Distance vector algorithm

iterative, asynchronous:
each local iteration caused by:

- local link cost change
- DV update message from neighbor

distributed:

- each node notifies neighbors *only* when its DV changes
  - neighbors then notify their neighbors if necessary

each node:

wait for (change in local link cost or msg from neighbor)

recompute estimates

if DV to any dest has changed, *notify* neighbors

$$D_y(x)=\min\{c(y,x)+D_x(x),c(y,z)+D_z(x)\}$$
$$D_z(x)=\min(c(z,x)+D_x(x),c(z,y)+D_y(x)\}$$

node x table

from \ cost to	x	y	z
x	0	~~4~~ 51	~~5~~ 50
y	4	0	1
z	5	1	0

Detect c(x,y)=c(y,x)=60 !

node y table

from \ cost to	x	y	z
x	0	4	5
y	~~4~~ 6	0	1
z	5	1	0

node z table

from \ cost to	x	y	z
x	0	4	5
y	4	0	1
z	5	1	0

from \ cost to	x	y	z
x			
y			
z			

from \ cost to	x	y	z
x	0	51	50
y	6	0	1
z	5	1	0

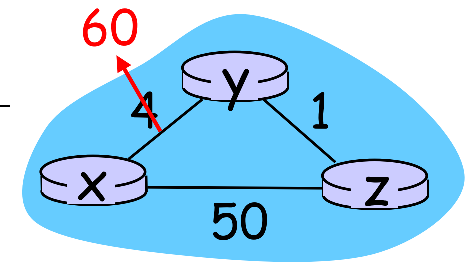
from \ cost to	x	y	z
x	0	51	50
y	6	0	1
z	7	1	0

from \ cost to	x	y	z
x			
y			
z			

from \ cost to	x	y	z
x	0	51	50
y	8	0	1
z	7	1	0

from \ cost to	x	y	z
x			
y			
z			

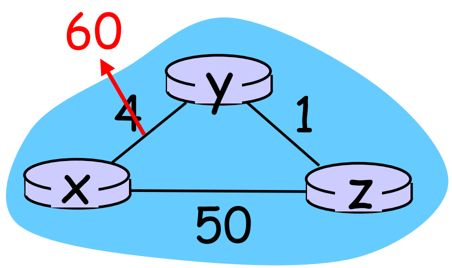
time



loop will persist for 44 iterations until z eventually computes the cost of its path via y to be greater than 50.

Poisoned reverse:

- If Z routes through Y to get to X :
  - Z tells Y its (Z' s) distance to X is infinite (so Y won' t route to X via Z)



node x table

from \ cost to	x	y	z
x	0	~~4~~51	~~5~~50
y	4	0	1
z	5	1	0

Detect c(x,y)=c(y,x)=60 !

node y table

from \ cost to	x	y	z
x	0	4	∞
y	~~4~~60	0	1
z	∞	1	0

node z table

from \ cost to	x	y	z
x	0	4	5
y	4	0	1
z	5	1	0

from \ cost to	x	y	z
x			
y			
z			

from \ cost to	x	y	z
x	0	51	50
y	6	0	1
z	5	1	0

from \ cost to	x	y	z
x	0	51	50
y	60	0	1
z	50	1	0

from \ cost to	x	y	z
x			
y			
z			

from \ cost to	x	y	z
x	0	51	50
y	51	0	1
z	50	1	0

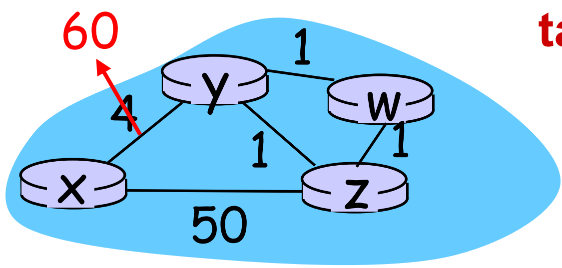
from \ cost to	x	y	z
x			
y			
z			

will this completely solve count to infinity problem?

No, when the loops involves three or more nodes

time

Distance vector: link cost changes



node x table

from \ cost to	x	y	z	w
x	0	4	5	5
y	4	0	1	1
z	5	1	0	1

node y table

from \ cost to	x	y	z	w
x	0	4	∞	∞
y	~~4~~ 60	0	1	1
z	∞	1	0	1
w	∞	1	1	0

node z table

from \ cost to	x	y	z	w
x	0	4	5	5
y	4	0	1	1
z	5	1	0	1
w	5	1	1	0

node z table

from \ cost to	x	y	z	w
x	0	4	5	5
y	60	0	1	1
z	6	1	0	1
w	5	1	1	0

node w table

from \ cost to	x	y	z	w
x				
y	60	0	1	1
z	5	1	0	1
w	6	1	1	0

node w table

from \ cost to	x	y	z	w
y	4	0	1	1
z	5	1	0	1
w	5	1	1	0

node y table

from \ cost to	x	y	z	w
x	0	4	∞	∞
y	7	0	1	1
z	6	1	0	1
w	6	1	1	0

- Knows only one-hop neighbors' information
- Sends infinity to only the first-hop node along the path

CS 305: Computer Networks
Fall 2022

Link Layer

Ming Tang

Department of Computer Science and Engineering
Southern University of Science and Technology (SUSTech)

Link layer, LANs: outline

6.1 introduction, services

6.2 error detection, correction

6.3 multiple access protocols

6.4 LANs

- addressing, ARP
- Ethernet
- switches
- VLANS

6.5 link virtualization: MPLS

6.6 data center networking

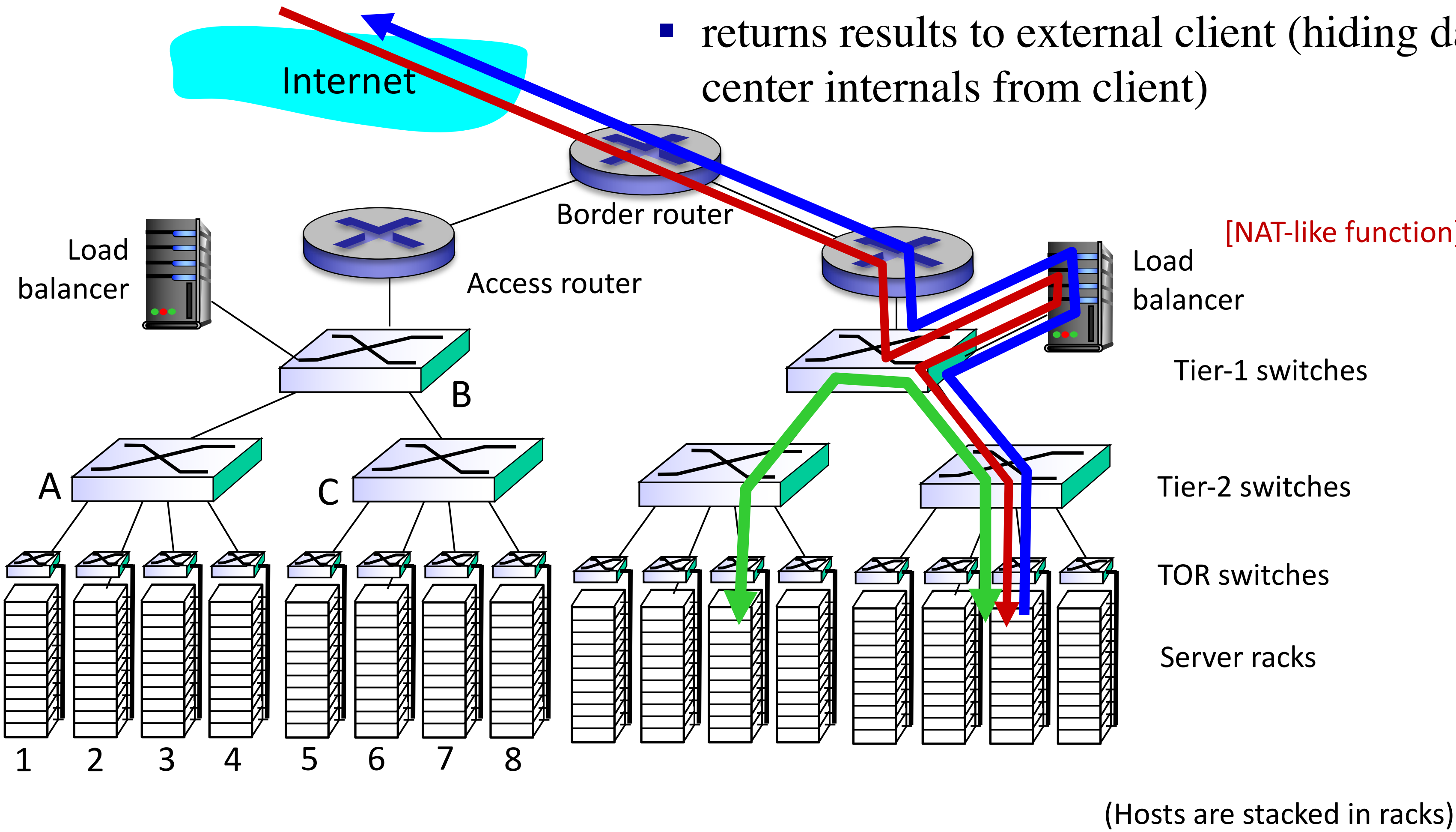
6.7 a day in the life of a web request

Data center networks

- 10's to 100's of thousands of hosts, often closely coupled, in close proximity:
  - e-business (e.g. Amazon)
  - content-servers (e.g., YouTube, Akamai, Apple, Microsoft)
  - search engines, data mining (e.g., Google)
- challenges:
  - multiple applications, each serving massive numbers of clients
  - managing/balancing load, avoiding processing, networking, data bottlenecks

Inside a 40-ft Microsoft container, Chicago data center

Data center networks

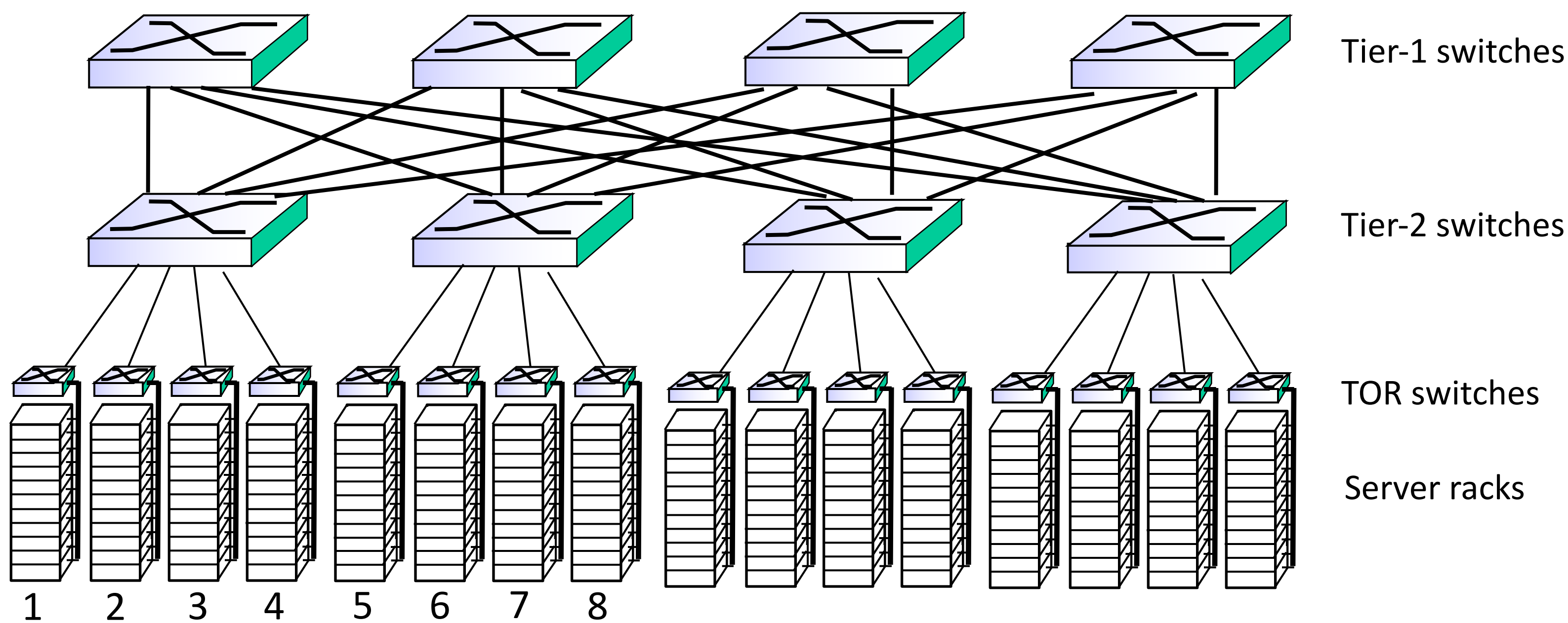


load balancer: application-layer routing

- receives external client requests
- directs workload within data center
- returns results to external client (hiding data center internals from client)

Data center networks

- rich interconnection among switches, racks:
  - increased throughput between racks (multiple routing paths possible)
  - increased reliability via redundancy



