COMP 3331/9331: Computer Networks and Applications

Week 9

Wireless Networks

Reading Guide: Chapter 7, Sections 7.1 – 7.3

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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)!*
  - *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*

We will only focus on wireless challenges

Outline

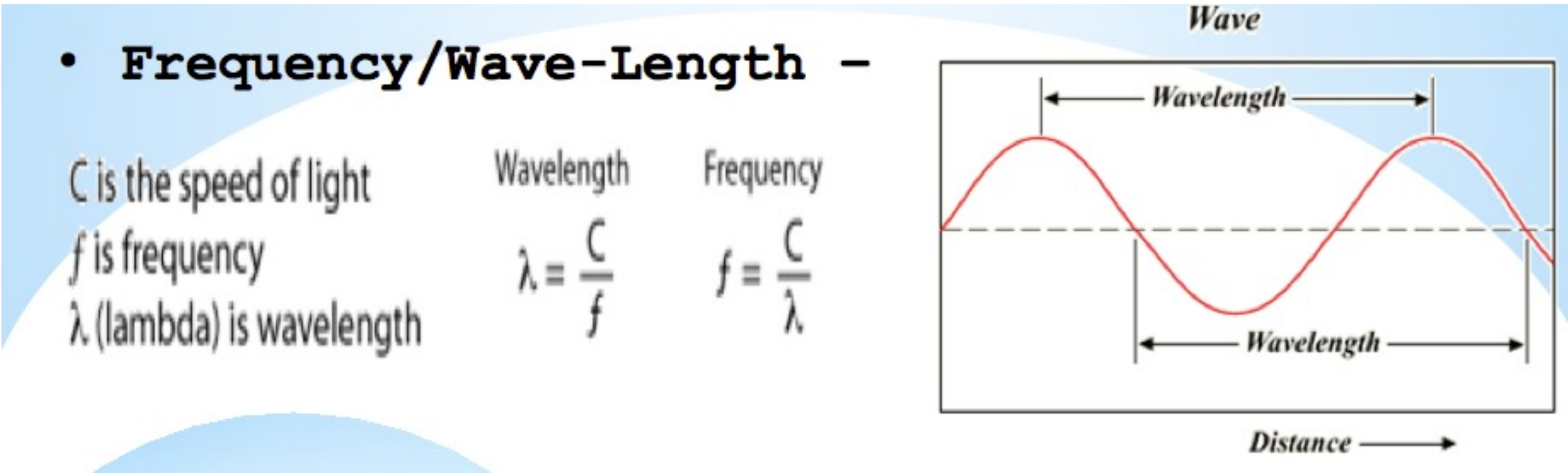
7.1 Introduction

Wireless

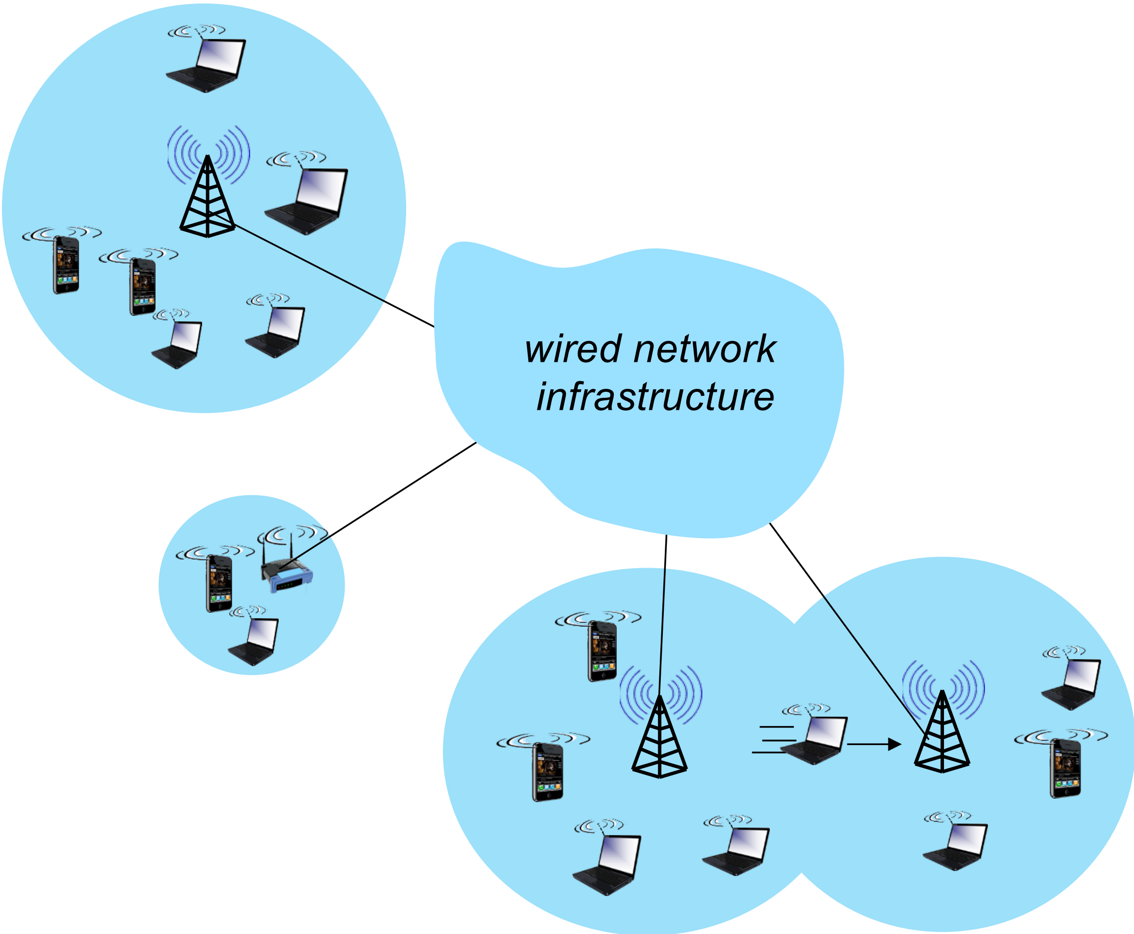
7.2 Wireless links, characteristics

7.3 IEEE 802.11 wireless LANs ("Wi-Fi")

Wireless 101



Elements of a wireless network



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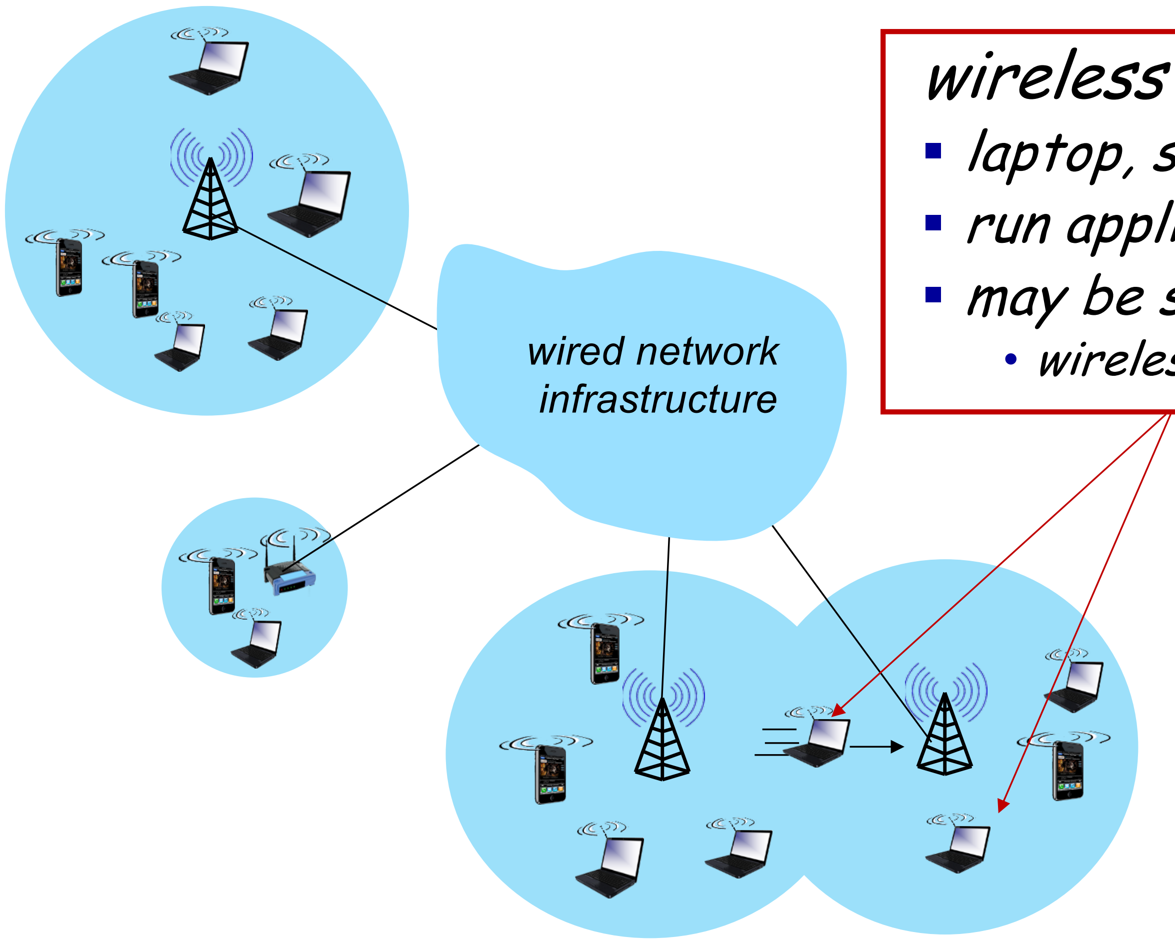
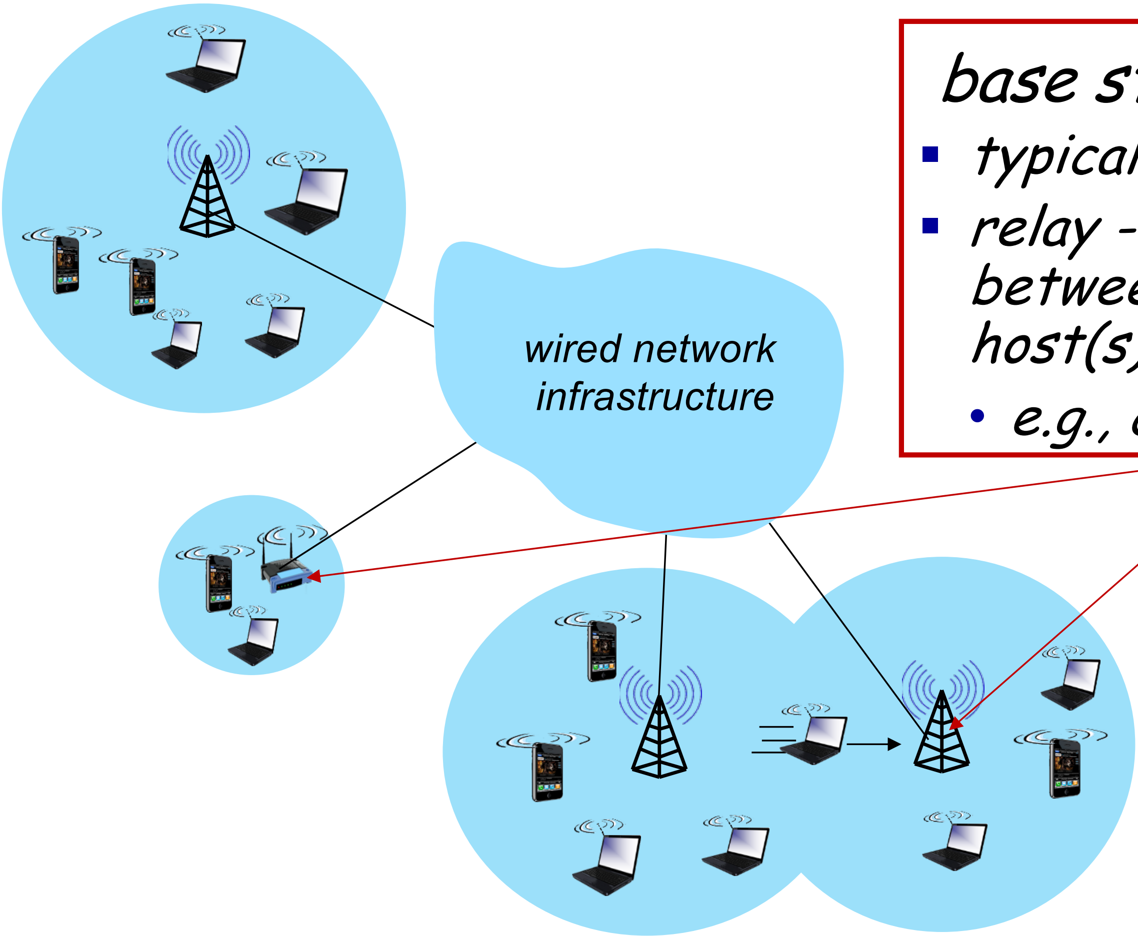


