CS 305 Computer Networks

Chapter 7 Wireless and Mobile Networks

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Ch. 7: 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 7 outline

7.1 Introduction

Wireless

7.2 Wireless links, characteristics
- CDMA

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

7.4 Cellular Internet Access
- architecture
- standards (e.g., 3G, LTE)

Mobility

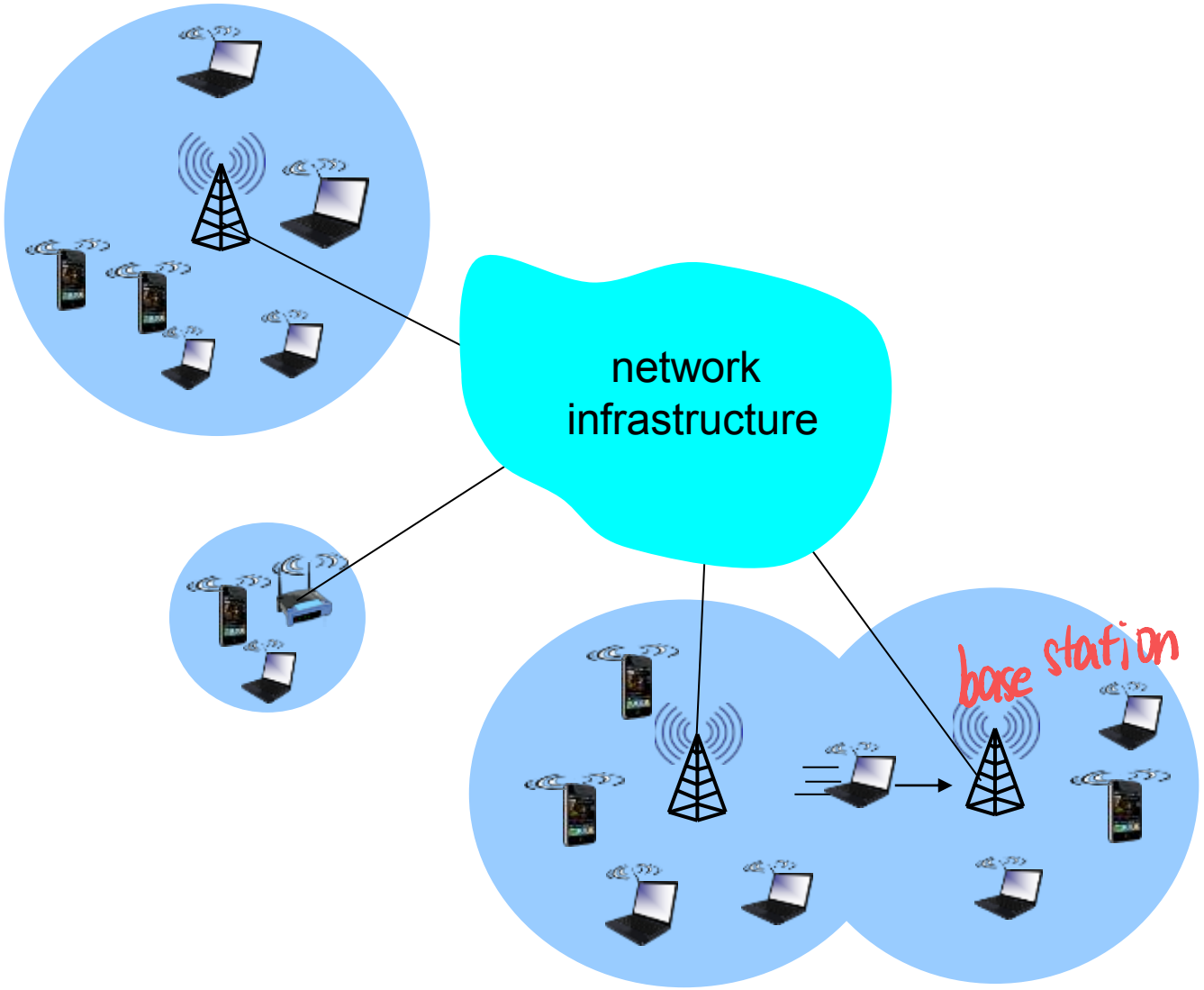
7.5 Principles: addressing and routing to mobile users

7.6 Mobile IP

7.7 Handling mobility in cellular networks

7.8 Mobility and higher-layer protocols

Elements of a wireless network



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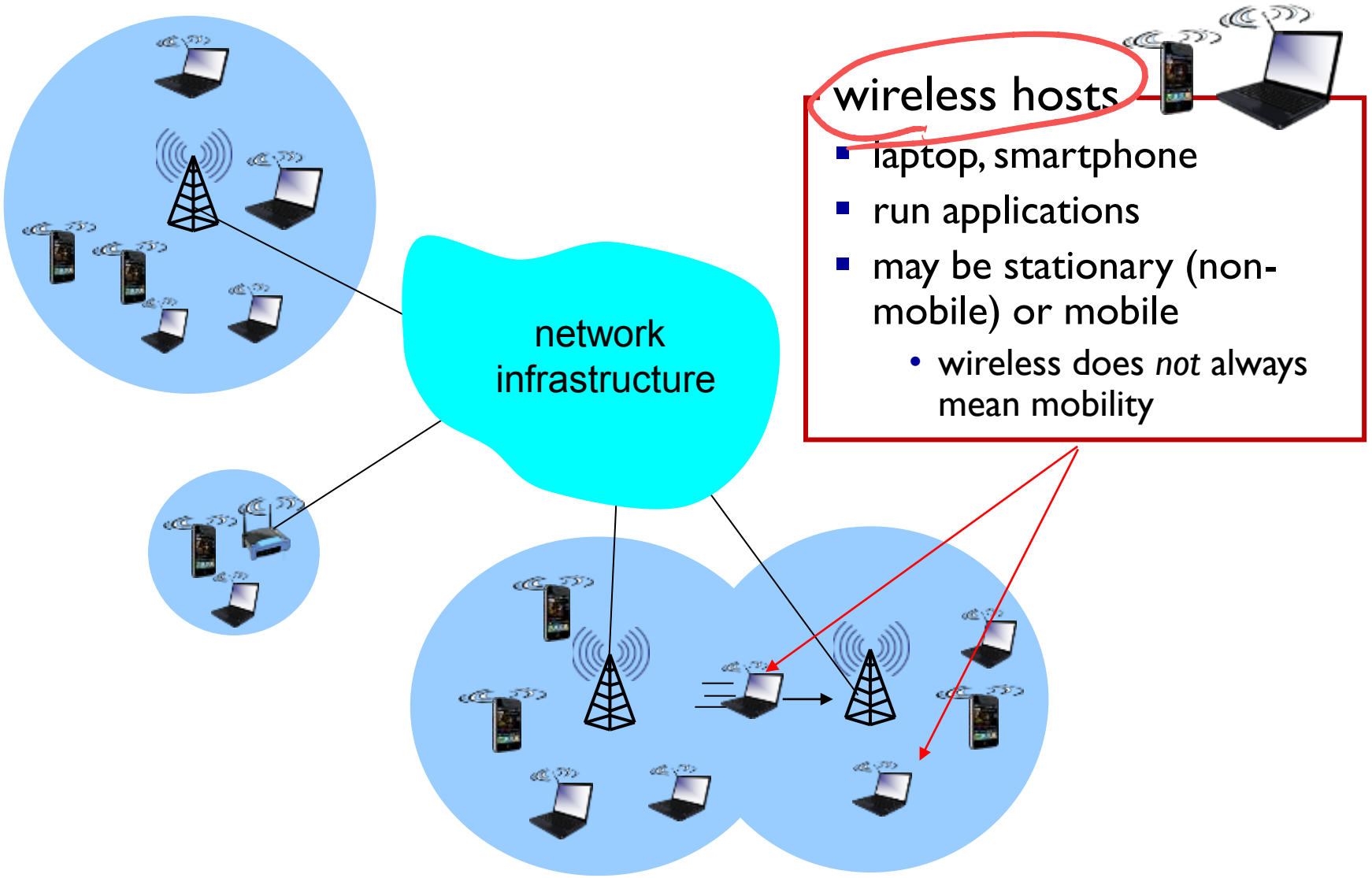
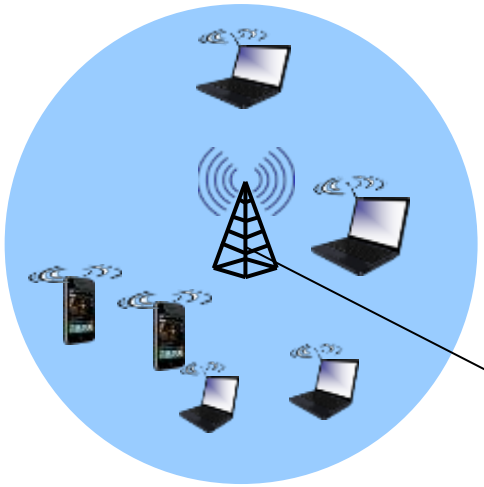
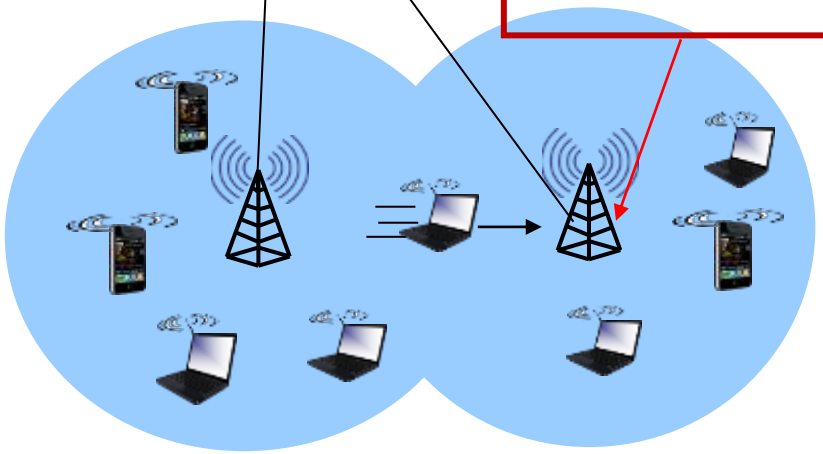


- wireless hosts
  - laptop, smartphone
  - run applications
  - may be stationary (non-mobile) or mobile
    - wireless does *not* always mean mobility

Elements of a wireless network





network infrastructure

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

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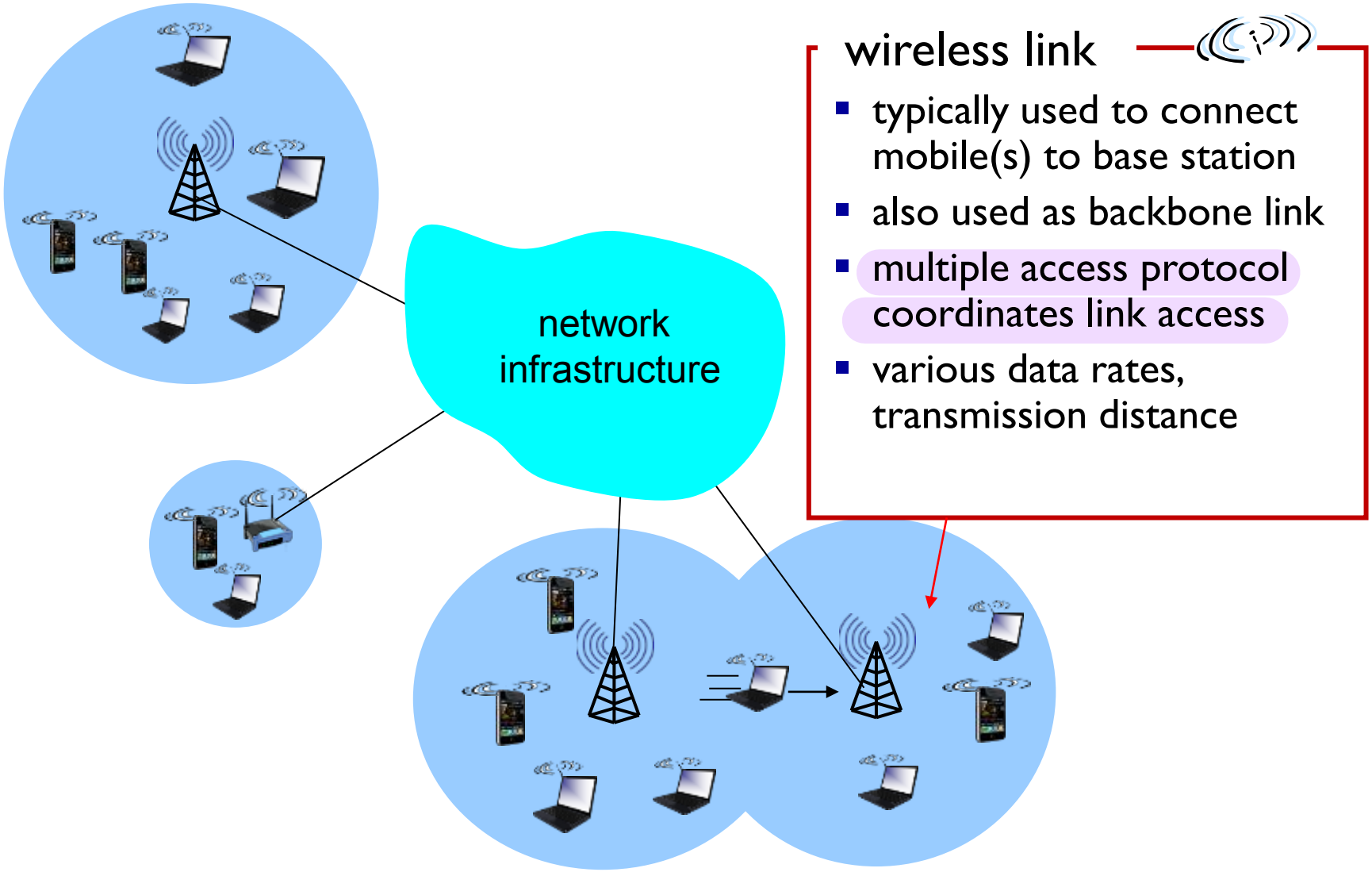
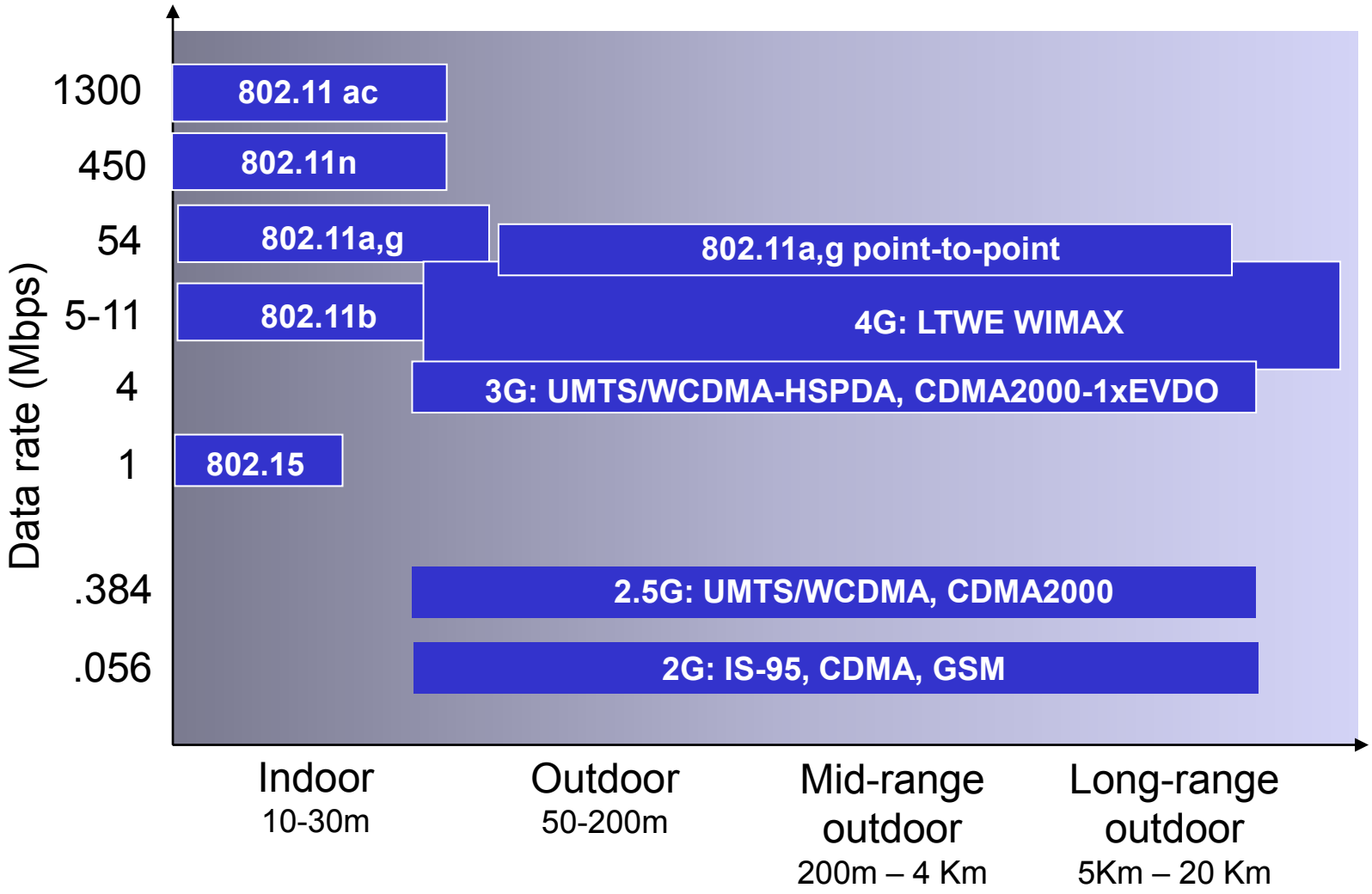


