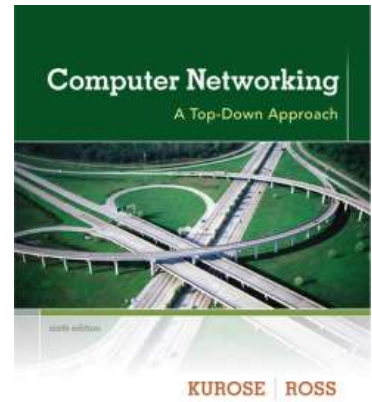


# Chapter 6

## Wireless and Mobile Networks

---



### A note on the use of these ppt slides:

We're making these slides freely available to all (faculty, students, readers). They're in PowerPoint form so you see the animations; and can add, modify, and delete slides (including this one) and slide content to suit your needs. They obviously represent a *lot* of work on our part. In return for use, we only ask the following:

- ❖ If you use these slides (e.g., in a class) that you mention their source (after all, we'd like people to use our book!)
- ❖ If you post any slides on a www site, that you note that they are adapted from (or perhaps identical to) our slides, and note our copyright of this material.

Thanks and enjoy! JFK/KWR

©All material copyright 1996-2012  
J.F Kurose and K.W. Ross, All Rights Reserved

*Computer  
Networking: A Top  
Down Approach*  
6<sup>th</sup> edition  
Jim Kurose, Keith Ross  
Addison-Wesley  
March 2012

Wireless, Mobile Networks 6-1

## 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

Wireless, Mobile Networks 6-2

# Chapter 6 outline

## 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)

### Mobility

#### 6.5 Principles: addressing and routing to mobile users

#### 6.6 Mobile IP

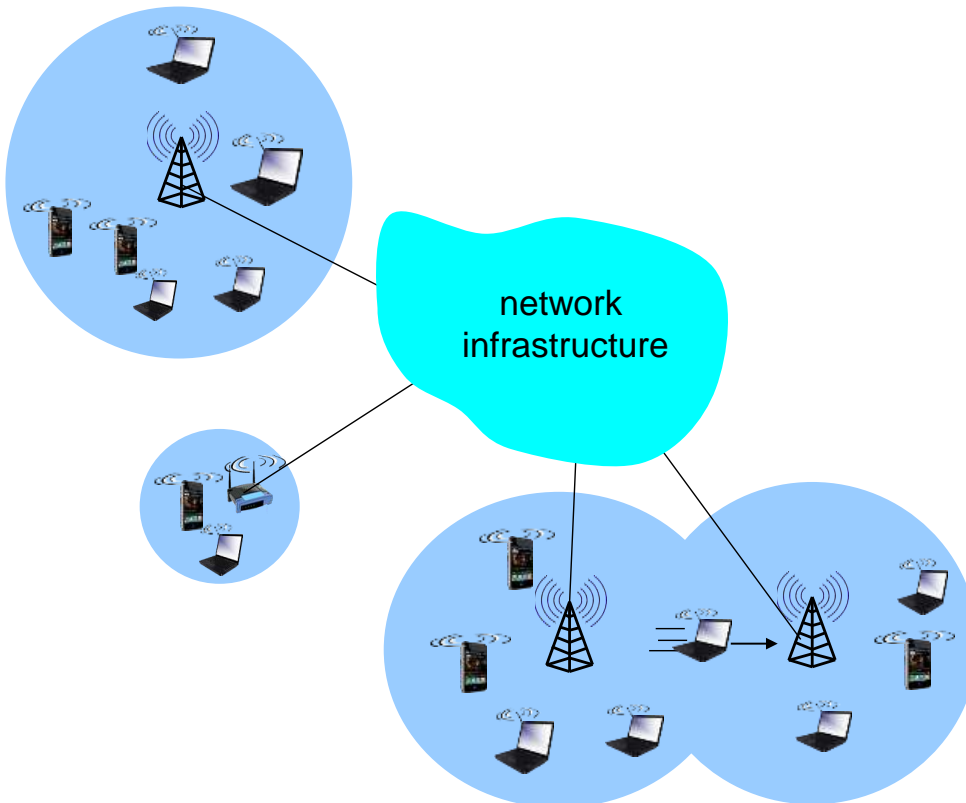
#### 6.7 Handling mobility in cellular networks

