



# Chapter 7: Wireless and Mobile Networks

## Background:

- ❑ # wireless (mobile) phone subscribers now exceeds # wired phone subscribers!
- ❑ computer nets: laptops, palmtops, PDAs, Internet-enabled phone promise anytime untethered Internet access
- ❑ two important (but different) challenges
  - communication over wireless link
  - handling 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., GSM)

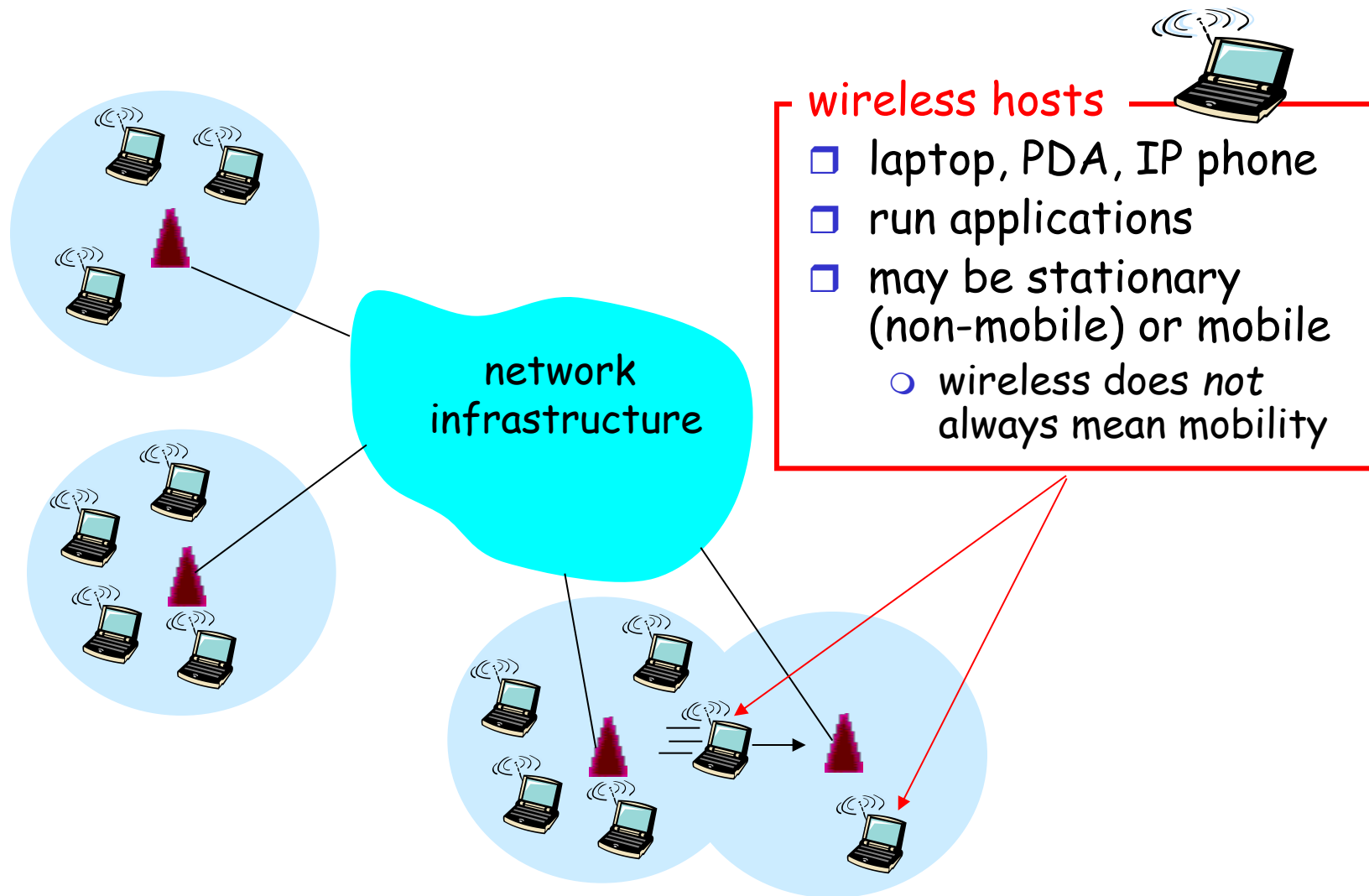
### Mobility

- ❑ 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

### 7.9 Summary

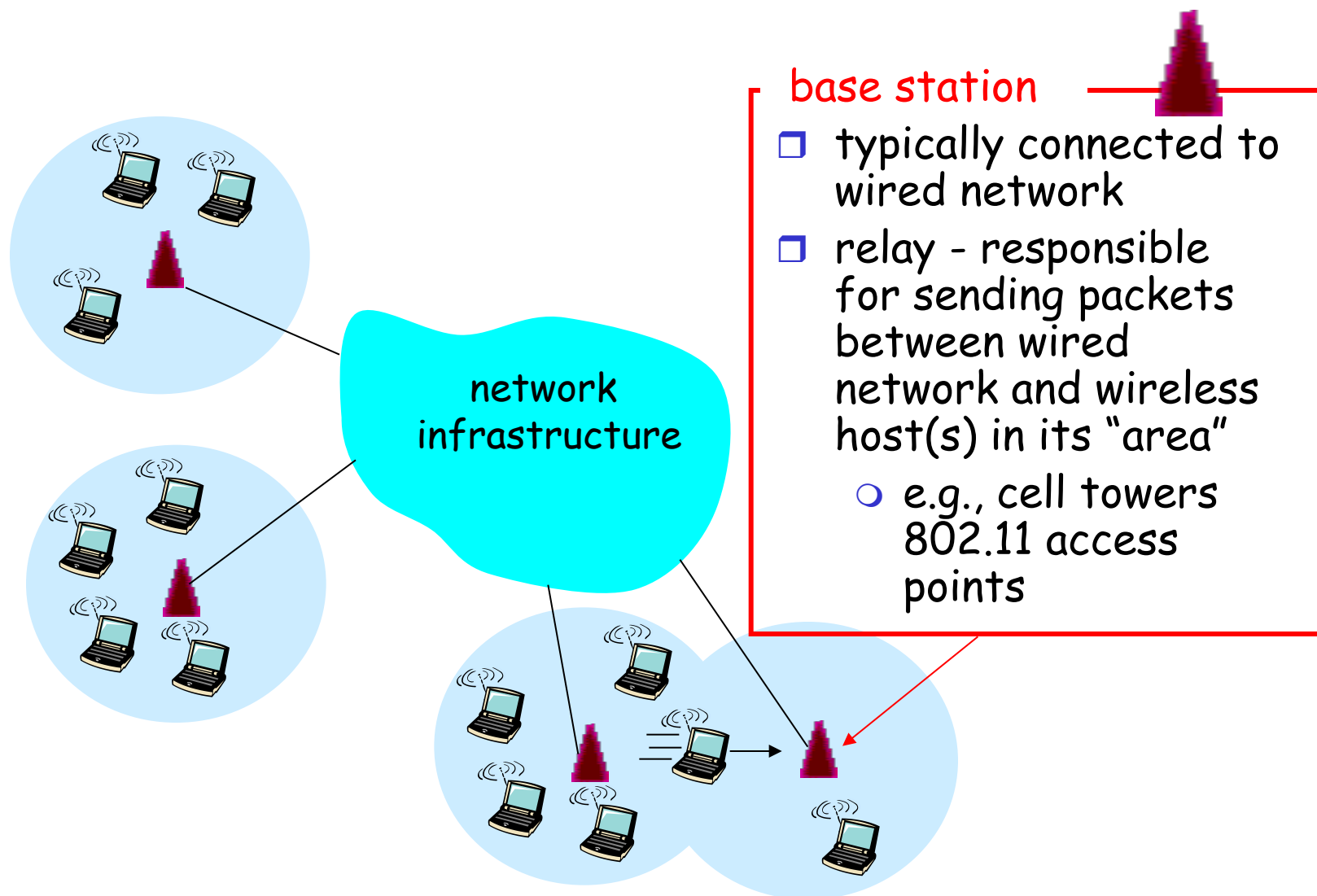


# Elements of a wireless network



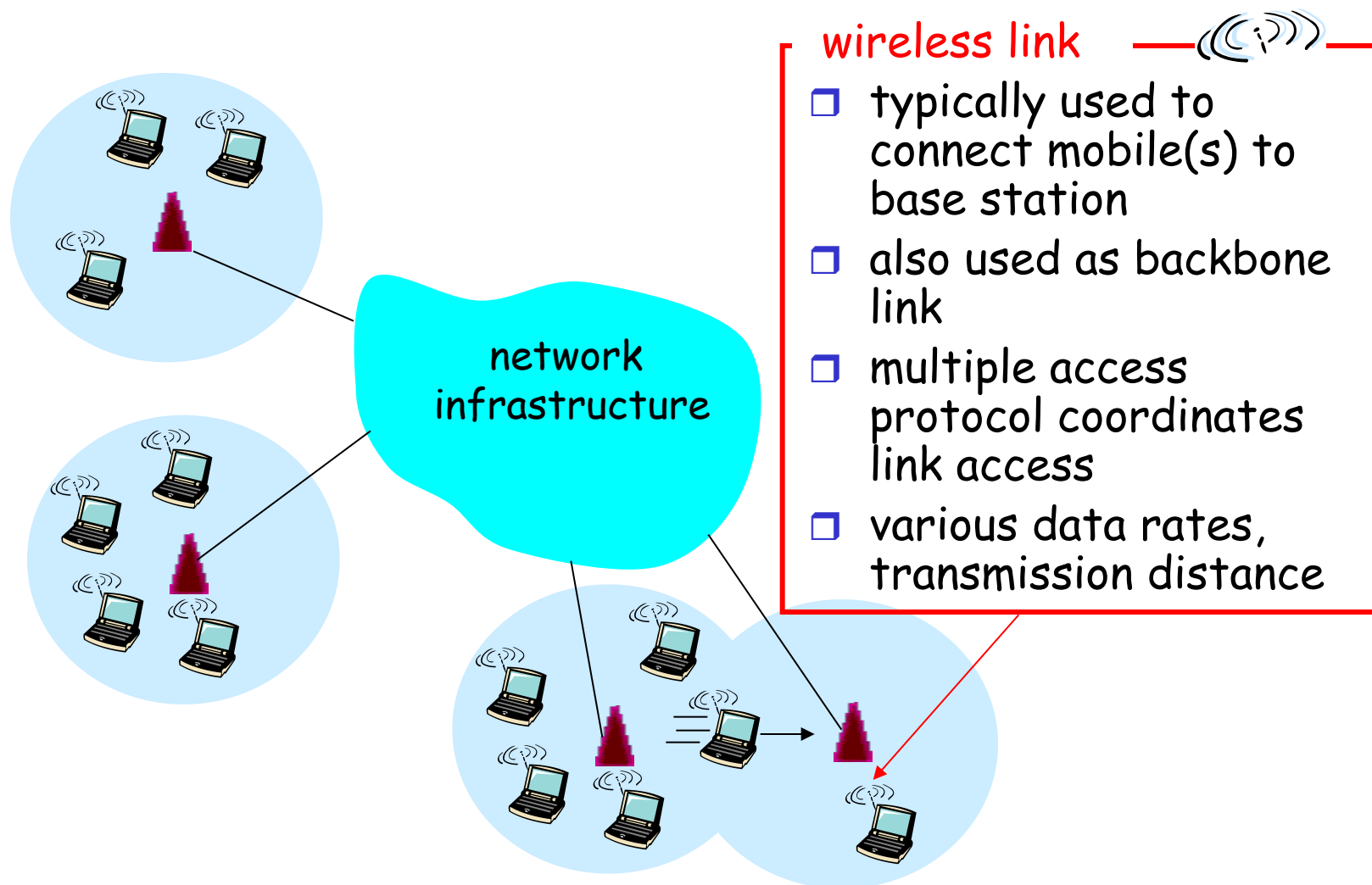


# Elements of a wireless network



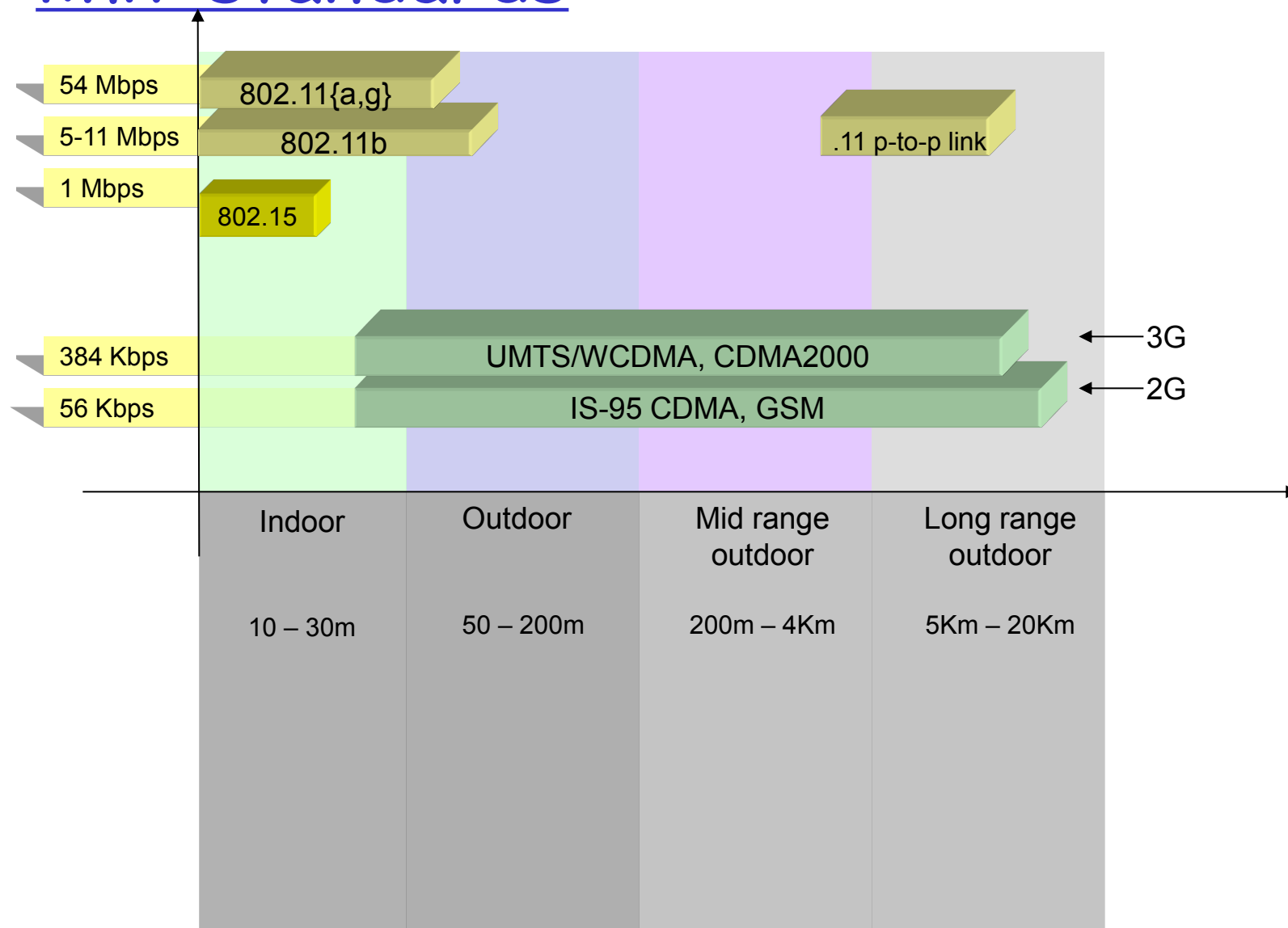


# Elements of a wireless network



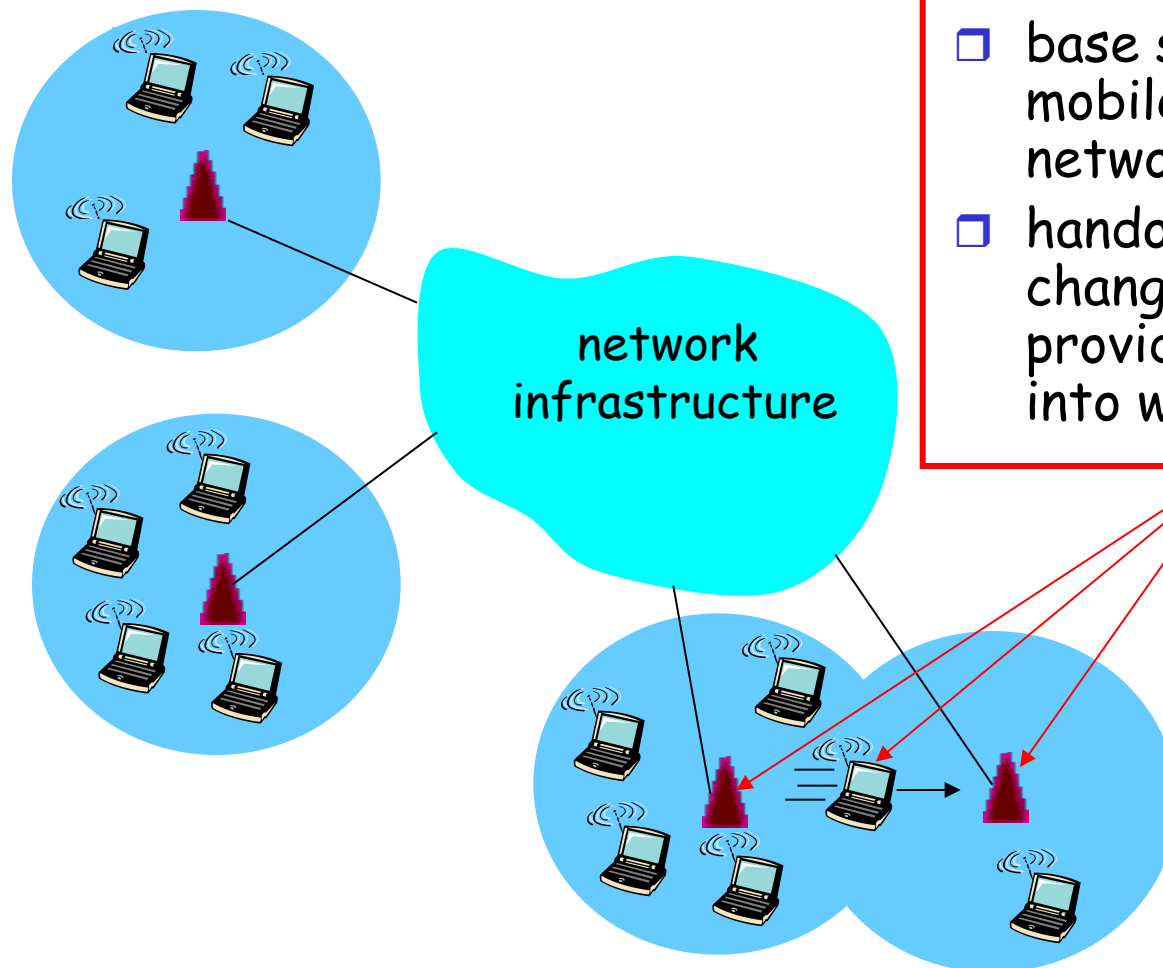


# Characteristics of selected wireless link standards





# Modes of wireless networks

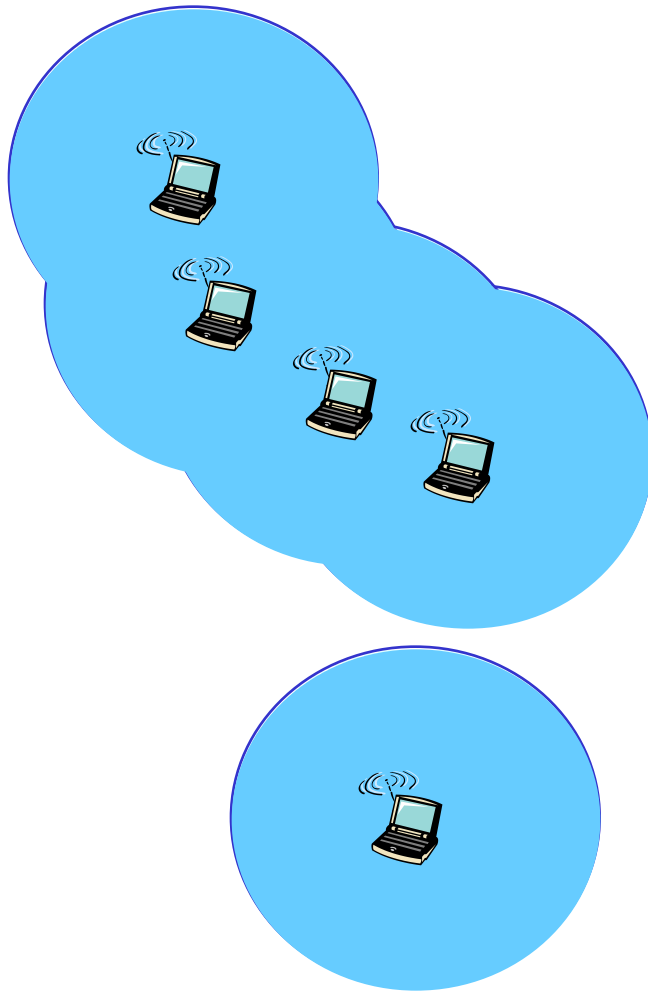


## infrastructure mode

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



# Modes of wireless networks



## 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 Link Characteristics

Differences from wired link ....

