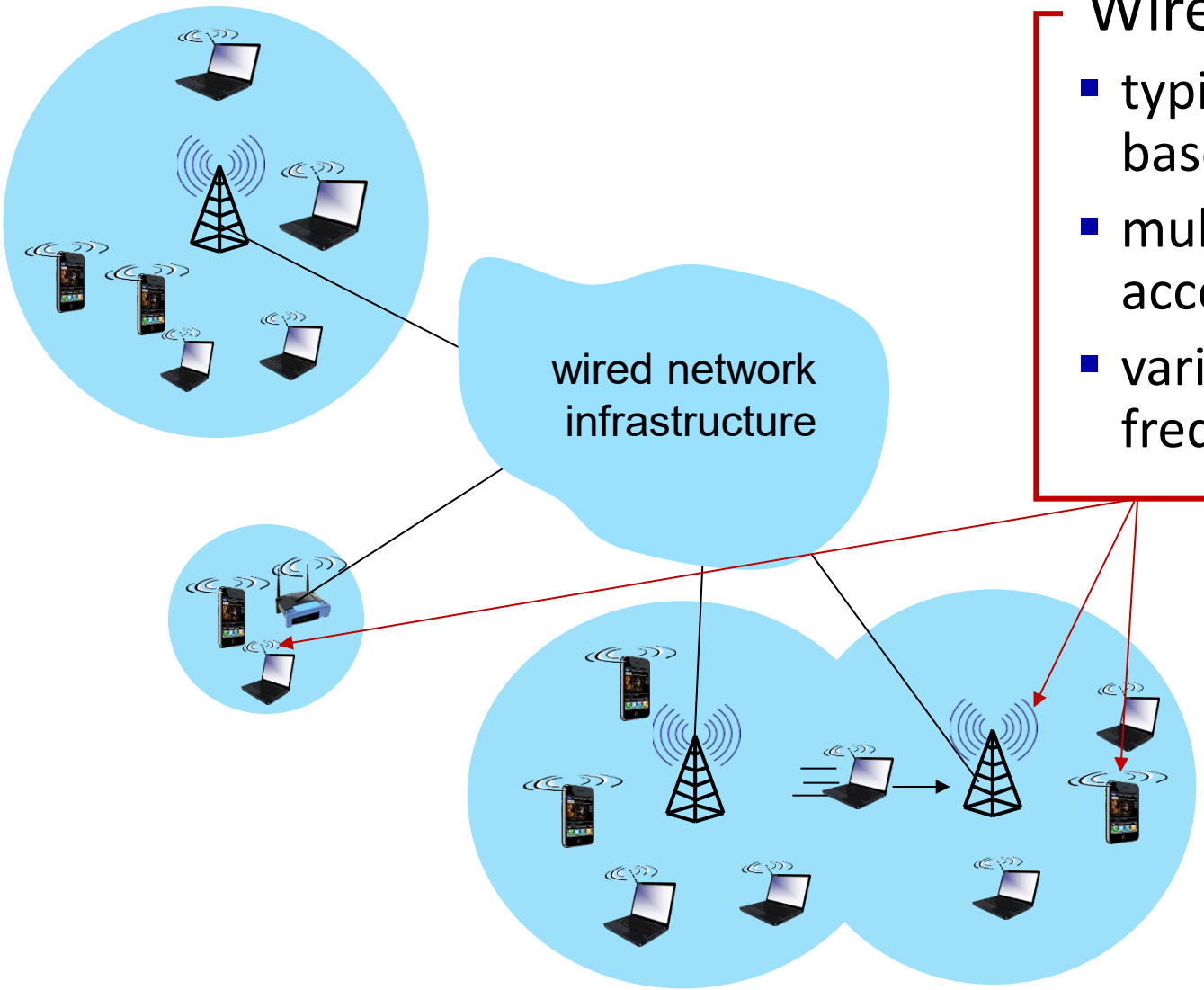
Elements of a wireless network



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 (APs)