wireless link

- 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



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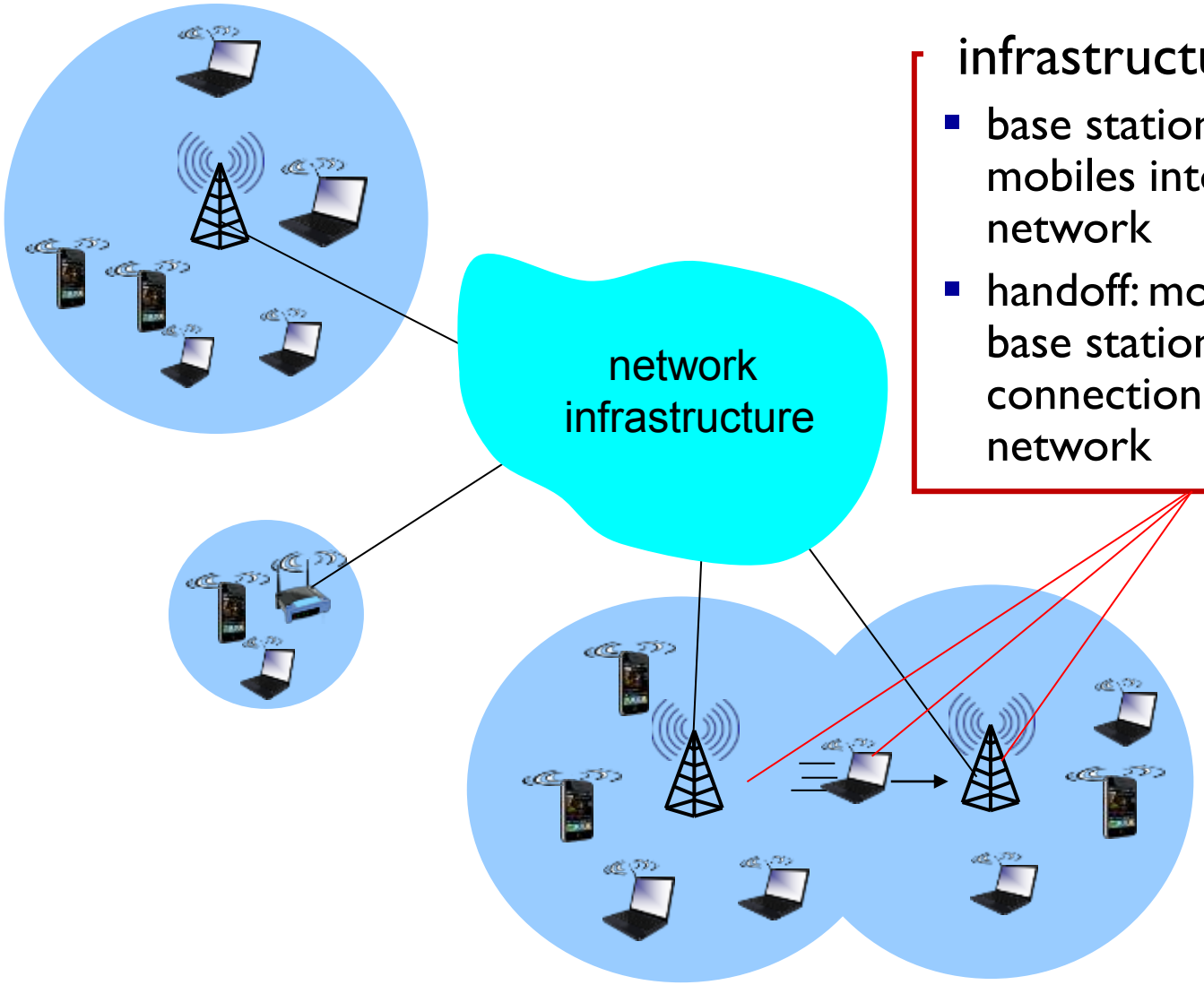
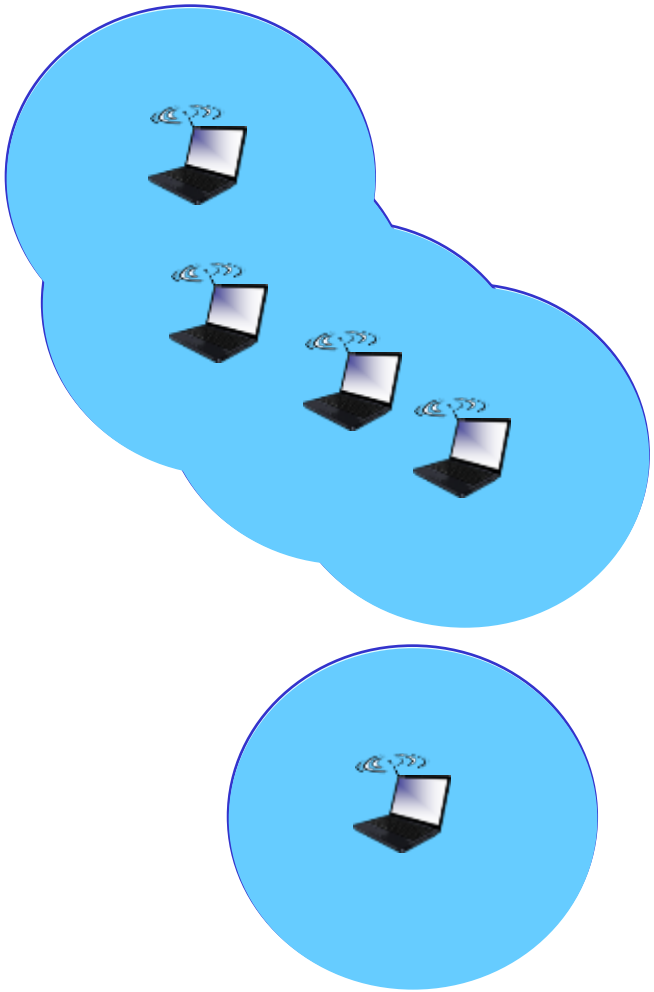


infrastructure mode

- 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)

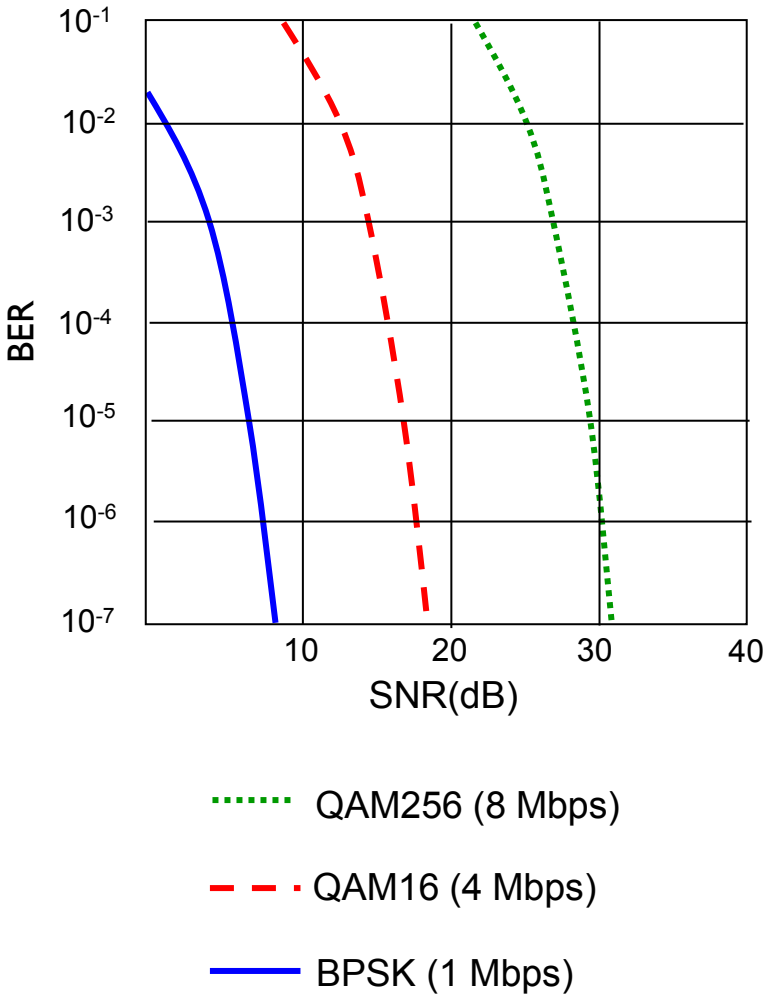
important differences from wired link ….

- *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 ad destination at slightly different times

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

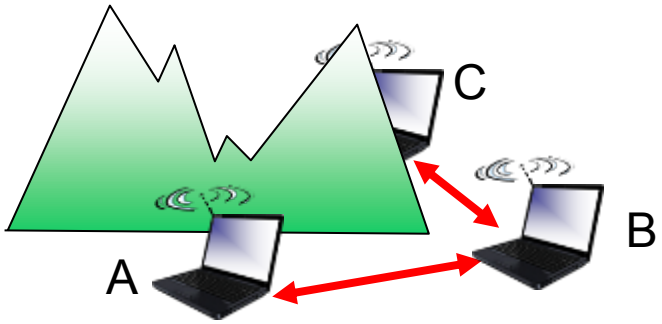
Wireless Link Characteristics (2)

- 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)



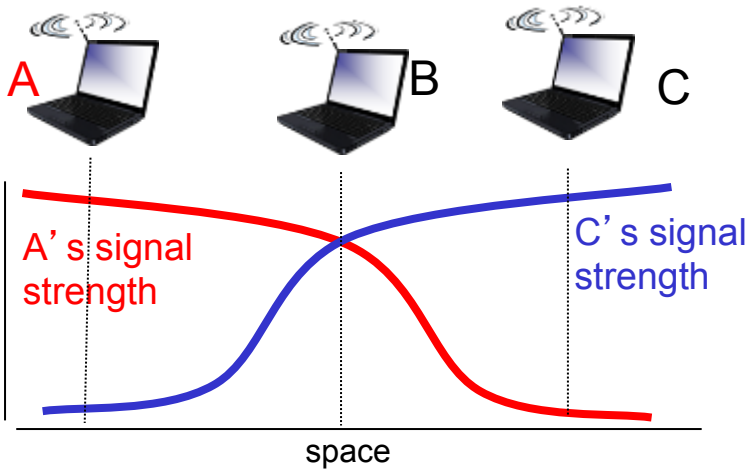
Wireless network characteristics

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



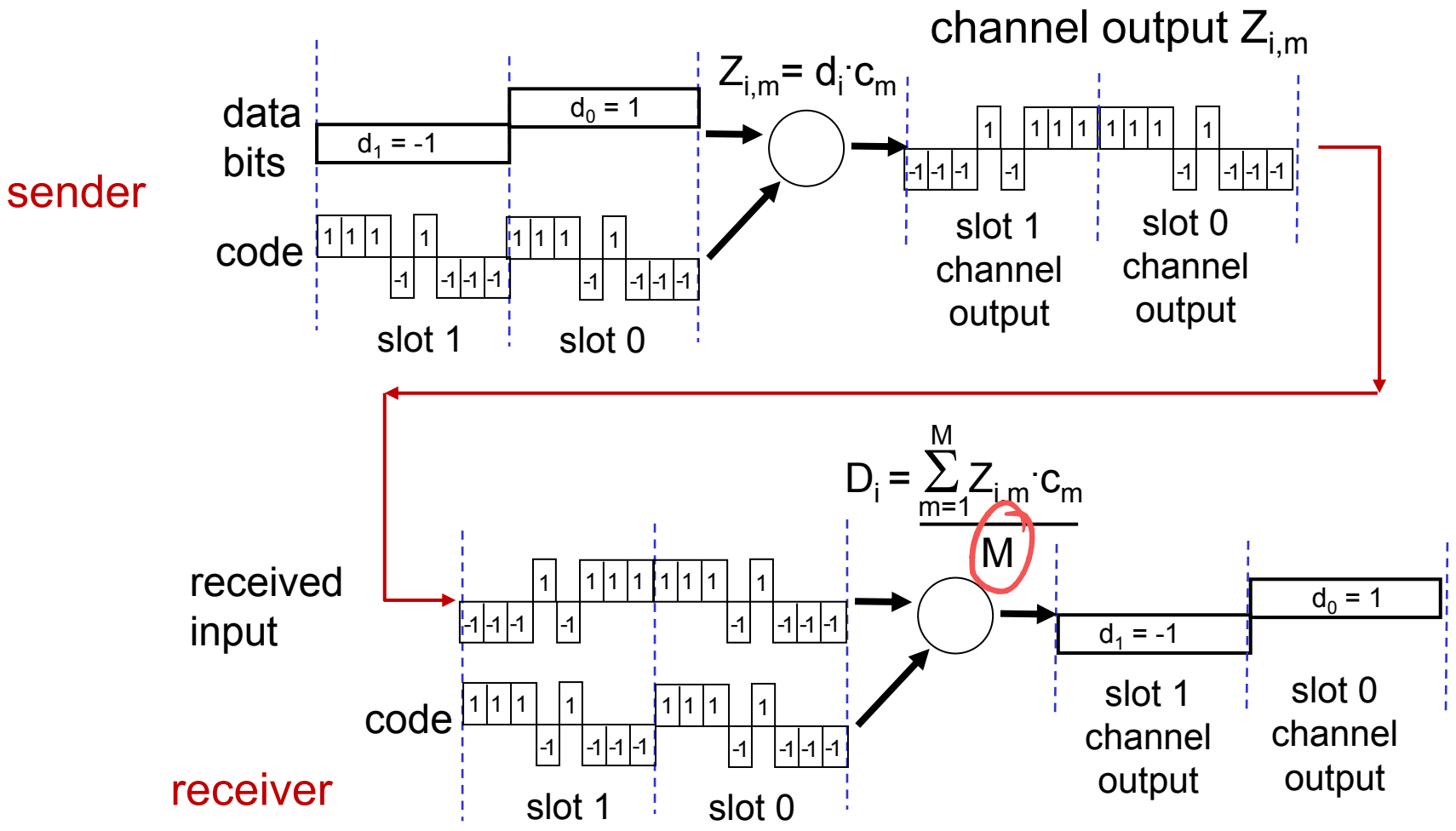
Signal attenuation:

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

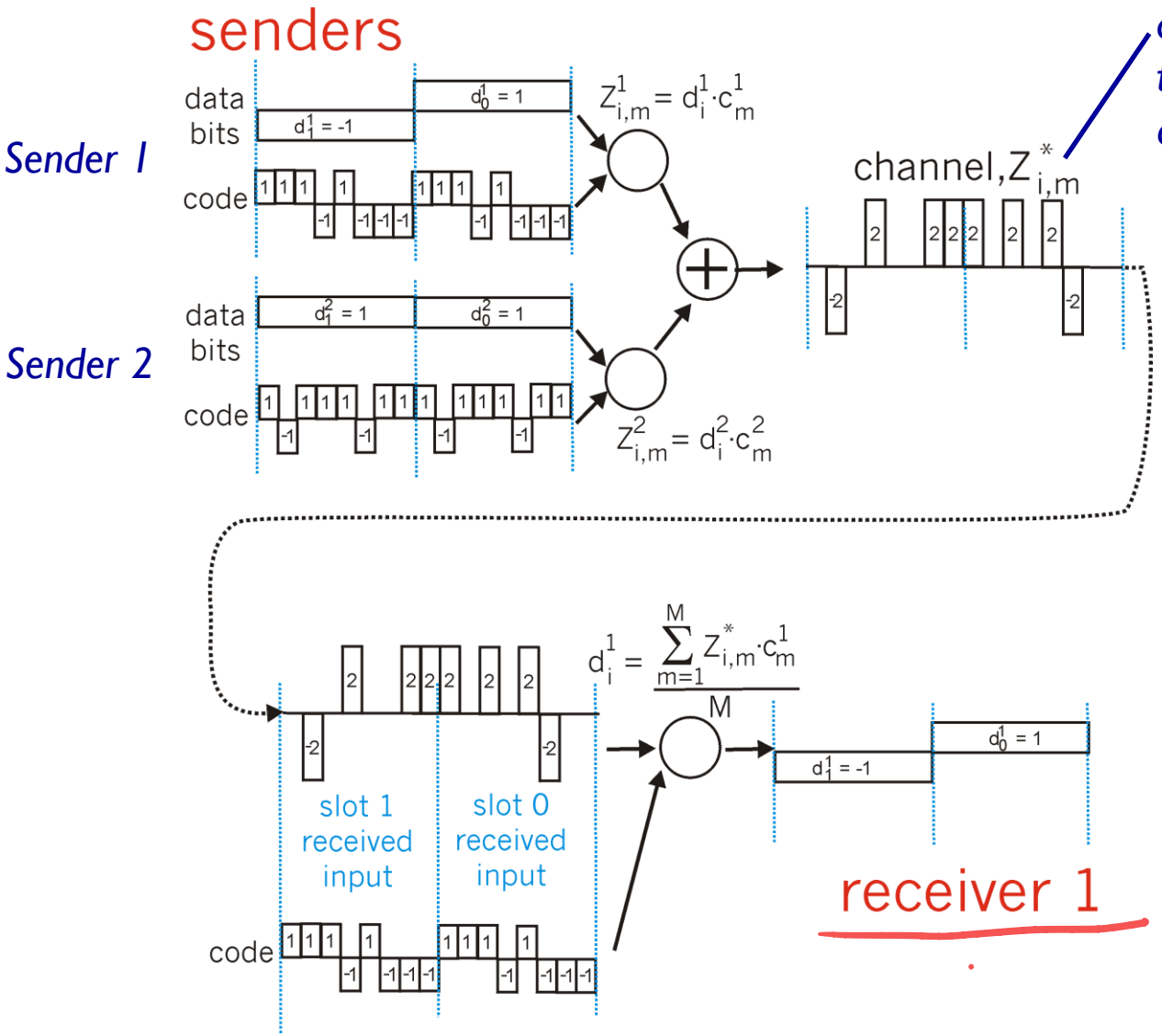
Code Division Multiple Access (CDMA)

- 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



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!

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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

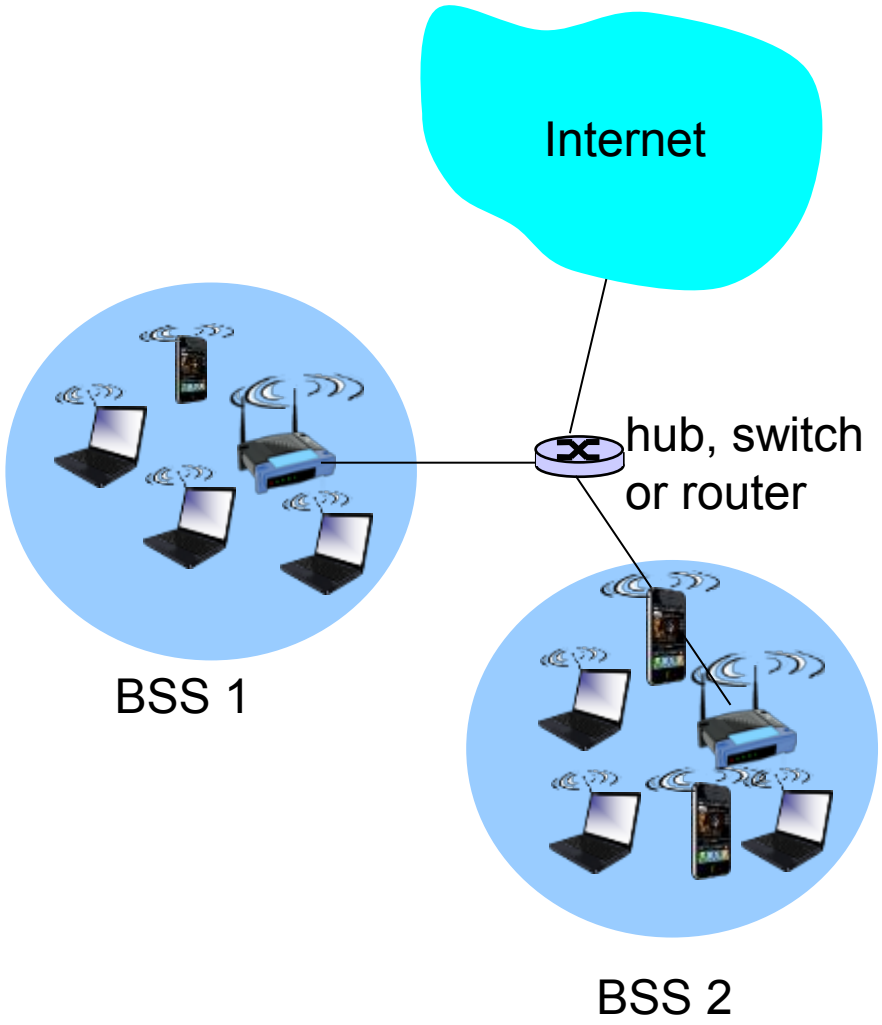
802.11a
- 5-6 GHz range
- up to 54 Mbps

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

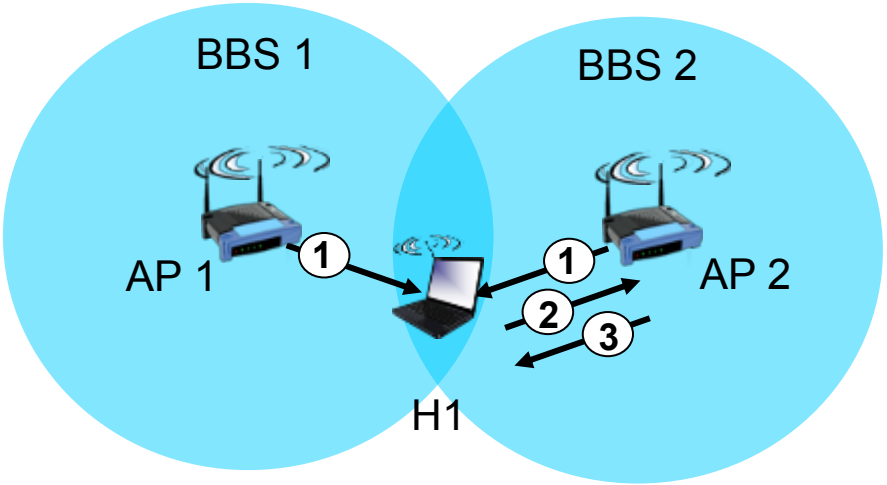


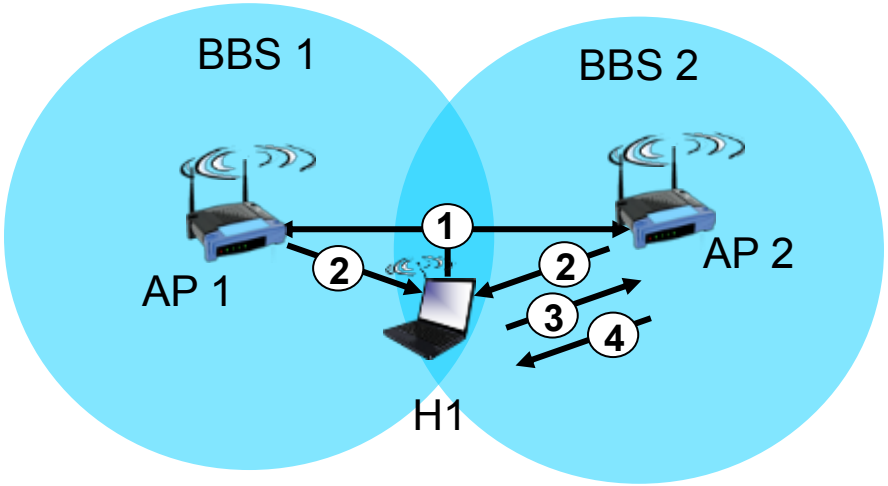
- wireless host communicates with base station
  - base station = access point (AP)
- Basic Service Set (BSS) (aka "cell") in infrastructure mode contains:
  - wireless hosts
  - access point (AP): base station
  - ad hoc mode: hosts only

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

802.11: 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

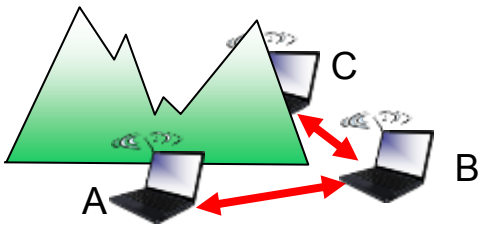
active scanning:

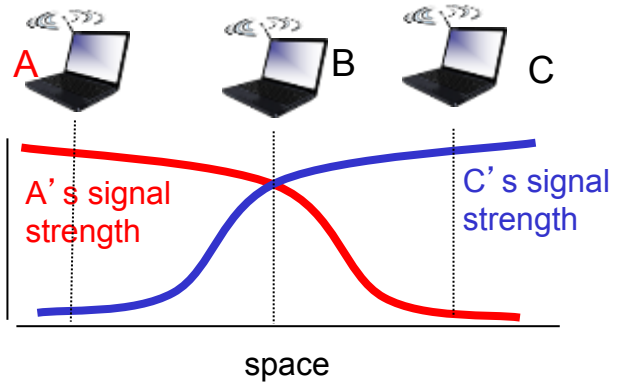
(1) Probe Request frame broadcast from H1
(2) Probe Response frames sent from APs
(3) Association Request frame sent: H1 to selected AP
(4) Association Response frame sent from selected AP to H1

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)

RtS
CtS





IEEE 802.11 MAC Protocol: CSMA/CA

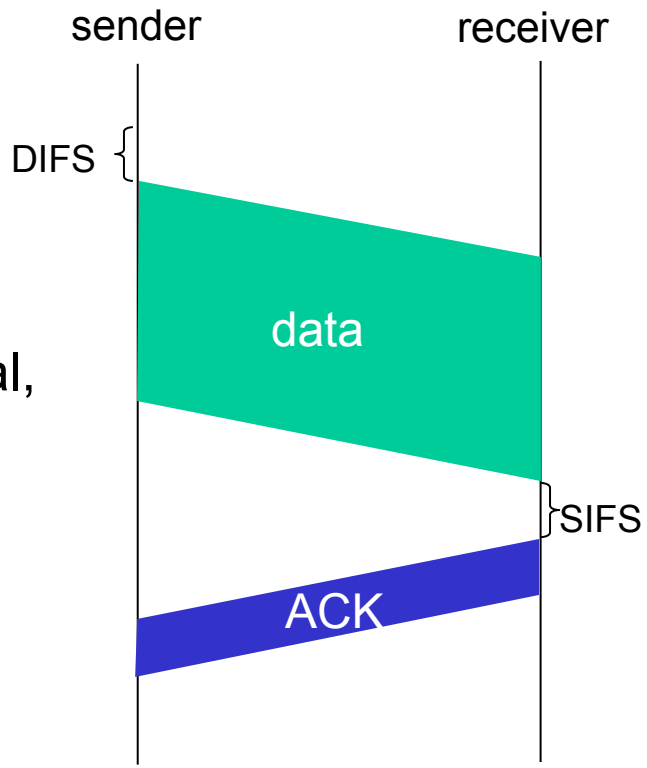
802.11 sender

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)