Link layer, LANs: outline

6.1 introduction, services

6.2 error detection, correction

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6.4 LANs

- addressing, ARP
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- VLANS

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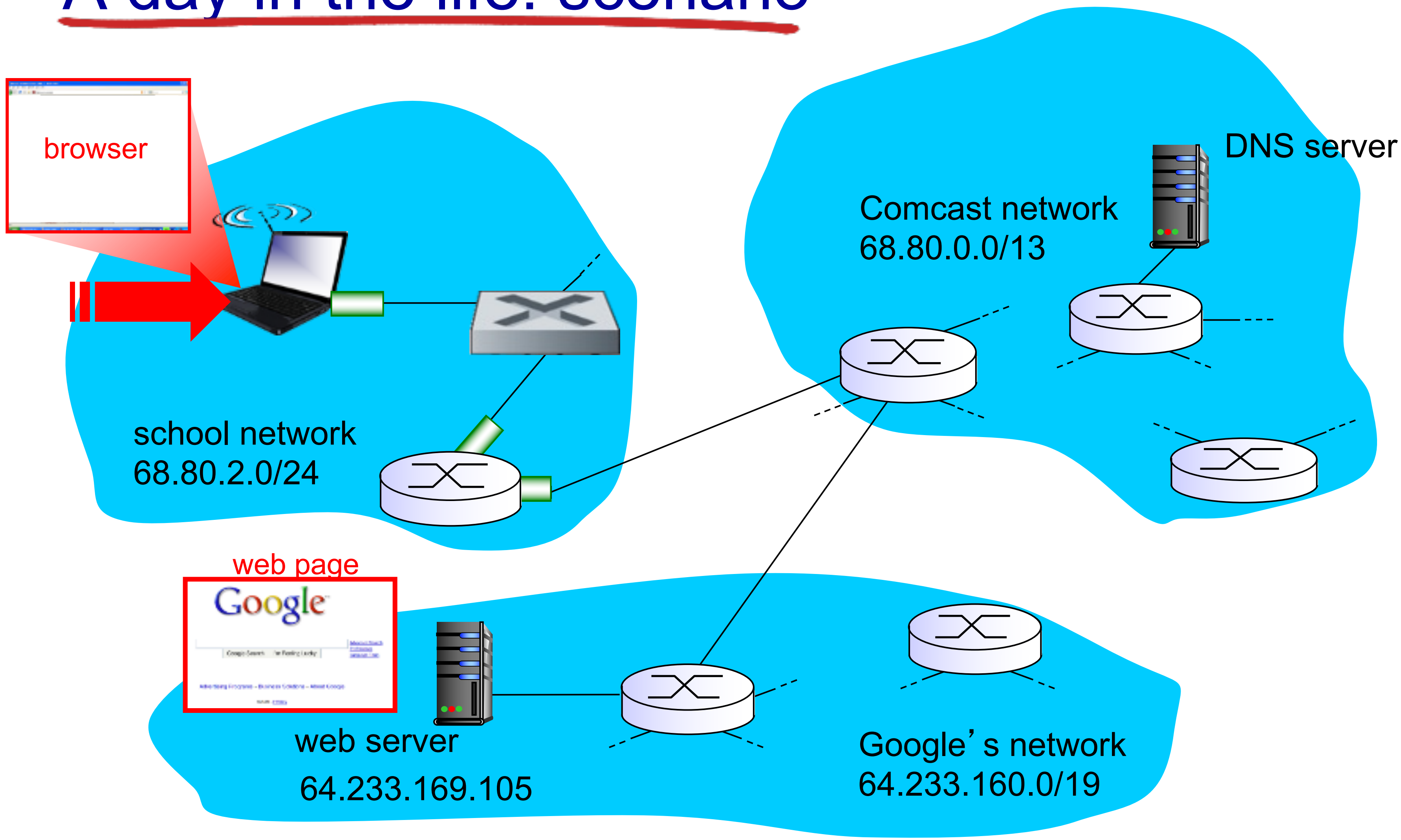
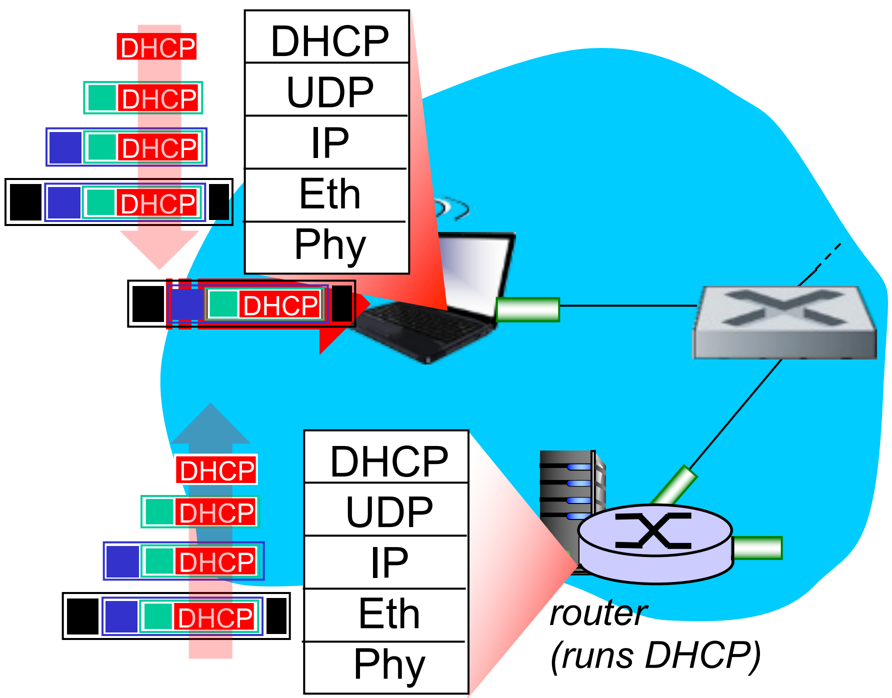
Synthesis: a day in the life of a web request

- journey down protocol stack complete!
  - application, transport, network, link
- putting-it-all-together: synthesis!
  - *goal:* identify, review, understand protocols (at all layers) involved in seemingly simple scenario: requesting www page
  - *scenario:* student attaches laptop to campus network, requests/receives www.google.com

A day in the life: scenario

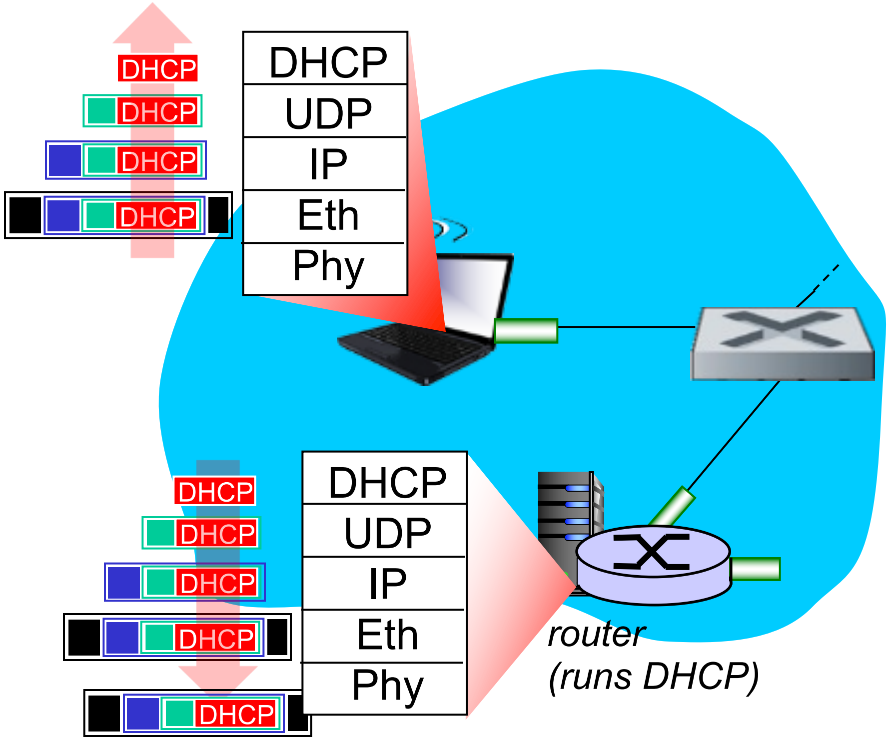


A day in the life… connecting to the Internet



- connecting laptop needs to get its own IP address, addr of first-hop router, addr of DNS server: use *DHCP*
- DHCP request encapsulated in UDP, encapsulated in IP, encapsulated in 802.3 Ethernet
- Ethernet frame broadcast (dest: FFFFFFFFFFFF) on LAN, received at router running DHCP server
- Ethernet demuxed to IP demuxed, UDP demuxed to DHCP

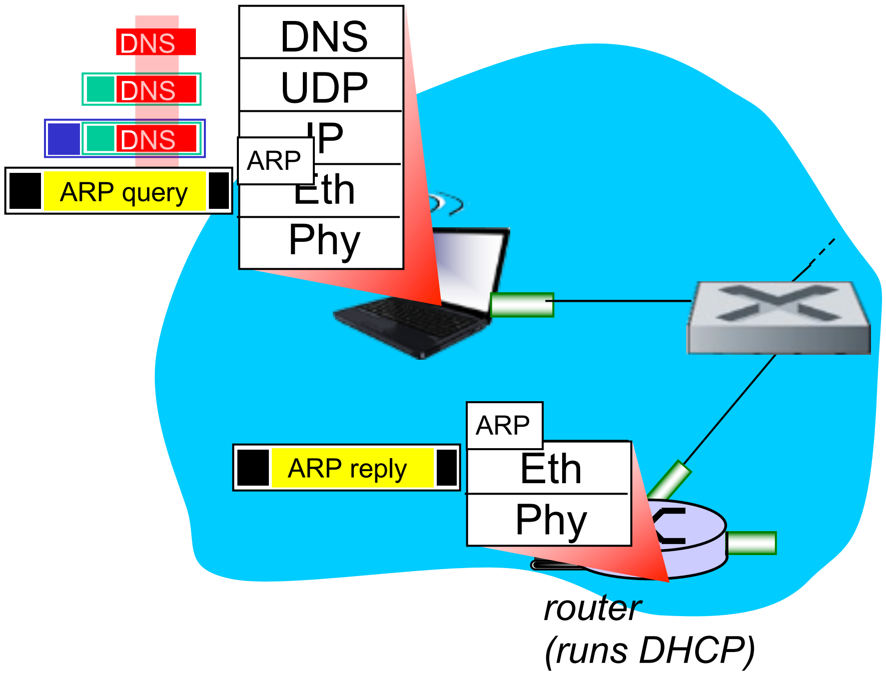
A day in the life… connecting to the Internet



- DHCP server formulates *DHCP ACK* containing client's IP address, IP address of first-hop router for client, name & IP address of DNS server
- encapsulation at DHCP server, frame forwarded (switch learning) through LAN, demultiplexing at client
- DHCP client receives DHCP ACK reply

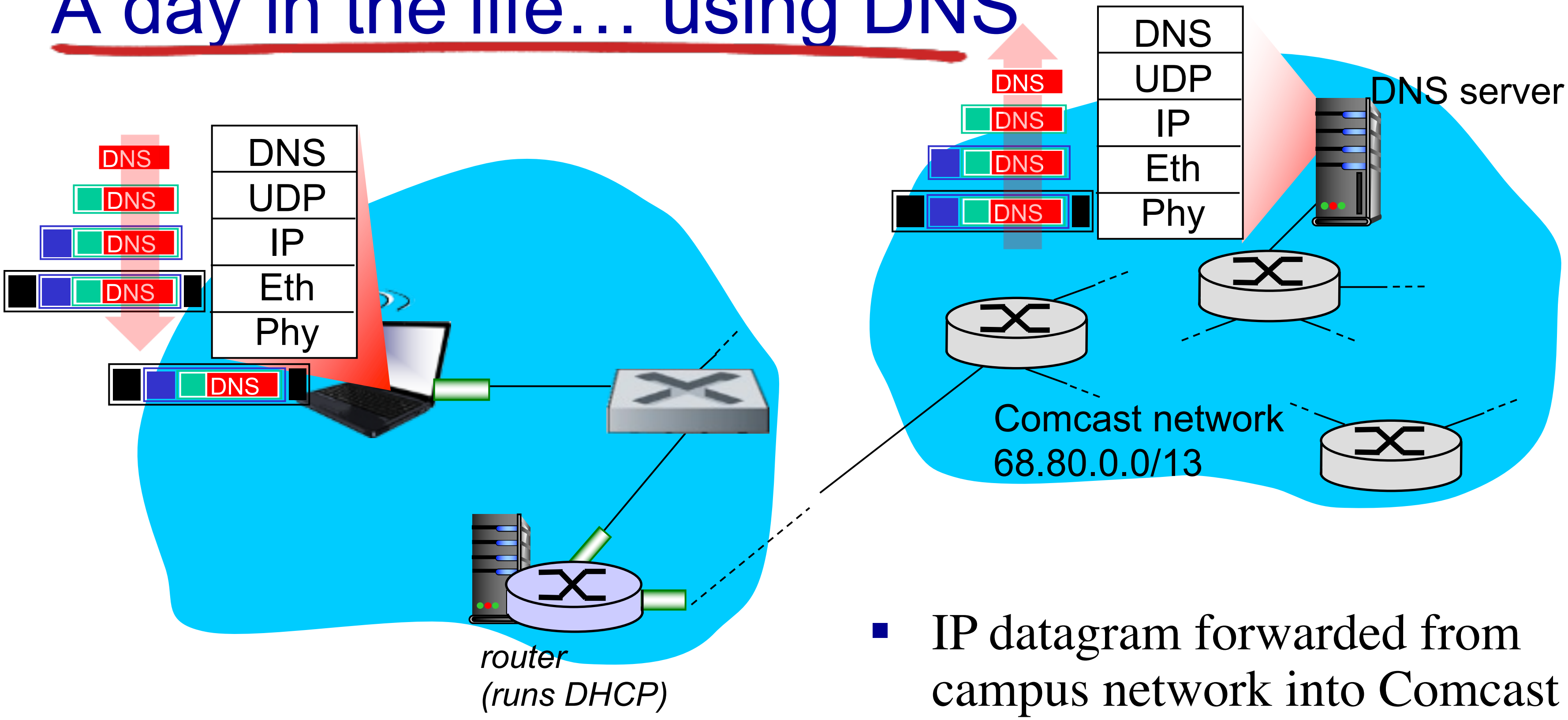
Client now has IP address, knows name & addr of DNS server, IP address of its first-hop router

A day in the life… ARP (before DNS, before HTTP)



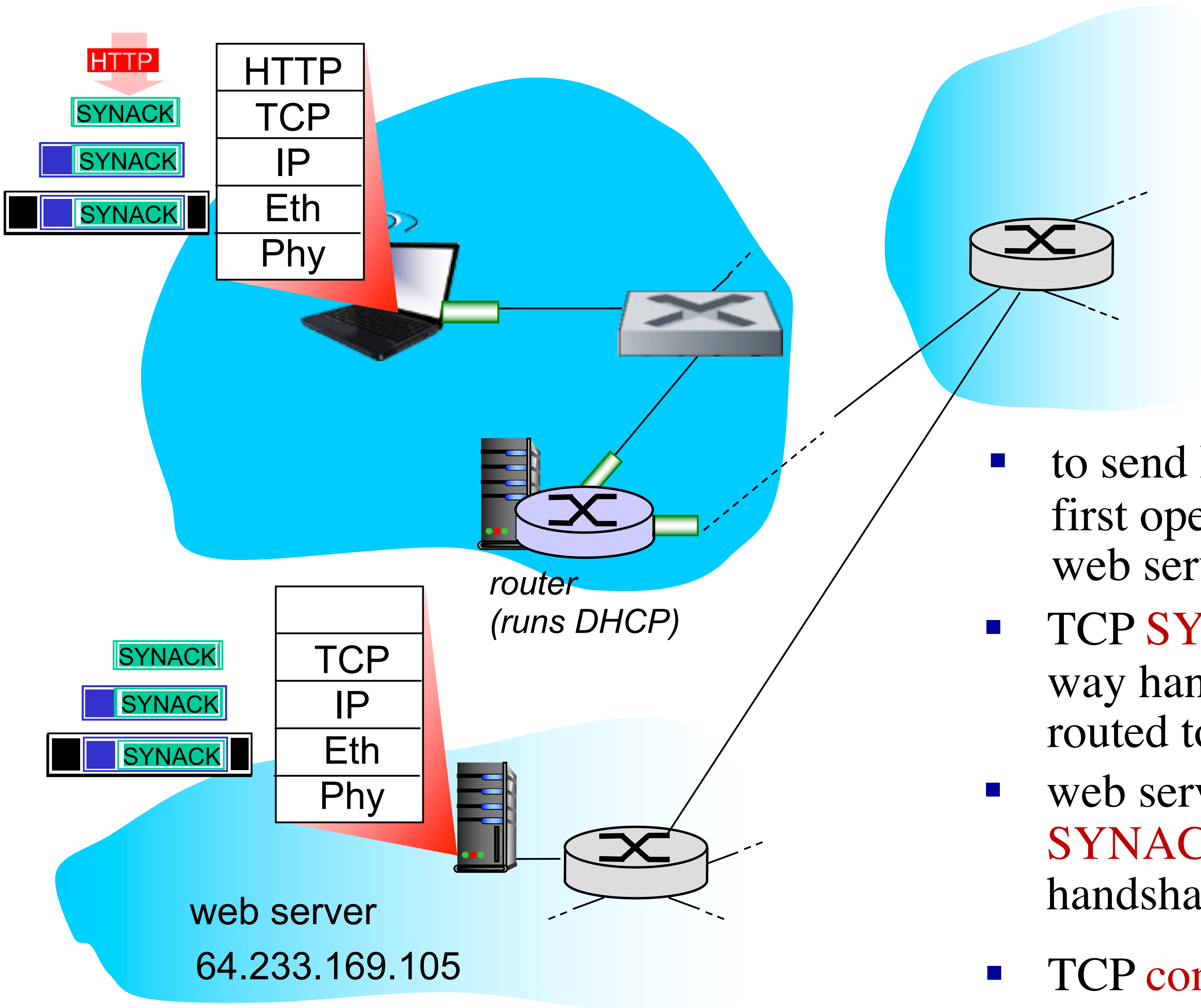
- before sending *HTTP* request, need IP address of www.google.com: *DNS*
- DNS query created, encapsulated in UDP, encapsulated in IP, encapsulated in Eth. To send frame to router, need MAC address of router interface: ARP
- ARP query broadcast, received by router, which replies with ARP reply giving MAC address of router interface
- client now knows MAC address of first hop router, so can now send frame containing DNS query

