COMP 3331/9331: Computer Networks and Applications

Week 9

Wireless Networks

Reading Guide: Chapter 7, Sections 7.1 – 7.3

Wireless Networks

Background:

- # wireless (mobile) phone subscribers now exceeds # wired phone subscribers (5-to-1)!
- # wireless Internet-connected devices equals # wireline Internet-connected devices
  - laptops, Internet-enabled phones promise anytime untethered Internet access
- 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")

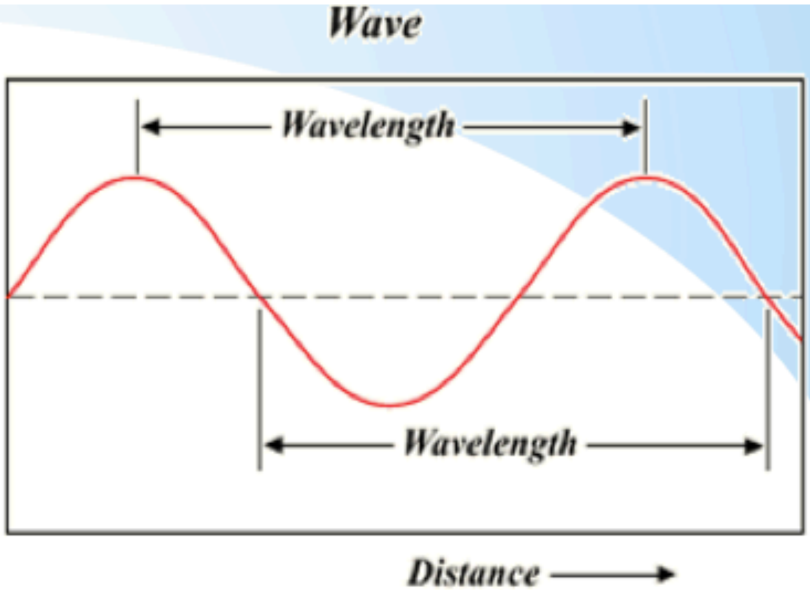
Wireless 101

- **Frequency/Wave-Length –**

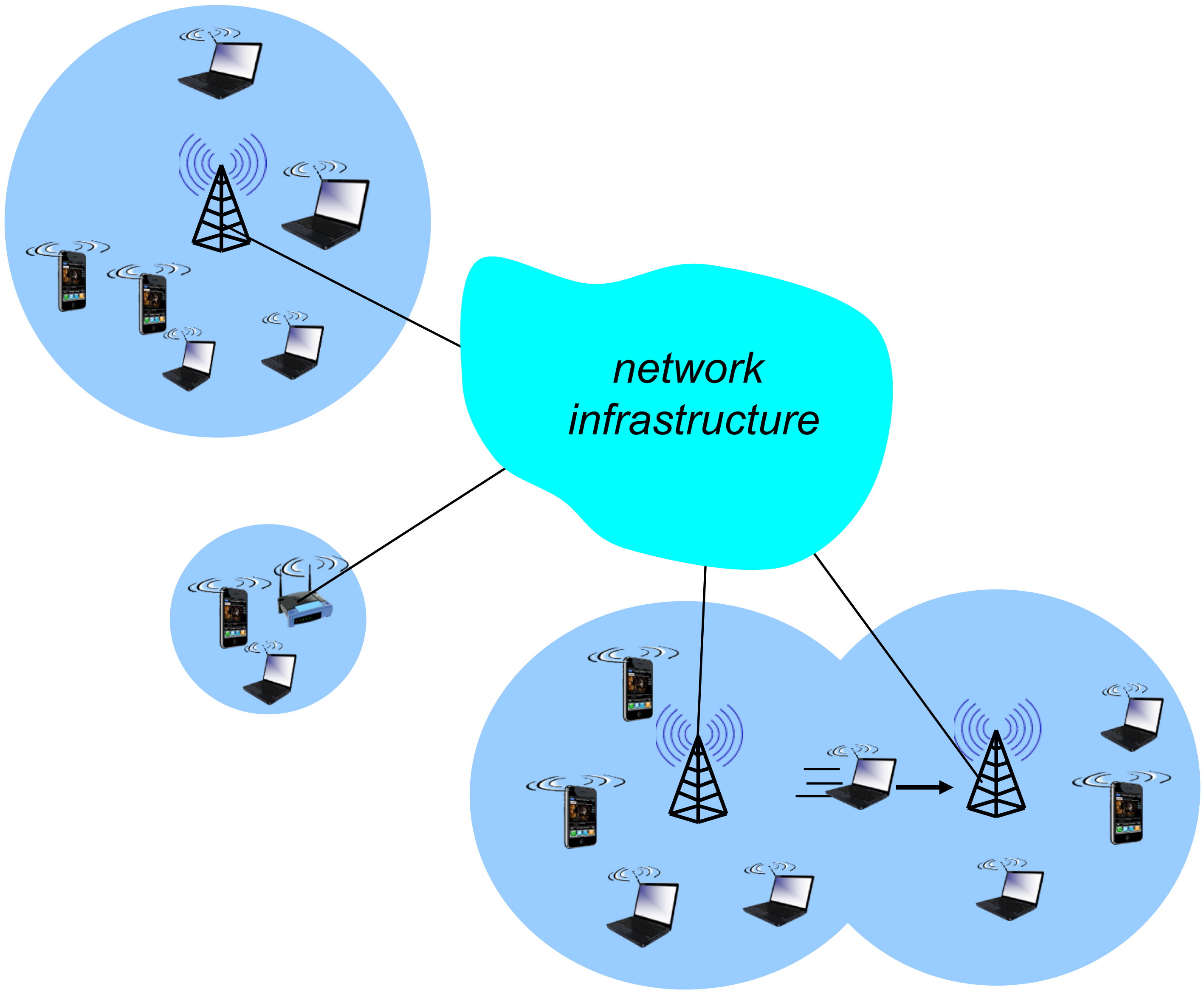
C is the speed of light
f is frequency
λ (lambda) is wavelength