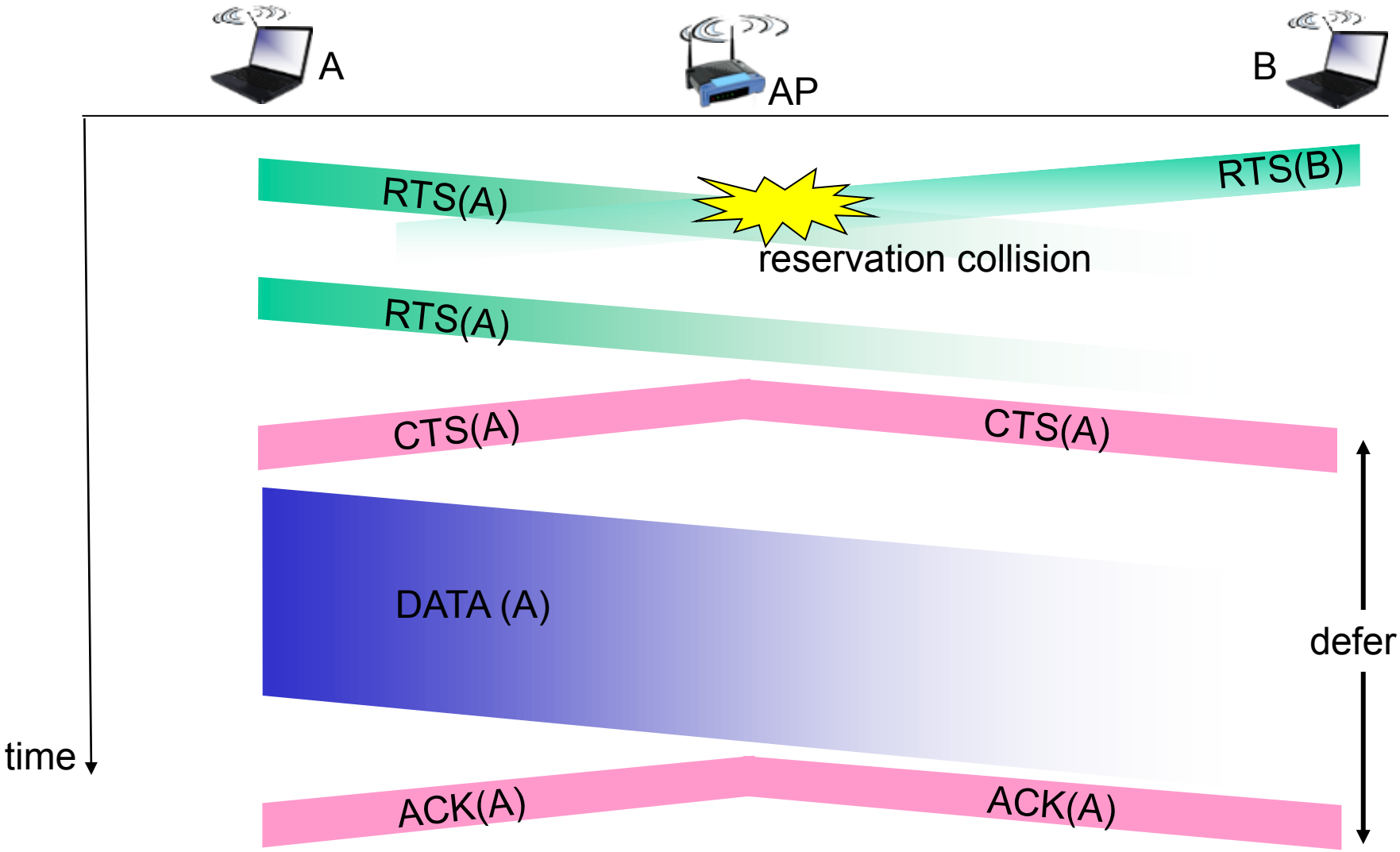
Avoiding collisions (more)

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

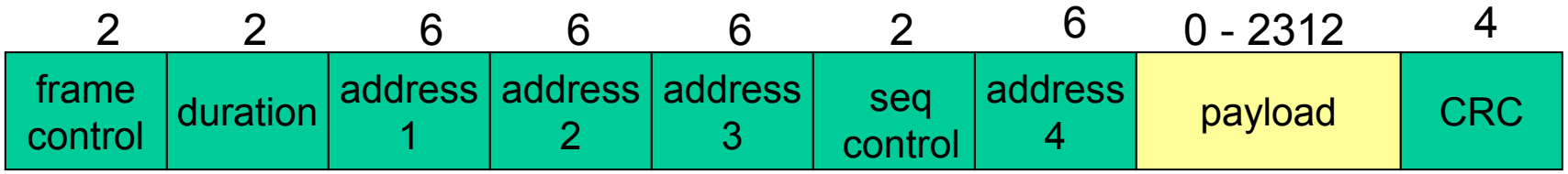
- sender first transmits *small* request-to-send (RTS) packets to BS using CSMA
  - RTSs may still collide with each other (but they're short)
- BS broadcasts clear-to-send CTS in response to RTS
- CTS heard by all nodes
  - sender transmits data frame
  - other stations defer transmissions

avoid data frame collisions completely using small reservation packets!

Collision Avoidance: RTS-CTS exchange



802.11 frame: addressing



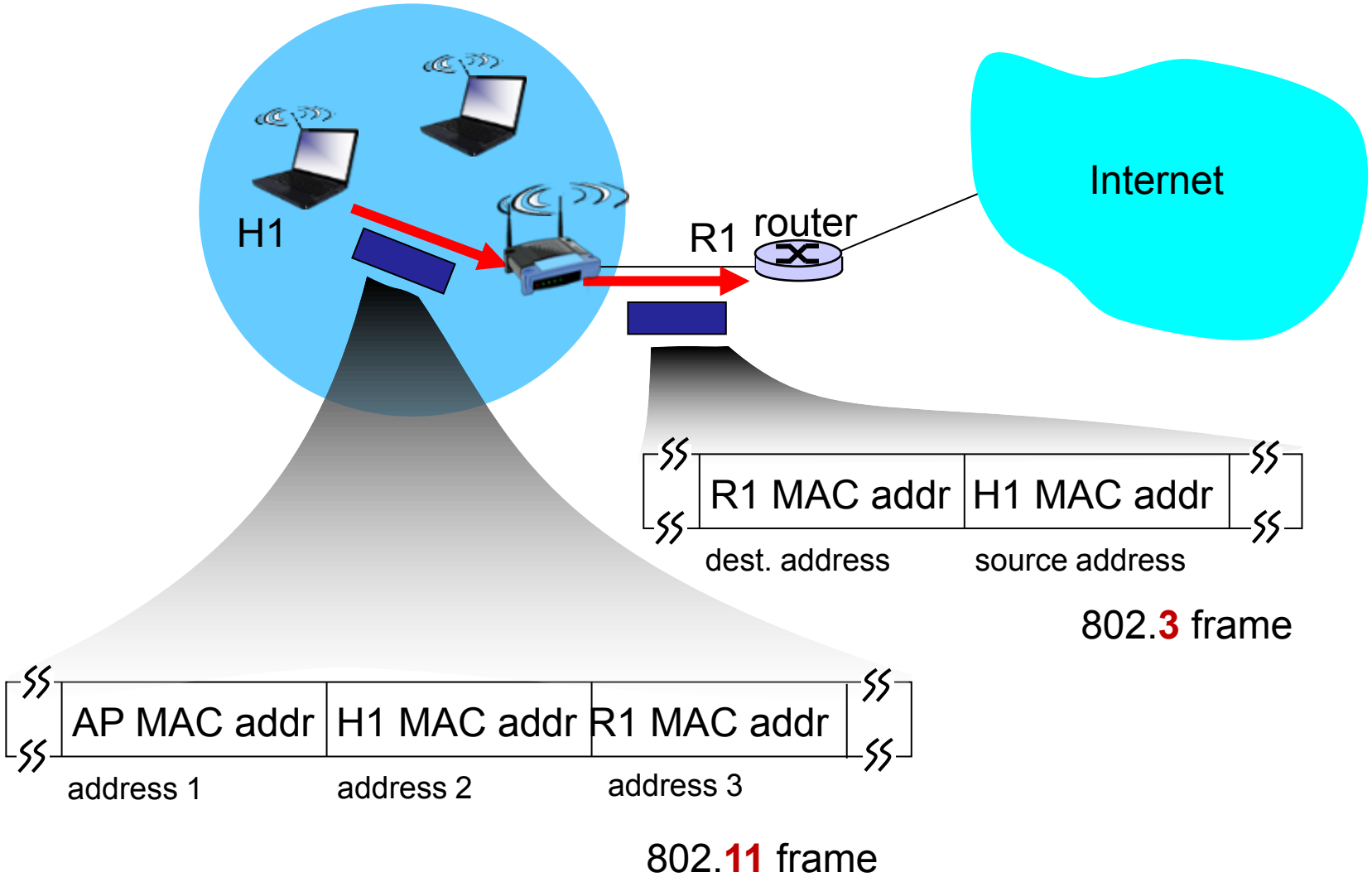
Address 1: MAC address of wireless host or AP to receive this frame

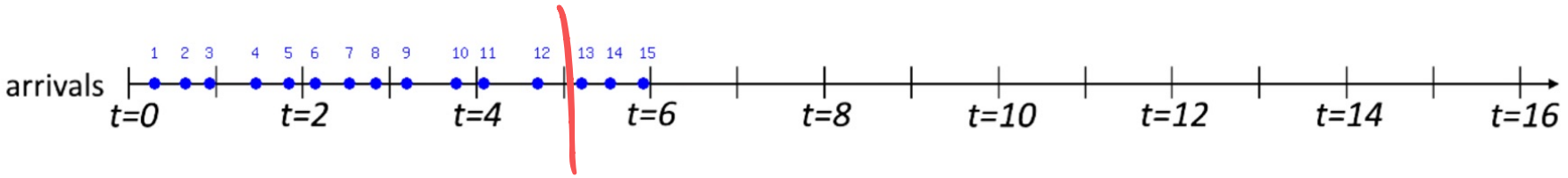
Address 2: MAC address of wireless host or AP transmitting this frame

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

Address 4: used only in ad hoc mode

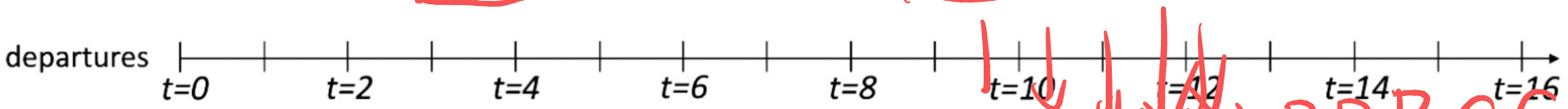
802.11 frame: addressing





Packets (#: time): 1: 0.3, 2: 0.65, 3: 0.93, 4: 1.46, 5: 1.83, 6: 2.13, 7: 2.52, 8: 2.82, 9: 3.17, 10: 3.73, 11: 4.04, 12: 4.65, 13: 5.15, 14: 5.48, 15: 5.86

Packets (#: class): 1: 2 , 2: 2 , 3: 2 , 4: 1 , 5: 1 , 6: 2 , 7: 2 , 8: 2 , 9: 2 , 10: 2 , 11: 1 , 12: 1 , 13: 1 , 14: 1 , 15: 1



AAAAABBBCC

Choose a specific packet scheduling discipline (FCFS, Priority, RR, and WFQ) from the list below. In the case of Priority, RR, and WFQ there will be three classes of traffic (1, 2, 3), with lower class numbers having higher priority in the case of priority schedule, or beginning earlier in the case of RR and WFQ. In the case of WFQ, scheduling weights are 0.5, 0.3, and 0.2.

