Chapter 6

6.1 Introduction

Wireless

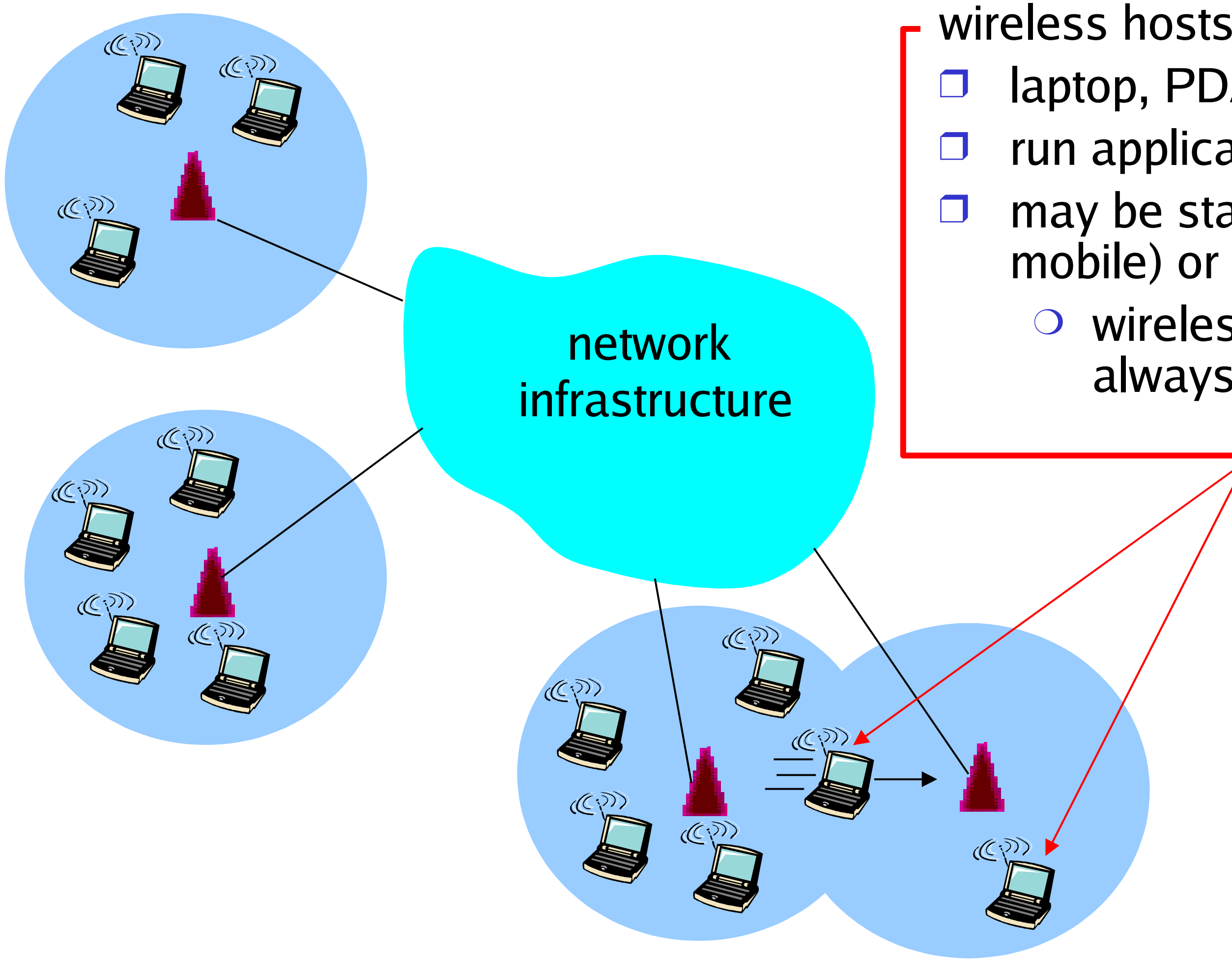
- 6.2 Wireless links, characteristics
  - CDMA
- 6.3 IEEE 802.11 wireless LANs (“wi-fi”)
- 6.4 Cellular Internet Access
  - architecture
  - standards (e.g., GSM)

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

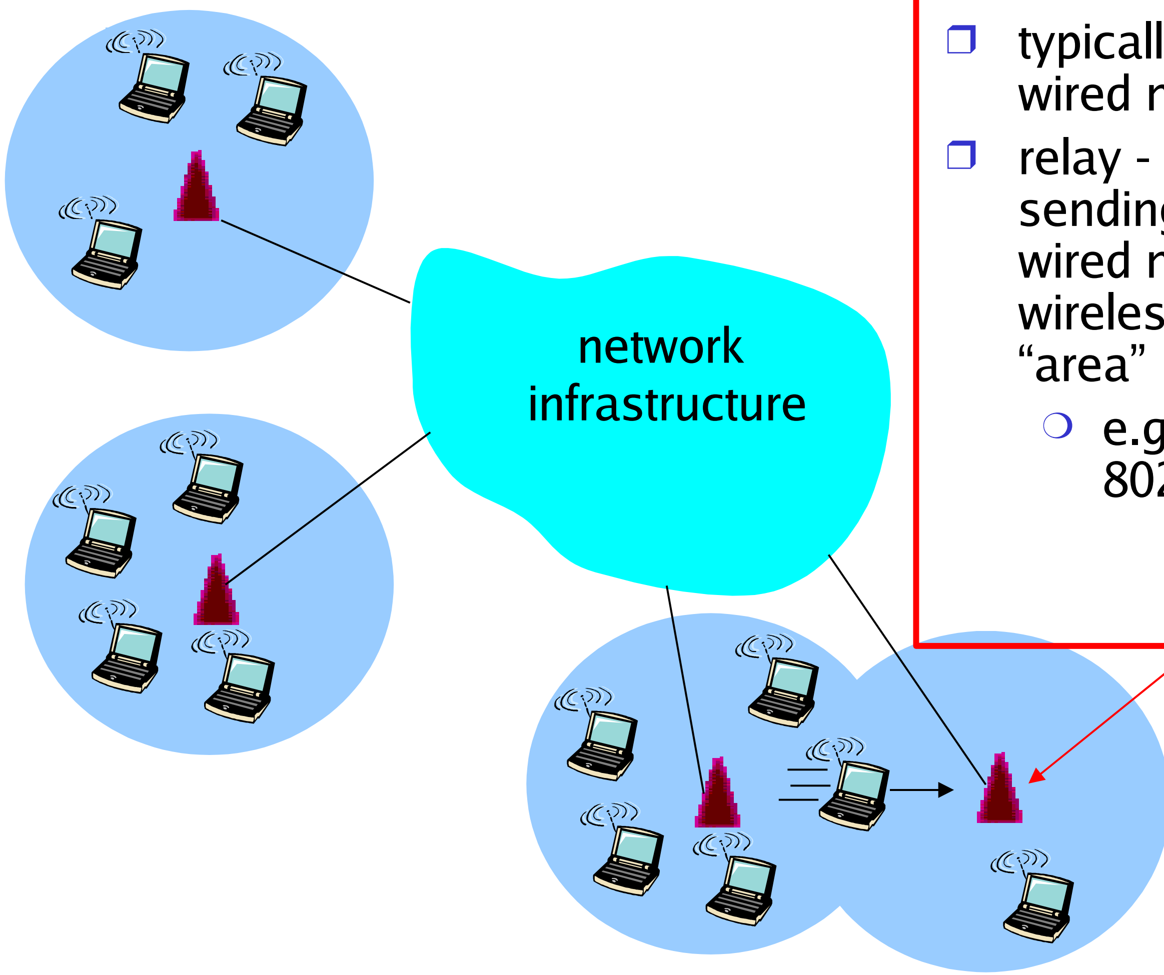
Elements of a wireless network



wireless hosts

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

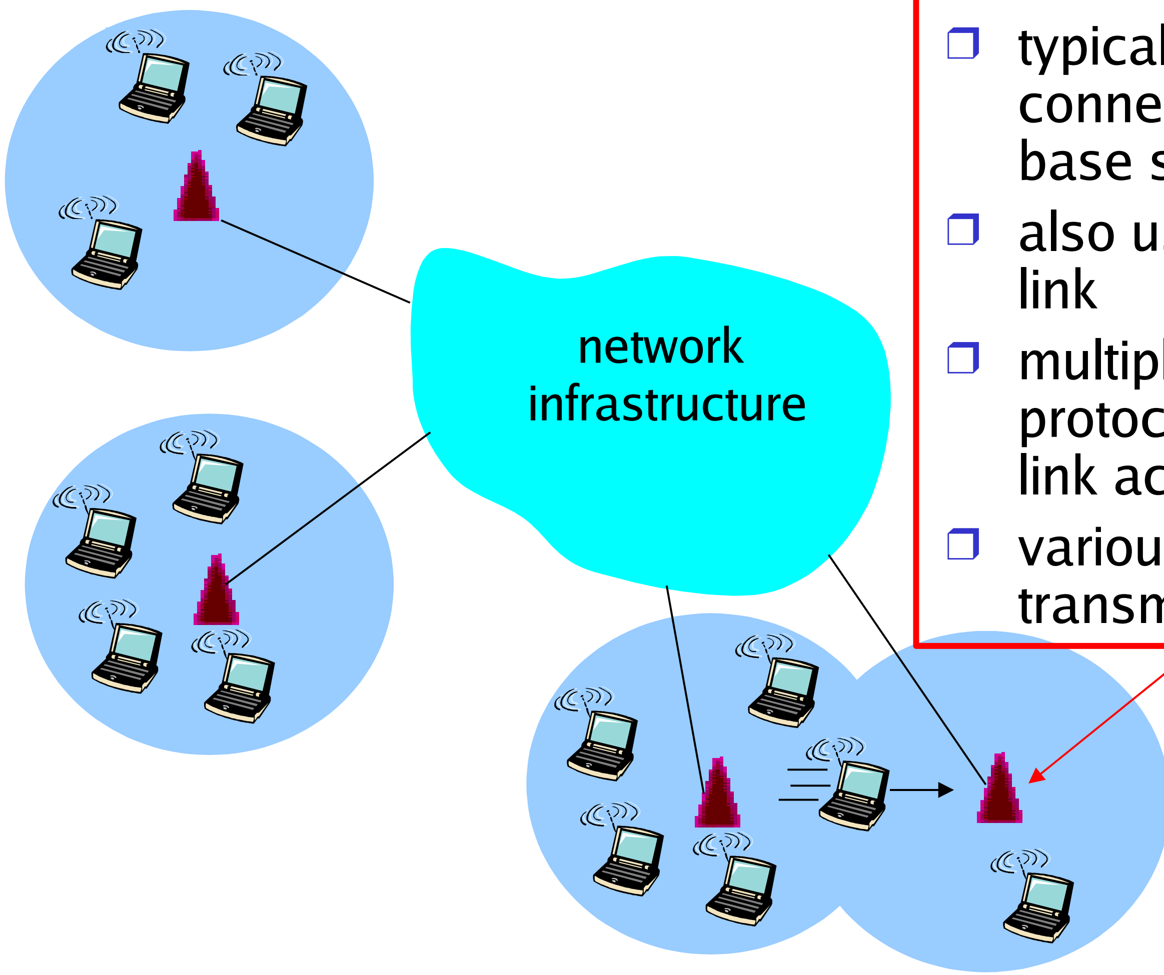
Elements of a wireless network



base station

- typically connected to wired network
- relay - responsible for sending packets between wired network and wireless host(s) in its “area”
  - e.g., cell towers, 802.11 access points