Wavelength
$$\lambda = \frac{C}{f}$$

Frequency
$$f = \frac{C}{\lambda}$$



Elements of a wireless network



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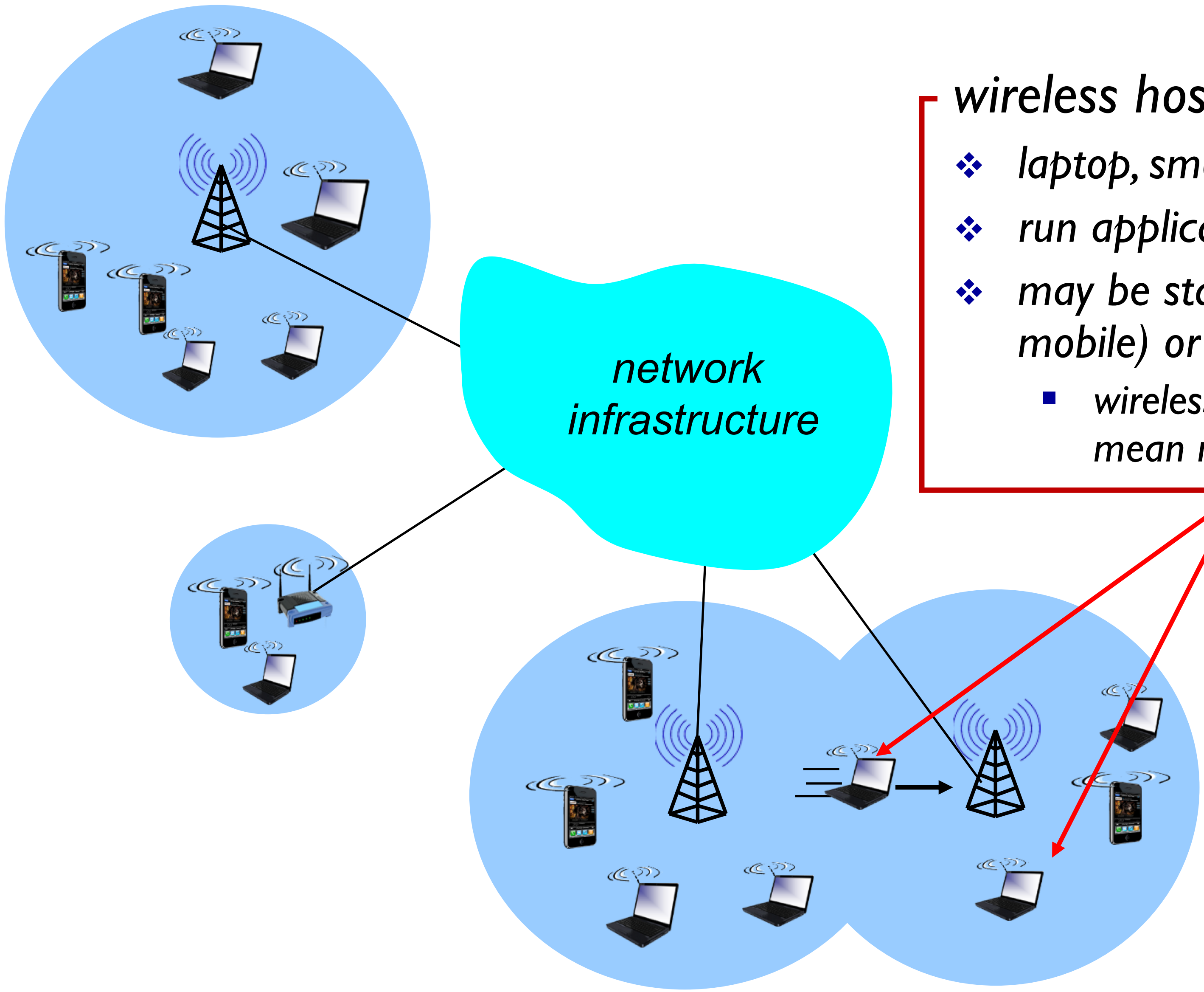
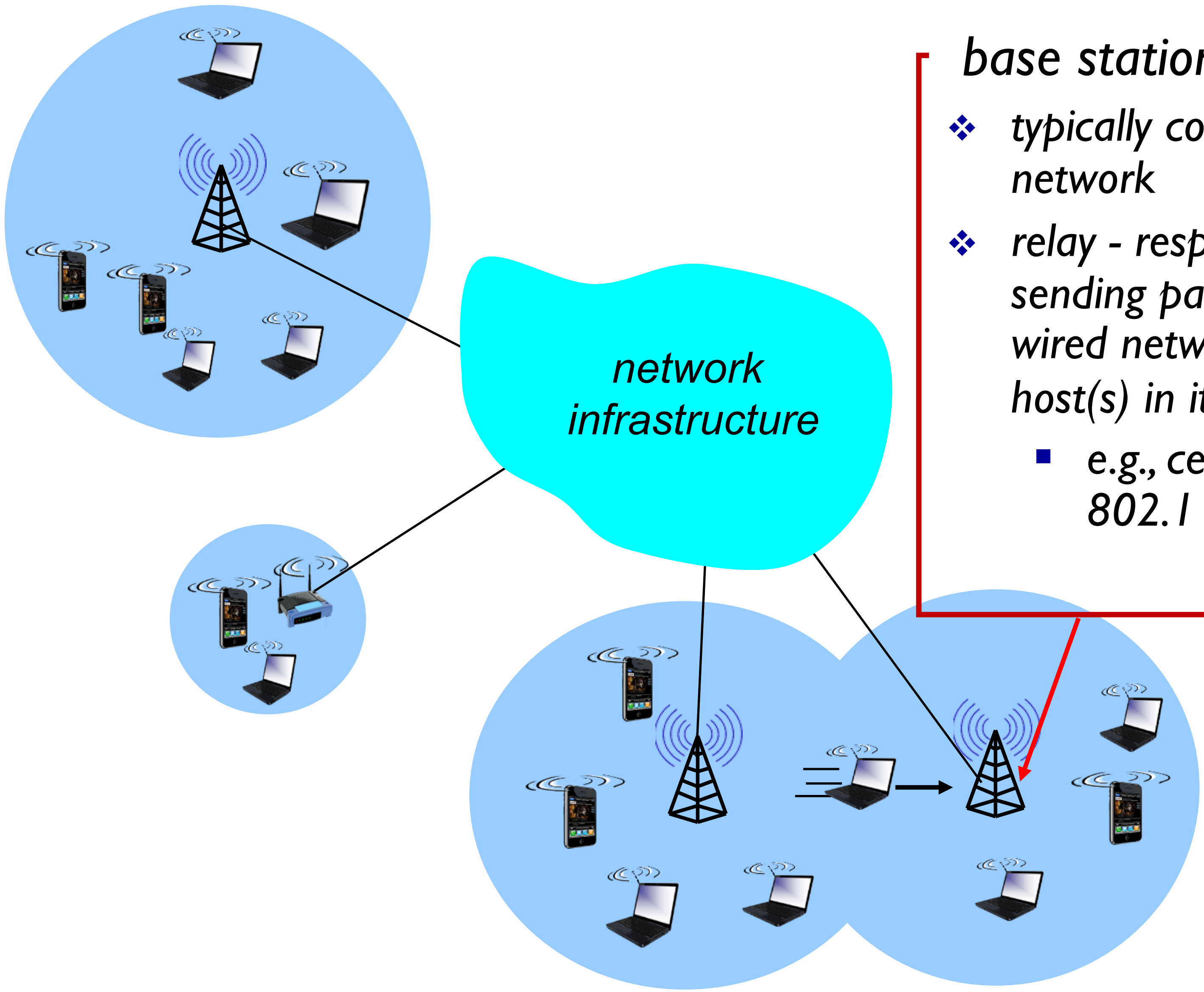