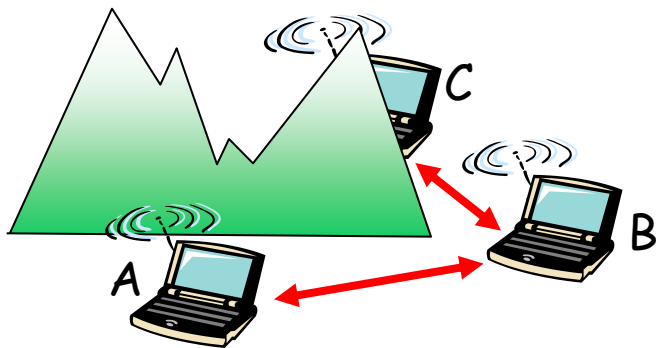
- **decreased signal strength:** radio signal attenuates as it propagates through matter (path loss)
- **interference from other sources:** standardized wireless network frequencies (e.g., 2.4 GHz) shared by other devices (e.g., phone); devices (motors) interfere as well
- **multipath propagation:**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



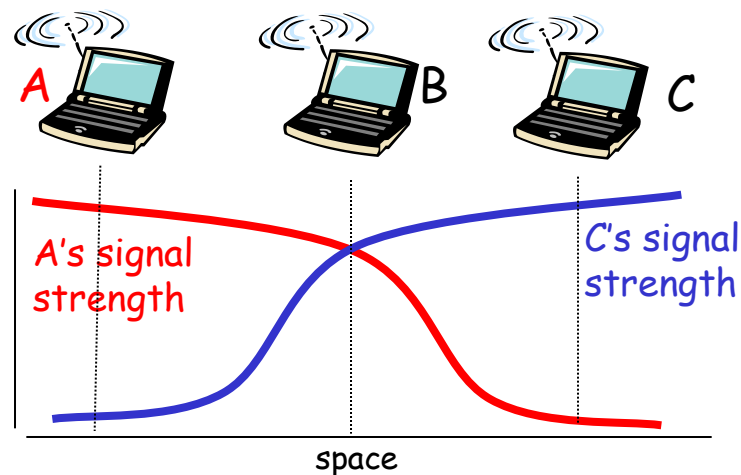
# Wireless network characteristics

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 fading:

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

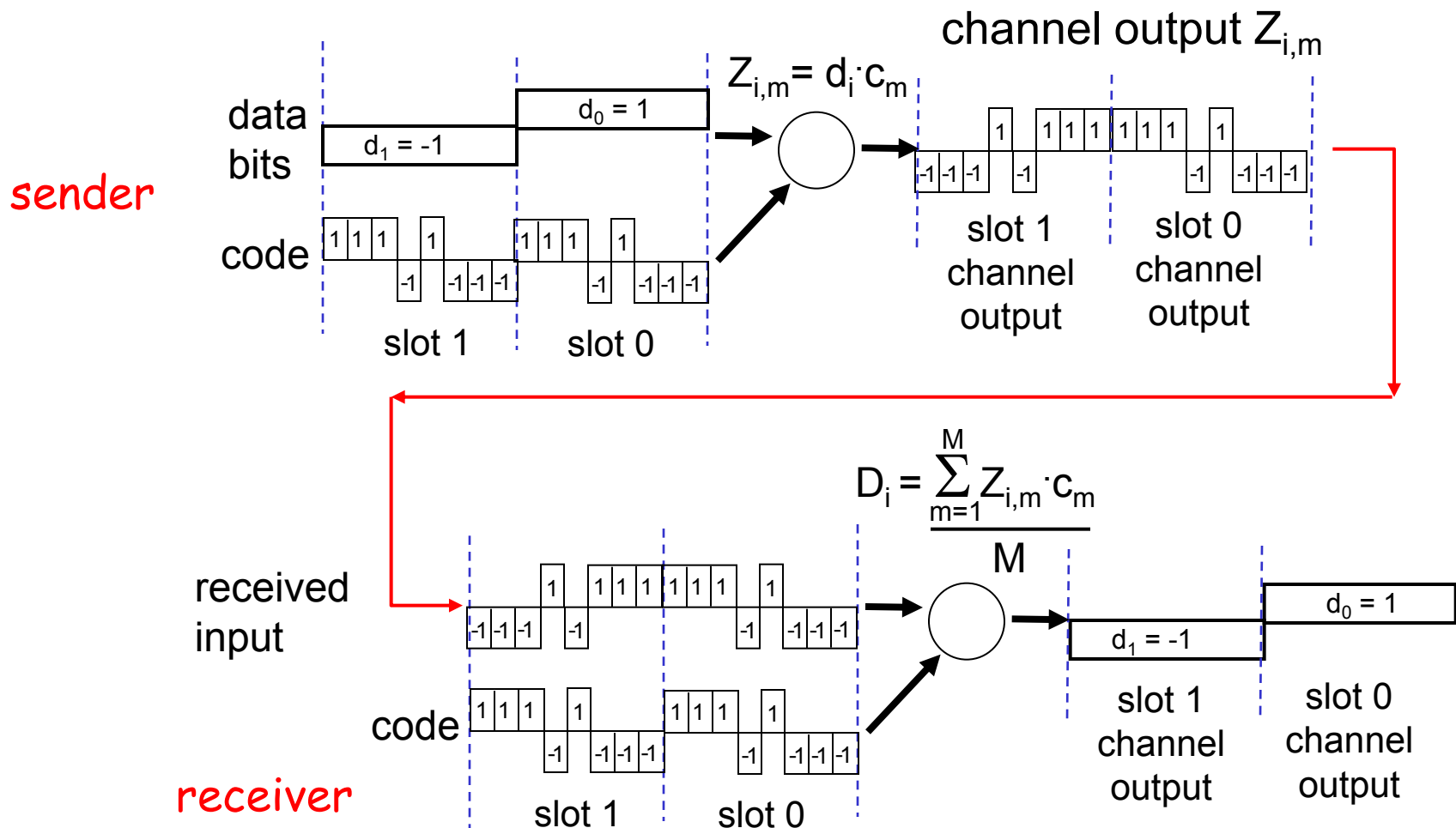


# Code Division Multiple Access (CDMA)

- ❑ used in several wireless broadcast channels (cellular, satellite, etc) standards
- ❑ 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
- ❑ **encoded signal** = (original data) X (chipping sequence)
- ❑ **decoding**: inner-product of encoded signal and chipping sequence
- ❑ allows multiple users to "coexist" and transmit simultaneously with minimal interference (if codes are **orthogonal**)