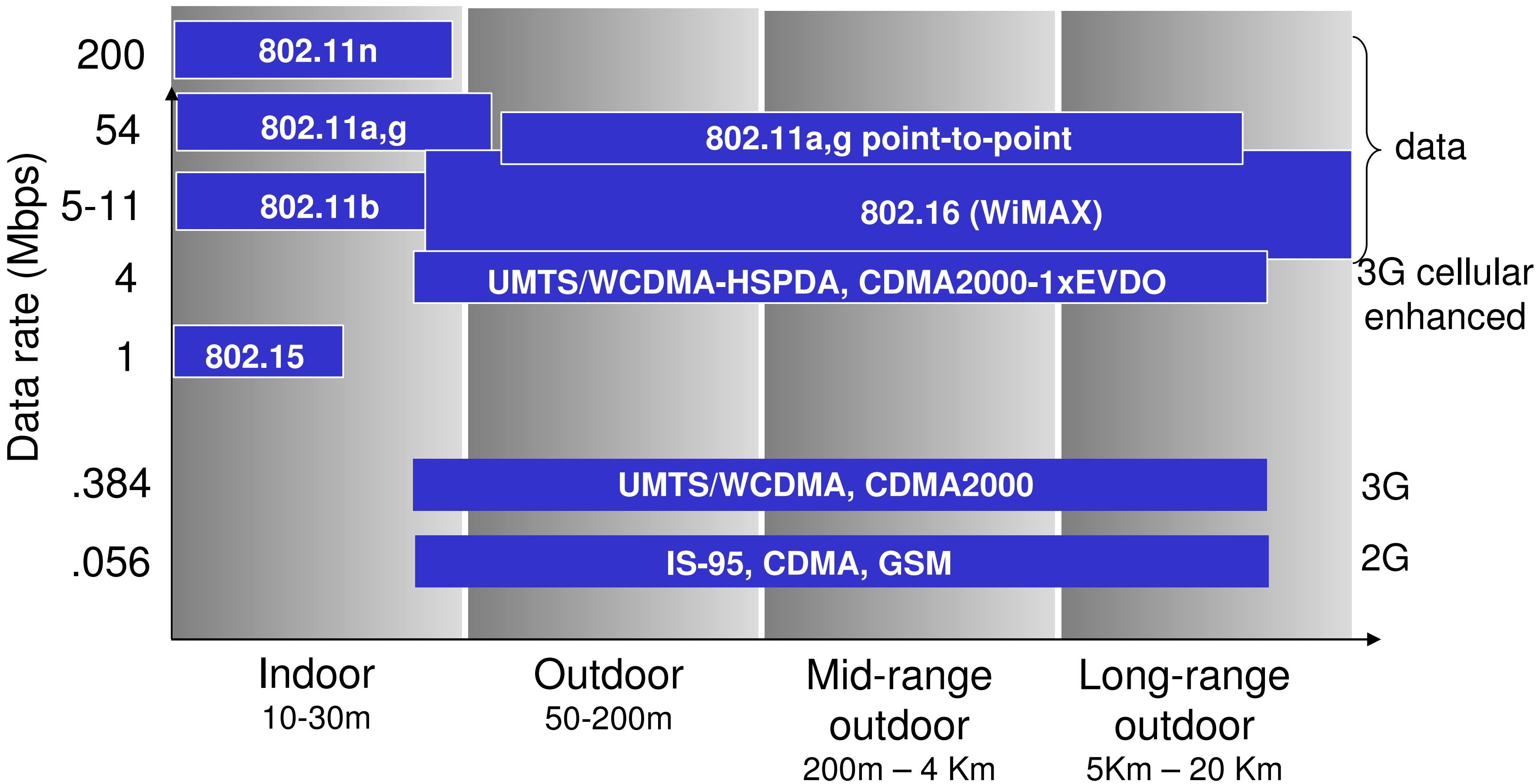
Elements of a wireless network



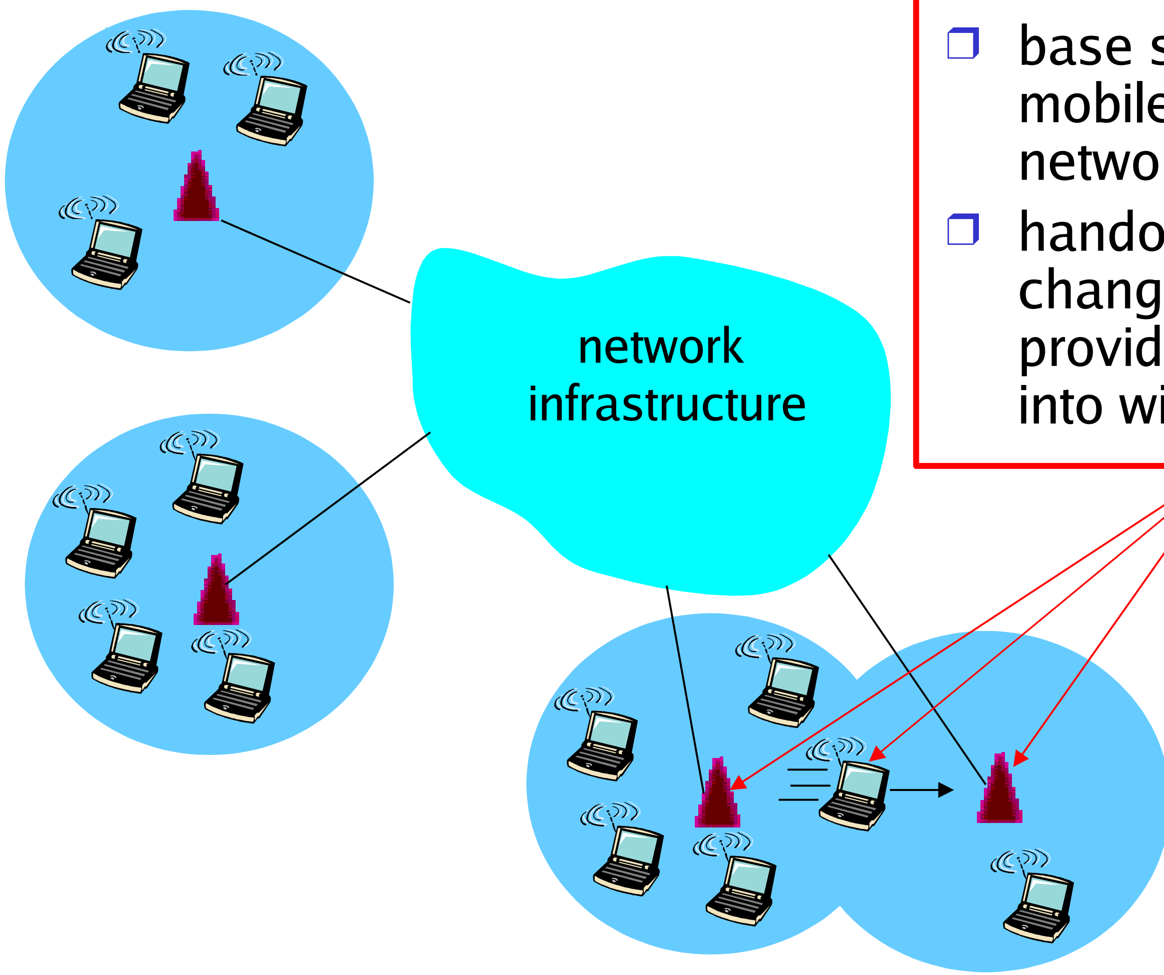
wireless link

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

Characteristics of selected wireless link standards



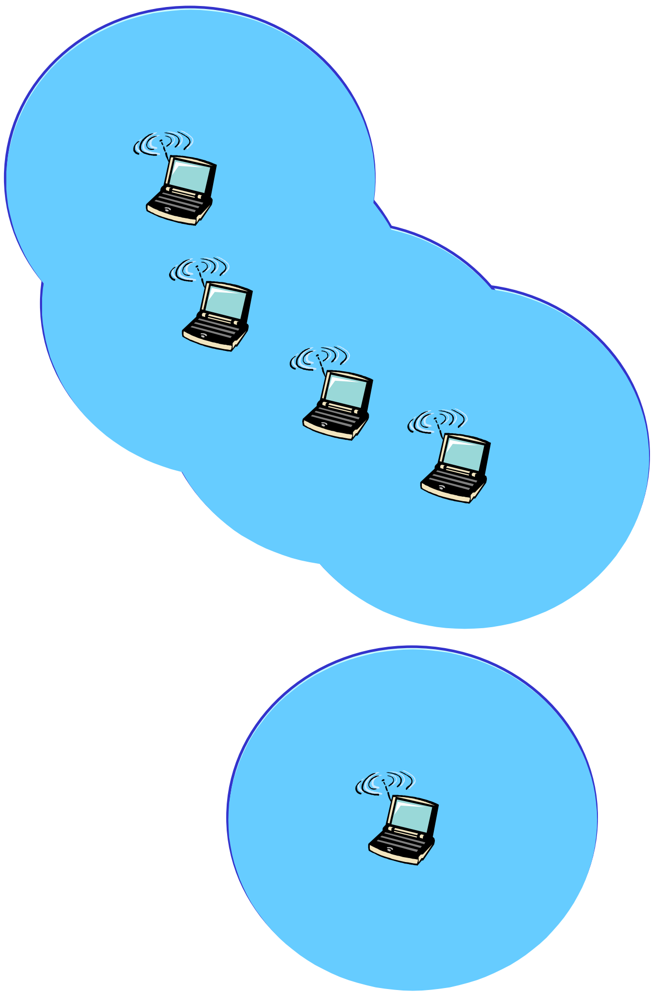
Elements of a wireless network



infrastructure mode

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

Elements of a wireless network



ad hoc mode

- no base stations
- nodes can only transmit to other nodes within link coverage
- nodes organize themselves into a network: route among themselves

Wireless network taxonomy

	single hop	multiple hops
infrastructure (e.g., APs)	host connects to base station (WiFi, WiMAX, cellular) which connects to larger Internet	host may have to relay through several wireless nodes to connect to larger Internet: *mesh net*
no infrastructure	no base station, no connection to larger Internet (Bluetooth, ad hoc nets)	no base station, no connection to larger Internet. May have to relay to reach other a given wireless node MANET, VANET

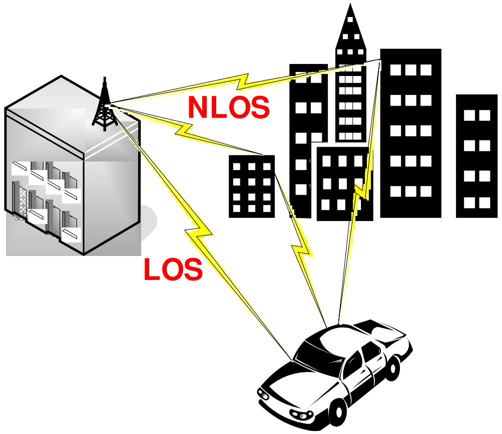
Wireless Link Characteristics

Main Issues:

- 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

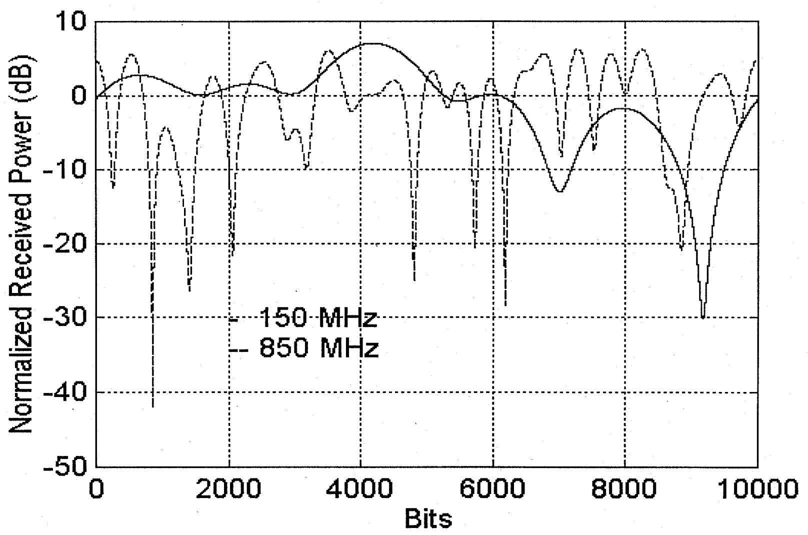
Multipath Fading

- Direct Line of Sight (**LOS**) **Reflected** Non Line of Sight (**NLOS**) paths



- Multiple copies of the transmitted signal will combine **constructively** or **destructively**

- Significant power **fluctuations** in the received signal, causing **deep fades**



Friis Equation

- Relationship between the transmitted and received power

$$\frac{P_R}{P_T} = G_R G_T \left(\frac{\lambda}{4\pi d}\right)^2 \quad \text{OR} \quad \frac{P_R}{P_T} = G_R G_T \left(\frac{\lambda}{4\pi}\right)^2 * \frac{1}{d^2}$$

->

$$P_R = \underbrace{\boxed{P_T G_R G_T \left(\frac{\lambda}{4\pi}\right)^2}}_{=P_N} * \frac{1}{d^2}$$

- **Normalized received power** at a distance of **1 m**

$$P_N = P_T G_R G_T \left(\frac{\lambda}{4\pi}\right)^2 * \frac{1}{1^2}$$

->

$$P_N = P_T G_R G_T \left(\frac{\lambda}{4\pi}\right)^2$$

- Received power decreases as the **square of the distance**

$$P_R = \frac{P_N}{d^2}$$

Friis Equation (cont.)

- Logarithmic (**dB**) form

$$10\log P_R = 10\log P_N - 20\log d$$

- The transmission delay is given as:

$$\tau = \frac{d}{c}$$

Antenna Principles

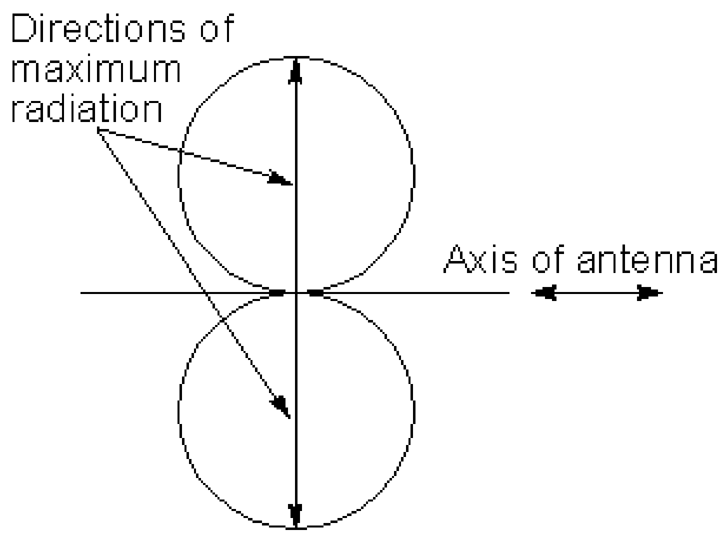
Antenna: an electronic component that is designed to transmit or receive electromagnetic signals or energy

- **Isotropic Radiator**
  - Hypothetical, lossless antenna
  - Spherical radiation pattern
- **Omni-directional**
- **Directional**: eg. Yagi-Uda antenna

Antenna Directivity

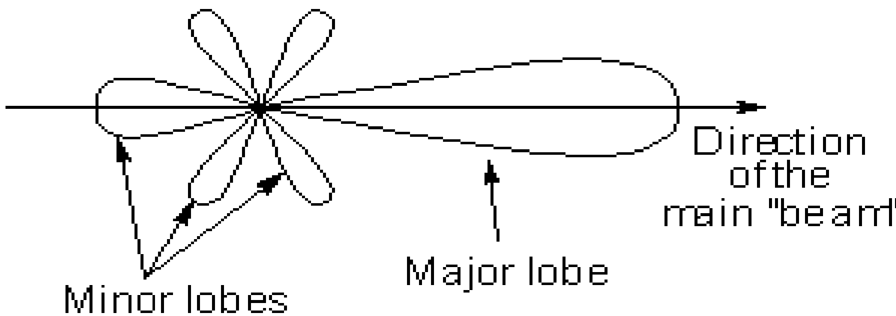
- Antennae do not radiate electromagnetic energy equally in all directions.
- Visualize the antenna directivity in terms of its radiated power.
- The Rx antenna operates equivalently, with identical directivity and gain.

- Although the radiation pattern of the antenna varies in three dimensions, it is more convenient to plot the pattern in a particular plane, usually the horizontal or vertical planes



Antenna Directivity

- Antennae are often categorized by the type of polar diagram they exhibit
  - **Omni-directional antenna**: radiates approximately equally in all directions
  - **Highly directional antenna** Eg.Yagi antenna.



- **Beam-width** of an antenna: angle between the two points where the power falls to half its maximum level (the half power beam-width).

Antenna Gain

- **Gain**: more power is radiated a specific direction
- **Forward gain**: ratio of the signal transmitted in the "maximum" direction to that of a standard or reference antenna
- Reference antenna
  - **Dipole**
  - **Isotropic source** (only exists in theory)
- **Front to back ratio**: ratio of the maximum signal in the forward direction to the signal in the opposite direction
- VHF and UHF systems: design is optimized for the optimum forward gain since this provides the maximum radiated signal in the required direction.

Gain/Beamwidth Balance

- Maximizing the gain of an antenna does not always optimize its performance.
- Increasing the gain will result in a reduction in the **beamwidth**.
- The orientation of the direction of the antenna is very critical.

Units & Measurements

- The term **dB** or **decibel**: a relative unit of measurement used frequently in electronic communications to describe power gain or loss.

$$dB = 10\log\left(\frac{P_1}{P_2}\right)$$

P1 = reference power
P2 = measured/calculated power

- The **Signal-to-Noise** (S/N) ratio:

$$\frac{S}{N} = 10\log\left(\frac{Signal\ Power}{Noise\ Power}\right)\ [\mathrm{dB}]$$

- Signal levels were normally quoted as power ratios and a reference point of 1 mW was chosen as a convenient size. The unit was named **dBm** with the “m” indicating a **reference point of 1 mW** and is therefore a measurement of power.
- Example: received signal power at a distance of 45m from an access point = 0.000000000316 mW. More conveniently represented as **-95.2 dBm**.

Units & Measurement

- **Sensitivity:** indicates the **minimum signal level** required at the antenna terminals to provide **reliable communications.**

  Eg. A manufacturer specification: PCMCIA 802.11 adapter has a receiver **sensitivity** of **"-84 dBm** at 11 Mbps".

  => receiver must have a minimum signal power of **4 pW** in order for it to successfully decode the 11 Mbps bit stream.

- The relationship between Tx and Rx power for **isotropic antennae**

$$P_R = P_T\left(\frac{\lambda}{4\pi d}\right)^2 = \frac{P_T}{L_P}$$

- L_P is referred to as the free-space path loss between two Isotropic antenna

$$L_P = \left(\frac{4\pi d}{\lambda}\right)^2$$

- The wavelength (λ) is related to the frequency as:

$$\lambda = \frac{c}{f}$$

λ= wavelength in meters
c = The speed of light in free space
f = Frequency of operation in Hertz (Hz)

The Friis Equation and Link Budget

- Non-isotropic antenna: Free-Space loss is given by the Friis equation:

$$P_R = P_T\left(\frac{G_T G_R}{L_P}\right)$$

- Obtain a link budget relationship from the above to determine the performance parameters (in dB) of a system:

$$10\log P_R = 10\log P_T + 10\log G_T + 10\log G_R - 10\log L_P$$

- Taking the logarithm of both sides of the equation and multiplying by ten we get:

$$P_R(dB) = P_T(dB) + G_T(dB) + G_R(dB) - L_P(dB)$$

The Friis Equation and Link Budget

- More conveniently we state the **link-budget equation** in dB:

$$[P_R(dB)+30]=[P_T(dB)+30]+G_T(dB)+G_R(dB)-L_P(dB)$$

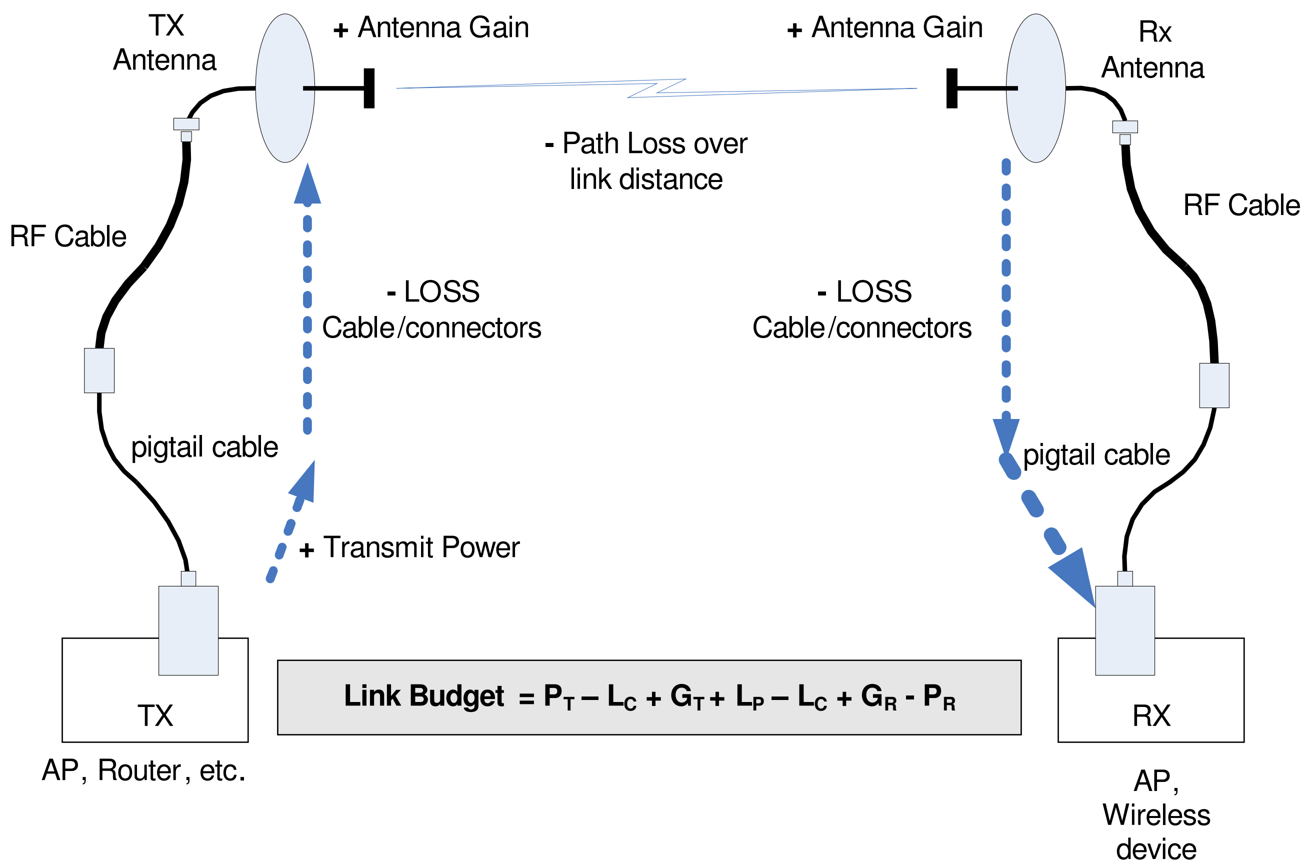
Or,

$$P_R(dBm)=P_T(dBm)+G_T(dB)+G_R(dB)-L_P(dB)$$

- Tx power has the antennae gains applied to it, and then the path loss over the link is subtracted from the result, thus giving us the signal power at the receiver.
- Rx power must be **equal to, or greater** than the receiver **sensitivity** for reliable data detection.