wireless hosts

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

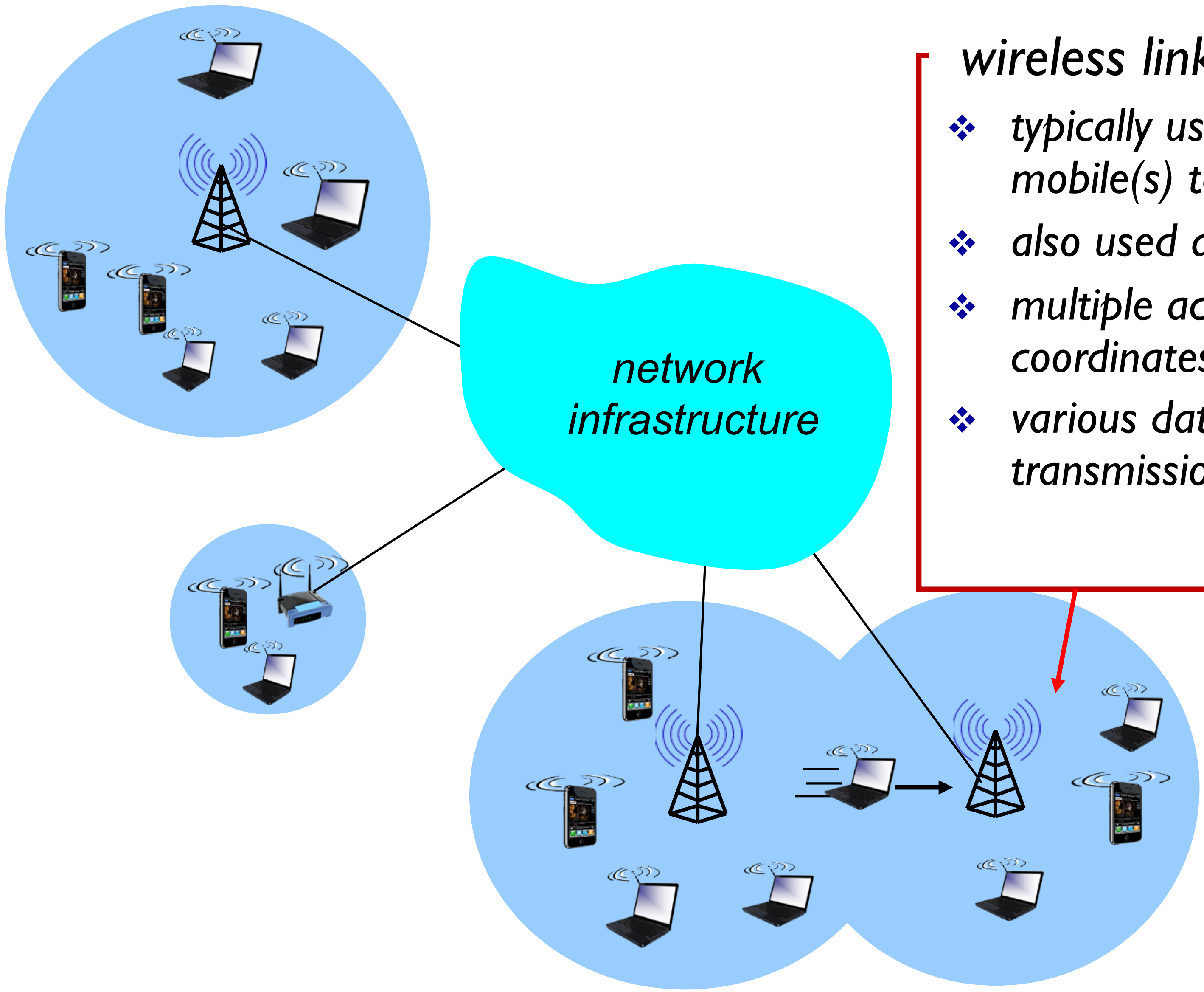
Elements of a wireless network



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*

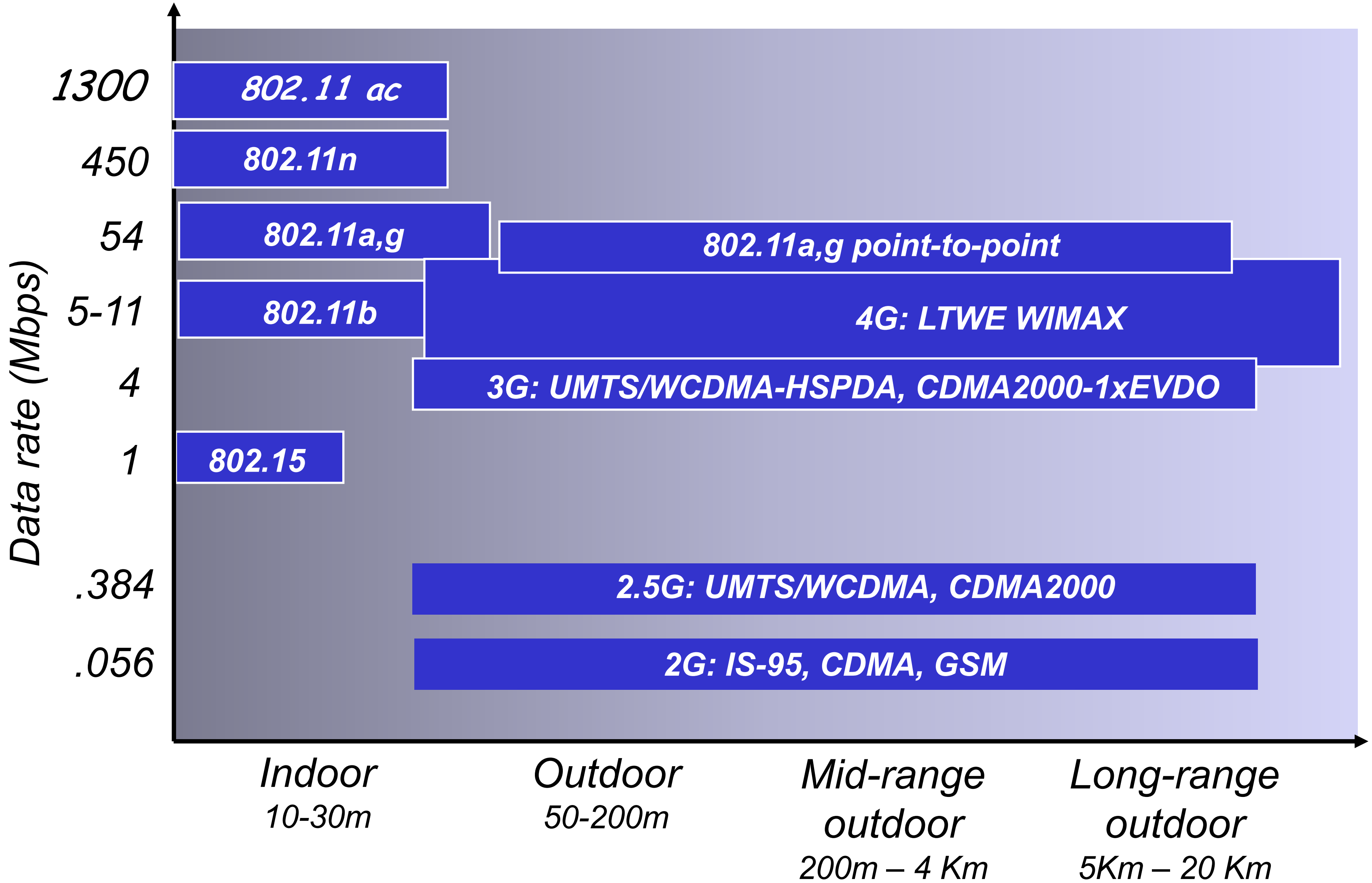
Elements of a wireless network



wireless link

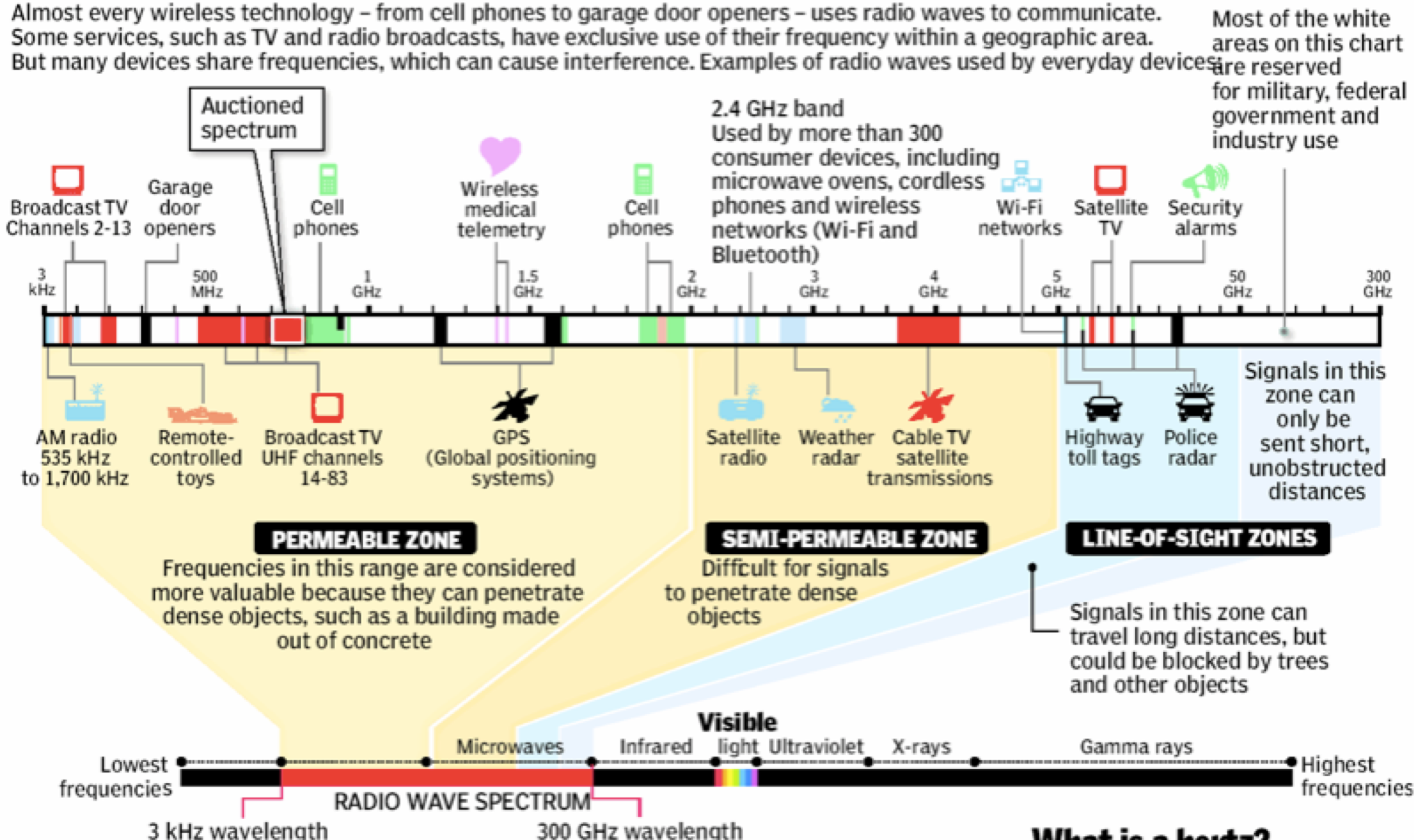
- *typically used to connect mobile(s) to base station*
- *also used as backbone link*
- *multiple access protocol coordinates link access*
- *various data rates, transmission distance*

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:



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

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

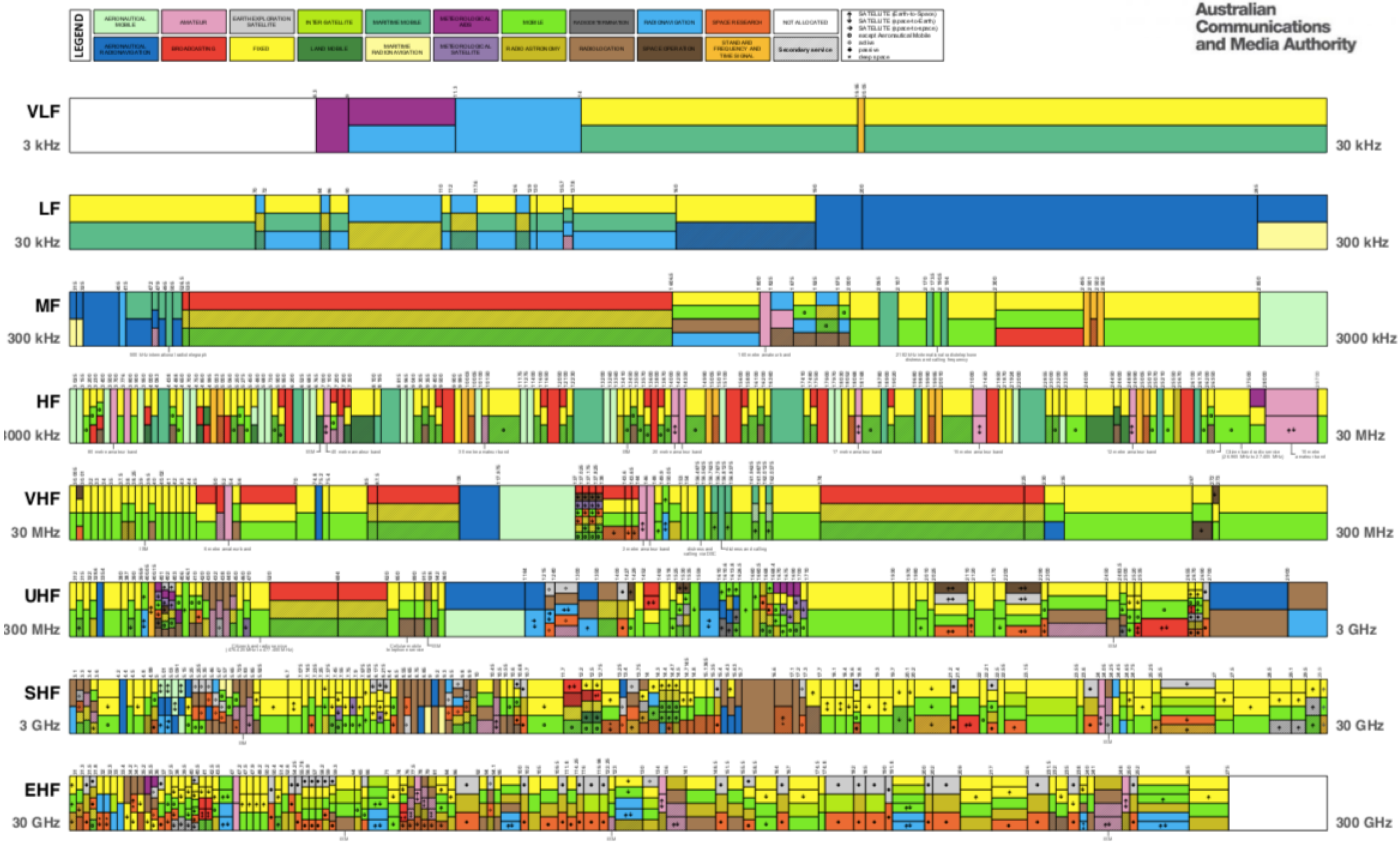
1 gigahertz (GHz) = 1 billion hertz

Source: New America Foundation, MCT, Howstuffworks.com
Graphic: Nathaniel Levine, Sacramento Bee