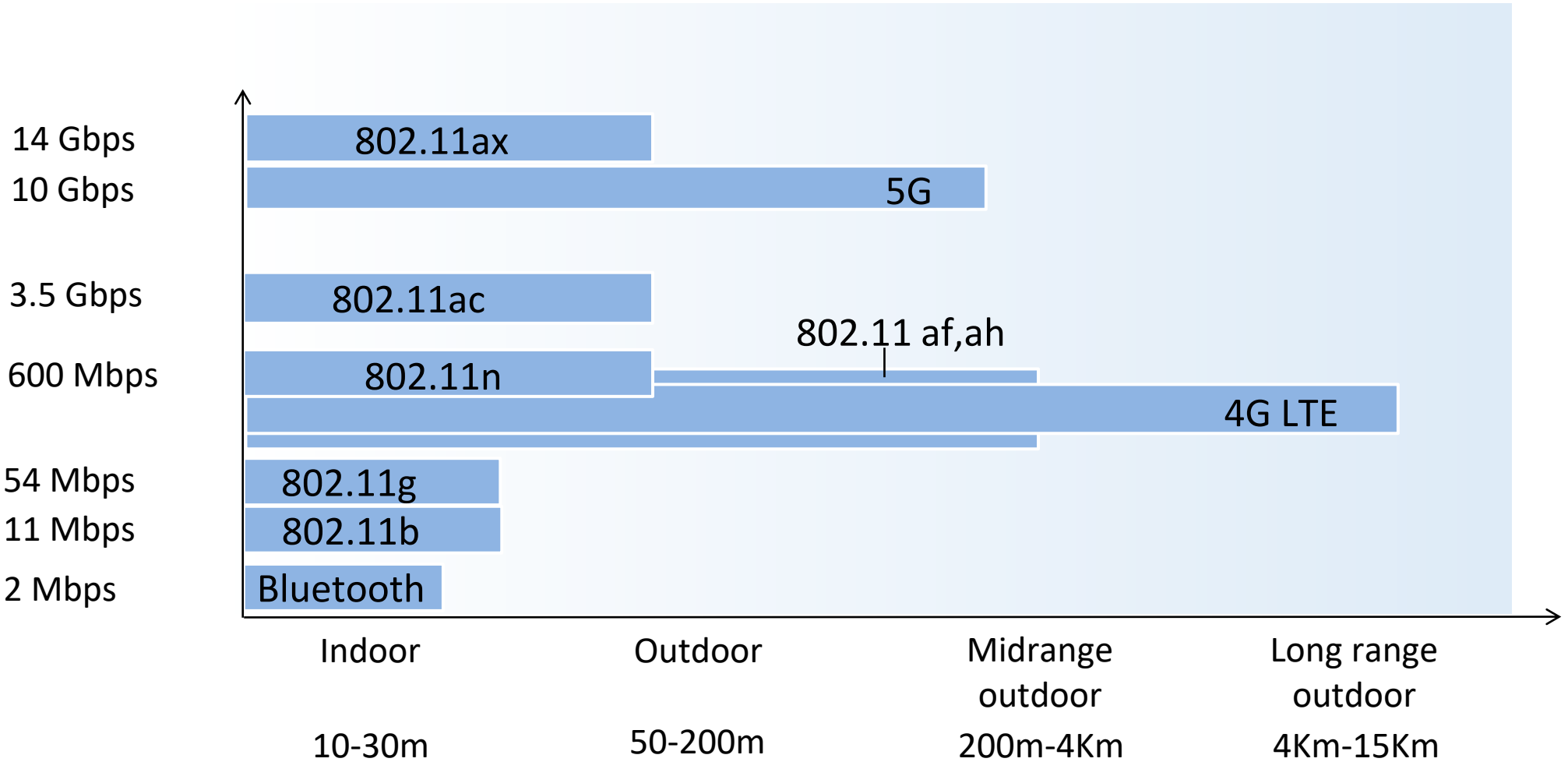
Elements of a wireless network



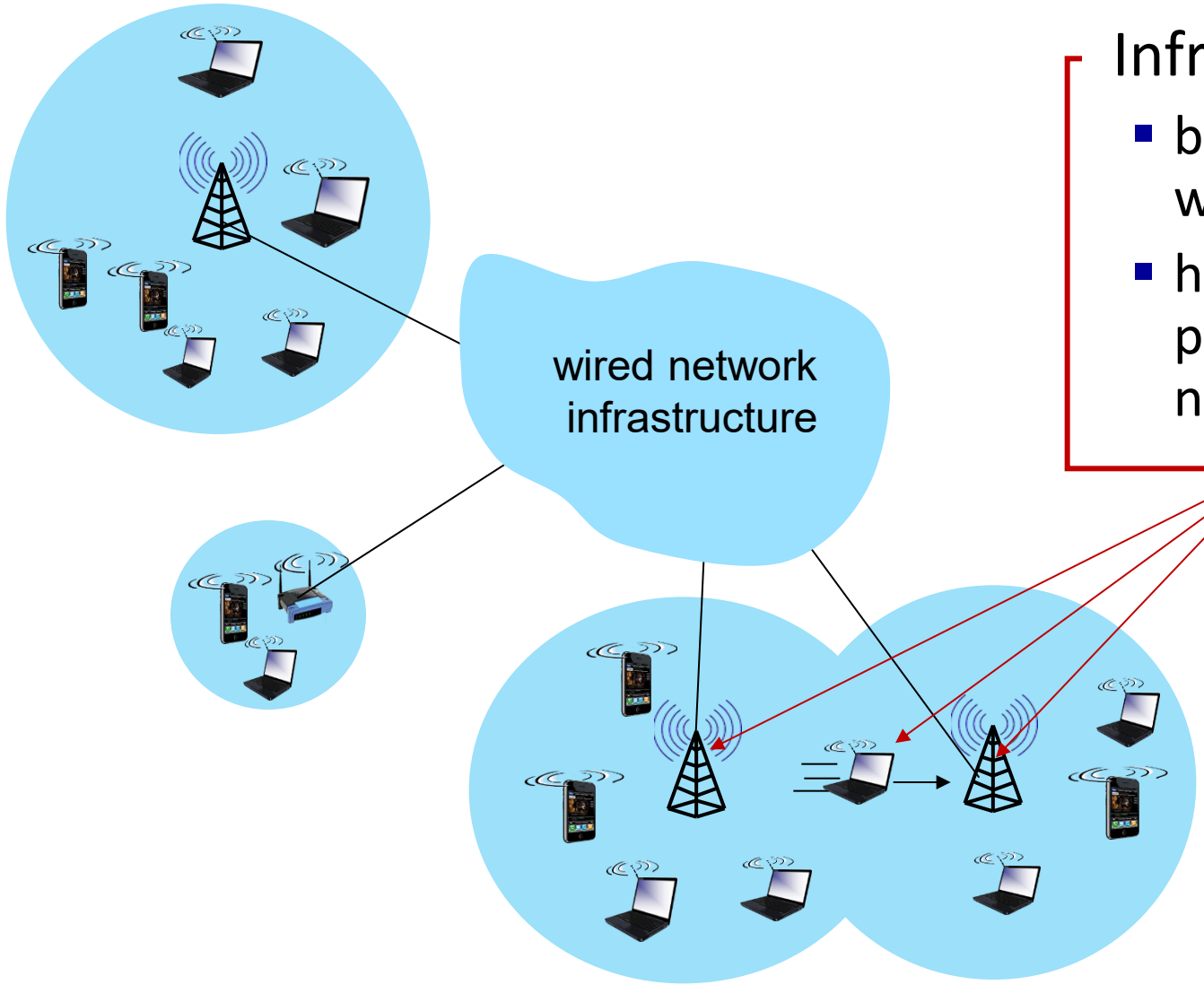
Wireless Link

- 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



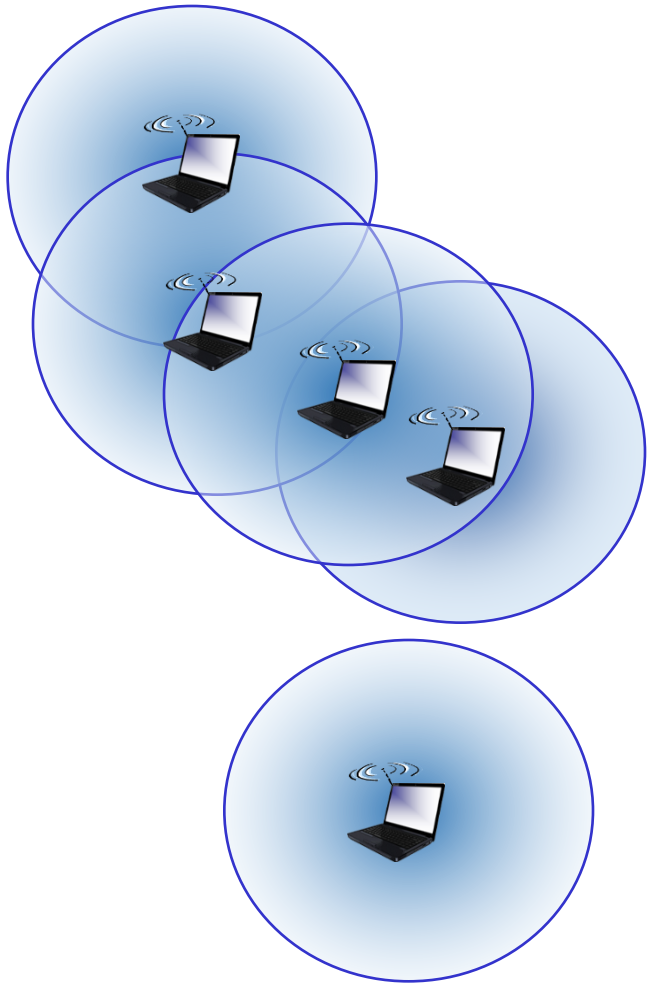
Elements of a wireless network



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: *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 another via other mobile(s) in MANET or VANET

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- Mobility management: practice
  - 4G/5G networks
  - Mobile IP
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Wireless link characteristics (1)

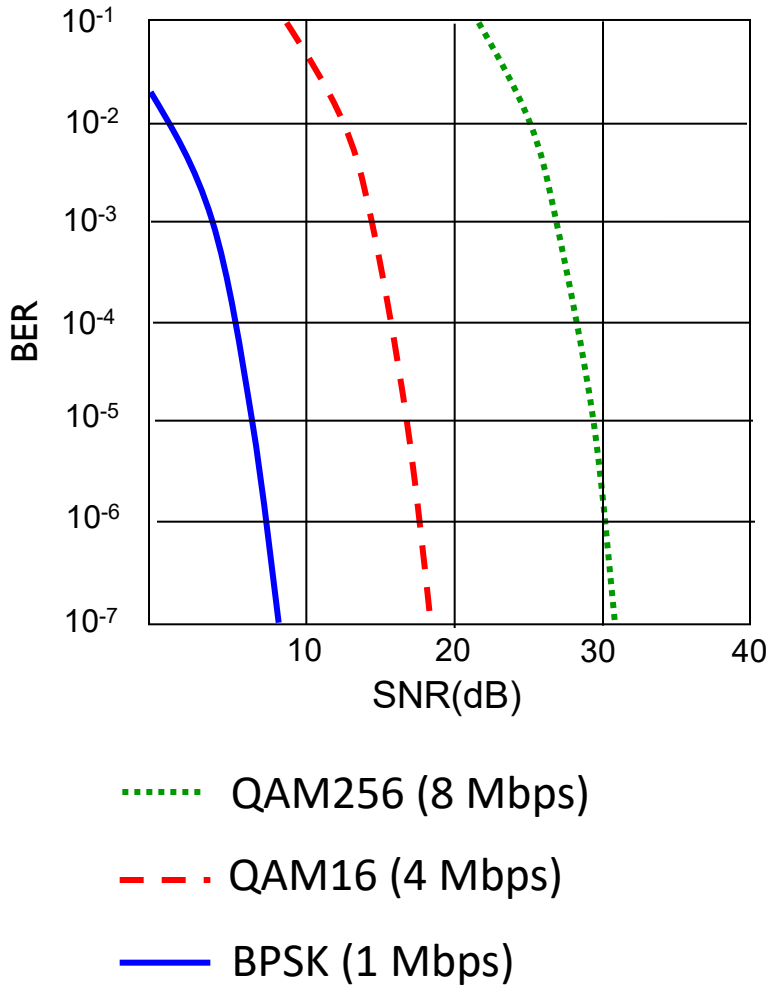
important differences from wired link ….