Typical wireless link - link-budget calculation.

- Minimum margin of **5 dB** is the **lowest level** that will provide acceptable results.



Link Budget $= P_T - L_C + G_T + L_P - L_C + G_R - P_R$

Link Analysis

- Link analysis in five stages, each contributes to the signal loss or gain:
  - The transmitter
  - The cabling and connectors at the transmitter end
  - The wireless link
  - Rx cabling and connectors
  - The receiver
  - The Tx and Rx antennae

Link Budget

- Reliable link: Received signal level (RSL) must be greater than the sensitivity of the wireless receiver.
- This is typically -82 dBm for 11 Mbps.
- Rewrite the link budget equation as:

$$RSL_{\min} = P_T + G_T - L_P + G_R - L_{CT} - L_{CR}$$

Link Budget

- LCT and LCR: cable and connector losses at the Tx and Rx.
- Typical specification: **RSL > -82 dBm** for the bits to be received and decoded reliably.

Example

<u>System parameters</u>:

- RF cable: 3.4 dB (50 ft. LMR 400)
- Pigtail and connectors: 2 dB
- Tx/Rx Antennae: 24 dBi
- Free-space path loss (16 Km) : 124 dB
- Receiver sensitivity: -82 dBm
- Tx power: -15 dB (32 mW)

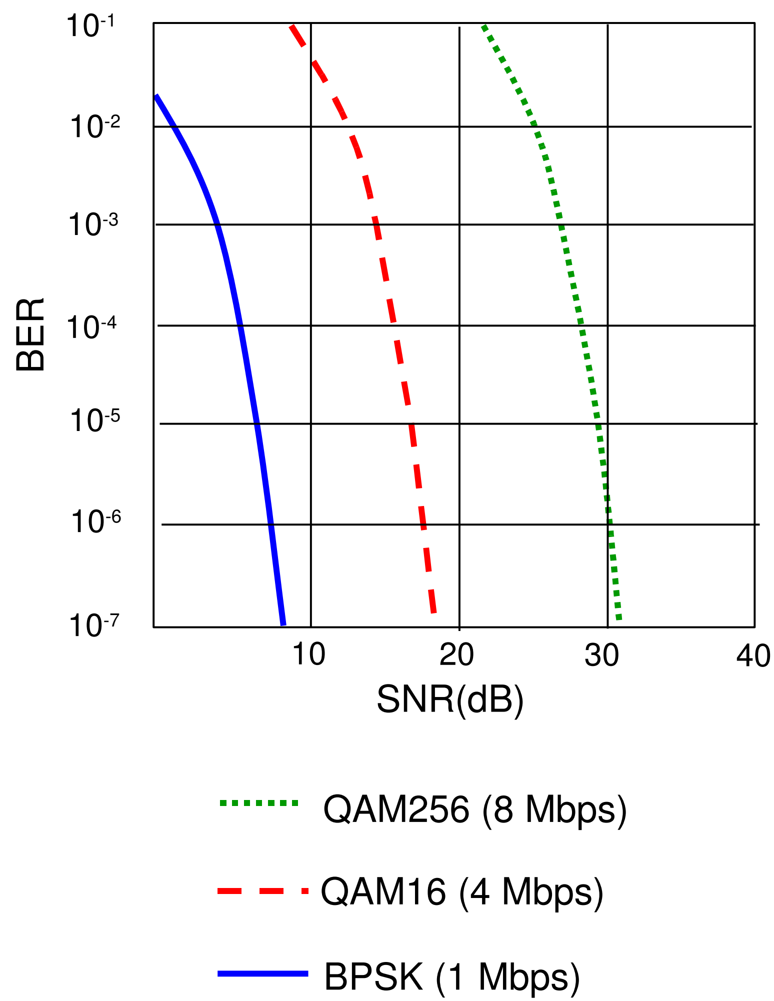
RSL = -15 dB + 24 dBi – 124 dB + 24 dBi – 5.4 dB – 5.4 dB = -101 dB

RSL = -101 dB + 30 = -71 dBm > -82 dBm, therefore the system will work.

<u>**Note**</u>: If **RSL < -82 dBm**, then solutions such as higher gain antennae, lower loss cables or signal amplifiers will be required to maintain a reliable link.

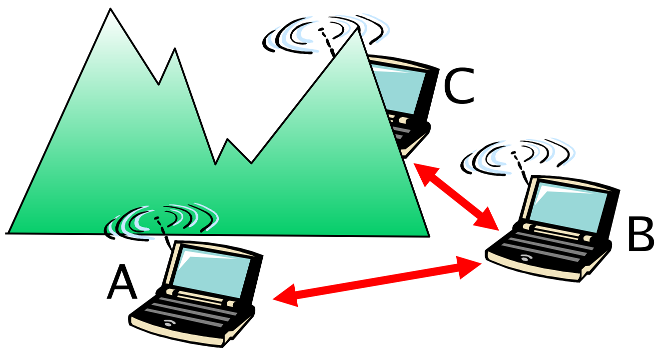
Wireless Link Performance

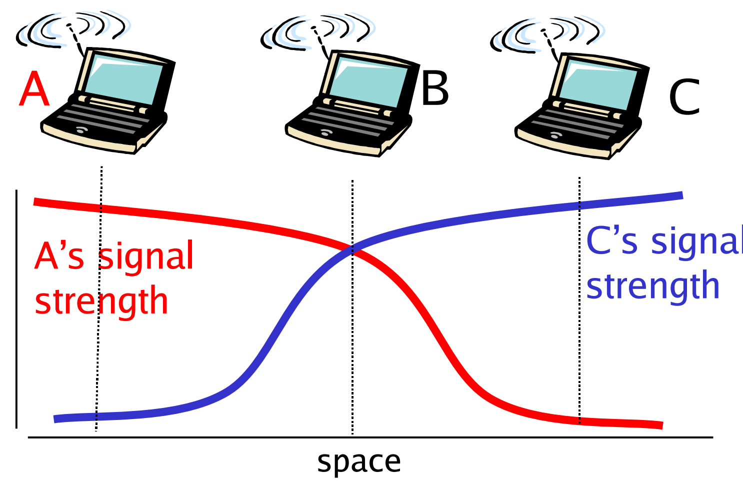
- SNR: signal-to-noise ratio
  - larger SNR – easier to extract signal from noise (a "good thing")
- *SNR versus BER tradeoffs*
  - *given physical layer:* increase power -> increase SNR->decrease BER
  - *given SNR:* choose physical layer that meets BER requirement, giving highest throughput
    - SNR 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

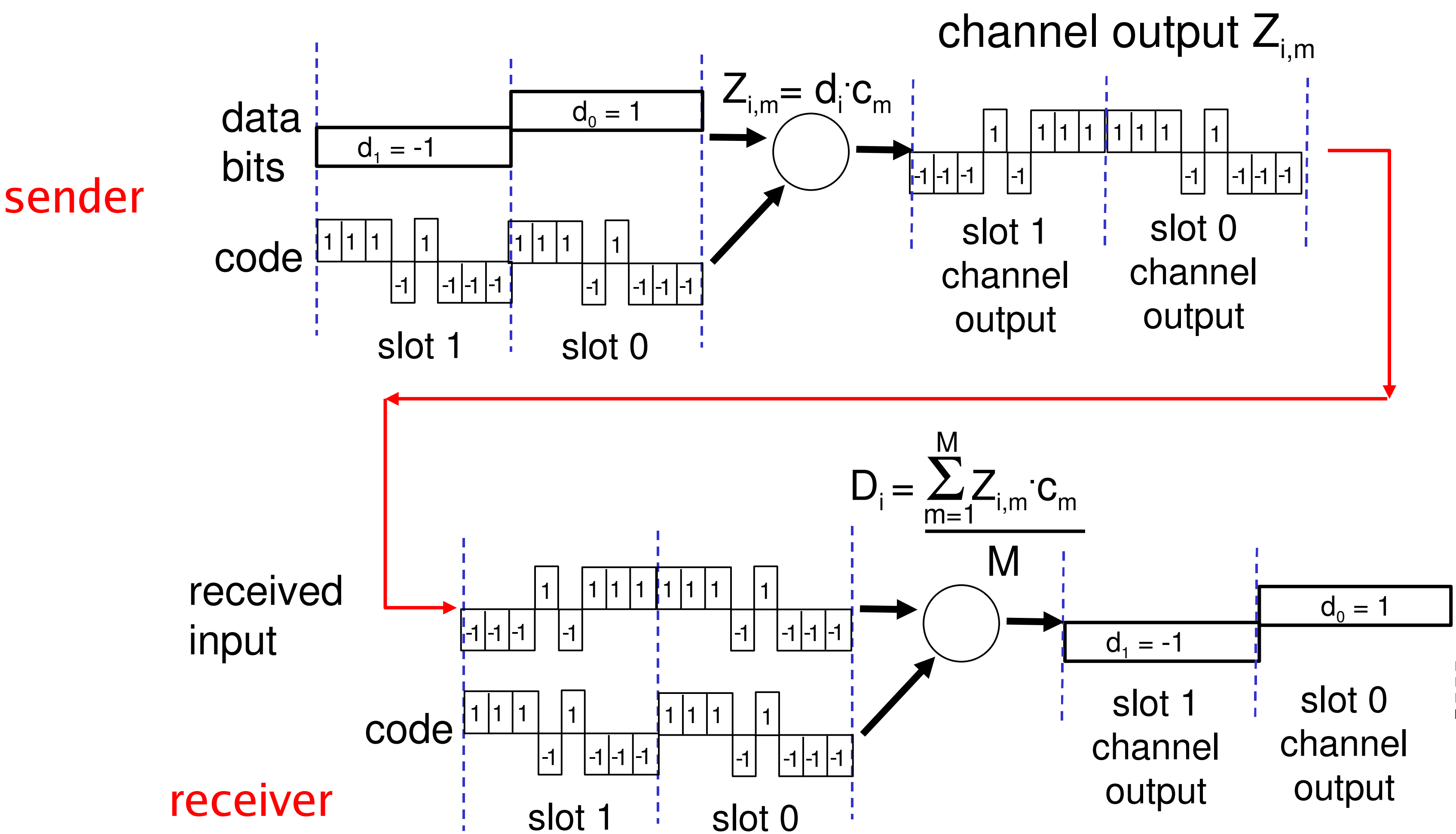
Signal attenuation:

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

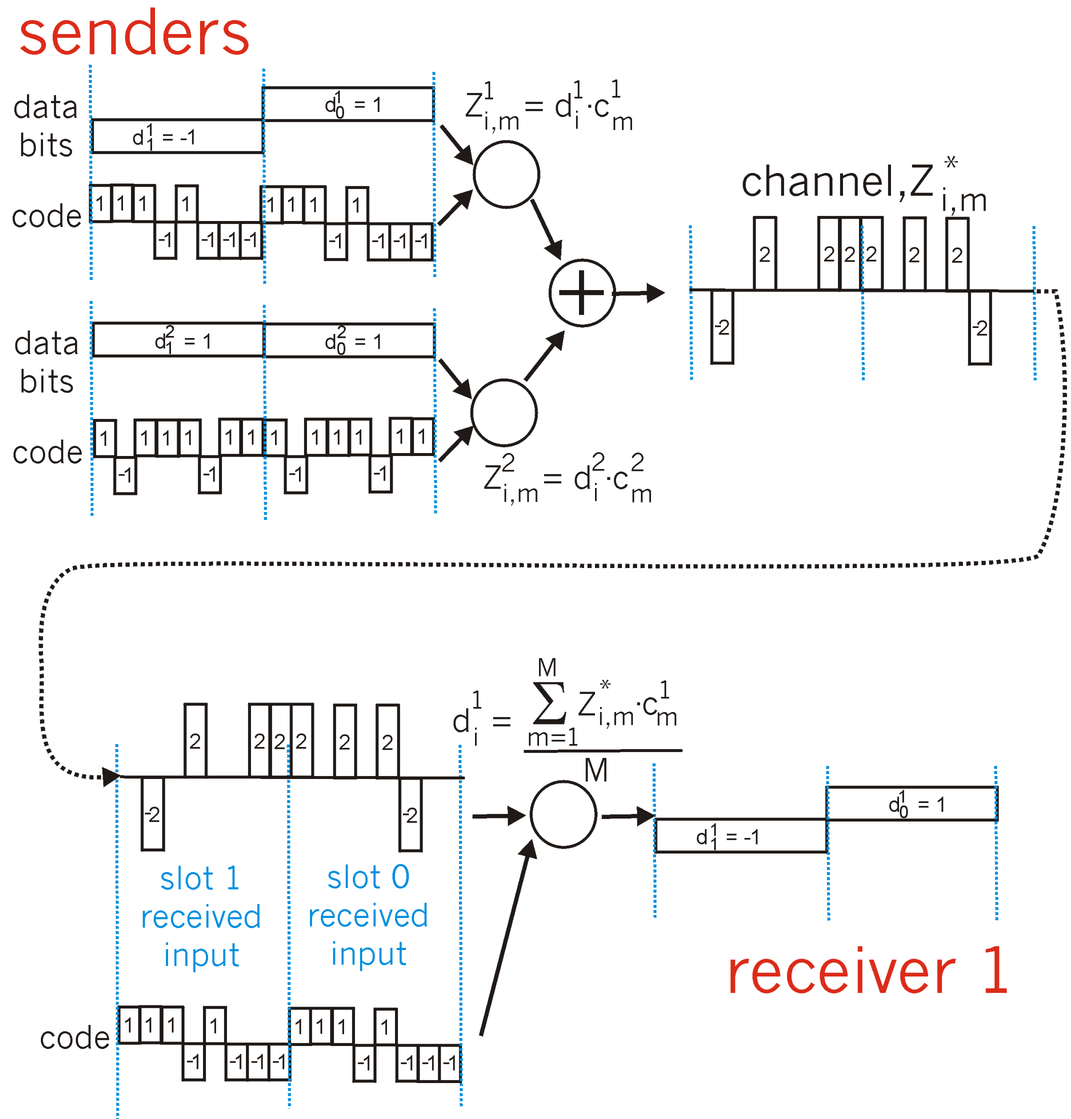
Code Division Multiple Access (CDMA)

- 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



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
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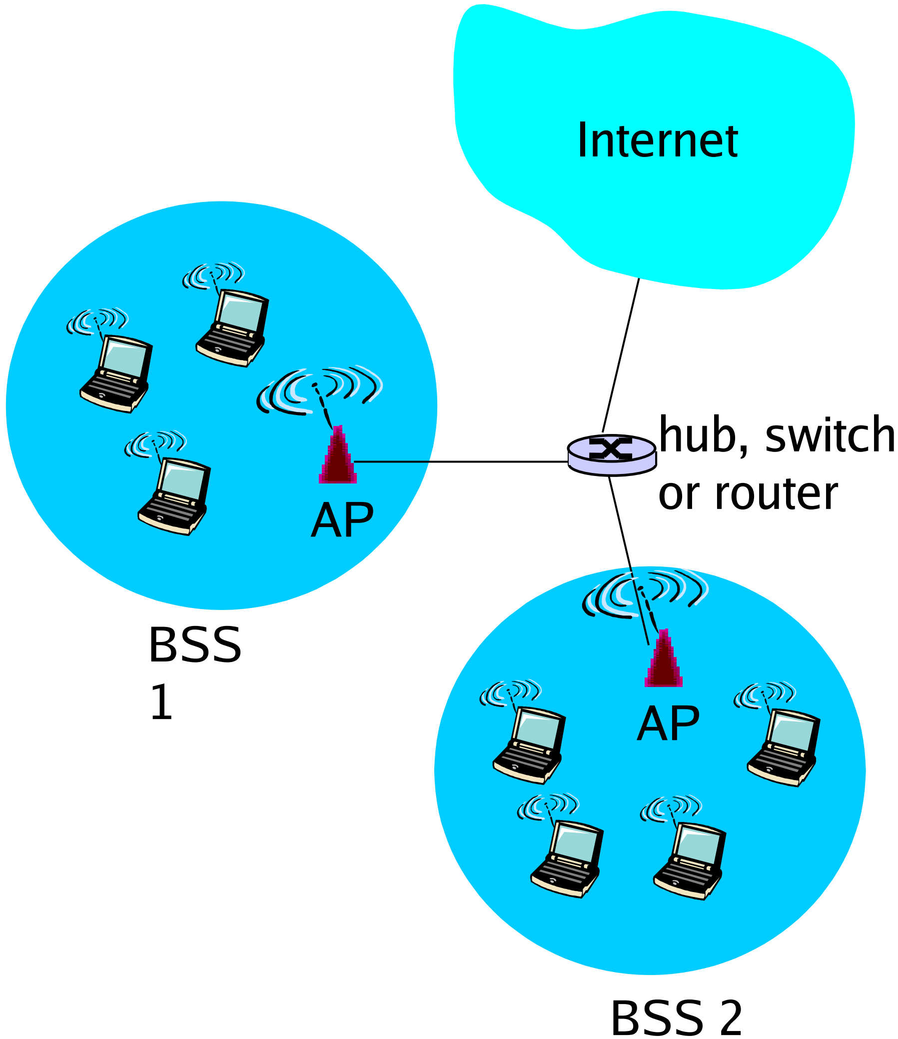
6.9 Summary