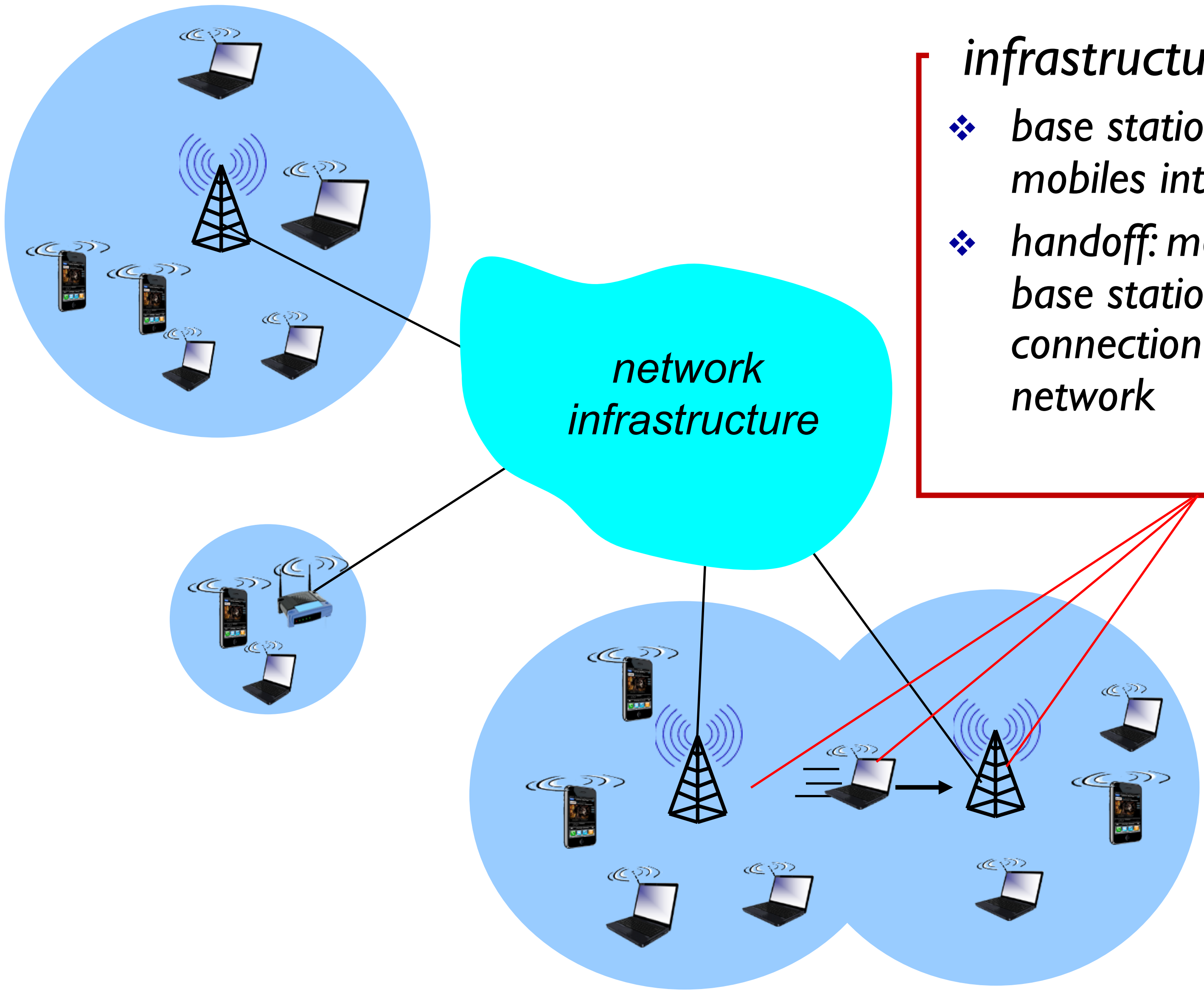
Australian radiofrequency spectrum
allocations chart

Australian Government

acma
Australian Communications and Media Authority



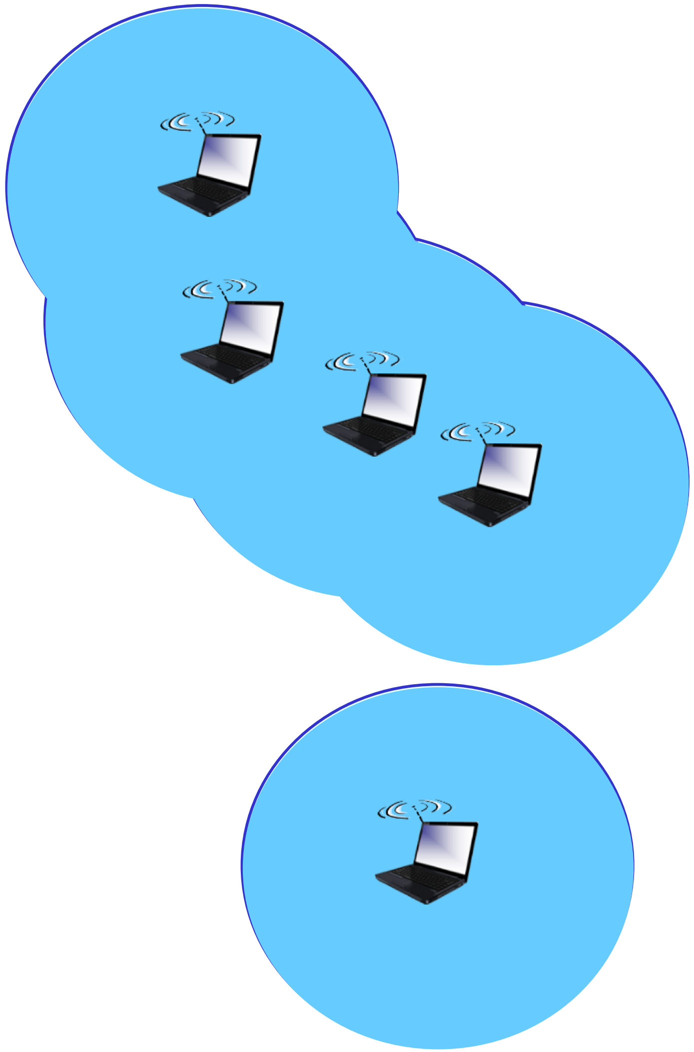
Elements of a wireless network



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, WiMAX, 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 other a given wireless node MANET, VANET*

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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:* standardized wireless network frequencies (e.g., 2.4 GHz) shared by other devices (e.g., phone); devices (motors) interfere as well
- *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"

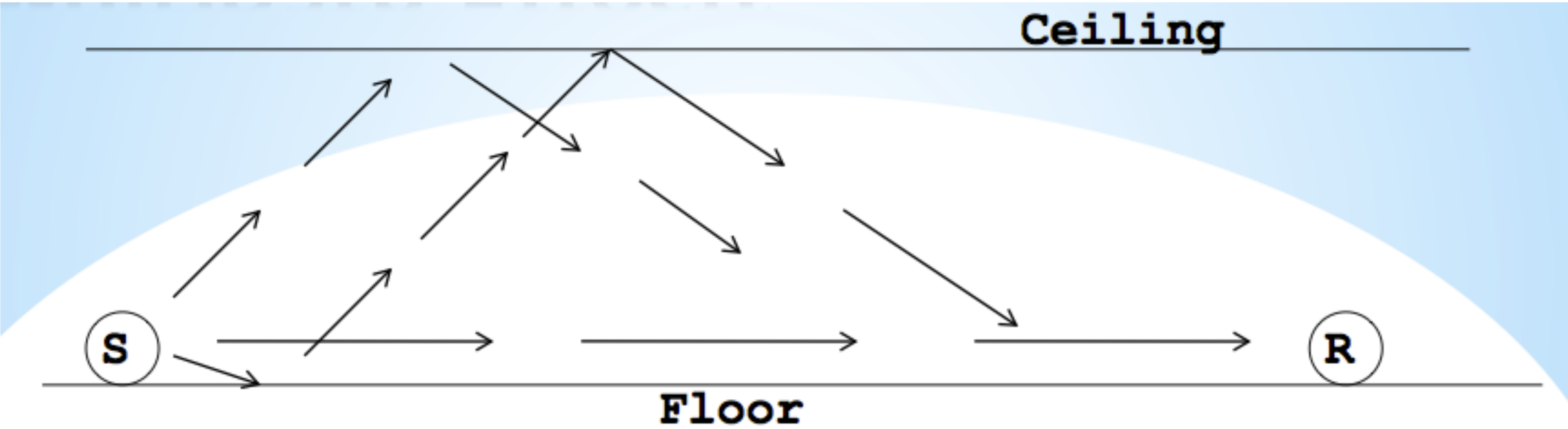
Path Loss/Path Attenuation

- Free Space Path Loss
  - d: distance
  - λ: wavelength
  - f: frequency
  - c: speed of light

$$\mathrm{FSPL} = \left(\frac{4\pi d}{\lambda}\right)^2 = \left(\frac{4\pi d f}{c}\right)^2$$

