Chapter 6
Wireless and Mobile Networks

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Ch. 6: Wireless and Mobile 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

Chapter 6 Outline of Lecture 27

6.1 Introduction
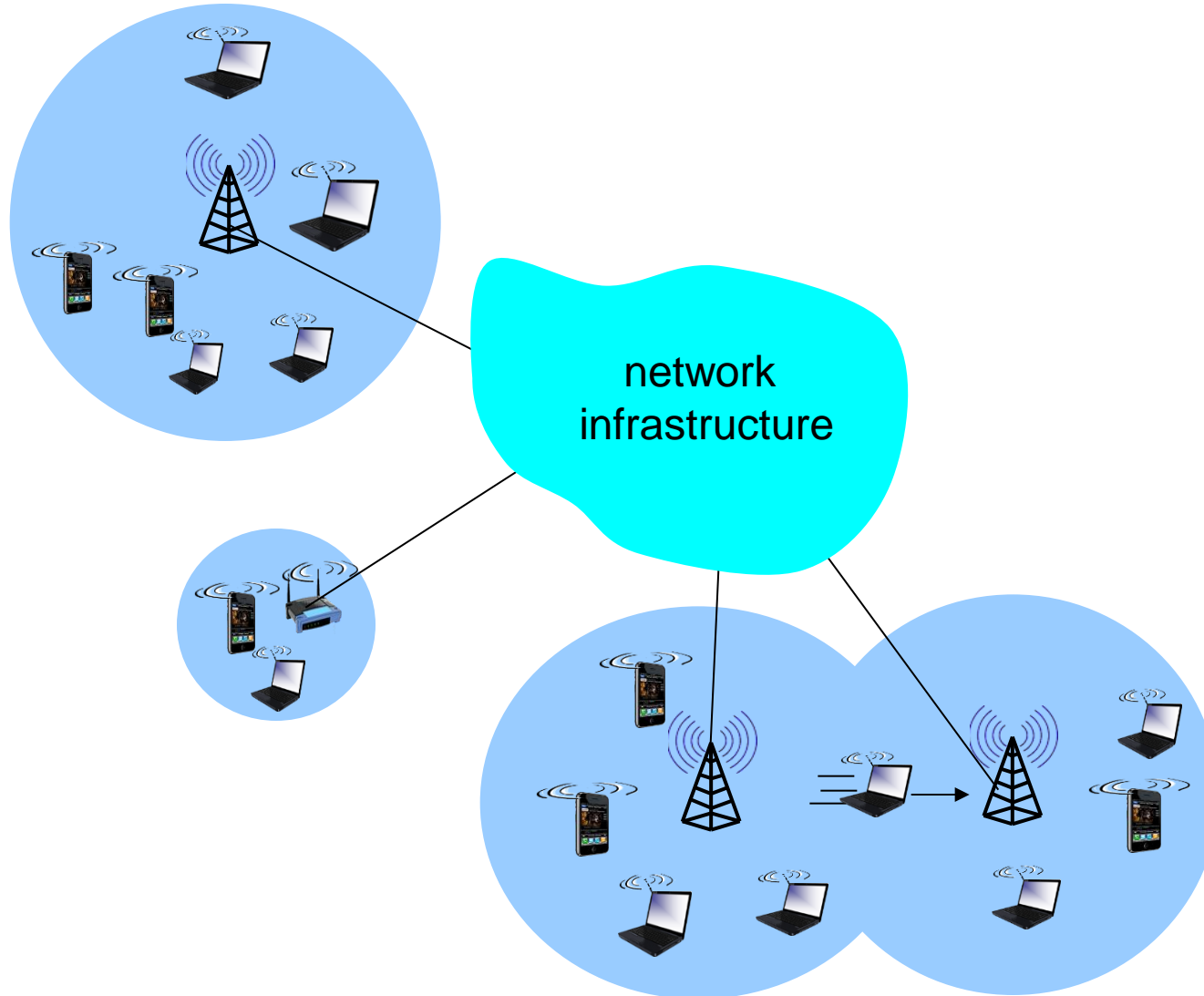
Wireless

6.2 Wireless links, characteristics
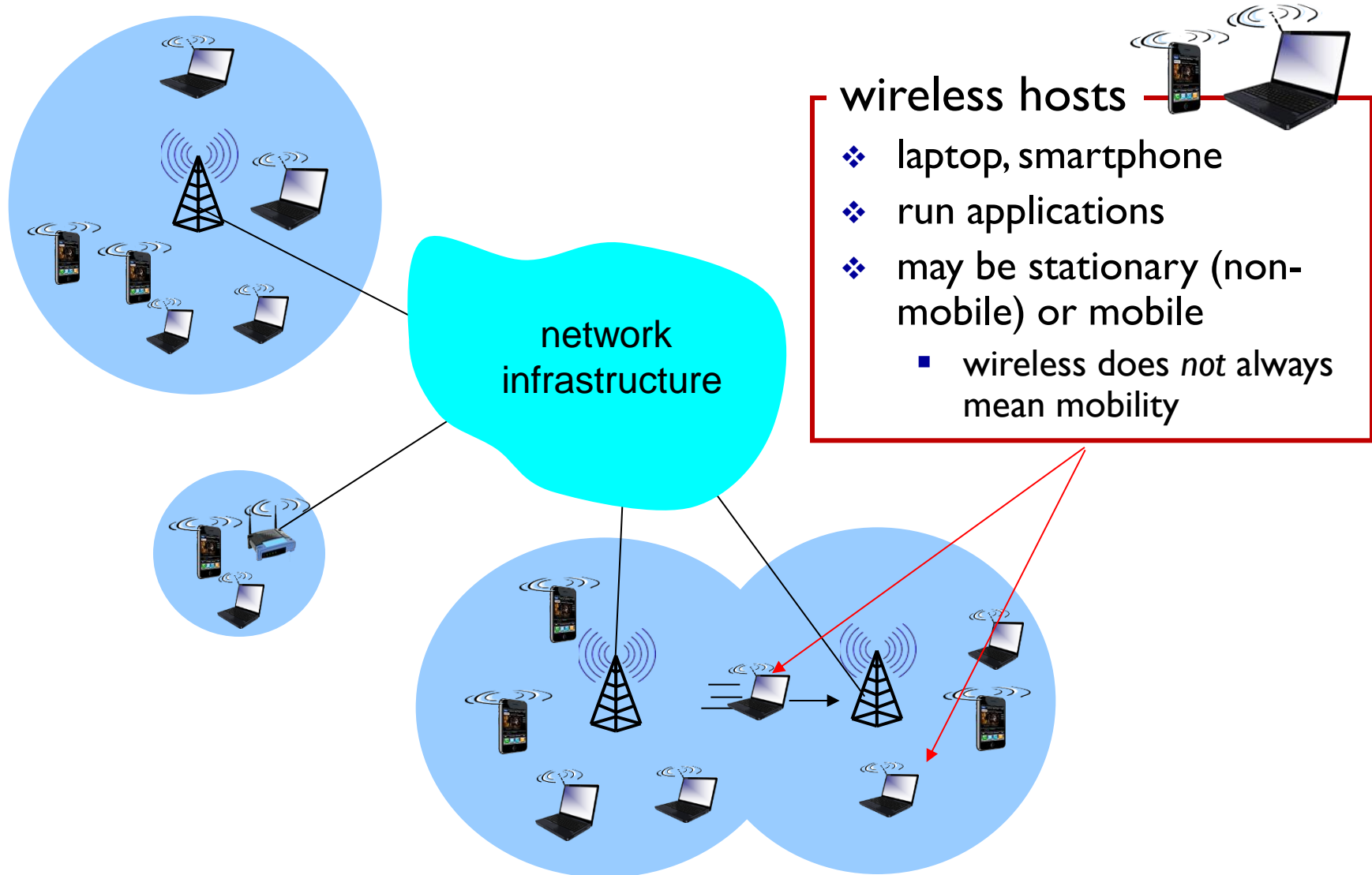- CDMA

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

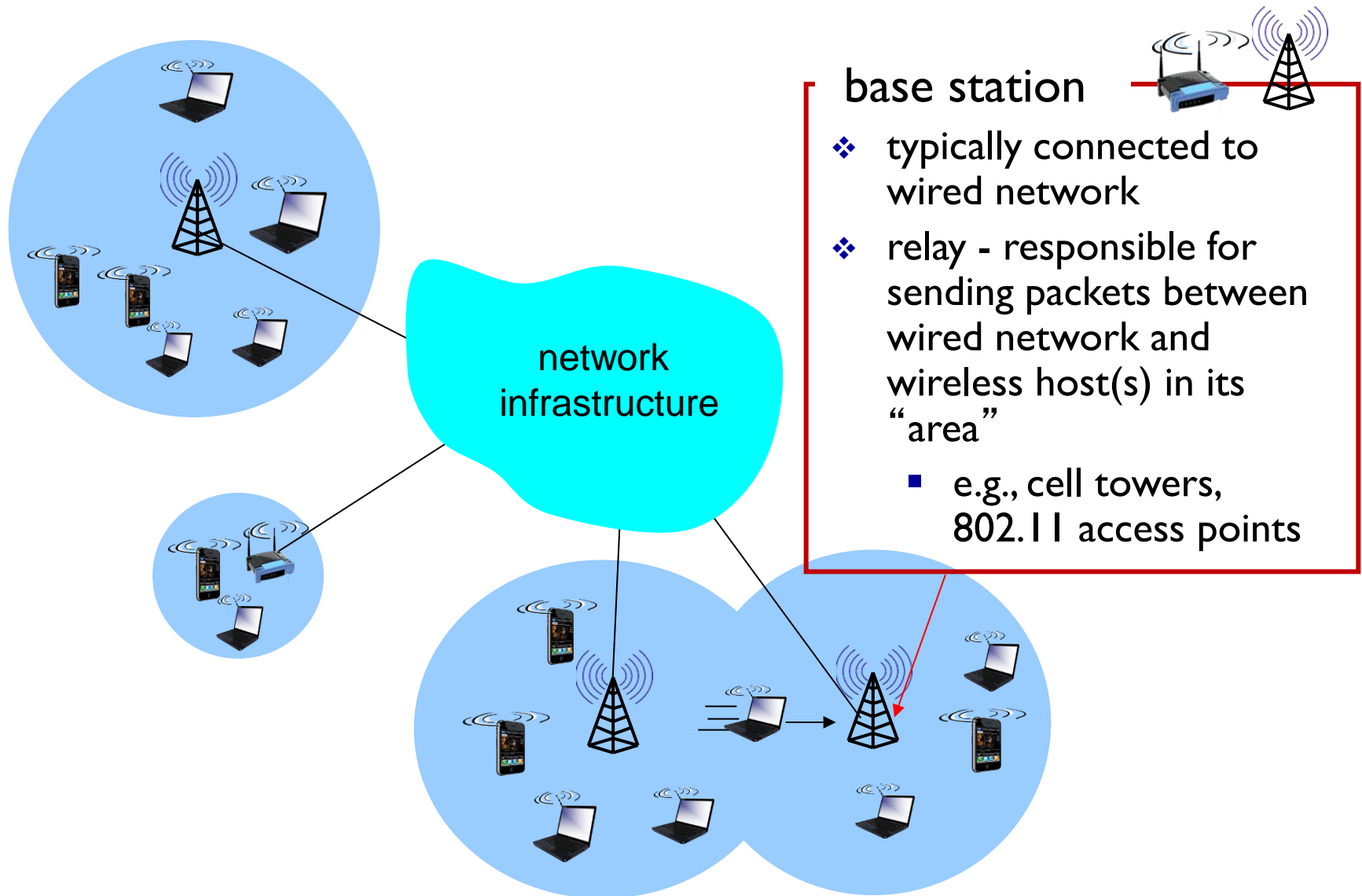6.4 Cellular Internet Access
- architecture
- standards (e.g., GSM)

Elements of a wireless network

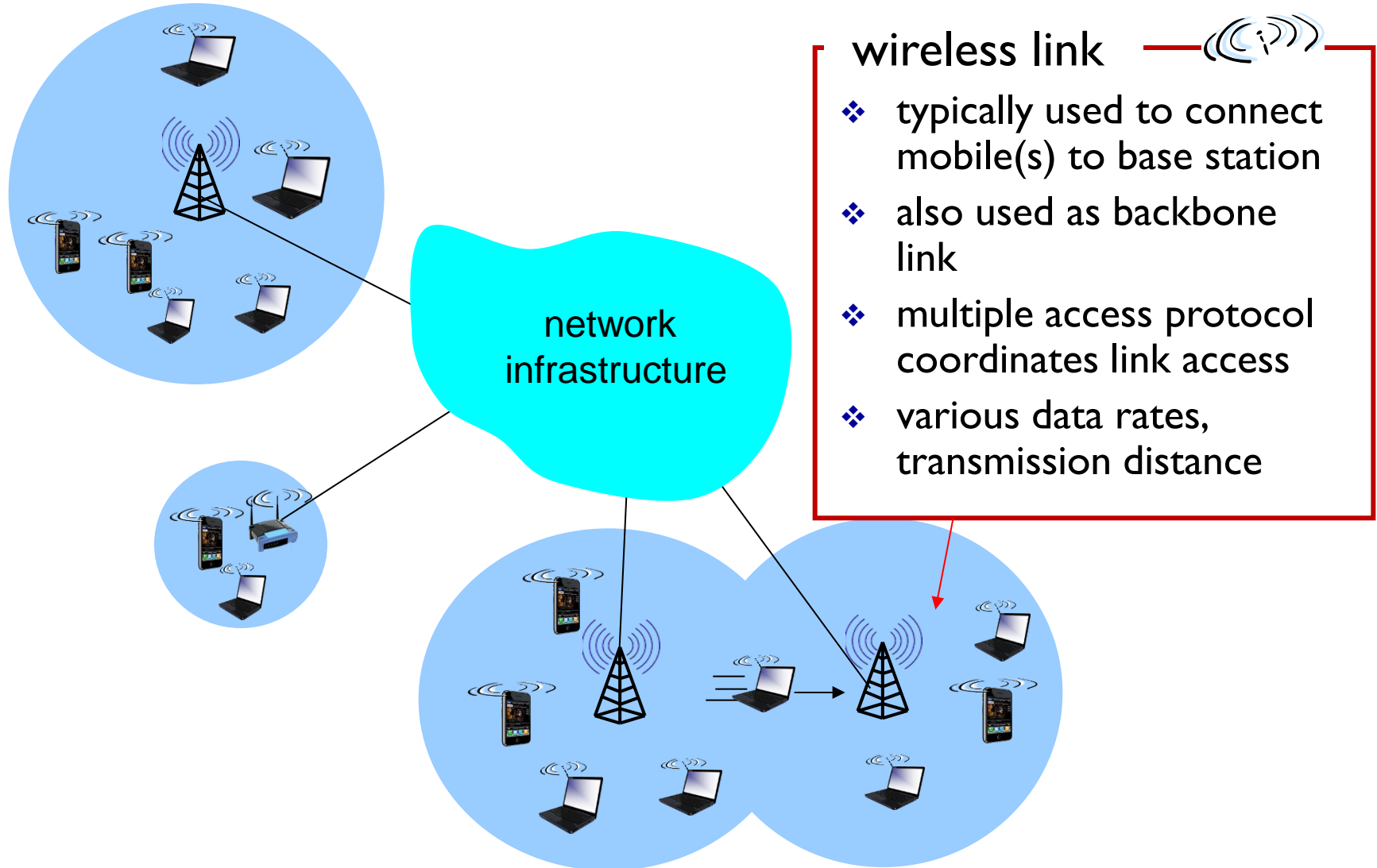network infrastructure

Elements of a wireless network

wireless hosts

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

network infrastructure

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

network infrastructure