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

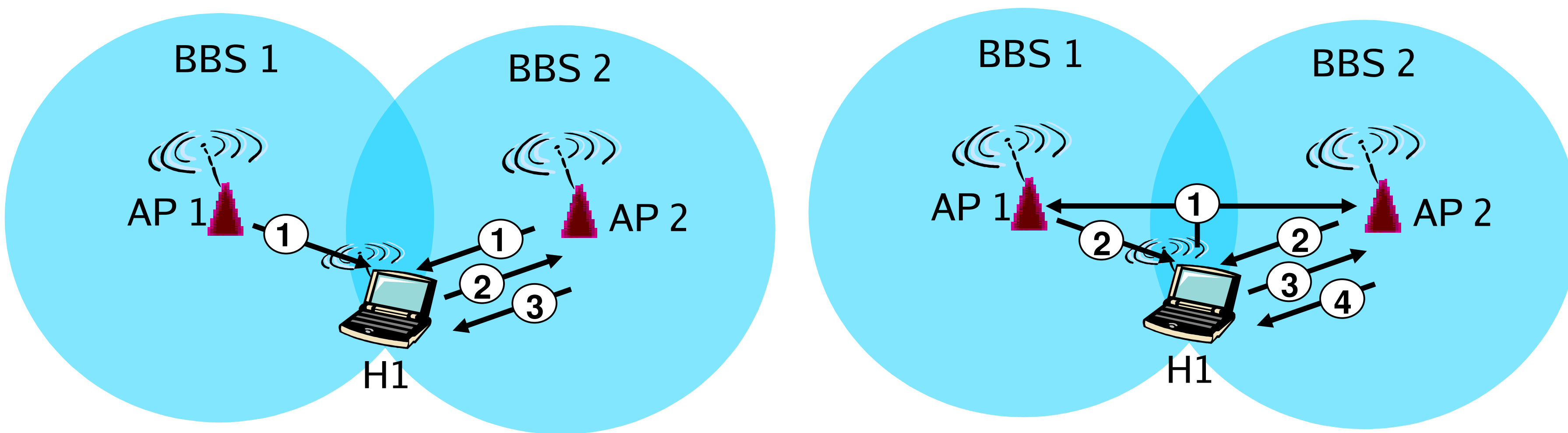


- wireless host communicates with base station
  - base station = access point (AP)
- Basic Service Set (BSS) (aka "cell") in infrastructure mode contains:
  - wireless hosts
  - access point (AP): base station
  - ad hoc mode: hosts only

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:

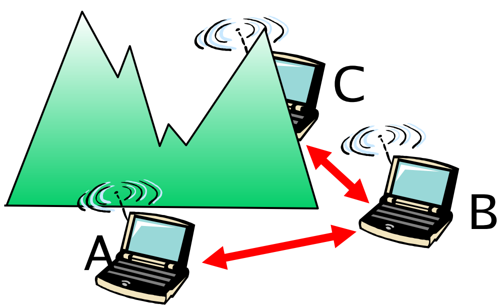
(2) beacon frames sent from APs
(3) association Request frame sent: H1 to selected AP
(4) association Response frame sent: H1 to selected AP

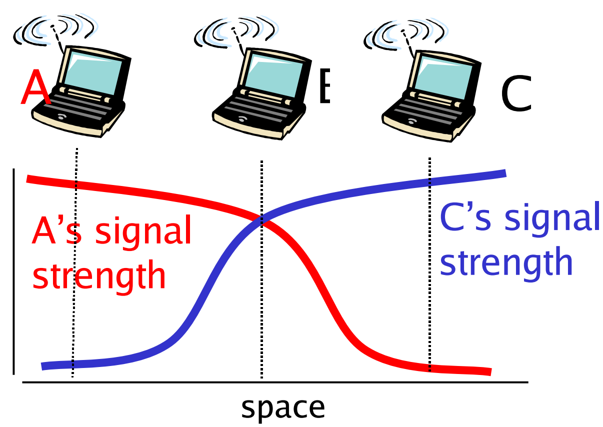
Active Scanning:

(2) Probe Request frame broadcast from H1
(3) Probes response frame sent from APs
(4) Association Request frame sent: H1 to selected AP
(5) Association Response frame sent: H1 to selected AP

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: Hidden terminal problem
  - 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

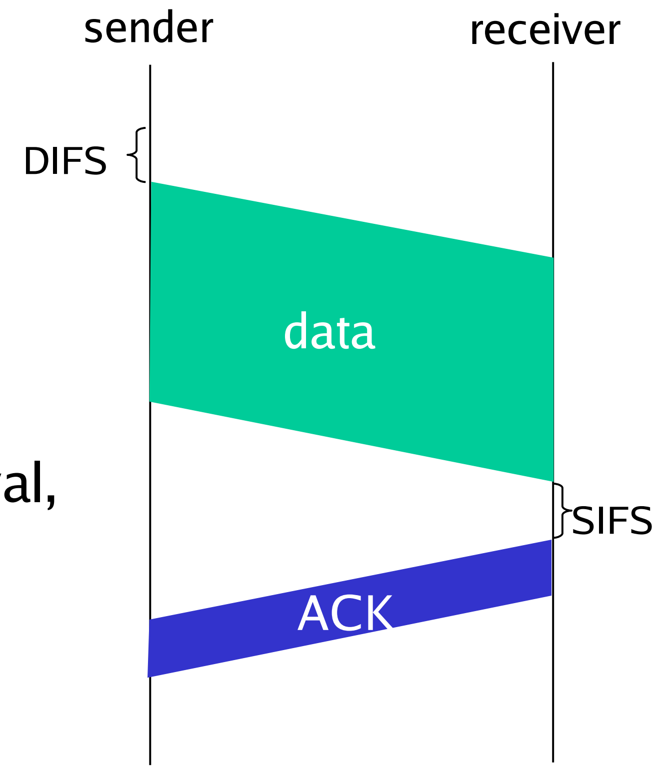
transmit when timer expires

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)



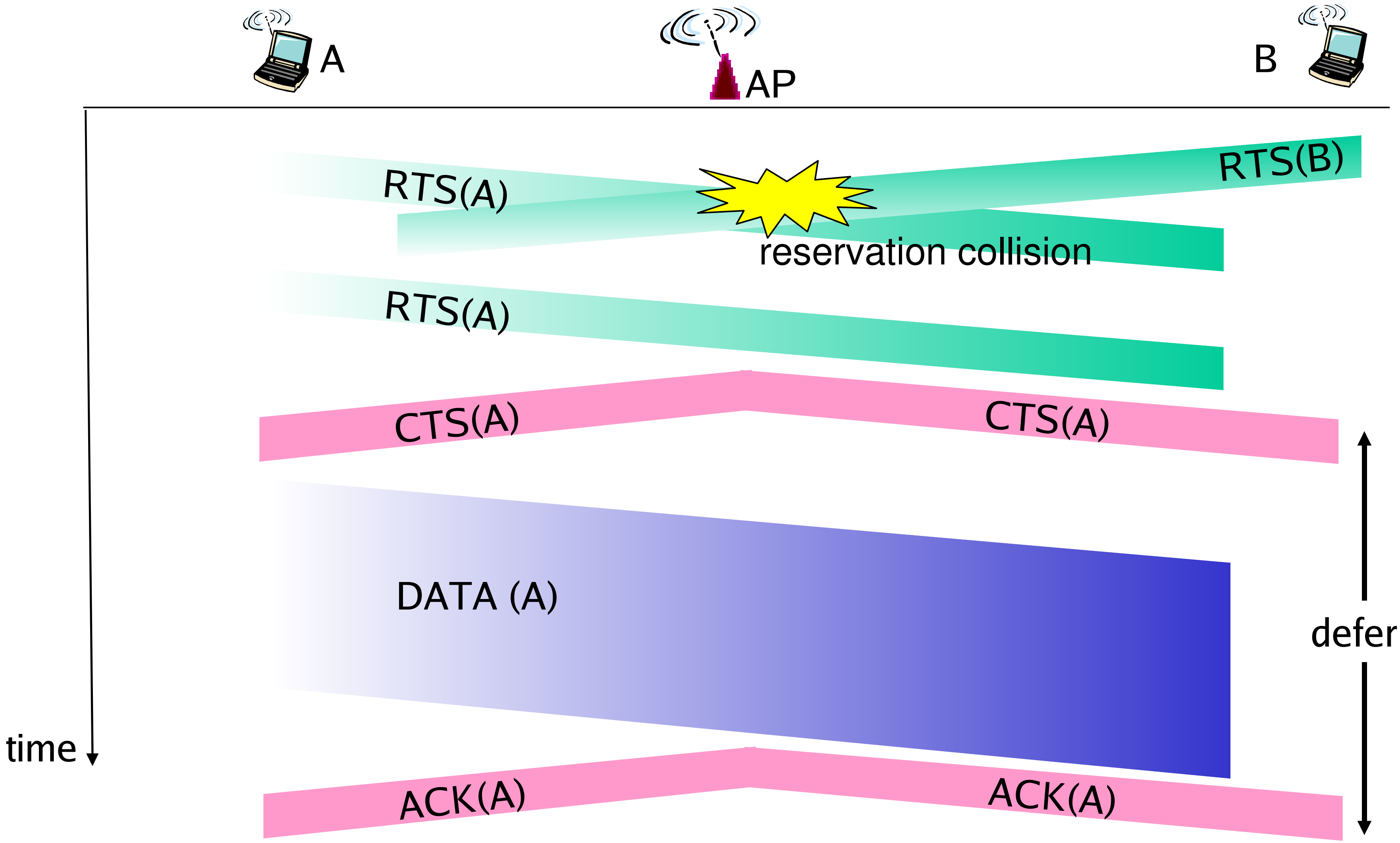
Avoiding collisions

Design: 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
- RTS 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

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

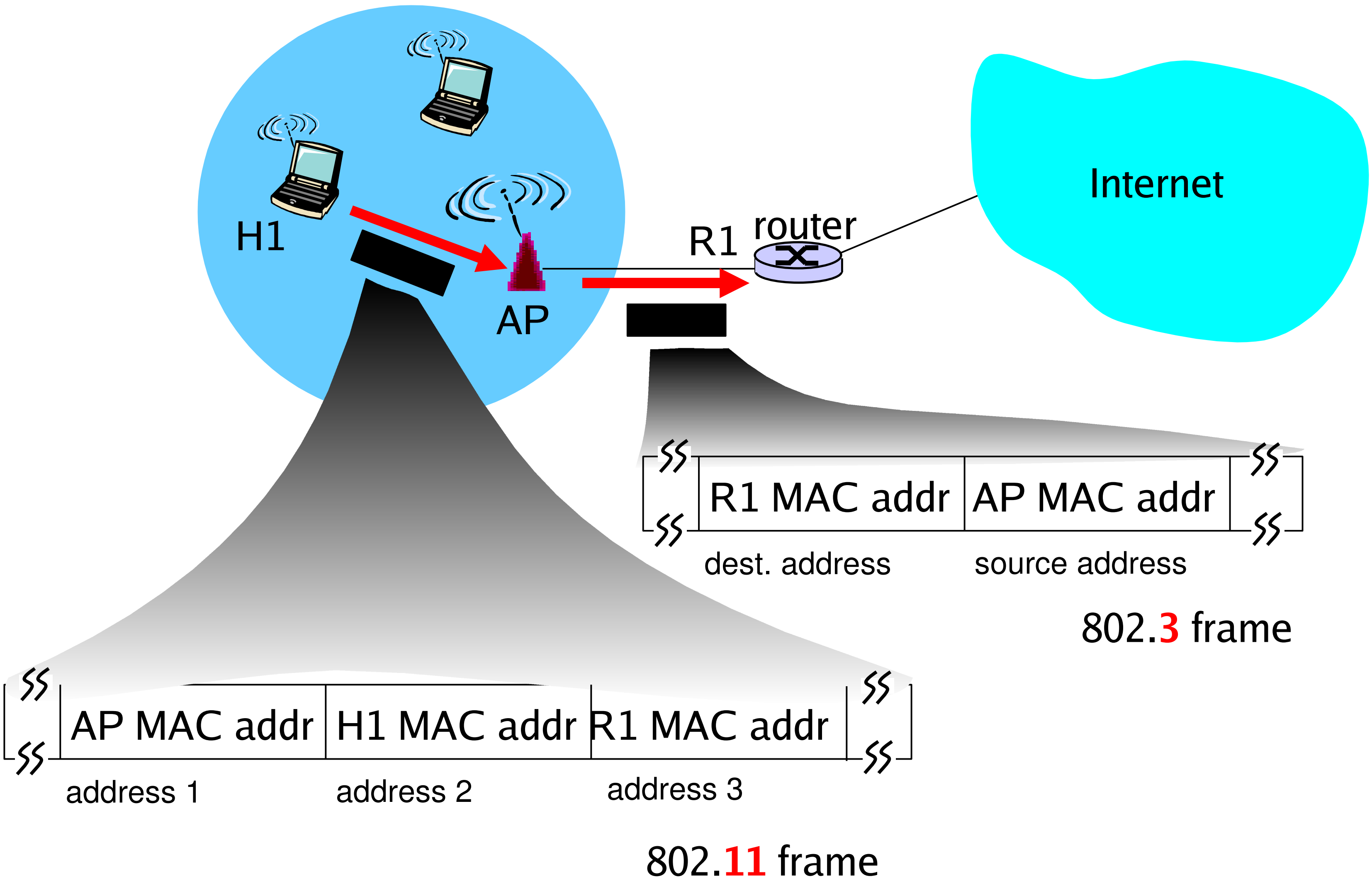
Address 1: MAC address of wireless host or AP to receive this frame

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

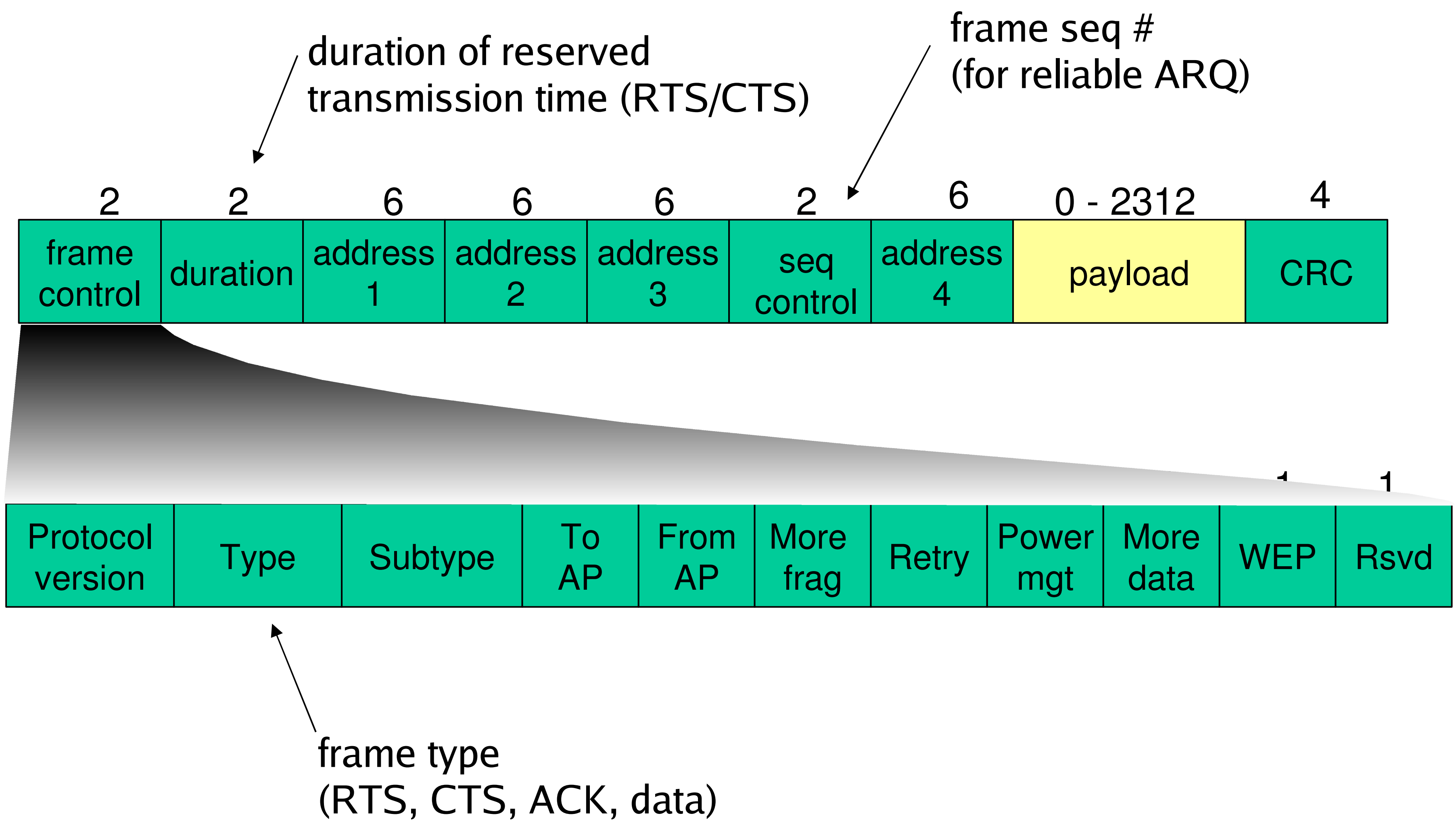
Address 3: MAC address of router interface to which AP is attached