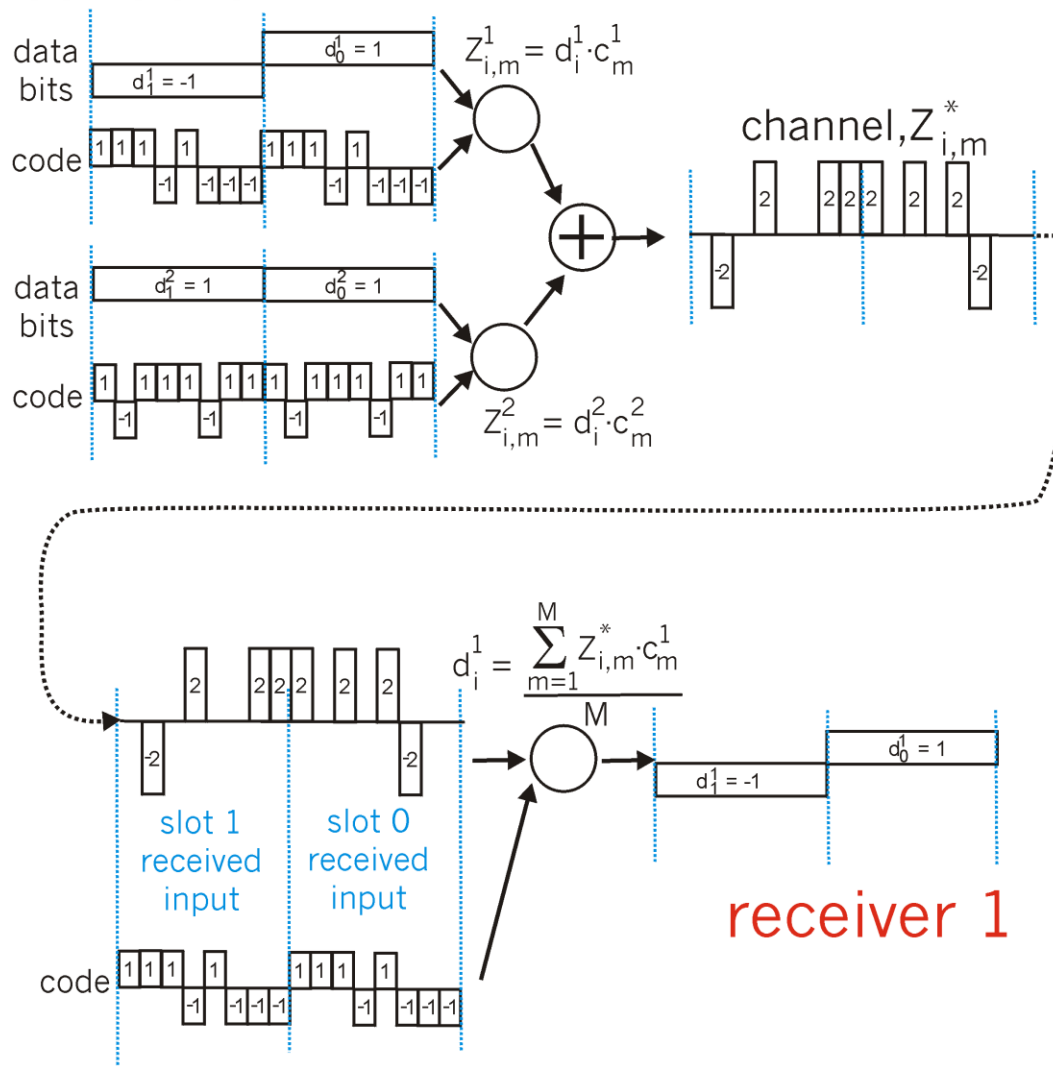
# CDMA Encode/Decode





# CDMA: two-sender interference

senders





# 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., GSM)

### 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

## 7.9 Summary



# IEEE 802.11 Wireless LAN

## ❑ 802.11b

- 2.4-5 GHz unlicensed radio spectrum
- up to 11 Mbps
- direct sequence spread spectrum (DSSS) in physical layer
  - all hosts use same chipping code
- widely deployed, using base stations

## ❑ 802.11a

- 5-6 GHz range
- up to 54 Mbps

## ❑ 802.11g

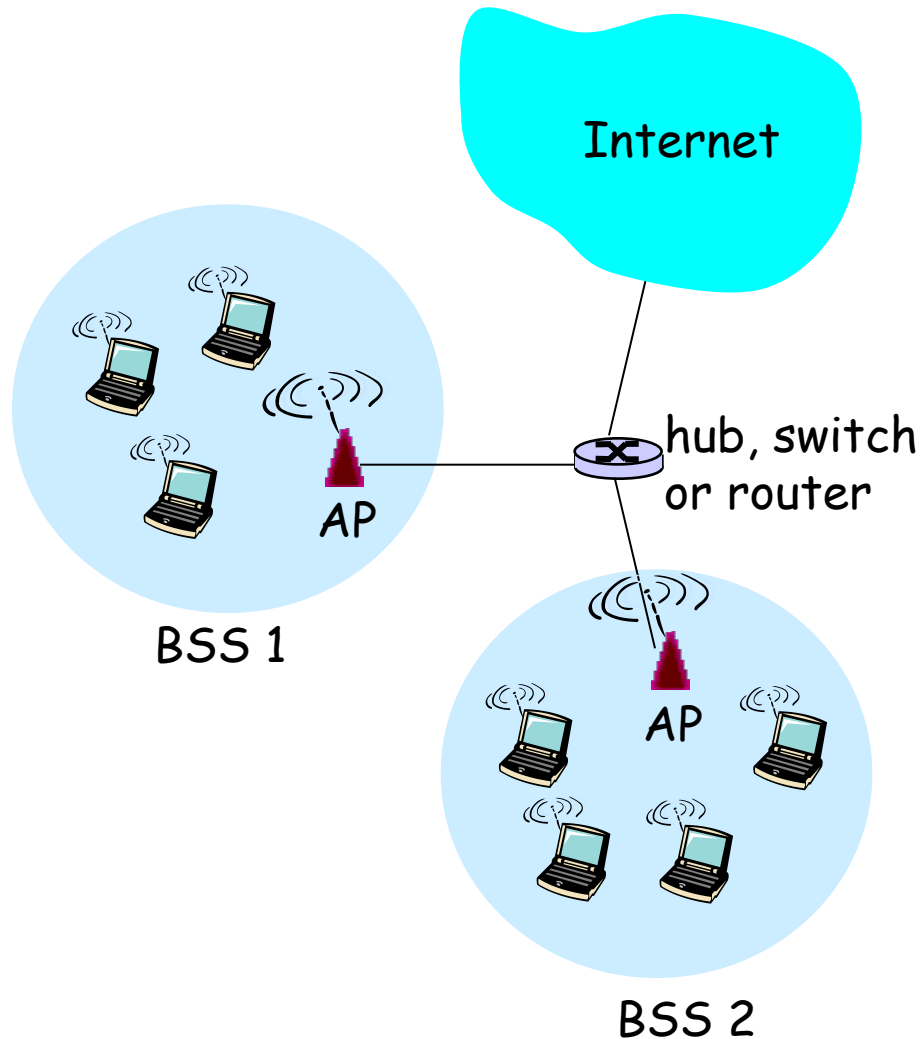
- 2.4-5 GHz range
- up to 54 Mbps

## ❑ 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





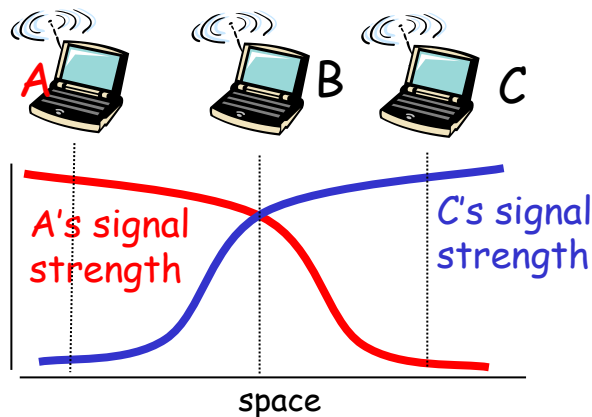
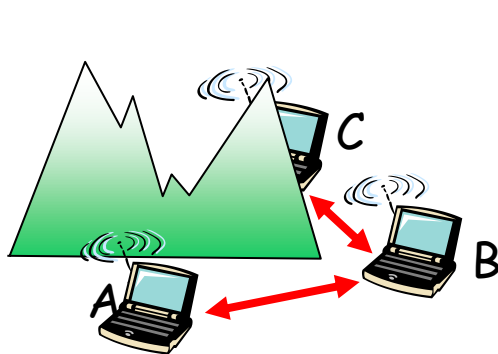
# 802.11: Channels, association

- ❑ 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
  - will typically run DHCP to get IP address in AP's subnet



# 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)





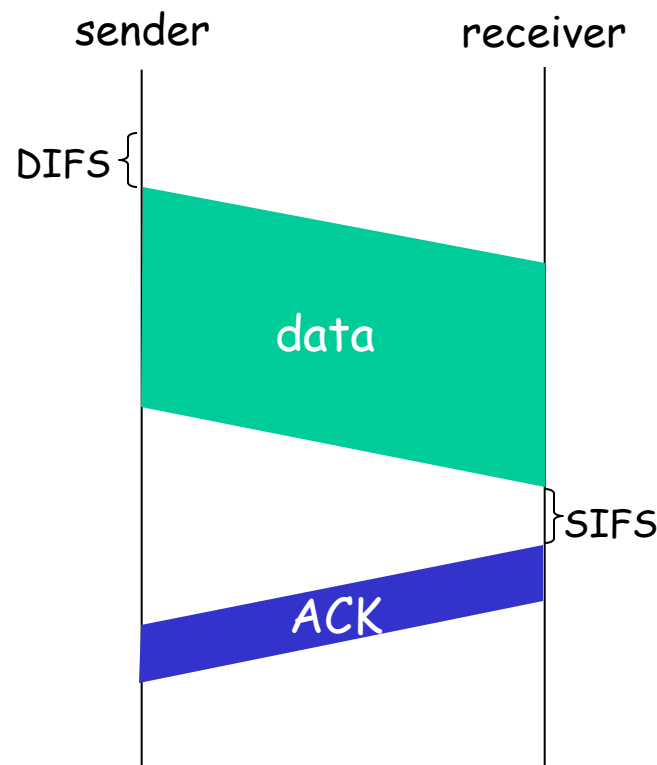
# IEEE 802.11 MAC Protocol: CSMA/CA

## 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

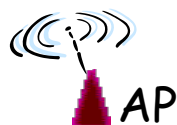
Avoid data frame collisions completely  
using small reservation packets!