#### 6.8 Mobility and higher-layer protocols

#### 6.9 Summary

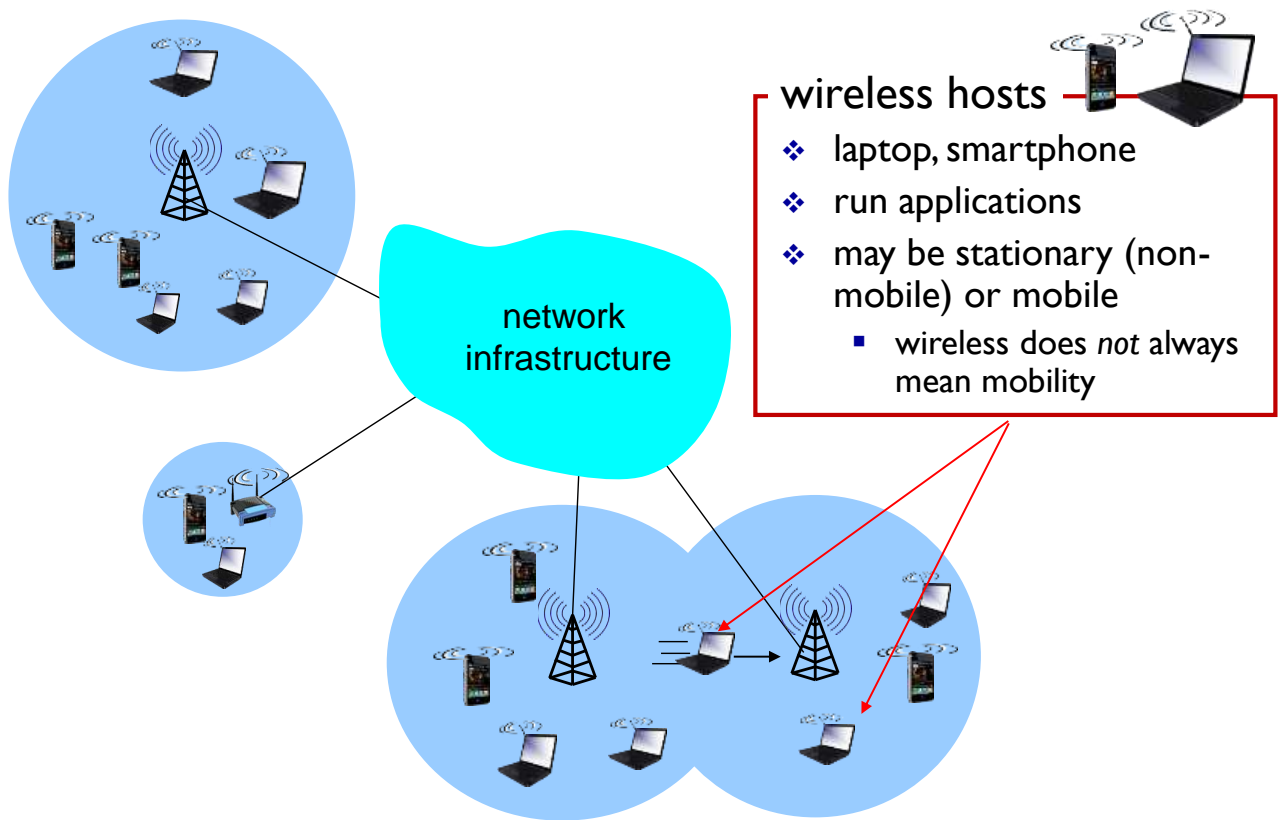
Wireless, Mobile Networks 6-3

## Elements of a wireless network



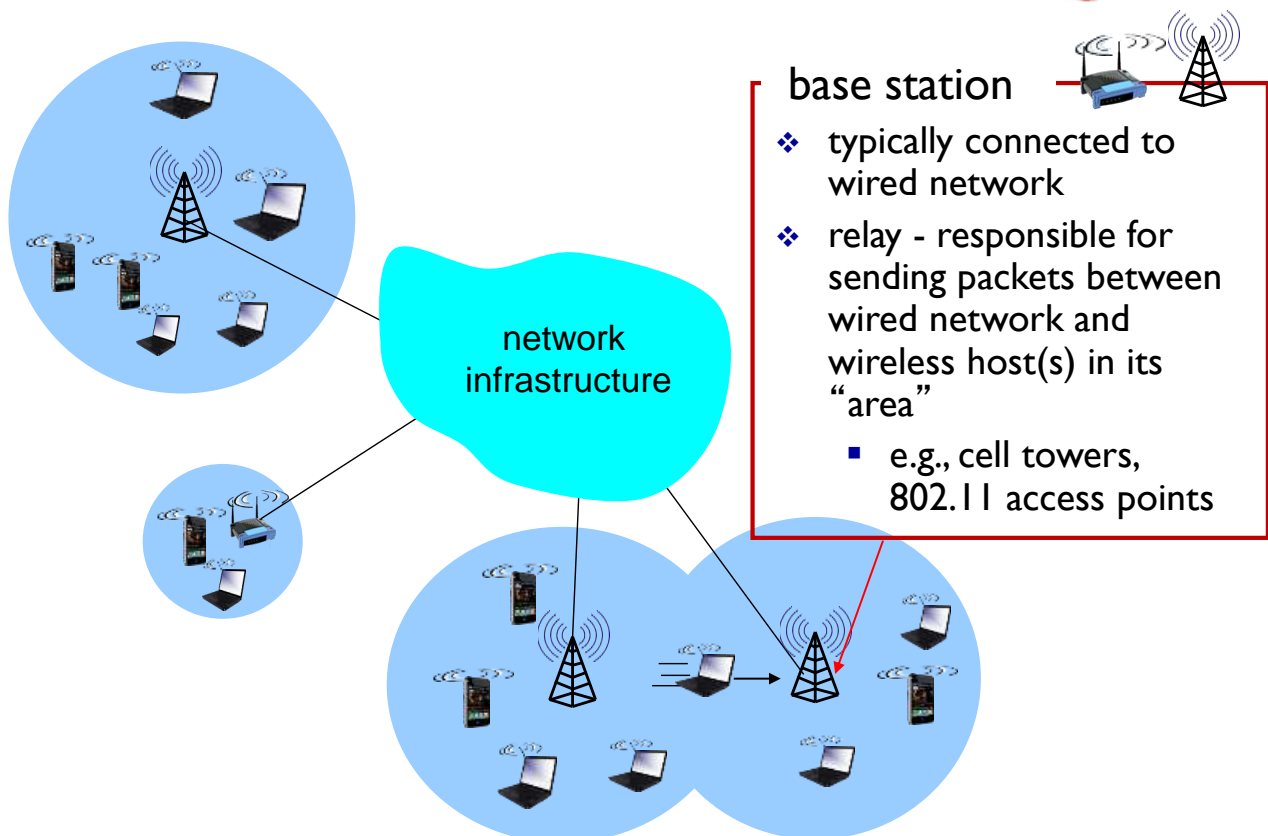
Wireless, Mobile Networks 6-4

# Elements of a wireless network



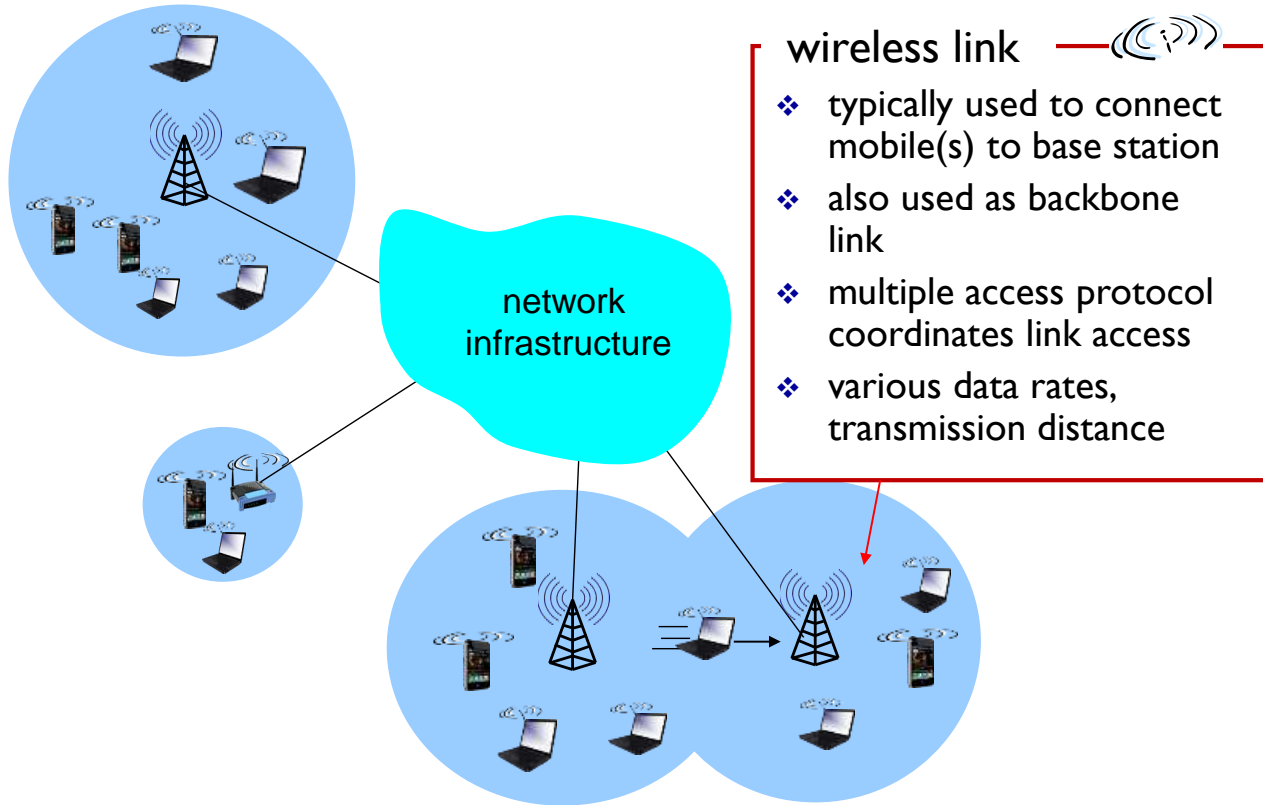
Wireless, Mobile Networks 6-5

# Elements of a wireless network



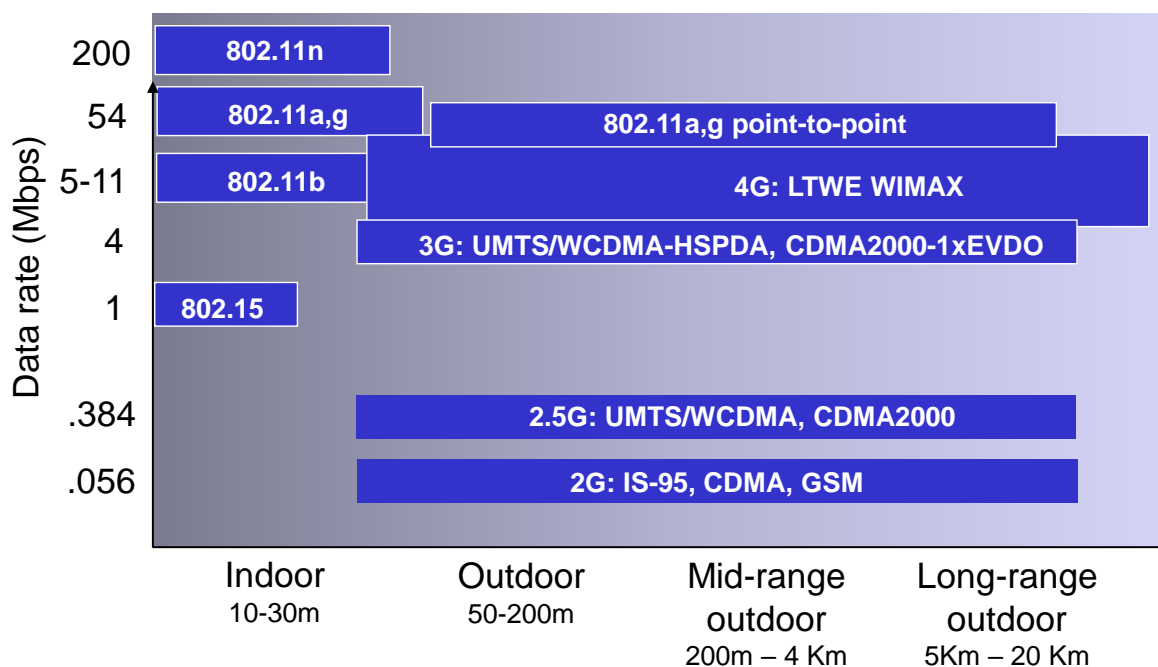
Wireless, Mobile Networks 6-6

# Elements of a wireless network



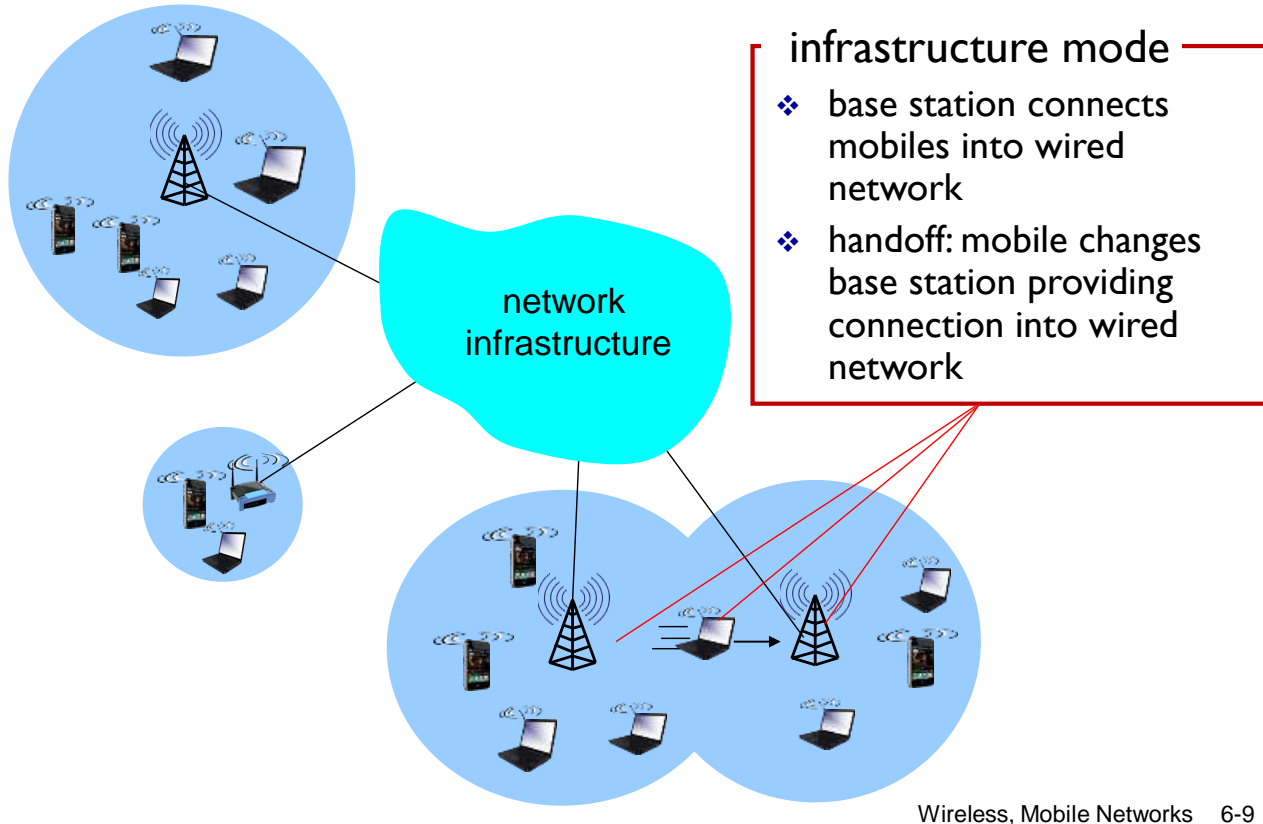
Wireless, Mobile Networks 6-7

## Characteristics of selected wireless links

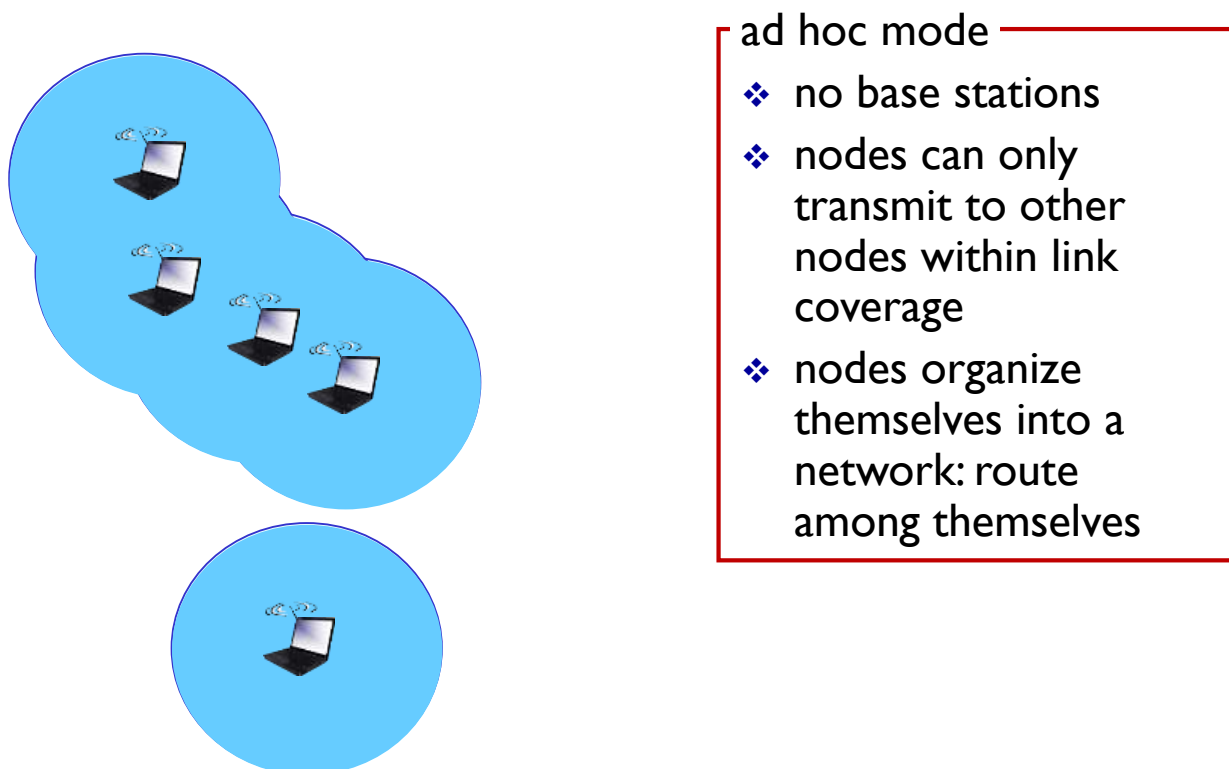


Wireless, Mobile Networks 6-8

# Elements of a wireless network



# Elements of a wireless network



# 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: <i>mesh net</i>
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

Wireless, Mobile Networks 6-11

## Chapter 6 outline

### 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)

### Mobility

#### 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

#### 6.9 Summary

Wireless, Mobile Networks 6-12

# Wireless Link Characteristics (1)

*important* differences from wired link ....

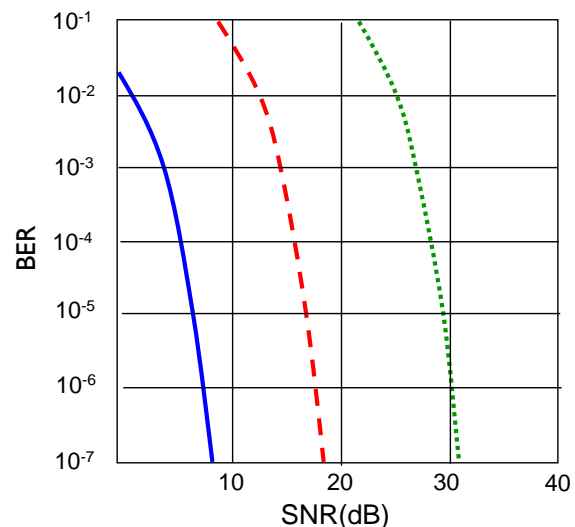
- *decreased signal strength*: radio signal attenuates as it propagates through matter (path loss)
- *interference from other sources*: standardized wireless network frequencies (e.g., 2.4 GHz) shared by other devices (e.g., phone); devices (motors) interfere as well
- *multipath propagation*: radio 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”

Wireless, Mobile Networks 6-13

# 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  $\rightarrow$  increase SNR  $\rightarrow$  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)



..... QAM256 (8 Mbps)

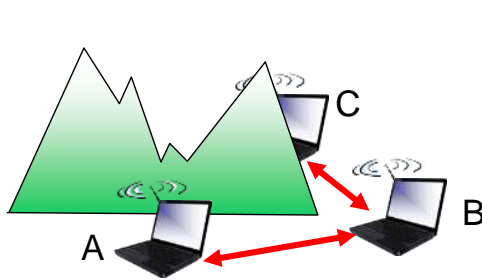
- - - QAM16 (4 Mbps)

— BPSK (1 Mbps)