A day in the life… using DNS



- IP datagram containing DNS query forwarded via LAN switch from client to 1st hop router
- IP datagram forwarded from campus network into Comcast network, routed (tables created by RIP, OSPF, IS-IS and/or BGP routing protocols) to DNS server
- demuxed to DNS server
- DNS server replies to client with IP address of www.google.com

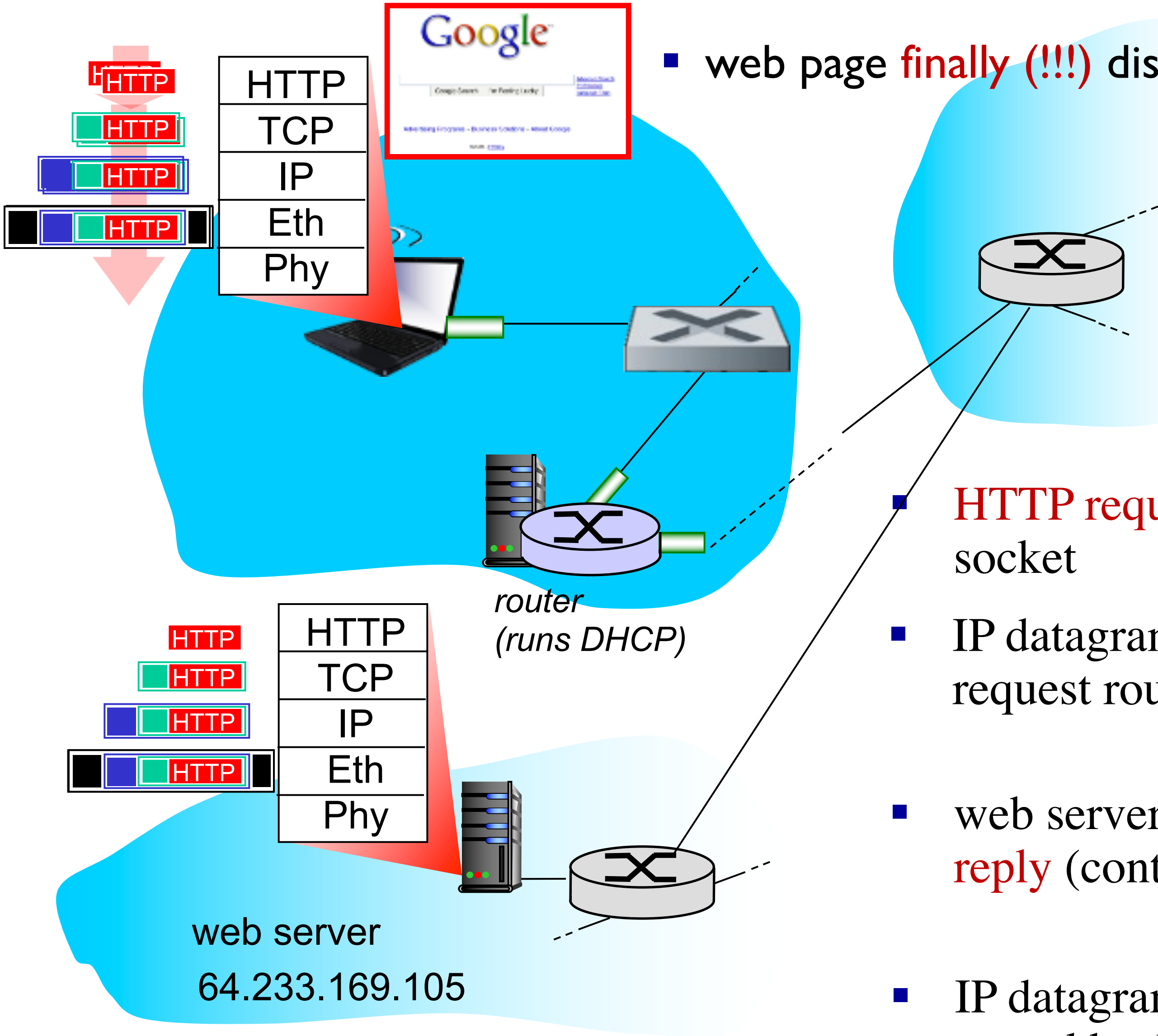
A day in the life…TCP connection carrying HTTP



- to send HTTP request, client first opens TCP socket to web server
- TCP SYN segment (step 1 in 3-way handshake) inter-domain routed to web server
- web server responds with TCP SYNACK (step 2 in 3-way handshake)
- TCP connection established!

A day in the life… HTTP request/reply

- web page finally (!!!) displayed



- HTTP request sent into TCP socket
- IP datagram containing HTTP request routed to www.google.com
- web server responds with HTTP reply (containing web page)
- IP datagram containing HTTP reply routed back to client

Chapter 6: Summary

- principles behind data link layer services:
  - error detection, correction
  - sharing a broadcast channel: multiple access
  - link layer addressing
- instantiation and implementation of various link layer technologies
  - Ethernet
  - switched LANS, VLANs
- synthesis: a day in the life of a web request

CS 305: Computer Networks

Fall 2022

Week 14 Wireless and Mobile Networks

Ming Tang

Department of Computer Science and Engineering
Southern University of Science and Technology (SUSTech)

Ch. 7: Wireless and Mobile Networks

Background:

- # wireless (mobile) phone subscribers now exceeds # wired phone subscribers (5-to-1)!
- # wireless Internet-connected devices equals # wireline Internet-connected devices
  - laptops, Internet-enabled phones promise anytime untethered Internet access
- two important (but different) challenges
  - *wireless:* communication over wireless link
  - *mobility:* point of attachment to networkhandling the mobile user who changes

Chapter 7 outline

7.1 Introduction

Wireless

7.2 Wireless links, characteristics

- CDMA

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

7.4 Cellular Internet Access

- architecture
- standards (e.g., 3G, LTE)

Mobility

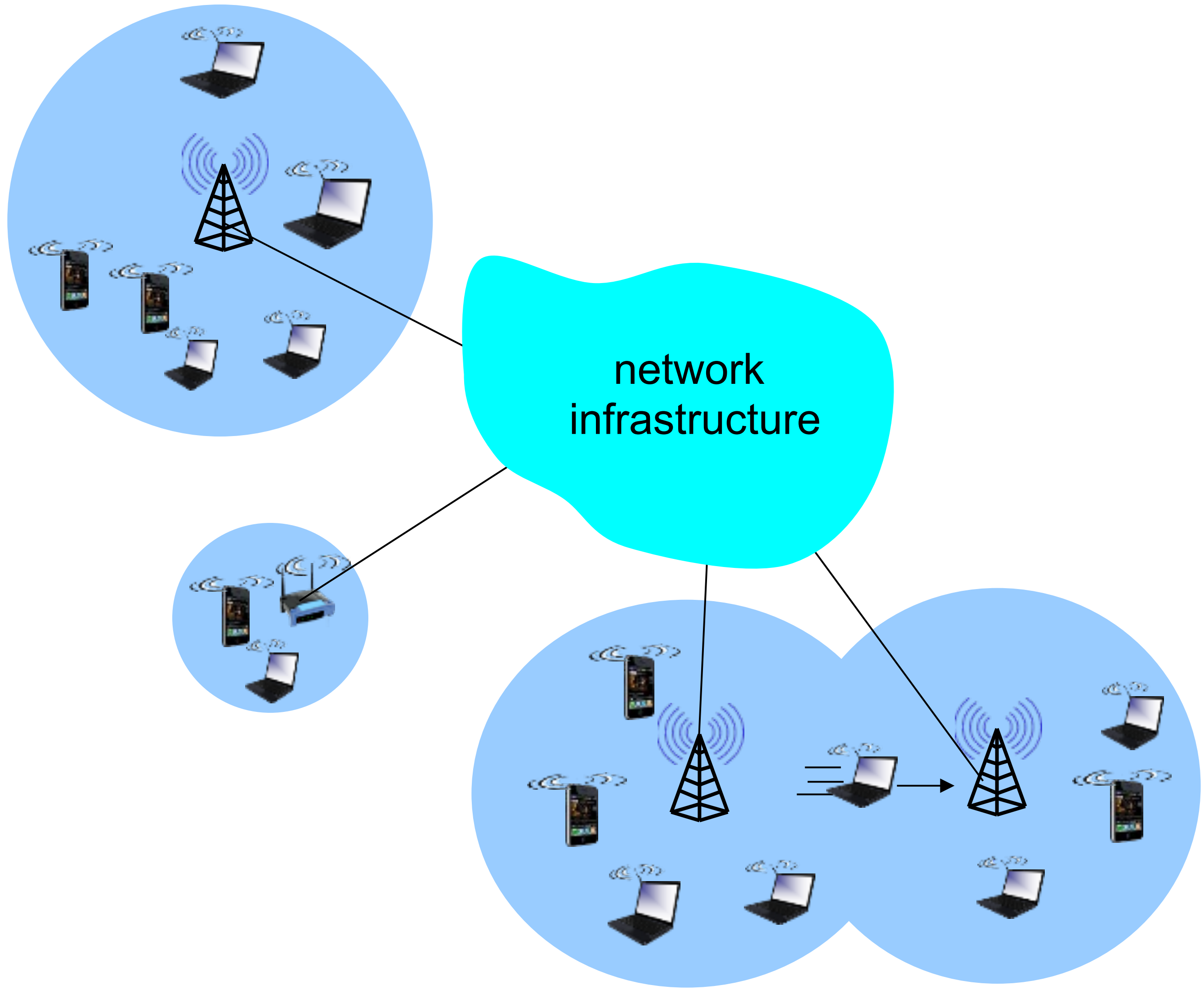
7.5 Principles: addressing and routing to mobile users

7.6 Mobile IP

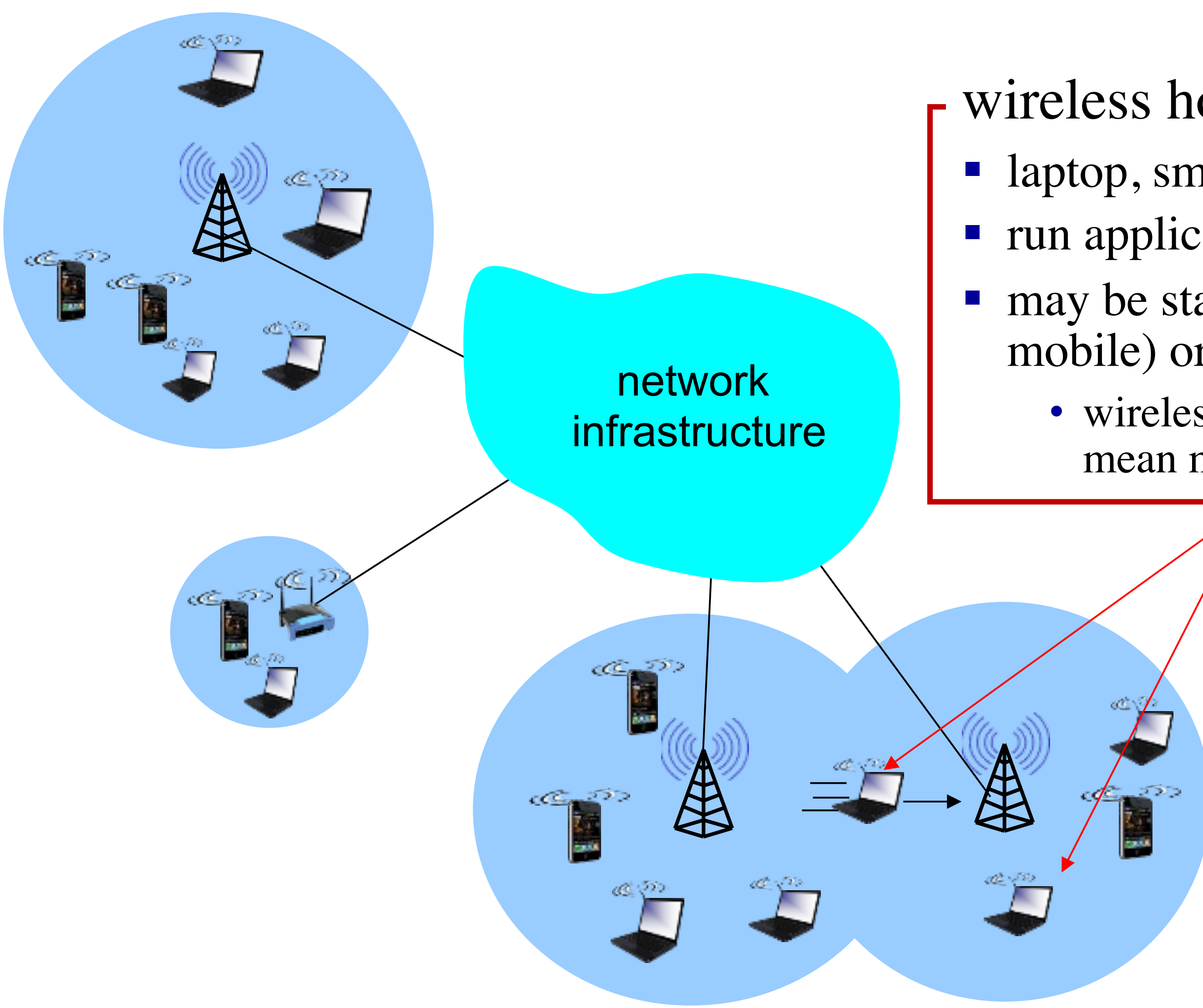
7.7 Handling mobility in cellular networks