# Collision Avoidance: RTS-CTS exchange



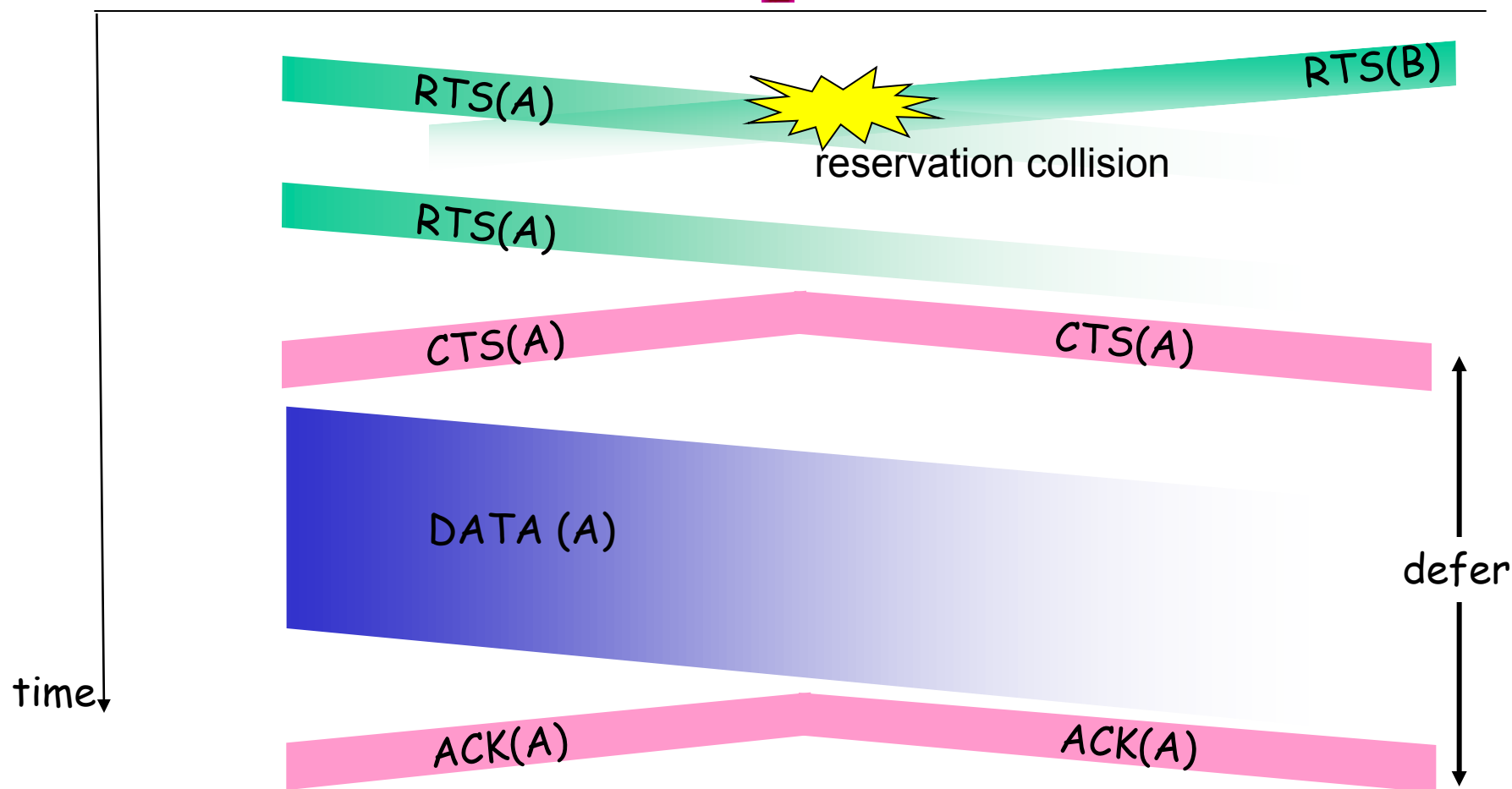
A



AP

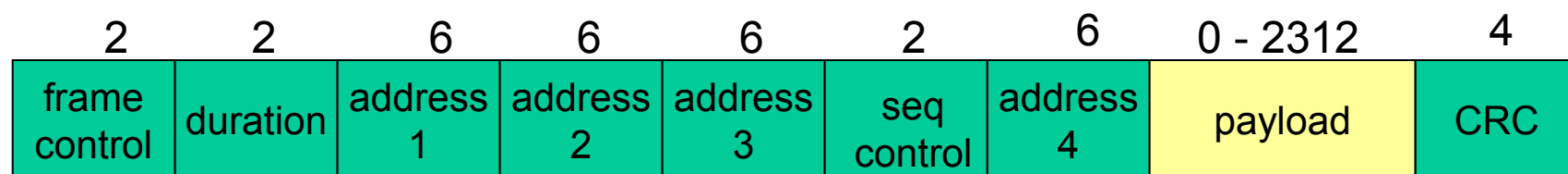


B





# 802.11 frame: addressing



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

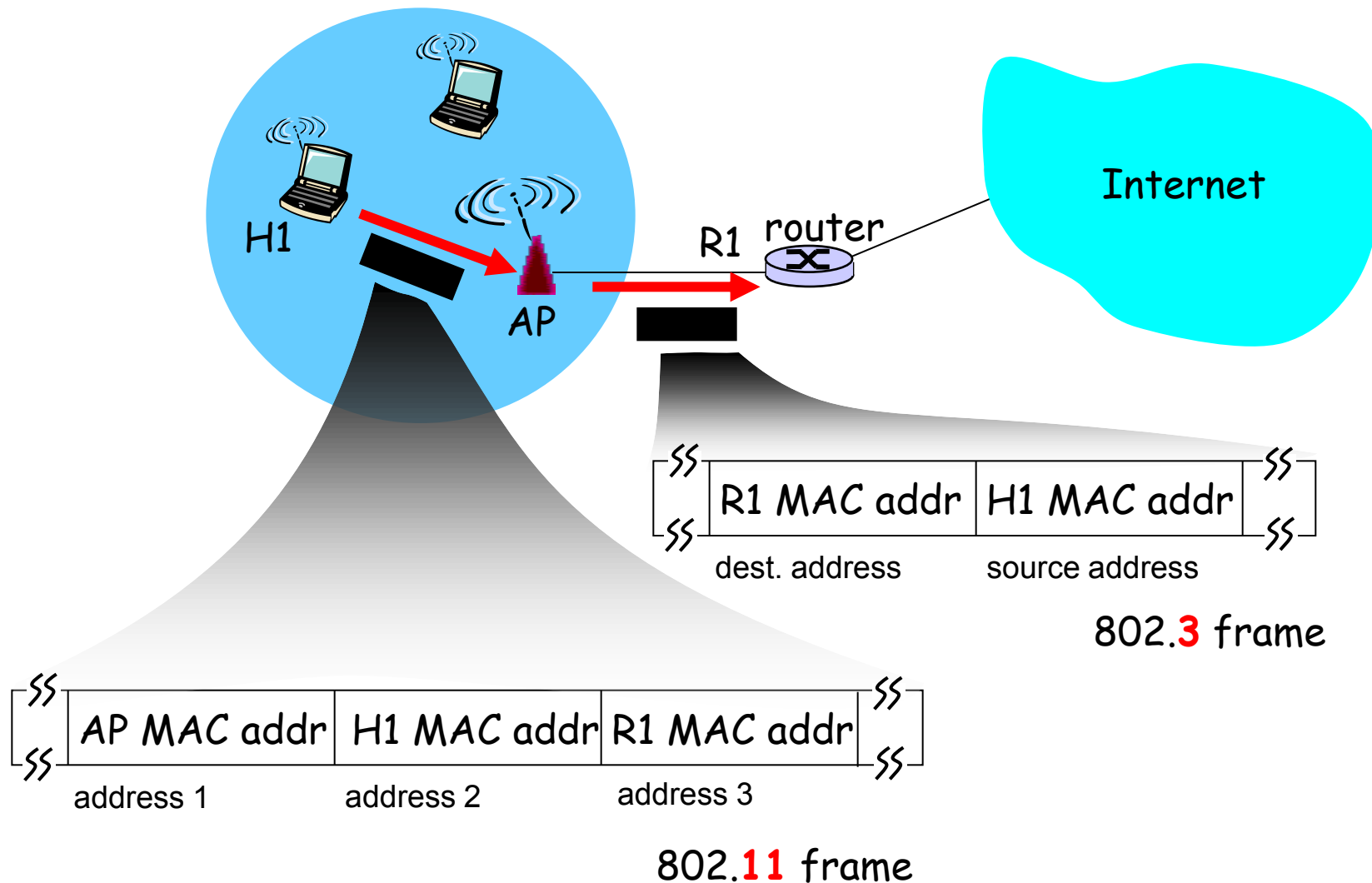
**Address 2:** MAC address of wireless host or AP transmitting this frame

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

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

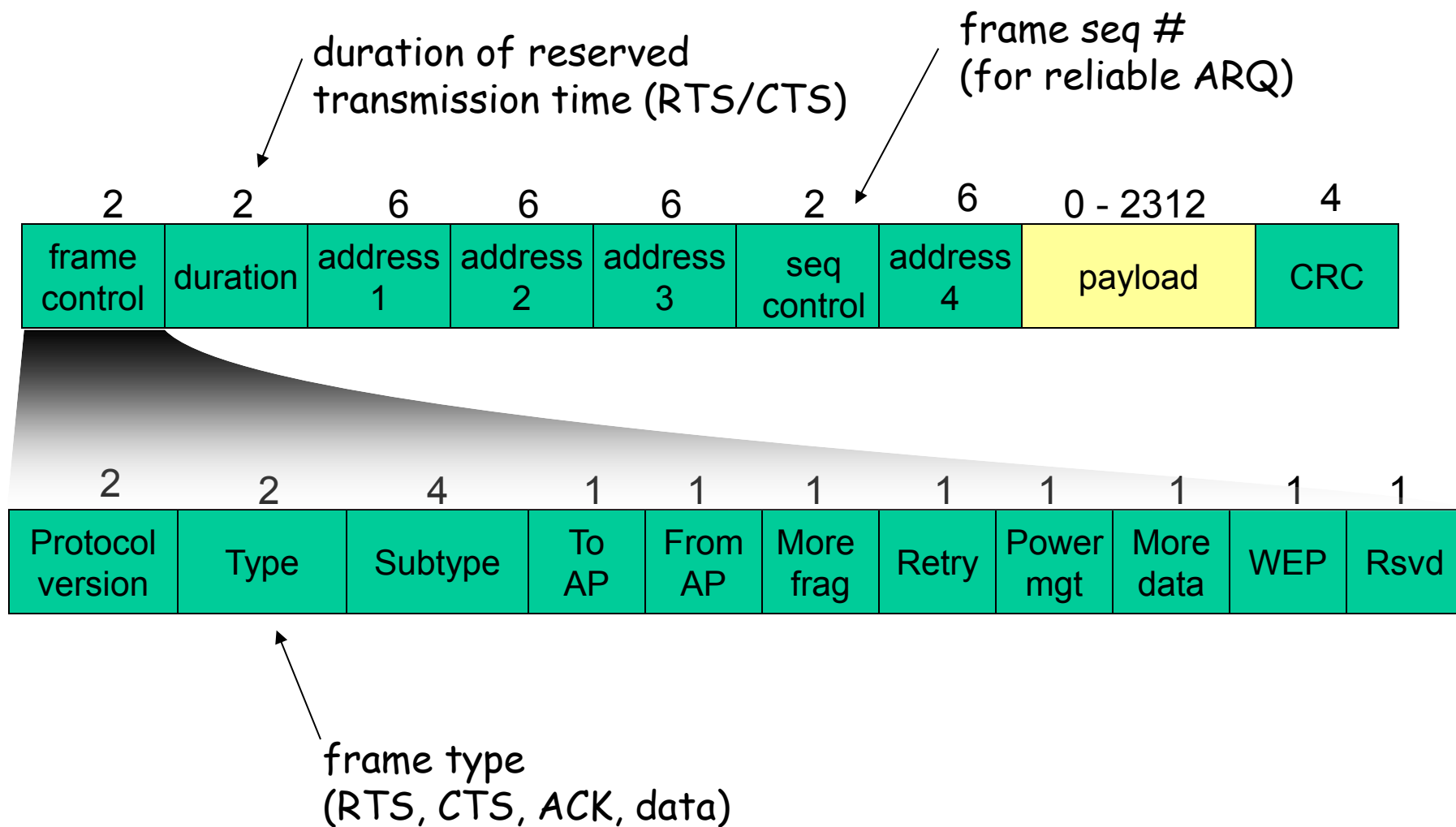


# 802.11 frame: addressing





# 802.11 frame: more

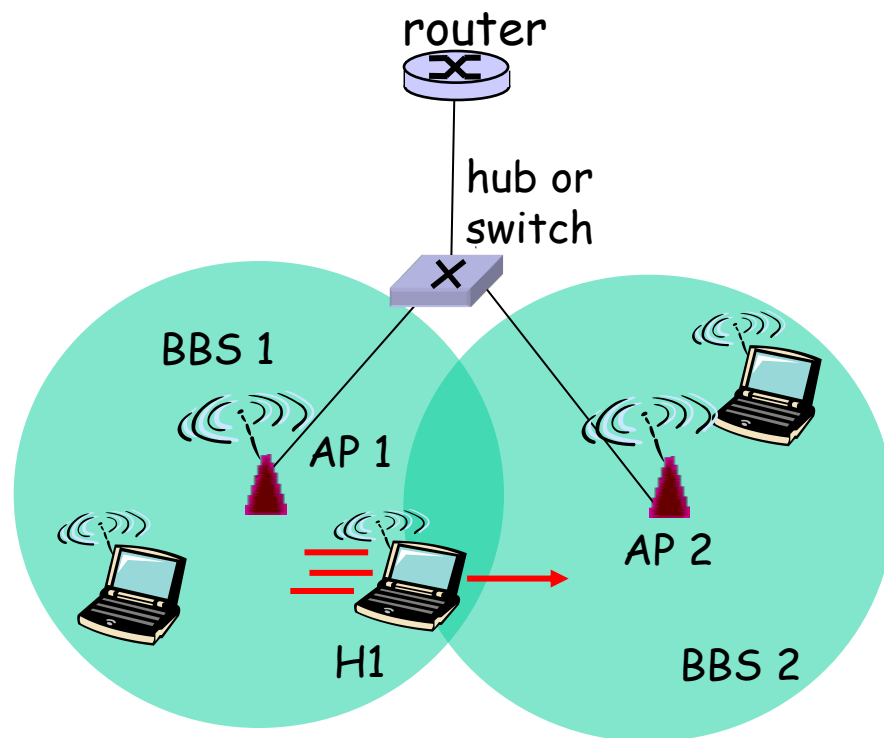






# 802.11: mobility within same subnet

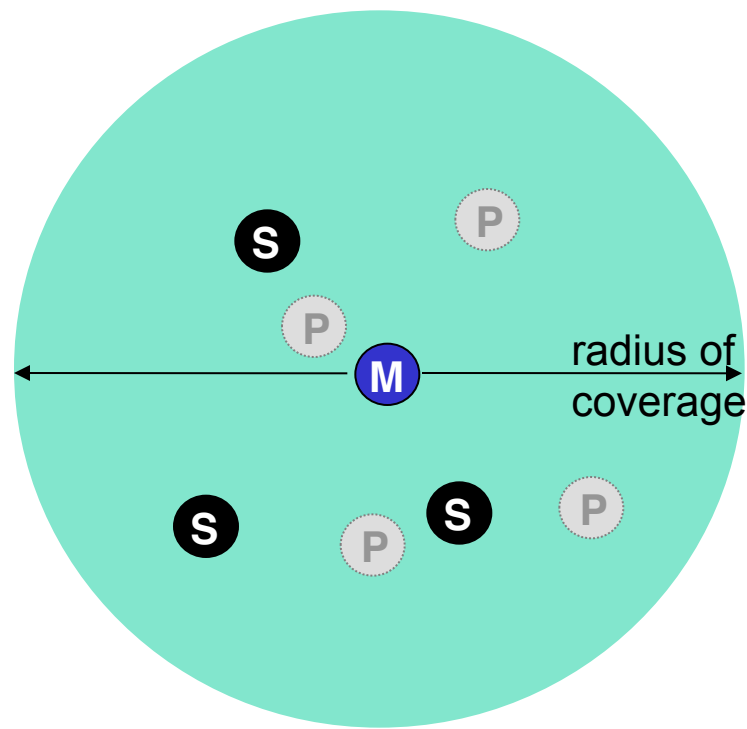
- ❑ H1 remains in same IP subnet: IP address can remain same
- ❑ switch: which AP is associated with H1?
  - self-learning (Ch. 5): switch will see frame from H1 and "remember" which switch port can be used to reach H1





# 802.15: 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)



# 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., GSM)

### 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

## 7.9 Summary



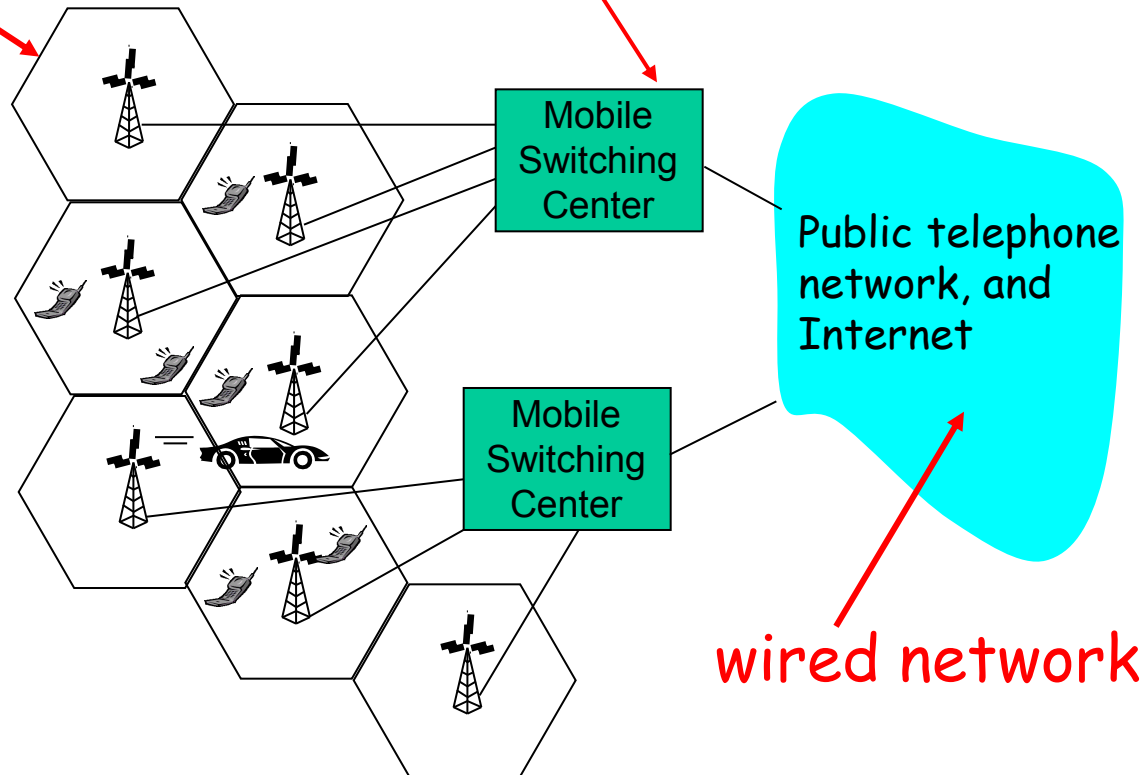
# Components of cellular network architecture

## 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

## MSC

- connects cells to wide area net
- manages call setup (more later!)
- handles mobility (more later!)