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

network infrastructure

Characteristics of selected wireless links

Data rate (Mbps) — vertical axis with values: 200, 54, 5-11, 4, 1, .384, .056

- **802.11n** — 200
- **802.11a,g** — 54
- **802.11a,g point-to-point**
- **802.11b** — 5-11
- **4G: LTWE WIMAX**
- **3G: UMTS/WCDMA-HSPDA, CDMA2000-1xEVDO** — 4
- **802.15** — 1
- **2.5G: UMTS/WCDMA, CDMA2000** — .384
- **2G: IS-95, CDMA, GSM** — .056

Horizontal axis:
- Indoor 10-30m
- Outdoor 50-200m
- Mid-range outdoor 200m – 4 Km
- Long-range outdoor 5Km – 20 Km

Elements of a wireless network

infrastructure mode

- ❖ base station connects mobiles into wired network

- ❖ handoff: mobile changes base station providing connection into wired network

network infrastructure
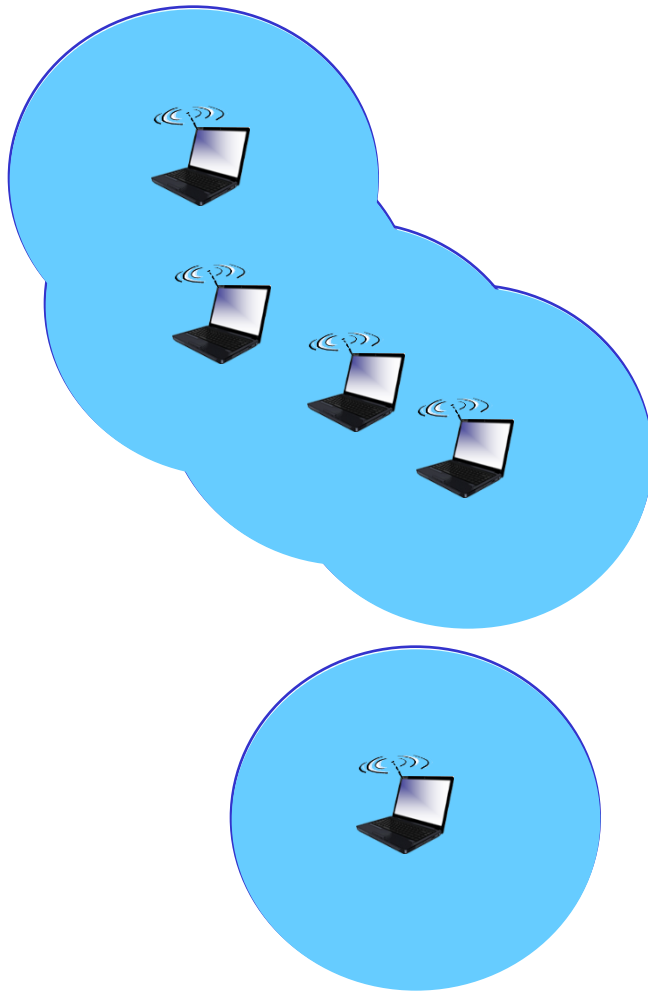
Elements of a wireless network