- 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 on the ground, arriving at destination at slightly different times

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

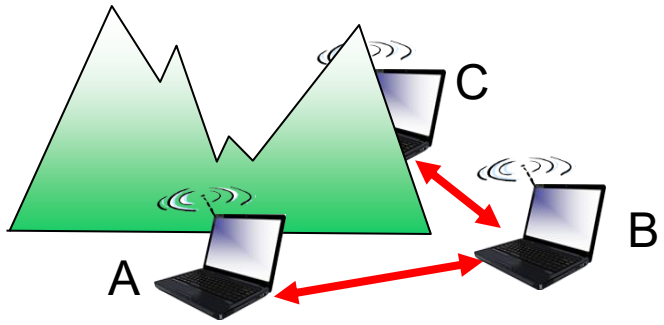
Wireless link characteristics (2)

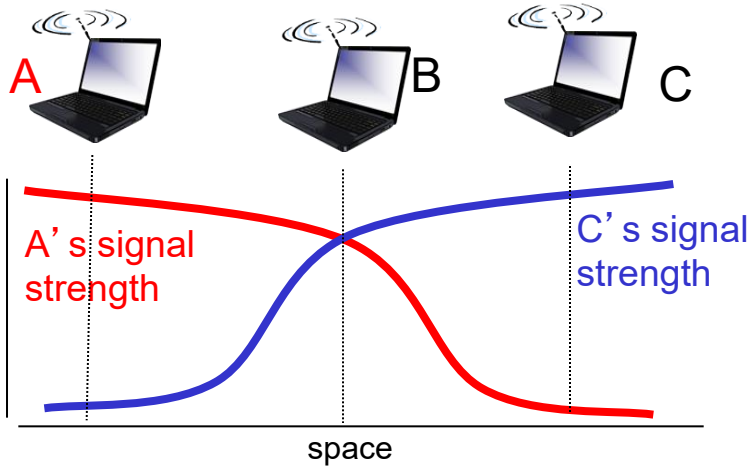
- SNR: signal-to-noise ratio
  - larger SNR – easier to extract signal from noise (a "good thing")
- SNR versus BER (bit error rate) tradeoffs
  - *given physical layer:* increase power -> increase SNR->decrease BER
  - *given SNR:* choose physical layer that meets BER requirement, giving highest throughput
    - 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 cannot hear each other means A, C are unaware of their interference at B

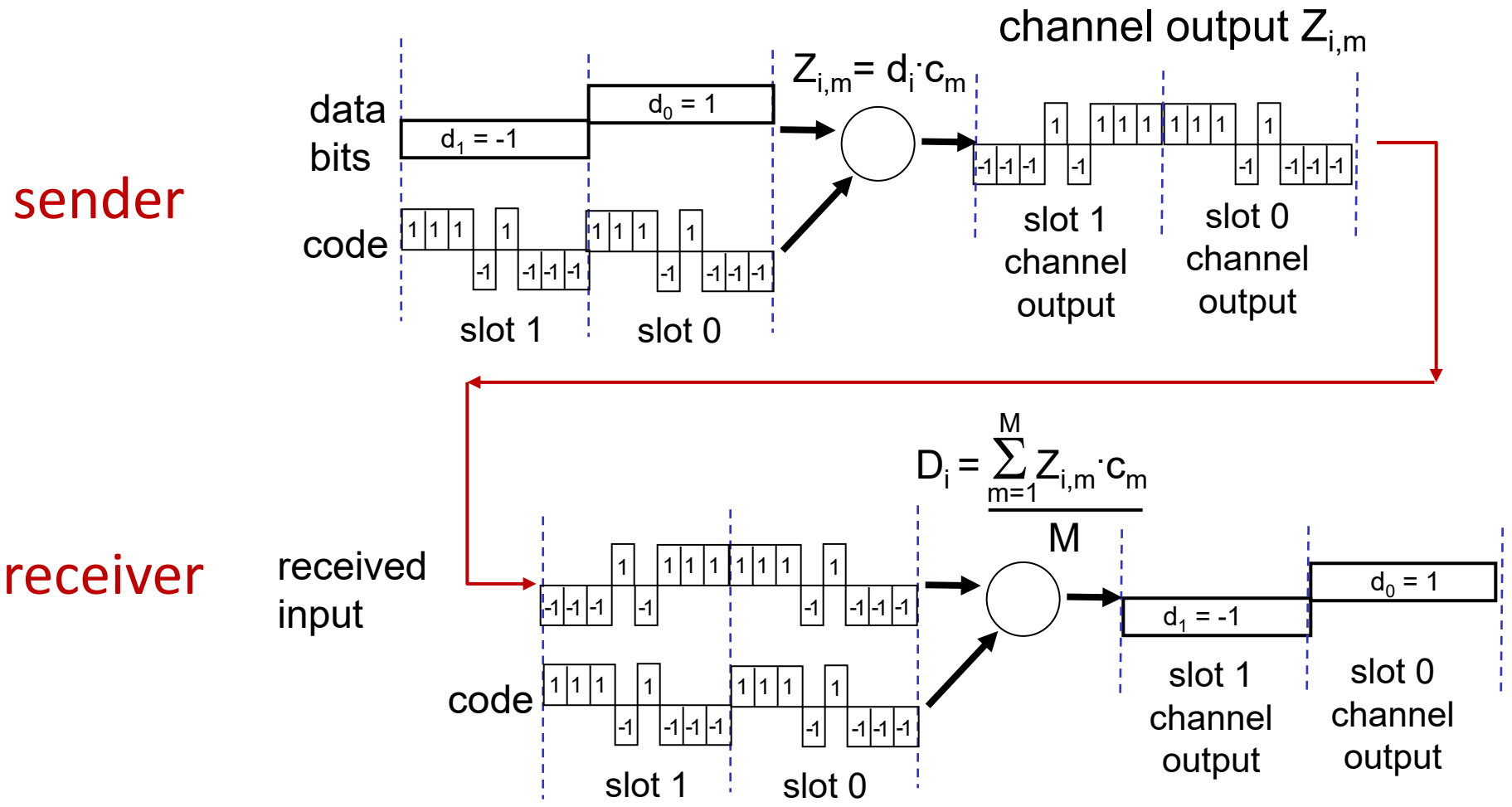
Signal attenuation:

- B, A hear each other
- B, C hear each other
- A, C cannot 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) X (chipping sequence)
- decoding: summed inner-product: (encoded data) X (chipping sequence)