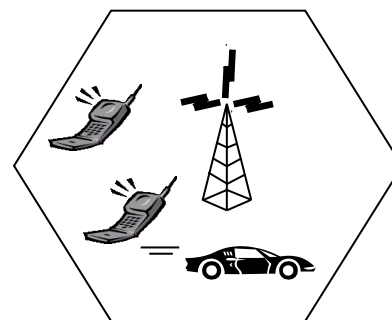
wired network



# Cellular networks: the first hop

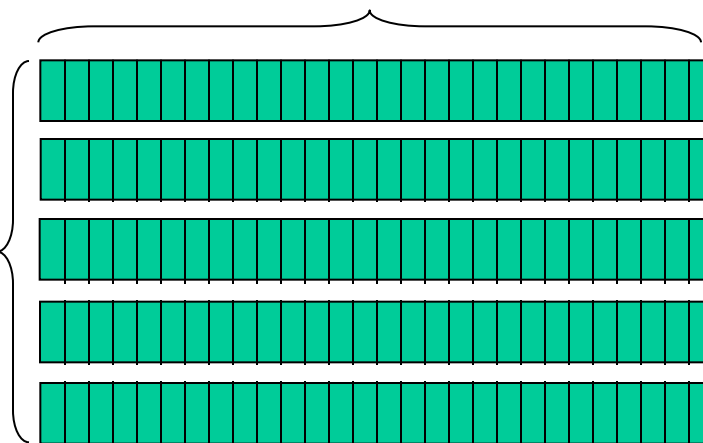
Two techniques for sharing mobile-to-BS radio spectrum

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



time slots

frequency bands

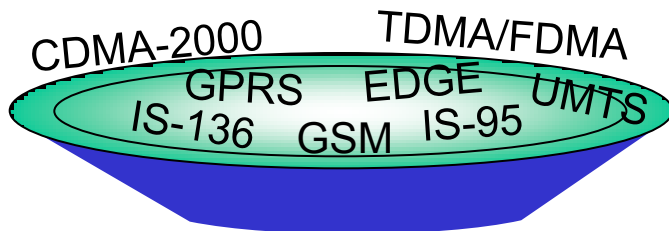




# Cellular standards: brief survey

## 2G systems: voice channels

- ❑ IS-136 TDMA: combined FDMA/TDMA (north america)
- ❑ GSM (global system for mobile communications): combined FDMA/TDMA
  - most widely deployed
- ❑ IS-95 CDMA: code division multiple access



Don't drown in a bowl  
of alphabet soup: use this  
as reference only



# Cellular standards: brief survey

## 2.5 G systems: voice and data channels

- ❑ for those who can't wait for 3G service: 2G extensions
- ❑ general packet radio service (GPRS)
  - evolved from GSM
  - data sent on multiple channels (if available)
- ❑ enhanced data rates for global evolution (EDGE)
  - also evolved from GSM, using enhanced modulation
  - Data rates up to 384K
- ❑ CDMA-2000 (phase 1)
  - data rates up to 144K
  - evolved from IS-95



# Cellular standards: brief survey

## 3G systems: voice/data

- ❑ Universal Mobile Telecommunications Service (UMTS)
  - GSM next step, but using CDMA
- ❑ CDMA-2000

..... more (and more interesting) cellular topics due to mobility (stay tuned for details)





# 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., GSM)

### Mobility

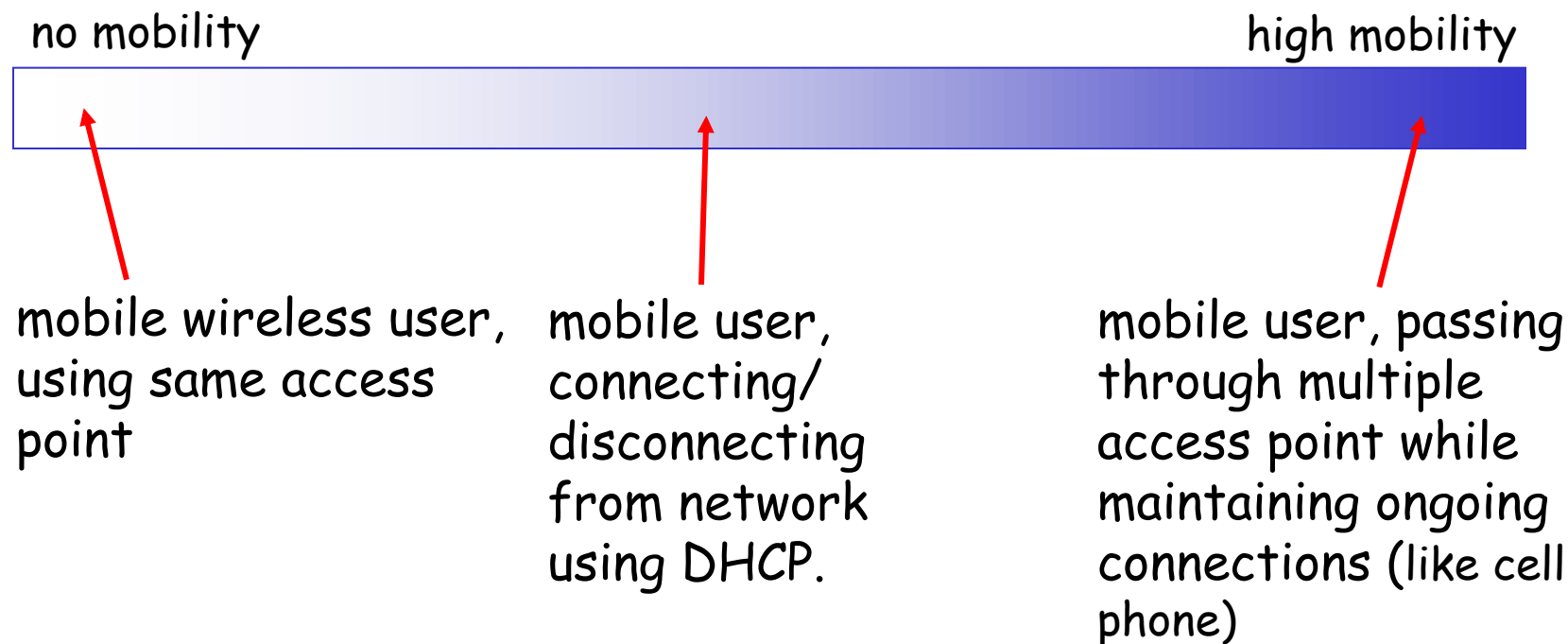
- ❑ 7.5 Principles: addressing and routing to mobile users
- ❑ 7.6 Mobile IP
- ❑ 7.7 Handling mobility in cellular networks
- ❑ 7.8 Mobility and higher-layer protocols

### 7.9 Summary



# What is mobility?

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





# 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?

I wonder where Alice moved to?





# Mobility: approaches

- *Let routing handle it:* routers advertise permanent address of mobile-nodes-in-residence via usual routing table exchange. 仅适用于小规模网络
  - routing tables indicate where each mobile located
  - no changes to end-systems
- *Let end-systems handle it:*
  - *indirect routing:* 间接路由 communication from correspondent to mobile goes through home agent, then forwarded 转发 to remote
  - *direct routing:* 直接路由 correspondent gets foreign address of mobile, sends directly to mobile



# Mobility: approaches

- ❑ *Let routing handle it:* routers advertise permanent address of mobile, mobile residence via usual routing table entries
  - routing table entries for 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

not  
scalable  
to millions of  
mobiles



# Mobility: Vocabulary

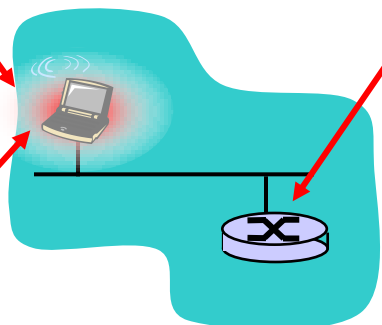
归属网络

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

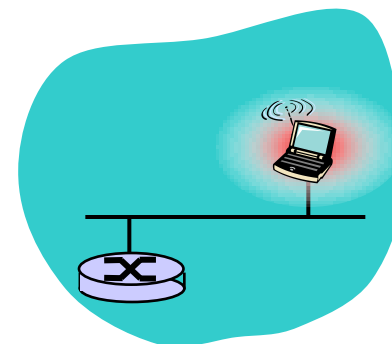
家代理/归属代理

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

**Permanent address:** 永久地址  
address in home  
network, can always be  
used to reach mobile  
e.g., 128.119.40.186



wide area  
network



  
correspondent

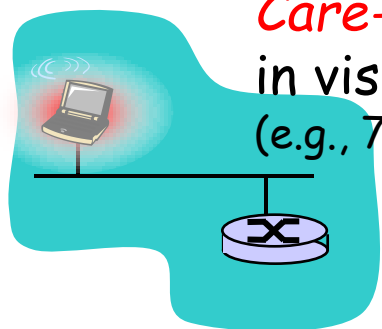


# Mobility: more vocabulary

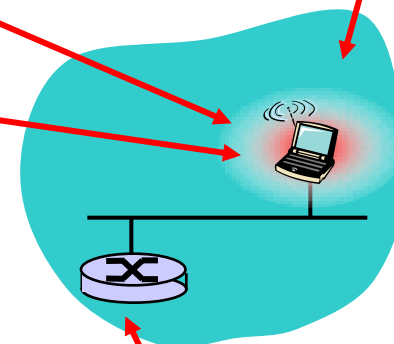
**Permanent address:** remains constant (e.g., 128.119.40.186)

外网/受访网络  
**visited network:** network in which mobile currently resides (e.g., 79.129.13/24)

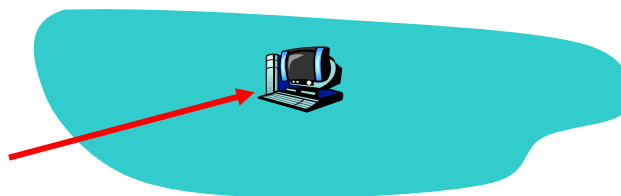
转交地址  
**Care-of-address:** address in visited network. (e.g., 79.129.13.2)



wide area network



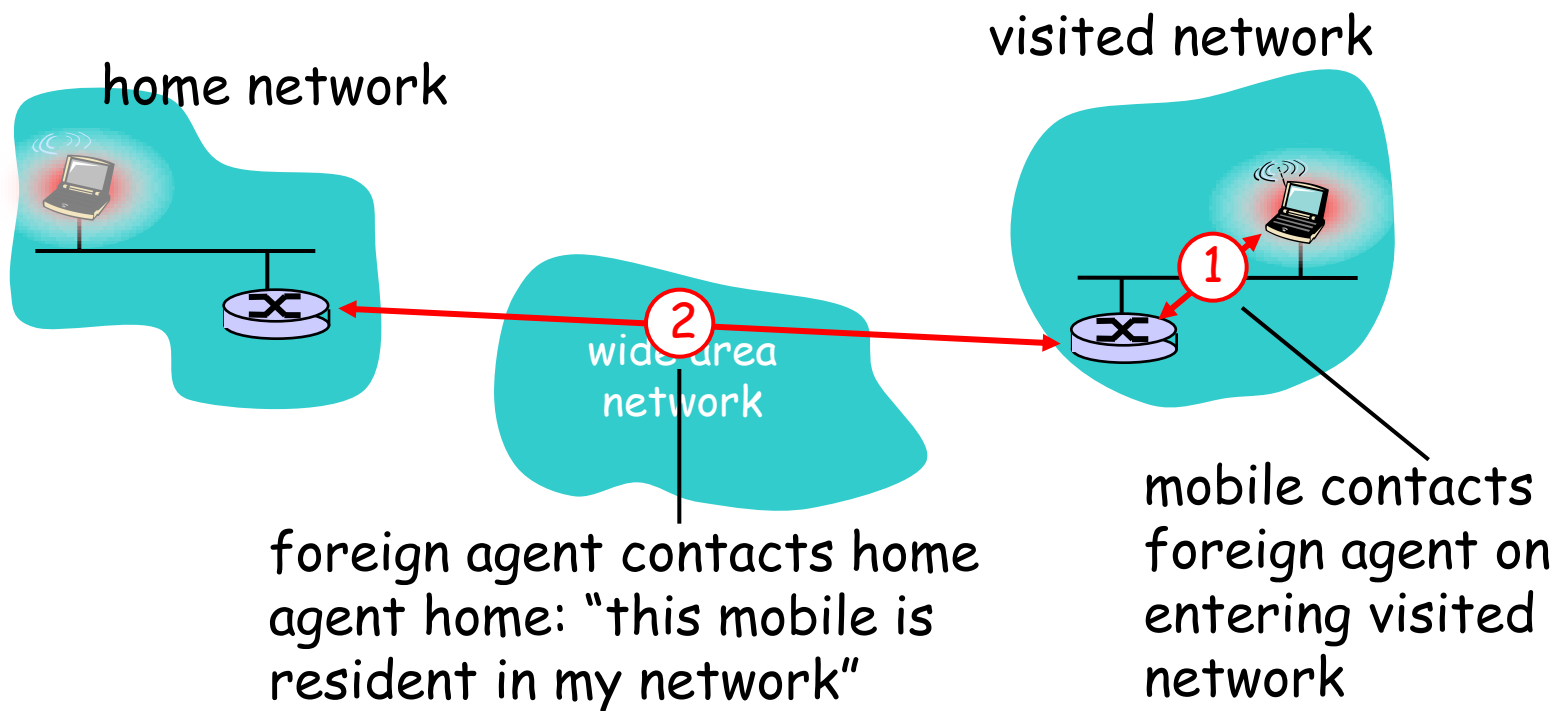
**correspondent:** wants to communicate with mobile