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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6.2 Wireless links, characteristics
- CDMA

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6.4 Cellular Internet Access
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6.5 Principles: addressing and routing to mobile users

6.6 Mobile IP

6.7 Handling mobility in cellular networks

6.8 Mobility and higher-layer protocols

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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 ad 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 thruput

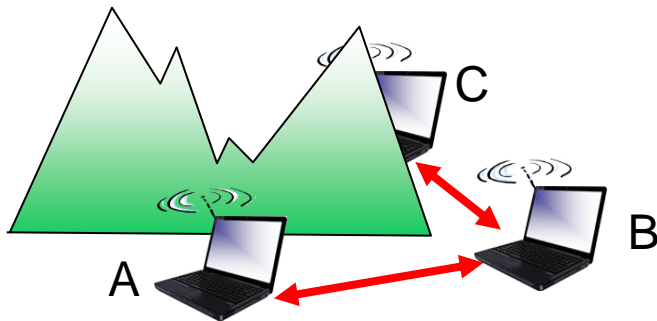   • SNR may change with mobility: dynamically adapt physical layer (modulation technique, rate)
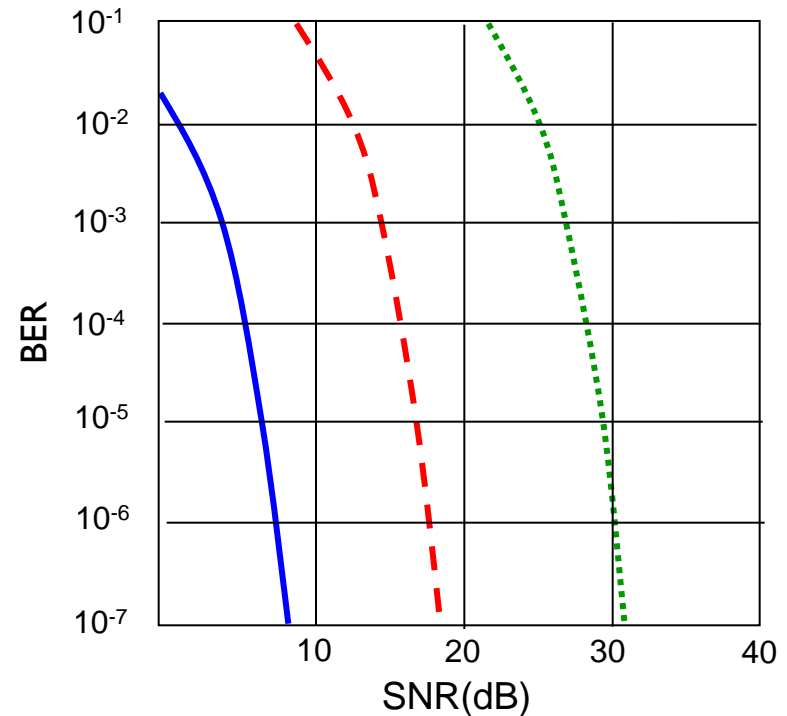
.... QAM256 (8 Mbps)

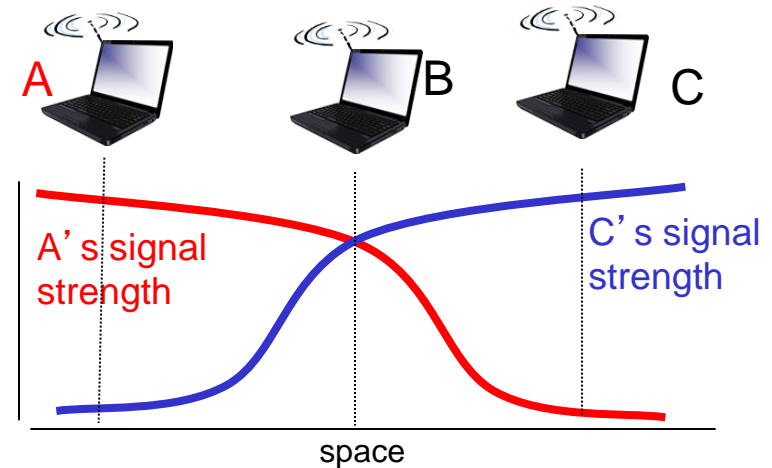– – – QAM16 (4 Mbps)

——— BPSK (1 Mbps)

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
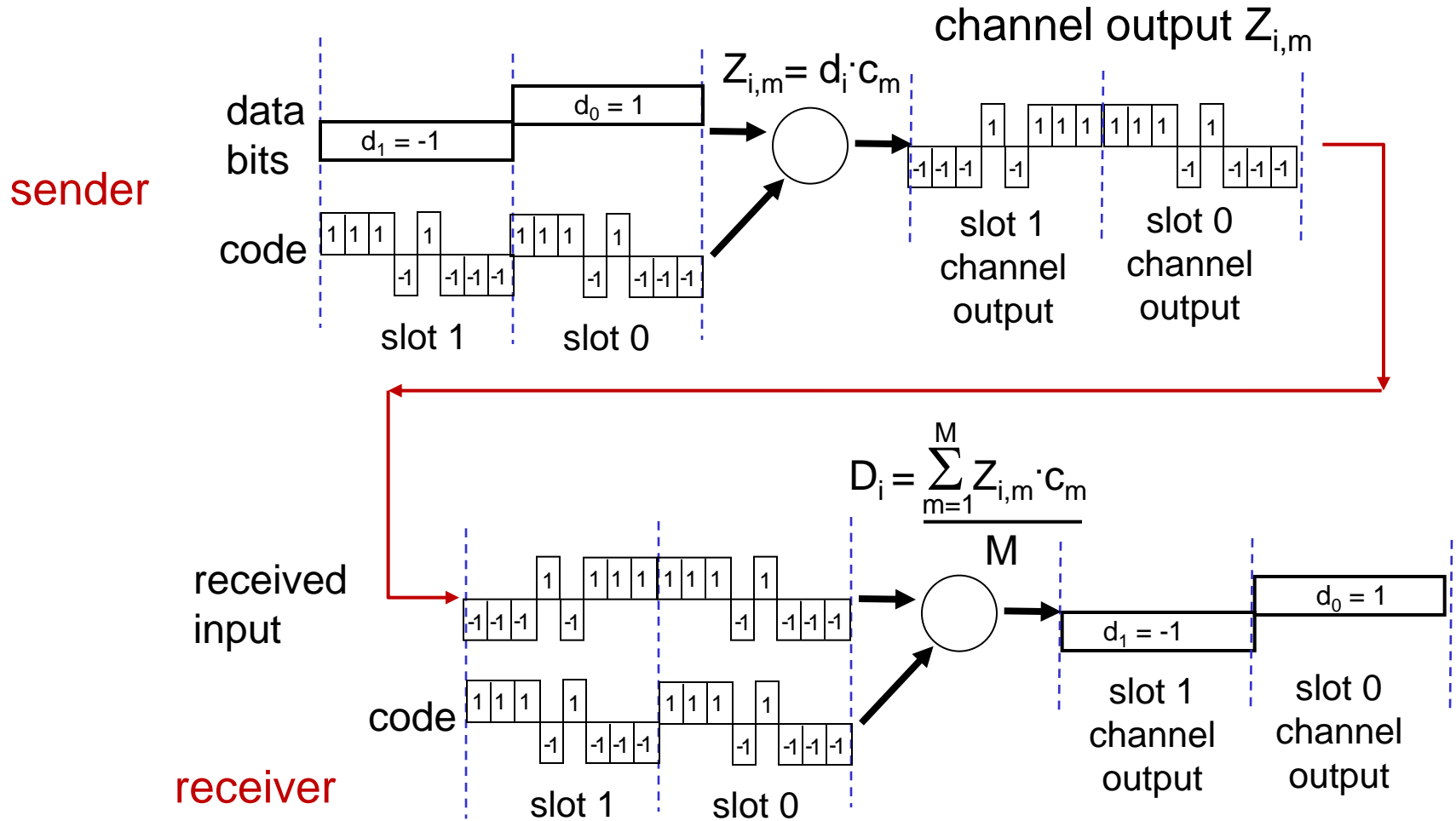
Signal attenuation:

❖ B, A hear each other
❖ B, C hear each other
❖ A, C can not hear each other interfering at B
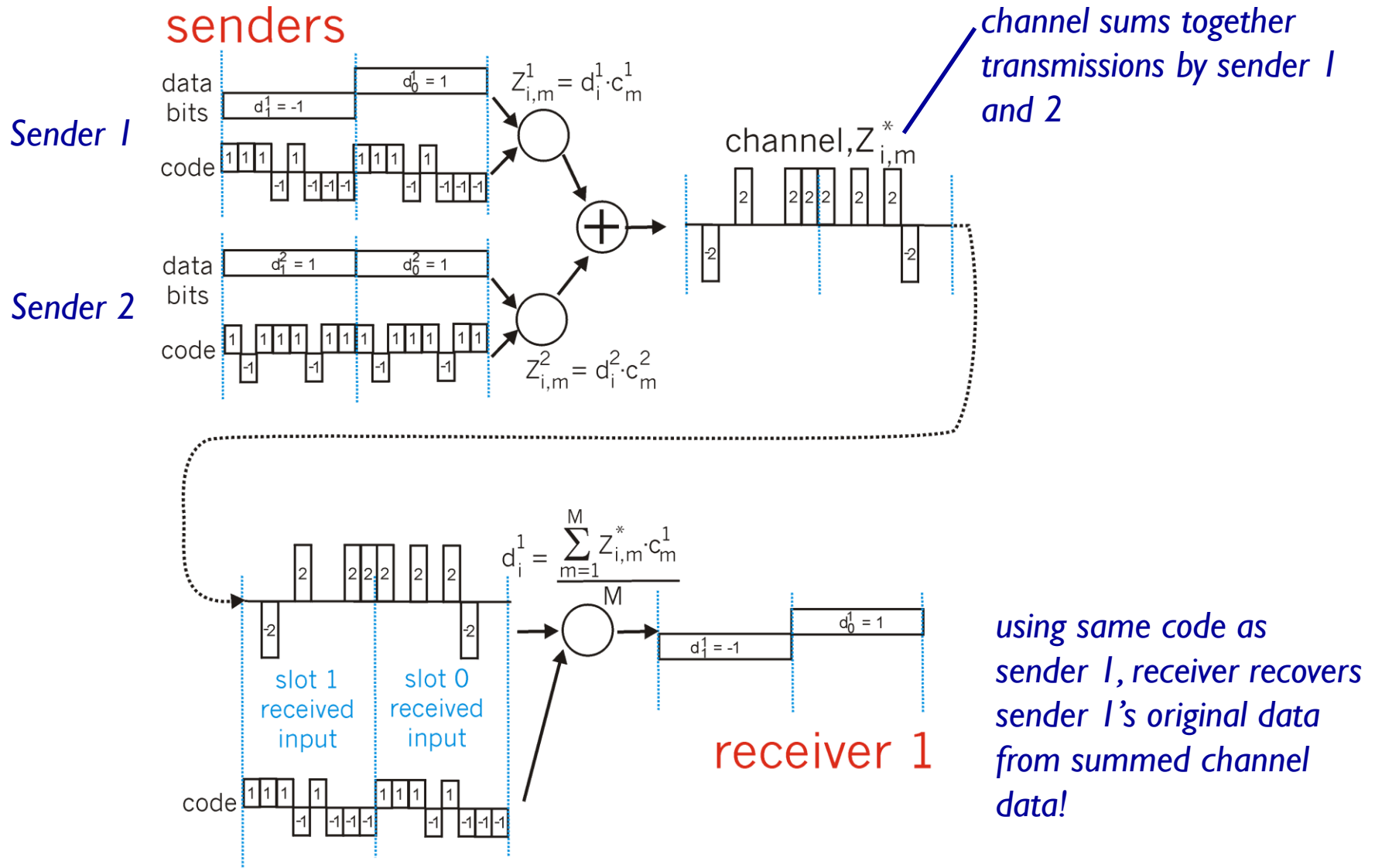
Code Division Multiple Access (CDMA)

❖ 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")

❖ *encoded signal* = (original data) X (chipping sequence)

❖ *decoding:* inner-product of encoded signal and chipping sequence

CDMA encode/decode

CDMA: two-sender interference

senders

Sender 1

Sender 2

data bits

code

$Z_{i,m}^1 = d_i^1 \cdot c_m^1$

$d_1^1 = -1$

$d_0^1 = 1$

channel, $Z_{i,m}^*$

channel sums together transmissions by sender 1 and 2

$d_1^2 = 1$

$d_0^2 = 1$

$Z_{i,m}^2 = d_i^2 \cdot c_m^2$

$d_i^1 = \dfrac{\displaystyle\sum_{m=1}^{M} Z_{i,m}^* \cdot c_m^1}{M}$

slot 1 received input

slot 0 received input

$d_1^1 = -1$

$d_0^1 = 1$

receiver 1

code

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

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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

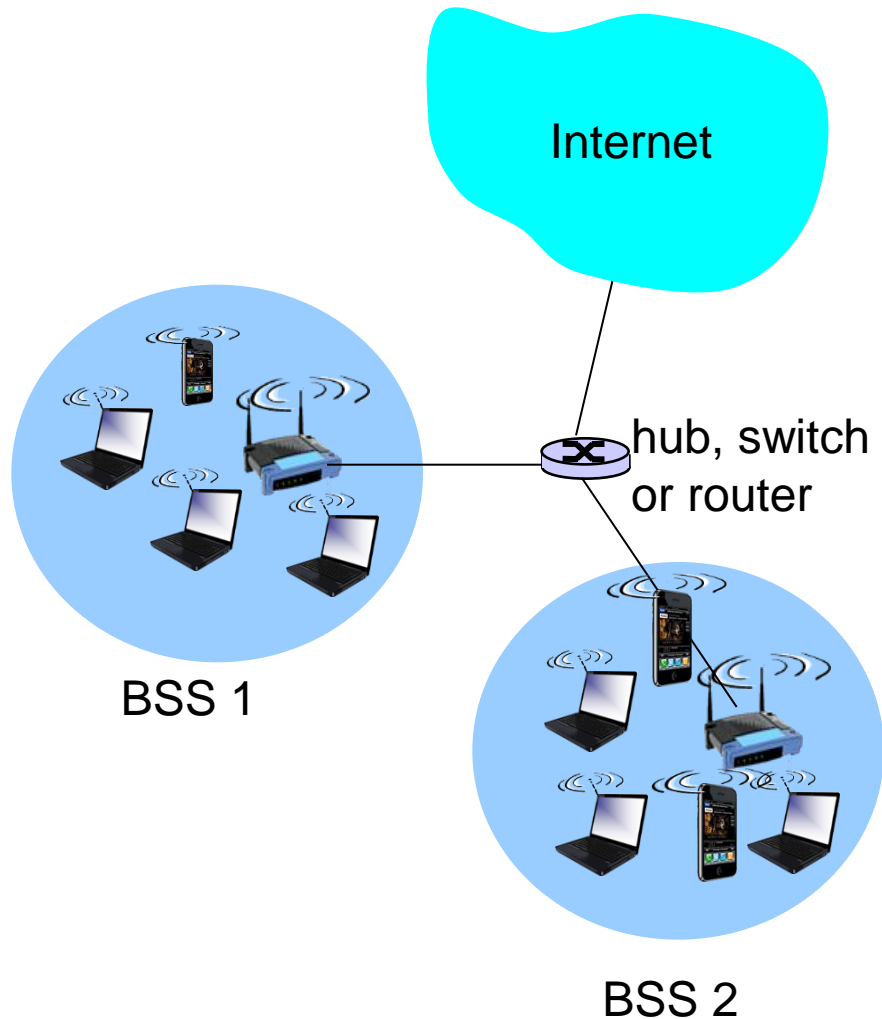- 5-6 GHz range
- up to 54 Mbps

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

Internet

BSS 1

hub, switch or router

BSS 2

❖ **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

802.11: passive/active scanning
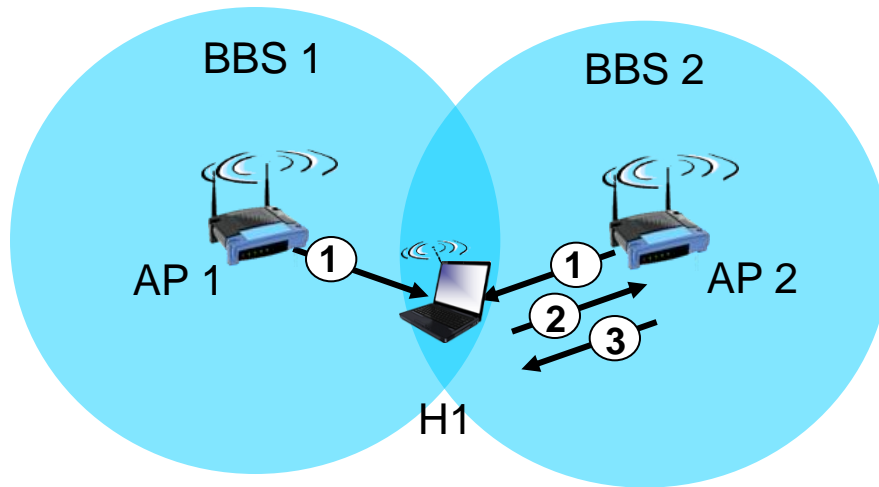
passive scanning:

(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
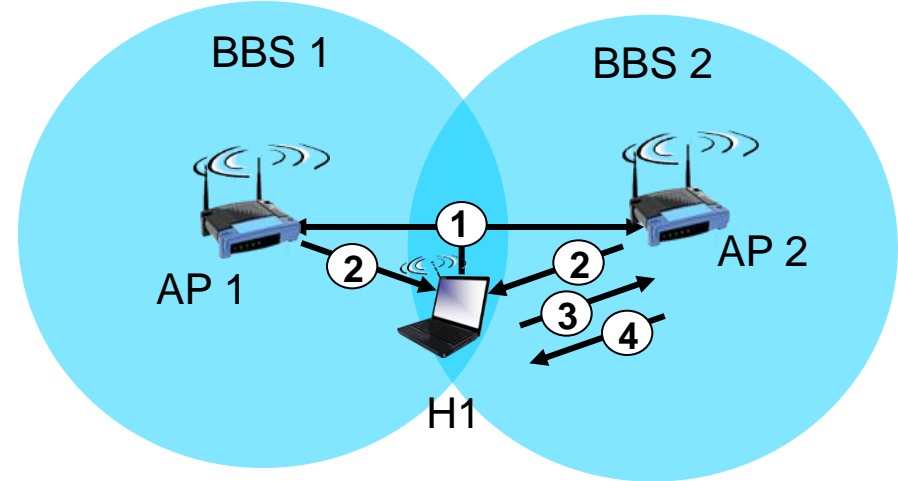
active scanning:

(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)

C

B

A

A

B

C

A's signal strength

C's signal strength

space
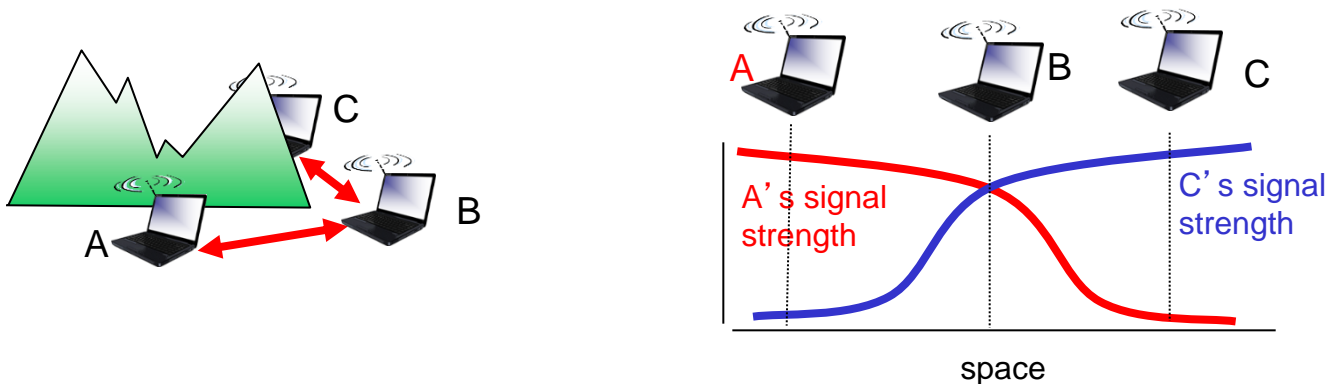
IEEE 802.11 MAC Protocol: CSMA/CA

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)
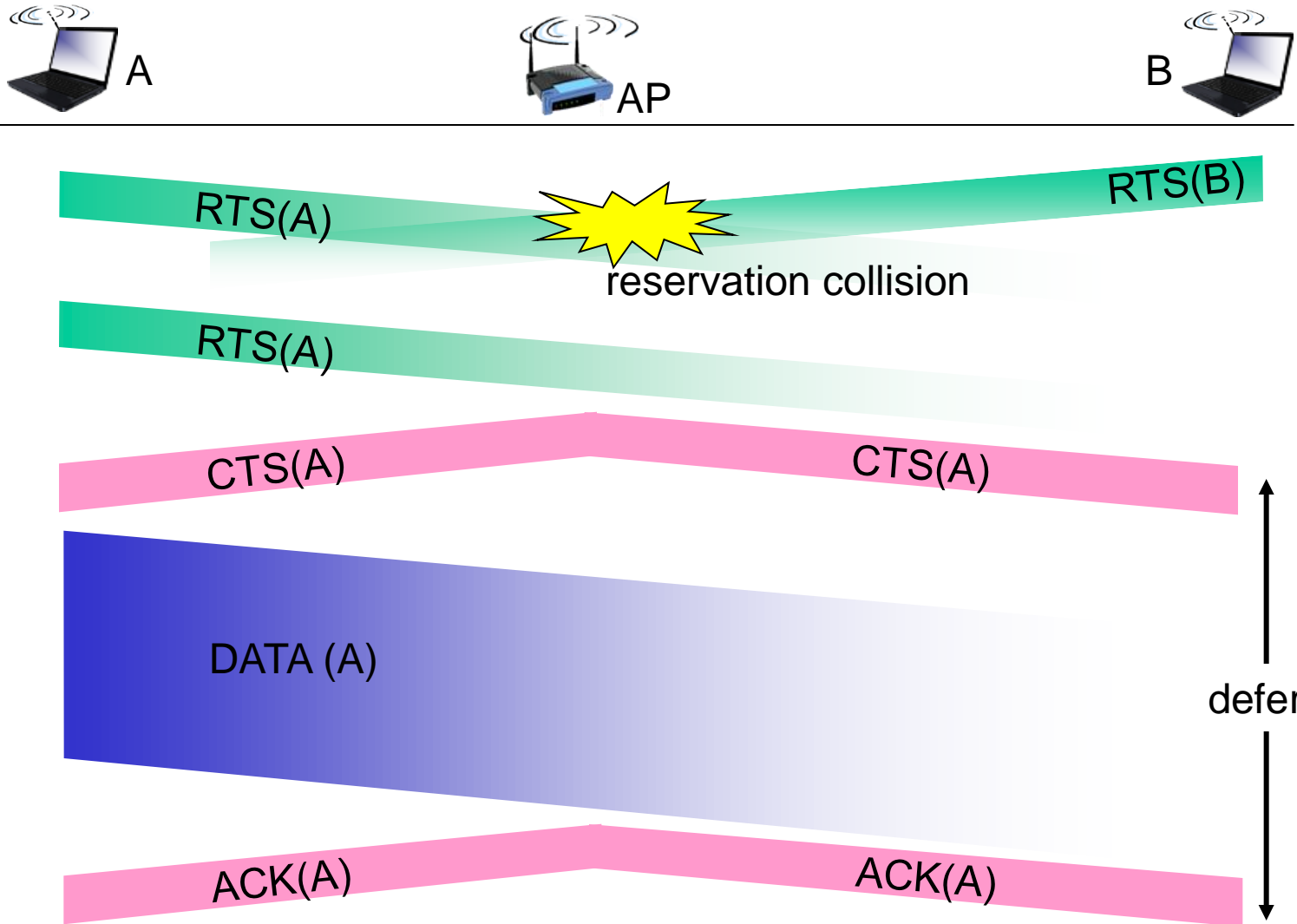
sender   receiver
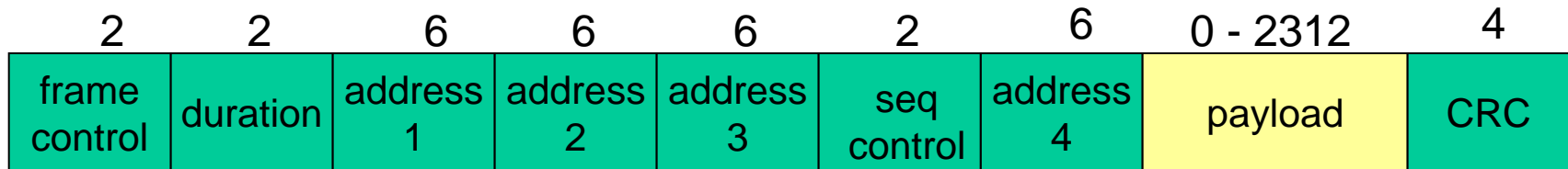
DIFS

data

SIFS

ACK
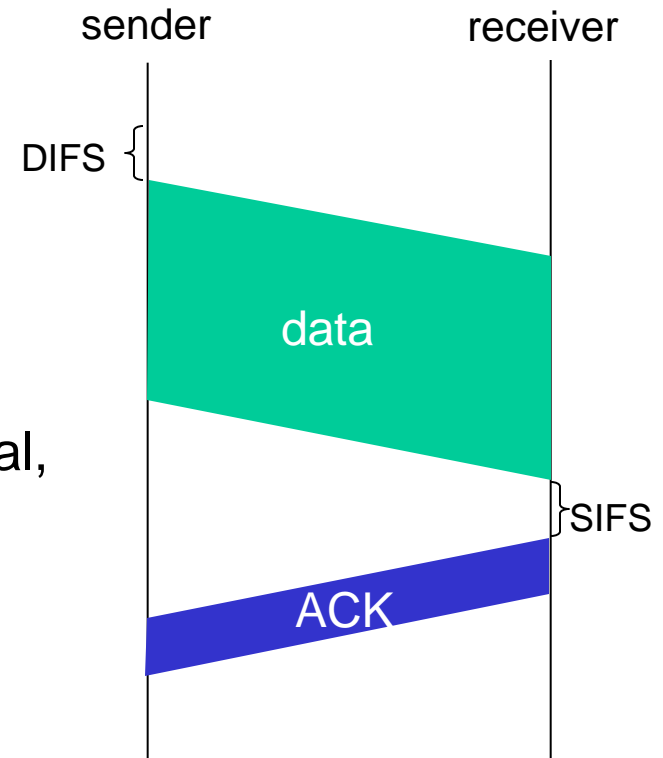
Avoiding collisions (more)

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

A

AP

B

RTS(A)

RTS(B)

reservation collision

RTS(A)

CTS(A)

CTS(A)

DATA (A)

defer

time

ACK(A)

ACK(A)