7.8 Mobility and higher-layer protocols

Elements of a wireless network



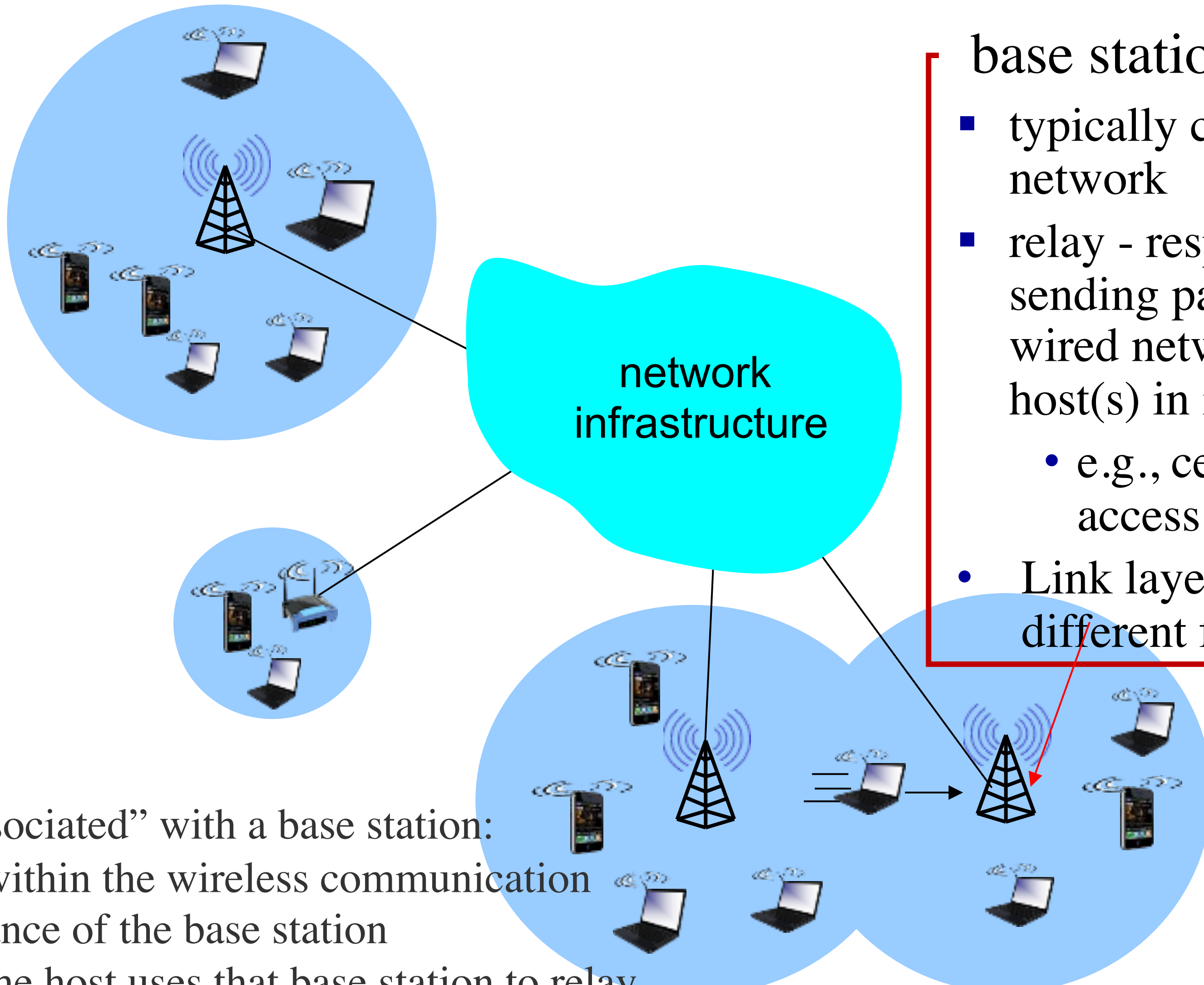
Elements of a wireless network



wireless hosts

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

Elements of a wireless network

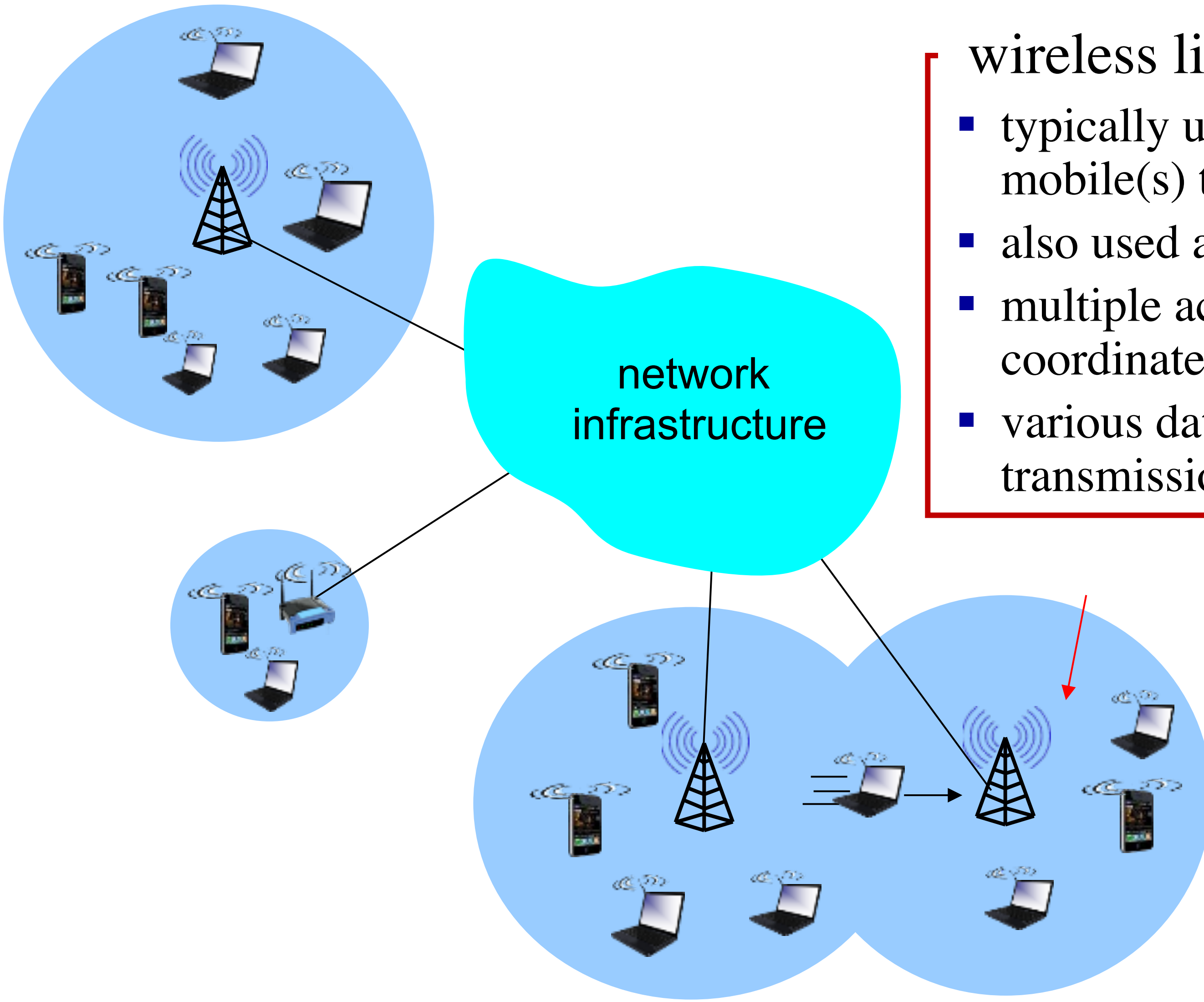


base station

- 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
- Link layer relay; but different from switches

"Associated" with a base station:
(1) within the wireless communication distance of the base station
(2) the host uses that base station to relay data between it and the larger network.