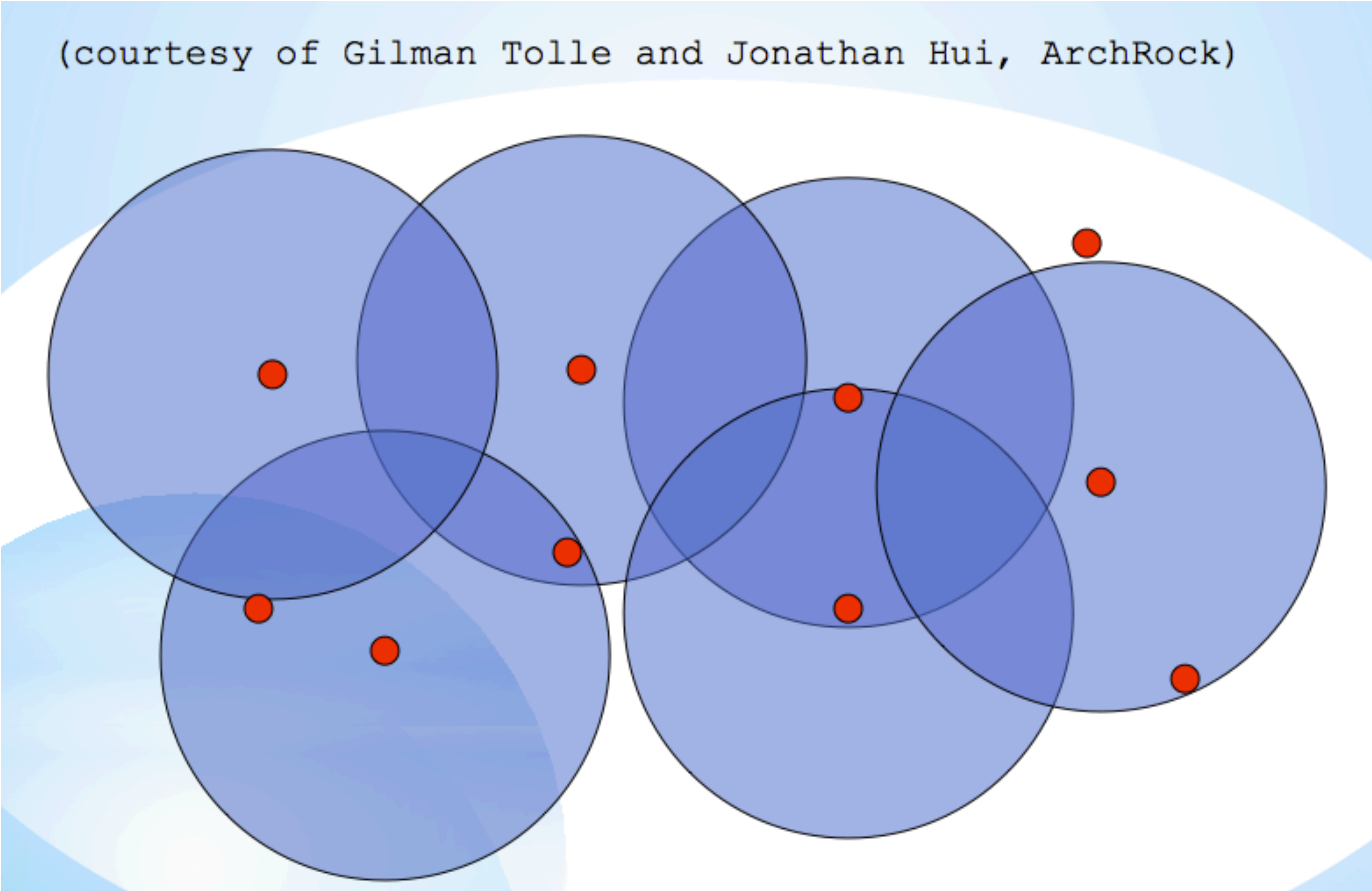
- Reflection, Diffraction, Absorption
- Terrain contours (urban, rural, vegetation)
- Humidity

Multipath Effects

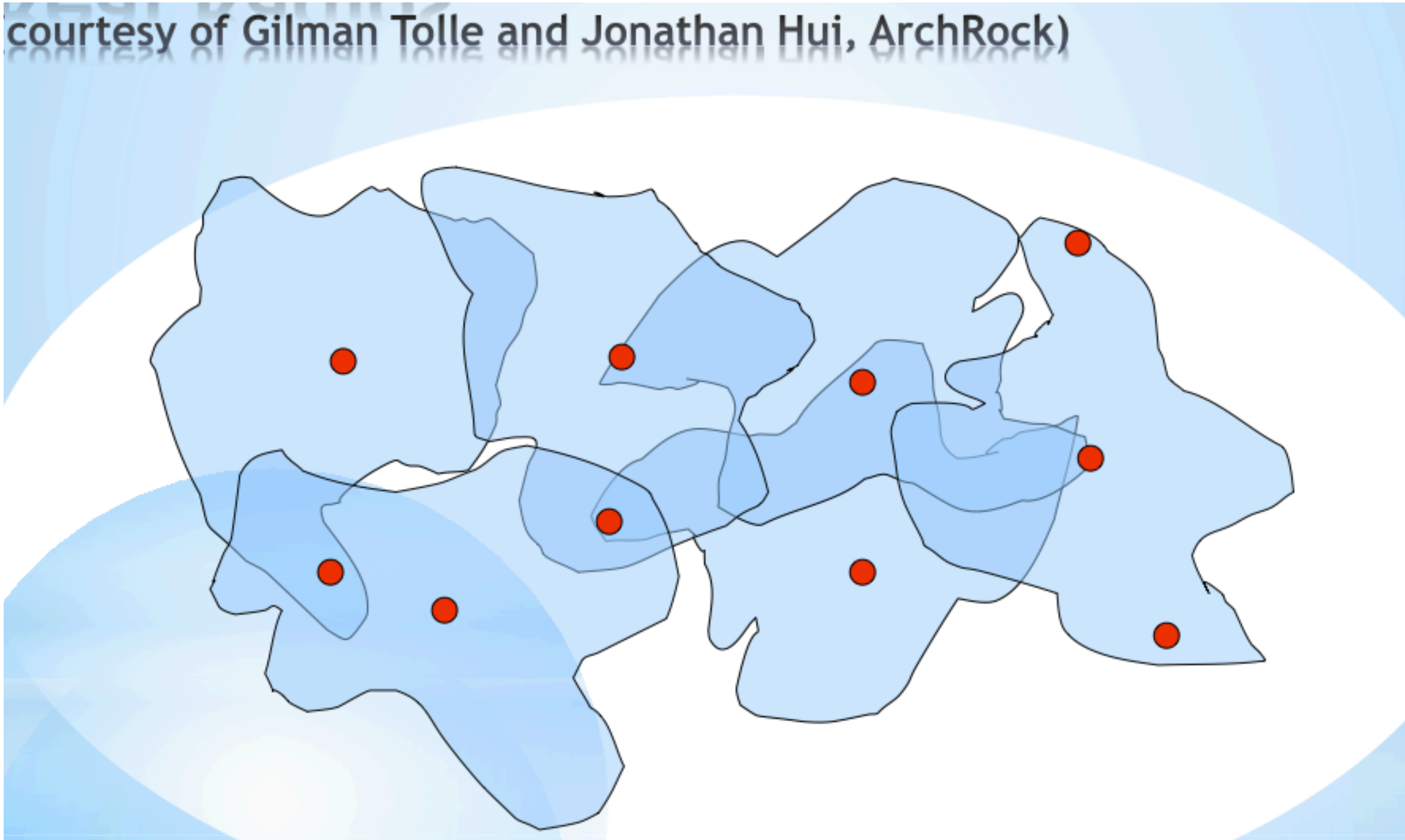


- Signals bounce off surface and interfere (constructive or destructive) with one another
- Self-interference