802.11 frame: addressing

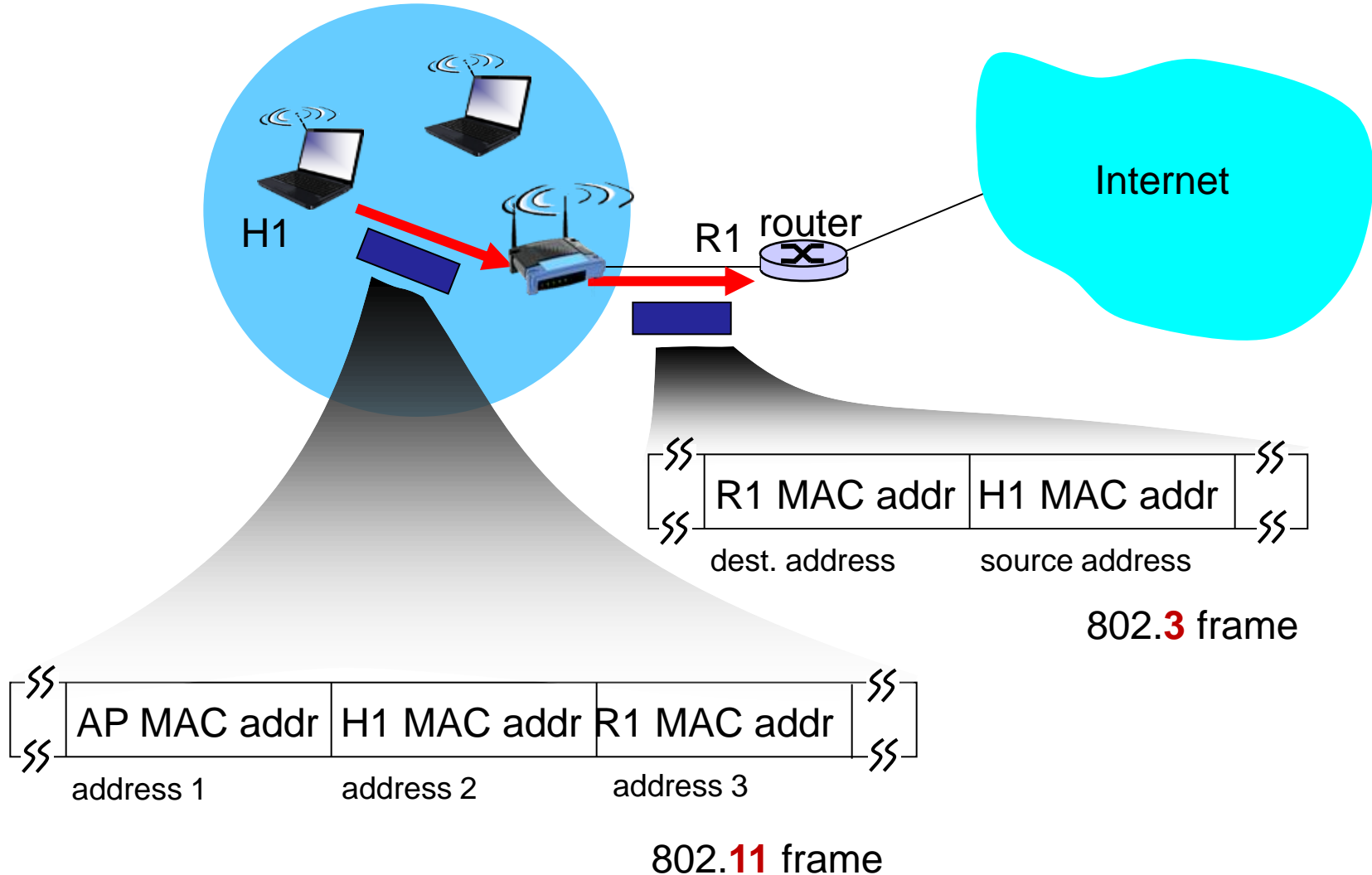| 2	2	6	6	6	2	6	0 - 2312	4
frame control	duration	address 1	address 2	address 3	seq control	address 4	payload	CRC

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

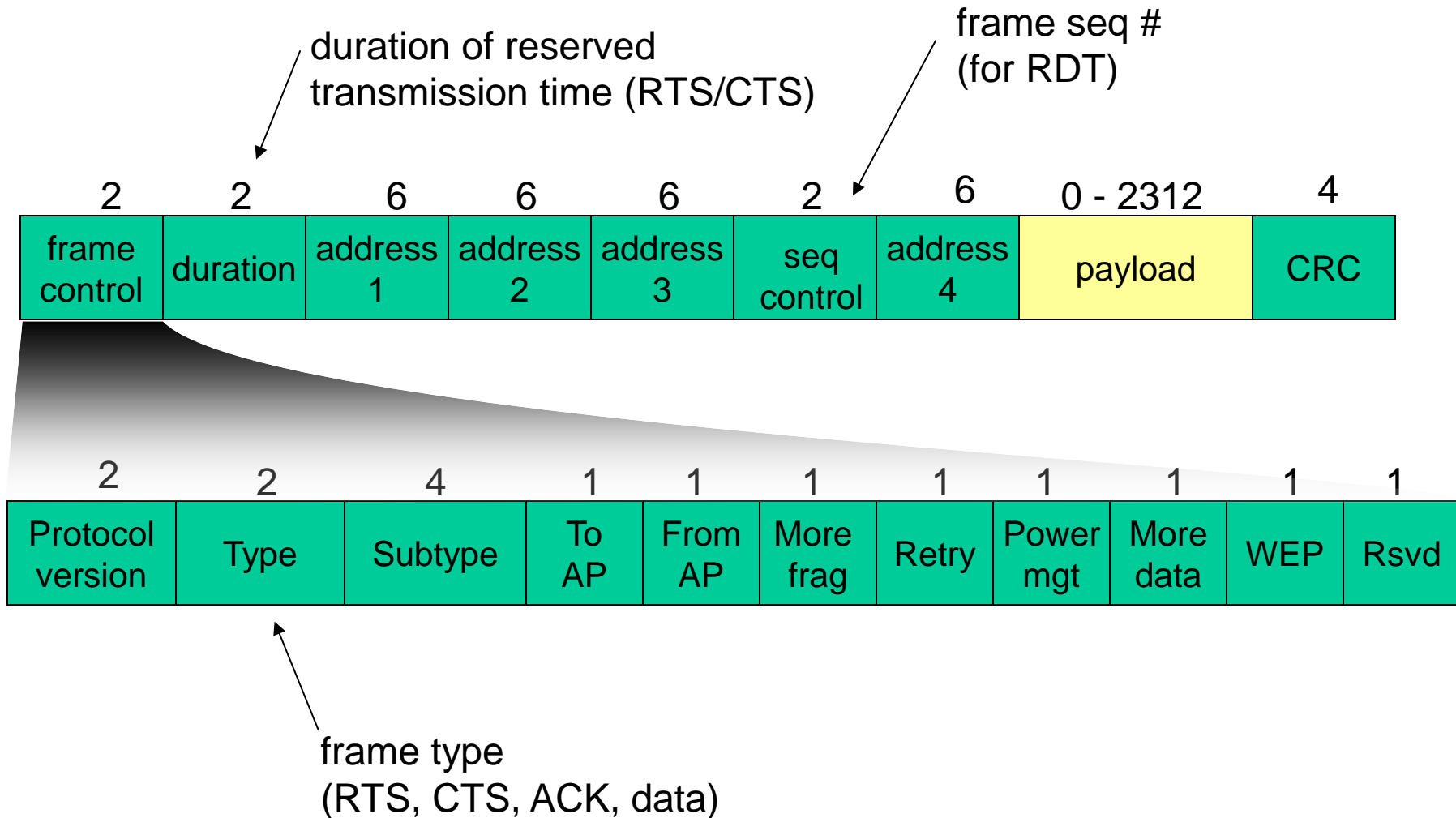Address 3: MAC address of router interface to which AP is attached

Address 4: used only in ad hoc mode

802.11 frame: addressing

Internet

H1

router

R1

R1 MAC addr	H1 MAC addr
dest. address	source address

802.**3** frame

AP MAC addr	H1 MAC addr	R1 MAC addr
address 1	address 2	address 3

802.**11** frame

802.11 frame: more

duration of reserved
transmission time (RTS/CTS)

frame seq #
(for RDT)

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

2	2	4	1	1	1	1	1	1	1	1
Protocol version	Type	Subtype	To AP	From AP	More frag	Retry	Power mgt	More data	WEP	Rsvd

frame type
(RTS, CTS, ACK, data)

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. 5): switch will see frame from H1 and "remember" which switch port can be used to reach H1