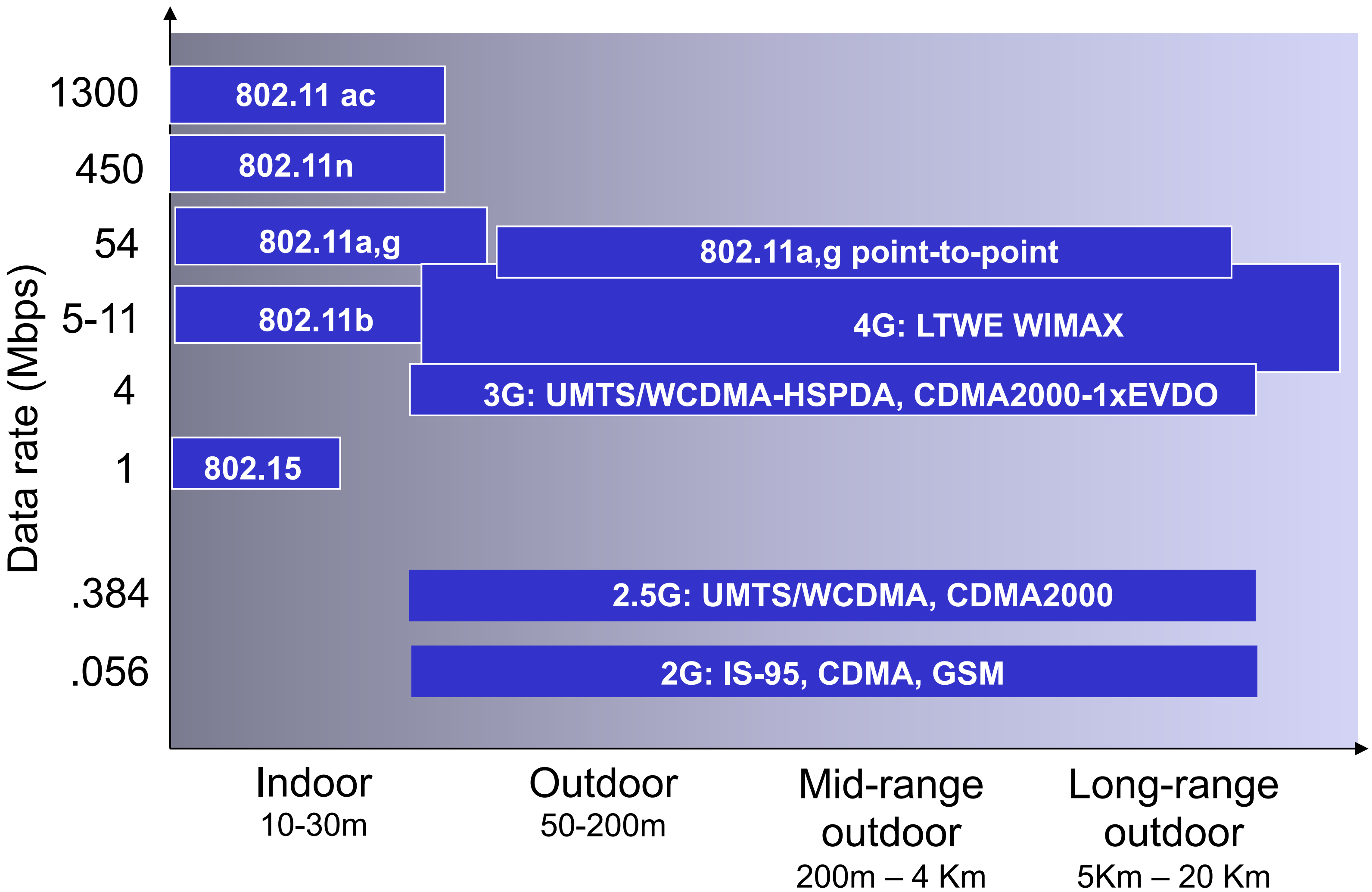
Elements of a wireless network



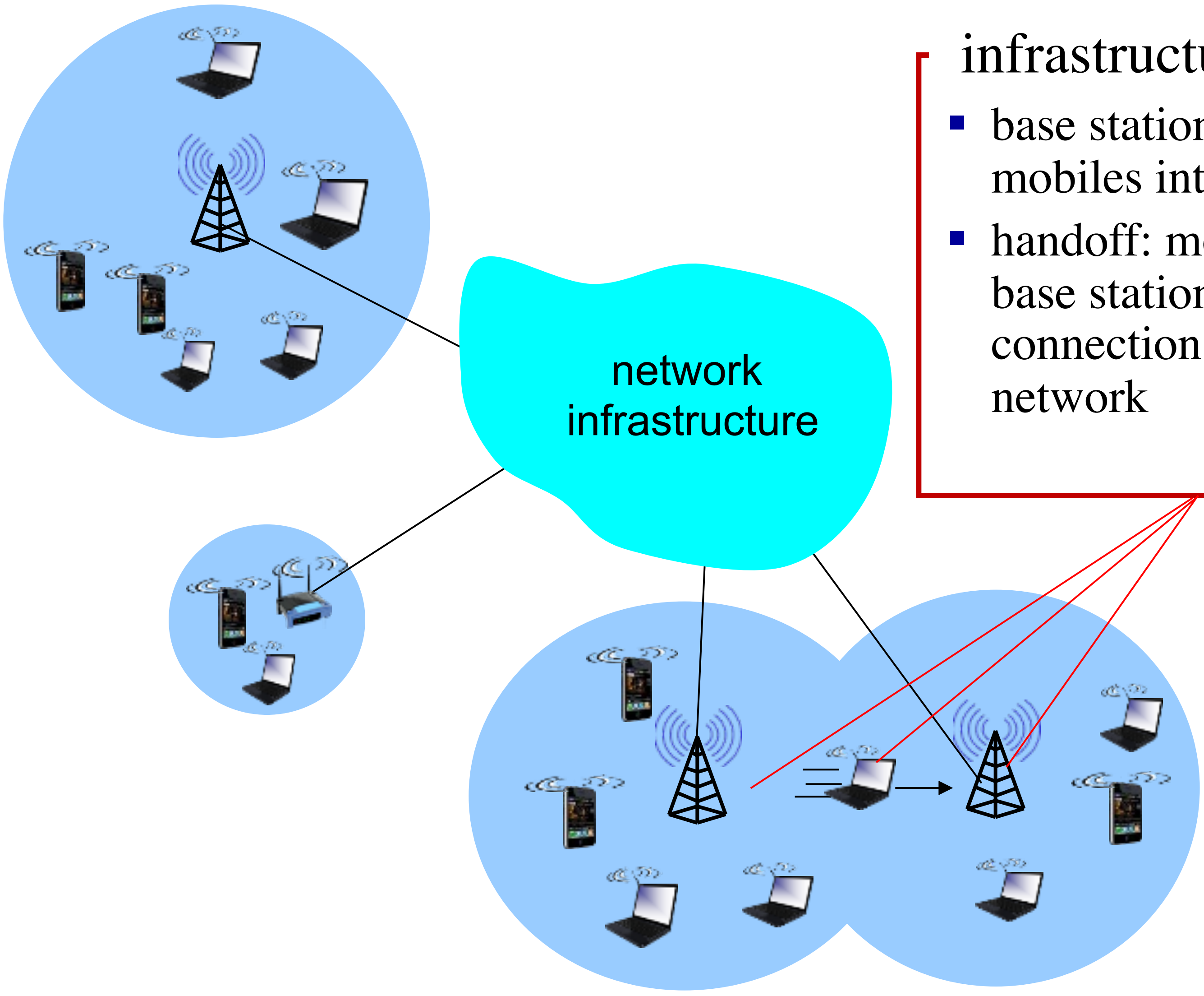
wireless link

- 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 links



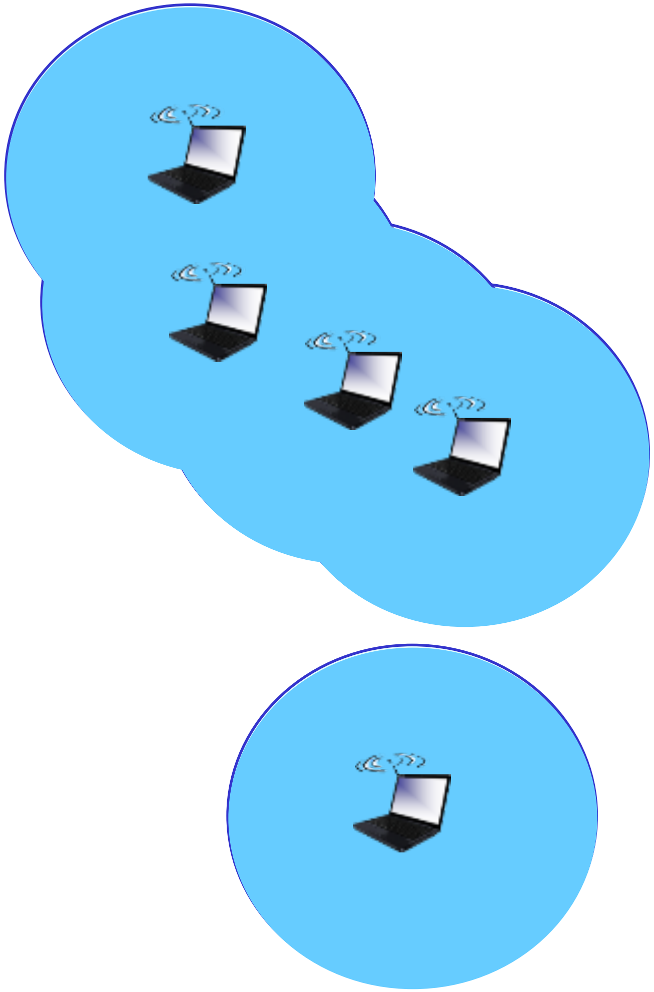
Elements of a wireless network



infrastructure mode

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

Elements of a wireless network

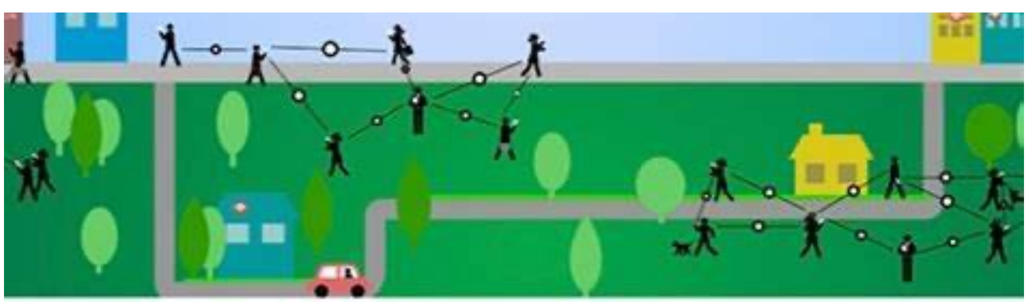


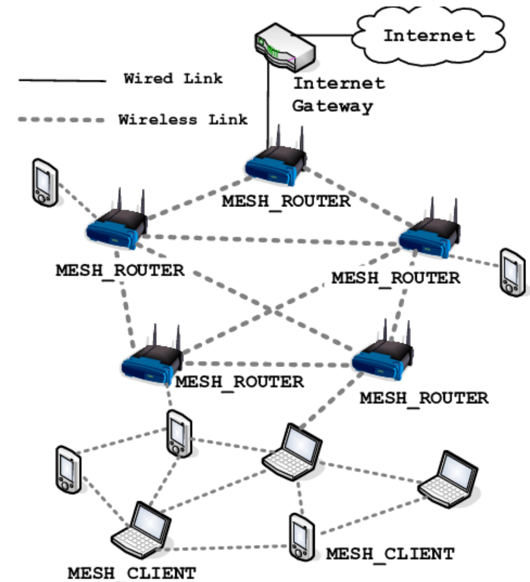
ad hoc mode

- 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





Chapter 7 outline

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7.2 Wireless links, characteristics

- CDMA

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

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- architecture
- standards (e.g., 3G, LTE)

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7.5 Principles: addressing and routing to mobile users

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7.7 Handling mobility in cellular networks

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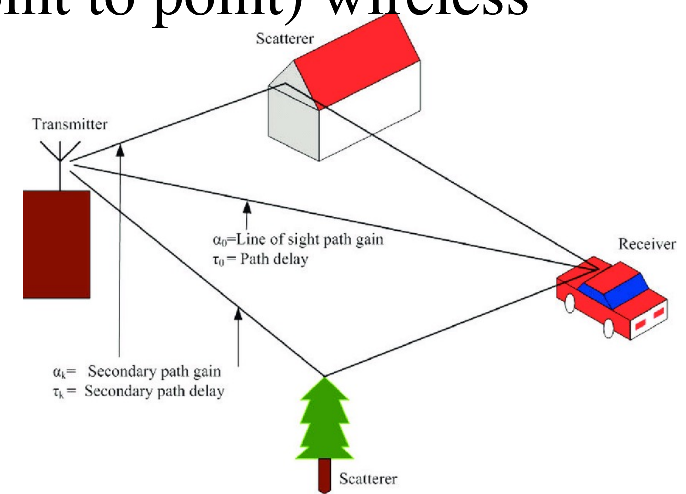
Wireless Link Characteristics

important differences from wired link ….

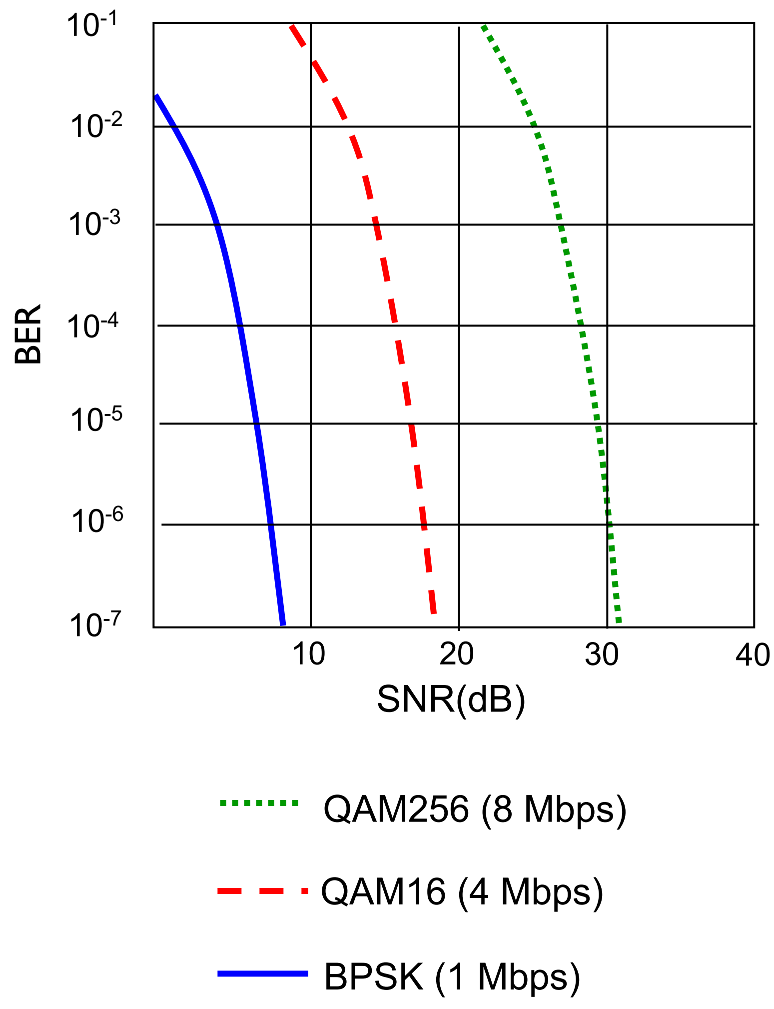
- *decreased signal strength:* radio signal attenuates as it propagates through matter (path loss)
- *interference from other sources:* standardized wireless network frequencies (e.g., 2.4 GHz) shared by other devices (e.g., phone); devices (motors) interfere as well
- *multipath propagation:* radio signal reflects off objects ground, arriving ad destination at slightly different times

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



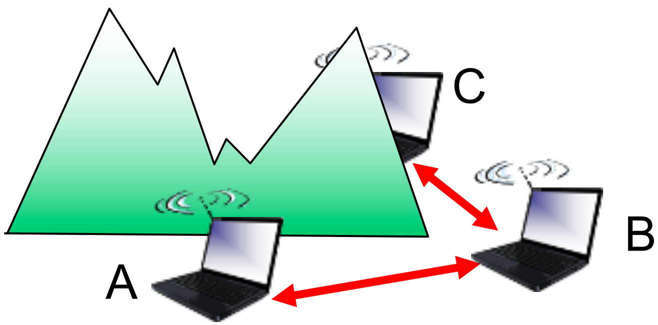
Wireless Link Characteristics

- SNR: signal-to-noise ratio
  - larger SNR – easier to extract signal from noise (a "good thing")
- *SNR versus BER tradeoffs*
  - *given physical layer:* increase power -> increase SNR->decrease BER
  - *given SNR:* choose physical layer that meets BER requirement, giving highest thruput
    - SNR may change with mobility: dynamically adapt physical layer (modulation technique, rate)



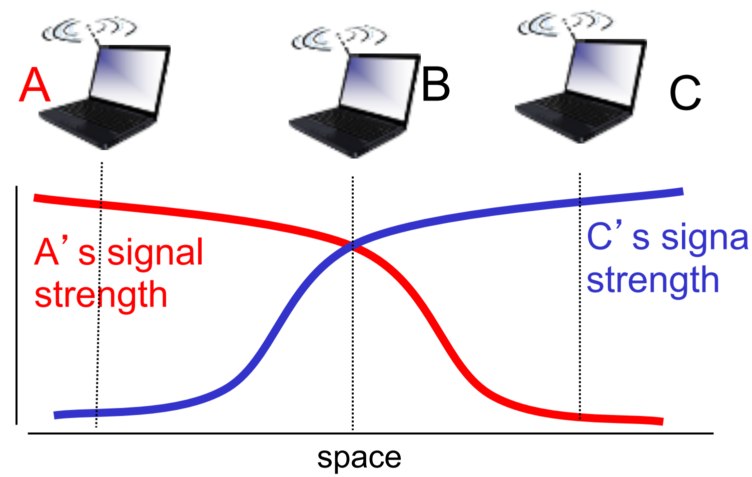
Wireless network characteristics

Multiple wireless senders and receivers create additional problems (beyond multiple access): ***Hidden terminal problem***



Caused by obstacle:

- 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



Caused by fading

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

CSMA/CD -> CSMA/CA

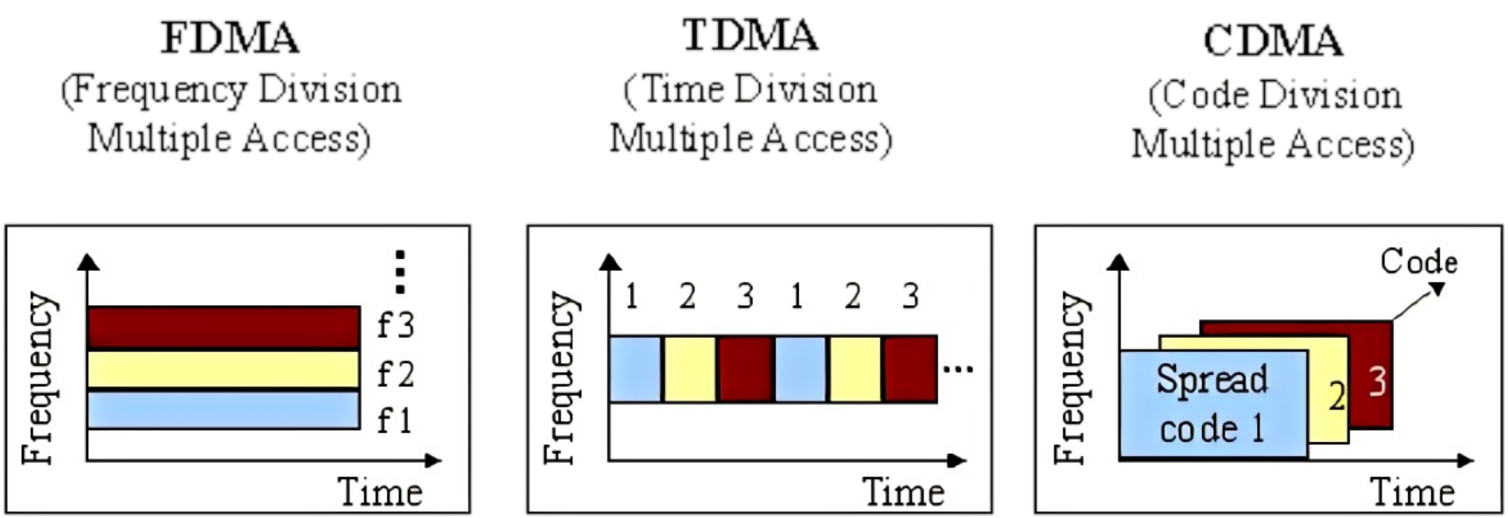
Code Division Multiple Access (CDMA)

Medium access protocols:

Channel partitioning, random access, taking turns:

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")



Code Division Multiple Access (CDMA)

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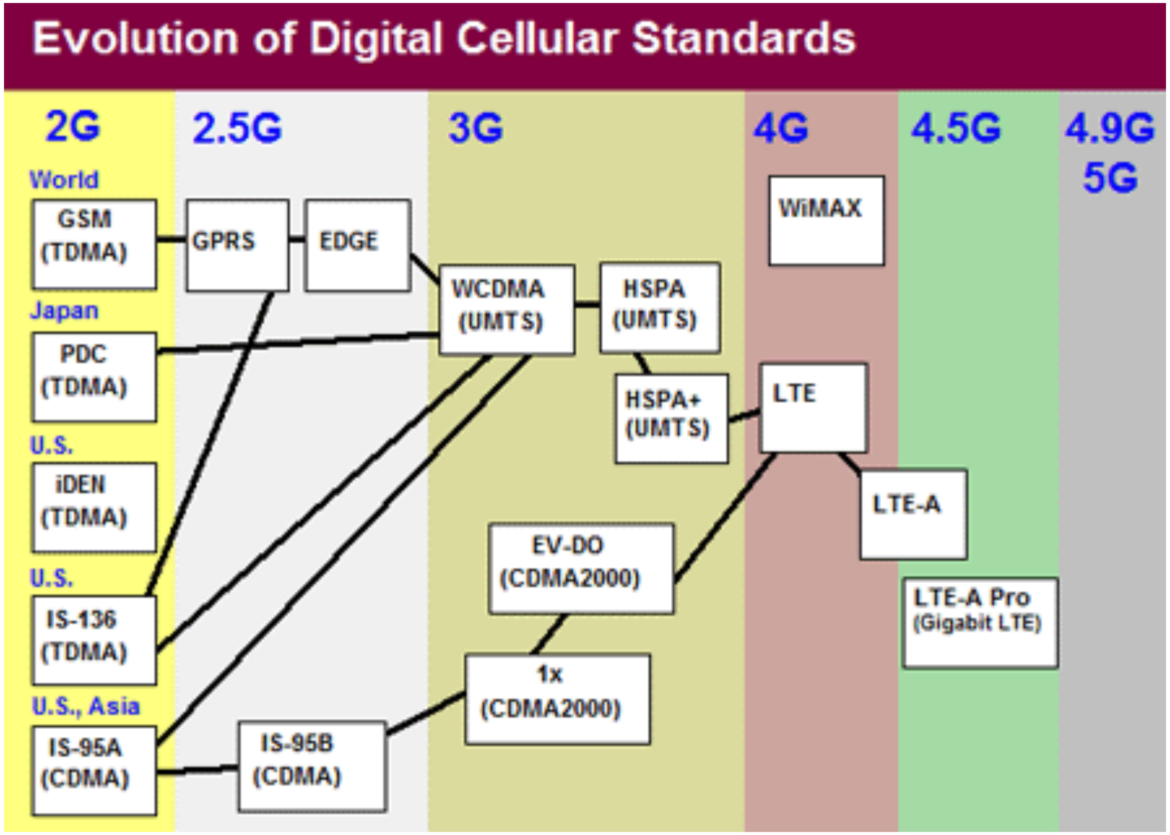

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Code Division Multiple Access (CDMA)