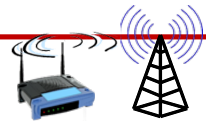
wireless hosts

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

Elements of a wireless network

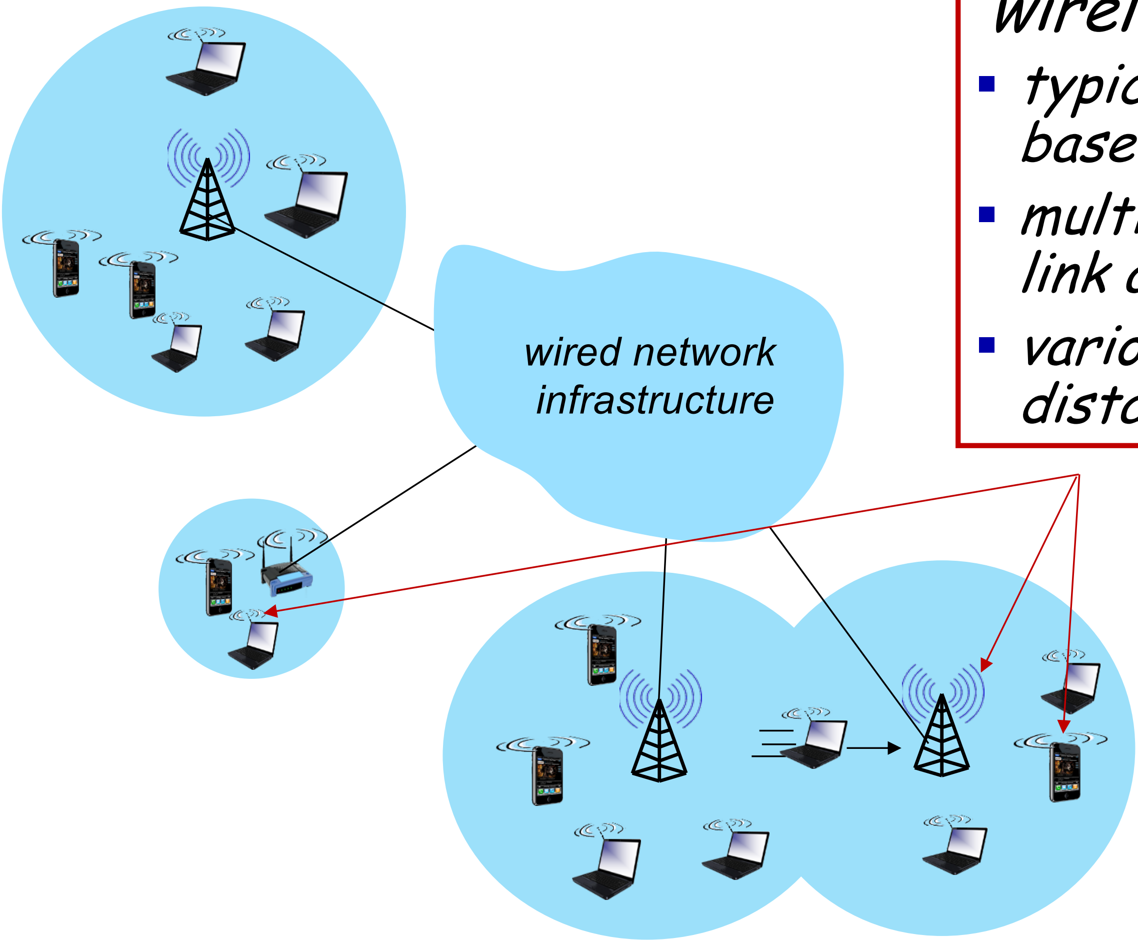


base station



- *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*

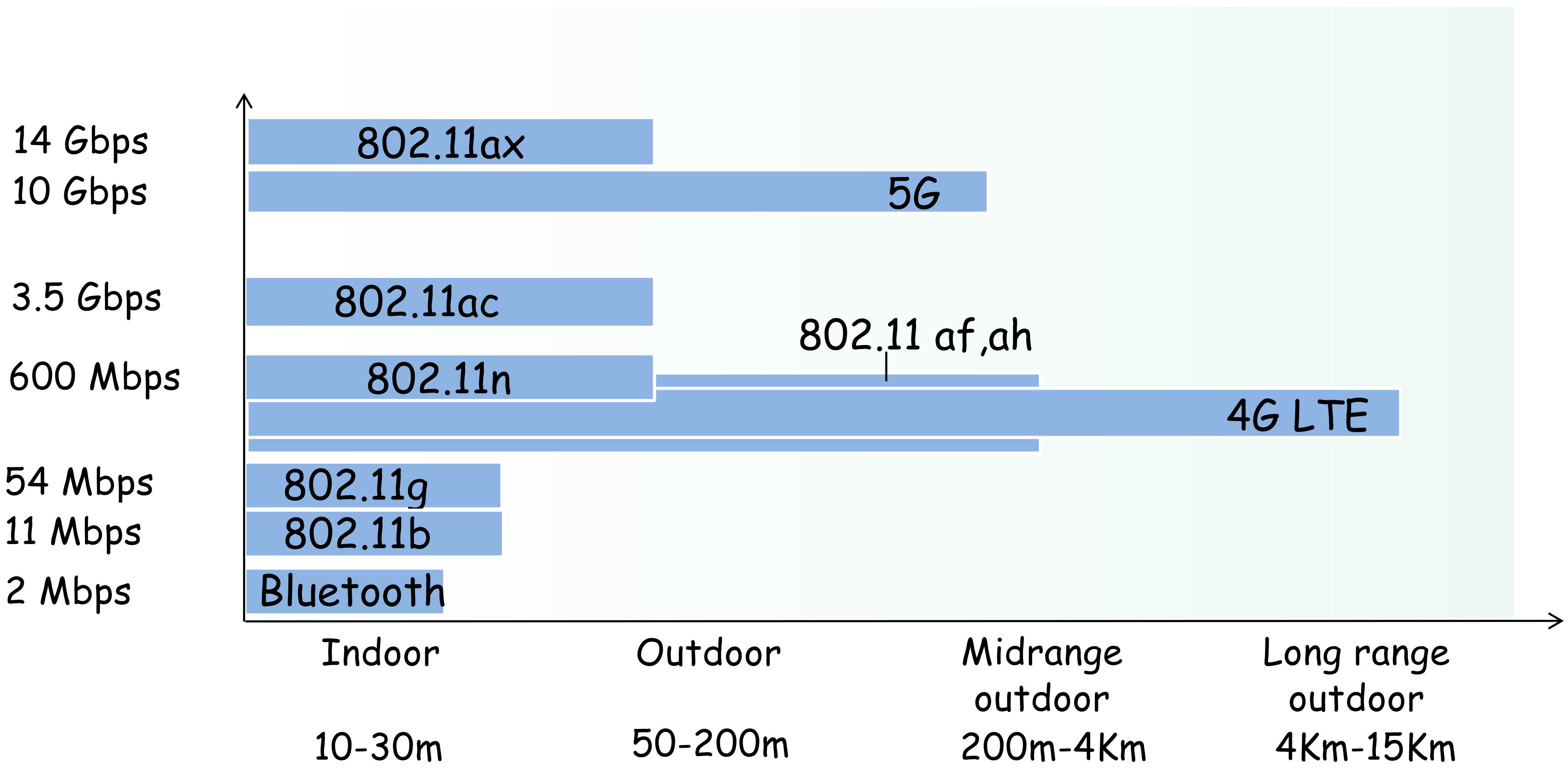
Elements of a wireless network

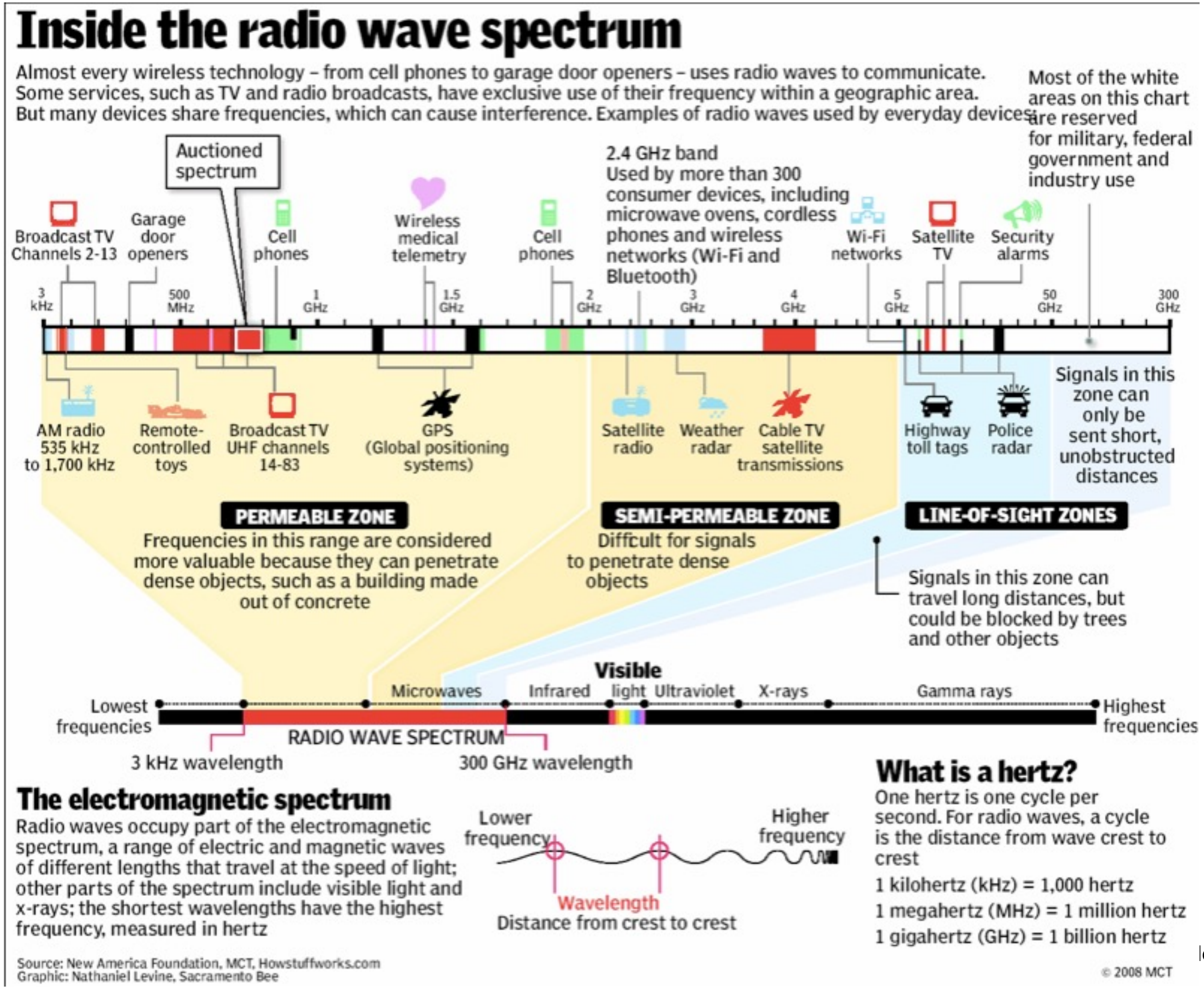


wireless link

- *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*

Characteristics of selected wireless links




Inside the radio wave spectrum
Almost every wireless technology – from cell phones to garage door openers – uses radio waves to communicate. Some services, such as TV and radio broadcasts, have exclusive use of their frequency within a geographic area. But many devices share frequencies, which can cause interference. Examples of radio waves used by everyday devices:
Most of the white areas on this chart are reserved for military, federal government and industry use
Auctioned spectrum
2.4 GHz band
Used by more than 300 consumer devices, including microwave ovens, cordless phones and wireless networks (Wi-Fi and Bluetooth)
Broadcast TV Channels 2-13
Garage door openers
Cell phones
Wireless medical telemetry
Cell phones
Wi-Fi networks
Satellite TV
Security alarms
3 kHz
500 MHz
1 GHz
1.5 GHz
2 GHz
3 GHz
4 GHz
5 GHz
50 GHz
300 GHz
AM radio 535 kHz to 1,700 kHz
Remote-controlled toys
Broadcast TV UHF channels 14-83
GPS (Global positioning systems)
Satellite radio
Weather radar
Cable TV satellite transmissions
Highway toll tags
Police radar
Signals in this zone can only be sent short, unobstructed distances
PERMEABLE ZONE
Frequencies in this range are considered more valuable because they can penetrate dense objects, such as a building made out of concrete