Wireless, Mobile Networks 6-14

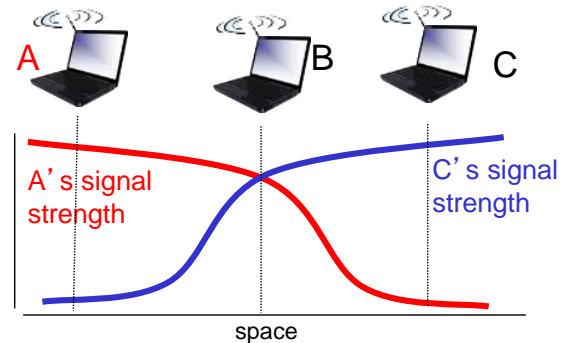
# Wireless network characteristics

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

Wireless, Mobile Networks 6-15

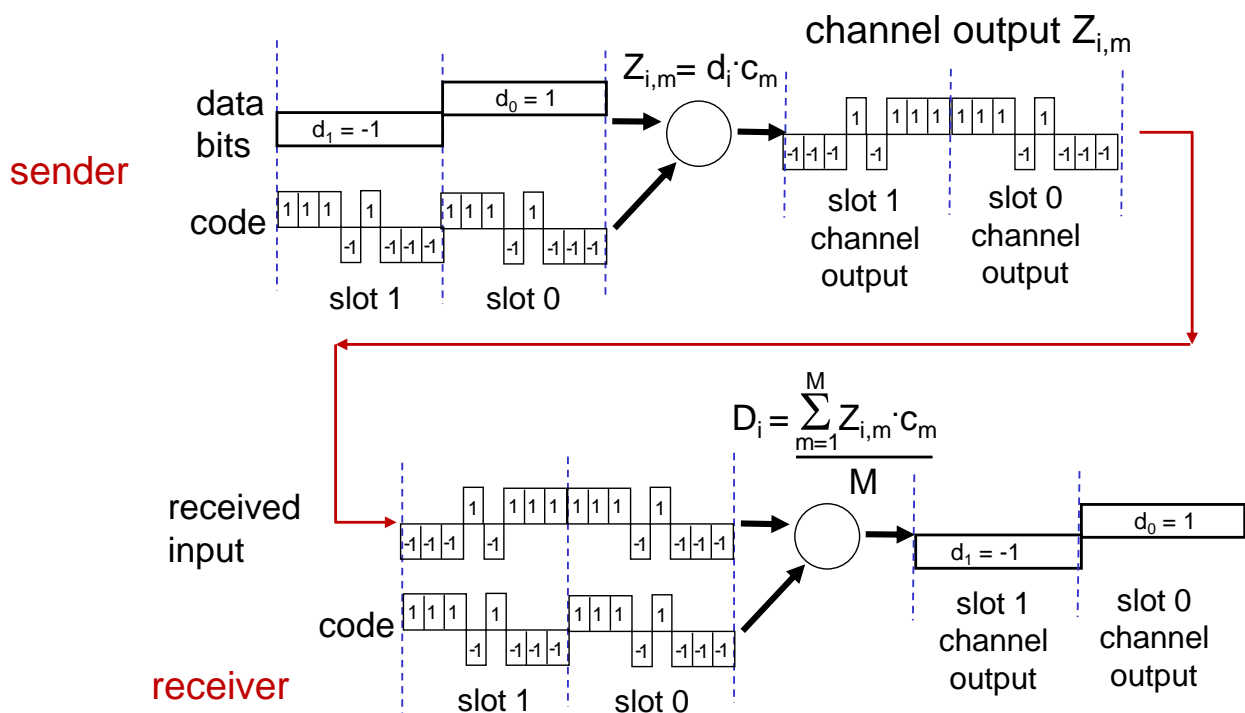
# Code Division Multiple Access (CDMA)

- ❖ 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

Wireless, Mobile Networks 6-16

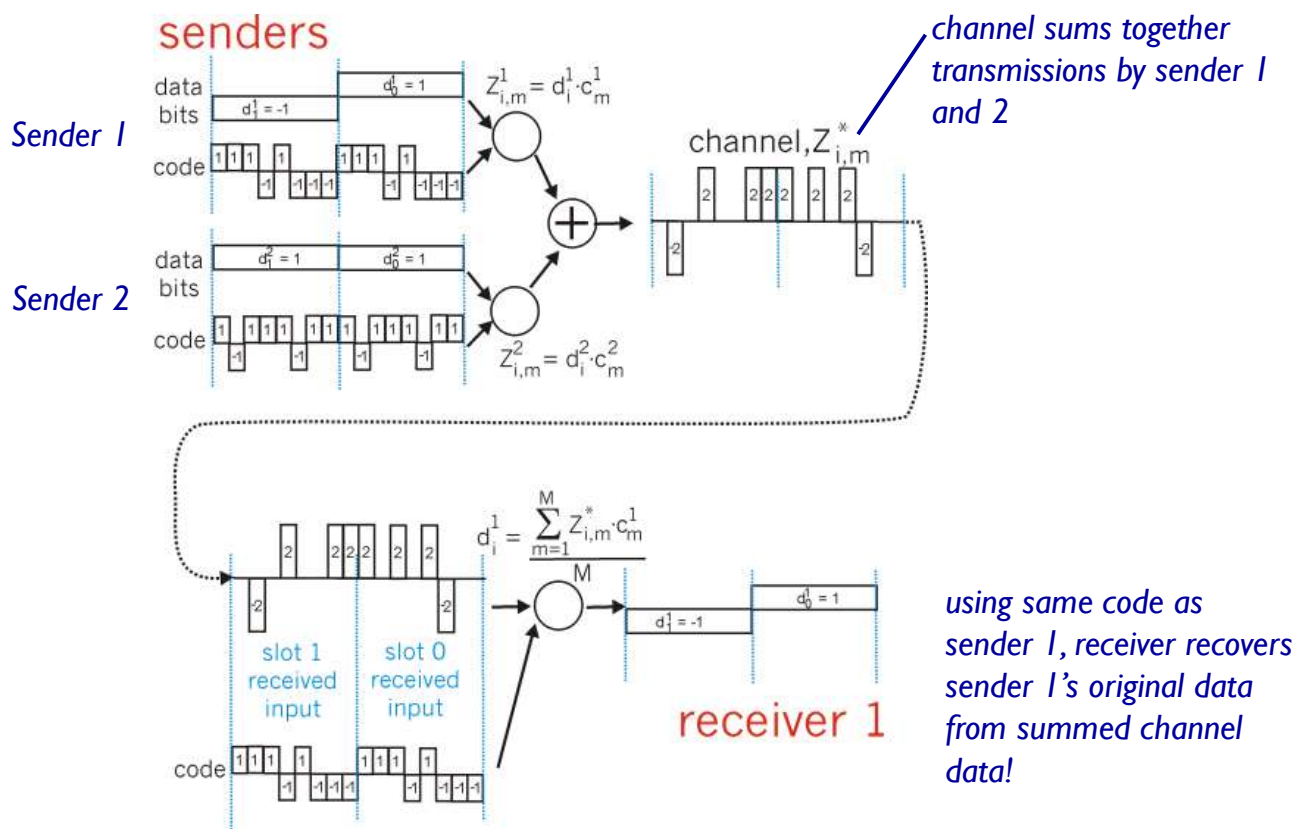


# CDMA encode/decode



Wireless, Mobile Networks 6-17

## CDMA: two-sender interference



Wireless, Mobile Networks 6-18

# Chapter 6 outline

## 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)

## Mobility

### 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

### 6.9 Summary

Wireless, Mobile Networks 6-19

# 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

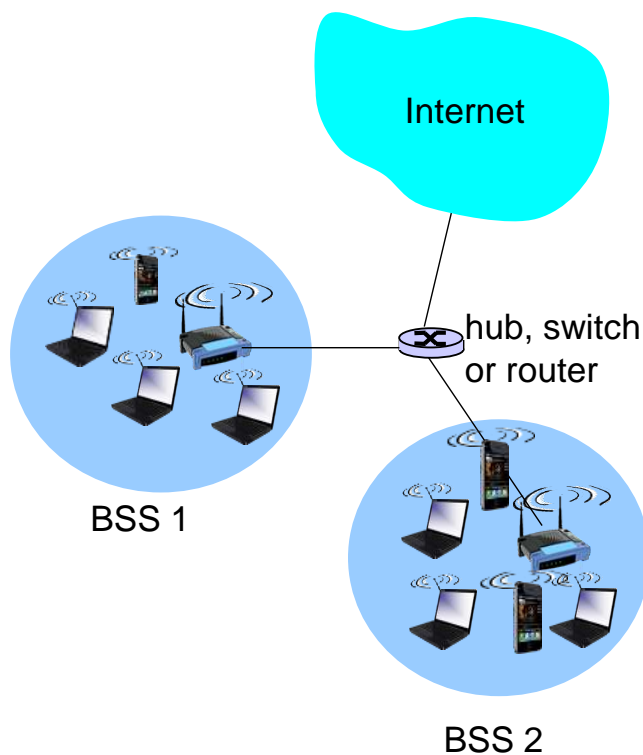
## 802.11n: multiple antennae

- 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

Wireless, Mobile Networks 6-20

# 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

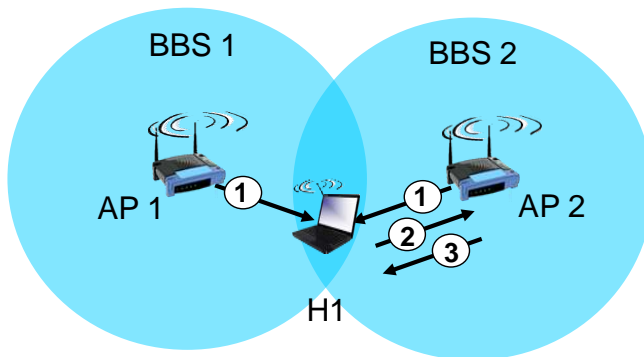
Wireless, Mobile Networks 6-21

## 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

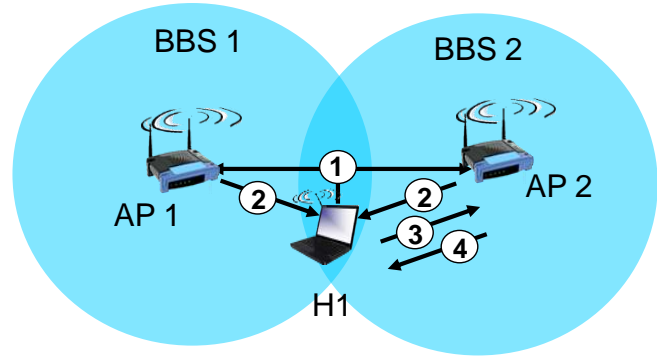
Wireless, Mobile Networks 6-22

# 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



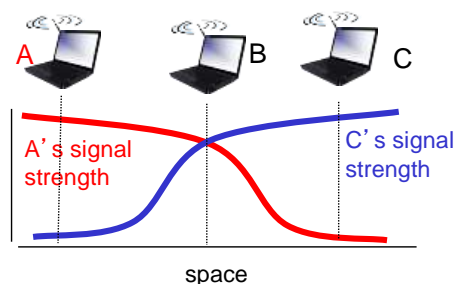
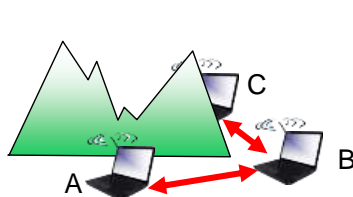
## active scanning:

- (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

Wireless, Mobile Networks 6-23

# 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)



Wireless, Mobile Networks 6-24

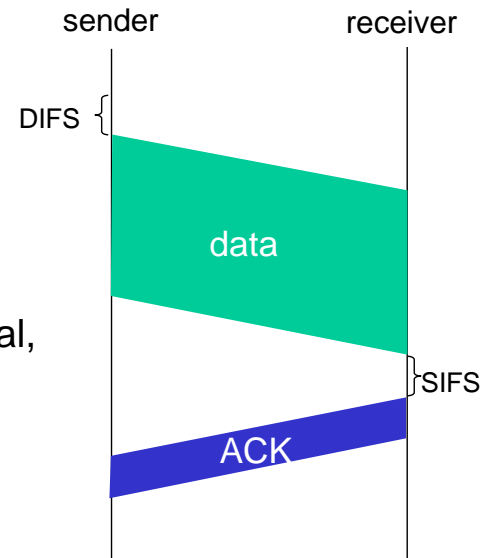
# IEEE 802.11 MAC Protocol: CSMA/CA

## 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)



Wireless, Mobile Networks 6-25

## Avoiding collisions (more)

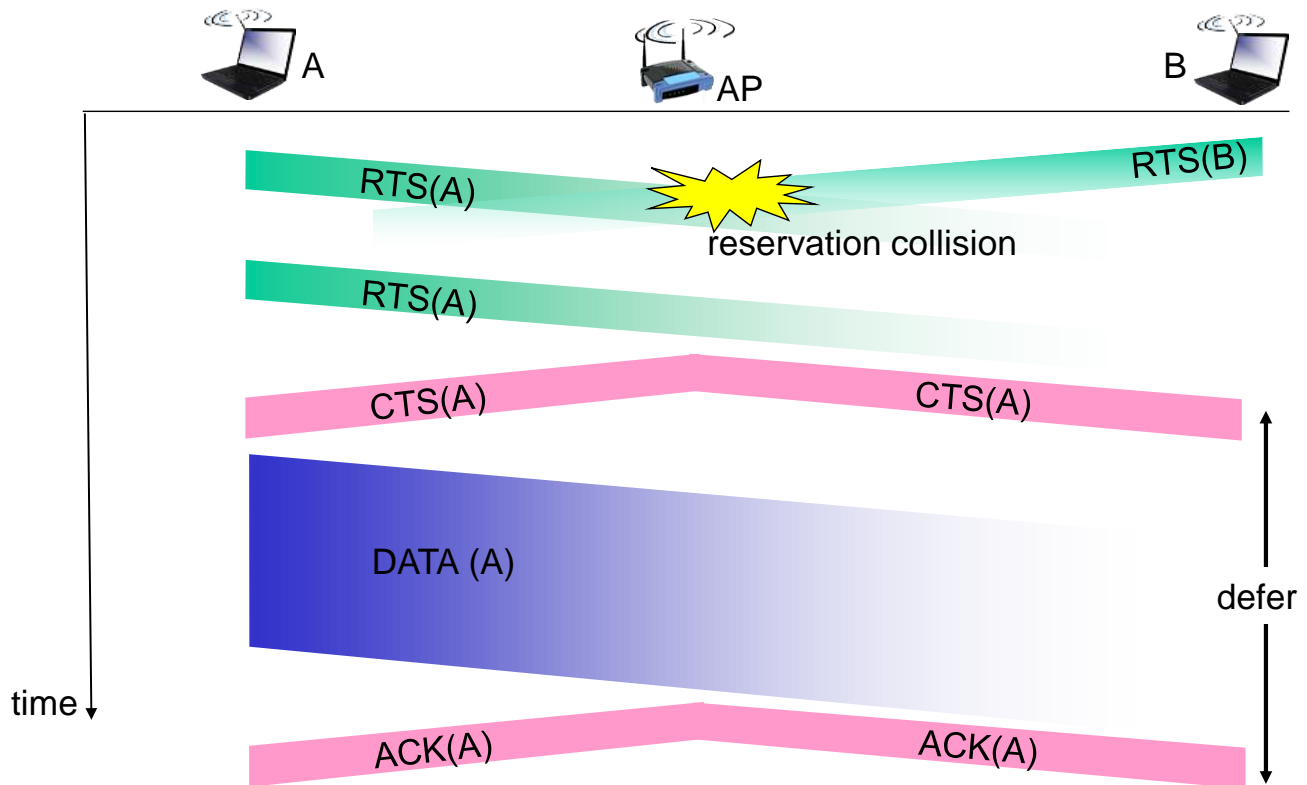
*idea:* allow sender to “reserve” channel rather than random access of data frames: avoid collisions of long data frames