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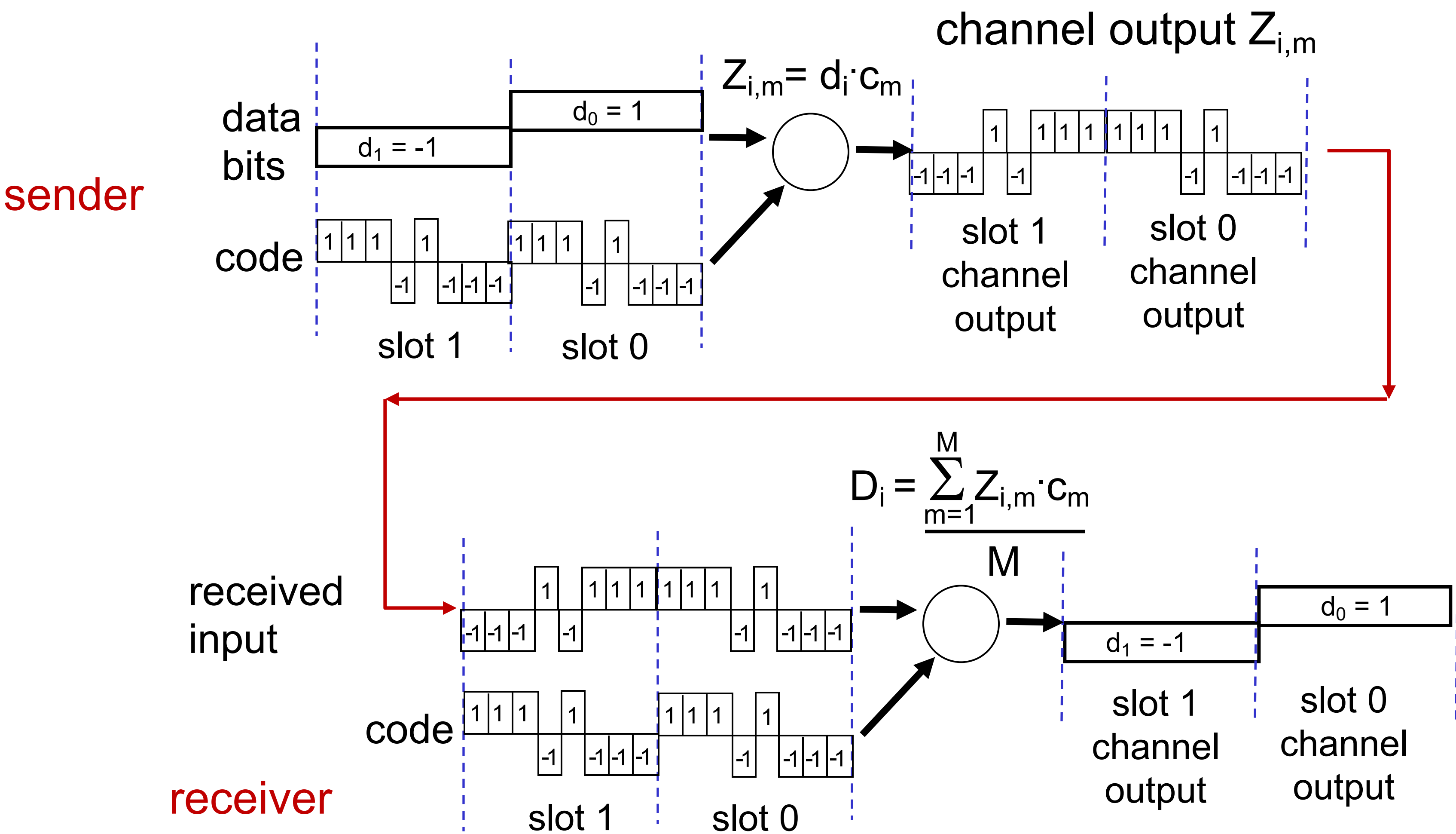
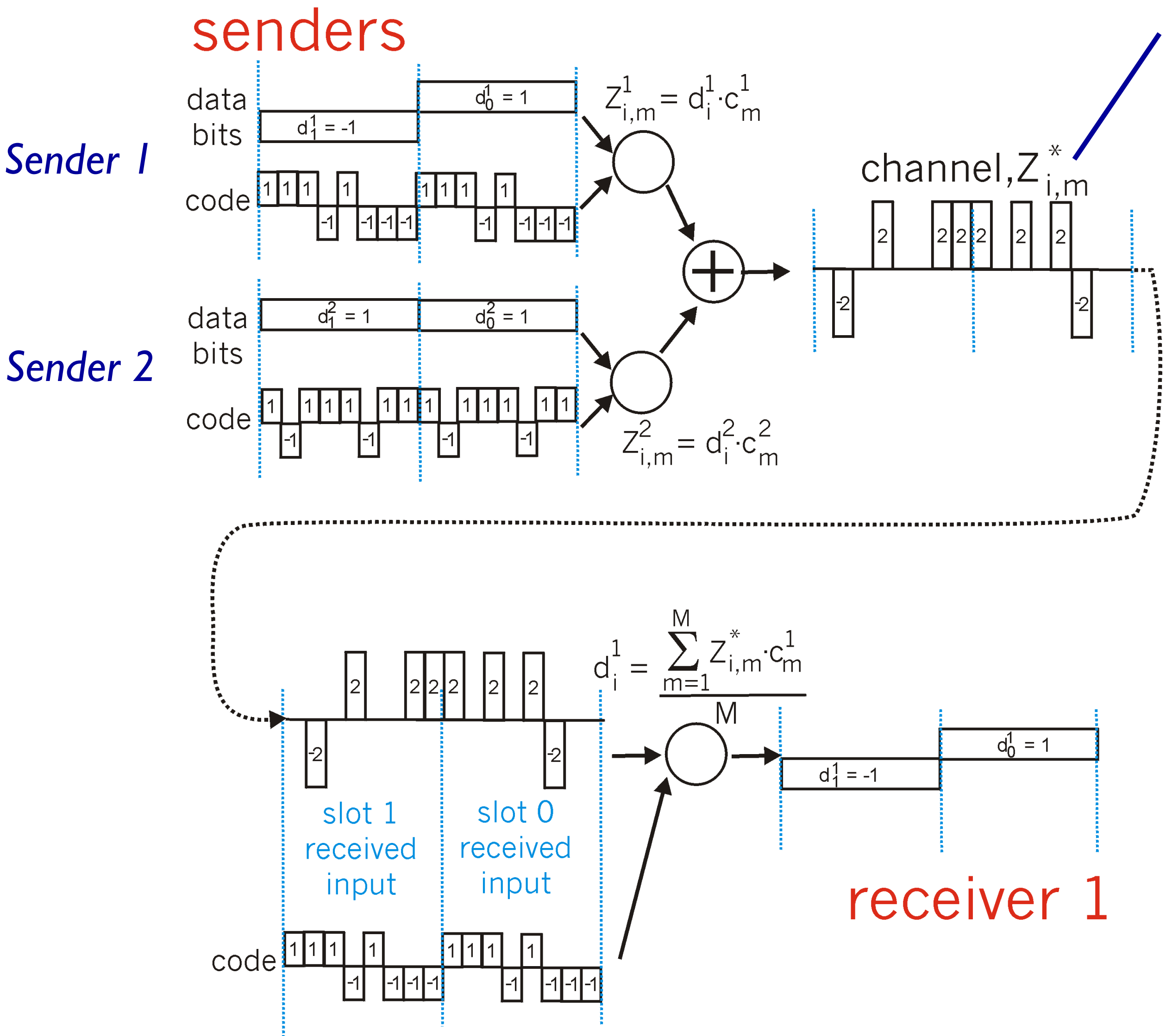
  - all users share same frequency, but each user has own "chipping" sequence (i.e., code) to encode data
  - allows multiple users to "coexist" and transmit simultaneously with minimal interference (if codes are "orthogonal")
- *encoded signal* = (original data) X (chipping sequence)
- *decoding:* inner-product of encoded signal and chipping sequence

CDMA encode/decode



CDMA: two-sender interference



channel sums together transmissions by sender 1 and 2

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

Code must be carefully chosen!

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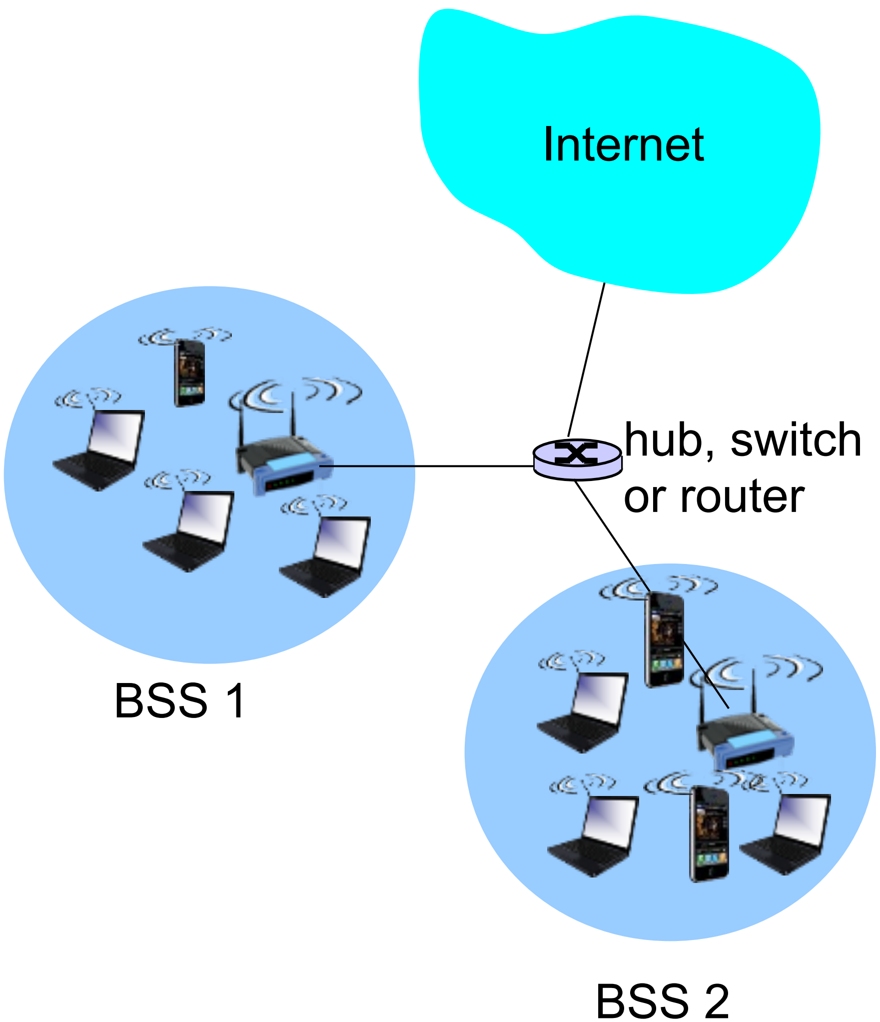
IEEE 802.11 Wireless LAN

Standard	Frequency Range	Data Rate
802.11b	2.4 GHz	up to 11 Mbps
802.11a	5 GHz	up to 54 Mbps
802.11g	2.4 GHz	up to 54 Mbps
802.11n	2.5 GHz and 5 GHz	up to 450 Mbps
802.11ac	5 GHz	up to 1300 Mbps

- all use CSMA/CA for multiple access
- all have base-station and ad-hoc network versions

802.11 LAN architecture

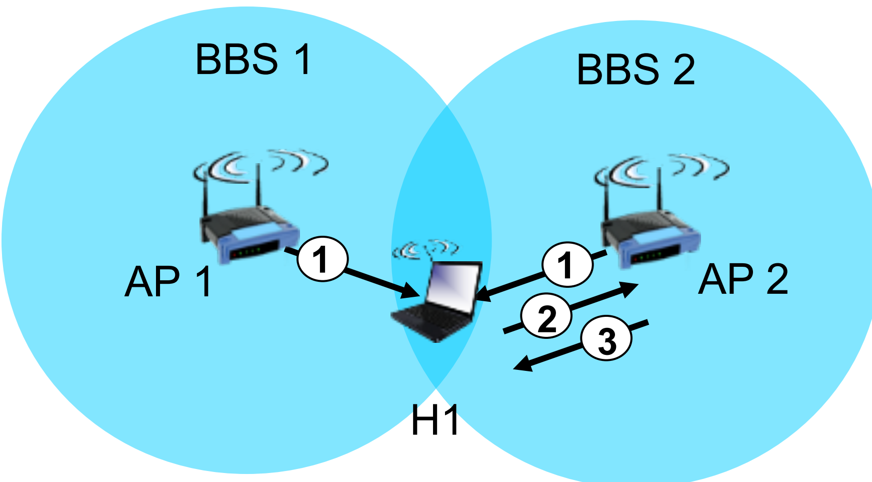


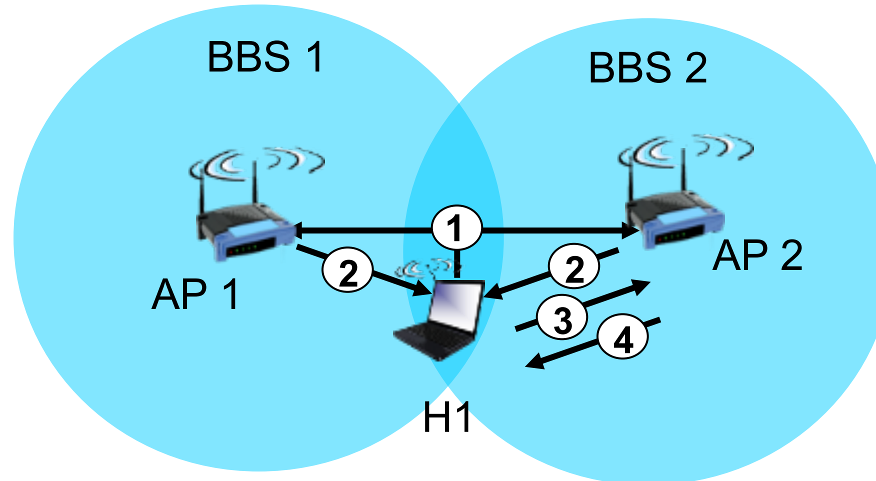
- wireless host communicates with base station
  - base station = access point (AP)
- Basic Service Set (BSS) (aka "cell") in infrastructure mode contains:
  - wireless hosts
  - access point (AP): base station
  - ad hoc mode: hosts only

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 (service set identifier SSID) and MAC address
  - selects AP to associate with
  - may perform authentication [Chapter 8]
  - will typically run DHCP to get IP address in AP's subnet

802.11: passive/active scanning





passive scanning:

(1) beacon frames sent from APs

(2) association Request frame sent: H1 to selected AP

(3) association Response frame sent from selected AP to H1

Once associated with an AP, the device will want to join the subnet through sending a DHCP discovery message via the AP.

active scanning:

(1) Probe Request frame broadcast from H1

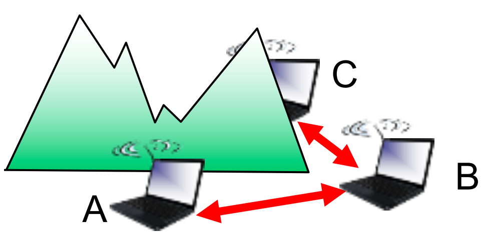
(2) Probe Response frames sent from APs

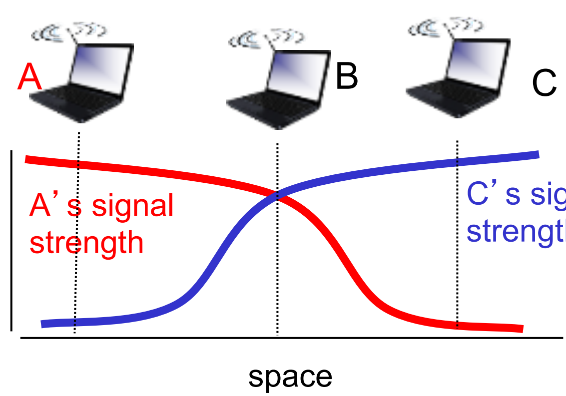
(3) Association Request frame sent: H1 to selected AP