SEMI-PERMEABLE ZONE
Difficult for signals to penetrate dense objects
LINE-OF-SIGHT ZONES
Signals in this zone can travel long distances, but could be blocked by trees and other objects
Lowest frequencies
Microwaves
Infrared
Visible light
Ultraviolet
X-rays
Gamma rays
Highest frequencies
RADIO WAVE SPECTRUM
3 kHz wavelength
300 GHz wavelength
The electromagnetic spectrum
Radio waves occupy part of the electromagnetic spectrum, a range of electric and magnetic waves of different lengths that travel at the speed of light; other parts of the spectrum include visible light and x-rays; the shortest wavelengths have the highest frequency, measured in hertz
Lower frequency
Higher frequency
Wavelength
Distance from crest to crest
What is a hertz?
One hertz is one cycle per second. For radio waves, a cycle is the distance from wave crest to crest
1 kilohertz (kHz) = 1,000 hertz
1 megahertz (MHz) = 1 million hertz
1 gigahertz (GHz) = 1 billion hertz
Source: New America Foundation, MCT, Howstuffworks.com
Graphic: Nathaniel Levine, Sacramento Bee
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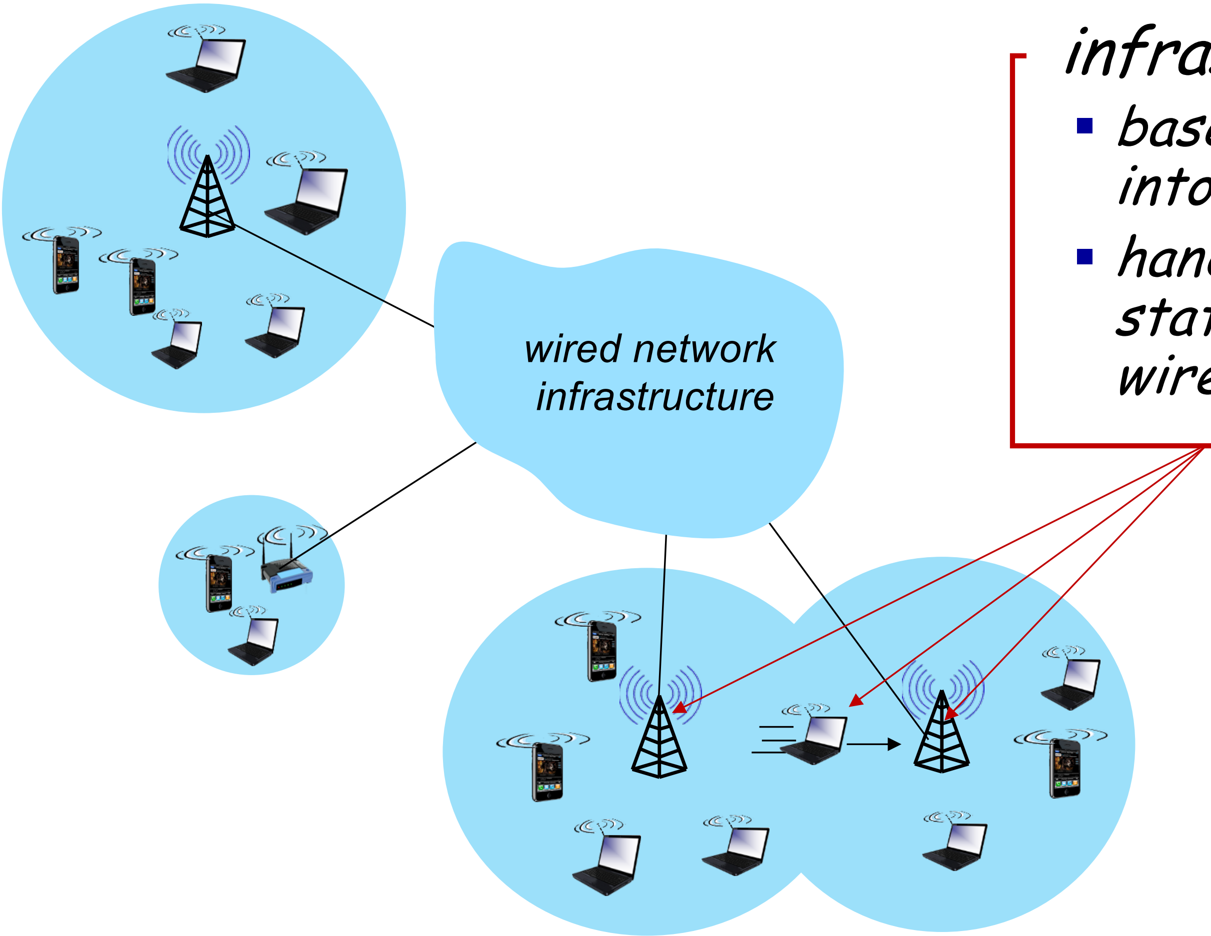
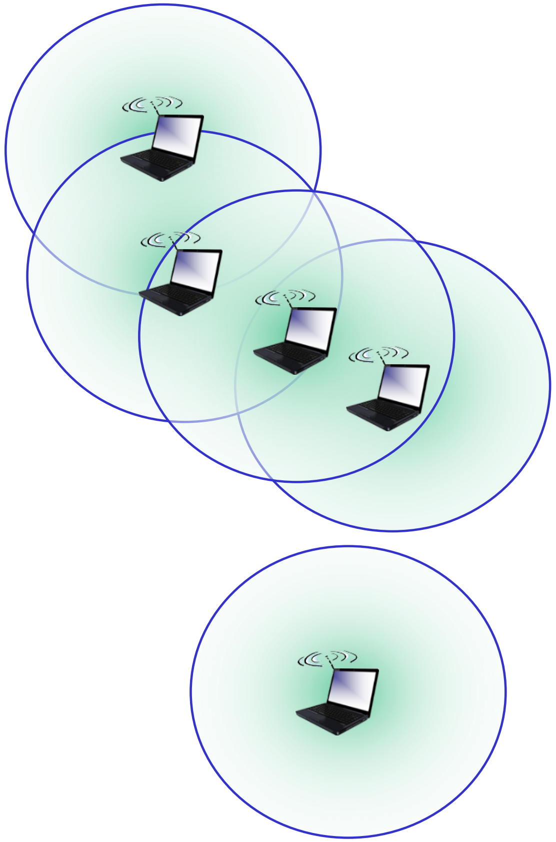
Elements of a wireless network



infrastructure mode

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

Elements of a wireless network

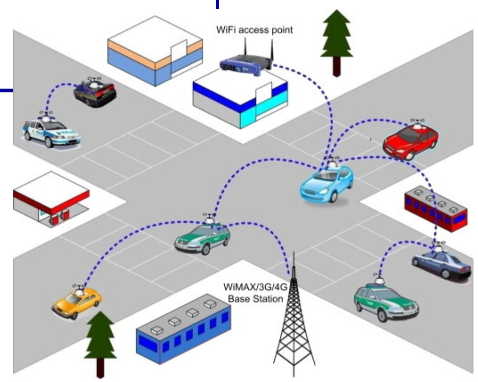


ad hoc mode

- *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 a given wireless node; MANET, VANET*



Outline

7.1 Introduction

Wireless

7.2 Wireless links, characteristics

7.3 IEEE 802.11 wireless LANs ("Wi-Fi")

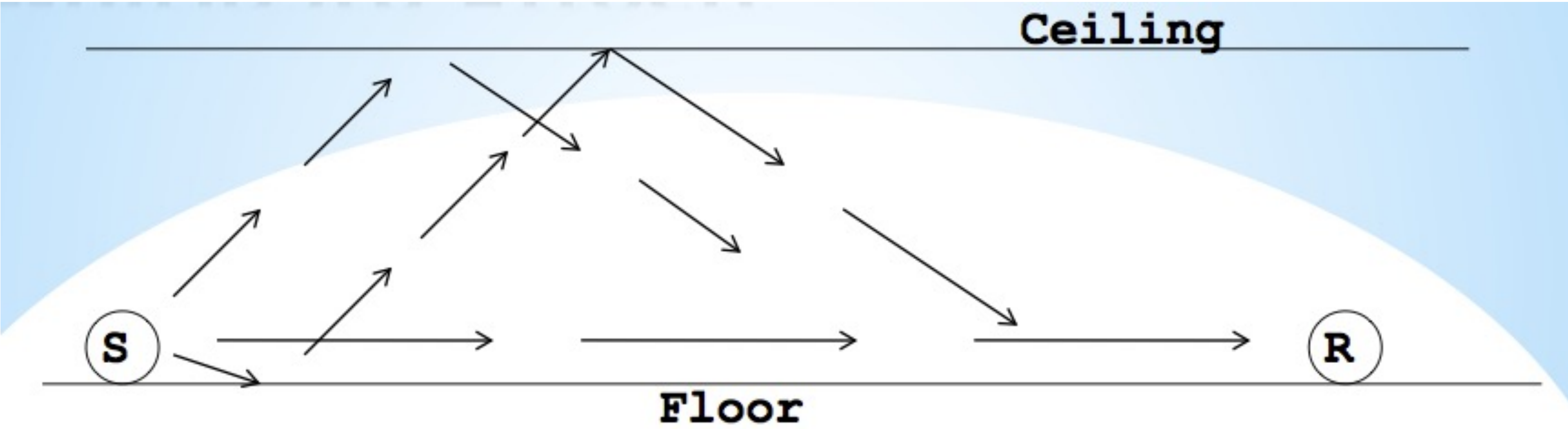
Wireless link characteristics (1)