A 0.5 1

B 0.3 2

C 0.2 3

4 5 11 12 13 14 15

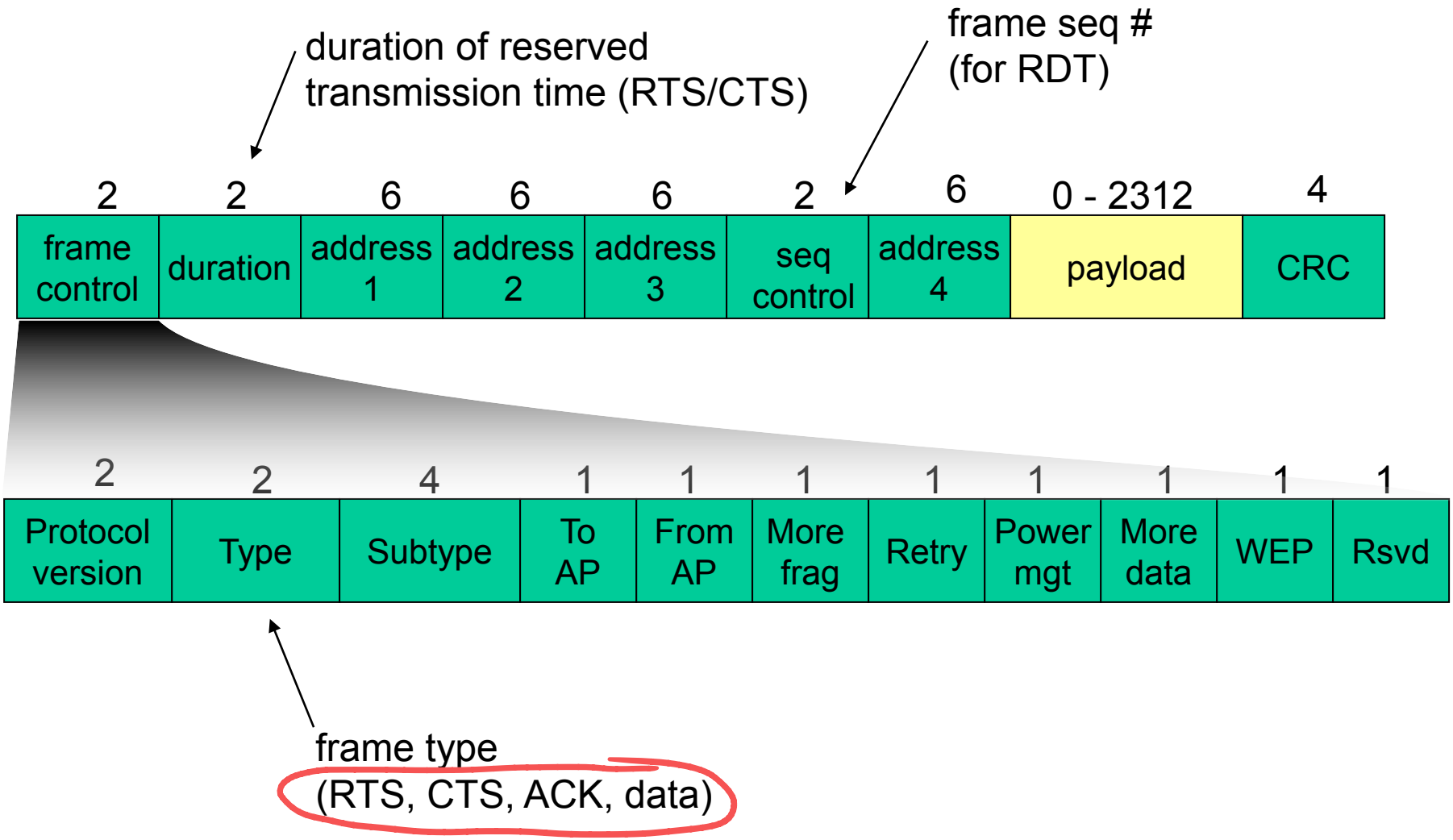
1 2 3 6 7 8 9 10

15

1, 4, 5 2, 11, 12, 3, 13, 14, 6

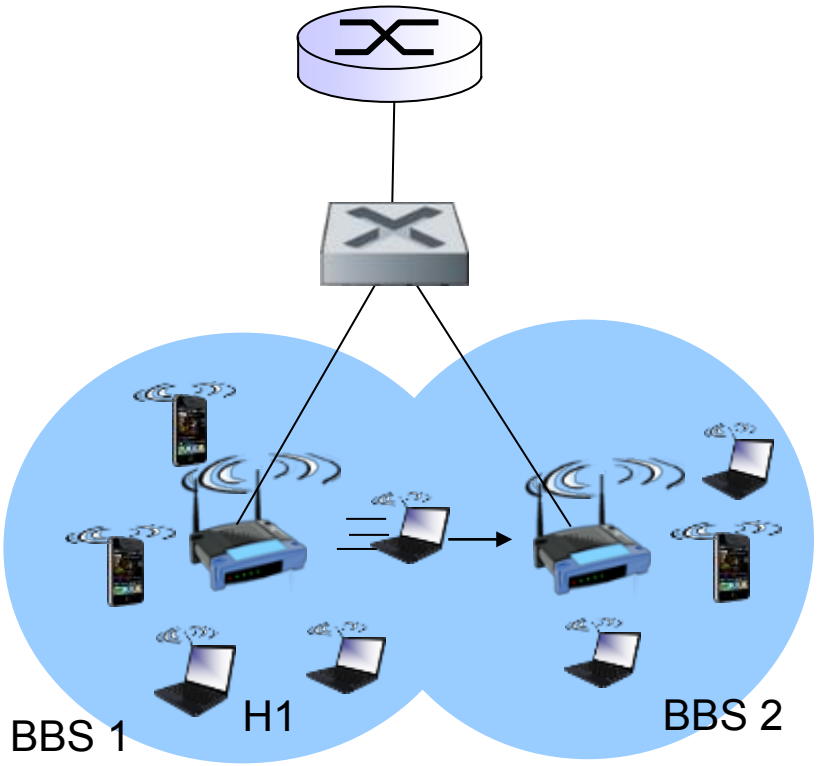
1 2 3 4 5 6 7 8 9 10

802.11 frame: more



802.11: mobility within same subnet

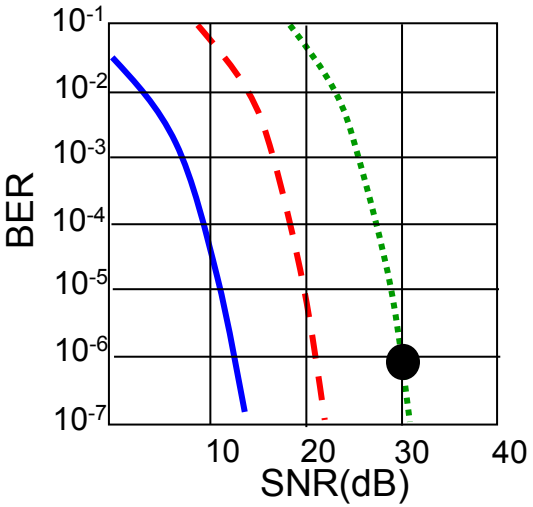
- H1 remains in same IP subnet: IP address can remain same
- switch: which AP is associated with H1?
  - self-learning (Ch. 5): switch will see frame from H1 and "remember" which switch port can be used to reach H1

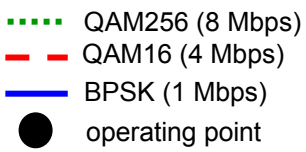


802.11: advanced capabilities

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

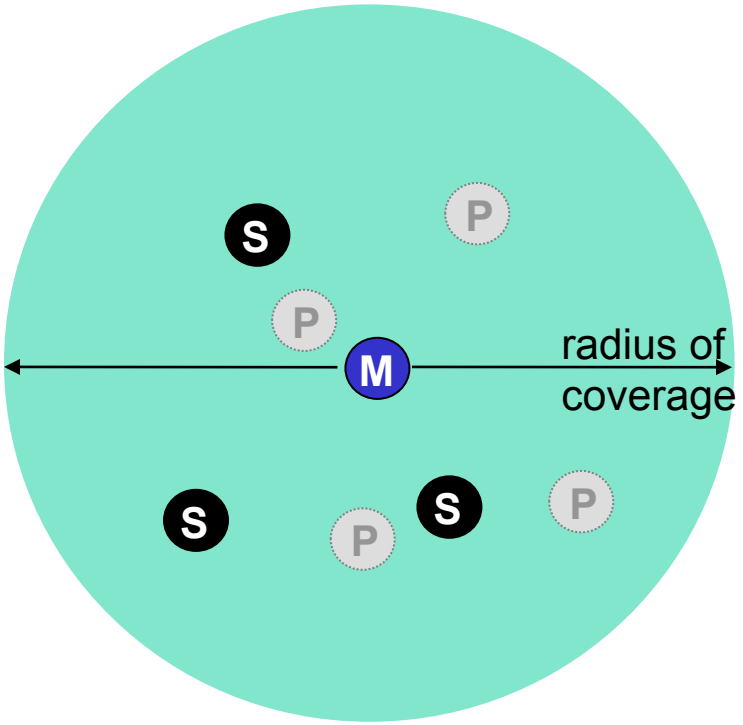
802.11: advanced capabilities

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

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



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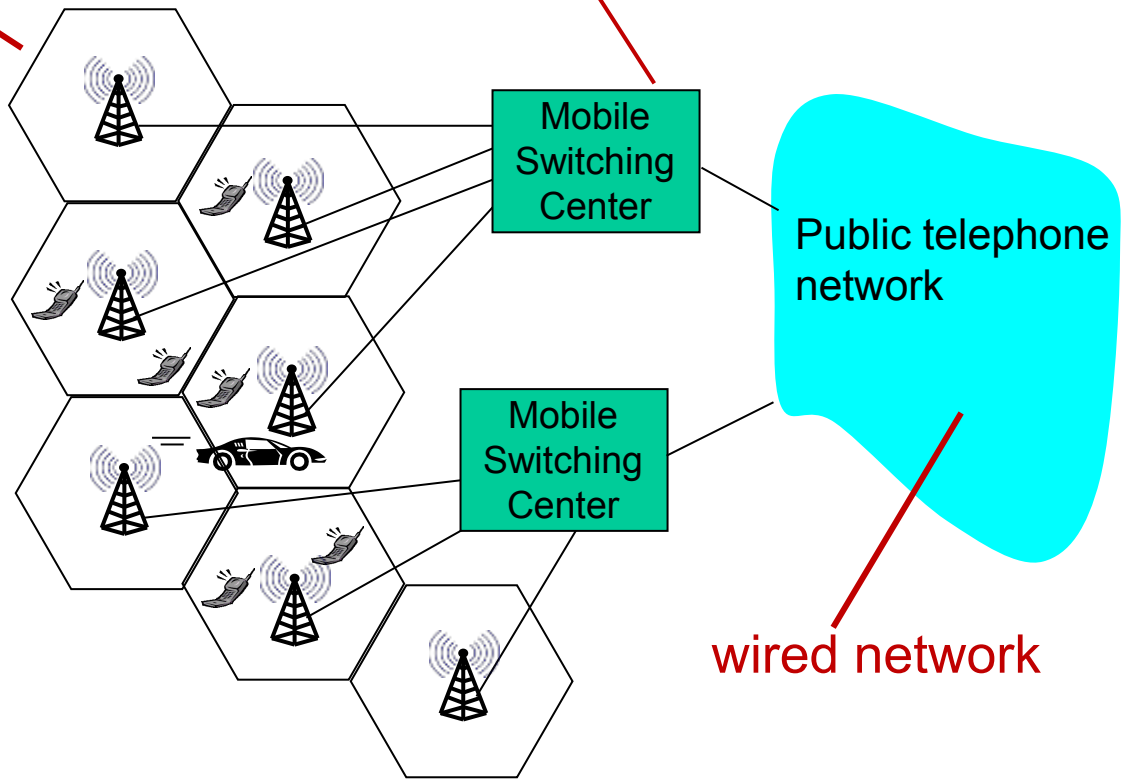
Components of cellular network architecture

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

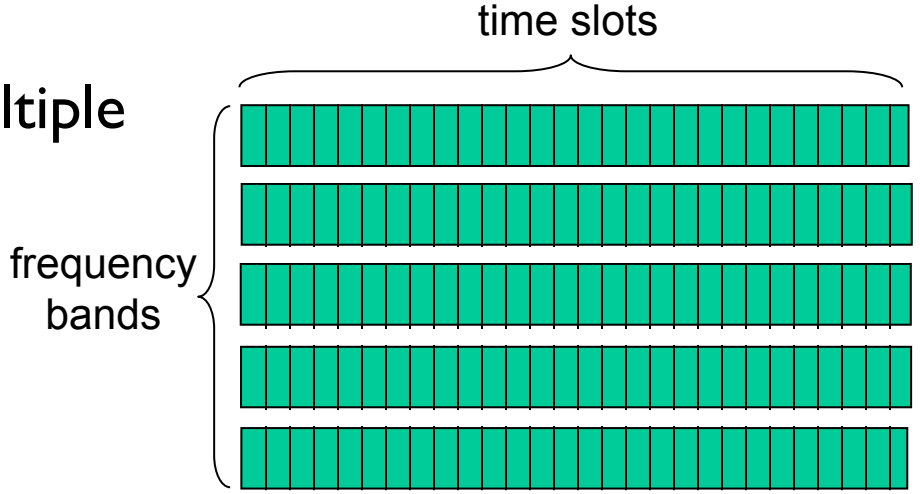
cell
- covers geographical region
- *base station* (BS) analogous to 802.11 AP
- *mobile users* attach to network through BS
- *air-interface:* physical and link layer protocol between mobile and BS