(4) Association Response frame sent from selected AP to H1

IEEE 802.11: multiple access

- avoid collisions: 2^+ nodes transmitting at same time
- 802.11: CSMA - sense before transmitting
  - don't collide with ongoing transmission by other node
  - CSMA/CD: if collision, stop transmitting
- 802.11: *no* collision detection!
  - Signal strength: difficult to receive (sense collisions) when transmitting due to weak received signals (fading)
  - Hidden terminal problem: can't sense all collisions in any case
  - goal: *avoid collisions:* CSMA/C(ollision)A(voidance)
    - Once start transmission, no turning back





IEEE 802.11 MAC Protocol: CSMA/CA

802.11CSMA/CA protocol: (1) Congestion avoidance, (2) reliable

802.11 sender

1 if sense channel idle for distributed inter-frame space (**DIFS**) then transmit entire frame (no CD)

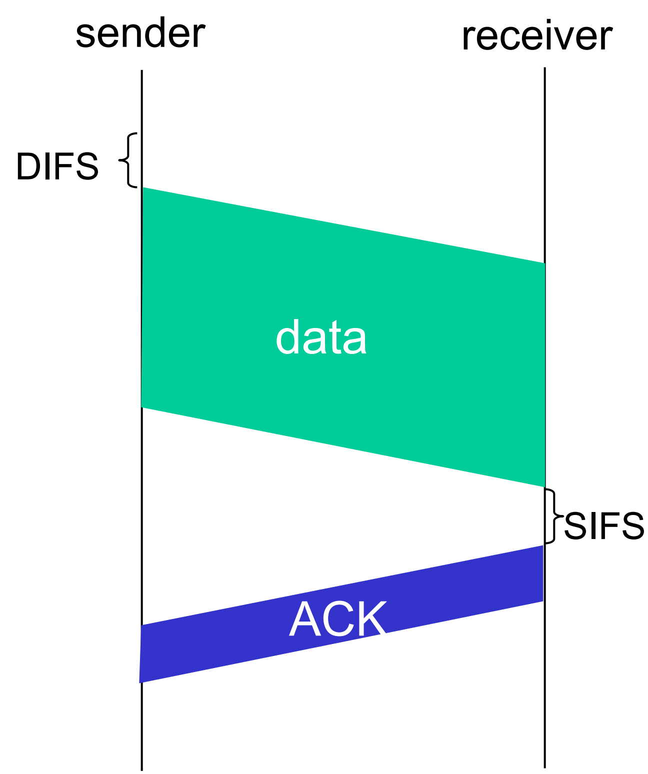
2 if sense channel busy then

- start random backoff time (why?)
- timer counts down while channel idle
- transmit when timer expires and wait for ACK
- if no ACK, increase random backoff interval, repeat 2

802.11 receiver

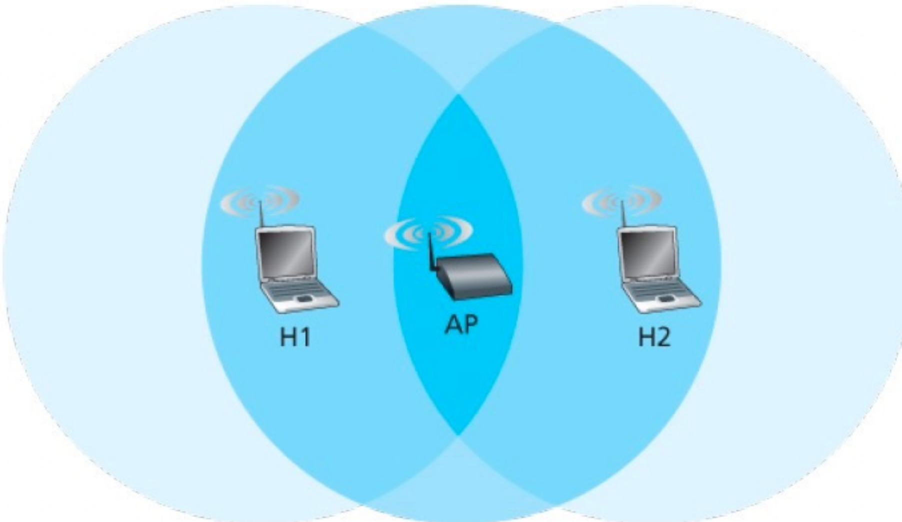
- if frame received OK

return ACK after **SIFS** (ACK needed due to hidden terminal problem)



Avoiding collisions (more)

However, collision may still occur due to hidden terminal problem



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

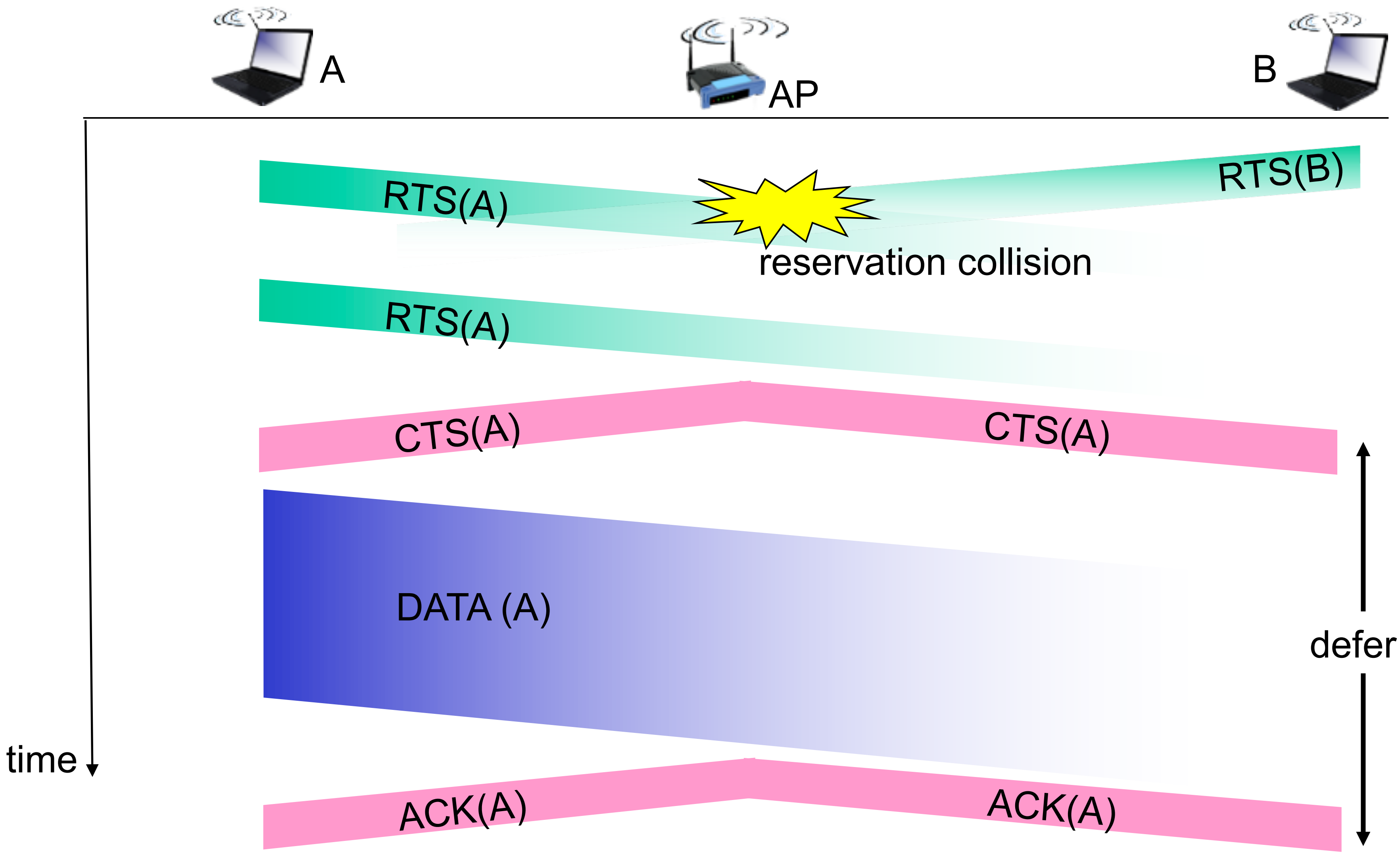
Avoiding collisions (more)

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)
  - Indicate total time required for transmitting
- BS broadcasts clear-to-send CTS in response to RTS
- CTS heard by all nodes
  - sender transmits data frame
  - other stations not send for reserved duration

avoid data frame collisions completely using small reservation packets!

Collision Avoidance: RTS-CTS exchange



802.11 frame: addressing

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

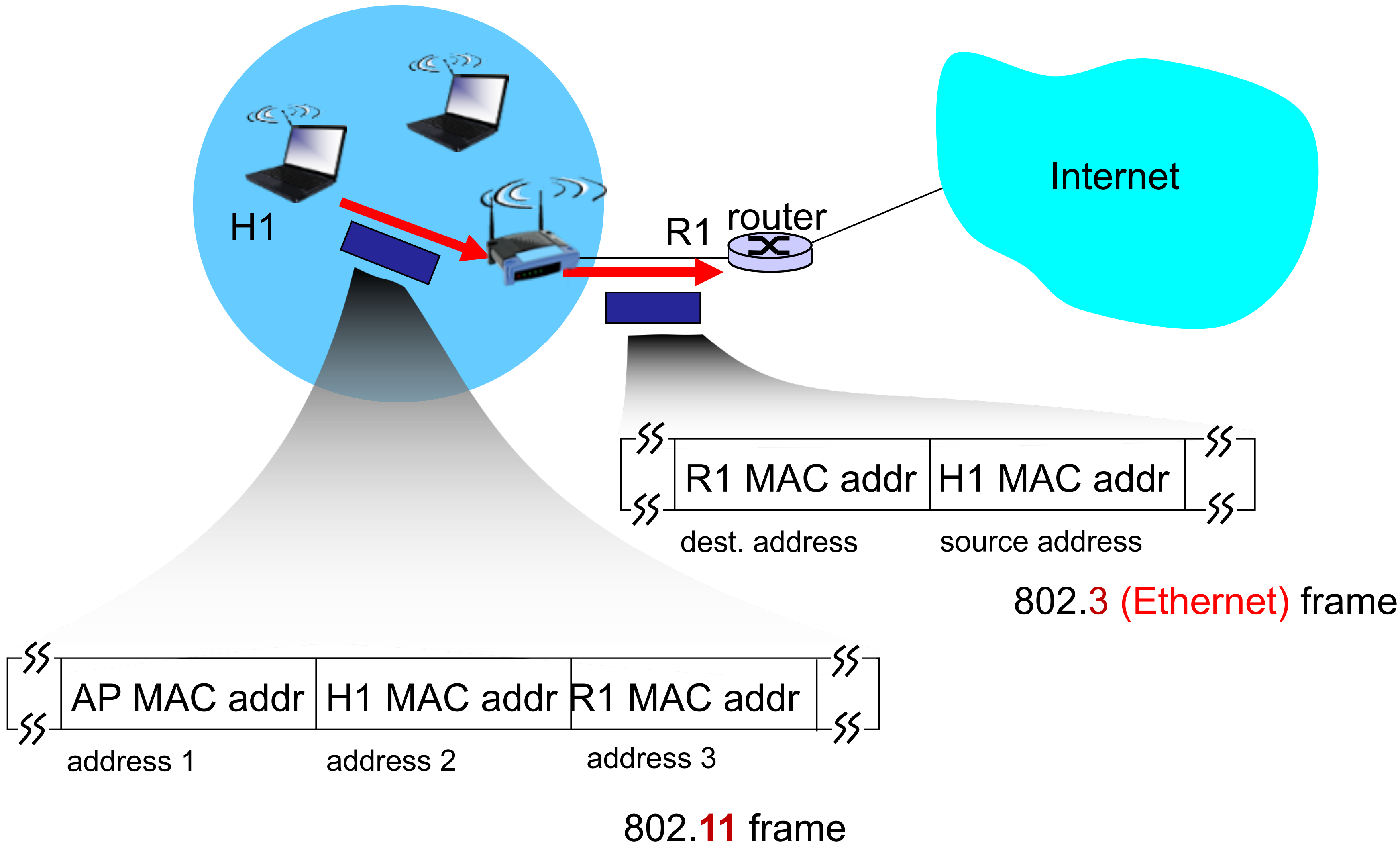
Address 1: MAC address of wireless host or AP to receive this frame

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

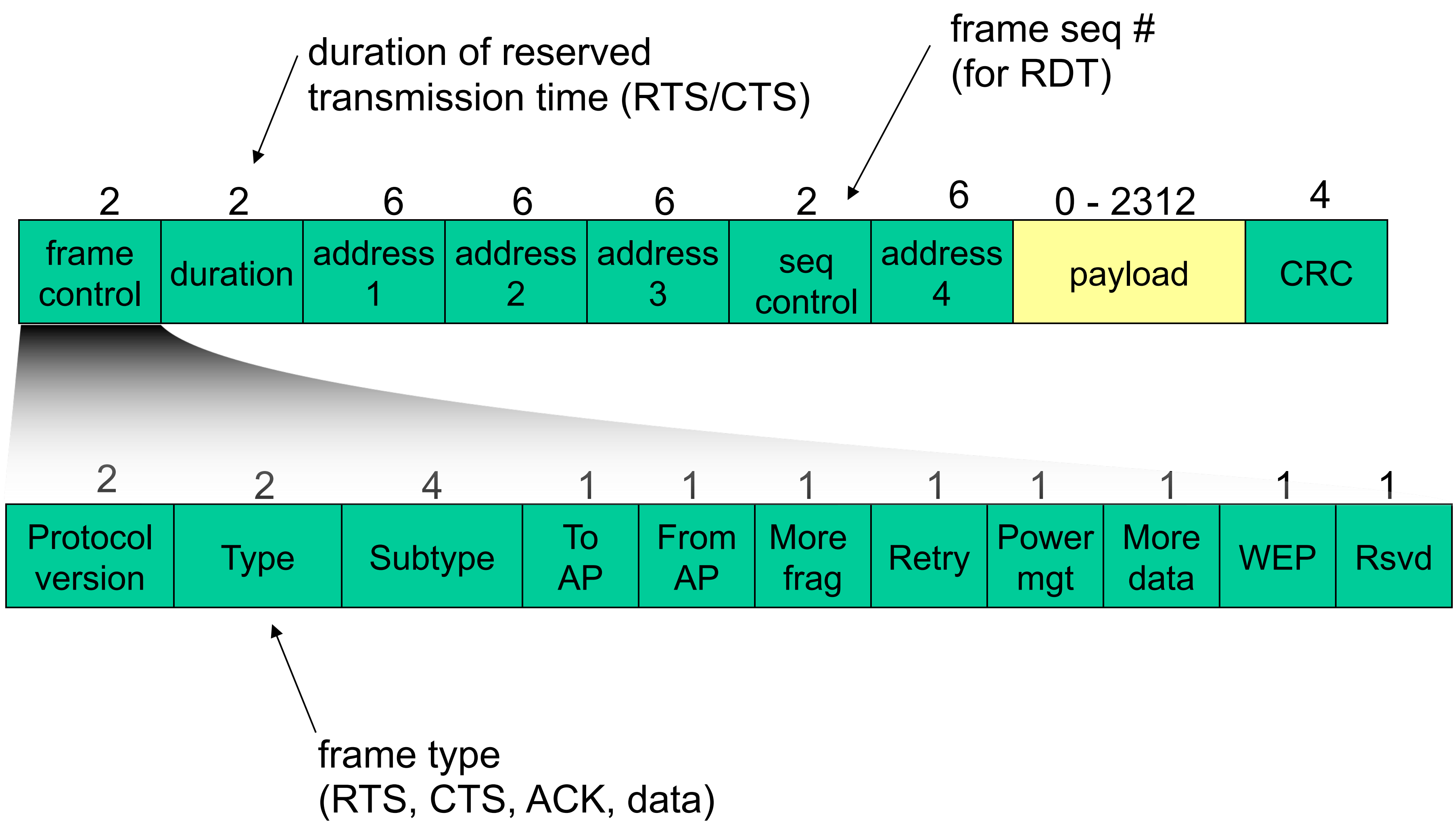
Address 3: MAC address of router interface to which AP is attached