CDMA encode/decode

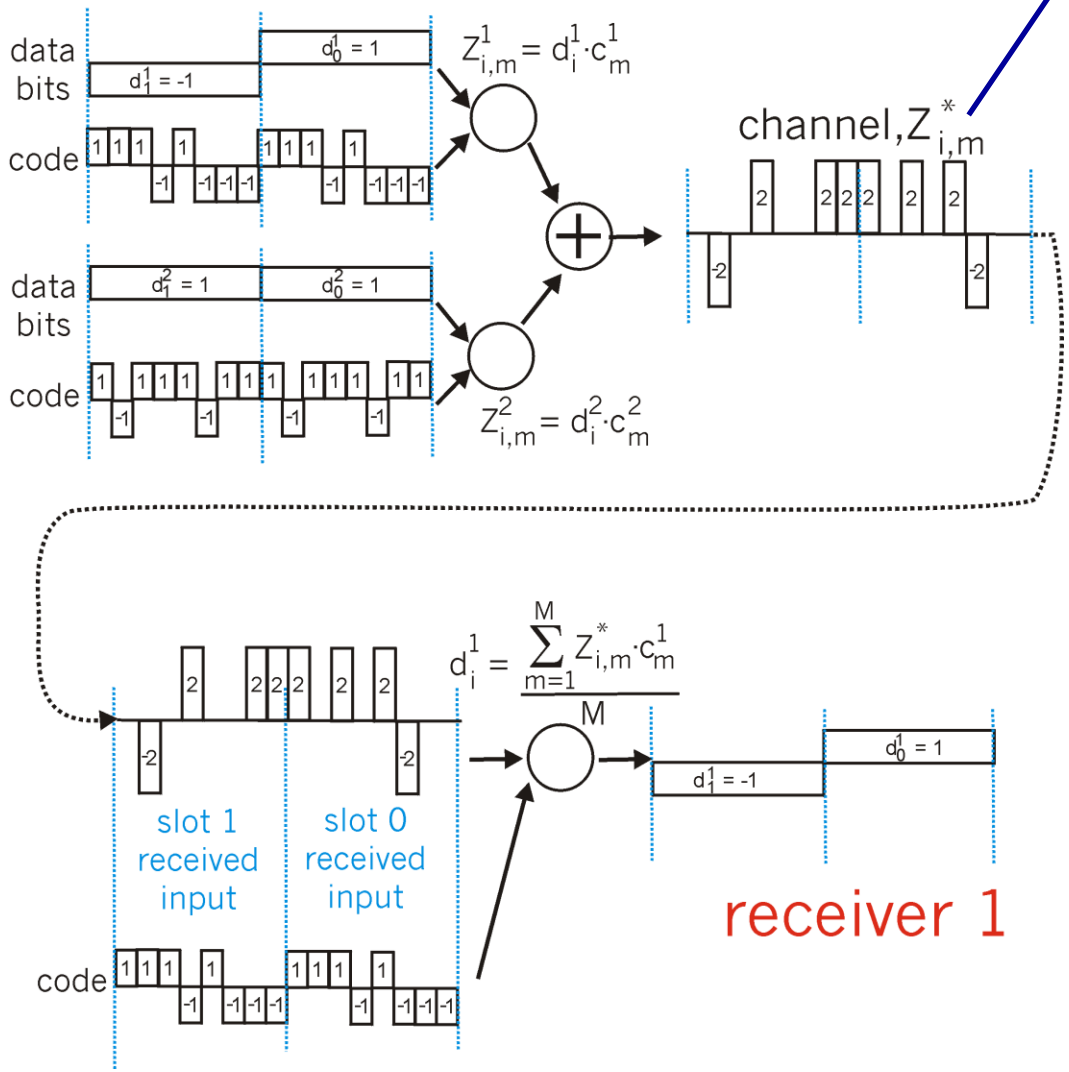


… but this isn't really useful yet!

CDMA: two-sender interference

Sender 1

Sender 2



channel sums together transmissions by sender 1 and 2

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

… now *that's* useful!

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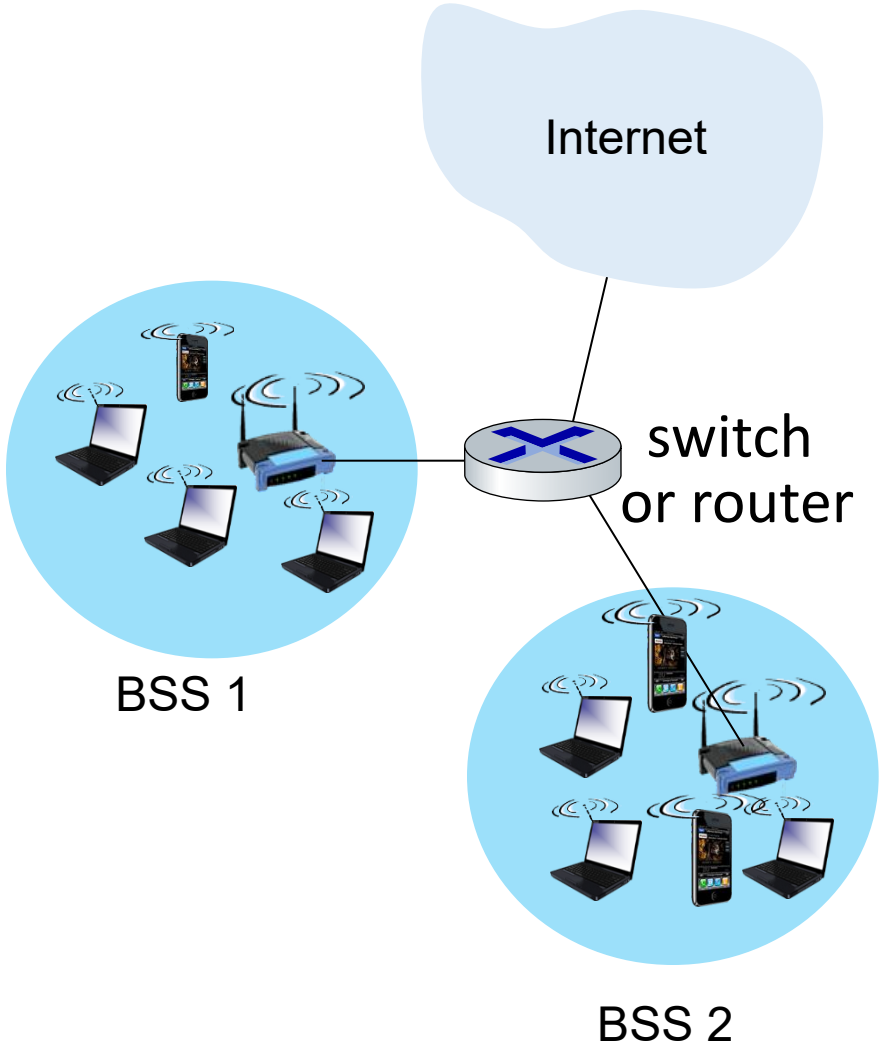
IEEE 802.11 Wireless LAN

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 (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