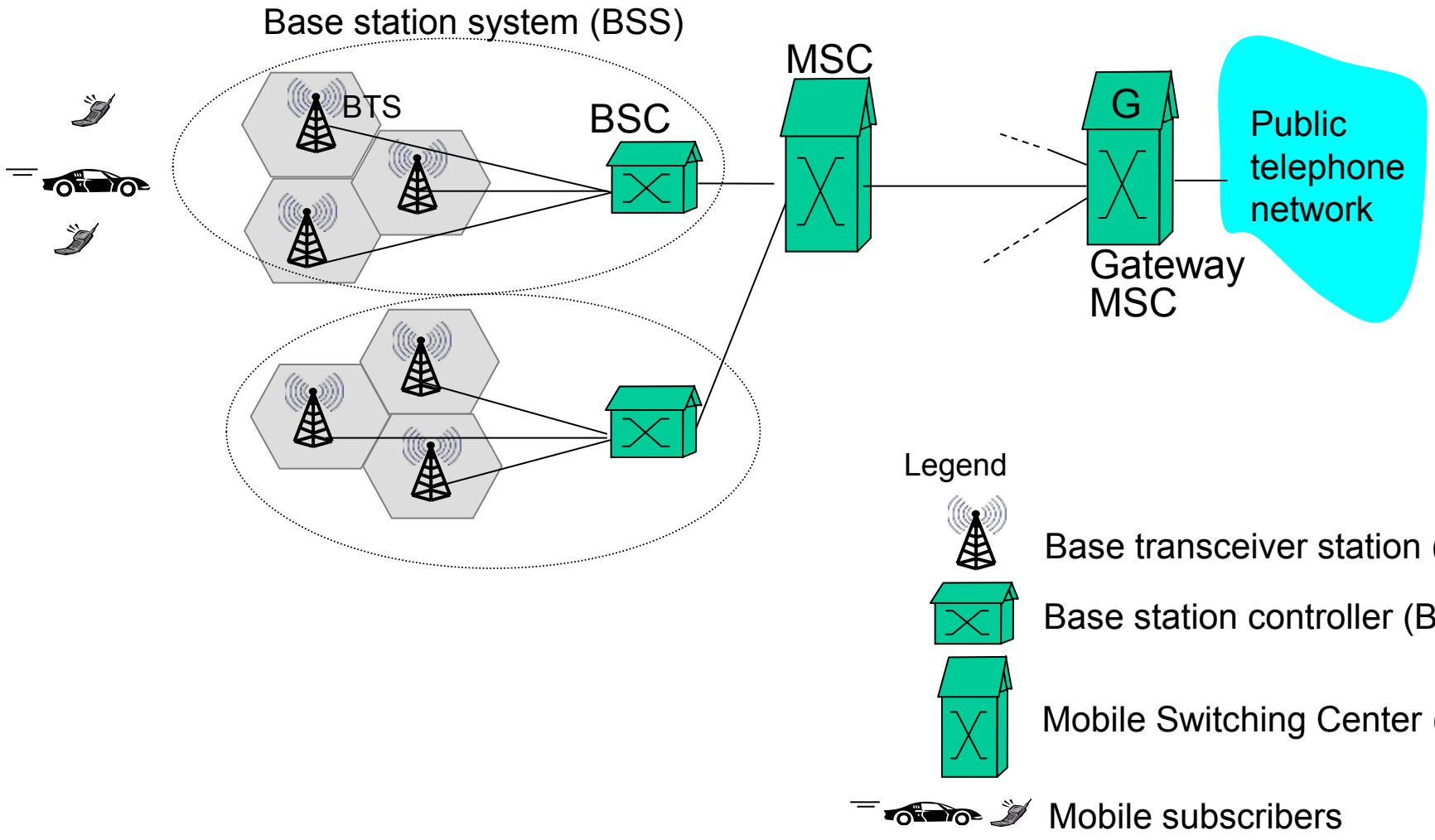
Cellular networks: the first hop

Two techniques for sharing mobile-to-BS radio spectrum

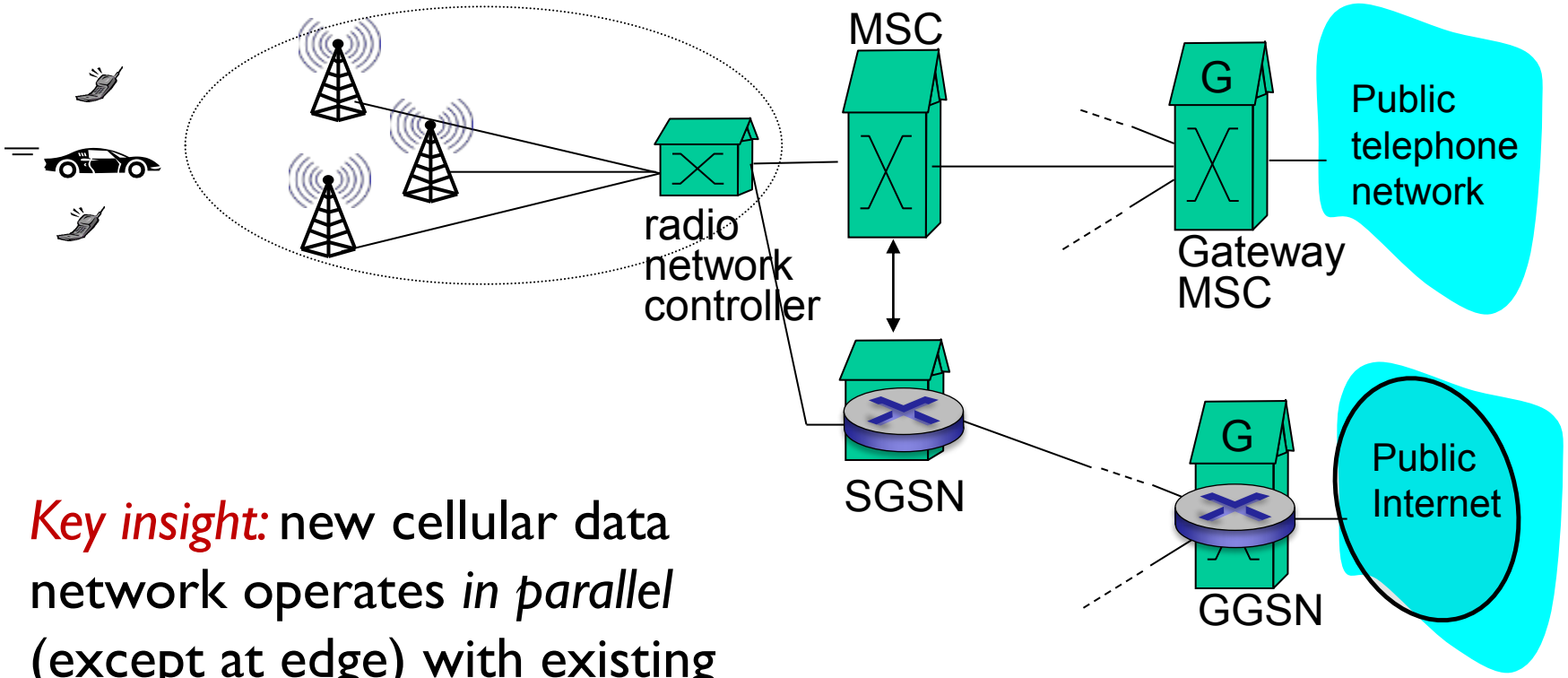
- combined FDMA/TDMA: divide spectrum in frequency channels, divide each channel into time slots
- CDMA: code division multiple access



2G (voice) network architecture



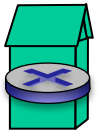
3G (voice+data) network architecture



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

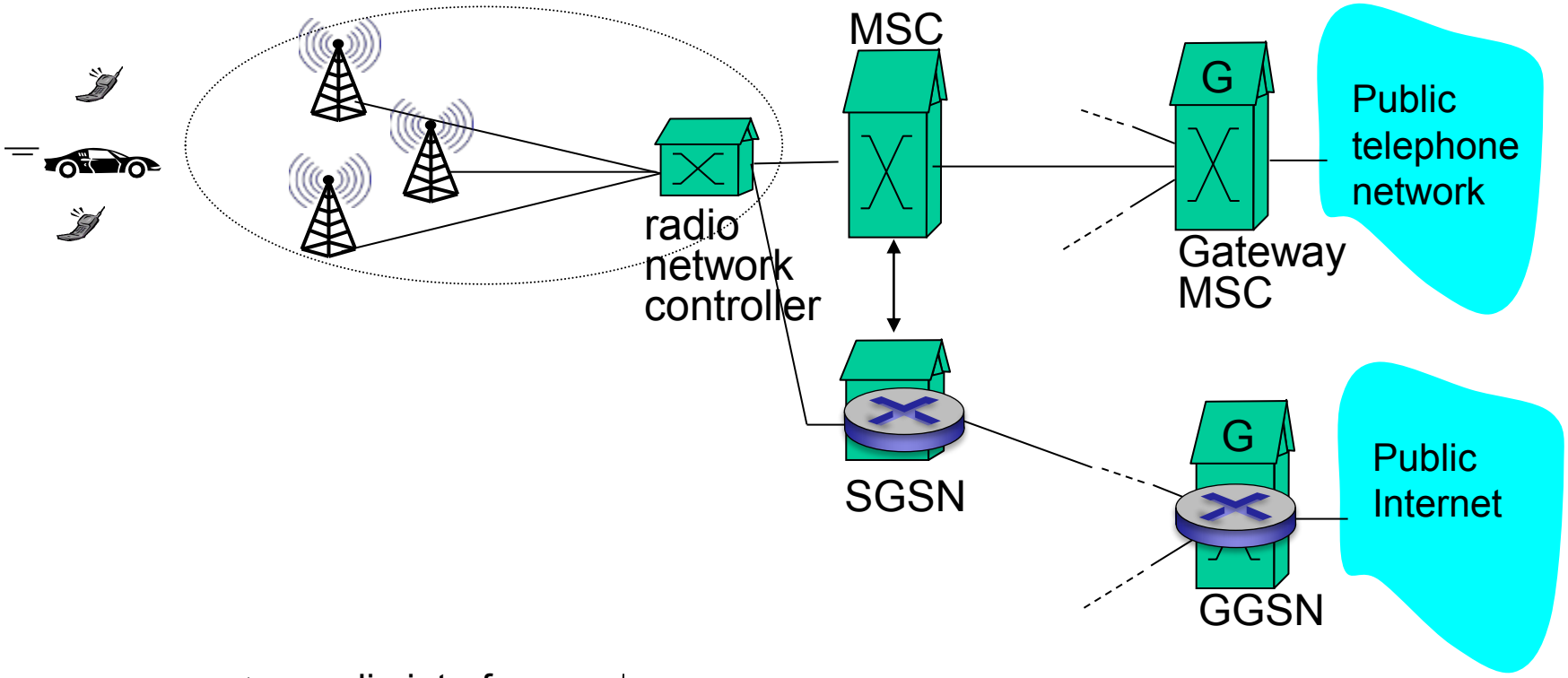
- voice network *unchanged* in core
- data network operates in parallel

Serving GPRS Support Node (SGSN)

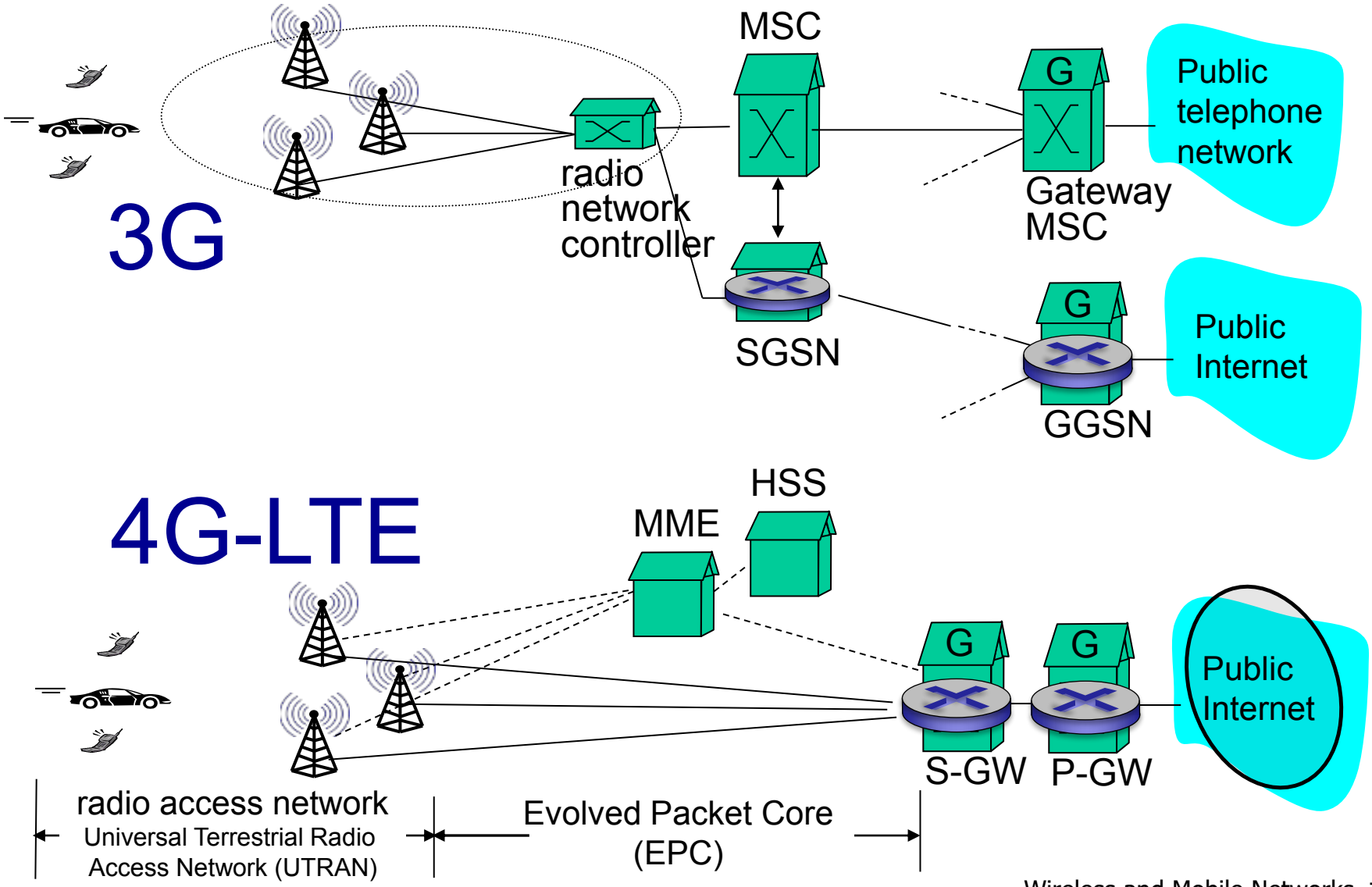


Gateway GPRS Support Node (GGSN)

3G (voice+data) network architecture

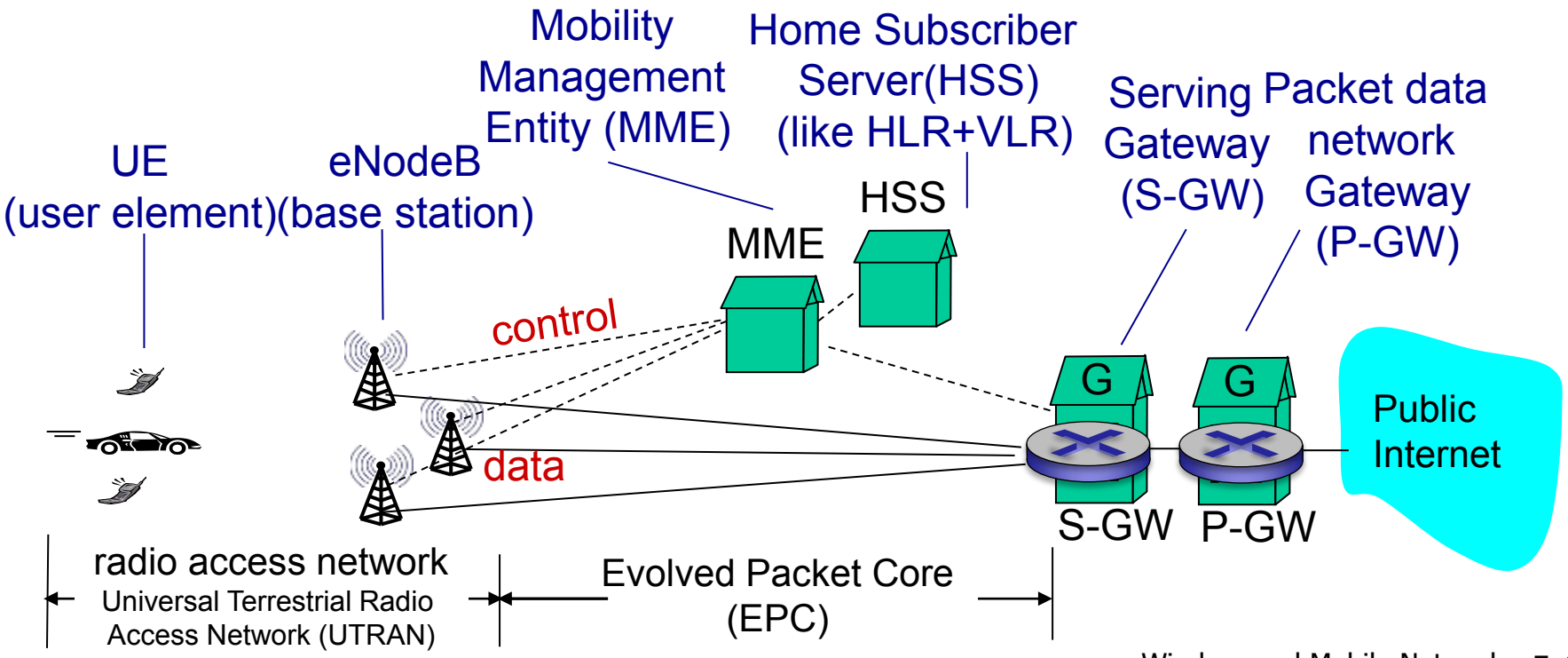


3G versus 4G LTE network architecture



4G: differences from 3G

- all IP core: IP packets tunneled (through core IP network) from base station to gateway
- no separation between voice and data – all traffic carried over IP core to gateway



Chapter 7 outline

7.1 Introduction

Wireless

7.2 Wireless links, characteristics
- CDMA

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

7.4 Cellular Internet Access
- architecture
- standards (e.g., 3G, LTE)

Mobility

7.5 Principles: addressing and routing to mobile users

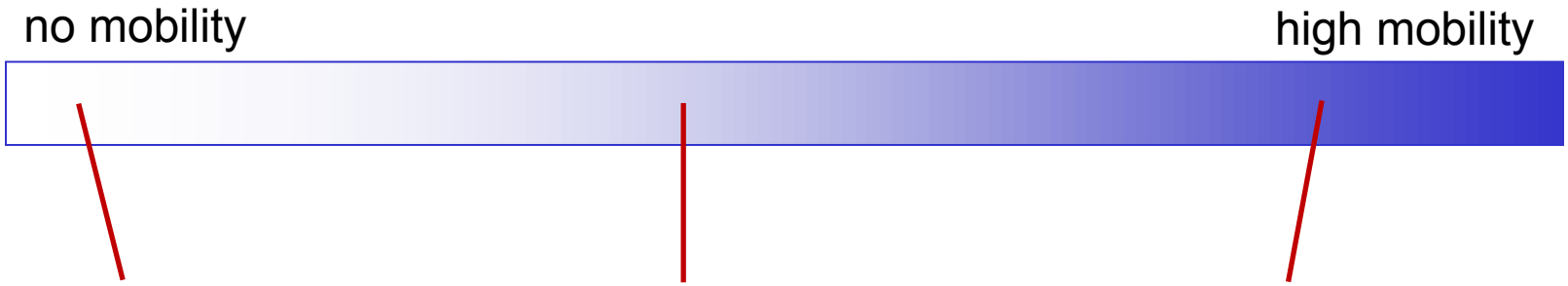
7.6 Mobile IP

7.7 Handling mobility in cellular networks

7.8 Mobility and higher-layer protocols

What is mobility?