- ❖ 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!*

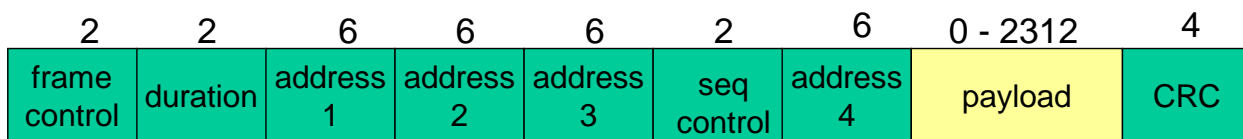
Wireless, Mobile Networks 6-26

## Collision Avoidance: RTS-CTS exchange



Wireless, Mobile Networks 6-27

## 802.11 frame: addressing



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

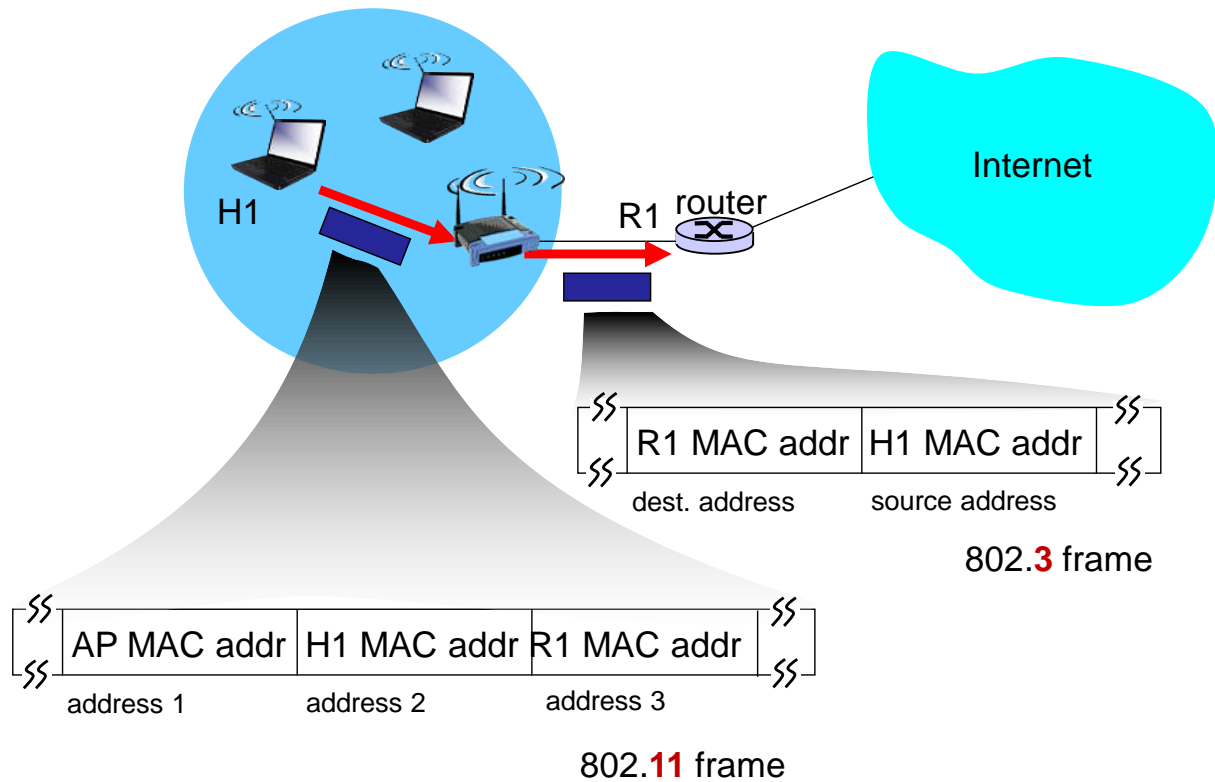
**Address 2:** MAC address of wireless host or AP transmitting this frame

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

**Address 4:** used only in ad hoc mode

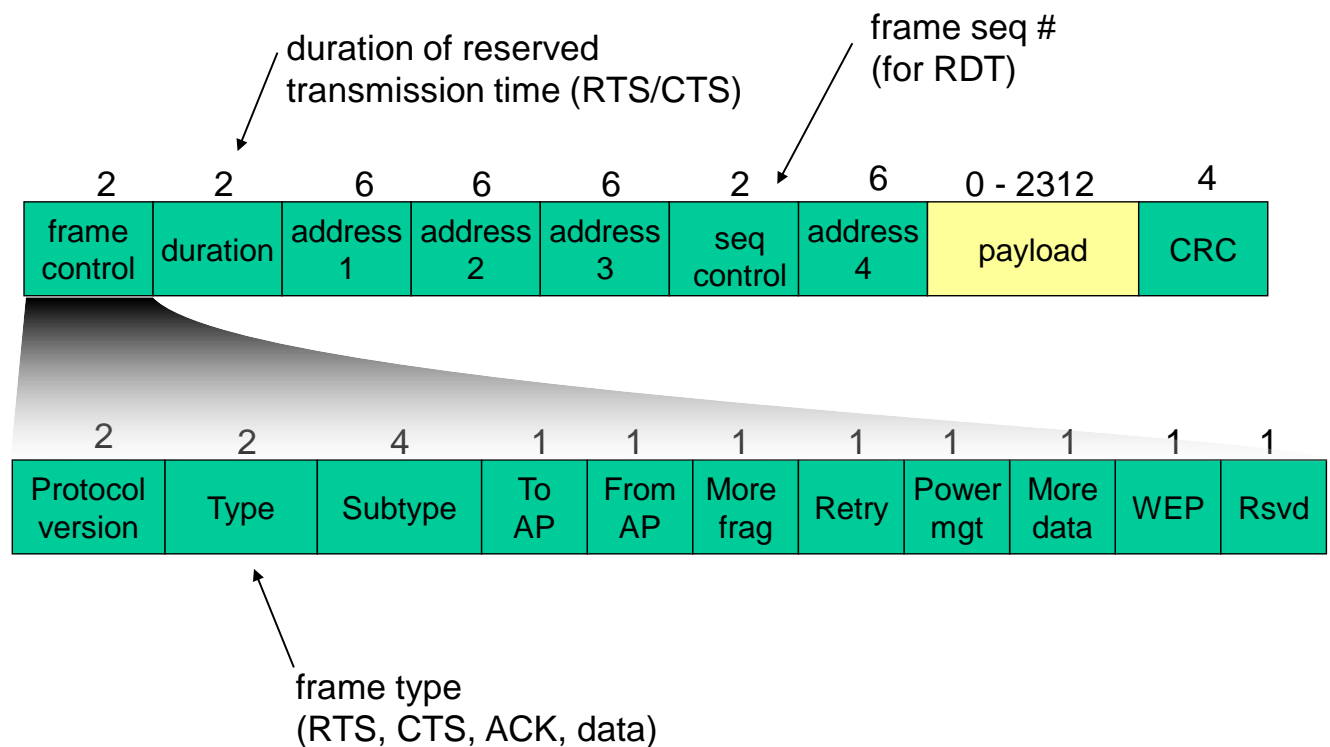
Wireless, Mobile Networks 6-28

# 802.11 frame: addressing



Wireless, Mobile Networks 6-29

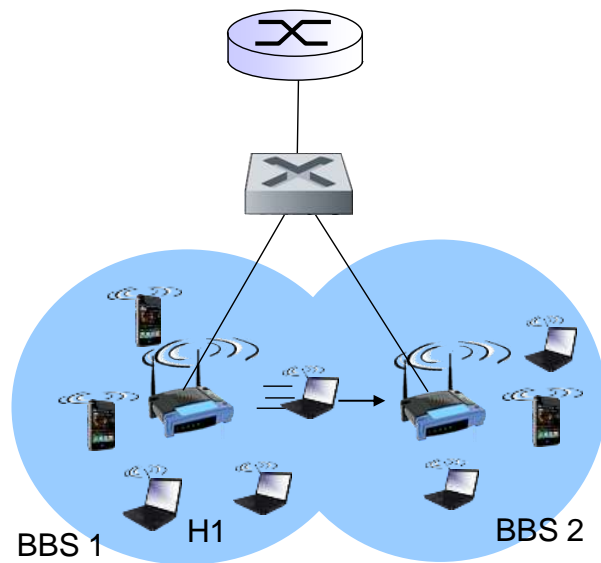
# 802.11 frame: more



Wireless, Mobile Networks 6-30

## 802.11: mobility within same subnet

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

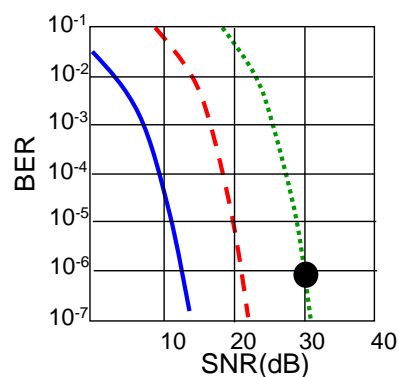


Wireless, Mobile Networks 6-31

## 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

Wireless, Mobile Networks 6-32



# 802.11: advanced capabilities

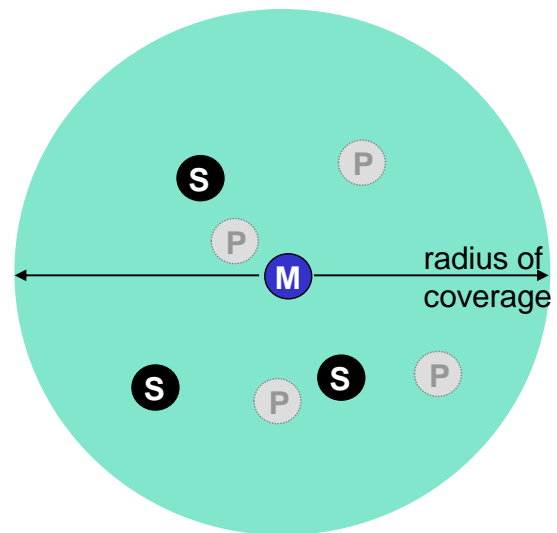
## *power management*

- ❖ 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

Wireless, Mobile Networks 6-33

# 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



- M** Master device
- S** Slave device
- P** Parked device (inactive)

Wireless, Mobile Networks 6-34

# Chapter 6 outline

## 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)

## Mobility

## 6.5 Principles: addressing and routing to mobile users

## 6.6 Mobile IP

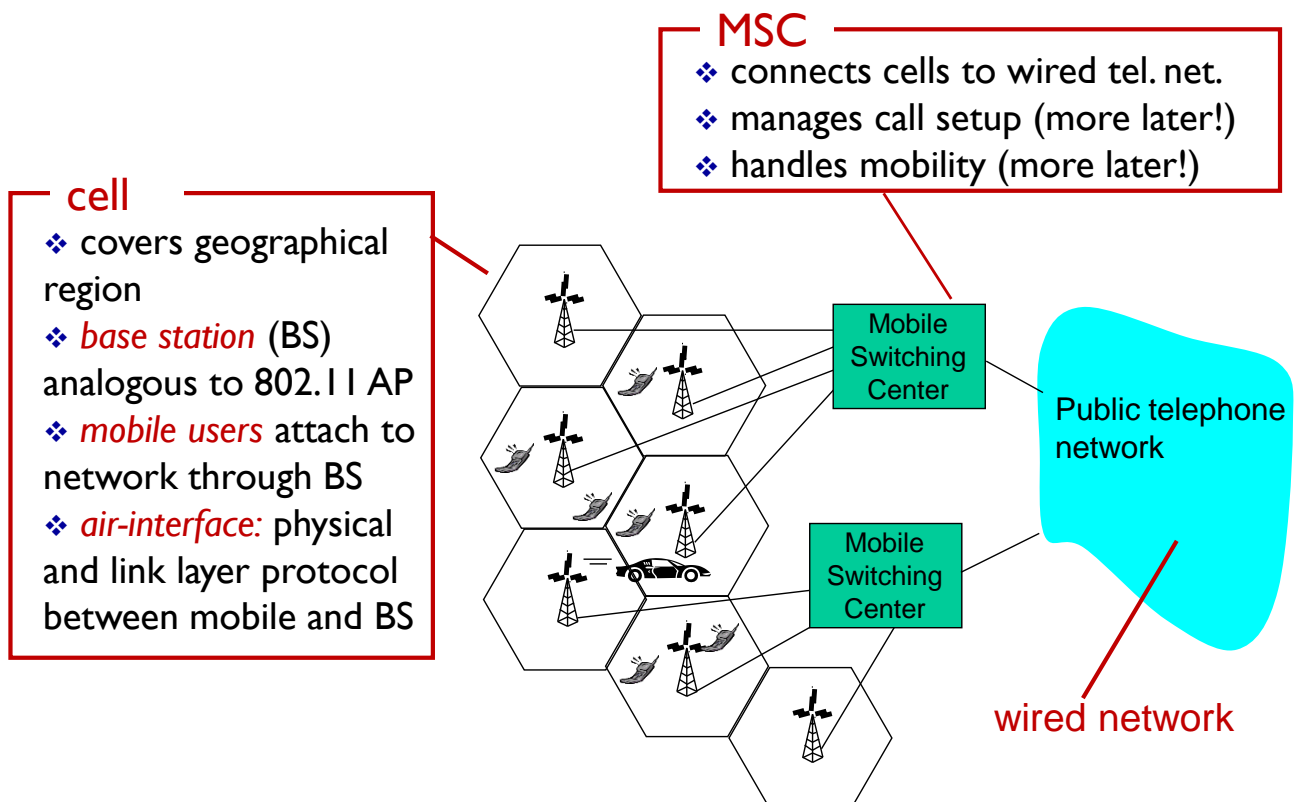
## 6.7 Handling mobility in cellular networks