Address 4: used only in ad hoc mode

802.11 frame: addressing

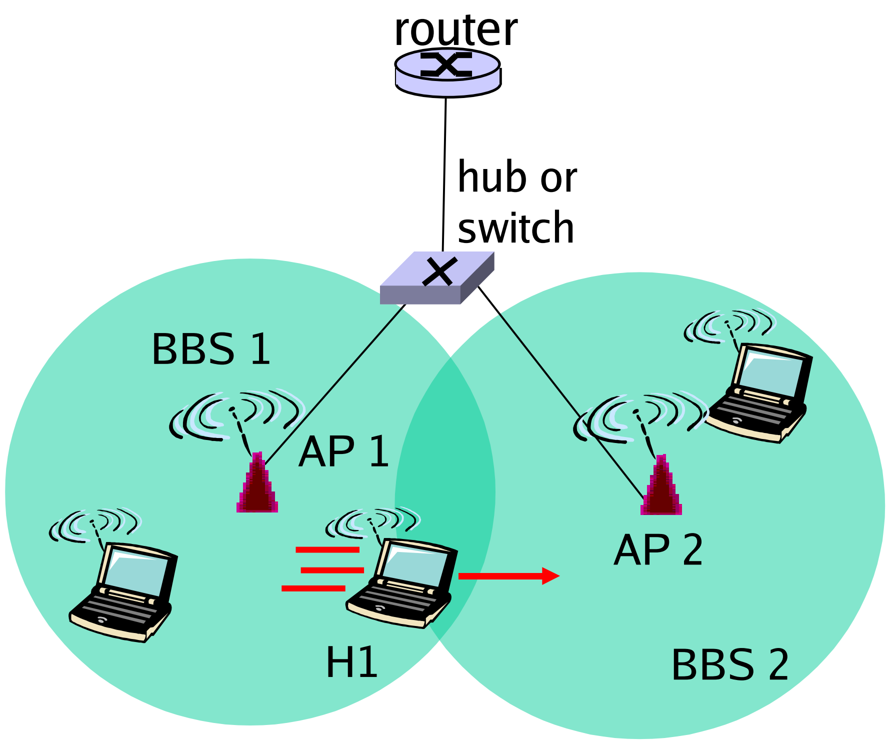


802.11 frame:


duration of reserved transmission time (RTS/CTS)
frame seq # (for reliable ARQ)
2
2
6
6
6
2
6
0 - 2312
4
frame control
duration
address 1
address 2
address 3
seq control
address 4
payload
CRC
1
Protocol version
Type
Subtype
To AP
From AP
More frag
Retry
Power mgt
More data
WEP
Rsvd
frame type (RTS, CTS, ACK, data)

802.11: mobility within same subnet

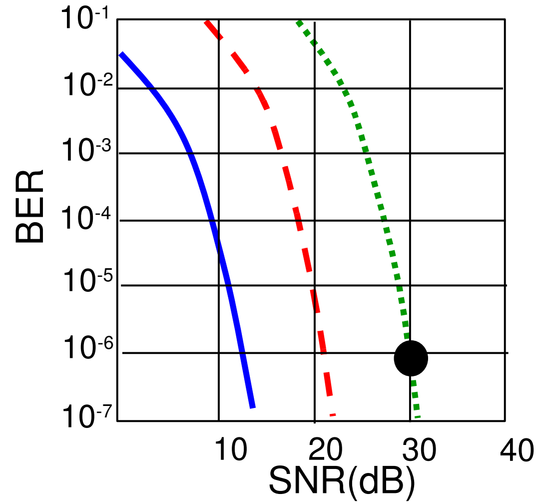
- H1 remains in same IP subnet: IP address can remain same
- switch: which AP is associated with H1?
  - self-learning (Ch. 5): switch will see frame from H1 and "remember" which switch port can be used to reach H1

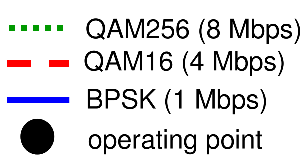


802.11: advanced capabilities

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

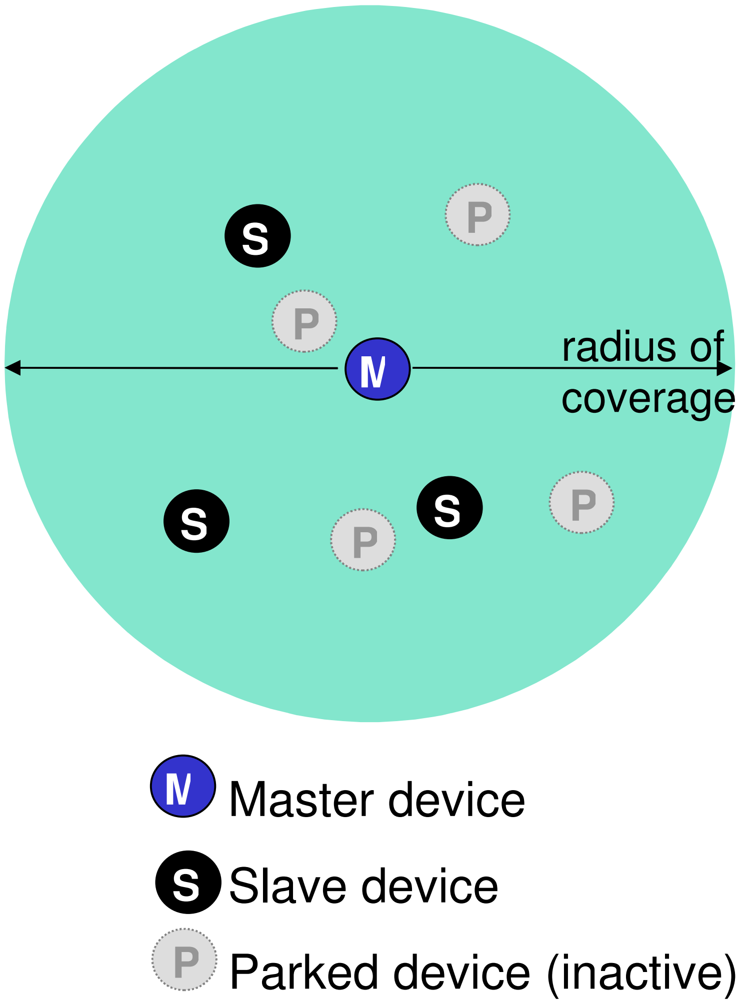
802.11: advanced capabilities

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

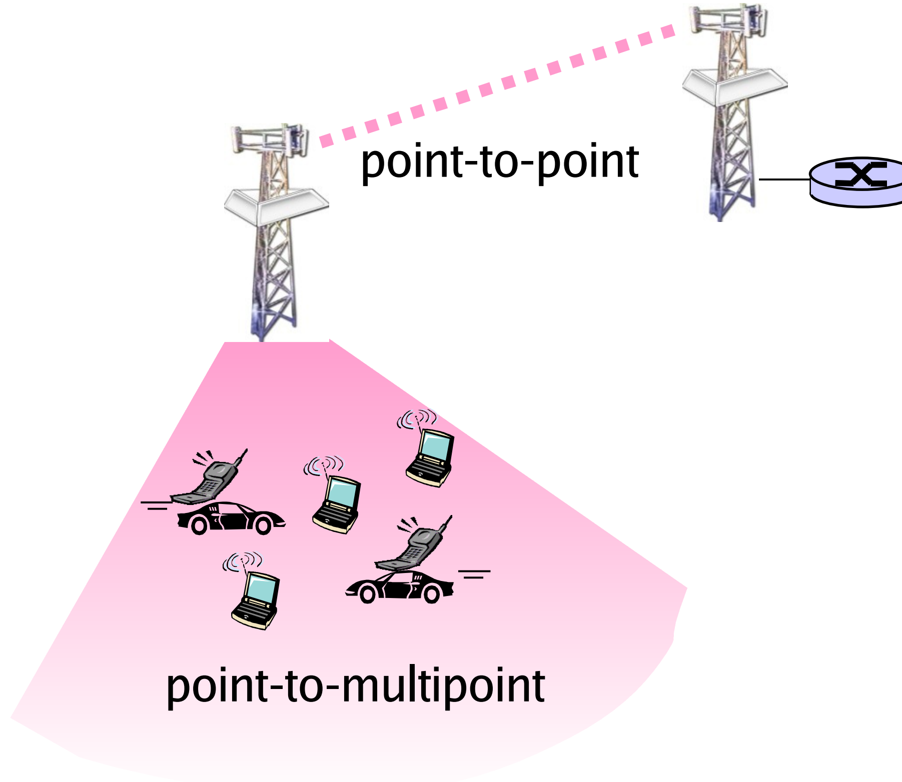
802.15: personal area network

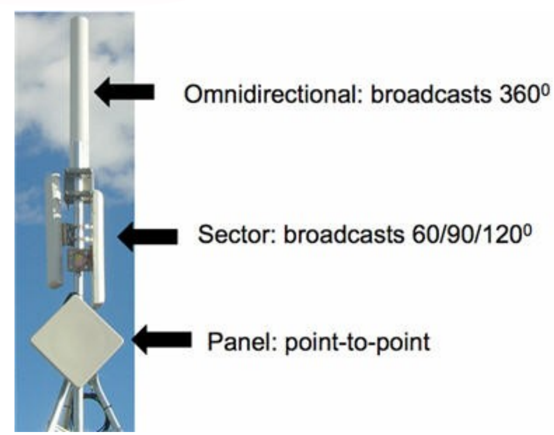
- less than 10 m diameter
- replacement for cables (mouse, keyboard, headphones)
- ad hoc: no infrastructure
- master/slaves:
  - slaves request permission to send (to master)
  - master grants requests
- 802.15: evolved from Bluetooth specification
  - 2.4-2.5 GHz radio band
  - up to 721 kbps



802.16: WiMAX

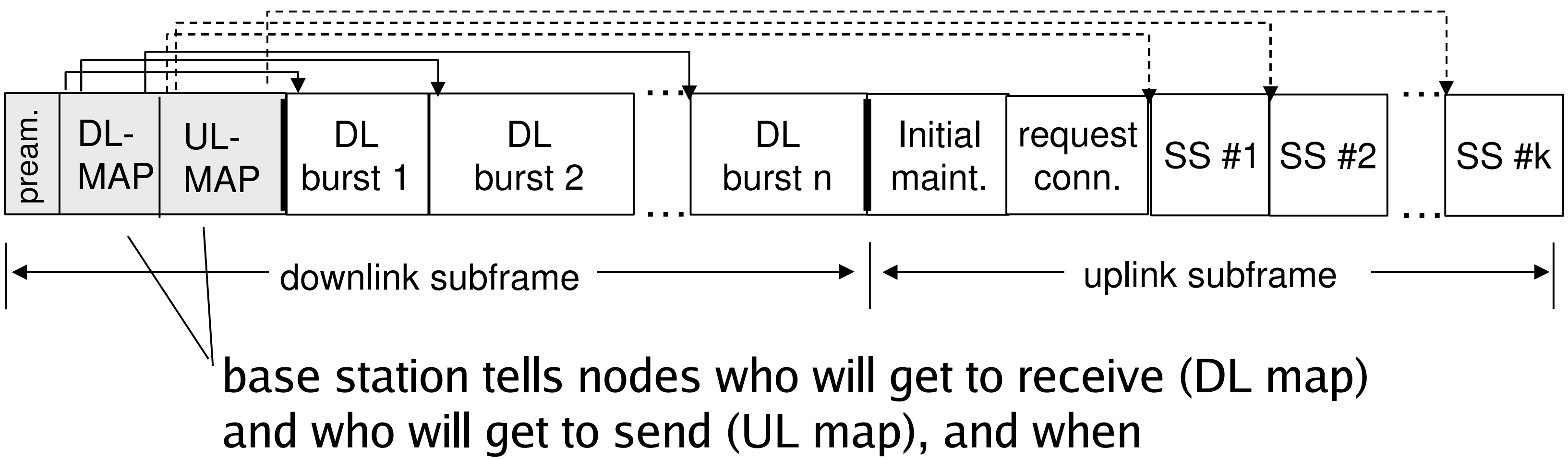
- like 802.11 & cellular: base station model
  - transmissions to/from base station by hosts with omnidirectional antenna
  - base station-to-base station backhaul with point-to-point antenna
- unlike 802.11:
  - range ~ 6 miles ("city rather than coffee shop")
  - ~14 Mbps





802.16: WiMAX: downlink, uplink scheduling

- transmission frame
  - down-link subframe: base station to node
  - uplink subframe: node to base station



- WiMAX standard provide mechanism for scheduling, but not scheduling algorithm

Chapter 6

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

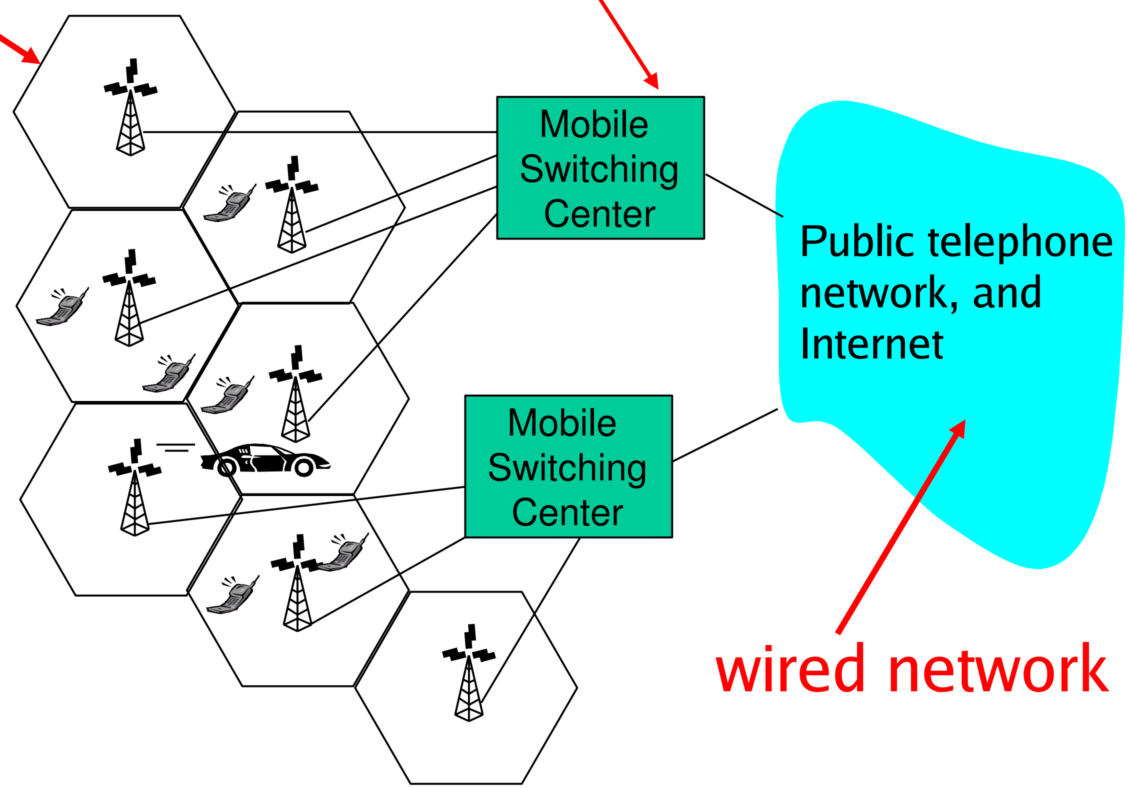
Components of cellular network architecture

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

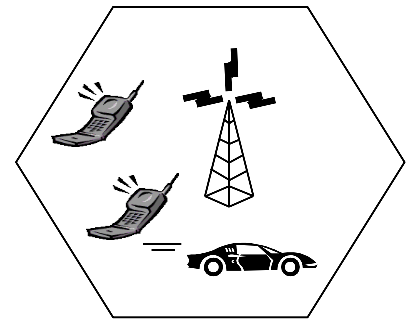
- connects cells to wide area net
- manages call setup (more later!)
- handles mobility (more later!)