Ideal Radios

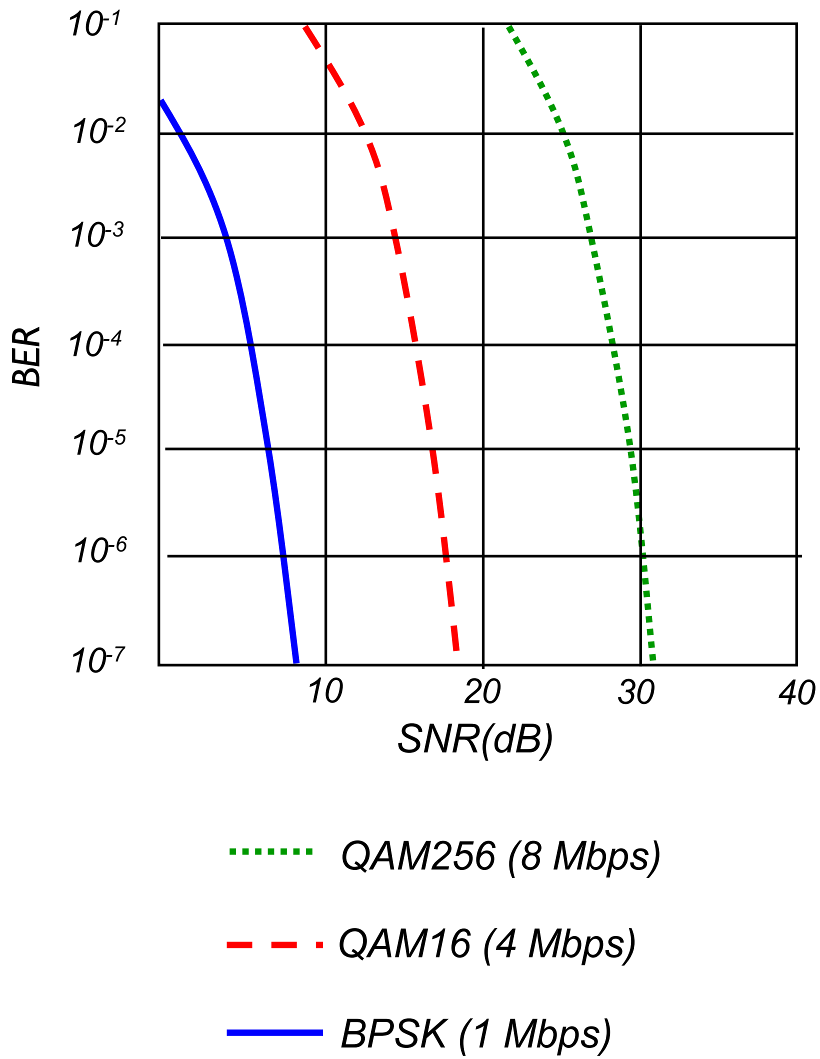


Real Radios



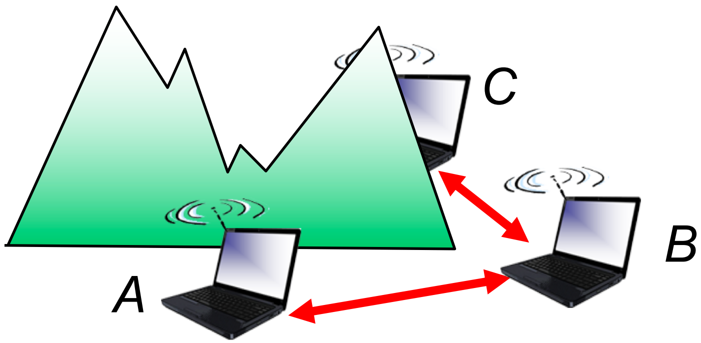
Wireless Link Characteristics (2)

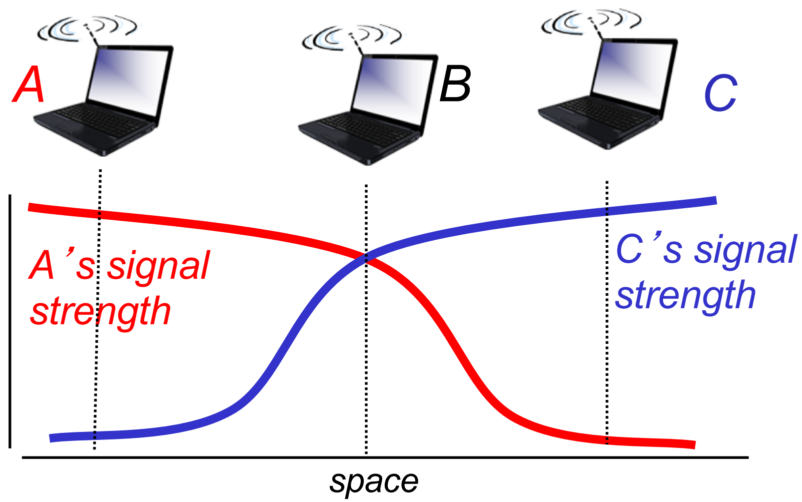
- SNR: signal-to-noise ratio
  - larger SNR – easier to extract signal from noise (a "good thing")
- *SNR versus BER tradeoffs*
  - *given physical layer:* increase power -> increase SNR->decrease BER
  - *given SNR:* choose physical layer that meets BER requirement, giving highest thruput
    - SNR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



Wireless network characteristics

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





Hidden terminal problem

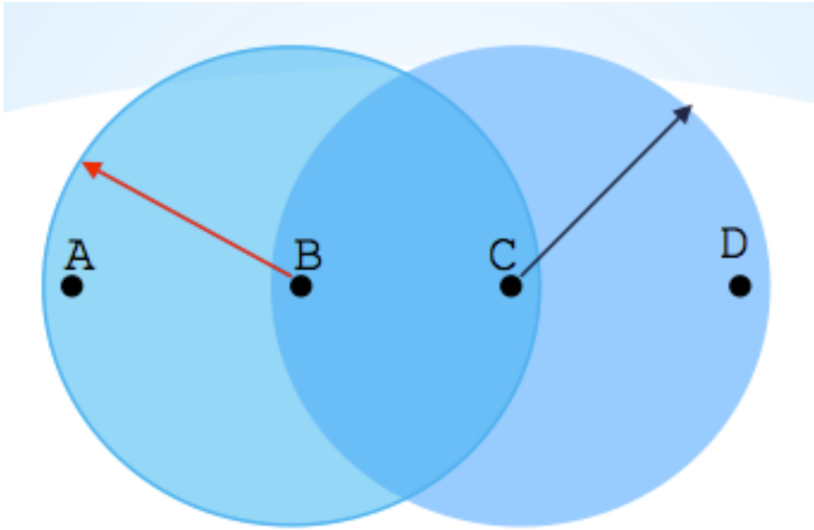
- *B, A hear each other*
- *B, C hear each other*
- *A, C can not hear each other means A, C unaware of their interference at B*
- *Carrier sense will be ineffective*

Signal attenuation:

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

Wireless network characteristics

- Exposed Terminals



- Node B sends a packet to A; C hears this and decides not to send a packet to D (despite the fact that this will not cause interference) !!
- Carrier sense would prevent a successful transmission

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IEEE 802.11 Wireless LAN

802.11b
- 2.4-5 GHz unlicensed spectrum
- up to 11 Mbps
- direct sequence spread spectrum (DSSS) in physical layer
  - all hosts use same chipping code

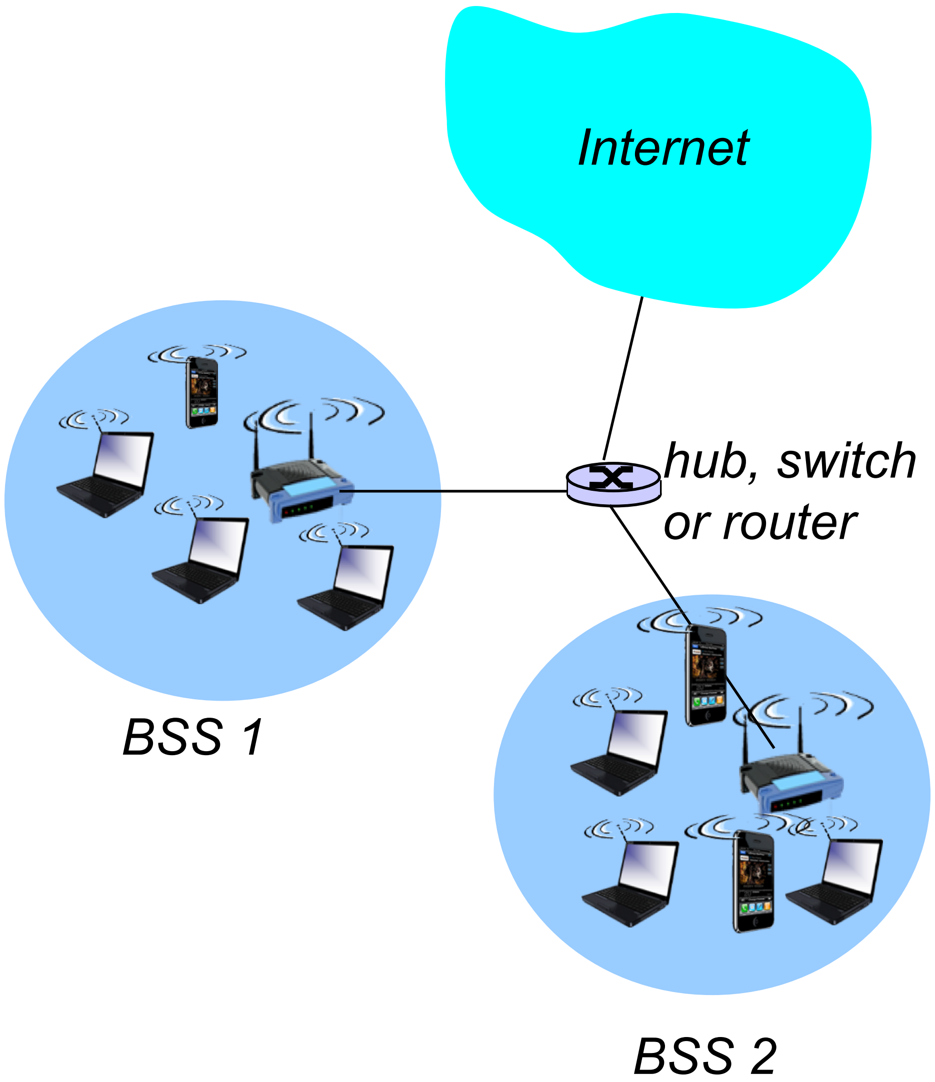
802.11a
- 5-6 GHz range
- up to 54 Mbps

802.11g
- 2.4-5 GHz range
- up to 54 Mbps

802.11n: multiple antennae
- 2.4-5 GHz range
- up to 200 Mbps

- *all use CSMA/CA for multiple access*
- *all have base-station and ad-hoc network versions*