## 6.8 Mobility and higher-layer protocols

## 6.9 Summary

Wireless, Mobile Networks 6-35

# Components of cellular network architecture

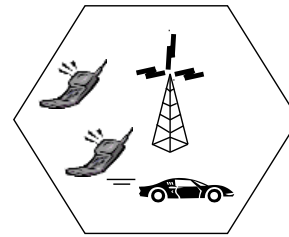


Wireless, Mobile Networks 6-36

# Cellular networks: the first hop

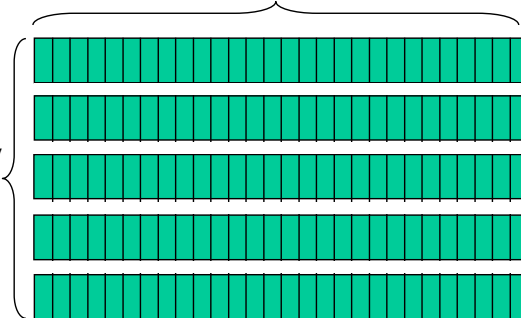
Two techniques for sharing mobile-to-BS radio spectrum

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



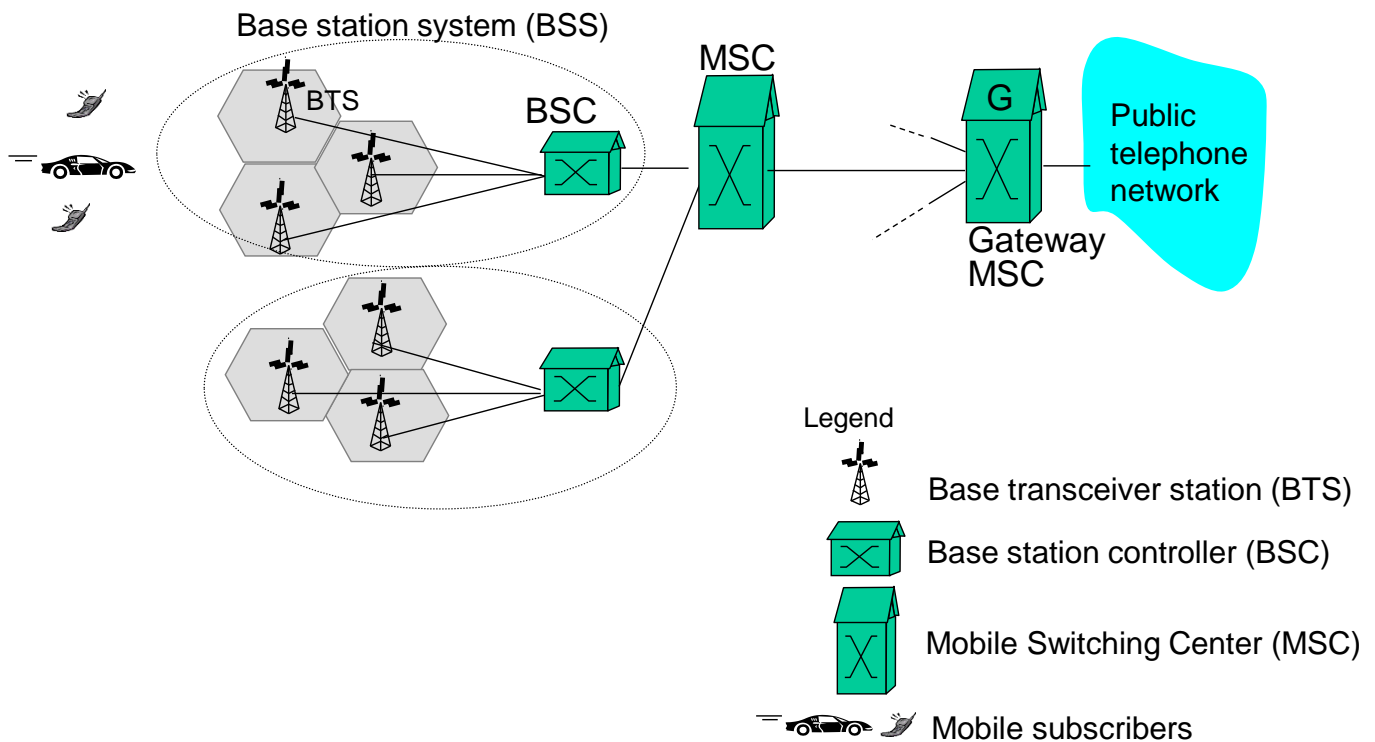
time slots

frequency bands



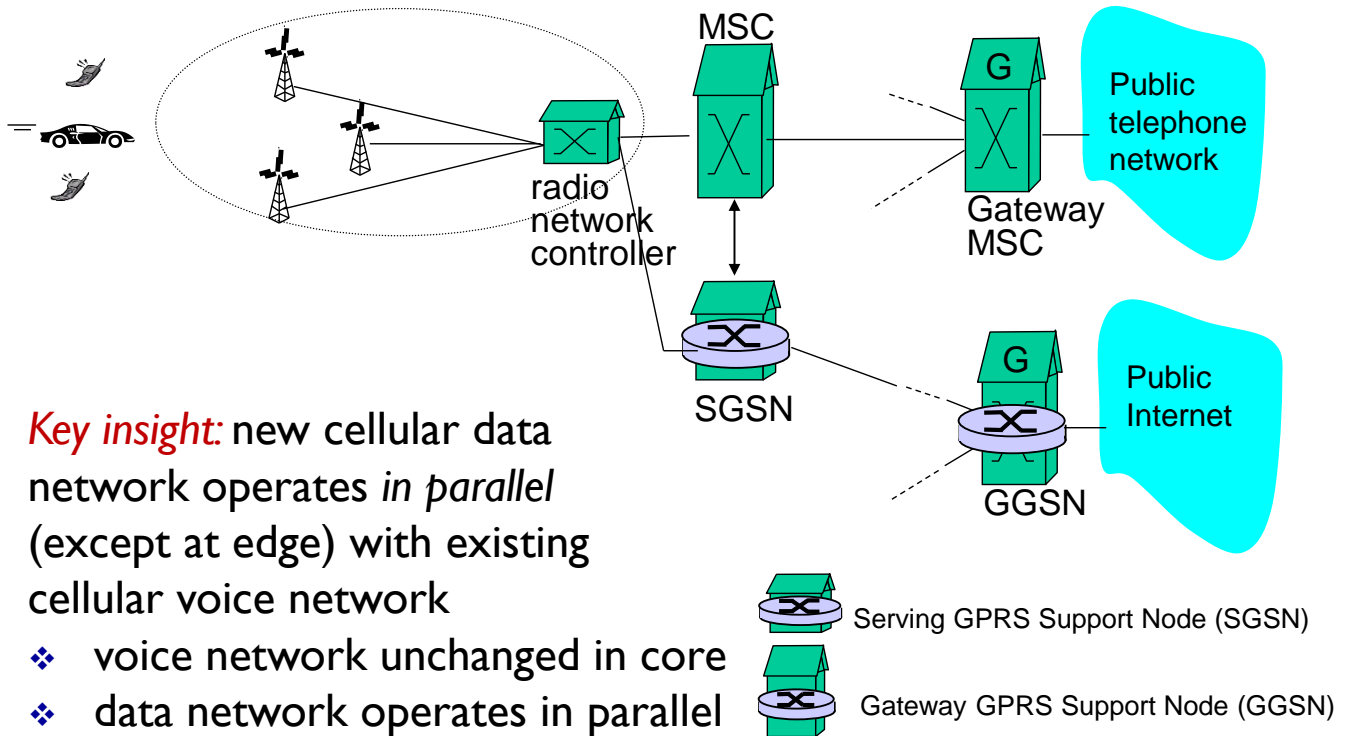
Wireless, Mobile Networks 6-37

## 2G (voice) network architecture



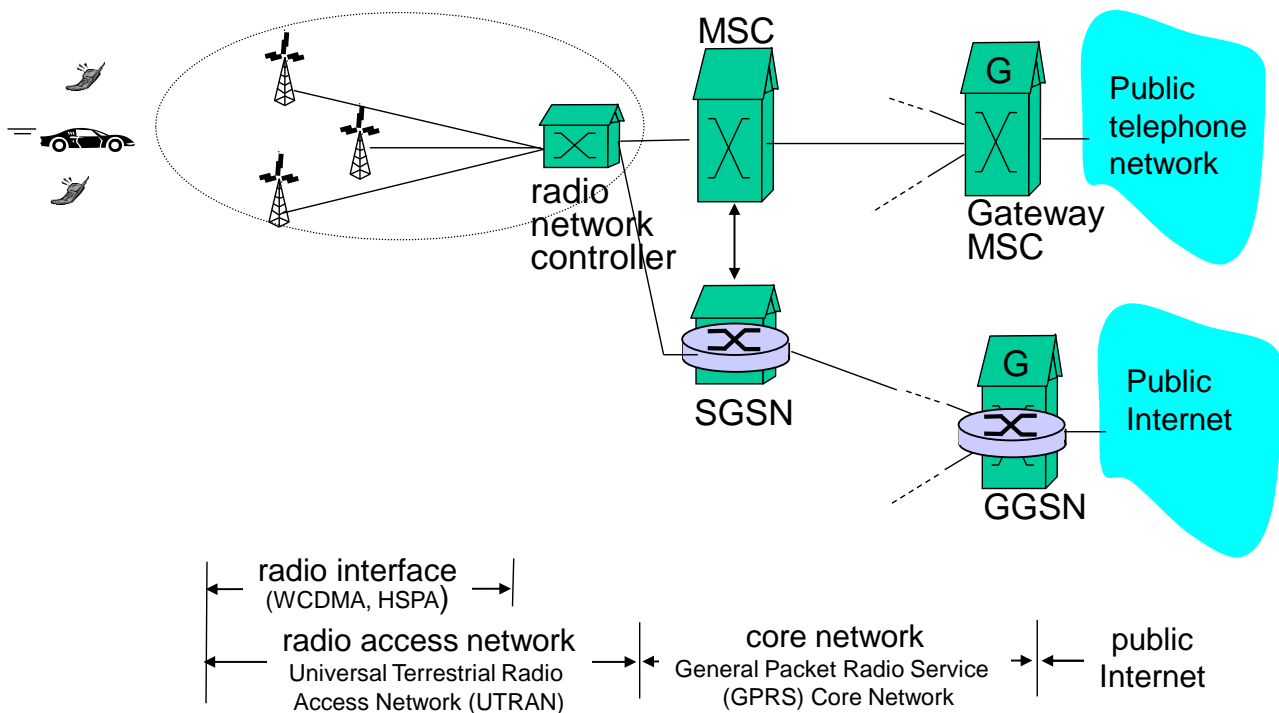
Wireless, Mobile Networks 6-38

# 3G (voice+data) network architecture



Wireless, Mobile Networks 6-39

# 3G (voice+data) network architecture



Wireless, Mobile Networks 6-40

# Chapter 6 outline

## 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)

## Mobility

## 6.5 Principles: addressing and routing to mobile users

## 6.6 Mobile IP

## 6.7 Handling mobility in cellular networks

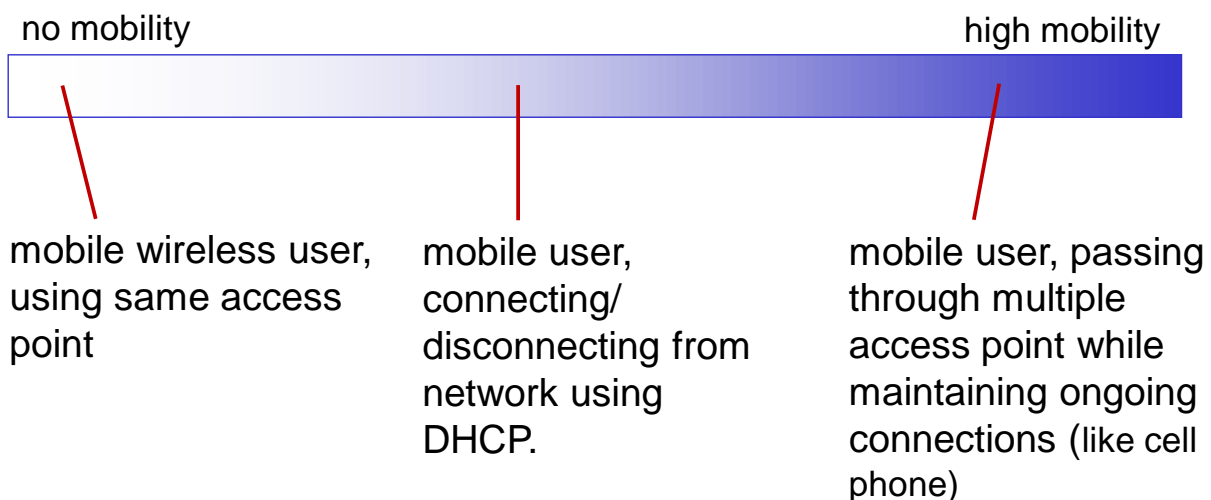
## 6.8 Mobility and higher-layer protocols