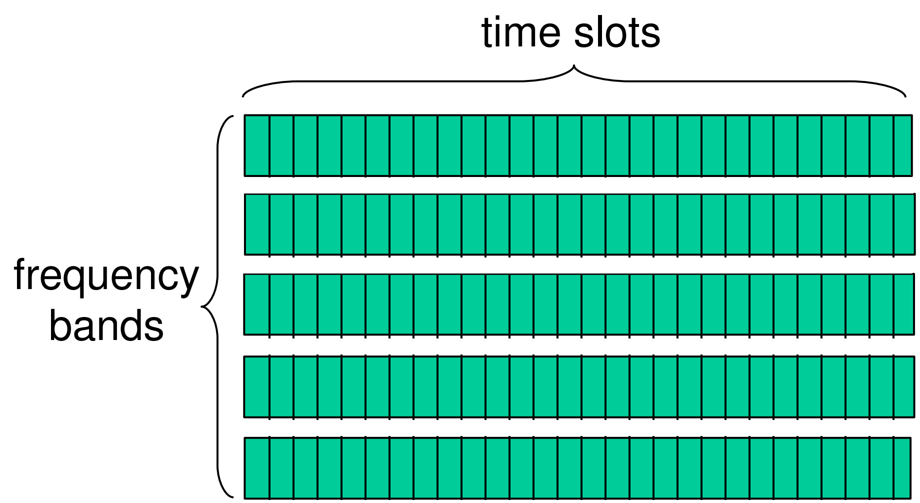


Cellular networks: the first hop

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

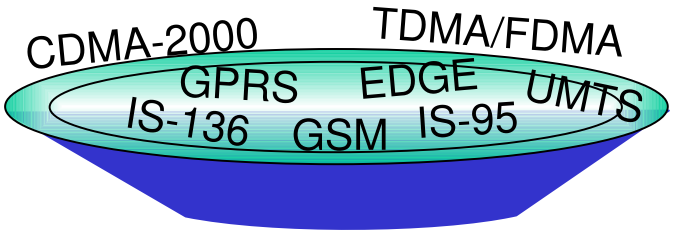




Cellular standards: brief survey

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



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)
  - data service: High Speed Uplink/Downlink packet Access (HSDPA/HSUPA): 3 Mbps
- CDMA-2000: CDMA in TDMA slots
  - data service: 1xEvlution Data Optimized (1xEVDO) up to 14 Mbps

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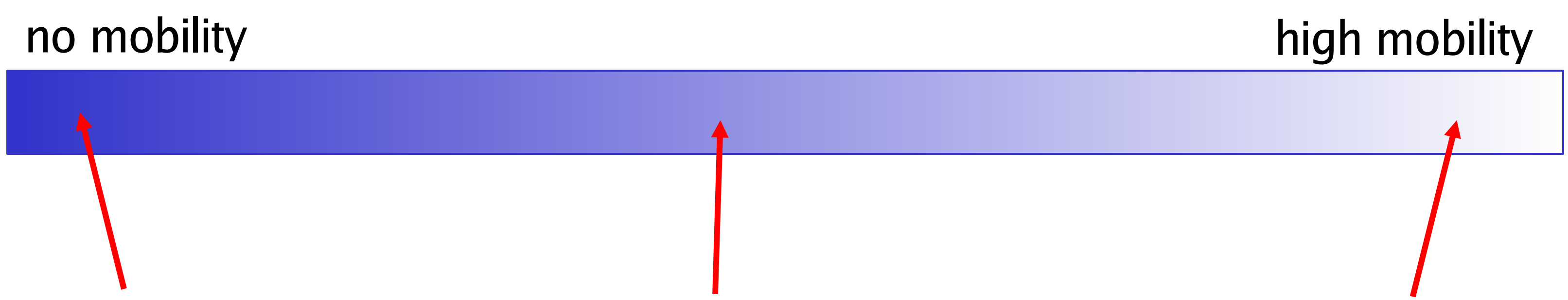
What is mobility?

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



mobile wireless user, using same access point

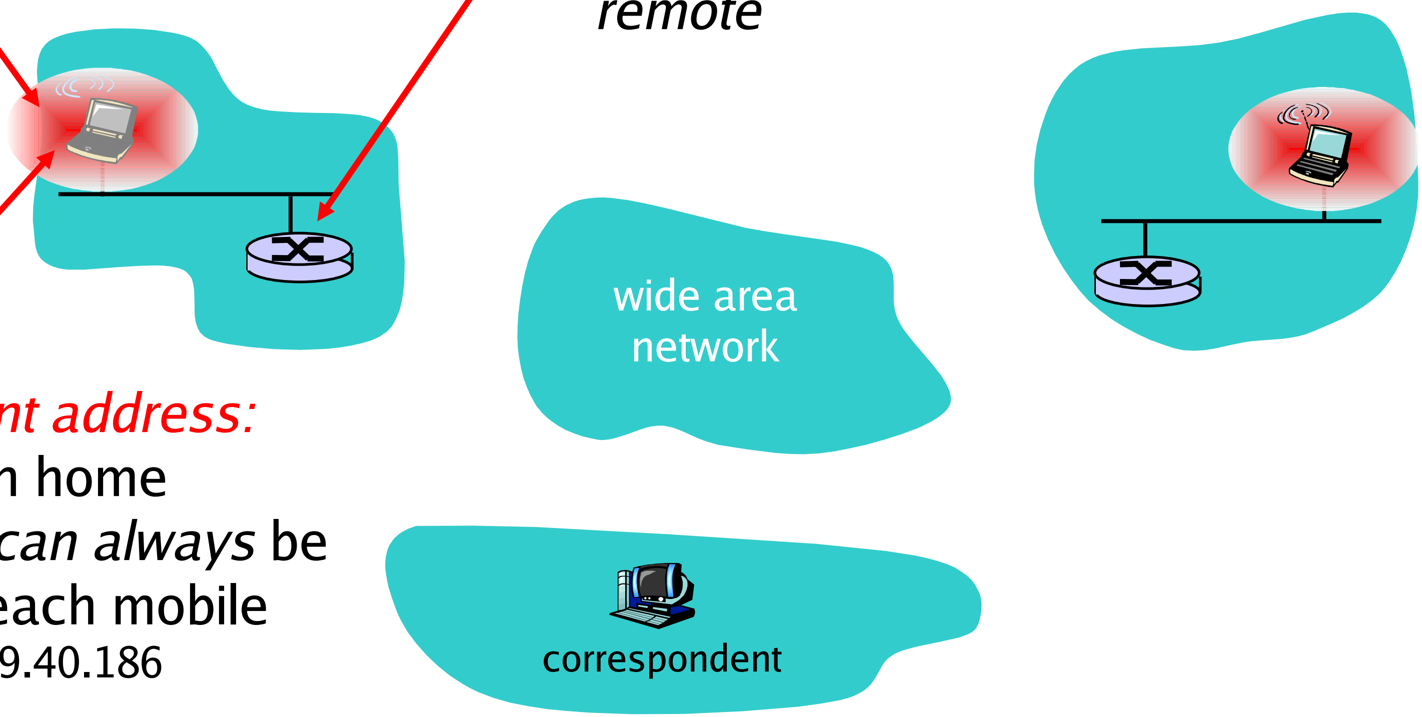
mobile user, connecting/ disconnecting from network using DHCP.

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



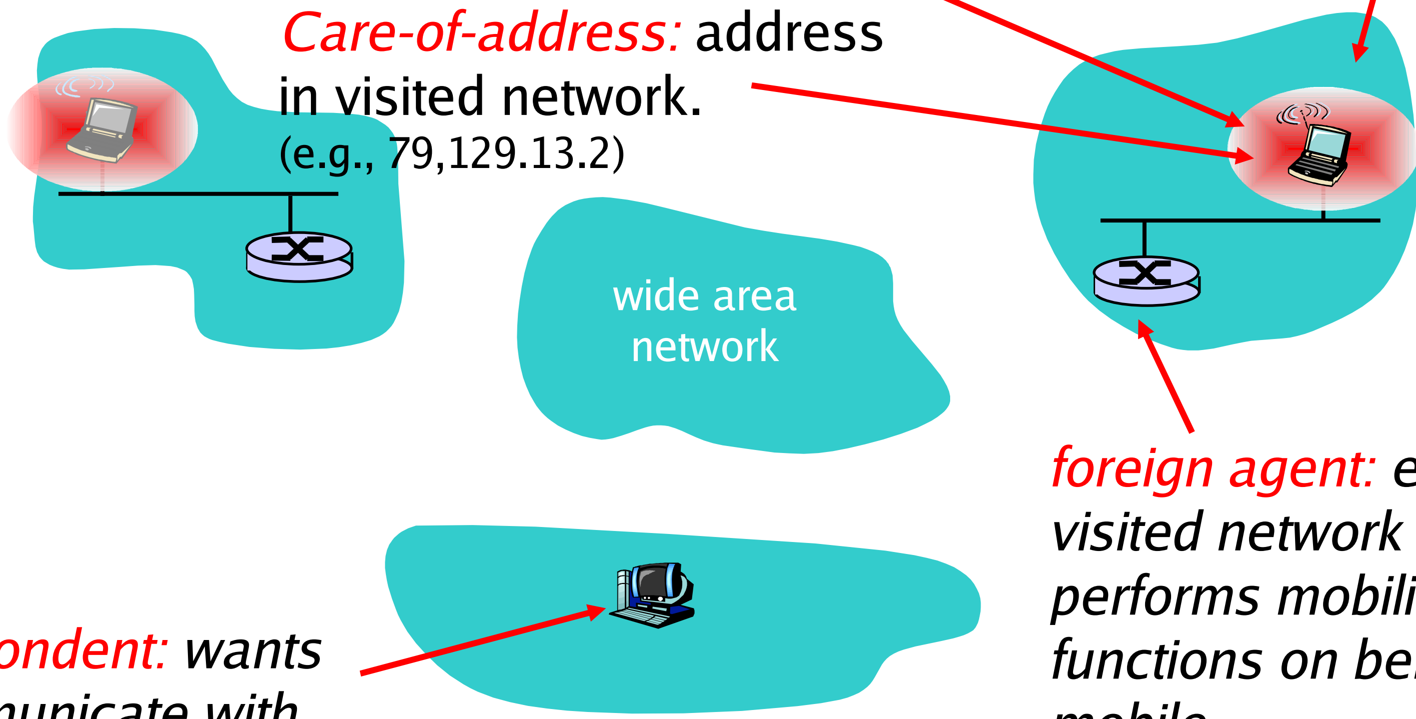
Permanent address:
address in home network, *can always* be used to reach mobile
e.g., 128.119.40.186

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)



correspondent: wants to communicate with mobile

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

How do *you* contact a mobile friend:

Consider a friend who 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?

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

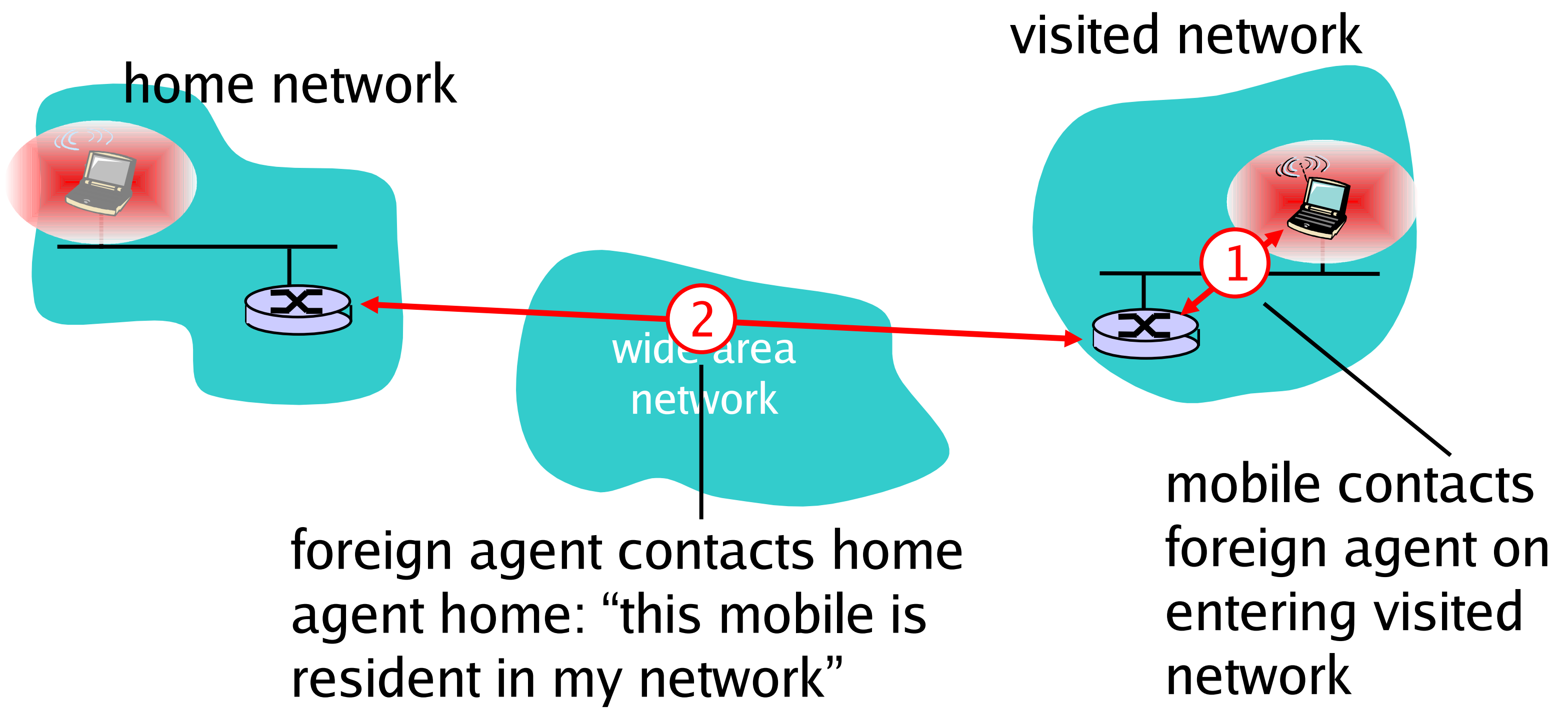
Mobility: possible solutions

- *Let routing handle it:* ...ers advertise permanent address of mobil... ...esidence via usual routing table exchange.
  - routing tables ... ...re each mobile located
  - no changes to en... ...stems

not
scalable
to millions of
mobiles

- *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

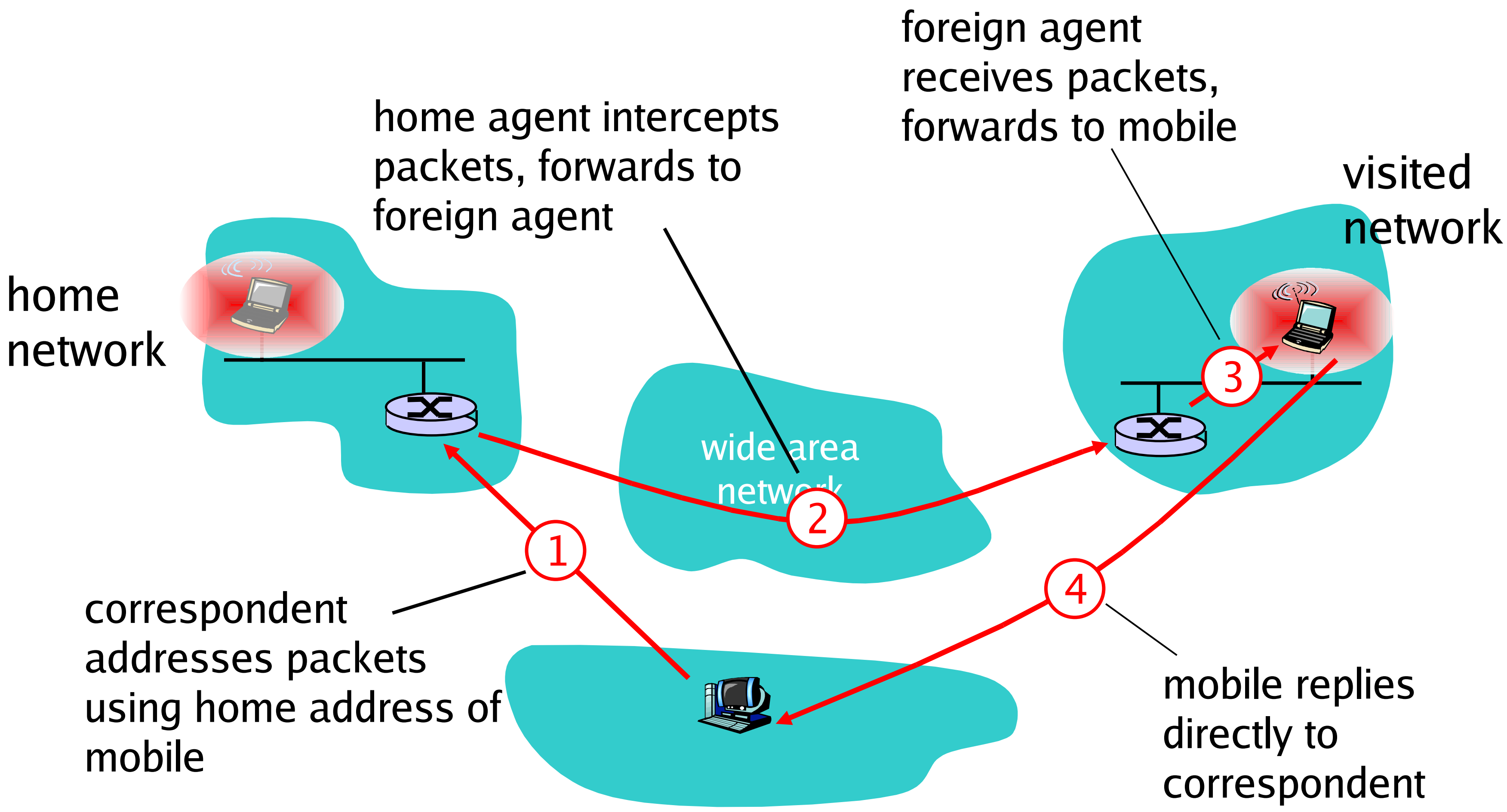
Mobility: registration



End result:

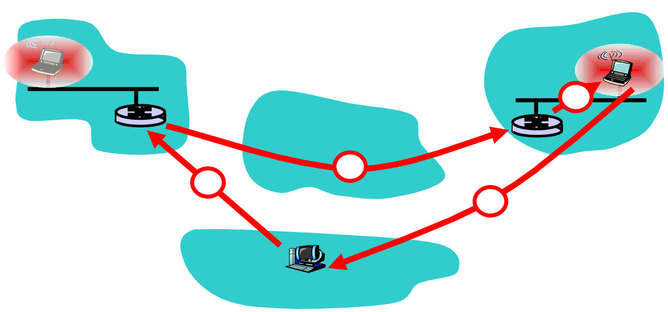
- Foreign agent knows about mobile
- Home agent knows location of mobile

Mobility via Indirect Routing



Indirect Routing: comments

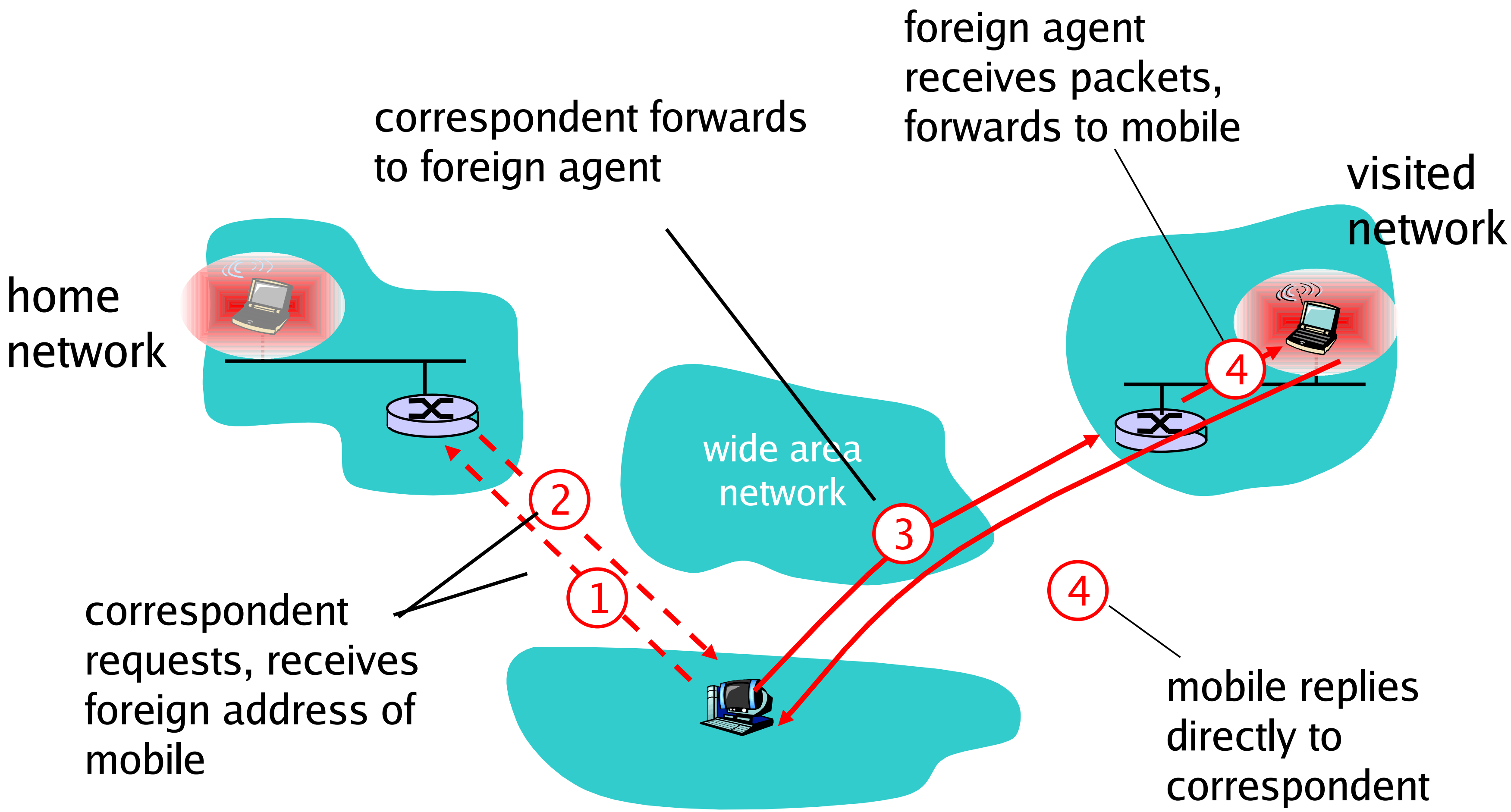
- Mobile uses two addresses:
  - permanent address: used by correspondent (hence mobile location is *transparent* to correspondent)
  - care-of-address: used by home agent to forward datagrams to mobile
- foreign agent functions may be done by mobile itself
- triangle routing: correspondent-home-network-mobile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



Indirect Routing: moving between networks

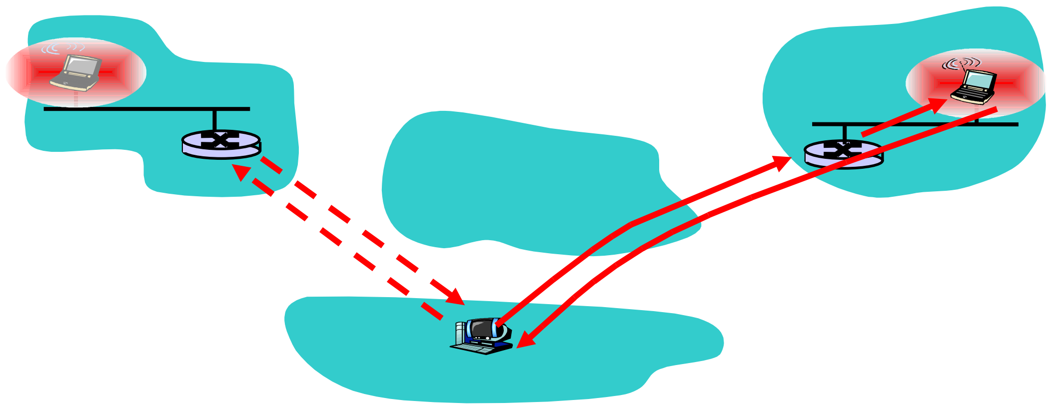
- suppose mobile user moves to another network
  - registers with new foreign agent
  - new foreign agent registers with home agent
  - home agent update care-of-address for mobile
  - packets continue to be forwarded to mobile (but with new care-of-address)
- mobility, changing foreign networks transparent: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

Mobility via Direct Routing



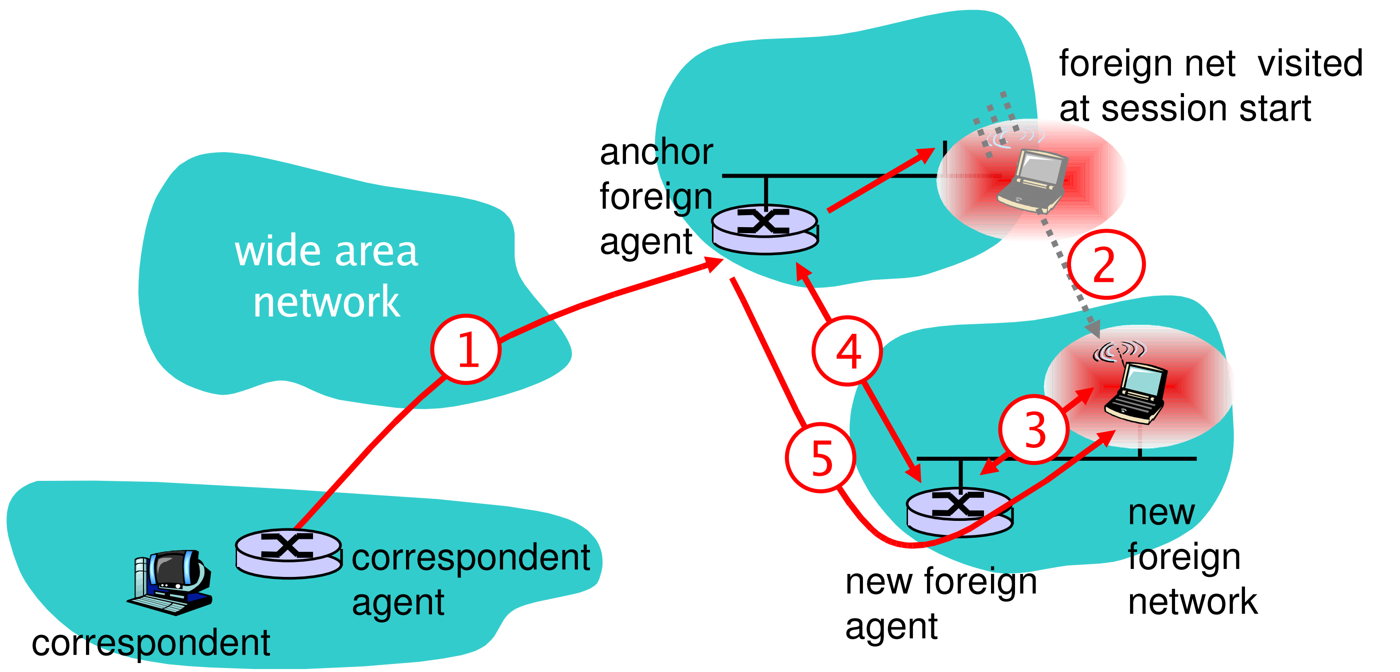
Mobility via Direct Routing: comments

- 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)



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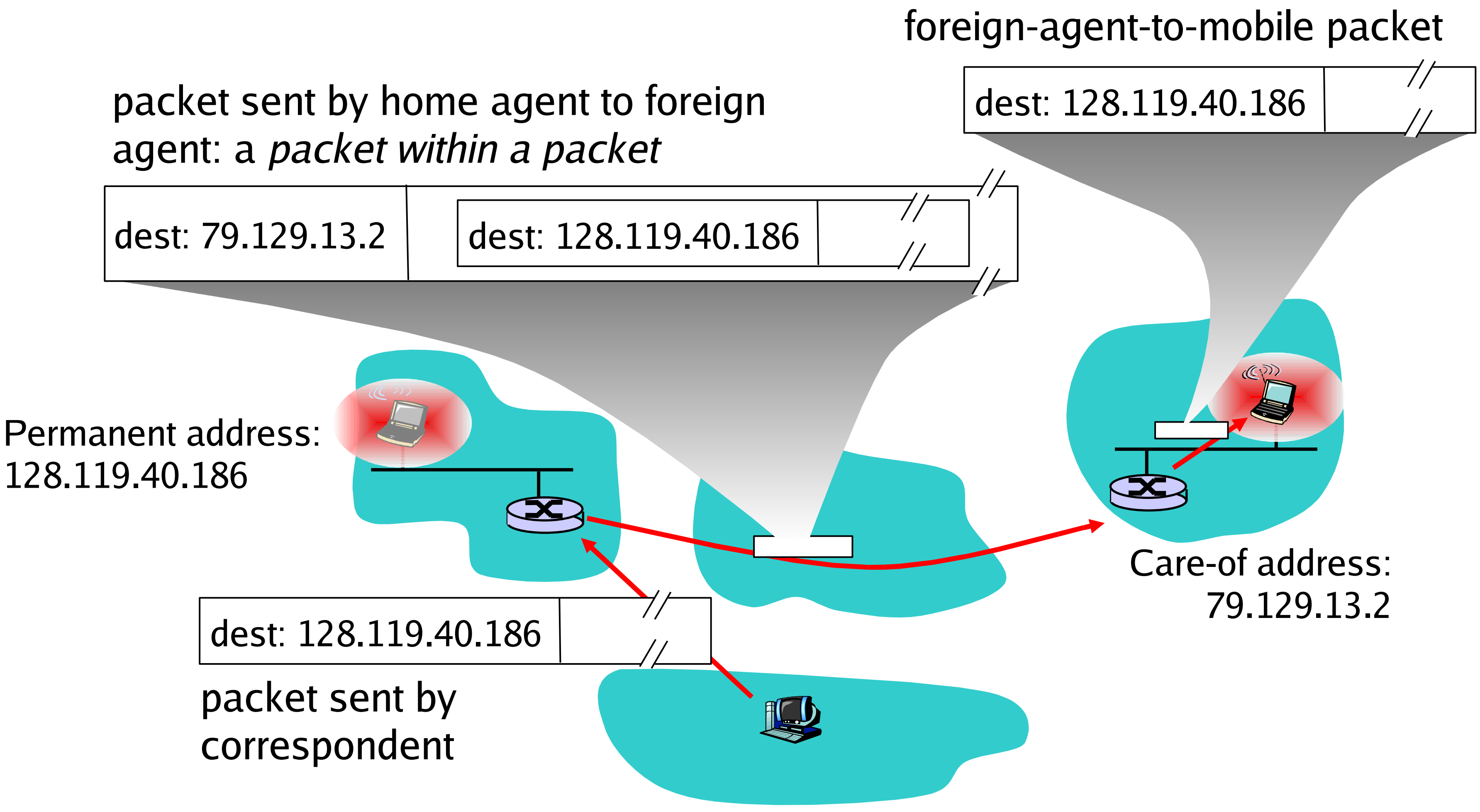
Mobile IP

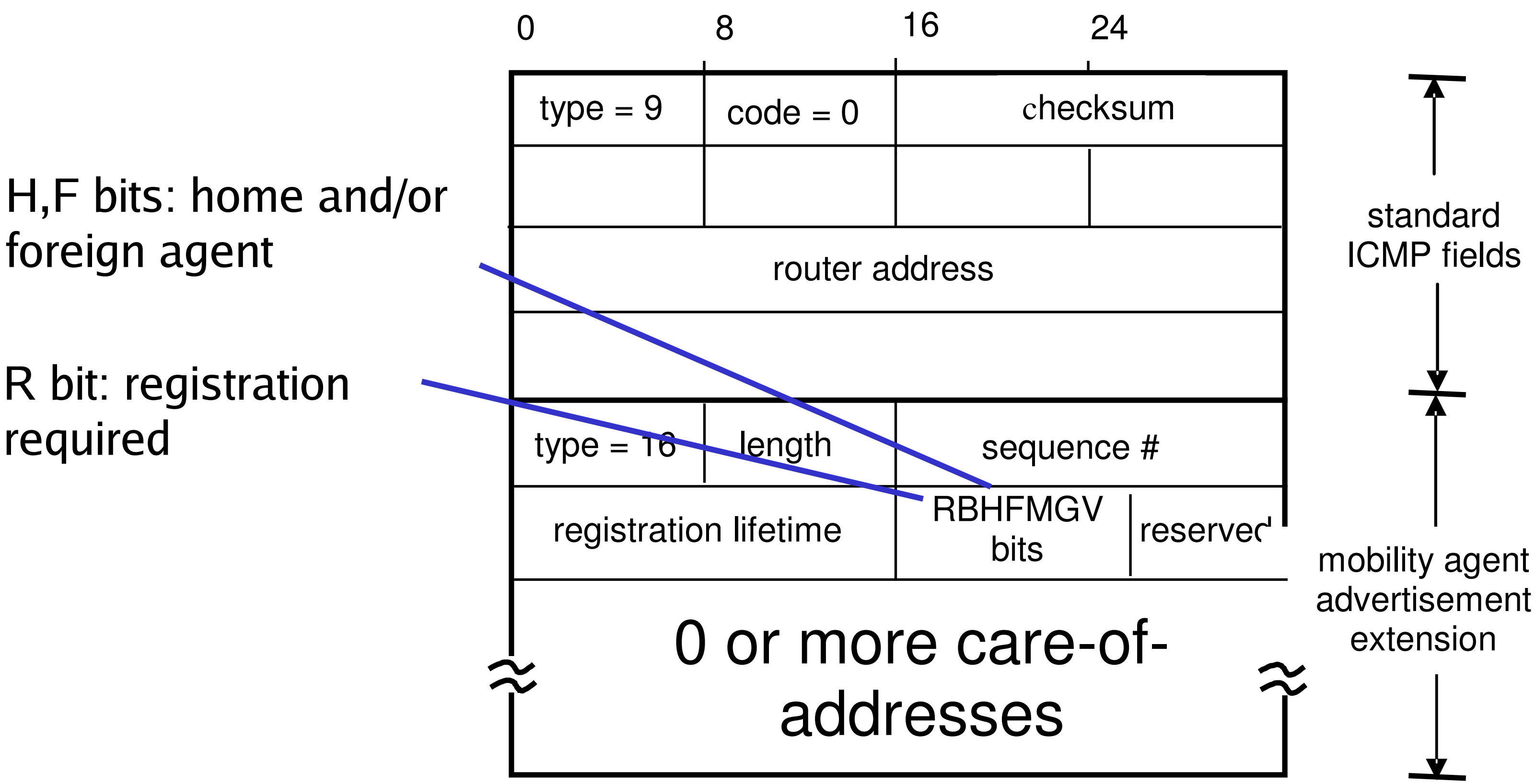
- RFC 3344
- has many features we've seen:
  - home agents, foreign agents, foreign-agent registration, care-of-addresses, encapsulation (packet-within-a-packet)
- three components to standard:
  - indirect routing of datagrams
  - agent discovery
  - registration with home agent