BBS 1   H1   BBS 2
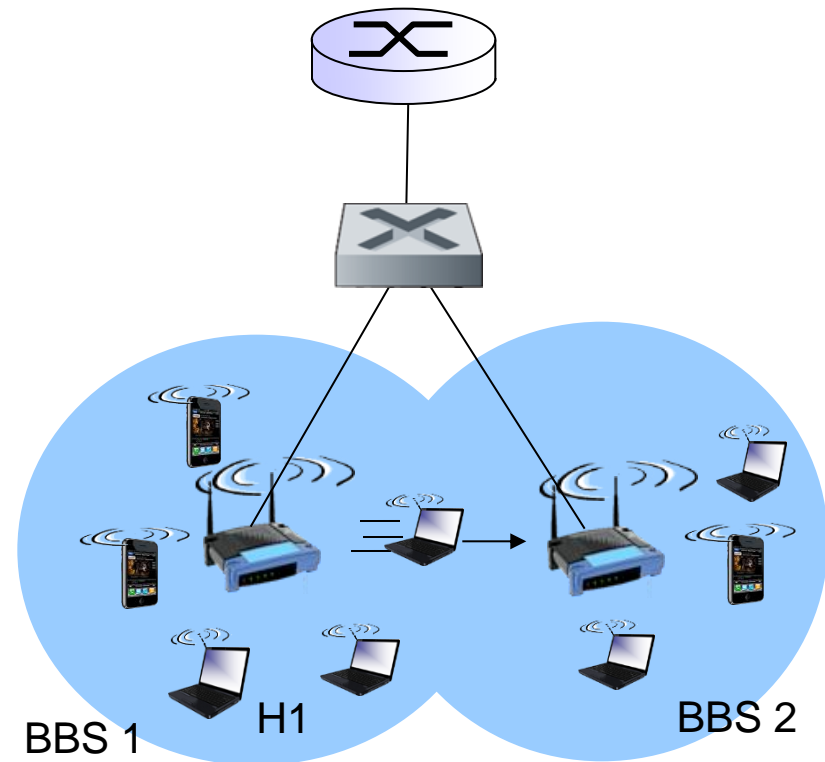
802.11: advanced capabilities

Rate adaptation

❖ base station, mobile dynamically change transmission rate (physical layer modulation technique) as mobile moves, SNR varies

- ····· QAM256 (8 Mbps)
- − − QAM16 (4 Mbps)
- ⎯ BPSK (1 Mbps)
- ● operating point
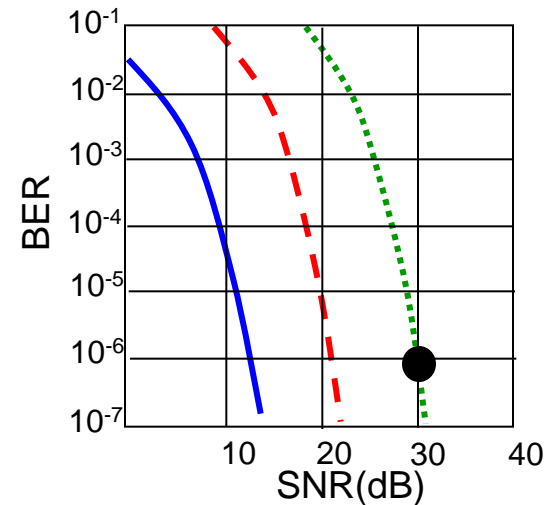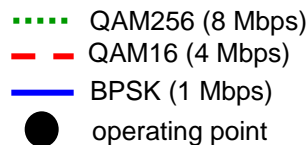
1. SNR decreases, BER increase as node moves away from base station

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

802.15: personal area network

- ❖ less than 10 m diameter

- ❖ replacement for cables (mouse, keyboard, headphones)

- ❖ ad hoc: no infrastructure

- ❖ master/slaves:
  - slaves request permission to send (to master)
  - master grants requests

- ❖ 802.15: evolved from Bluetooth specification
  - 2.4-2.5 GHz radio band
  - up to 721 kbps

radius of coverage
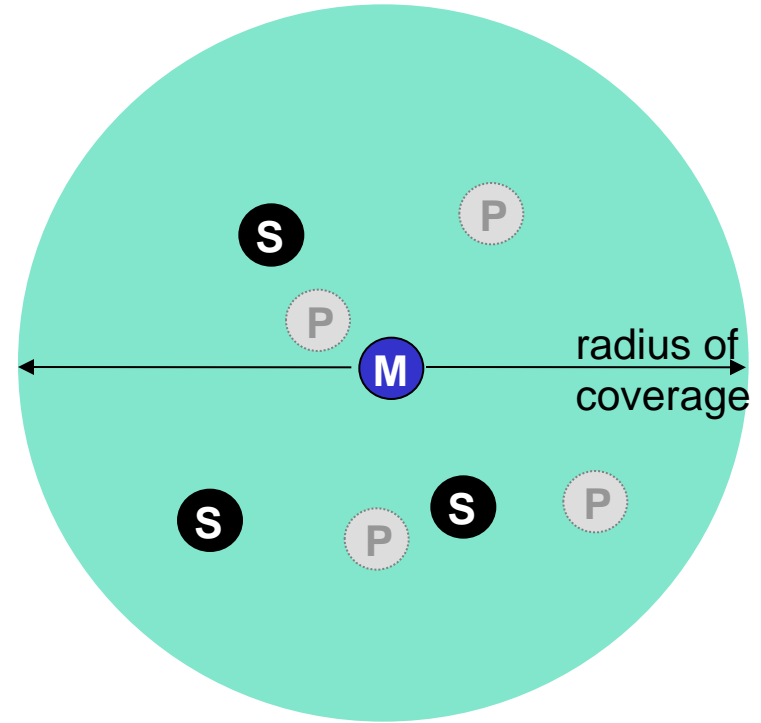
Ⓜ Master device

Ⓢ Slave device

Ⓟ Parked device (inactive)

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6.9 Summary

Components of cellular network architecture

MSC
- ❖ connects cells to wired tel. net.
- ❖ manages call setup (more later!)
- ❖ handles mobility (more later!)

cell
- ❖ covers geographical region
- ❖ *base station* (BS) analogous to 802.11 AP
- ❖ *mobile users* attach to network through BS
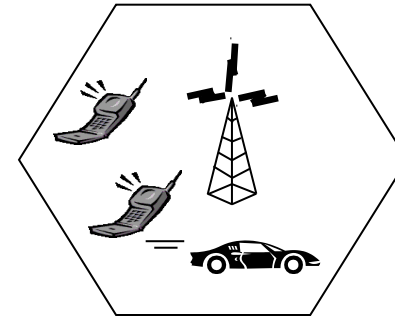- ❖ *air-interface:* physical and link layer protocol between mobile and BS

Mobile Switching Center

Mobile Switching Center

Public telephone network
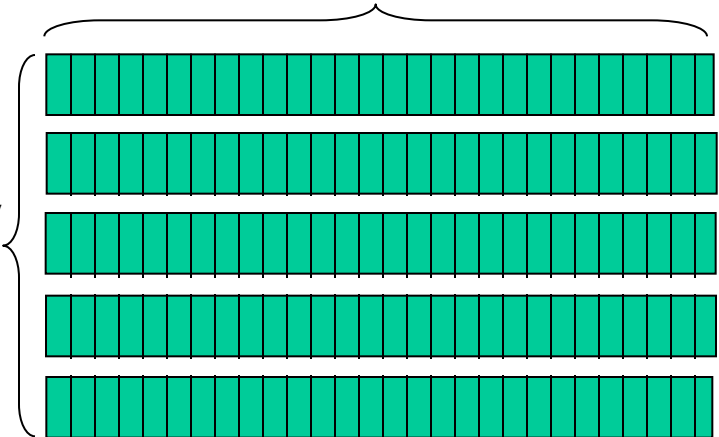
wired network
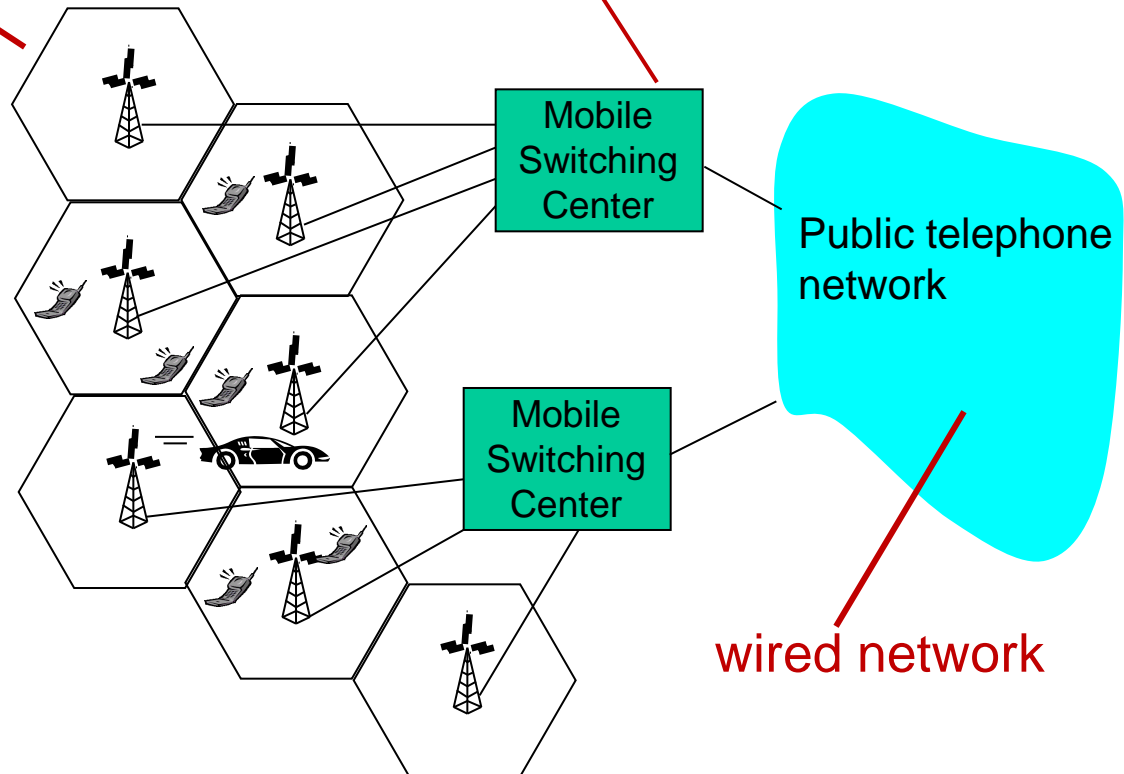
Cellular networks: the first hop