## 6.9 Summary

Wireless, Mobile Networks 6-41

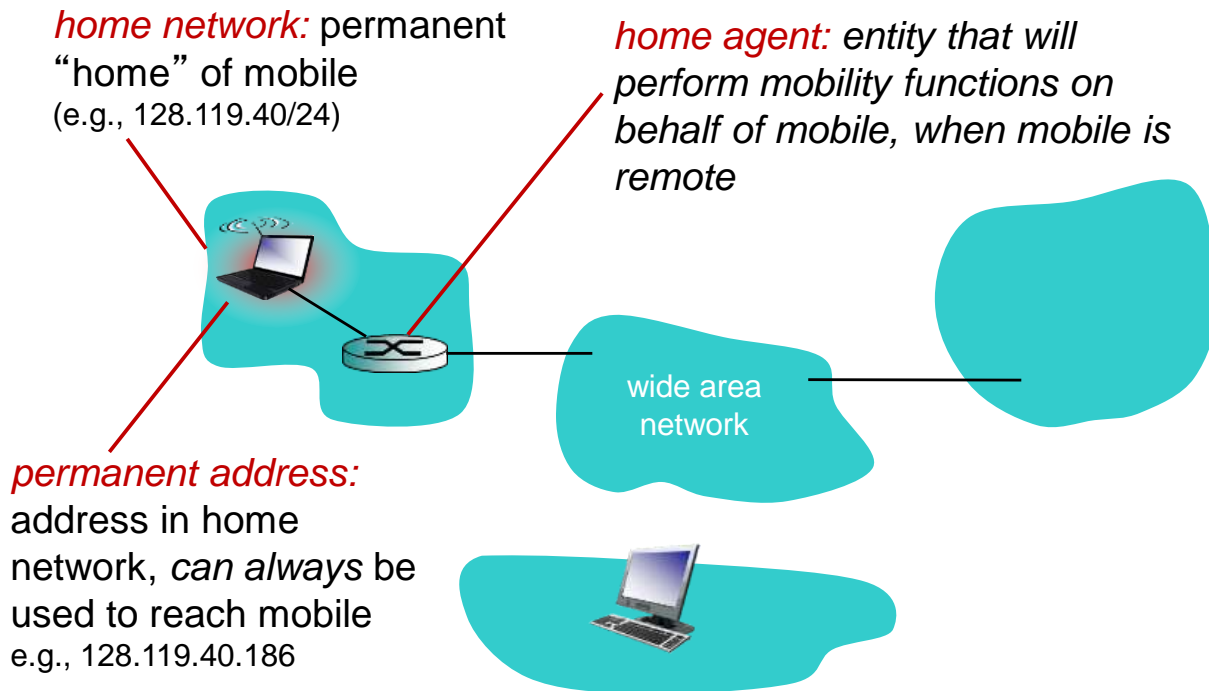
# What is mobility?

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



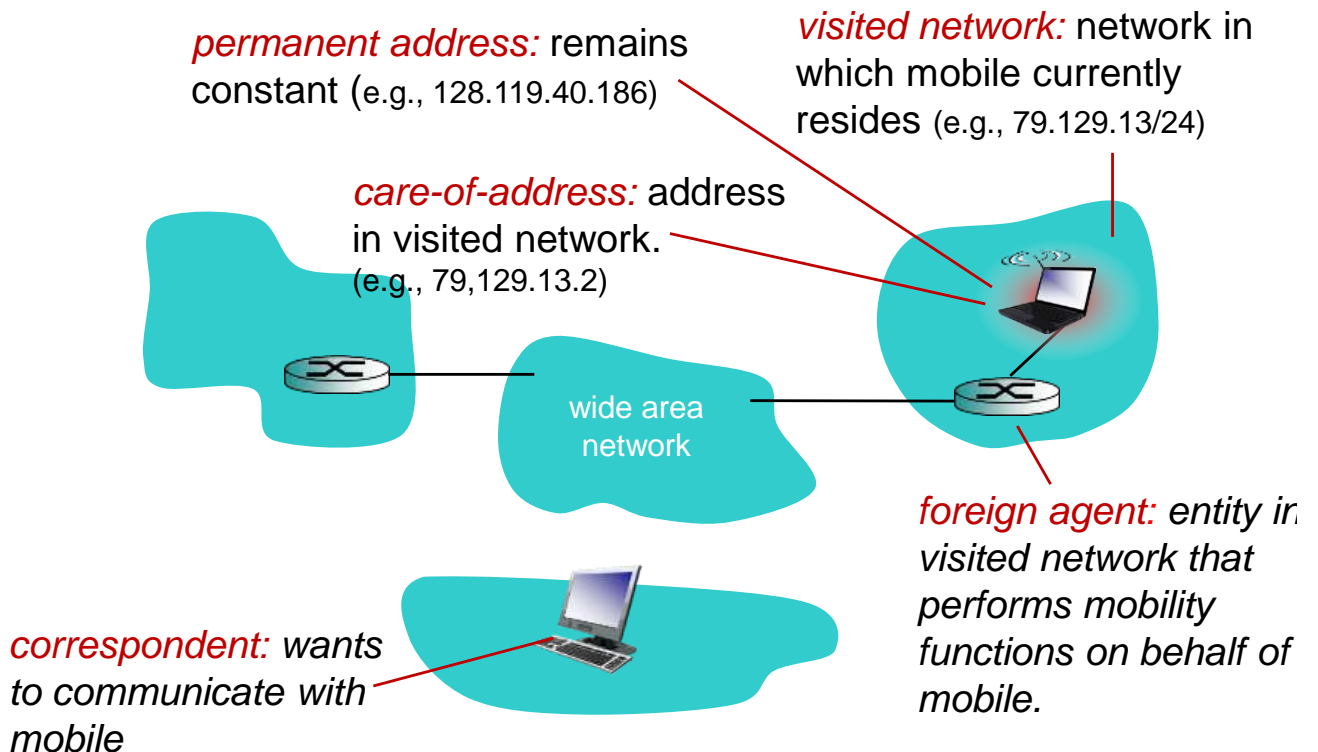
Wireless, Mobile Networks 6-42

# Mobility: vocabulary



Wireless, Mobile Networks 6-43

# Mobility: more vocabulary



Wireless, Mobile Networks 6-44

# 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?



Wireless, Mobile Networks 6-45

## 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

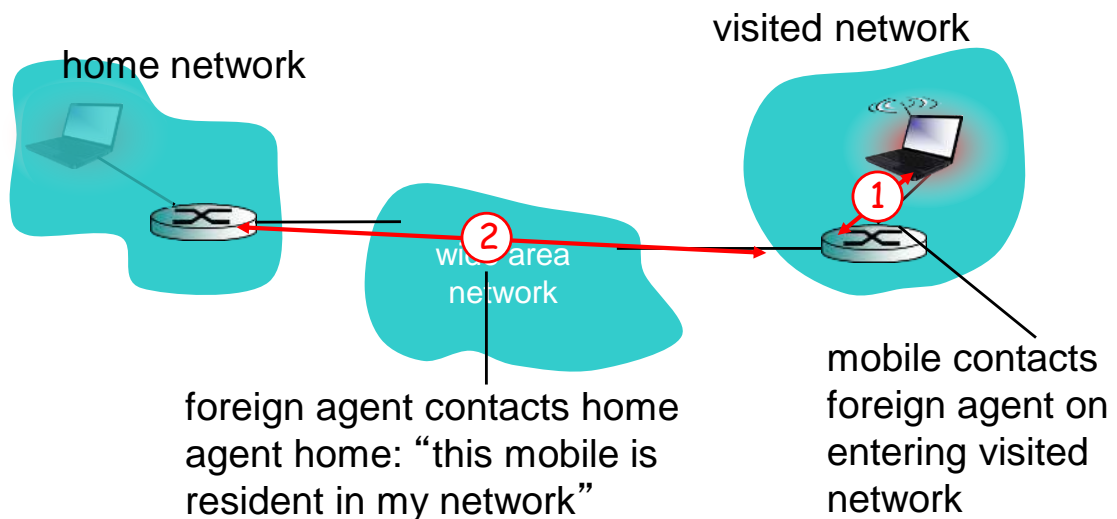
Wireless, Mobile Networks 6-46

# Mobility: approaches

- ❖ *let routing handle it:* route and advertise permanent address of mobile-nodes-in-residence through usual routing table exchange.
  - routing tables to millions of mobiles
  - no changes to each mobile located
- ❖ *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

Wireless, Mobile Networks 6-47

## Mobility: registration



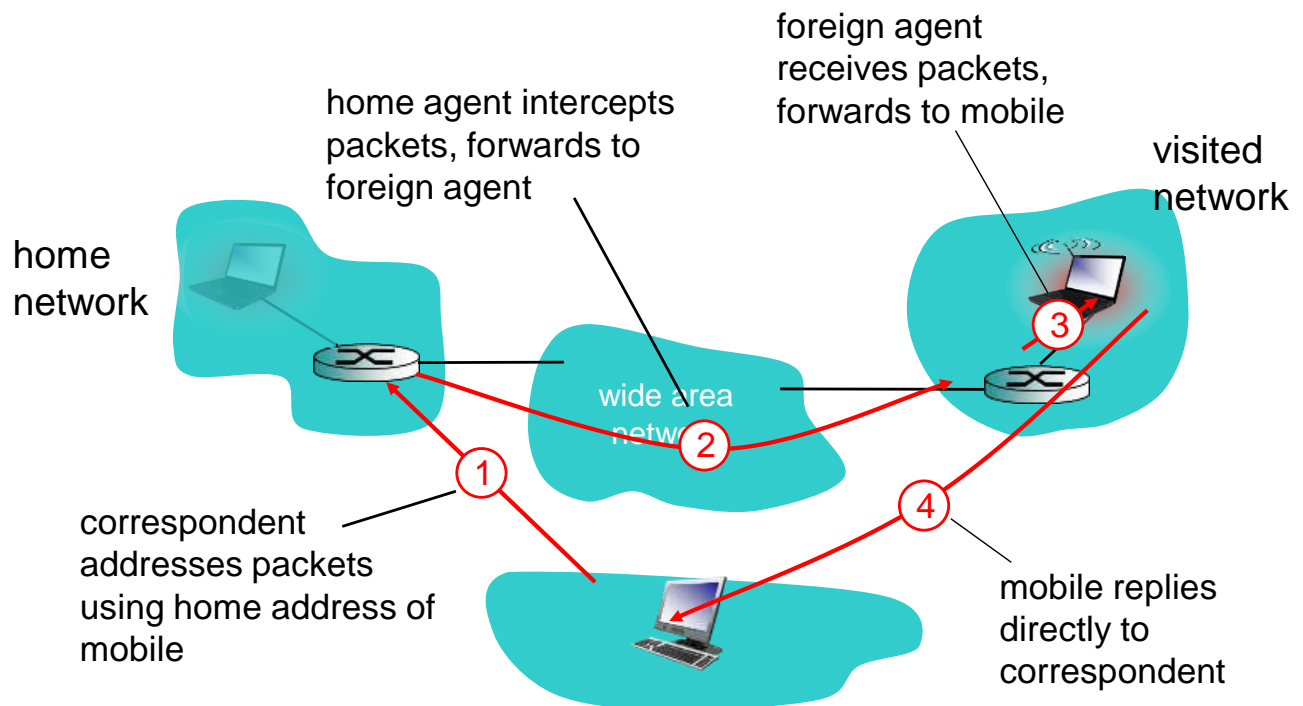
end result:

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

Wireless, Mobile Networks 6-48



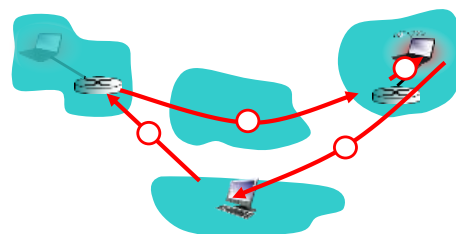
# Mobility via indirect routing



Wireless, Mobile Networks 6-49

## 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



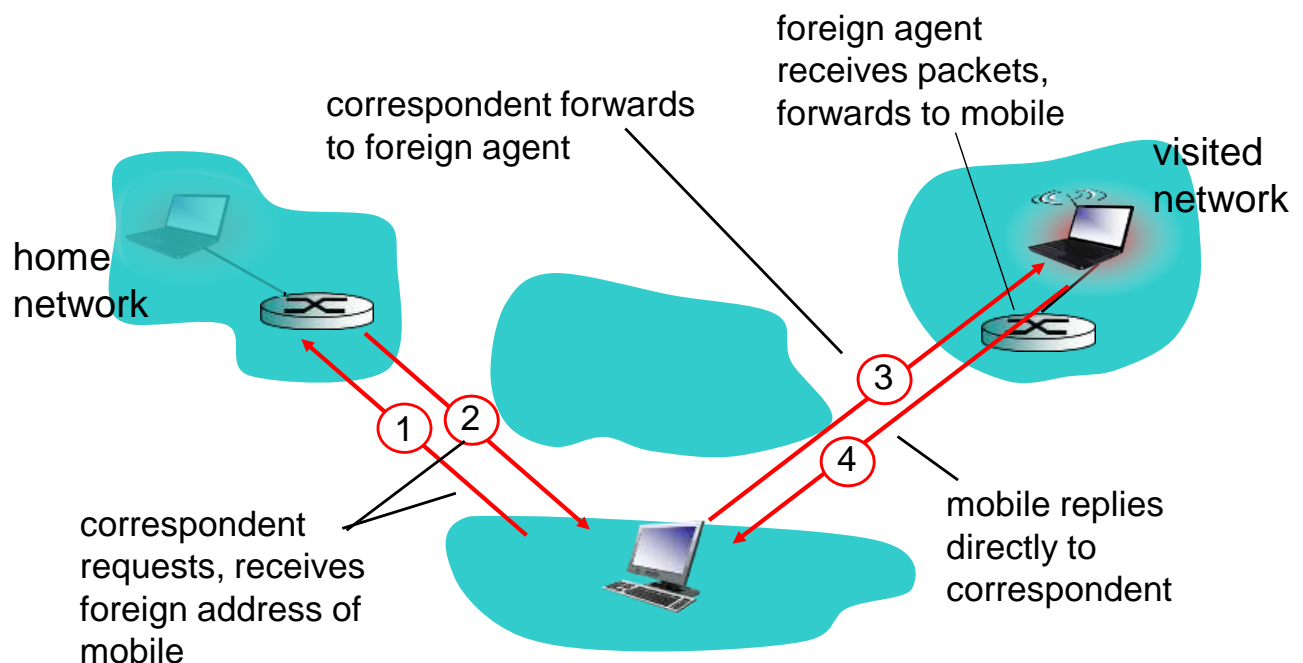
Wireless, Mobile Networks 6-50

# 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!*

Wireless, Mobile Networks 6-51

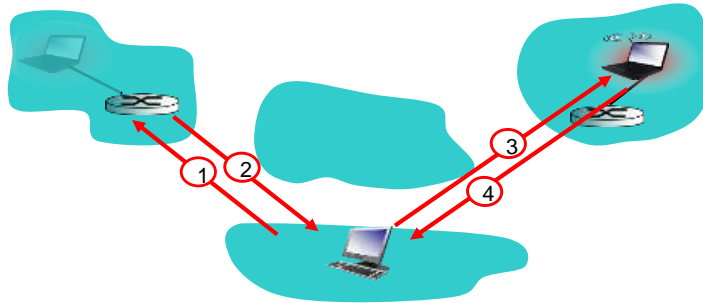
## Mobility via direct routing



Wireless, Mobile Networks 6-52

# Mobility via direct routing: comments

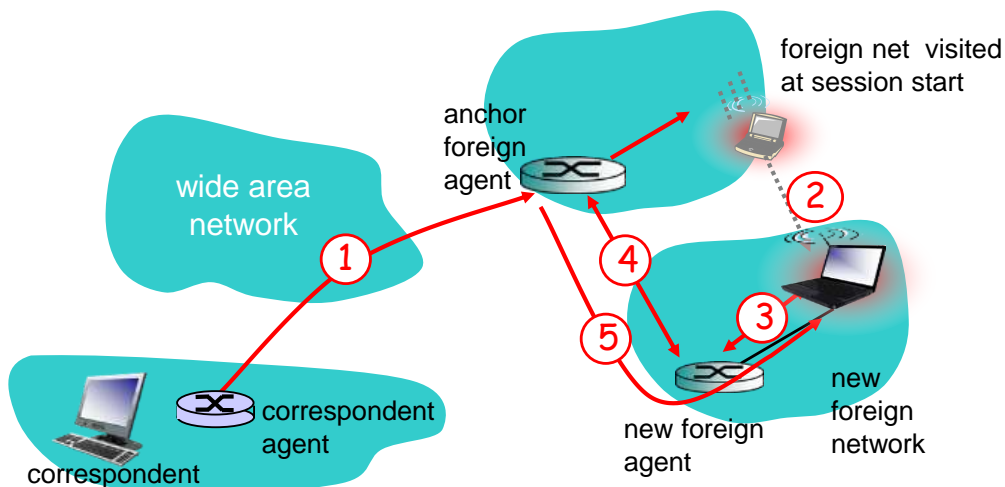
- ❖ overcome triangle routing problem
- ❖ *non-transparent to correspondent*: correspondent must get care-of-address from home agent
  - what if mobile changes visited network?



Wireless, Mobile Networks 6-53

## 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)



Wireless, Mobile Networks 6-54

# Chapter 6 outline

## 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)

## Mobility

## 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

## 6.9 Summary

Wireless, Mobile Networks 6-55

# Mobile IP

## ❖ RFC 3344

## ❖ has many features we’ve seen:

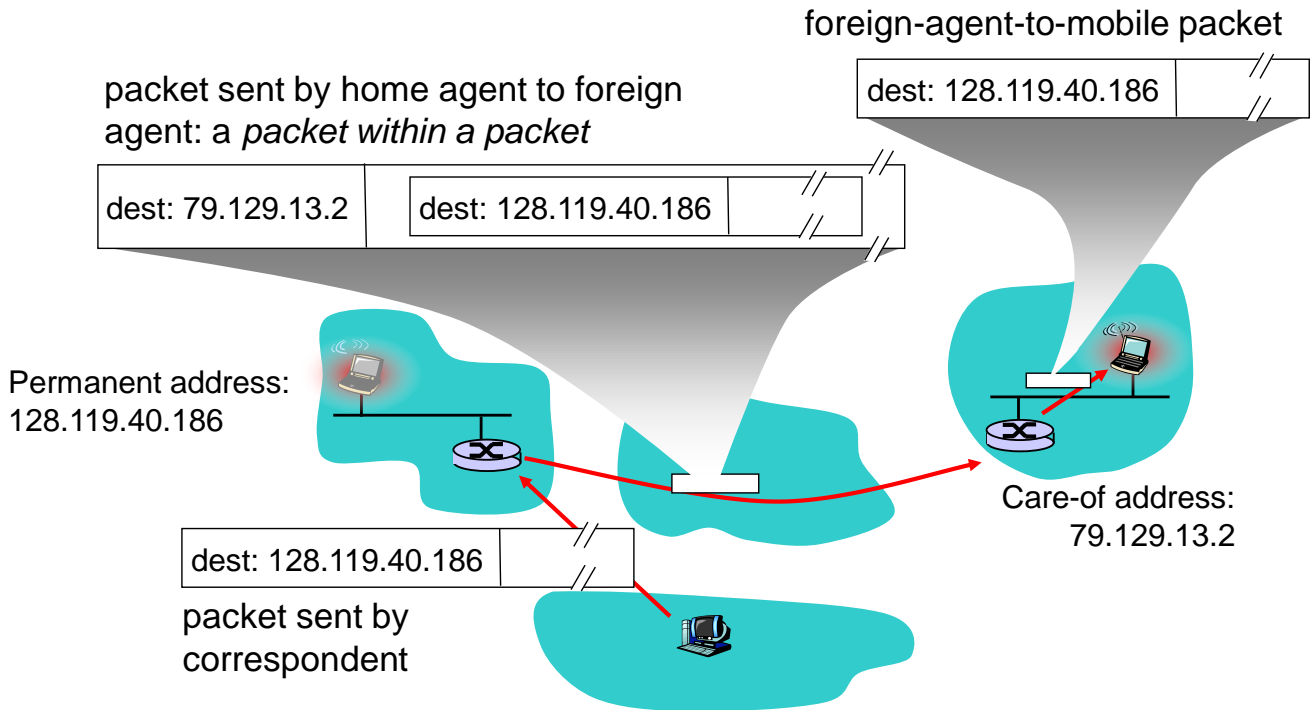
- home agents, foreign agents, foreign-agent registration, care-of-addresses, encapsulation (packet-within-a-packet)

## ❖ three components to standard:

- indirect routing of datagrams
- agent discovery
- registration with home agent

Wireless, Mobile Networks 6-56

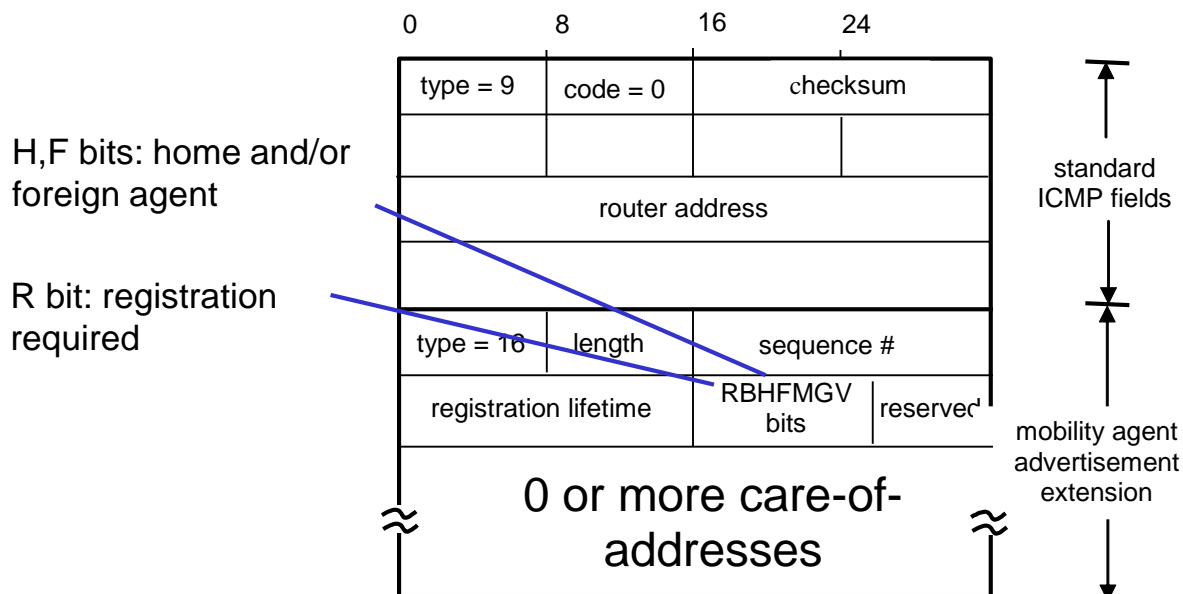
# Mobile IP: indirect routing



Wireless, Mobile Networks 6-57

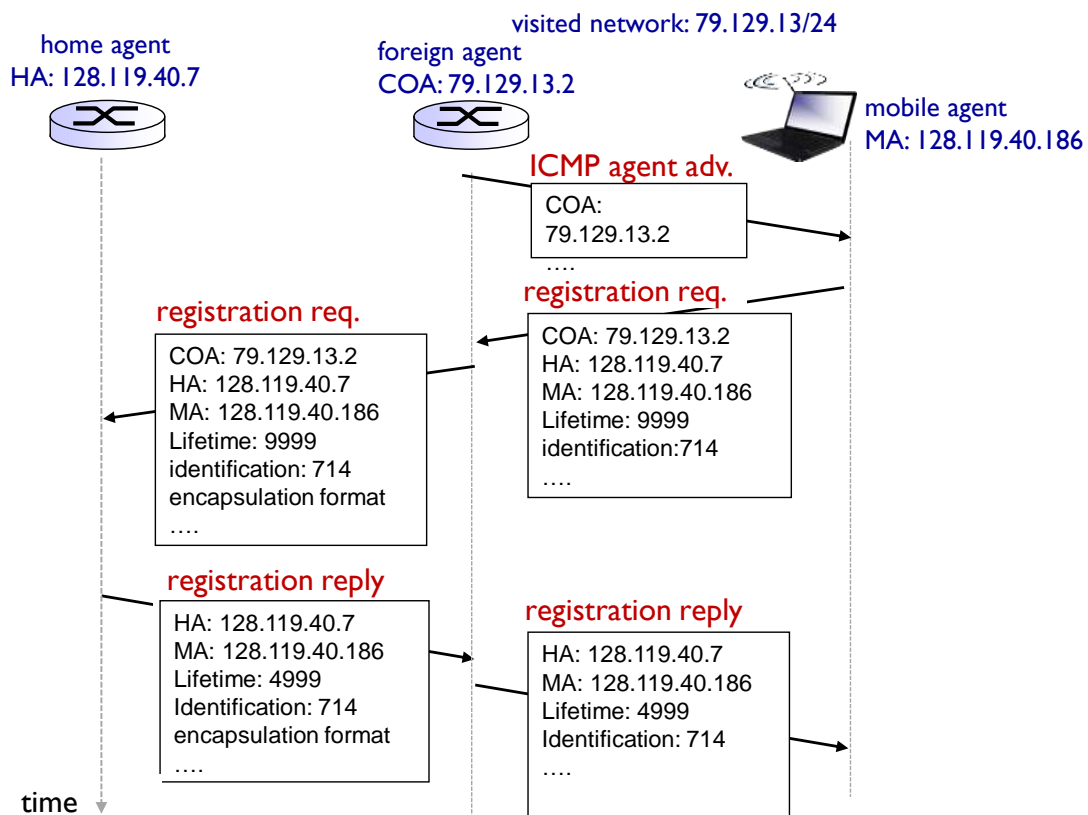
# Mobile IP: agent discovery

- ❖ **agent advertisement:** foreign/home agents advertise service by broadcasting ICMP messages (typefield = 9)