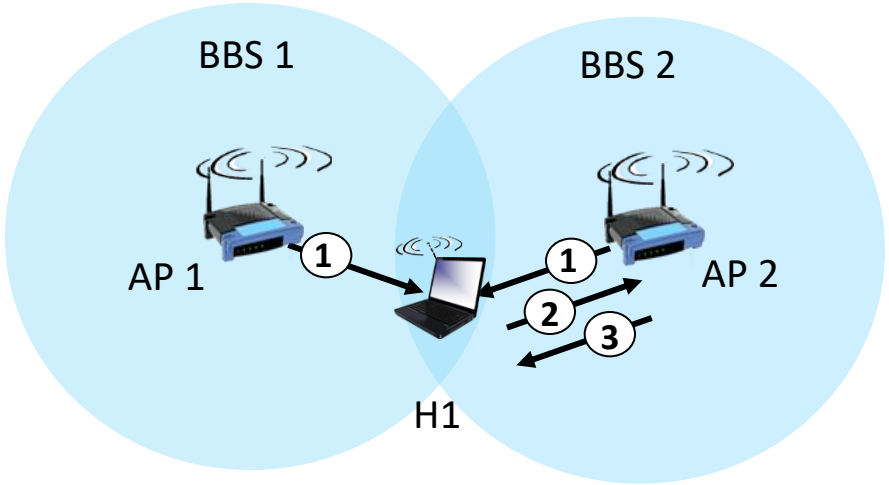


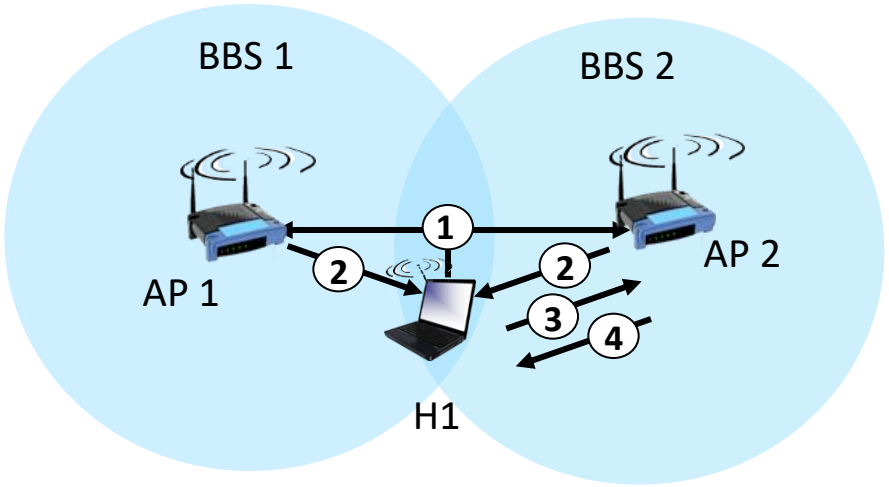
- wireless host communicates with base station
  - base station = access point (AP)
- Basic Service Set (BSS) (aka “cell”) in infrastructure mode contains:
  - wireless hosts
  - access point (AP): base station
  - ad hoc mode: hosts only

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 (Dynamic Host Configuration Protocol) to get IP address in AP's subnet

802.11: passive/active scanning





passive scanning:

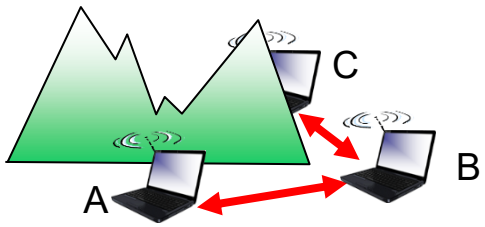
(1) beacon frames sent from APs
(2) association Request frame sent: H1 to selected AP
(3) association Response frame sent from selected AP to H1

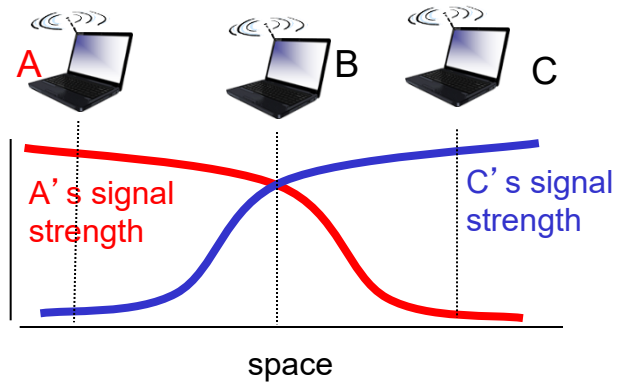
active scanning:

(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 (Carrier Sense Multiple Access) - 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

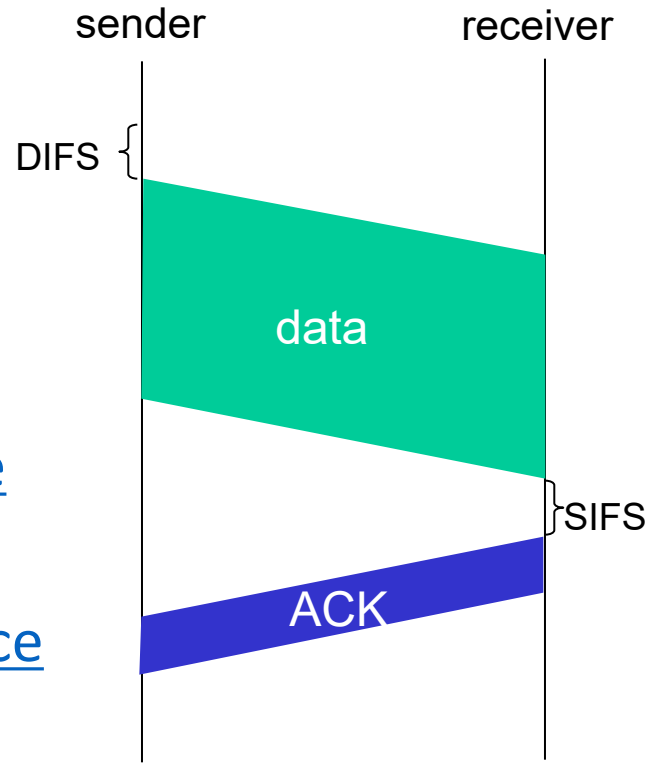




IEEE 802.11 MAC Protocol: CSMA/CA (1)

Definitions for 802.11

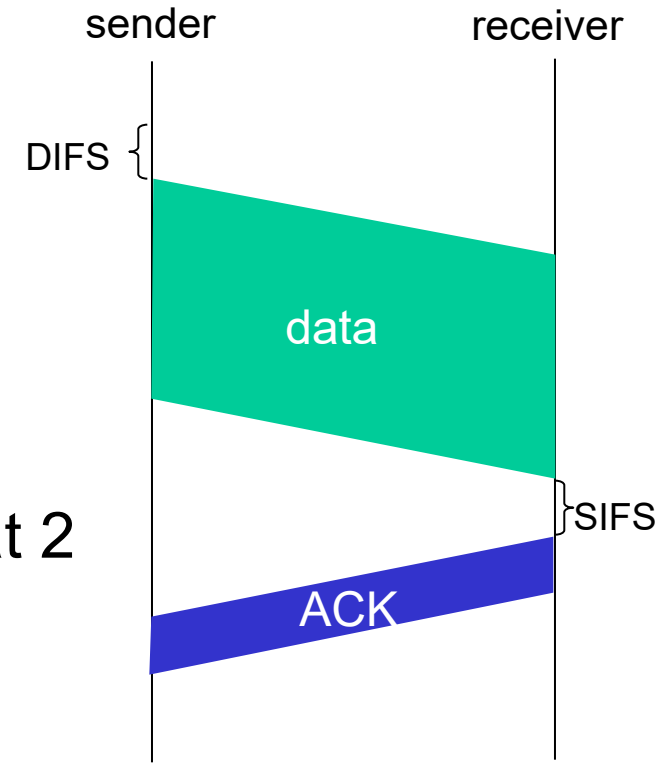
- DCF: Distributed Coordination Function
  - Ad Hoc Mode
- PCF: Point Coordination Function
  - Infrastructure Mode
- DIFS: DCF Interframe Space
  - https://en.wikipedia.org/wiki/DCF_Interframe_Space
- SIFS: Short Interframe Space
  - https://en.wikipedia.org/wiki/Short_Interframe_Space
- Slot time: 9 ~ 50 microseconds
- DIFS = SIFS + (2 * Slot time)



IEEE 802.11 MAC Protocol: CSMA/CA (2)