802.11 LAN architecture

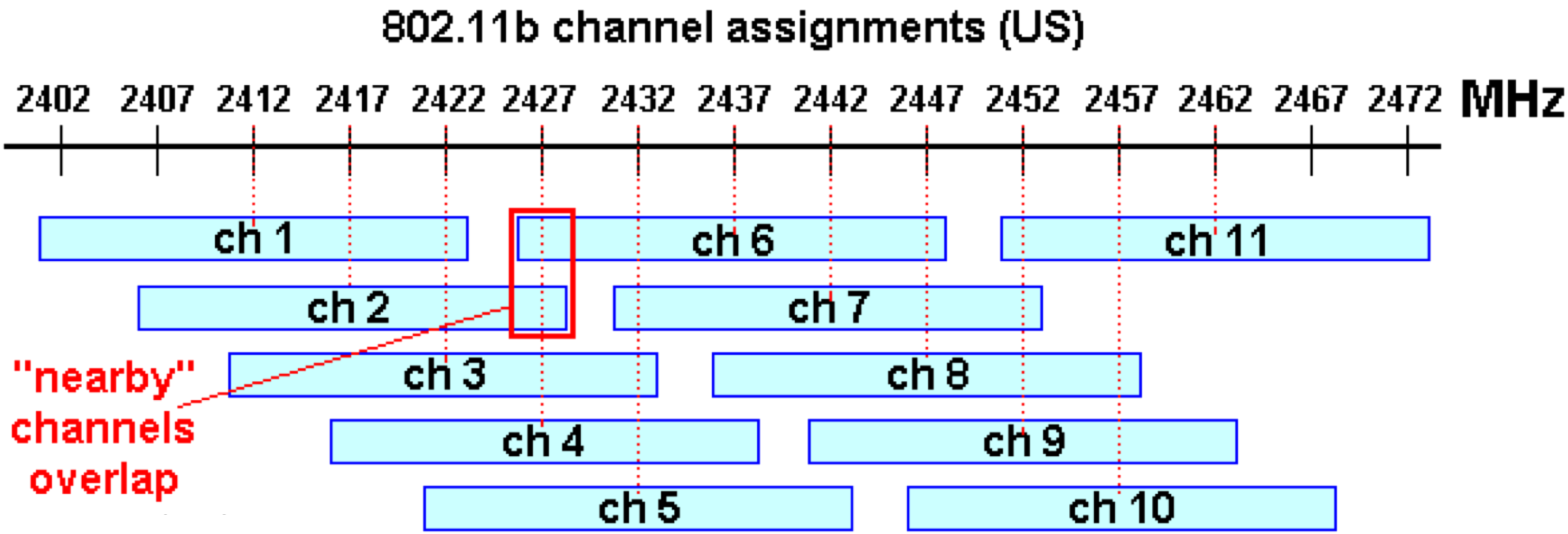


- *wireless host communicates with base station*
  - *base station = access point (AP)*
- *Basic Service Set (BSS) (aka "cell") in infrastructure mode contains:*
  - *wireless hosts*
  - *access point (AP): base station*
  - *ad hoc mode: hosts only*

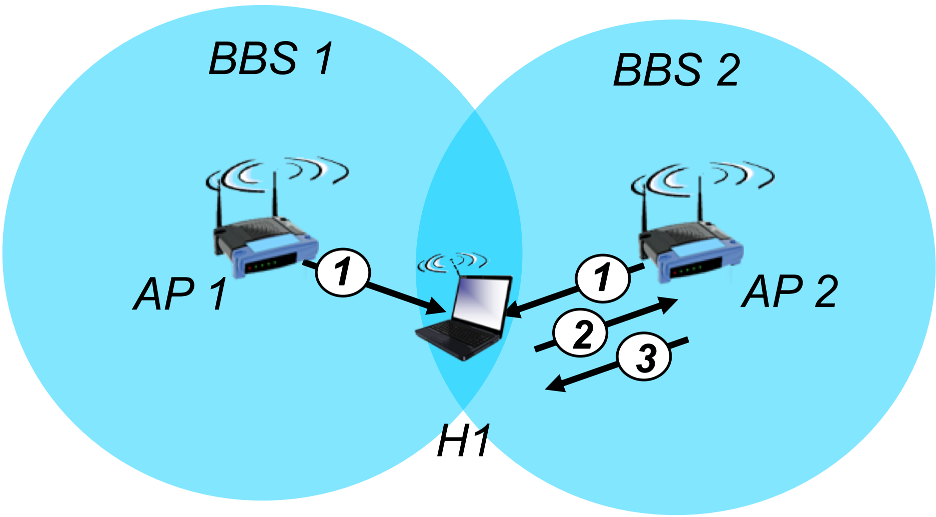
802.11: Channels, association

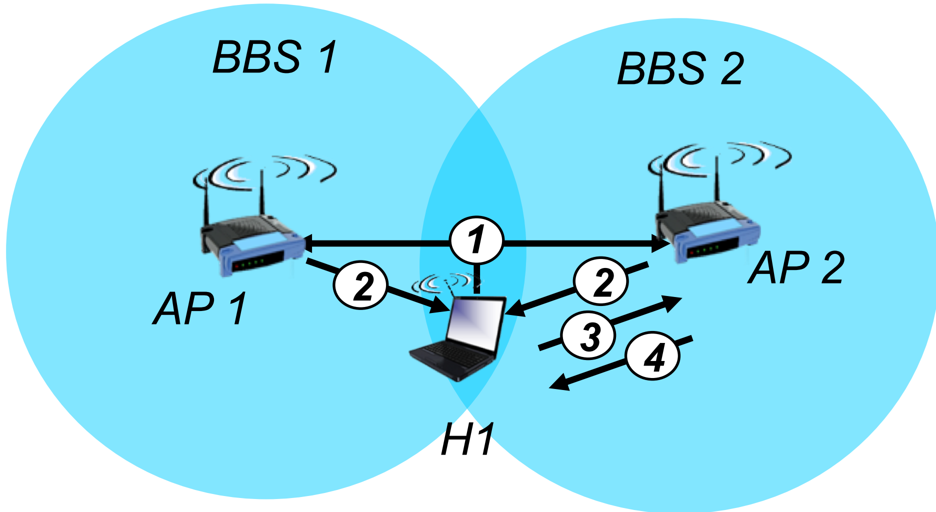
- 802.11b: 2.4GHz-2.485GHz spectrum divided into 11 channels at different frequencies
  - AP admin chooses frequency for AP
  - interference possible: channel can be same as that chosen by neighboring AP!
- host: must *associate* with an AP
  - scans channels, listening for *beacon frames* containing AP's name (SSID) and MAC address
  - selects AP to associate with
  - may perform authentication [Chapter 8]
  - will typically run DHCP to get IP address in AP's subnet

802.11b channels



802.11: passive/active scanning





passive scanning:

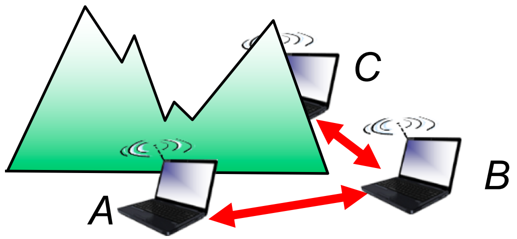
(1) beacon frames sent from APs
(2) association Request frame sent: H1 to selected AP
(3) association Response frame sent from selected AP to H1

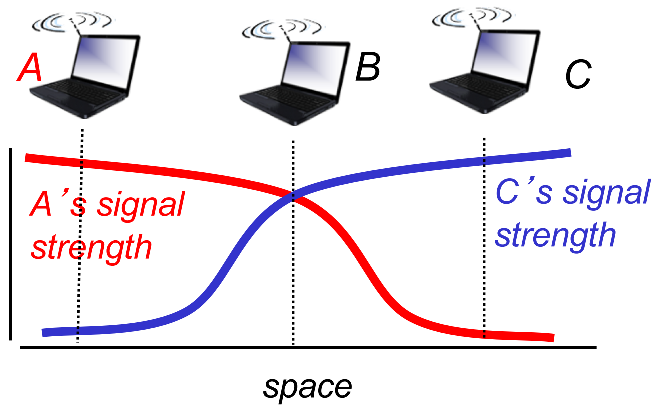
active scanning:

(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 ongoing transmission by other node
- 802.11: *no* collision detection!
  - difficult to receive (sense collisions) when transmitting due to weak received signals (fading)
  - can't sense all collisions in any case: hidden terminal, fading
  - goal: *avoid collisions:* CSMA/C(ollision)A(voidance)





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

Distributed Coordination Function (DCF)