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*

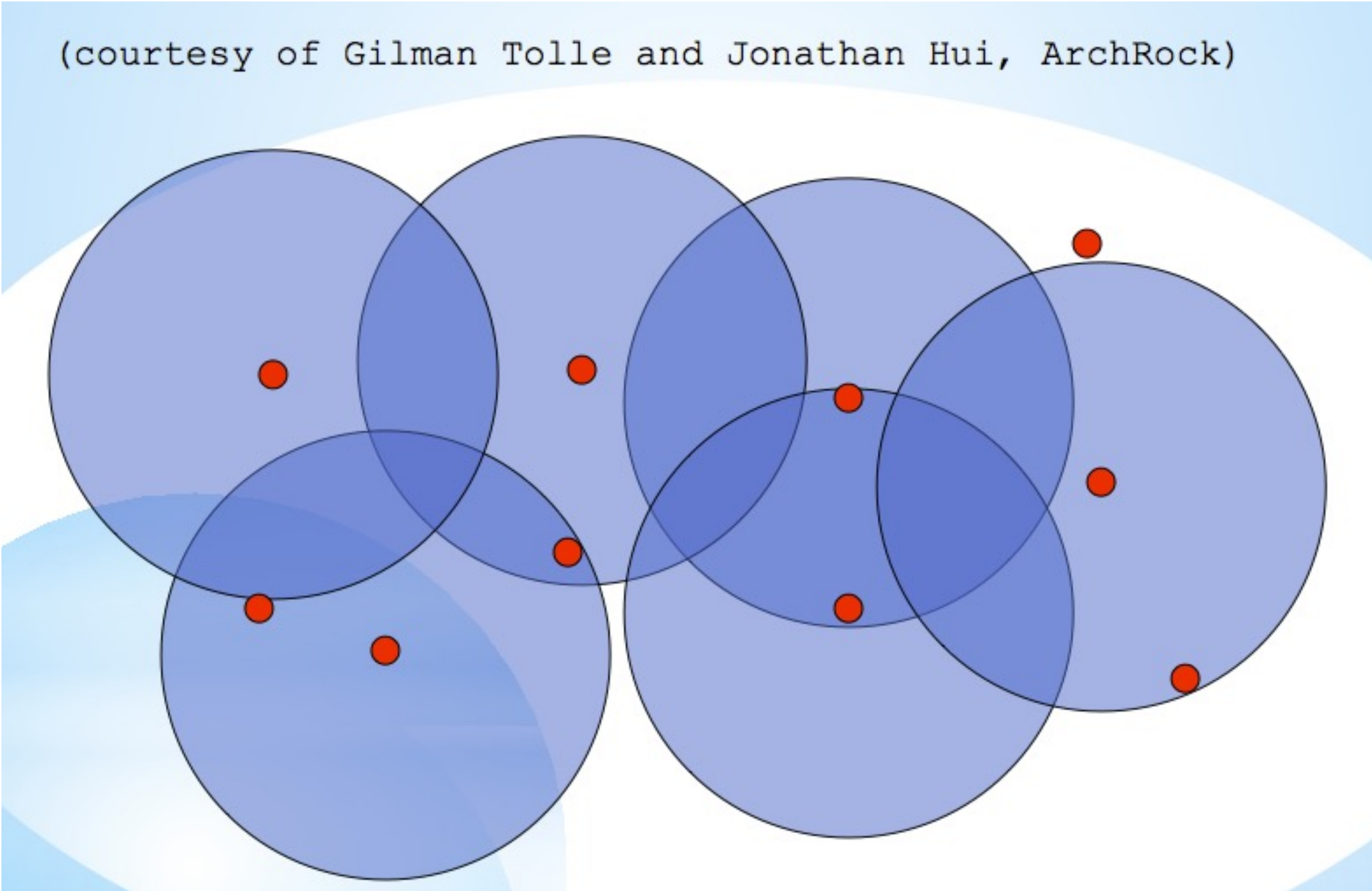
…. make communication across (even a point to point) wireless link much more "difficult"

Multipath Effects

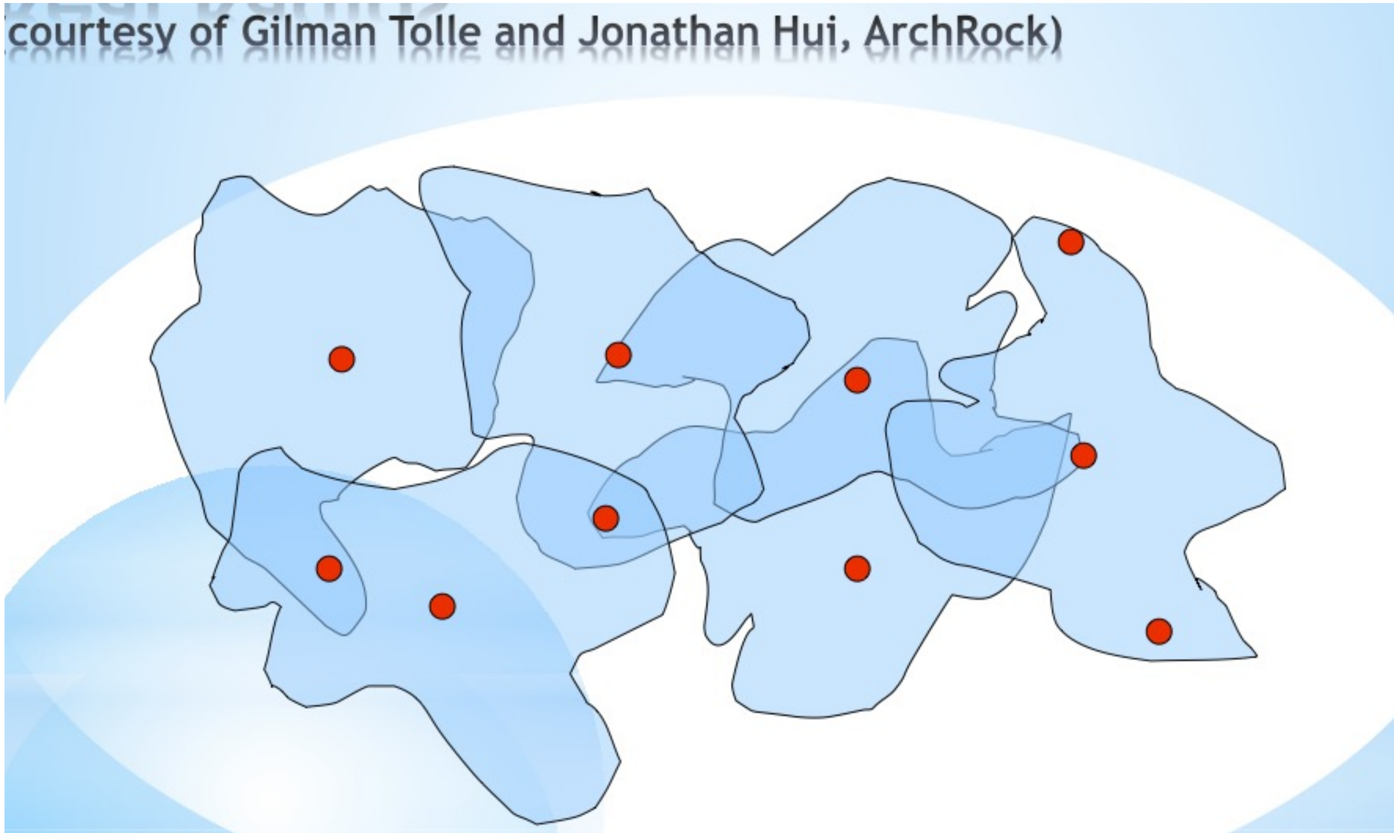


- Signals bounce off surface and interfere (constructive or destructive) with one another
- Self-interference

Ideal Radios

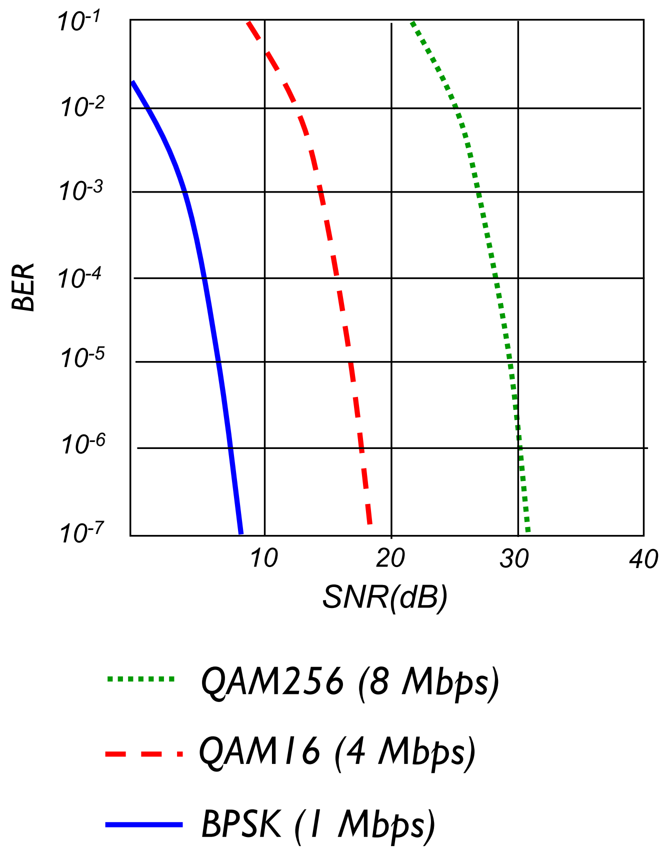


Real Radios



Wireless link characteristics (2)