Mobile IP: indirect routing

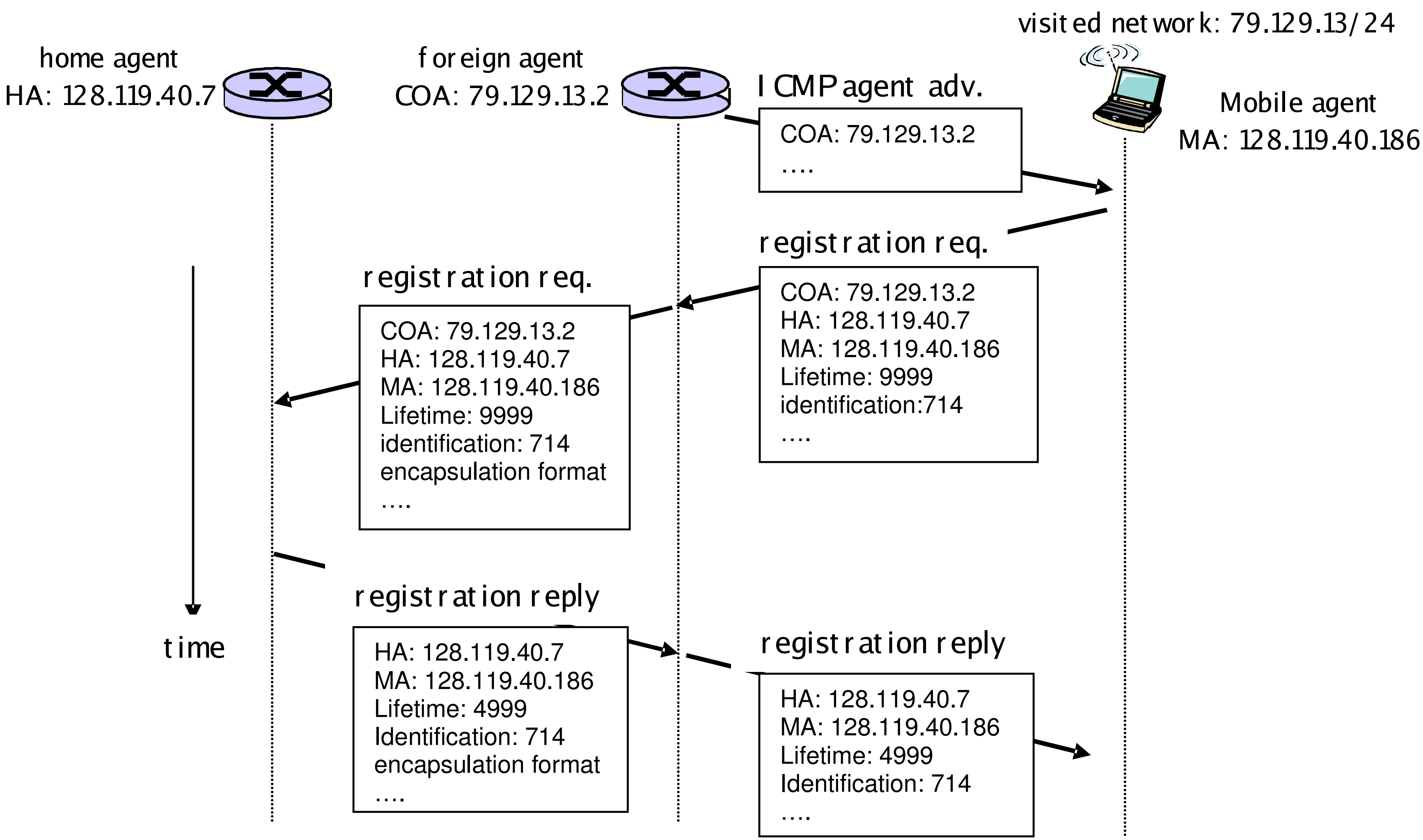


Mobile IP: agent discovery

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

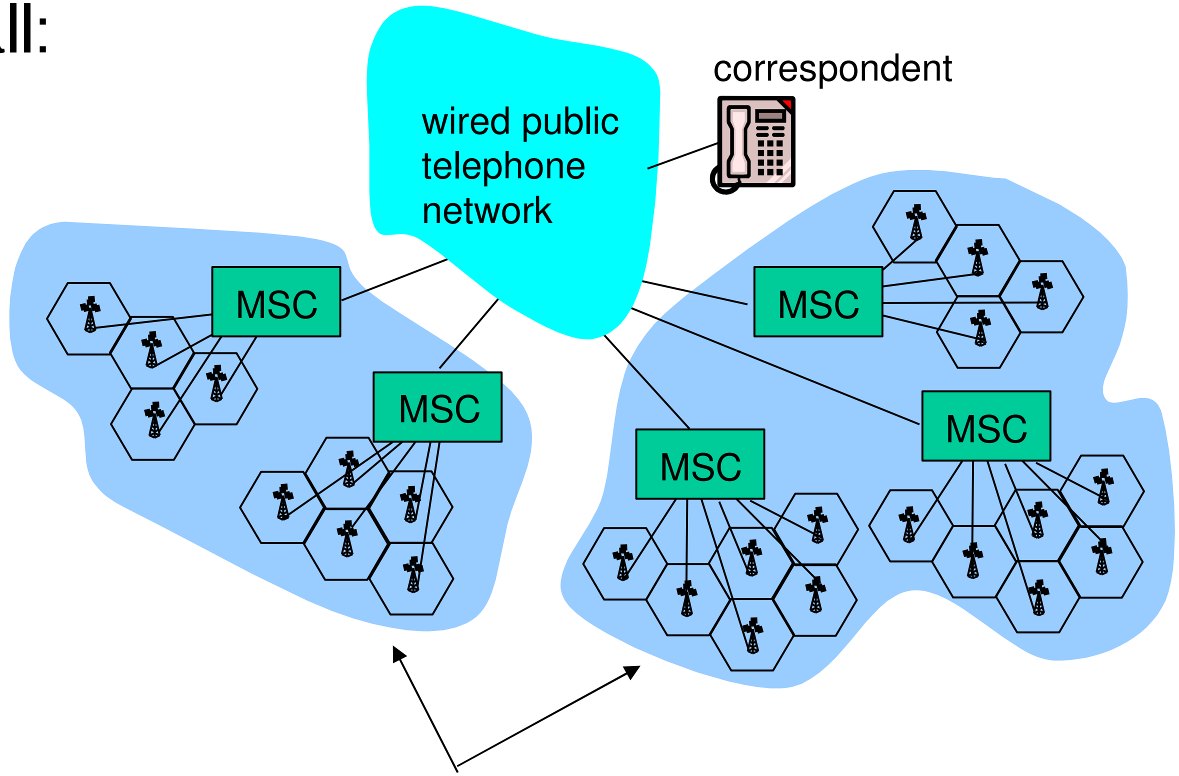


Mobile IP: registration example



Components of cellular network architecture

recall:

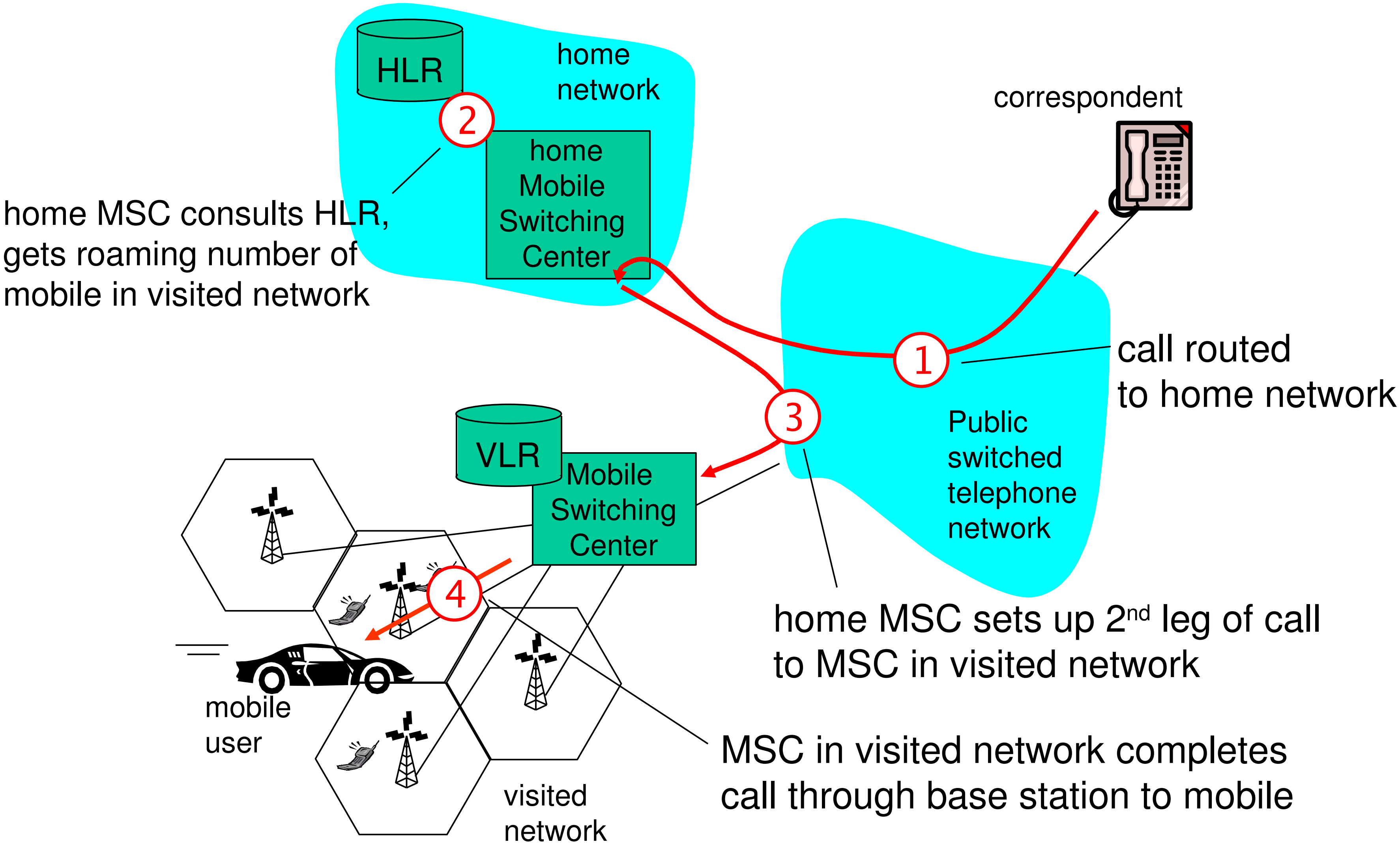


different cellular networks,
operated by different providers

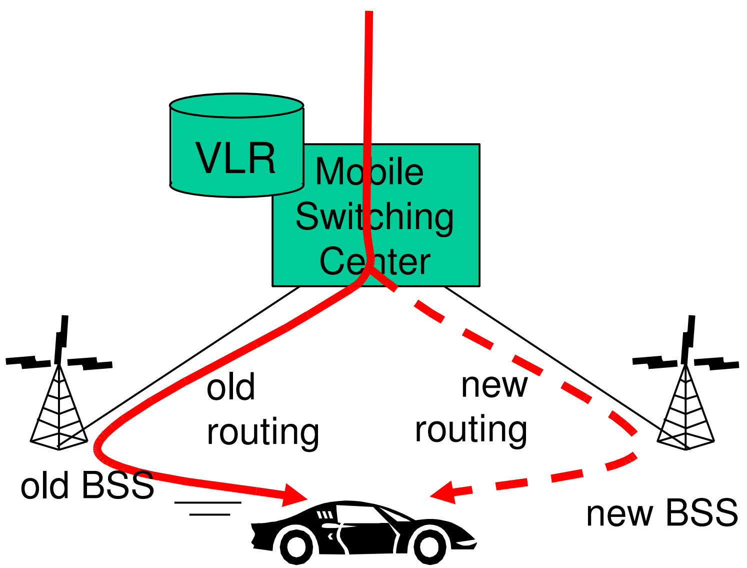
Handling mobility in cellular networks

- *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

GSM: indirect routing to mobile

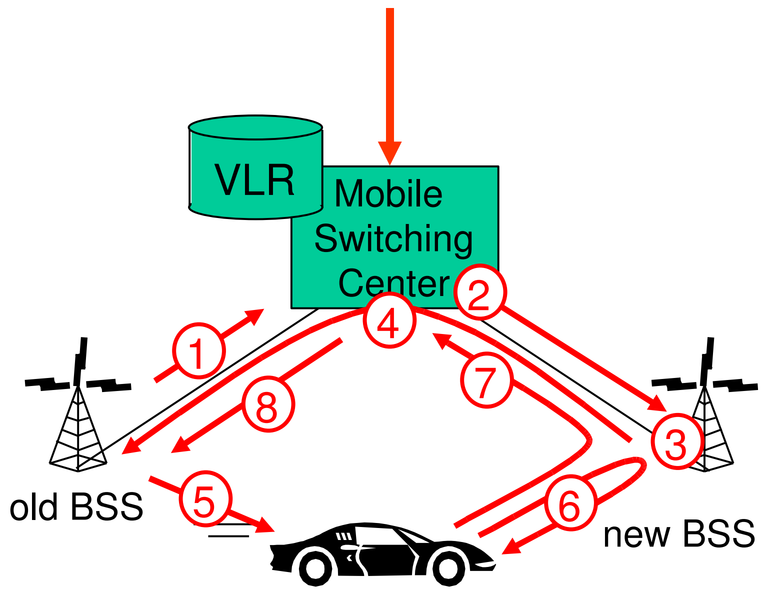


GSM: handoff with common MSC



- 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

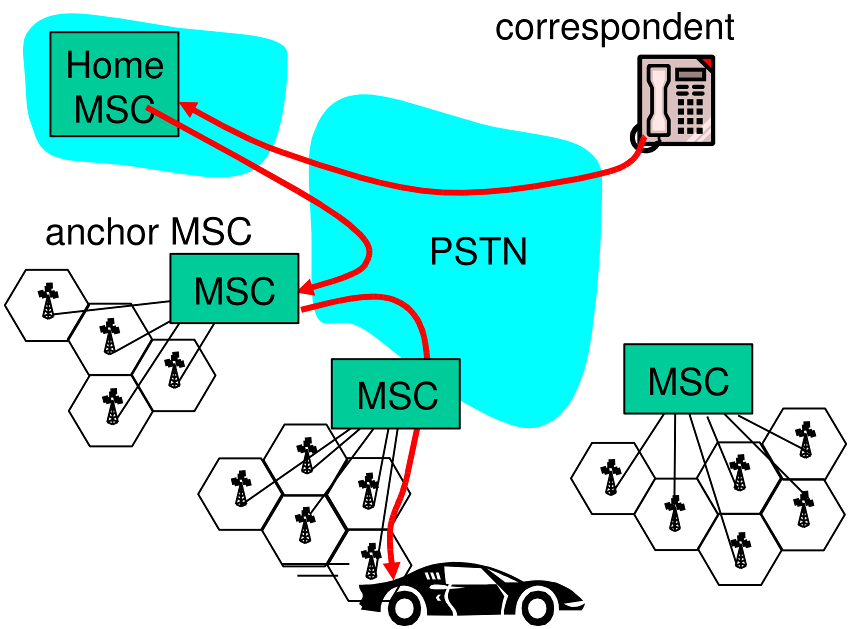
GSM: handoff with common MSC



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

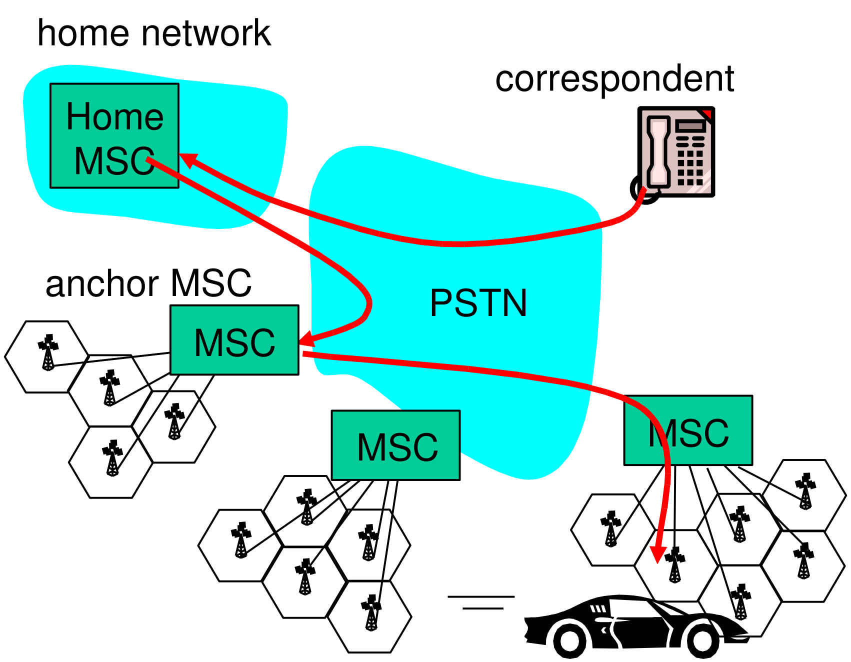
GSM: handoff between MSCs



(a) before handoff

- *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

GSM: handoff between MSCs



(b) after handoff

- *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 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, 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