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



# Mobility: registration



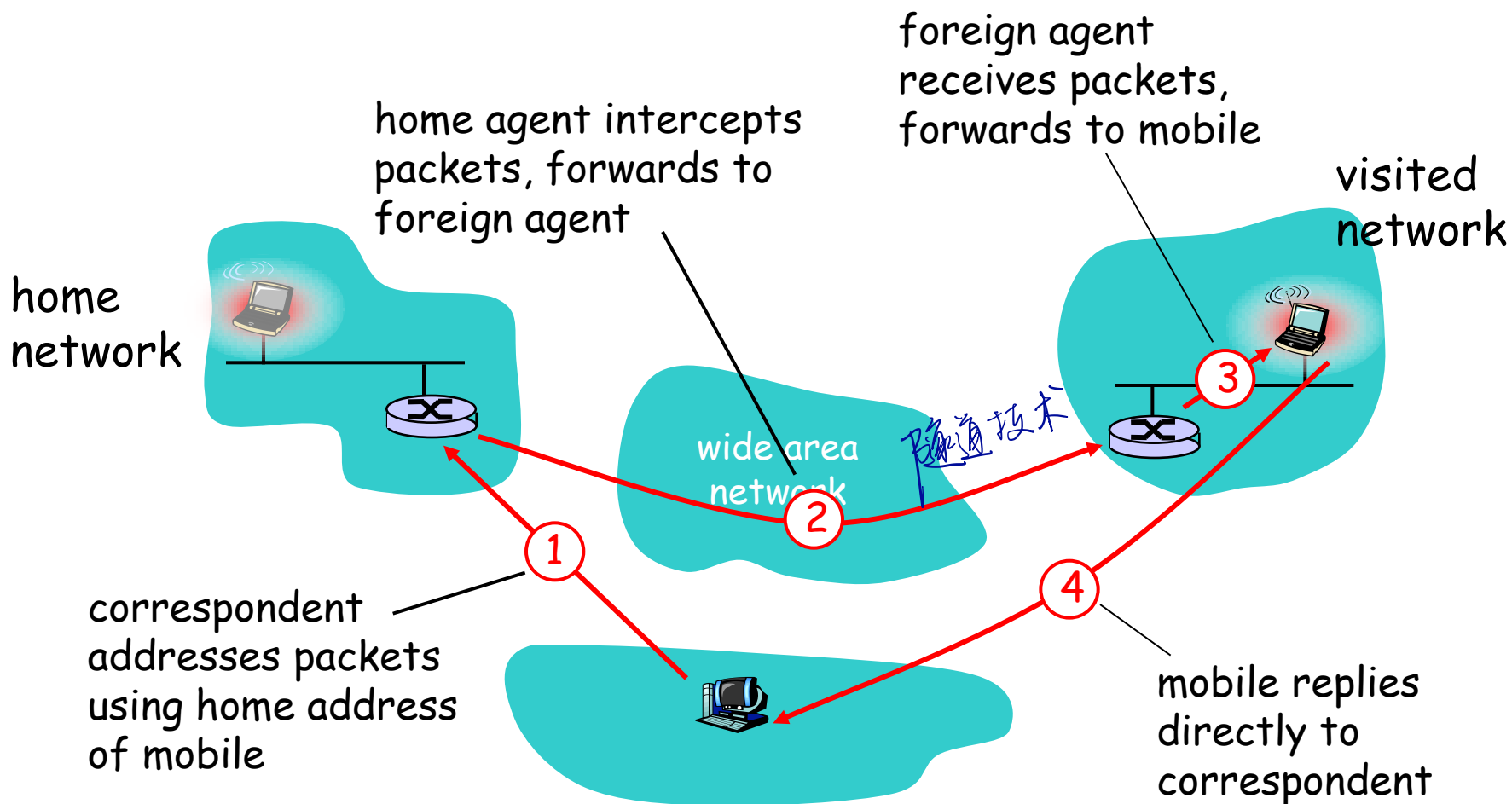
End result:

- ❑ Foreign agent knows about mobile
- ❑ Home agent knows location of mobile





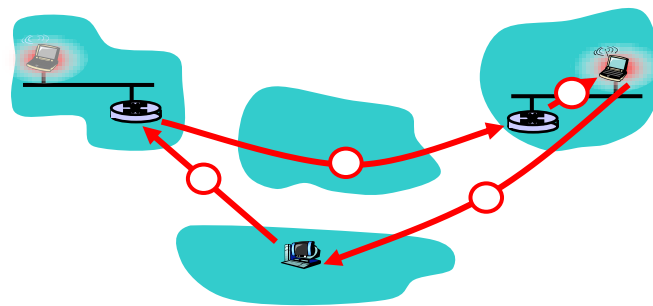
# Mobility via Indirect Routing





# 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 三角路由
  - inefficient when correspondent, mobile are in same network



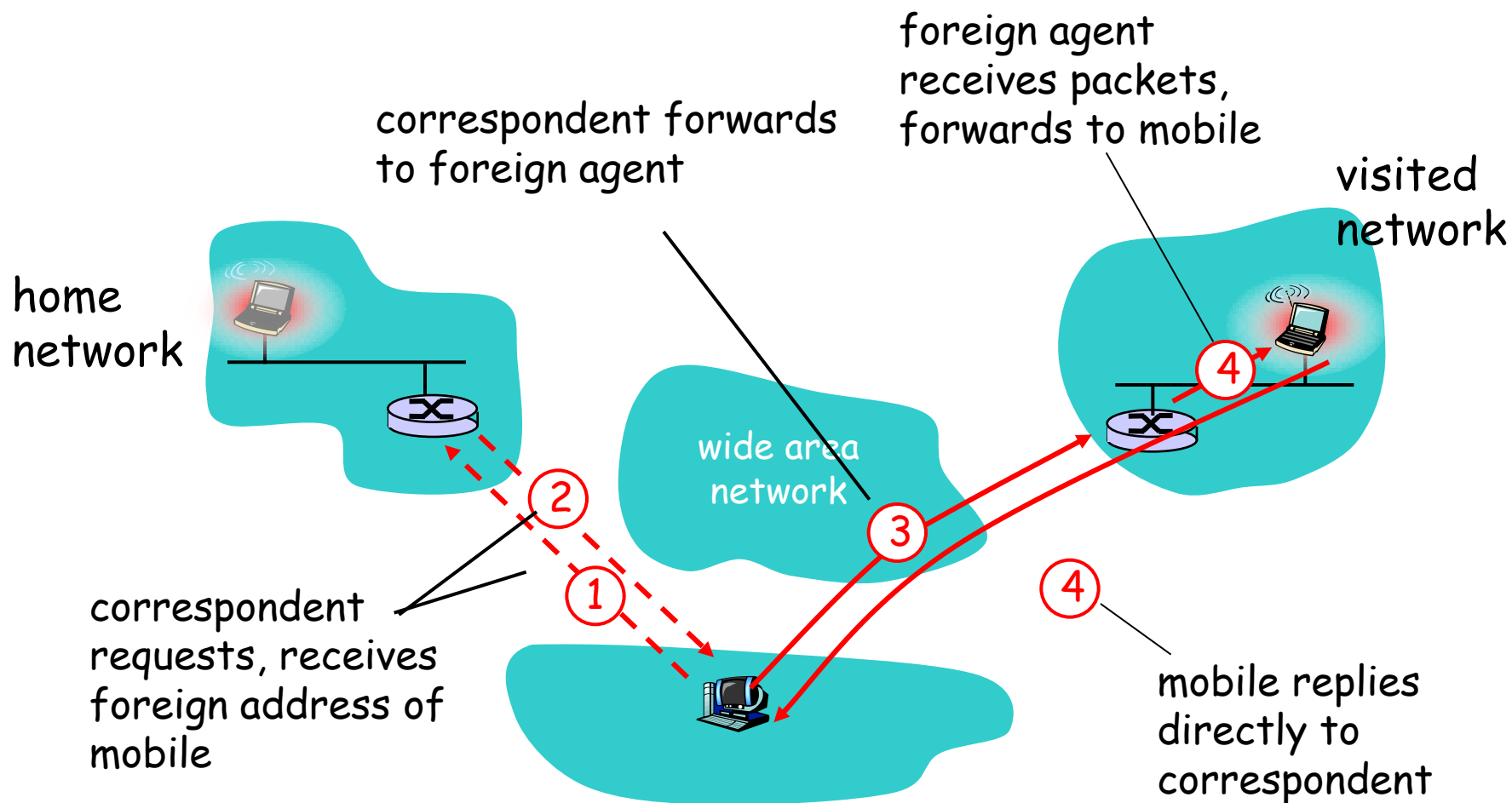


# Indirect Routing: moving between networks

- 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!*



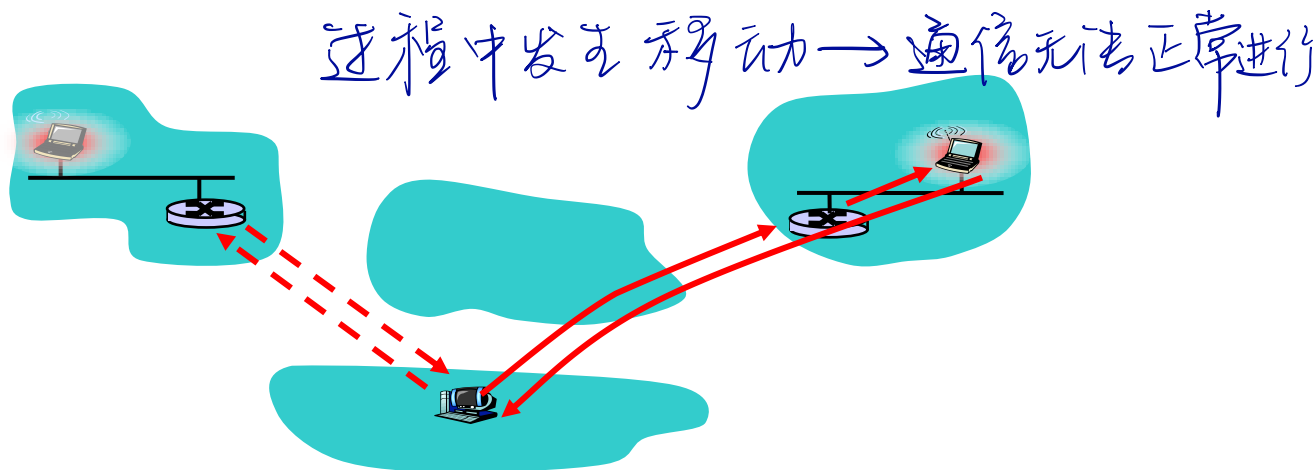
# Mobility via Direct Routing





# Mobility via Direct Routing: comments

- ❑ overcome triangle routing problem
- ❑ <sup>不透明</sup>non-transparent to correspondent:  
correspondent must get care-of-address  
from home agent
  - what if mobile changes visited network?