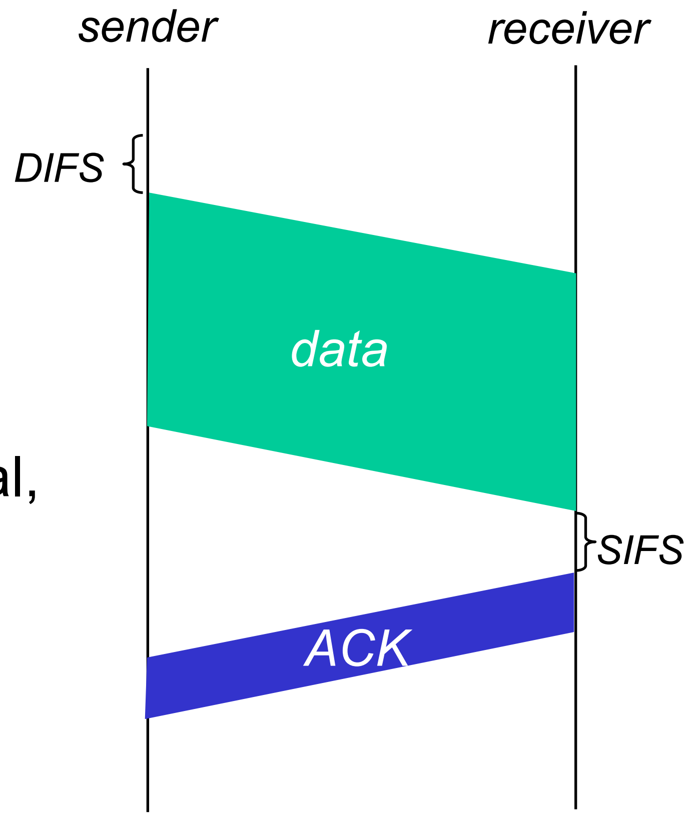
802.11 sender

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)



DIFS = DCF Inter Frame space
SIFS = Short Inter Frame Space

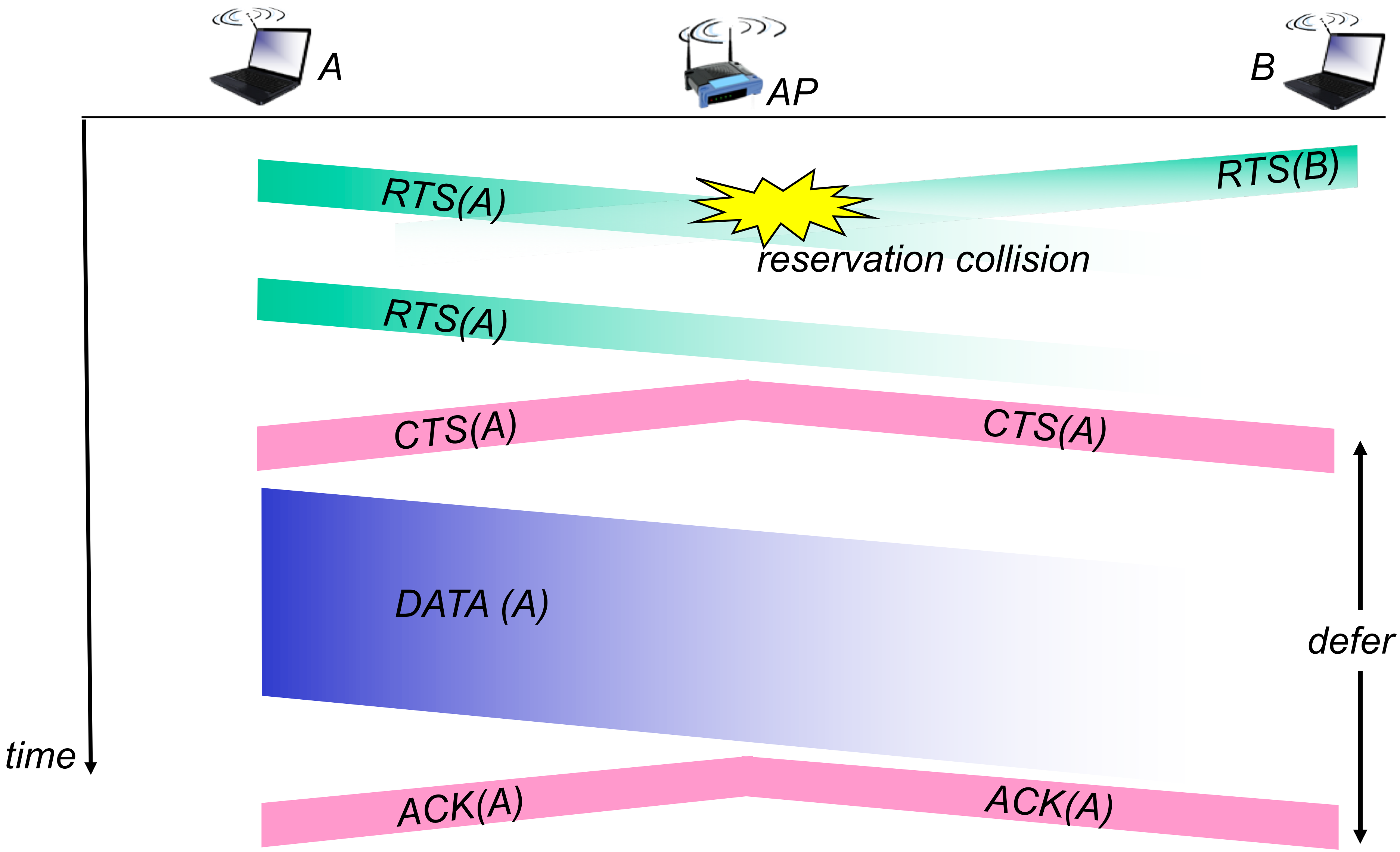
Avoiding collisions (more)

idea: allow sender to "reserve" channel rather than random access of data frames: avoid collisions of long data frames

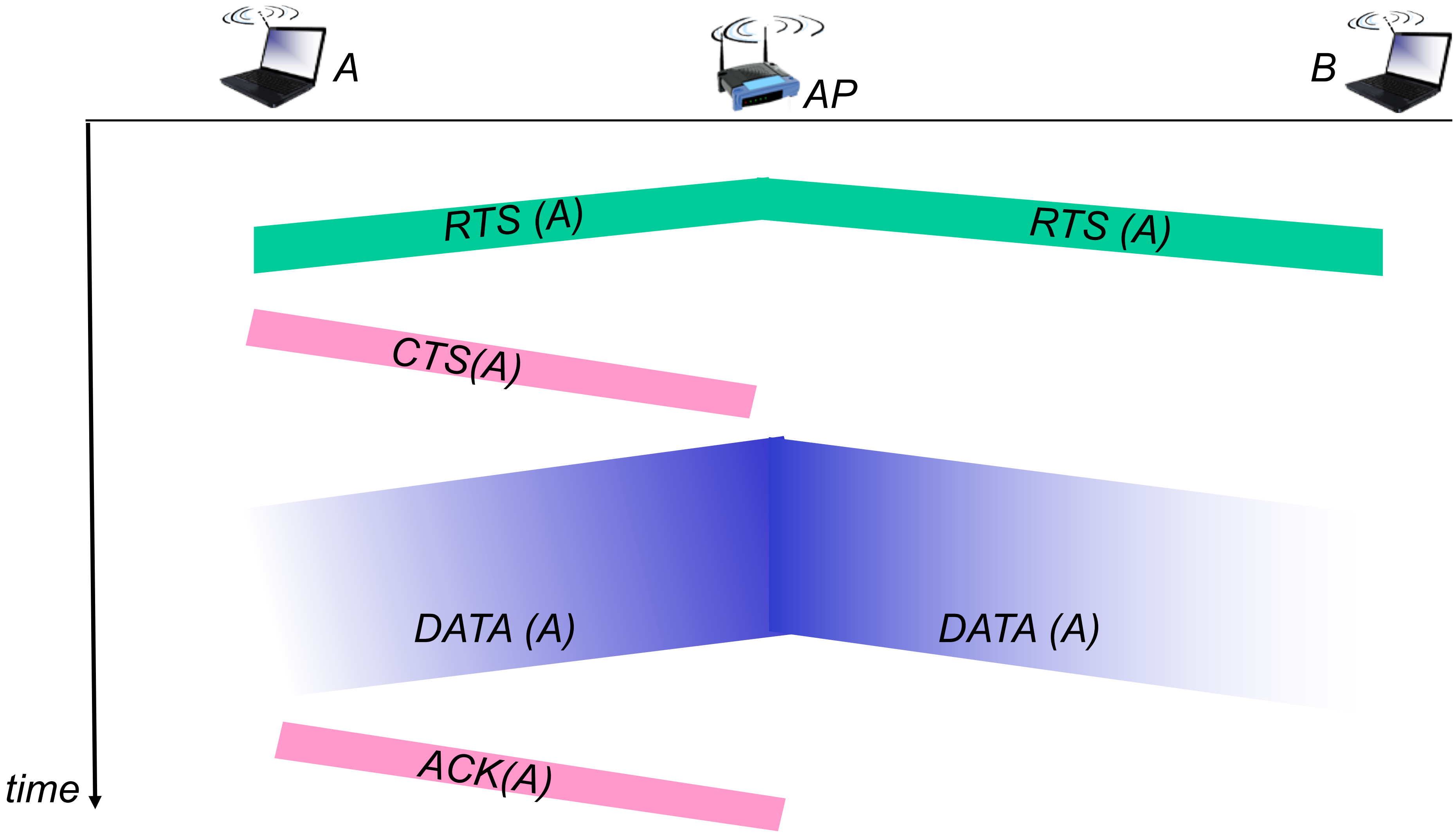
- sender first transmits *small* request-to-send (RTS) packets to BS using CSMA
  - RTSs may still collide with each other (but they're short)
- BS broadcasts clear-to-send CTS in response to RTS
- CTS heard by all nodes
  - sender transmits data frame
  - other stations defer transmissions

avoid data frame collisions completely using small reservation packets!

Collision Avoidance: RTS-CTS exchange



Collision Avoidance: RTS-CTS exchange



Summary

Wireless

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