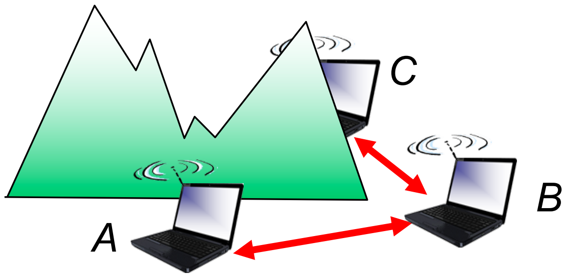
- *SNR: signal-to-noise ratio*
  - *larger SNR – easier to extract signal from noise (a "good thing")*
- *SNR versus BER tradeoffs*
  - *given physical layer: increase power -> increase SNR->decrease BER*
  - *given SNR: choose physical layer that meets BER requirement, giving highest throughput*
  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



BER: Bit Error Rate

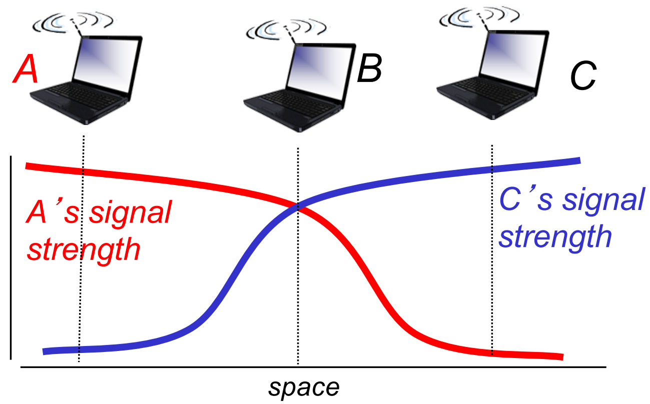
Wireless link characteristics (3)

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*

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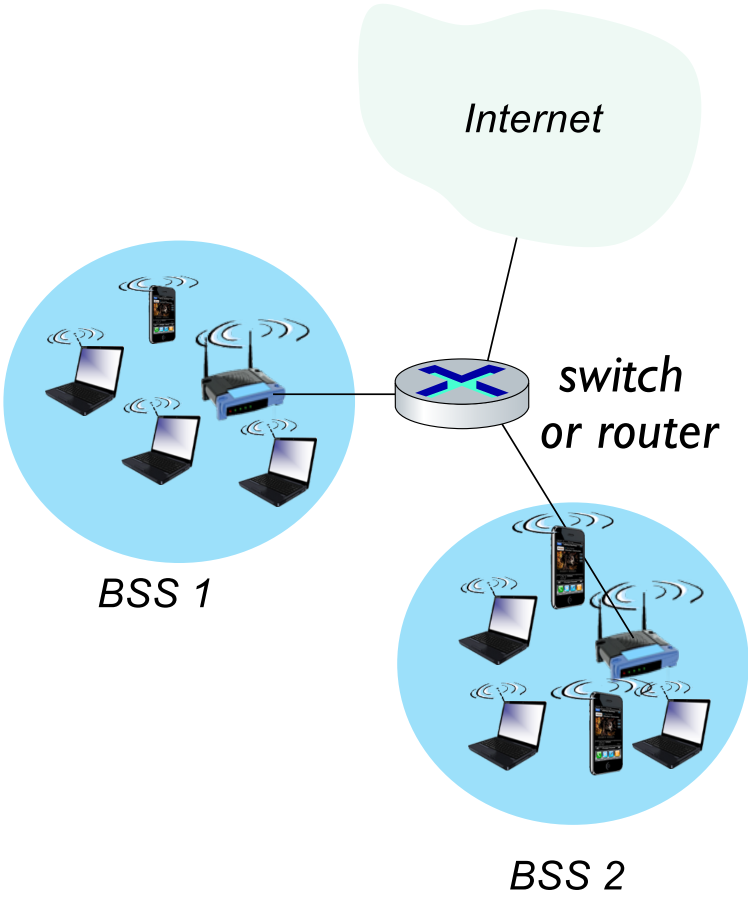
IEEE 802.11 Wireless LAN

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	70m	2.4, 5 Ghz
802.11ac (WiFi 5)	2013	3.47Gpbs	70m	5 Ghz
802.11ax (WiFi 6)	2021	14 Gbps	70m	2.4, 5 Ghz
802.11af	2014	35 – 560 Mbps	1 Km	unused TV bands (54-790 MHz)
802.11ah (WiFi Halow)	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

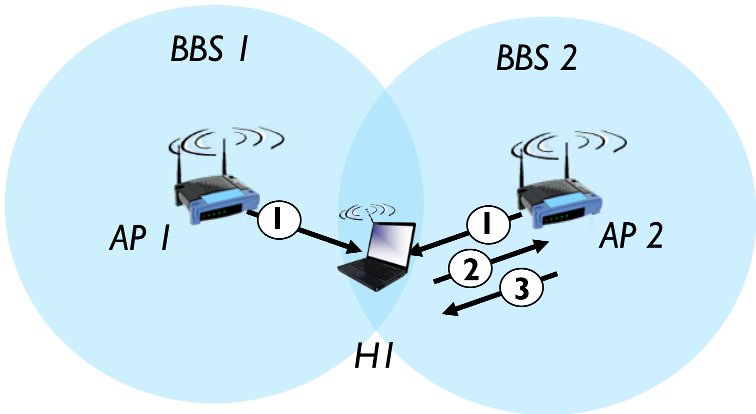


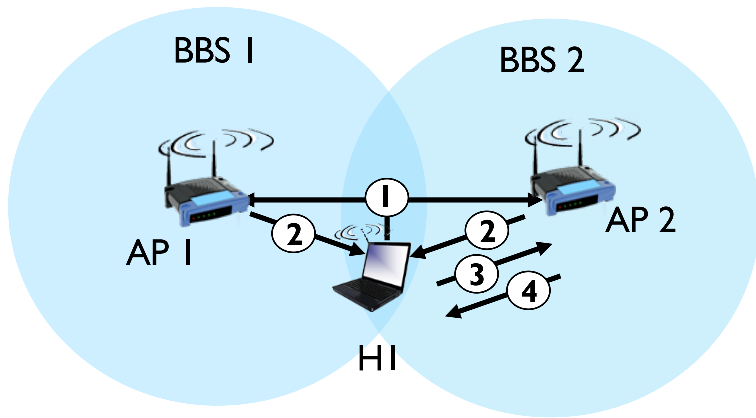
- *wireless host communicates with base station*
  - *base station = access point (AP)*
- *Basic Service Set (BSS) (aka "cell") in infrastructure mode contains:*
  - *wireless hosts*
  - *access point (AP): base station*
  - *ad hoc mode: hosts only*

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 [Security]*
  - *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

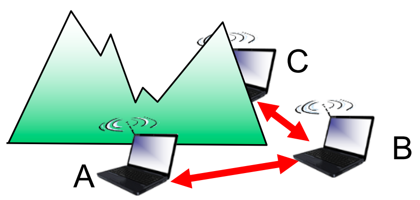
(2) Probe Response frames sent from APs

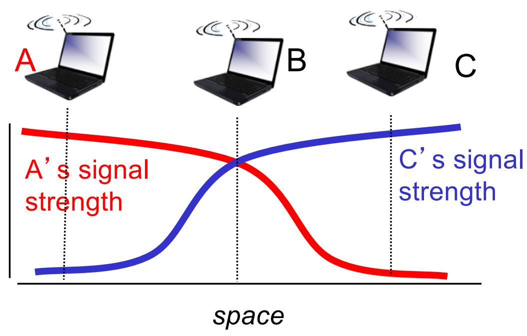
(3) Association Request frame sent: H1 to selected AP

(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/Collision Avoidance*





Multiple access: Key Points

- No concept of a global collision
  - Different receivers hear different signals
  - Different senders reach different receivers
- Collisions are at receiver, not sender
  - Only care if receiver can hear the sender clearly
  - It does not matter if sender can hear someone else
  - As long as that signal does not interfere with receiver
- Goal of protocol
  - Detect if receiver can hear sender
  - Tell senders who might interfere with receiver to shut up

IEEE 802.11 MAC Protocol: CSMA/CA

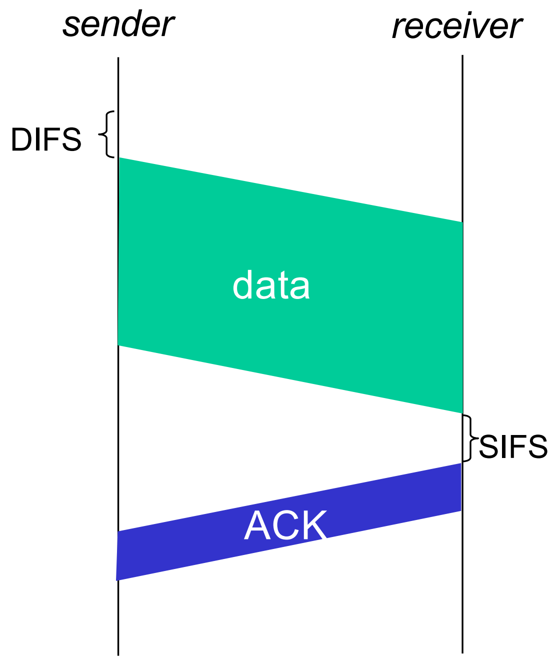
802.11 sender

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, double random backoff interval, repeat 2