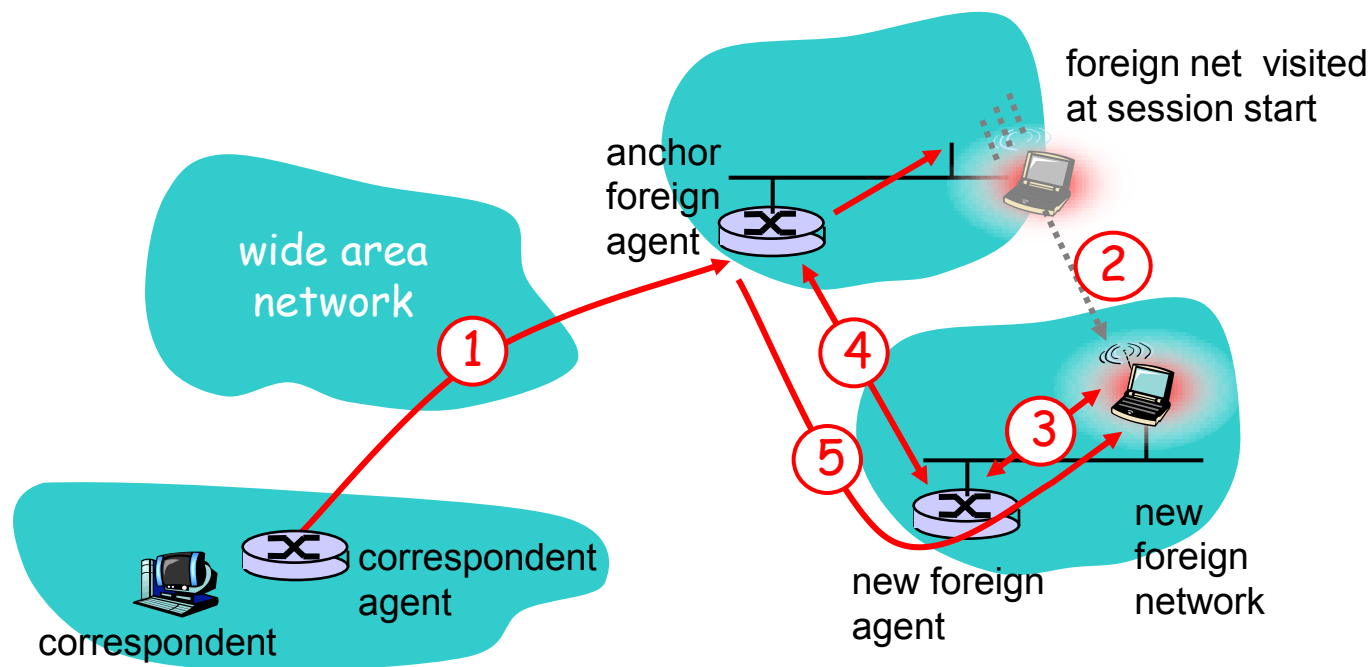




# Accommodating mobility with direct routing

锚外接代理

- 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 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., GSM)

### 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

## 7.9 Summary



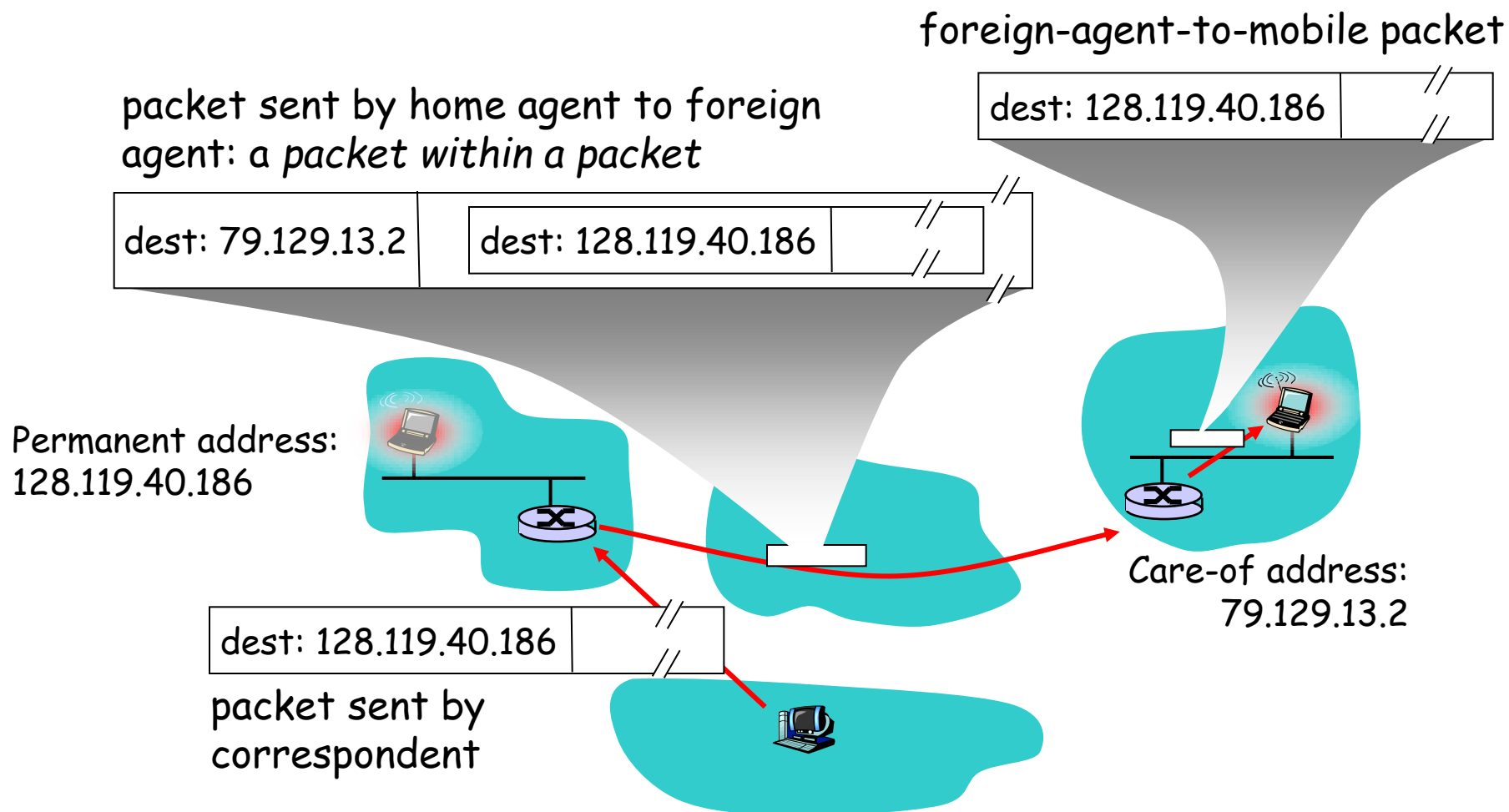
# Mobile IP

- ❑ RFC 3220 被 RFC 3344 代替
- ❑ 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





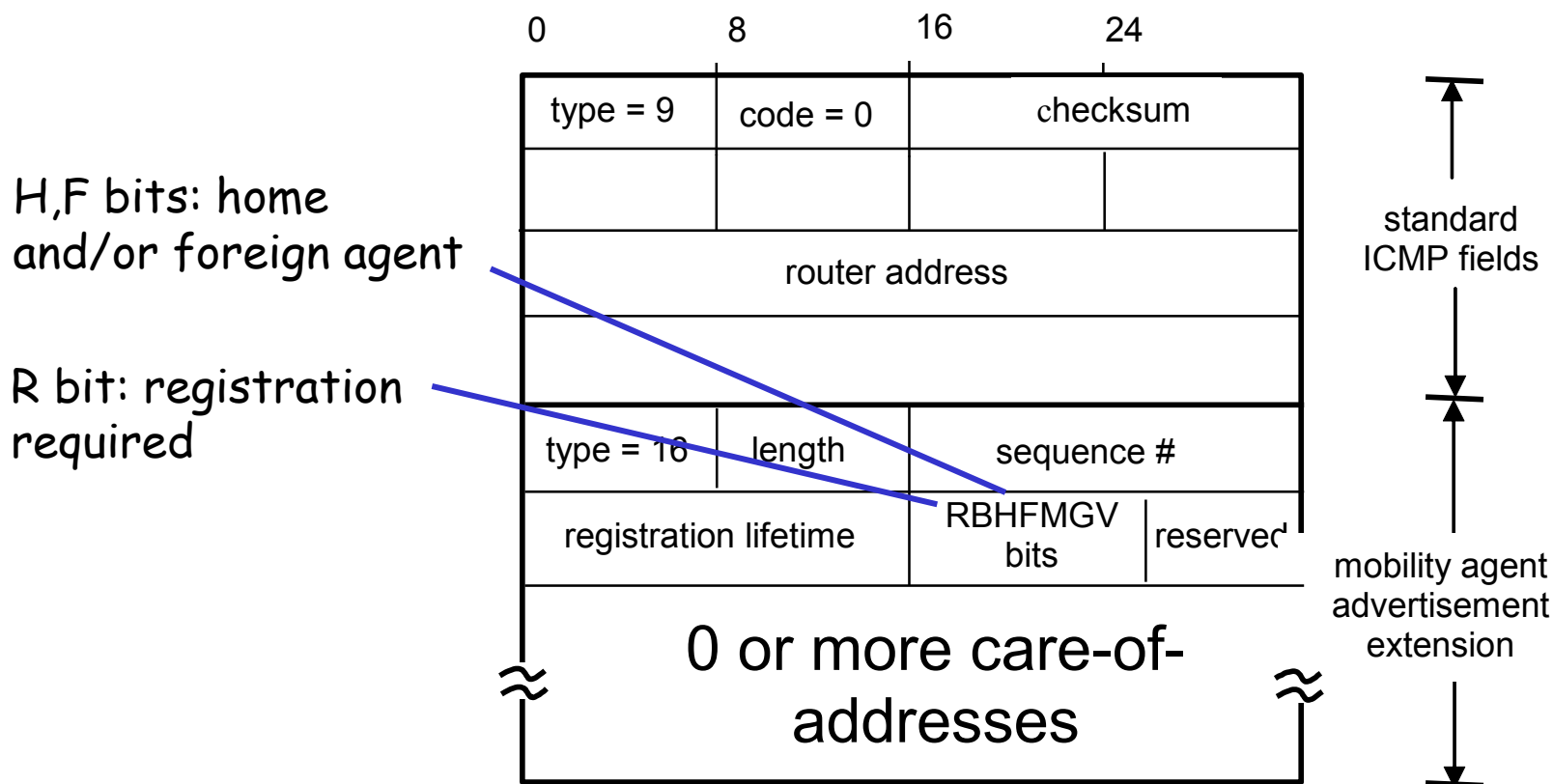
# Mobile IP: indirect routing





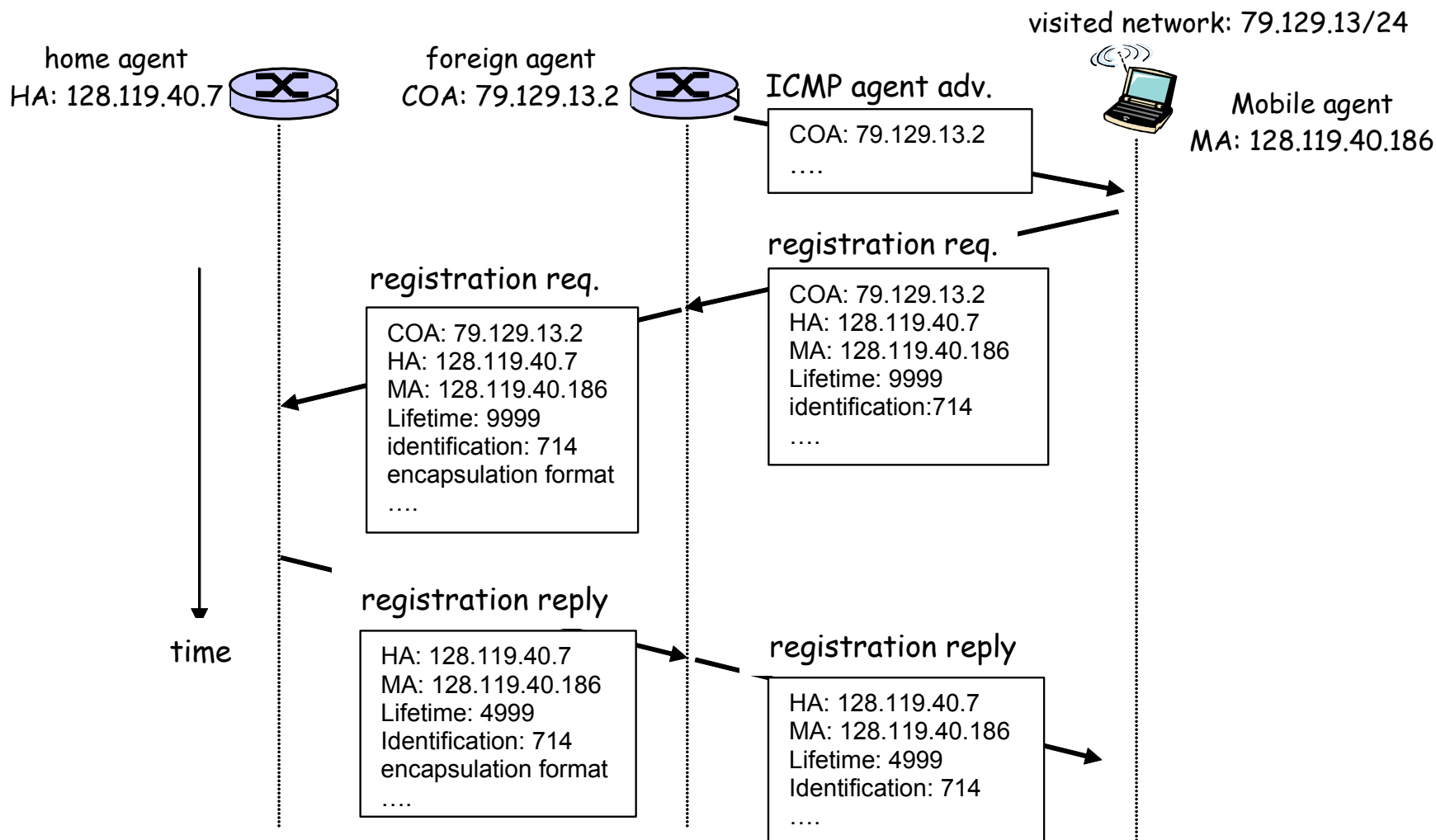
# Mobile IP: agent discovery

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





# Mobile IP: registration example





# 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., GSM)

### Mobility

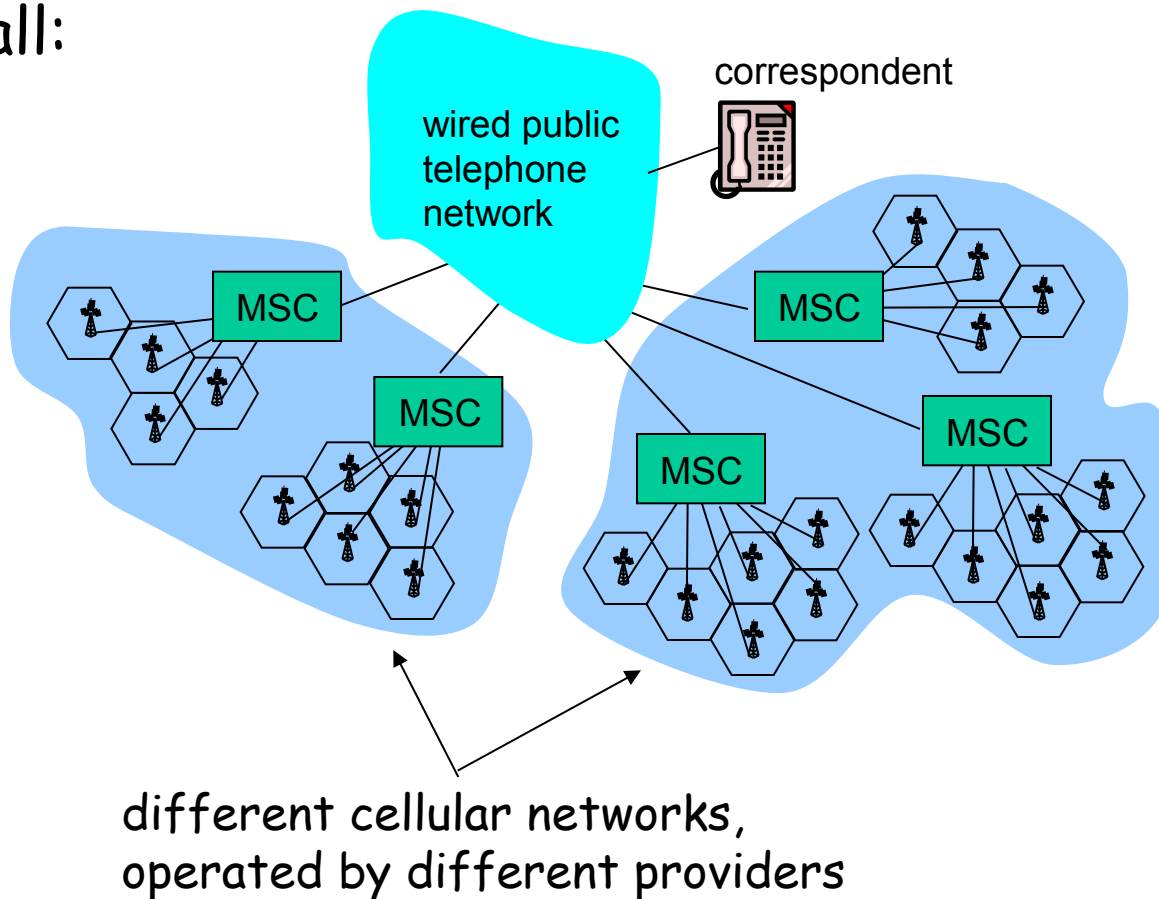
- ❑ 7.5 Principles: addressing and routing to mobile users
- ❑ 7.6 Mobile IP
- ❑ 7.7 Handling mobility in cellular networks
- ❑ 7.8 Mobility and higher-layer protocols