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

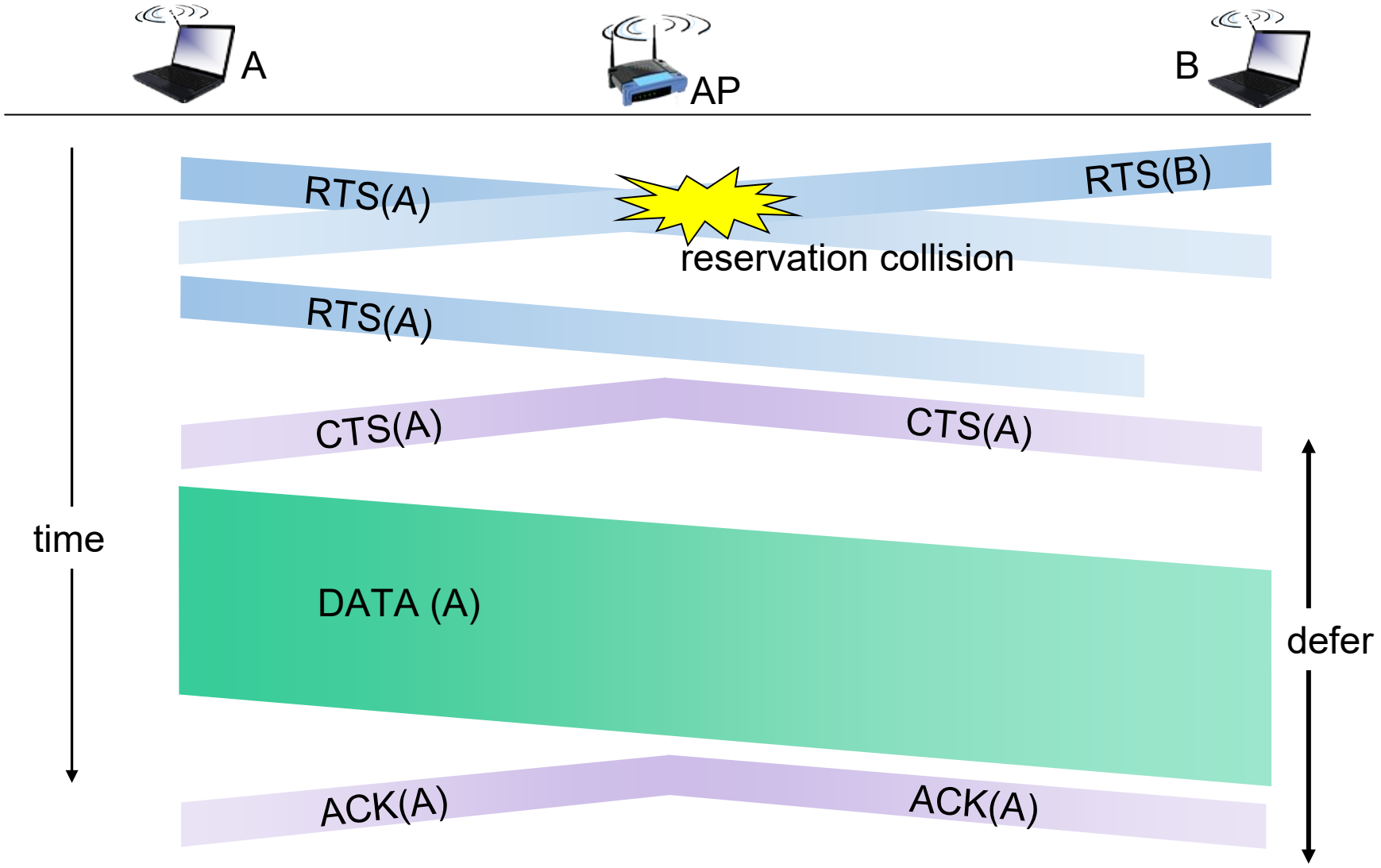
if frame received OK
return ACK after **SIFS** (ACK needed due to hidden terminal problem)

Avoiding collisions (more)

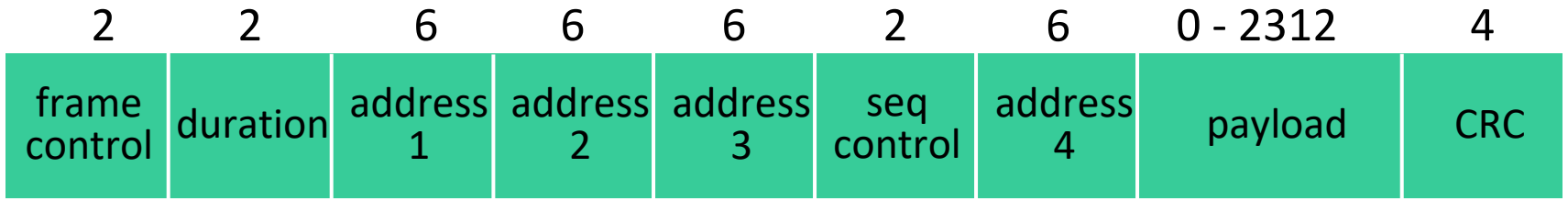
idea: sender "reserves" channel use for data frames using small reservation packets

- 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

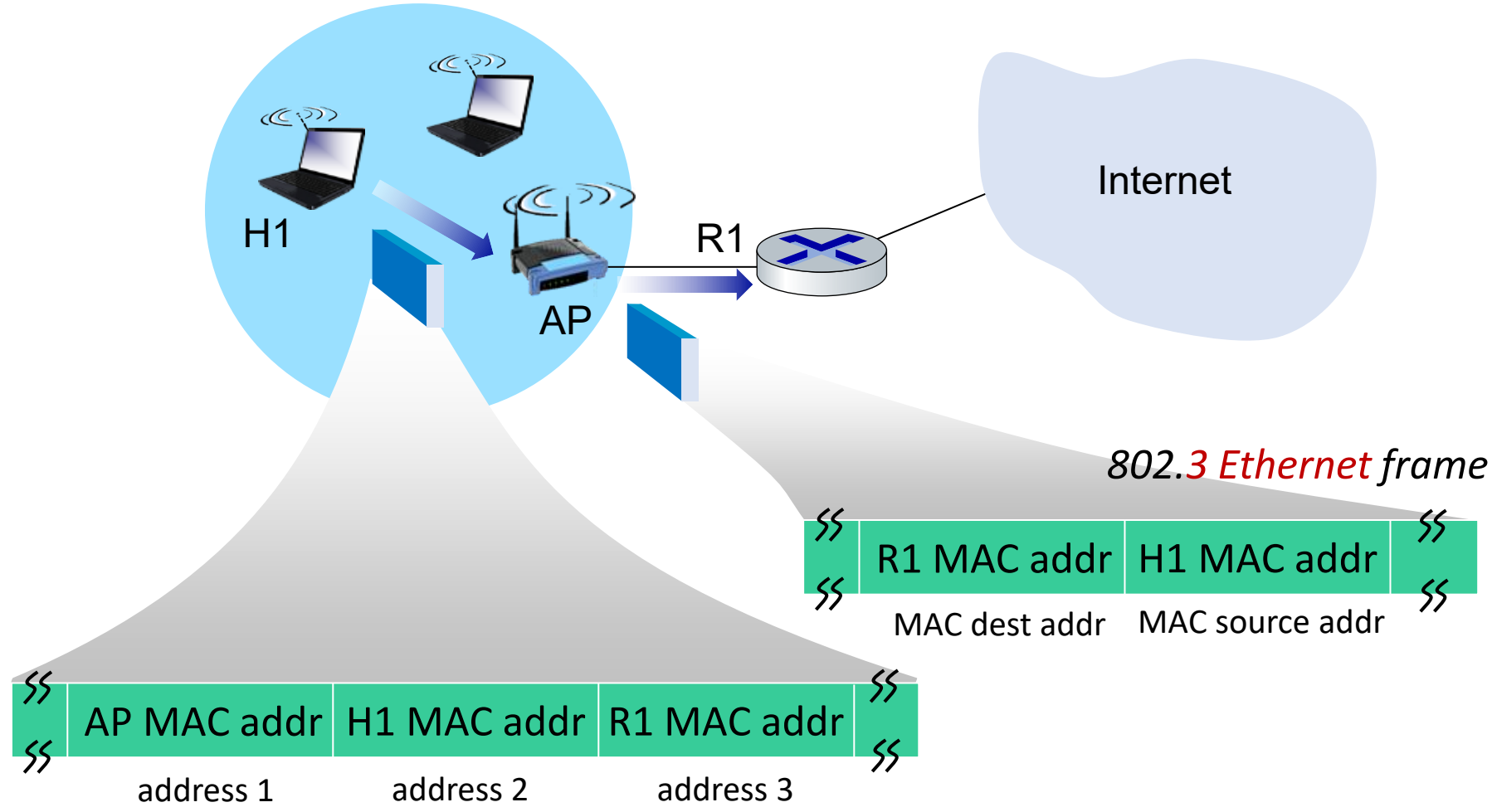
Address 3: MAC address of router interface to which AP is attached