- spectrum of mobility, from the *network* perspective:



mobile wireless user, using same access point

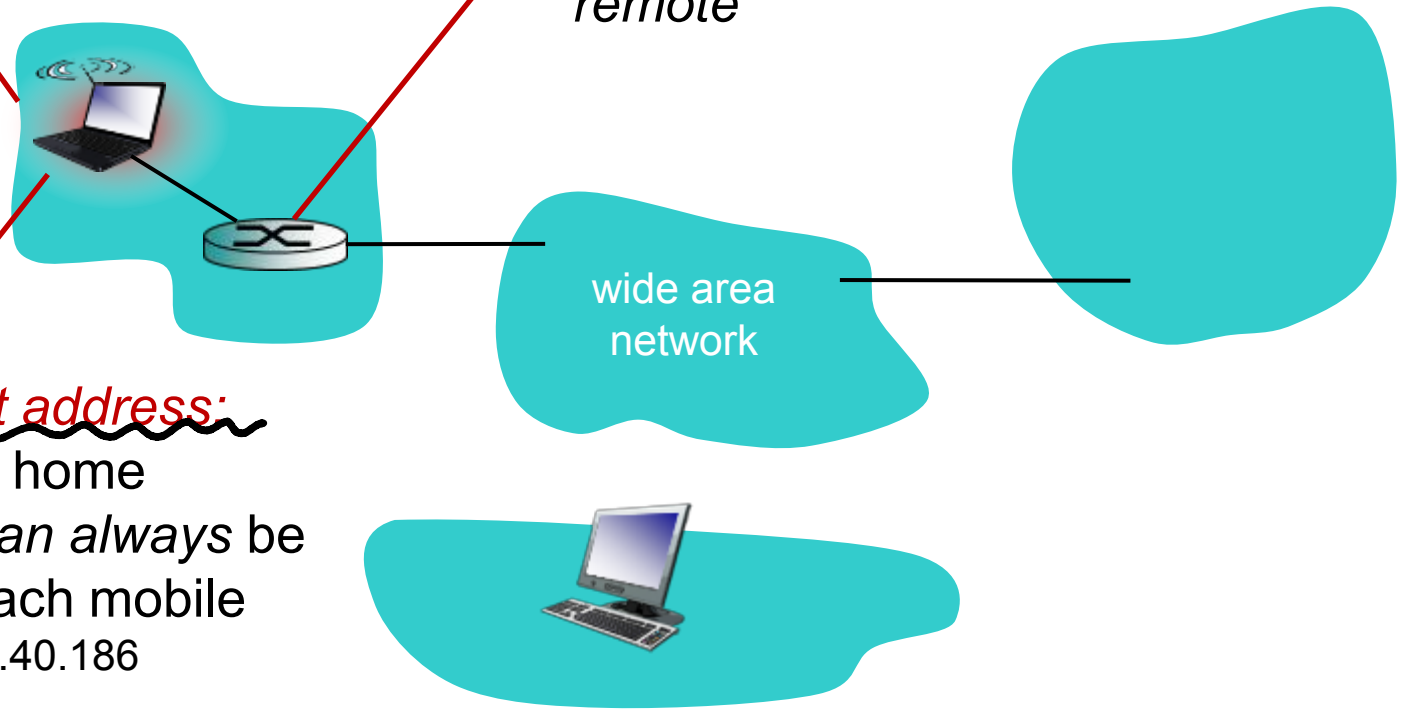
mobile user, connecting/ disconnecting from network using DHCP.

mobile user, passing through multiple access point while maintaining ongoing connections (like cell phone)

Mobility: vocabulary

home network: permanent "home" of mobile (e.g., 128.119.40/24)

home agent: entity that will perform mobility functions on behalf of mobile, when mobile is remote



permanent address: address in home network, *can always* be used to reach mobile e.g., 128.119.40.186

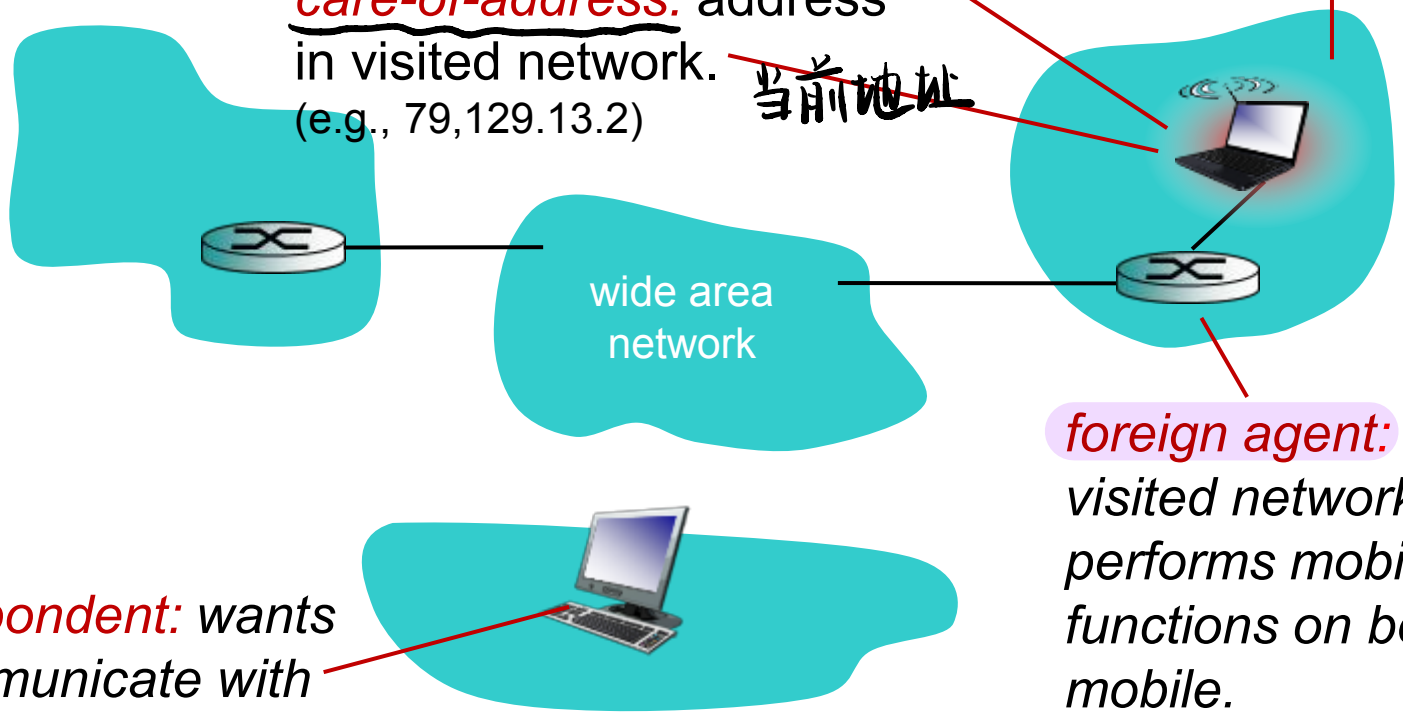
Mobility: more vocabulary

permanent address: remains constant (e.g., 128.119.40.186)

visited network: network in which mobile currently resides (e.g., 79.129.13/24)

care-of-address: address in visited network. (e.g., 79,129.13.2)

当前地址



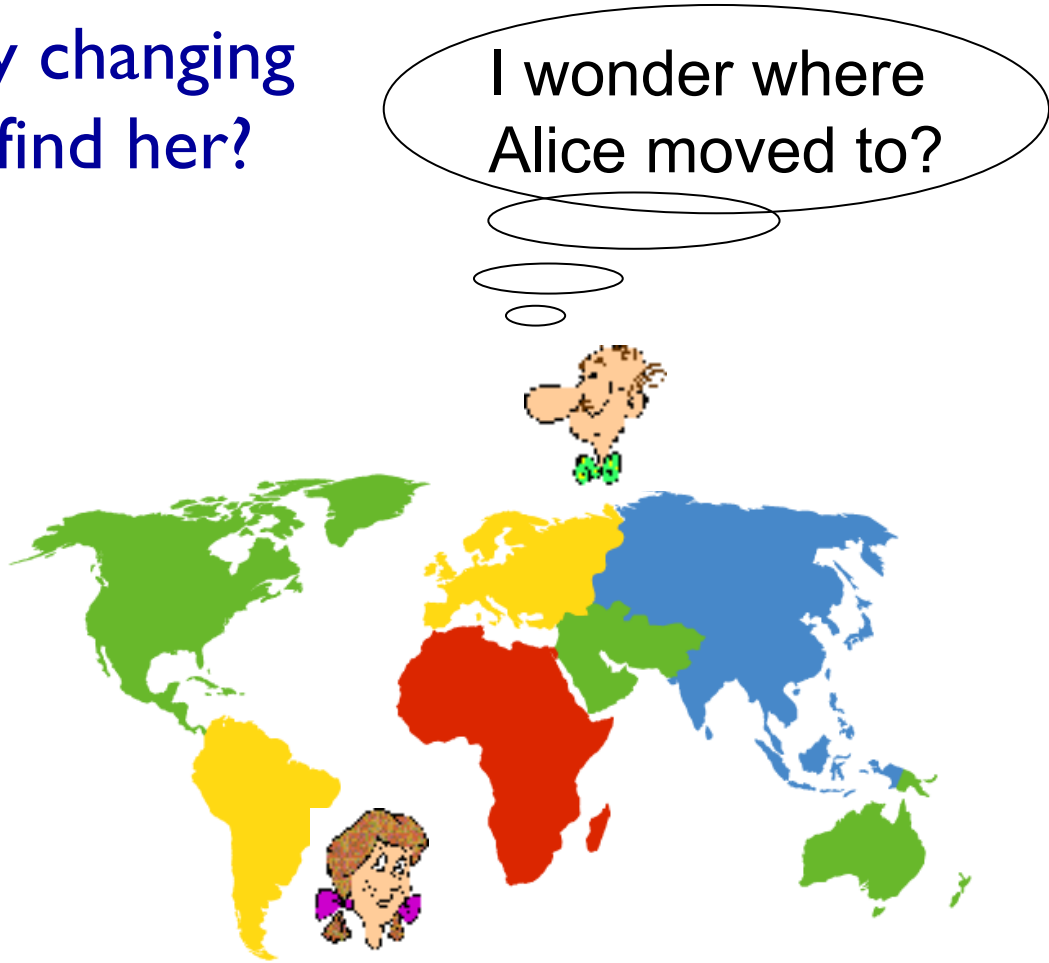
foreign agent: *entity in visited network that performs mobility functions on behalf of mobile.*

correspondent: *wants to communicate with mobile*

How do *you* contact a mobile friend:

Consider friend frequently changing addresses, how do you find her?

- search all phone books?
- call her parents?
- expect her to let you know where he/she is?
- Facebook!



Mobility: approaches

- *let routing handle it:* routers advertise permanent address of mobile-nodes-in-residence via usual routing table exchange.
  - routing tables indicate where each mobile located
  - no changes to end-systems
- *let end-systems handle it:*
  - *indirect routing:* communication from correspondent to mobile goes through home agent, then forwarded to remote
  - *direct routing:* correspondent gets foreign address of mobile, sends directly to mobile

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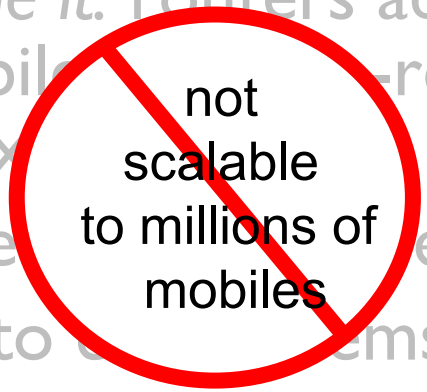
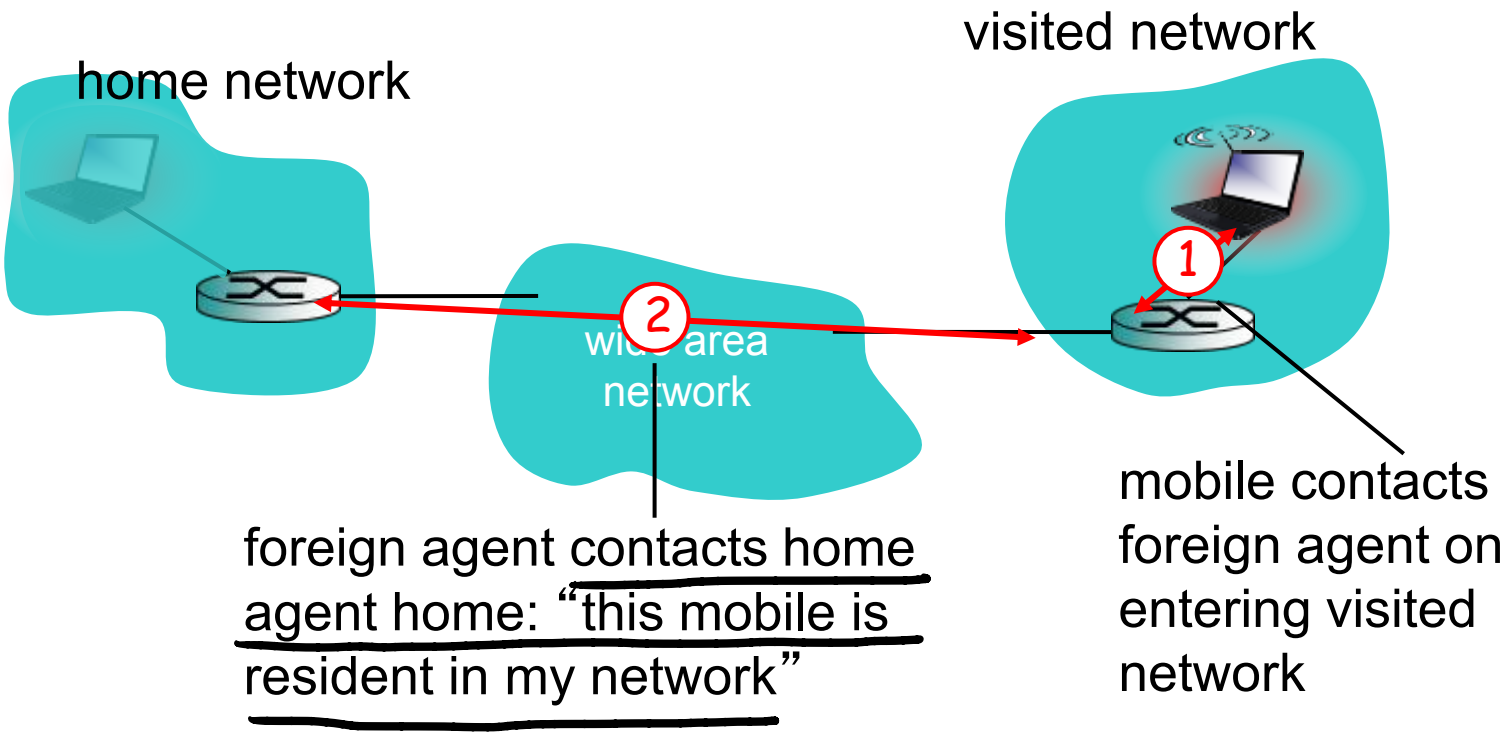