Two techniques for sharing mobile-to-BS radio spectrum

❖ combined FDMA/TDMA: divide spectrum in frequency channels, divide each channel into time slots

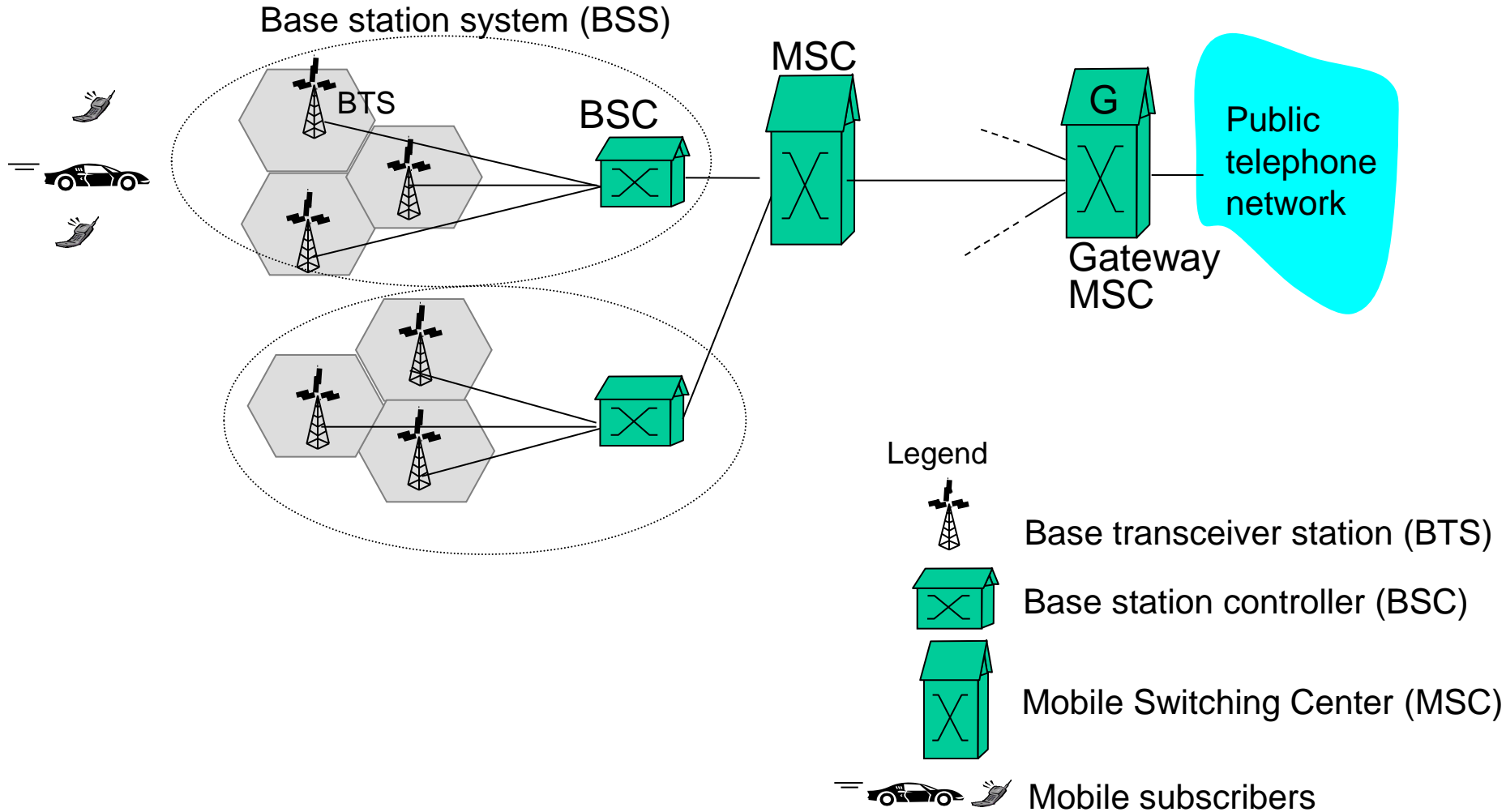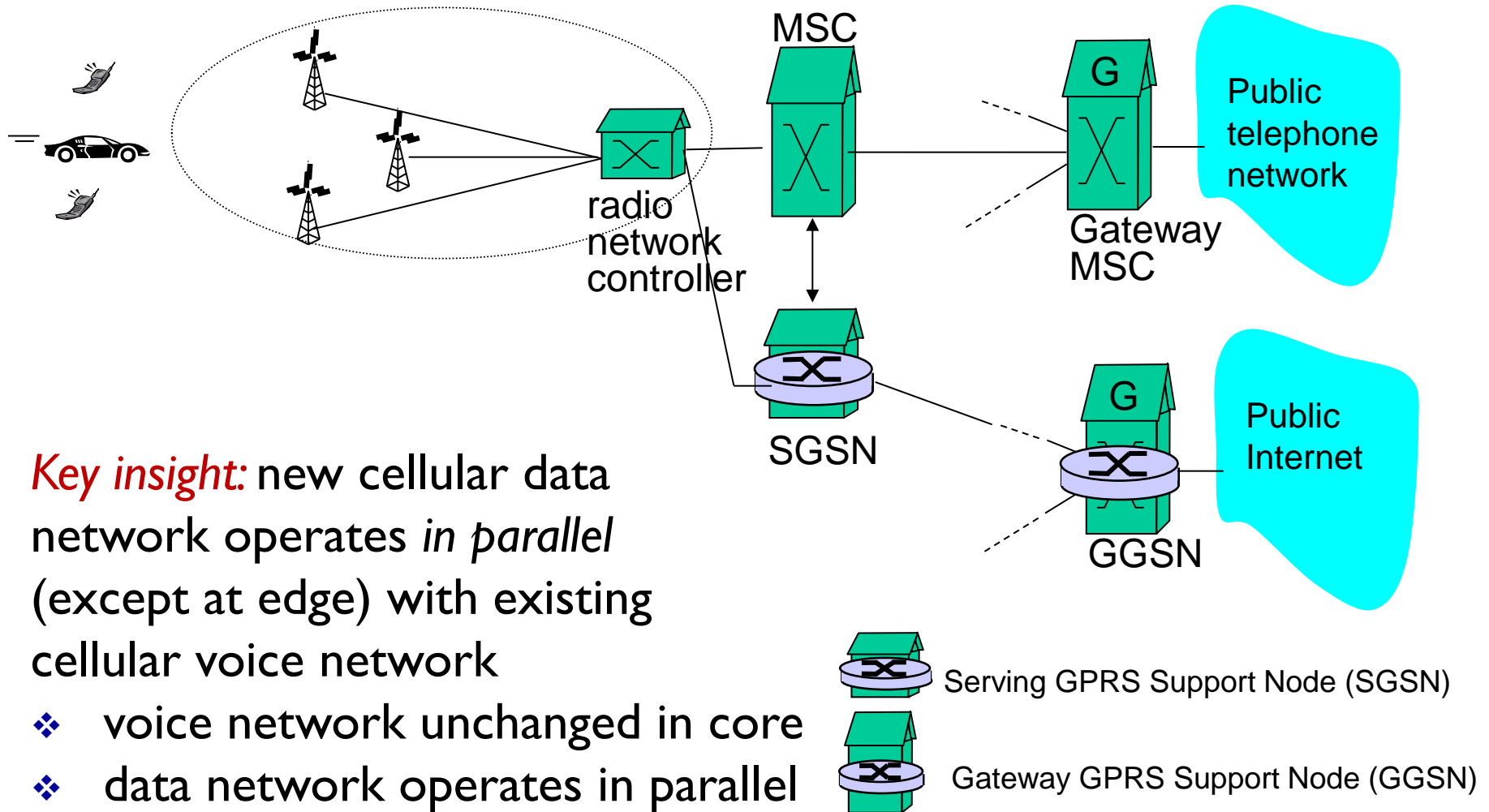❖ CDMA: code division multiple access

time slots

frequency bands

2G (voice) network architecture

Base station system (BSS)

Legend

Base transceiver station (BTS)

Base station controller (BSC)

Mobile Switching Center (MSC)

Mobile subscribers

3G (voice+data) network architecture

Key insight: new cellular data network operates *in parallel* (except at edge) with existing cellular voice network

❖ voice network unchanged in core
❖ data network operates in parallel

3G (voice+data) network architecture

radio interface (WCDMA, HSPA)

radio access network
Universal Terrestrial Radio Access Network (UTRAN)

core network
General Packet Radio Service (GPRS) Core Network

public Internet