Address 4: used only in ad hoc mode

how to use it? Source Address

https://mrncciew.com/2014/09/28/cwap-mac-headeraddresses/

802.11 frame: addressing



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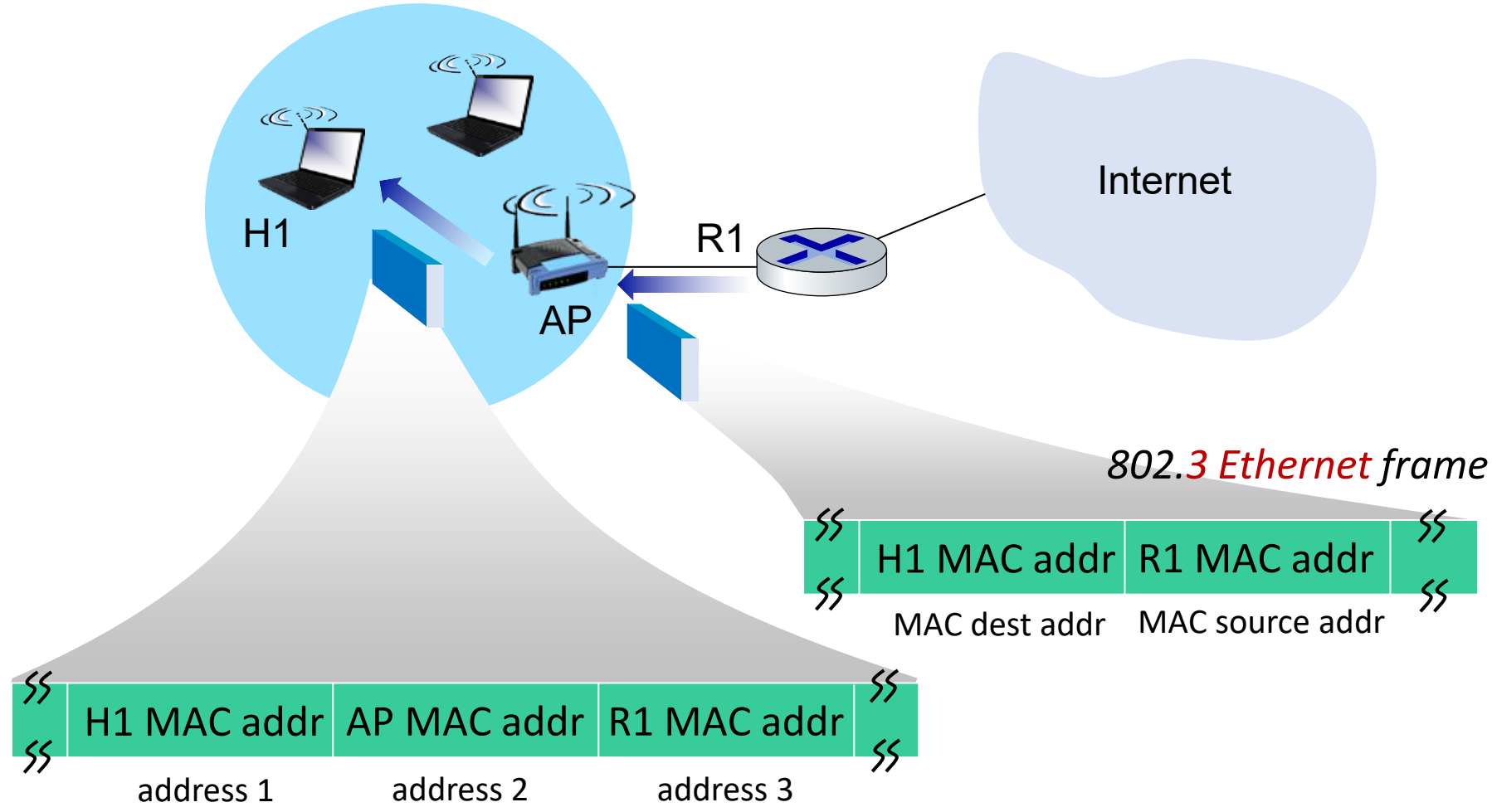
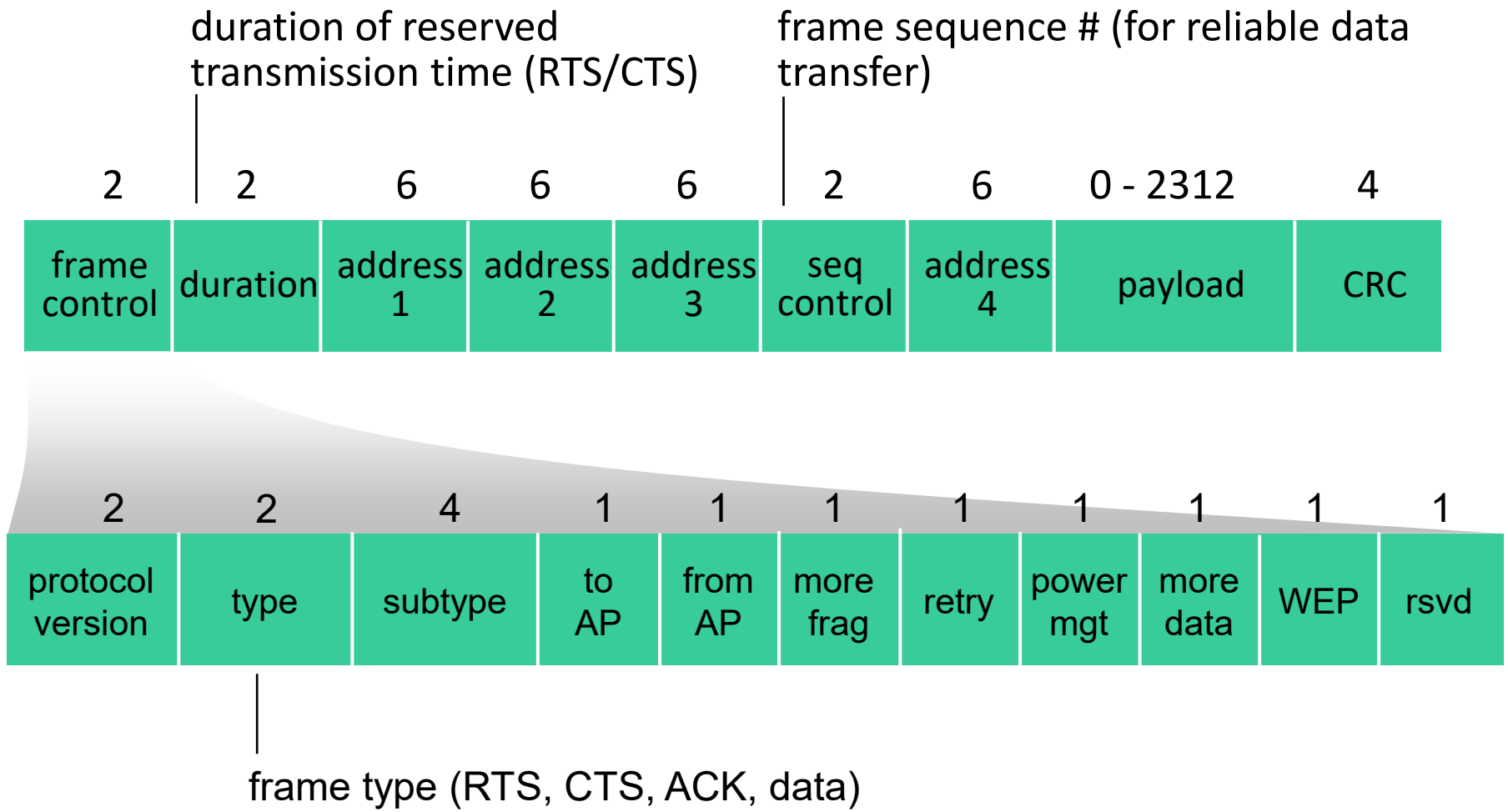
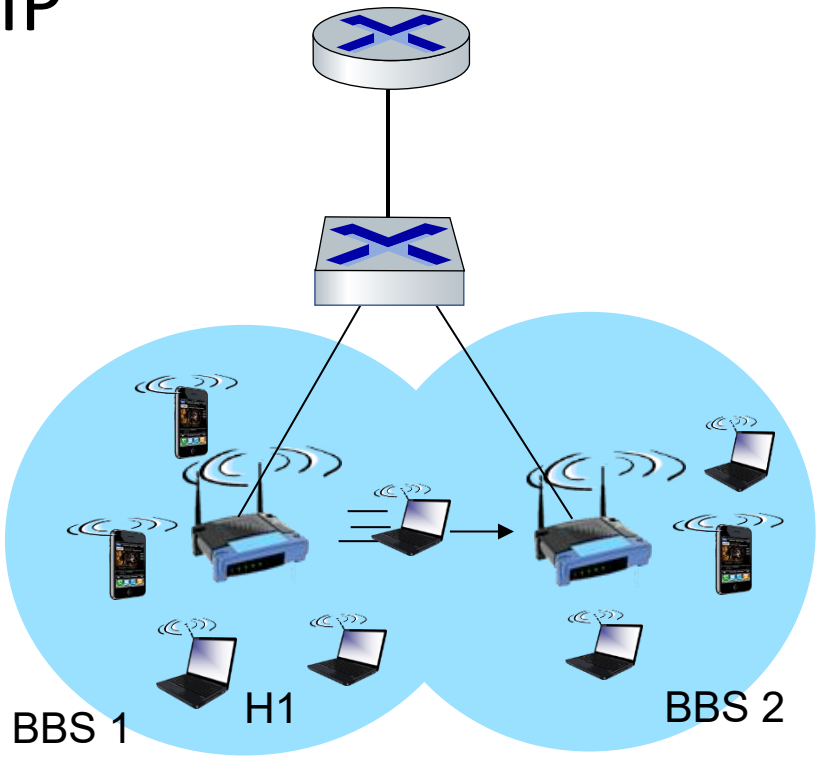