802.11 receiver

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

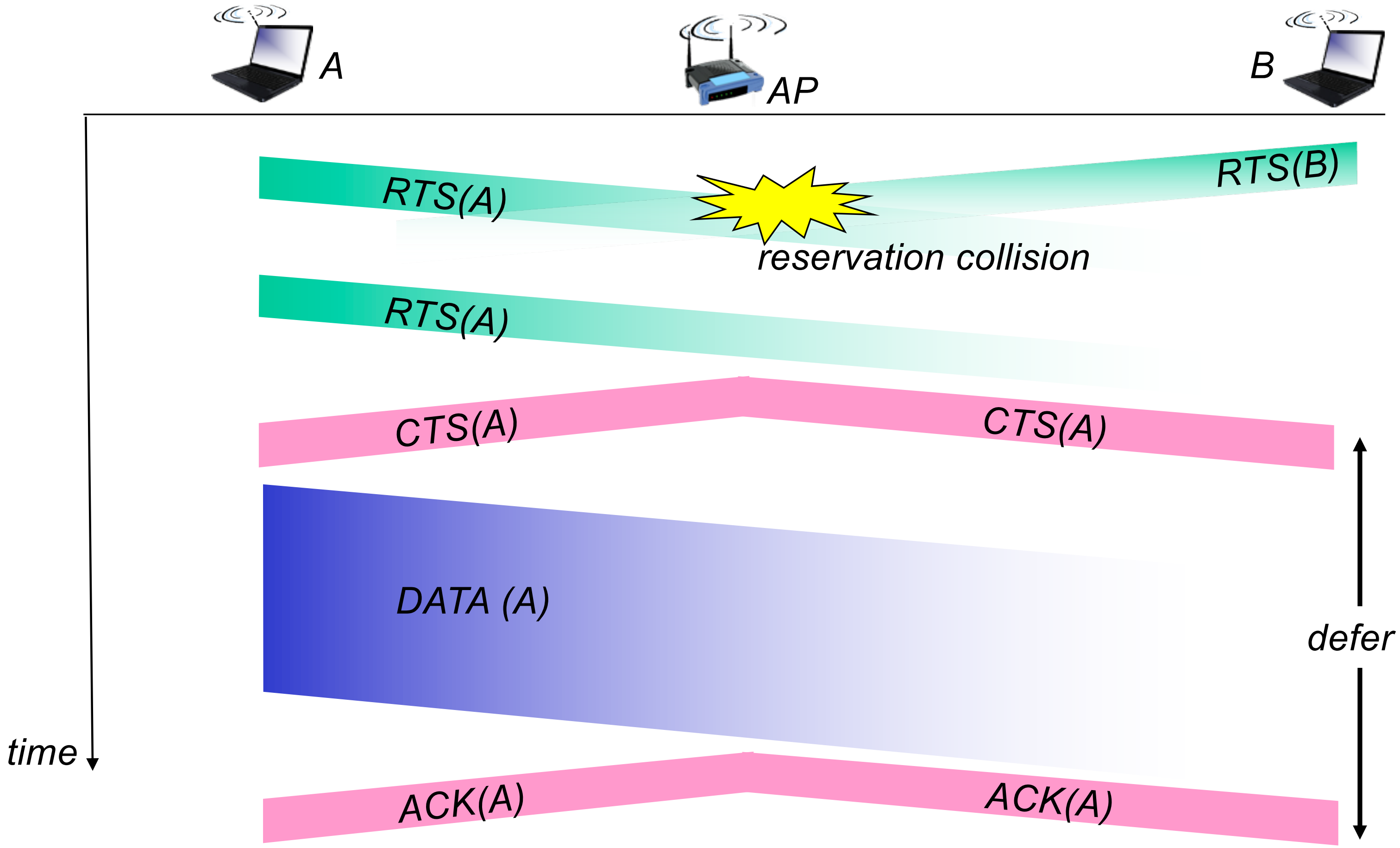


Avoiding collisions (more)

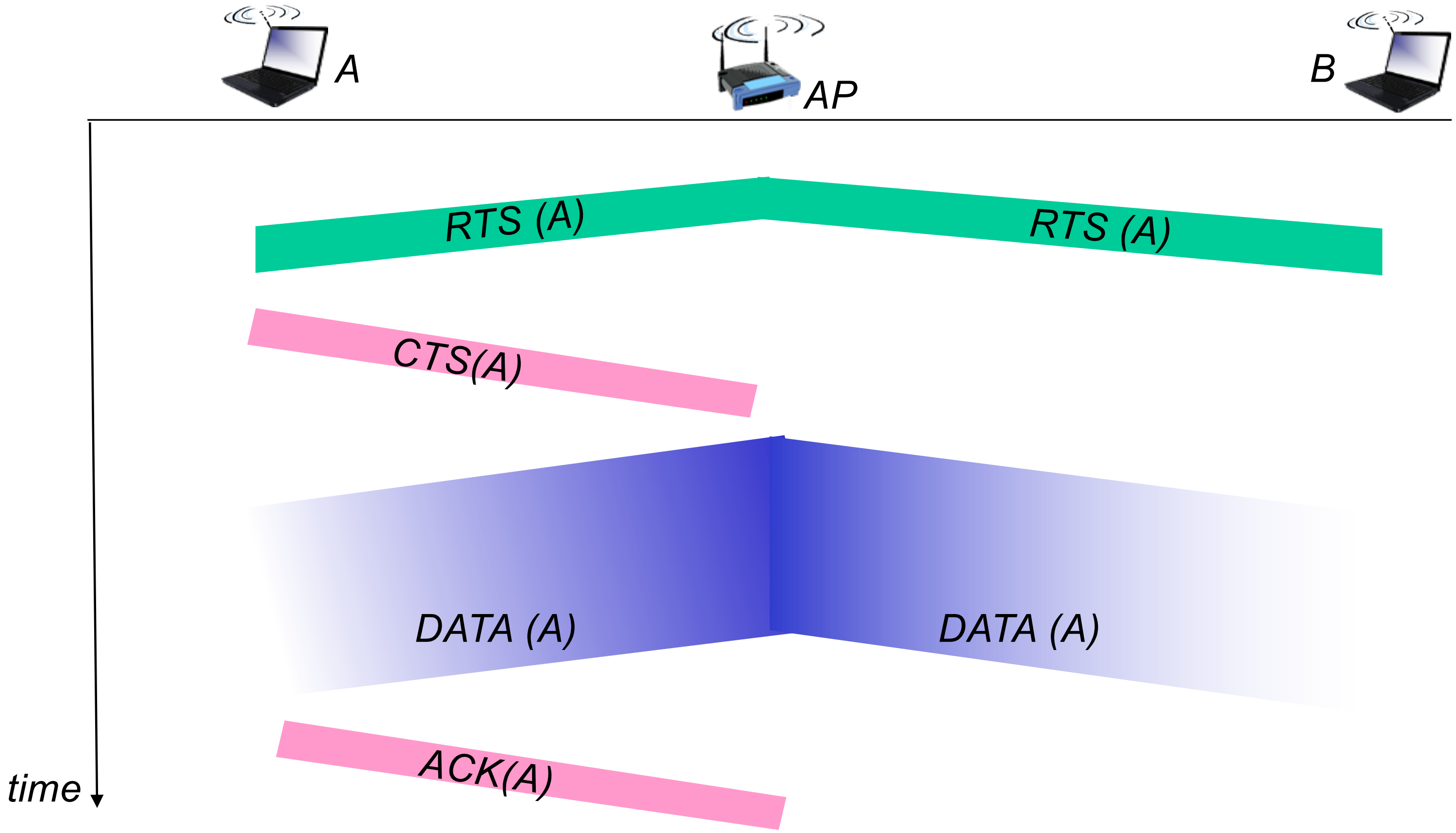
idea: *sender "reserves" channel use for data frames using small reservation packets*