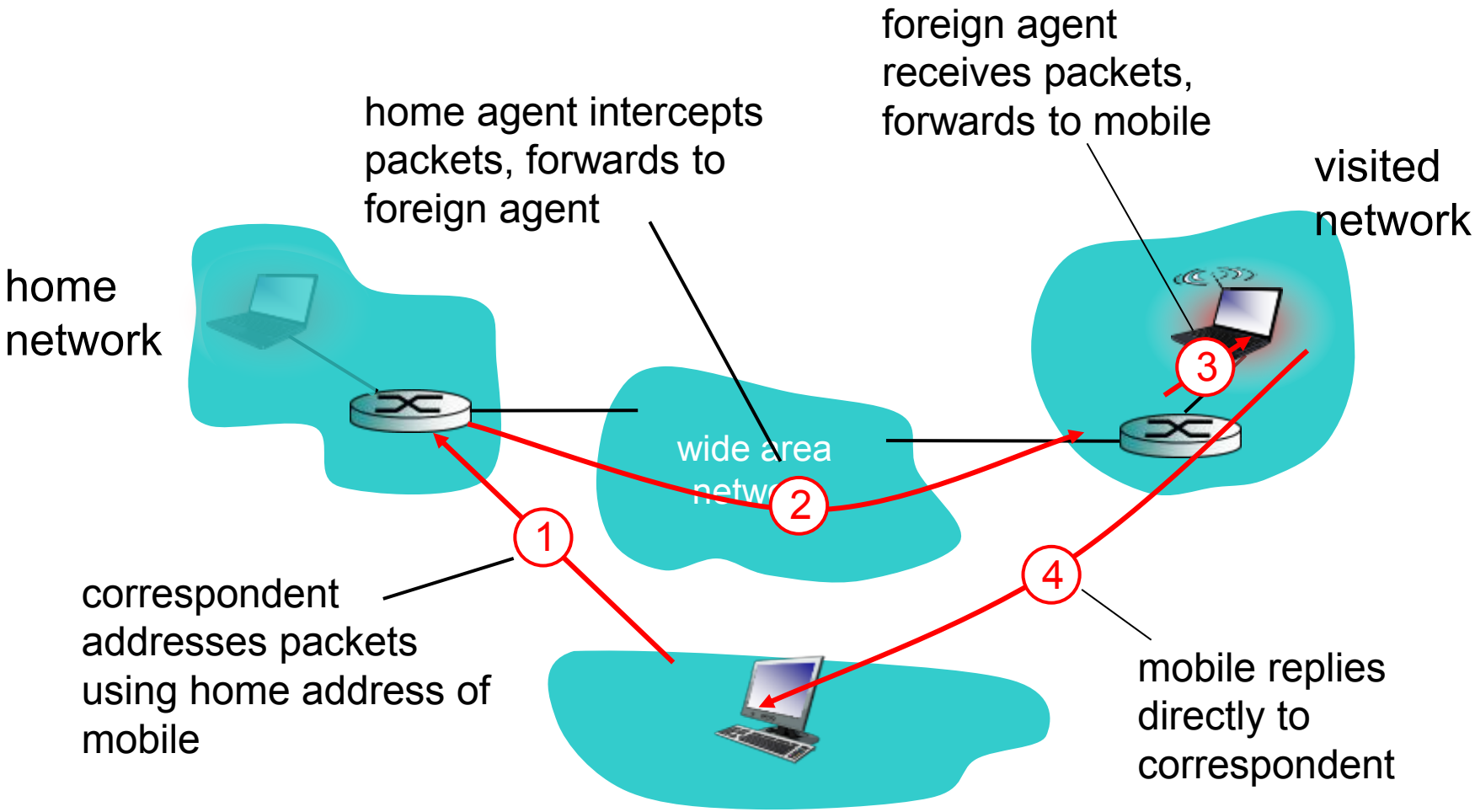
Mobility: registration



end result:

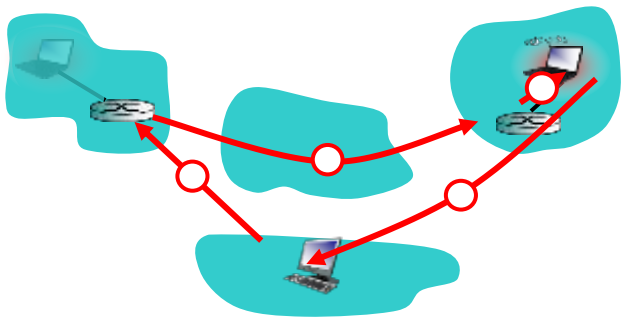
- foreign agent knows about mobile
- home agent knows location of mobile

Mobility via indirect routing



Indirect Routing: comments

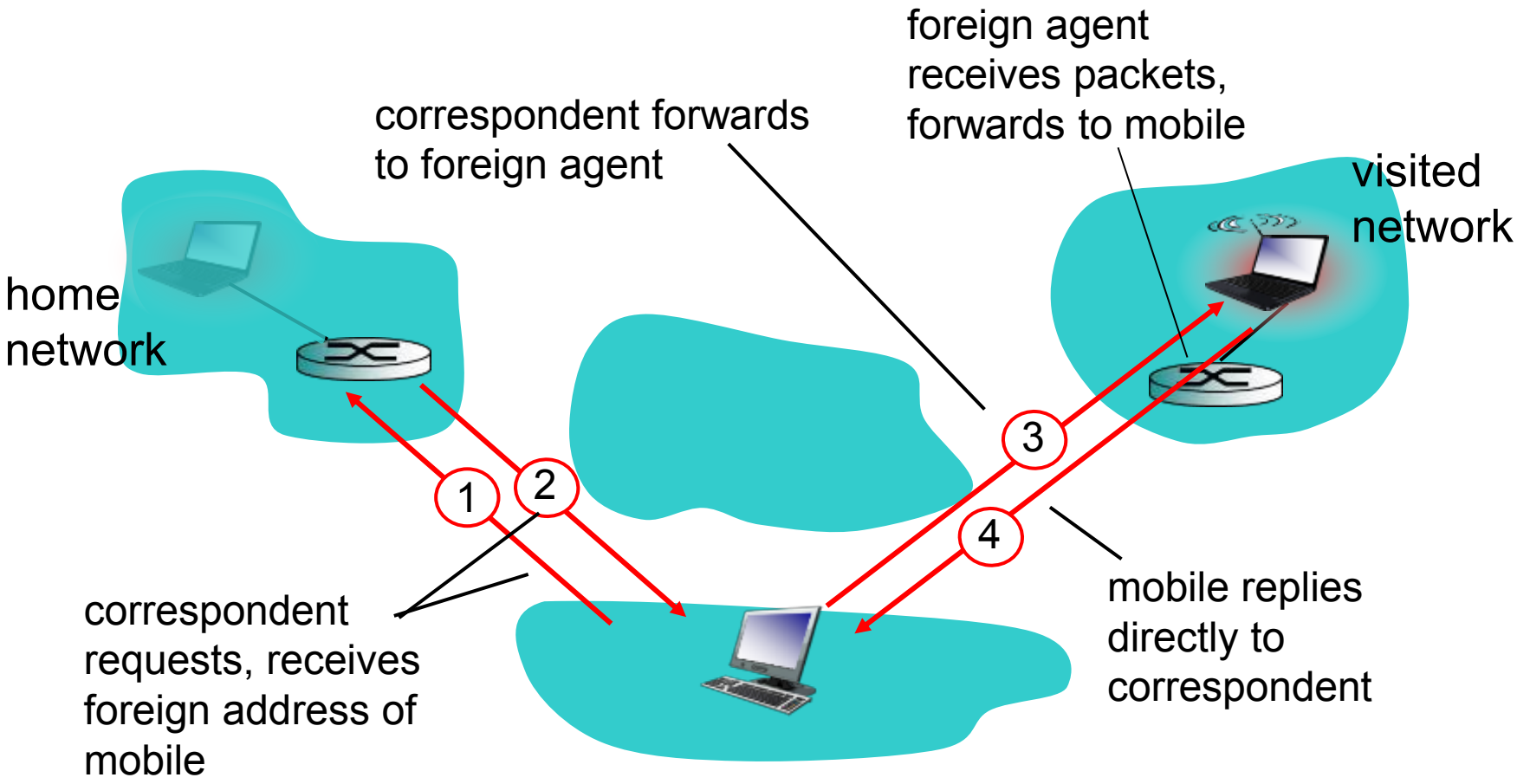
- mobile uses two addresses:
  - permanent address: used by correspondent (hence mobile location is *transparent* to correspondent)
  - care-of-address: used by home agent to forward datagrams to mobile
- foreign agent functions may be done by mobile itself
- triangle routing: correspondent-home-network-mobile
  - inefficient when correspondent, mobile are in same network



Indirect routing: moving between networks

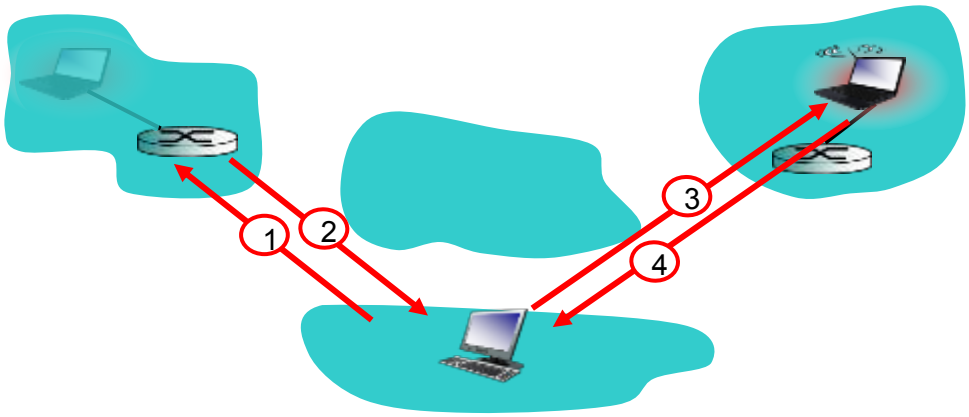
- suppose mobile user moves to another network
  - registers with new foreign agent
  - new foreign agent registers with home agent
  - home agent update care-of-address for mobile
  - packets continue to be forwarded to mobile (but with new care-of-address)
- mobility, changing foreign networks transparent: *on going connections can be maintained!*

Mobility via direct routing



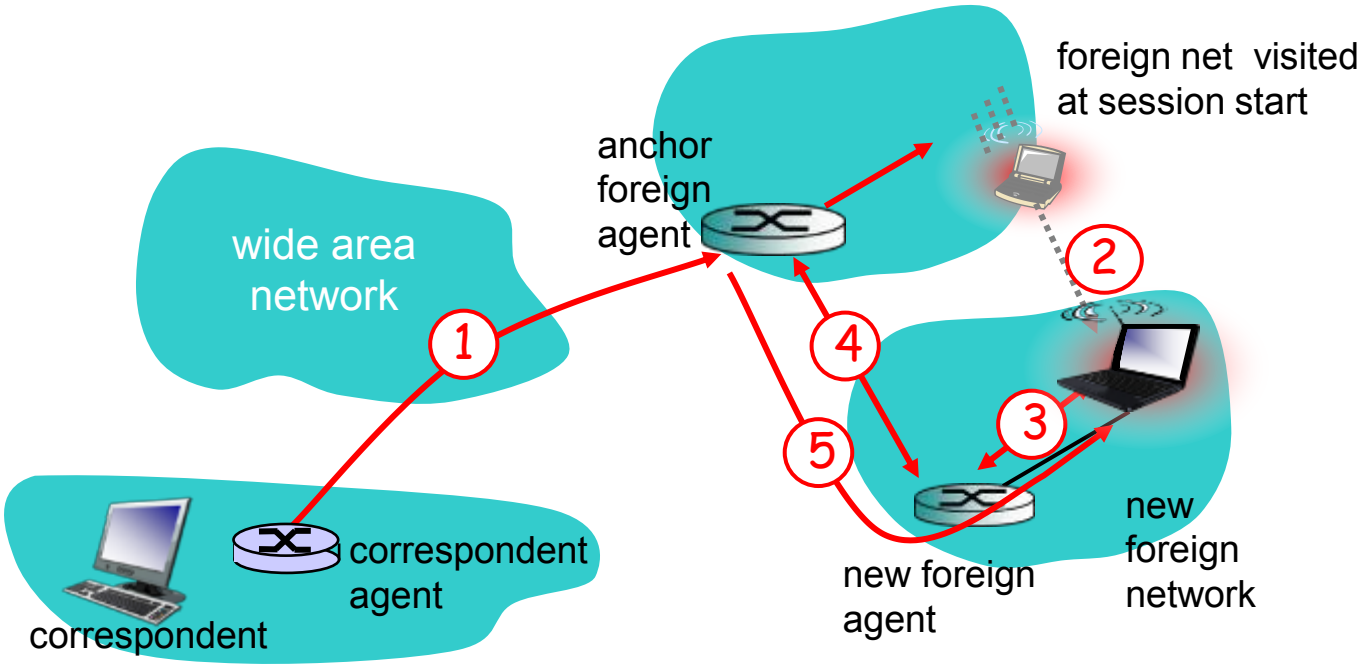
Mobility via direct routing: comments

- overcome triangle routing problem
- *non-transparent to correspondent:* correspondent must get care-of-address from home agent
  - what if mobile changes visited network?



Accommodating mobility with direct routing

- anchor foreign agent: FA in first visited network
- data always routed first to anchor FA
- when mobile moves: new FA arranges to have data forwarded from old FA (chaining)



Chapter 7 summary

Wireless

- wireless links:
  - capacity, distance
  - channel impairments
  - CDMA
- IEEE 802.11 ("Wi-Fi")
  - CSMA/CA reflects wireless channel characteristics
- cellular access
  - architecture
  - standards (e.g., 3G, 4G LTE)

Mobility

- principles: addressing, routing to mobile users
  - home, visited networks
  - direct, indirect routing
  - care-of-addresses
- case studies
  - mobile IP
  - mobility in GSM, LTE
- impact on higher-layer protocols

Final Exam

- Final: Jan. 10 14:00-16:00, Liyuan 102 201 203
  - 2-hours, Closed-book
  - Covering range: 4.1-6.4, 6.6-6.7, 7.1-7.5
- Q&A session:
  - Jan. 9 19:00-21:00, CoE South 443B
  - Before Jan. 9, on appointment