Wireless, Mobile Networks 6-58

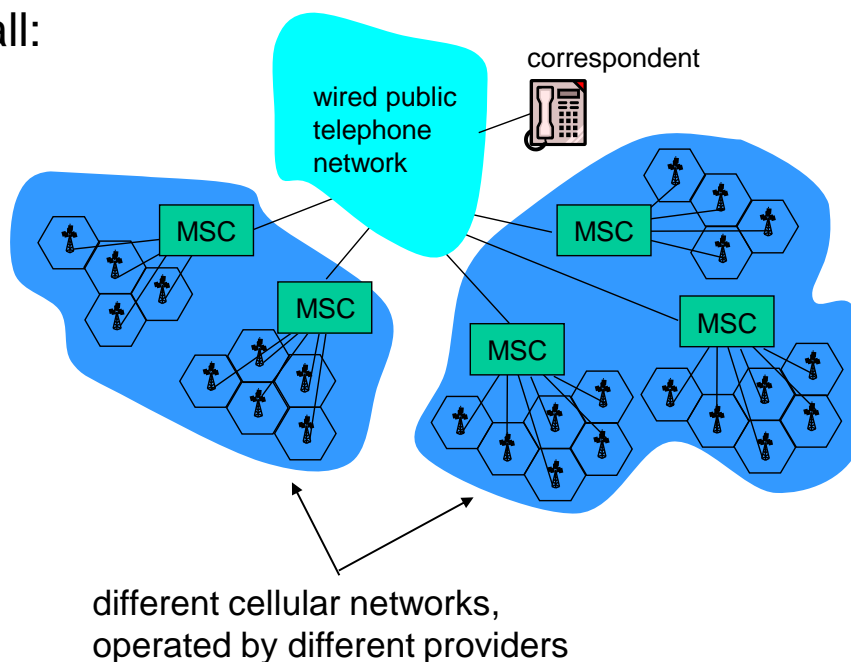
# Mobile IP: registration example



Wireless, Mobile Networks 6-59

## Components of cellular network architecture

recall:



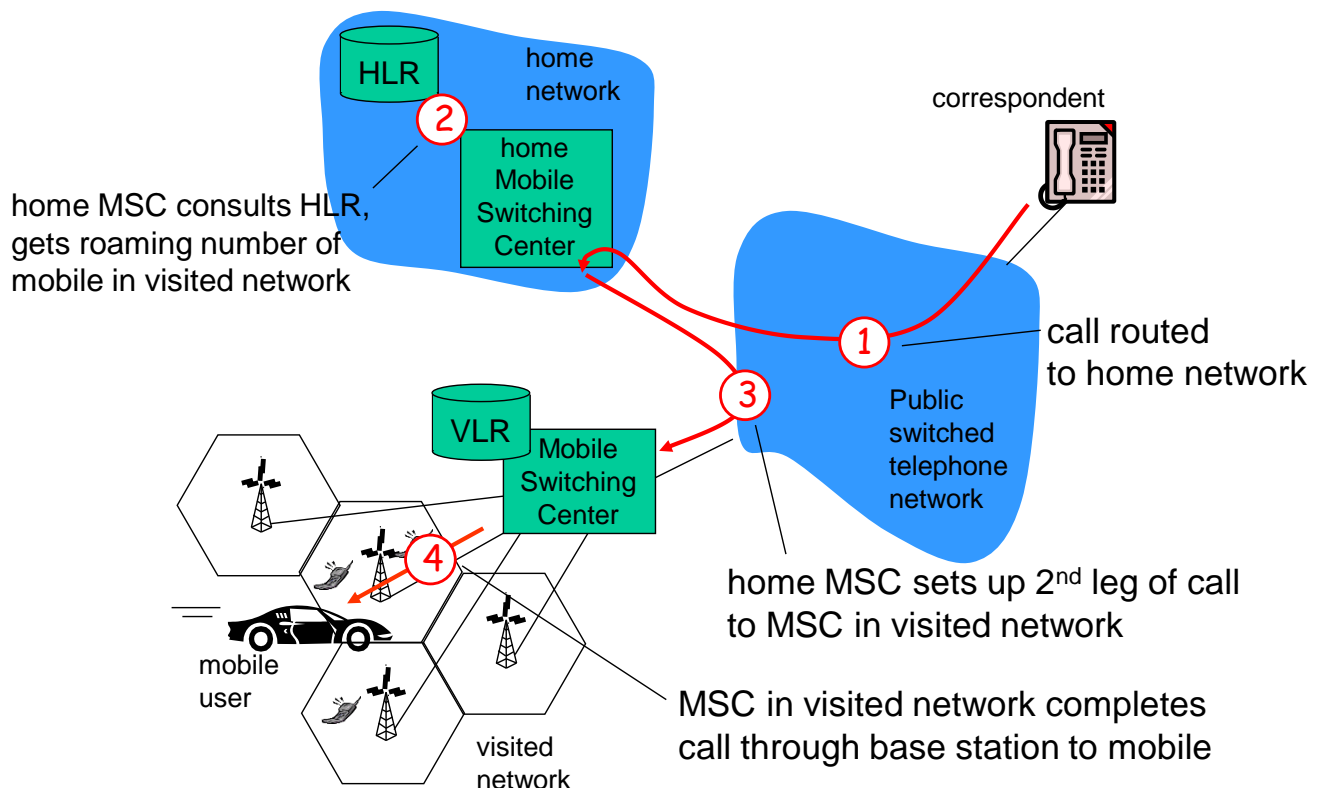
Wireless, Mobile Networks 6-60

# Handling mobility in cellular networks

- ❖ **home network:** network of cellular provider you subscribe to (e.g., Sprint PCS, Verizon)
  - **home location register (HLR):** database in home network containing permanent cell phone #, profile information (services, preferences, billing), information about current location (could be in another network)
- ❖ **visited network:** network in which mobile currently resides
  - **visitor location register (VLR):** database with entry for each user currently in network
  - could be home network

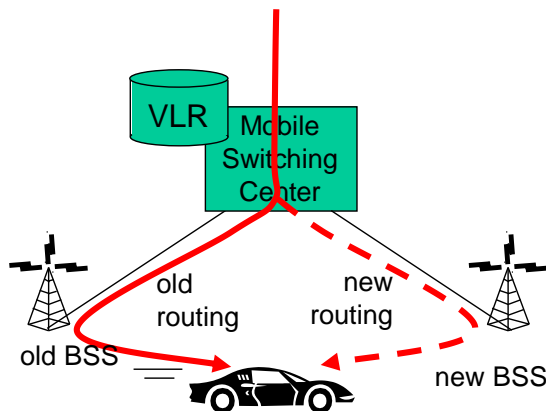
Wireless, Mobile Networks 6-61

## GSM: indirect routing to mobile



Wireless, Mobile Networks 6-62

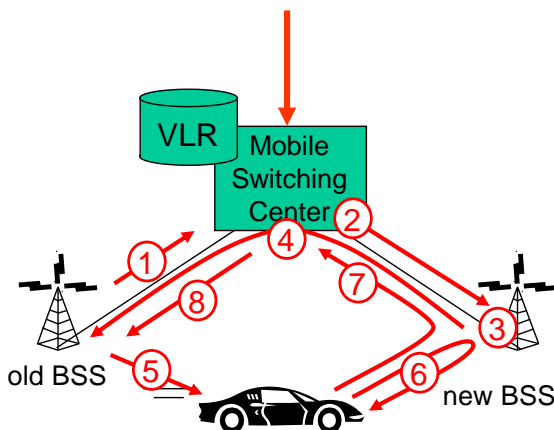
# GSM: handoff with common MSC



- ❖ *handoff goal*: route call via new base station (without interruption)
- ❖ reasons for handoff:
  - stronger signal to/from new BSS (continuing connectivity, less battery drain)
  - load balance: free up channel in current BSS
  - GSM doesn't mandate why to perform handoff (policy), only how (mechanism)
- ❖ handoff initiated by old BSS

Wireless, Mobile Networks 6-63

# GSM: handoff with common MSC

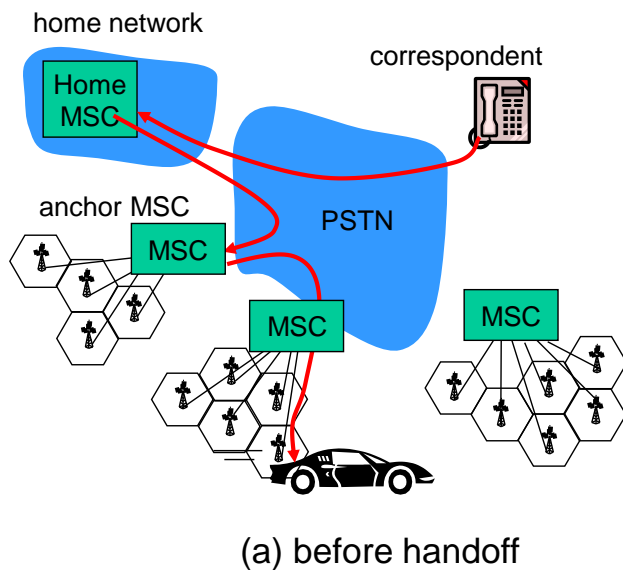


1. old BSS informs MSC of impending handoff, provides list of 1+ new BSSs
2. MSC sets up path (allocates resources) to new BSS
3. new BSS allocates radio channel for use by mobile
4. new BSS signals MSC, old BSS: ready
5. old BSS tells mobile: perform handoff to new BSS
6. mobile, new BSS signal to activate new channel
7. mobile signals via new BSS to MSC: handoff complete. MSC reroutes call
8. MSC-old-BSS resources released

Wireless, Mobile Networks 6-64



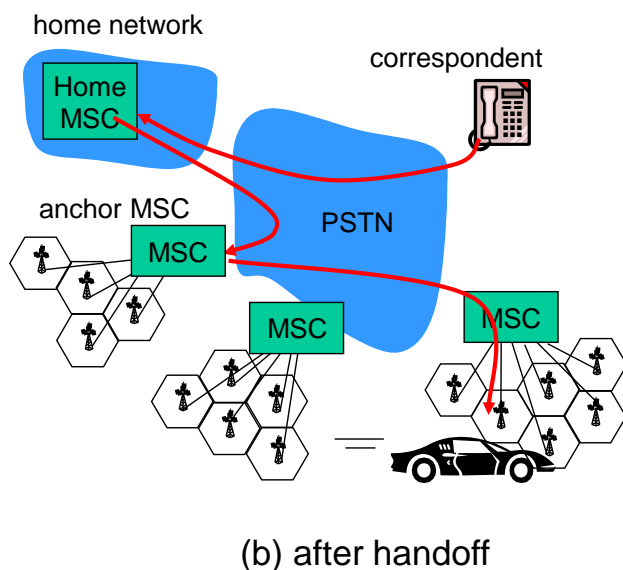
# GSM: handoff between MSCs



- ❖ *anchor MSC*: first MSC visited during call
  - call remains routed through anchor MSC
- ❖ new MSCs add on to end of MSC chain as mobile moves to new MSC
- ❖ optional path minimization step to shorten multi-MSC chain

Wireless, Mobile Networks 6-65

# GSM: handoff between MSCs



- ❖ *anchor MSC*: first MSC visited during call
  - call remains routed through anchor MSC
- ❖ new MSCs add on to end of MSC chain as mobile moves to new MSC
- ❖ optional path minimization step to shorten multi-MSC chain

Wireless, Mobile Networks 6-66

# Mobility: GSM versus Mobile IP

GSM element	Comment on GSM element	Mobile IP element
Home system	Network to which mobile user's permanent phone number belongs	Home network
Gateway Mobile Switching Center, or "home MSC". Home Location Register (HLR)	Home MSC: point of contact to obtain routable address of mobile user. HLR: database in home system containing permanent phone number, profile information, current location of mobile user, subscription information	Home agent
Visited System	Network other than home system where mobile user is currently residing	Visited network
Visited Mobile services Switching Center. Visitor Location Record (VLR)	Visited MSC: responsible for setting up calls to/from mobile nodes in cells associated with MSC. VLR: temporary database entry in visited system, containing subscription information for each visiting mobile user	Foreign agent
Mobile Station Roaming Number (MSRN), or "roaming number"	Routable address for telephone call segment between home MSC and visited MSC, visible to neither the mobile nor the correspondent.	Care-of-address

Wireless, Mobile Networks 6-67

## Wireless, mobility: impact on higher layer protocols

- ❖ logically, impact *should* be minimal ...
  - best effort service model remains unchanged
  - TCP and UDP can (and do) run over wireless, mobile
- ❖ ... but performance-wise:
  - packet loss/delay due to bit-errors (discarded packets, delays for link-layer retransmissions), and handoff
  - TCP interprets loss as congestion, will decrease congestion window un-necessarily
  - delay impairments for real-time traffic
  - limited bandwidth of wireless links

# Chapter 6 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., GSM, 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
- ❖ impact on higher-layer protocols