802.11 frame: addressing



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



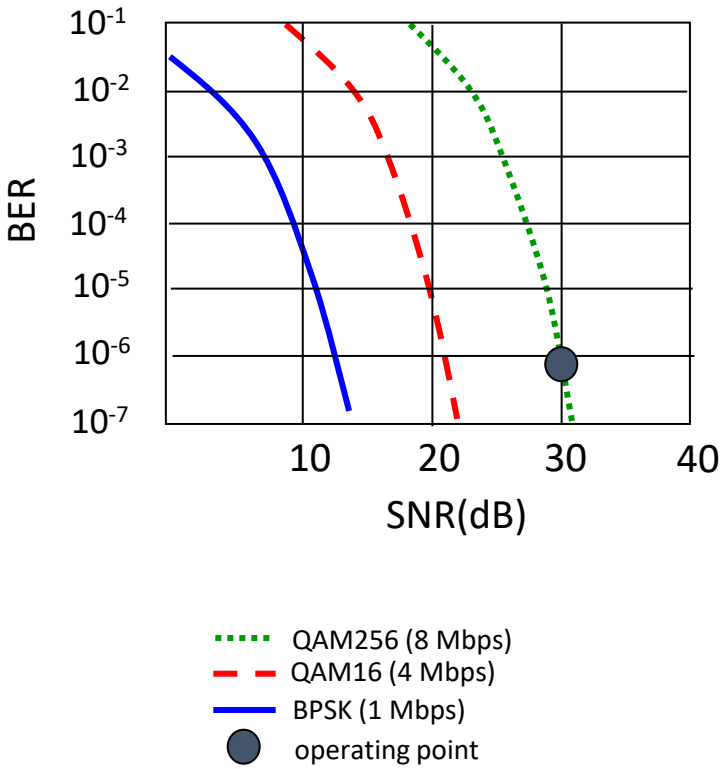
802.11: advanced capabilities

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



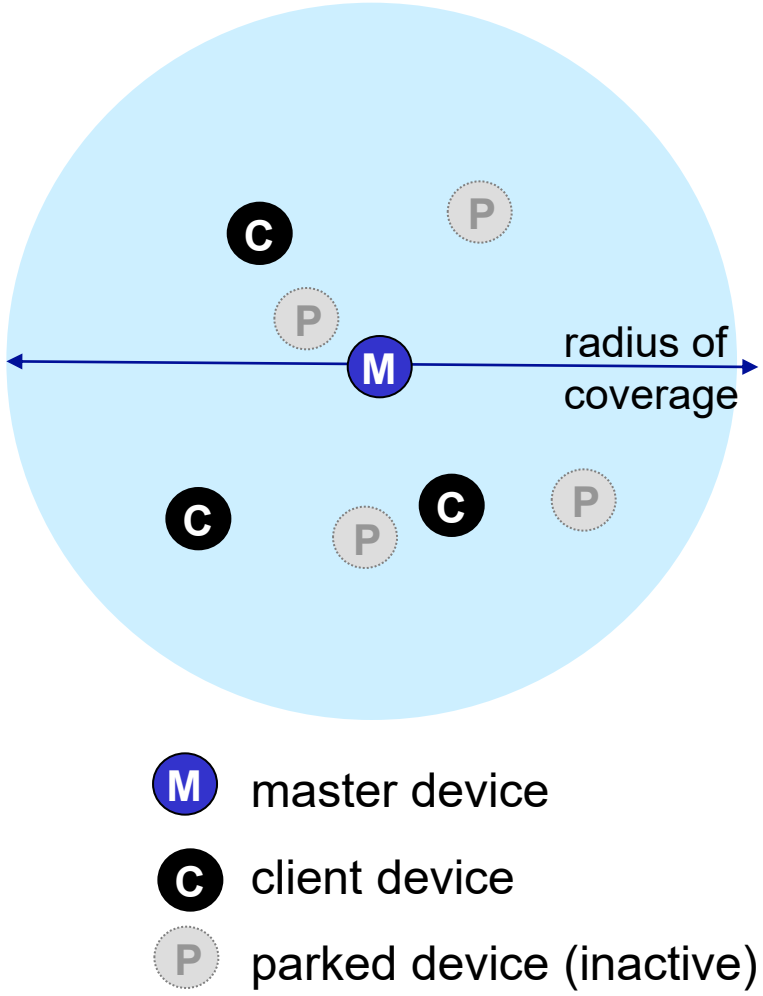
802.11: advanced capabilities

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 are sent; otherwise sleep again until next beacon frame

Personal area networks (PAN): Bluetooth

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



Personal area networks (PAN): Bluetooth

- 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