- *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



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

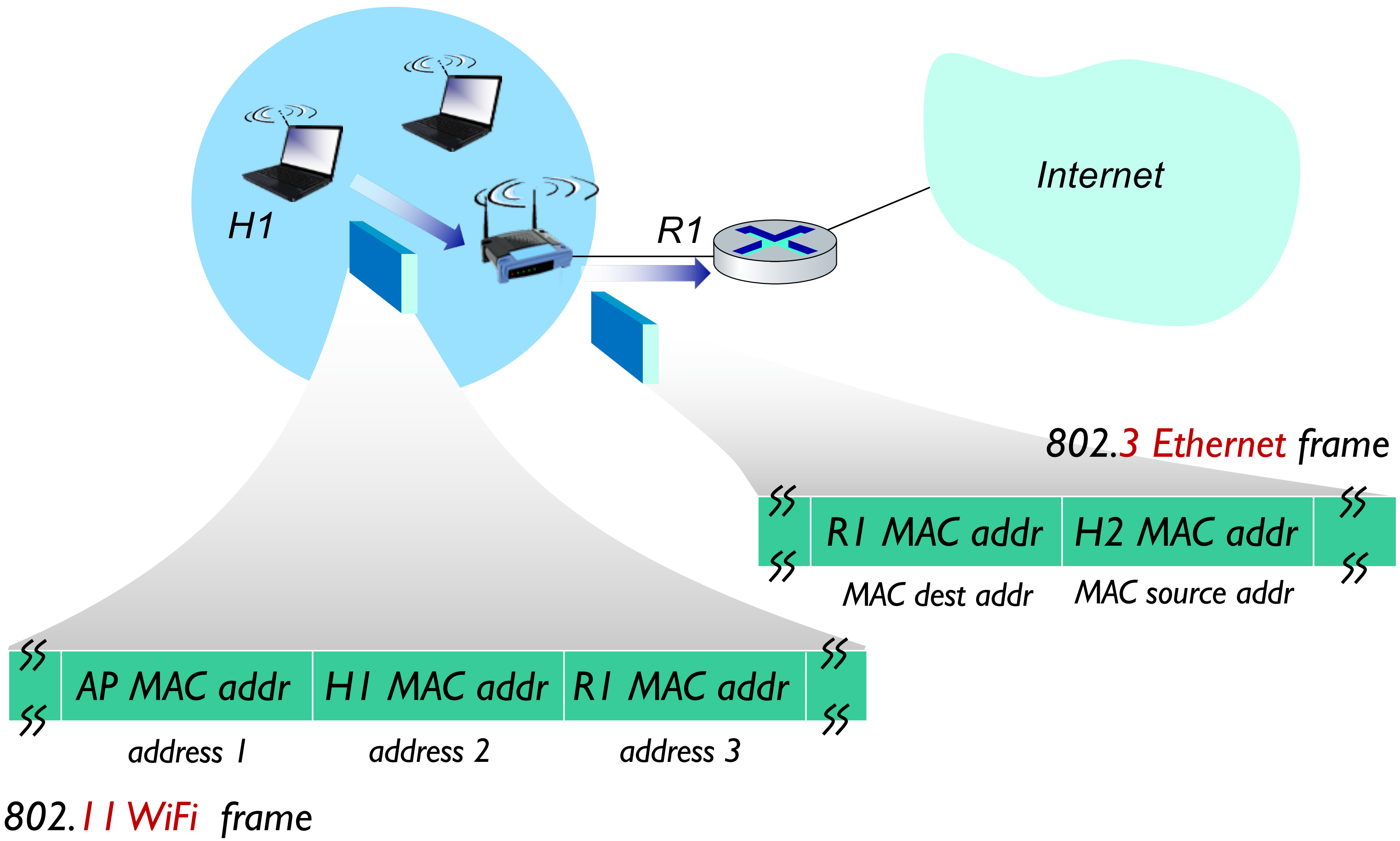
Address 1: MAC address of wireless host or AP to receive this frame

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

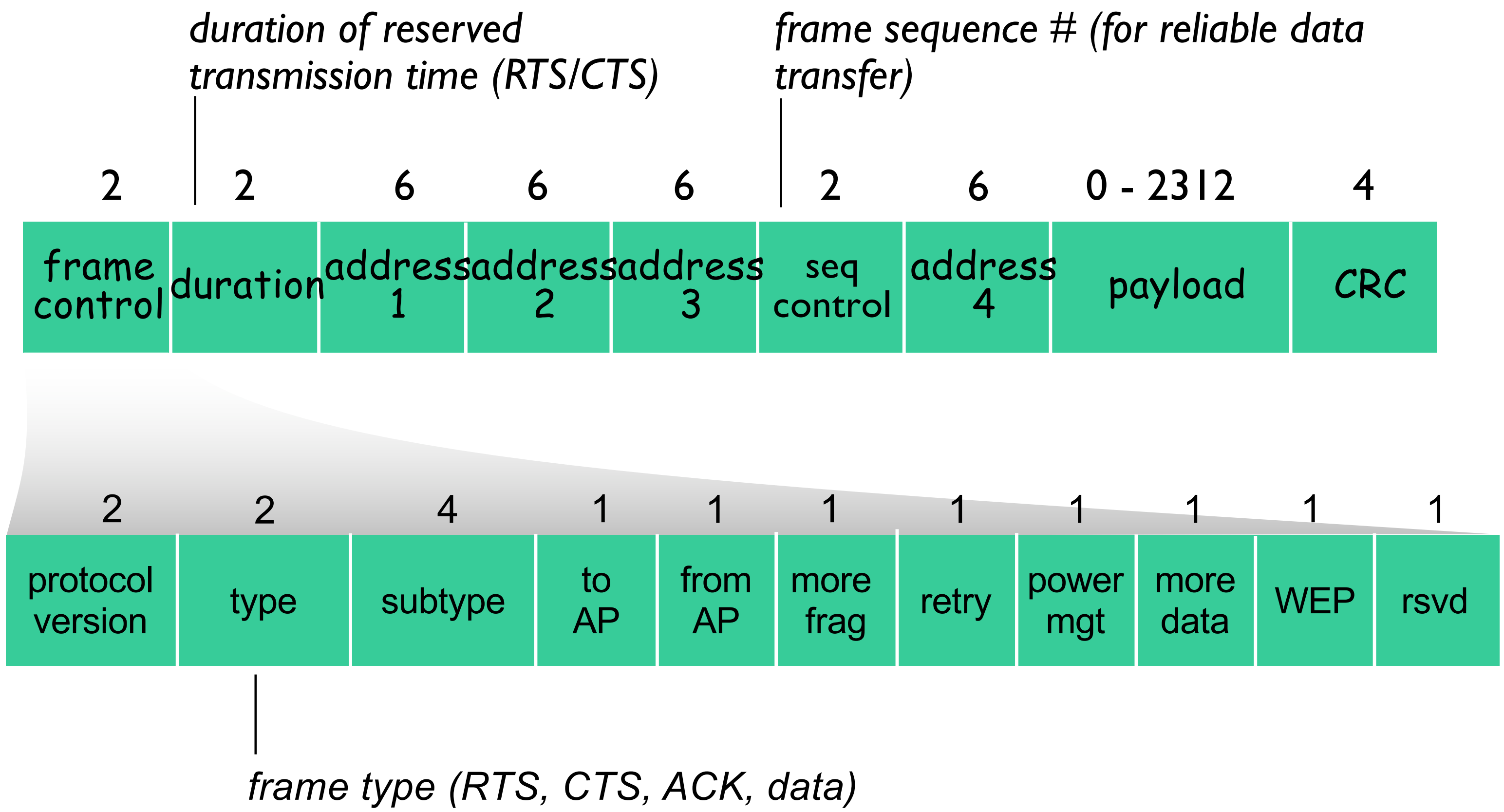
Address 3: MAC address of router interface to which AP is attached

Address 4: used only in ad hoc mode

802.11 frame: addressing



802.11 frame: addressing



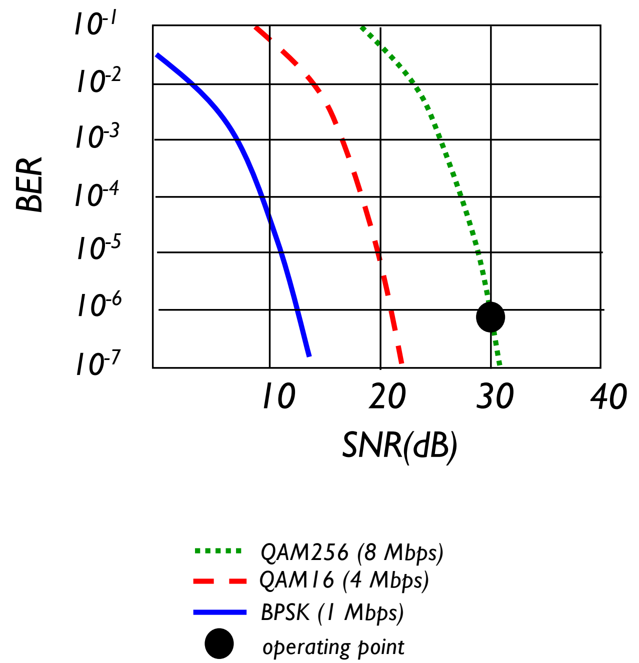
802.11: advanced capabilities

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



Quiz

The following is the correct sequence of message exchanges as per the reservation process of 802.11 CSMA/CA

A. RTS->CTS->DATA->CTS

B. CTS->RTS->DATA->ACK

C. RTS->CTS->DATA->ACK

D. RTS->ACK->DATA->CTS

ANSWER: C

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Quiz

- Which multiple access technique is used by IEEE 802.11?

  A. CSMA/CD

  B. Slotted ALOHA

  C. CSMA/CA

  D. TDMA

  E. FDMA

ANSWER: C

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Summary

Wireless

- wireless links:
  - capacity, distance
  - channel impairments
- IEEE 802.11 (“Wi-Fi”)
  - CSMA/CA reflects wireless channel characteristics