## 7.9 Summary



# Components of cellular network architecture

recall:





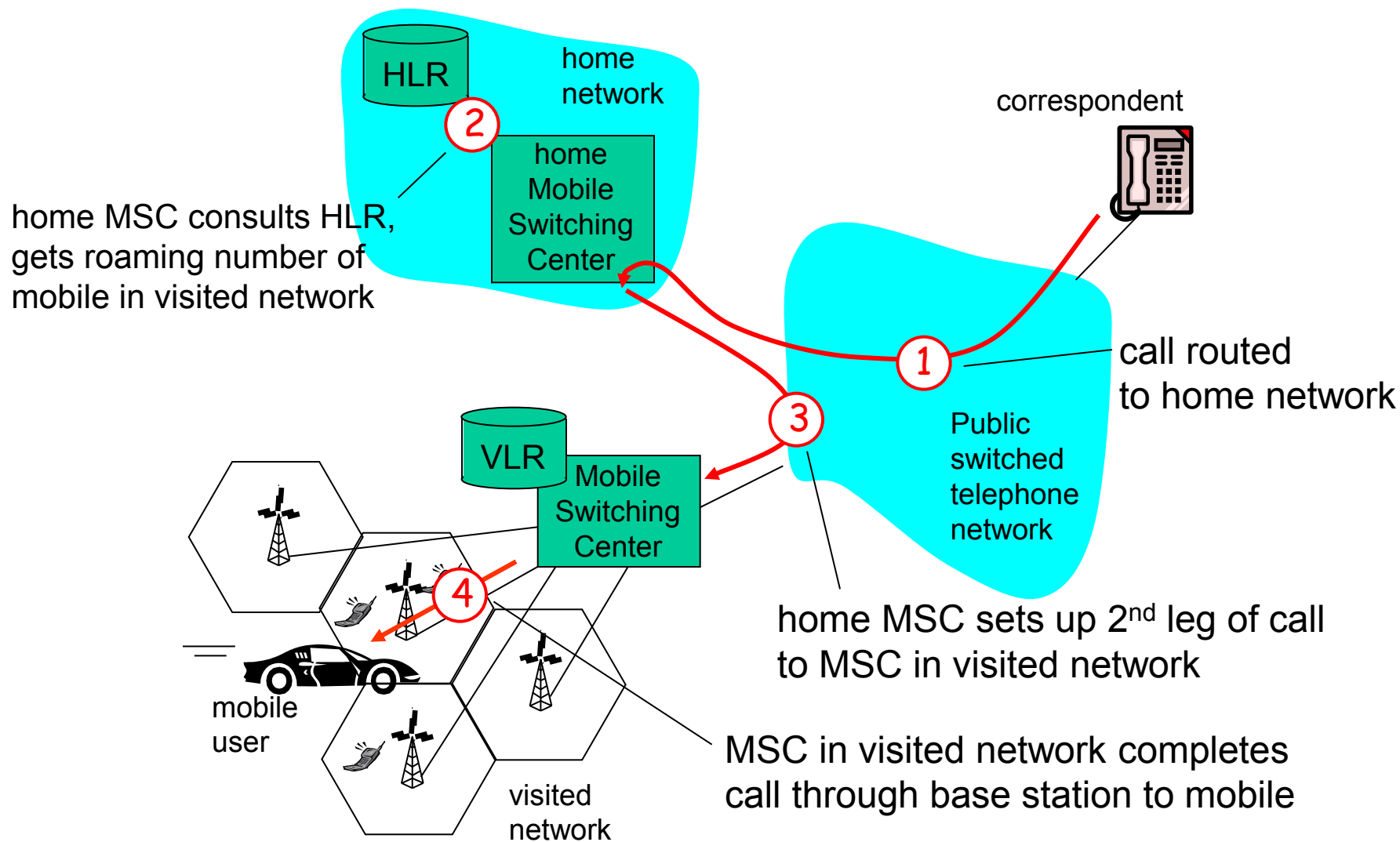
# Handling mobility in cellular networks

- **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

来访者位置寄存器

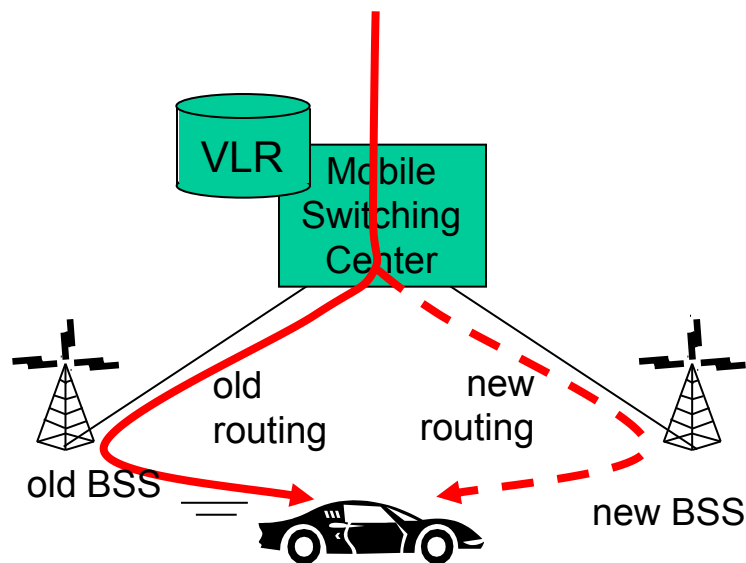


# GSM: indirect routing to mobile





# GSM: handoff with common MSC

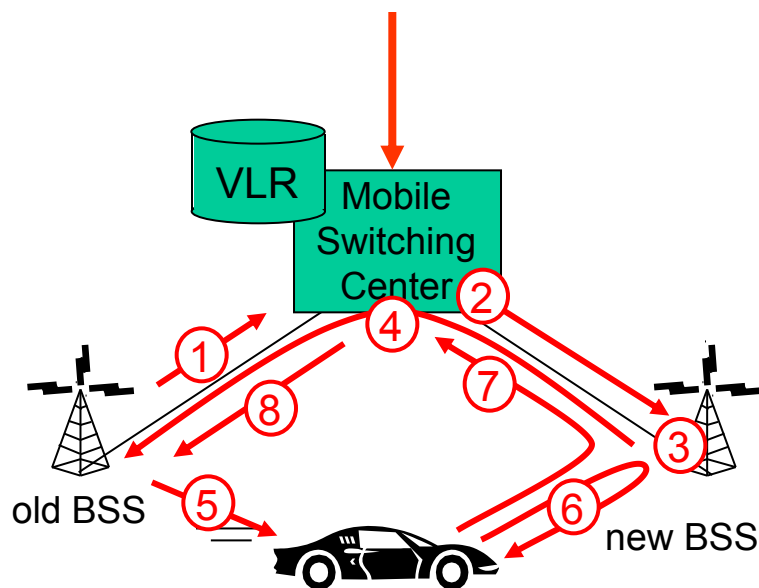


- ❑ Handoff goal: route call via new base station (without interruption)
- ❑ reasons for handoff:
  - stronger signal to/from new BSS (continuing connectivity, less battery drain)
  - load balance: free up channel in current BSS
  - GSM doesn't mandate why to perform handoff (policy), only how (mechanism)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





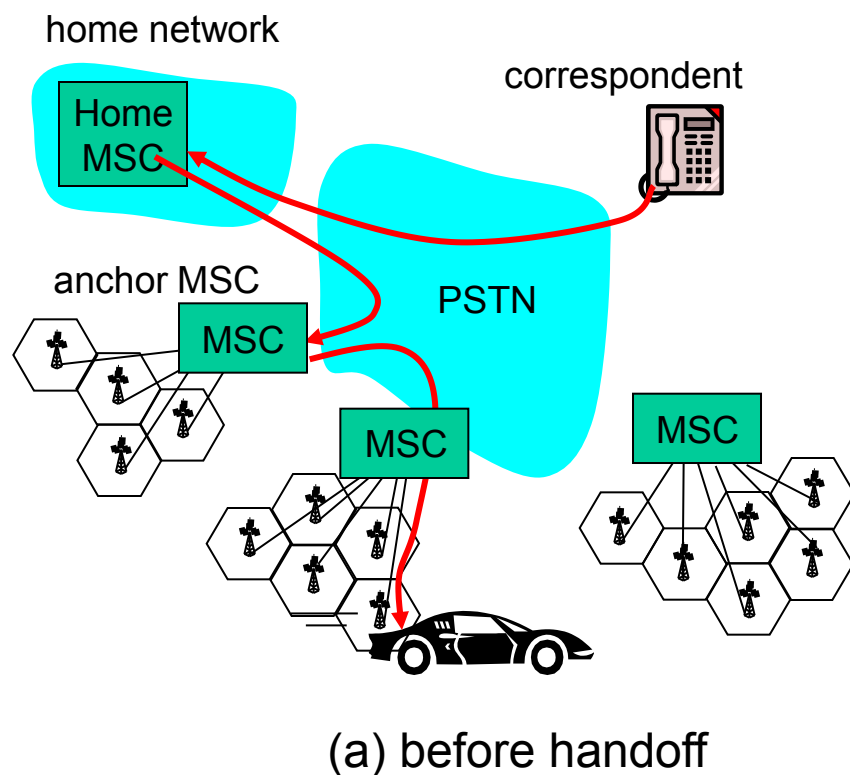
# GSM: handoff with common MSC



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



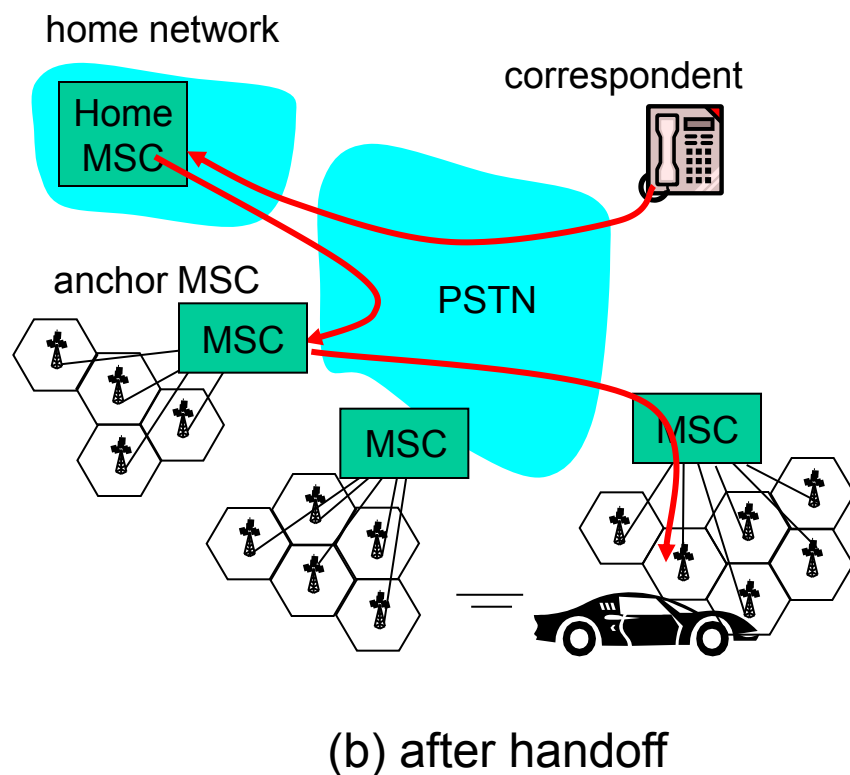
# GSM: handoff between MSCs



- **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
- IS-41 allows optional path minimization step to shorten multi-MSC chain



# GSM: handoff between MSCs



- **anchor MSC**: first MSC visited during cal
  - call remains routed through anchor MSC
- new MSCs add on to end of MSC chain as mobile moves to new MSC
- IS-41 allows optional path minimization step to shorten multi-MSC chain



# Mobility: GSM versus Mobile IP

| GSM element  | Comment on GSM element   | Mobile IP element |
|--|--|-------------------|
| Home system  | Network to which the 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   |



# 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., GSM)

### 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

## 7.9 Summary



# 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 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., GSM, CDMA-2000, UMTS)

## 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