Address 4: used only in ad hoc mode

802.11 frame: addressing

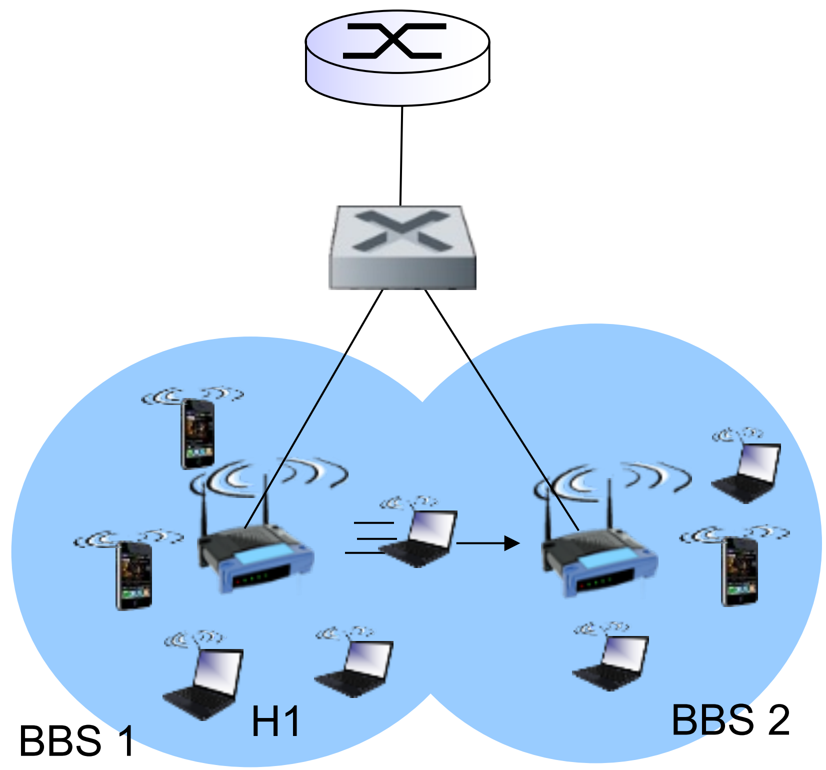


802.11 frame: more



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
  - Move to BBS2, AP2 broadcasts an Ethernet frame

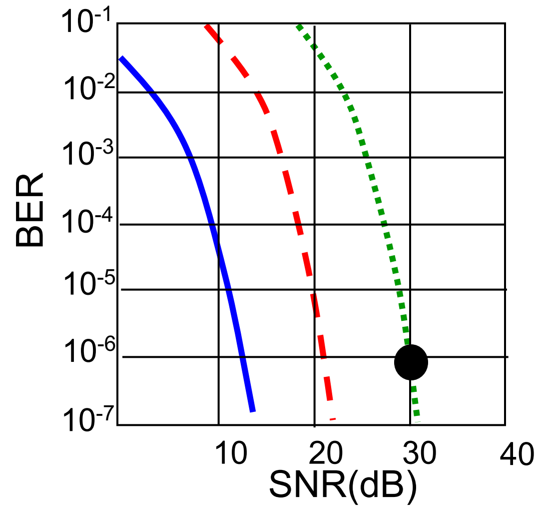


802.11: advanced capabilities

Rate adaptation

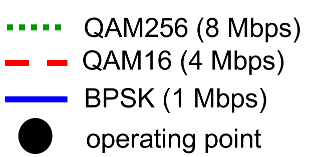
base station, mobile dynamically change transmission rate (physical layer modulation technique) as mobile moves, SNR varies

- no ACK, decreases rate
- ACK, increase rate



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



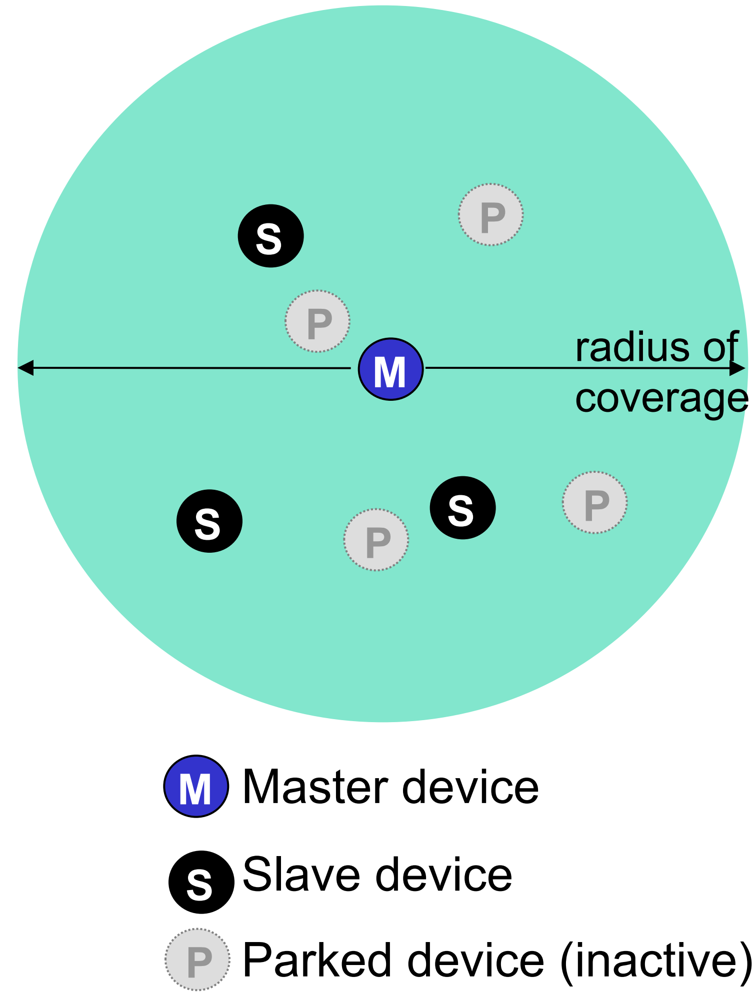
802.11: advanced capabilities

power management

- node-to-AP: "I am going to sleep until next beacon frame" (power mgt to 1)
  - 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

802.15.1: Bluetooth

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



Chapter 7 outline

7.1 Introduction

Wireless

7.2 Wireless links, characteristics

- CDMA

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

7.4 Cellular Internet Access

- architecture
- standards (e.g., 3G, LTE)

Mobility

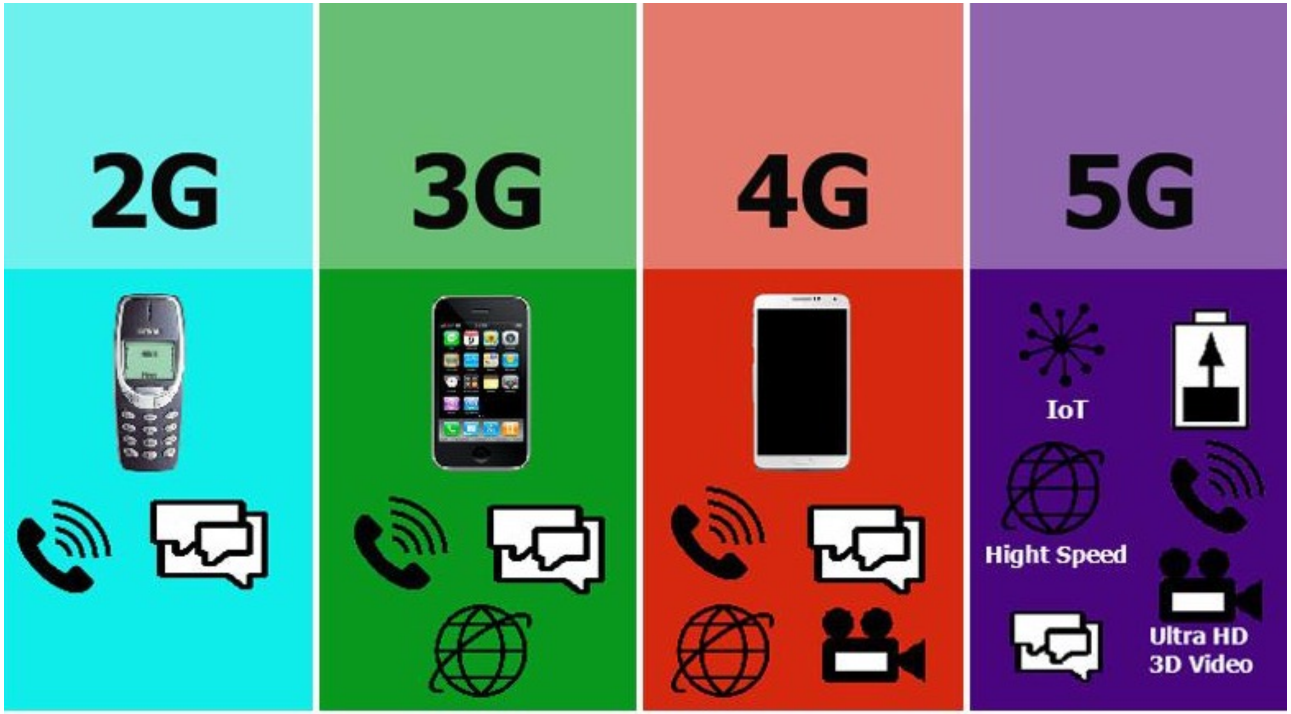
7.5 Principles: addressing and routing to mobile users

7.6 Mobile IP

7.7 Handling mobility in cellular networks

7.8 Mobility and higher-layer protocols

Cellular network



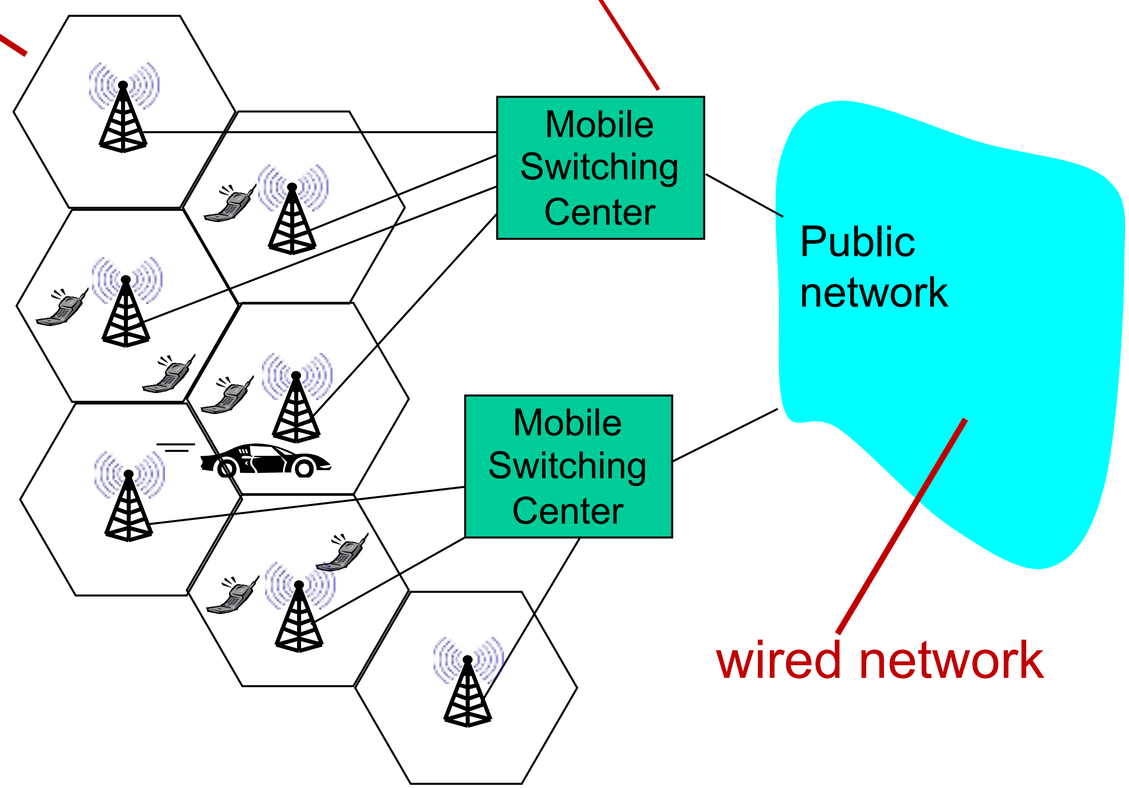
Components of cellular network architecture

MSC

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

cell

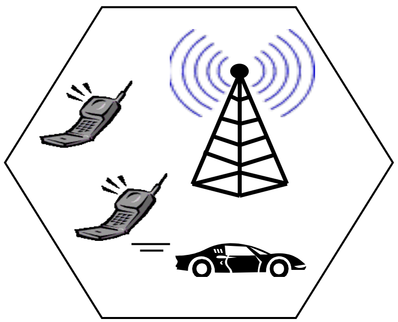
- covers geographical region
- *base station* (BS) analogous to 802.11 AP
- *mobile users* attach to network through BS
- *air-interface:* physical and link layer protocol between mobile and BS

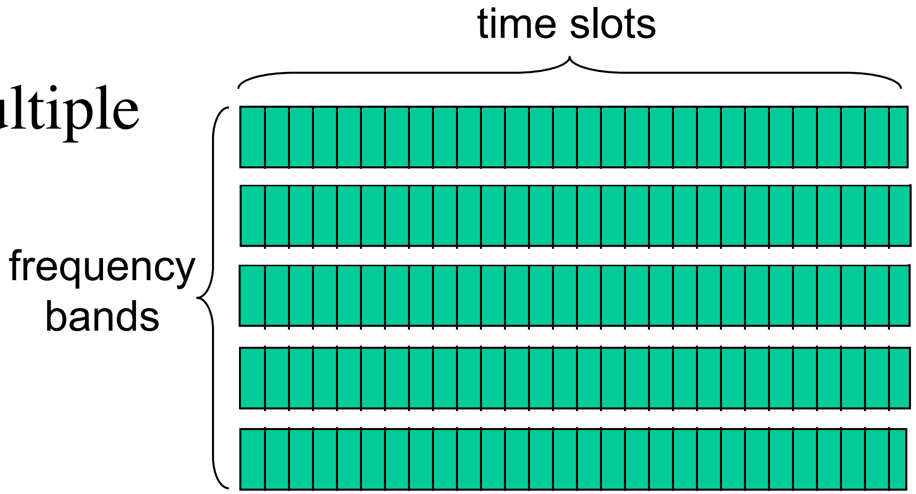


Cellular networks: the first hop

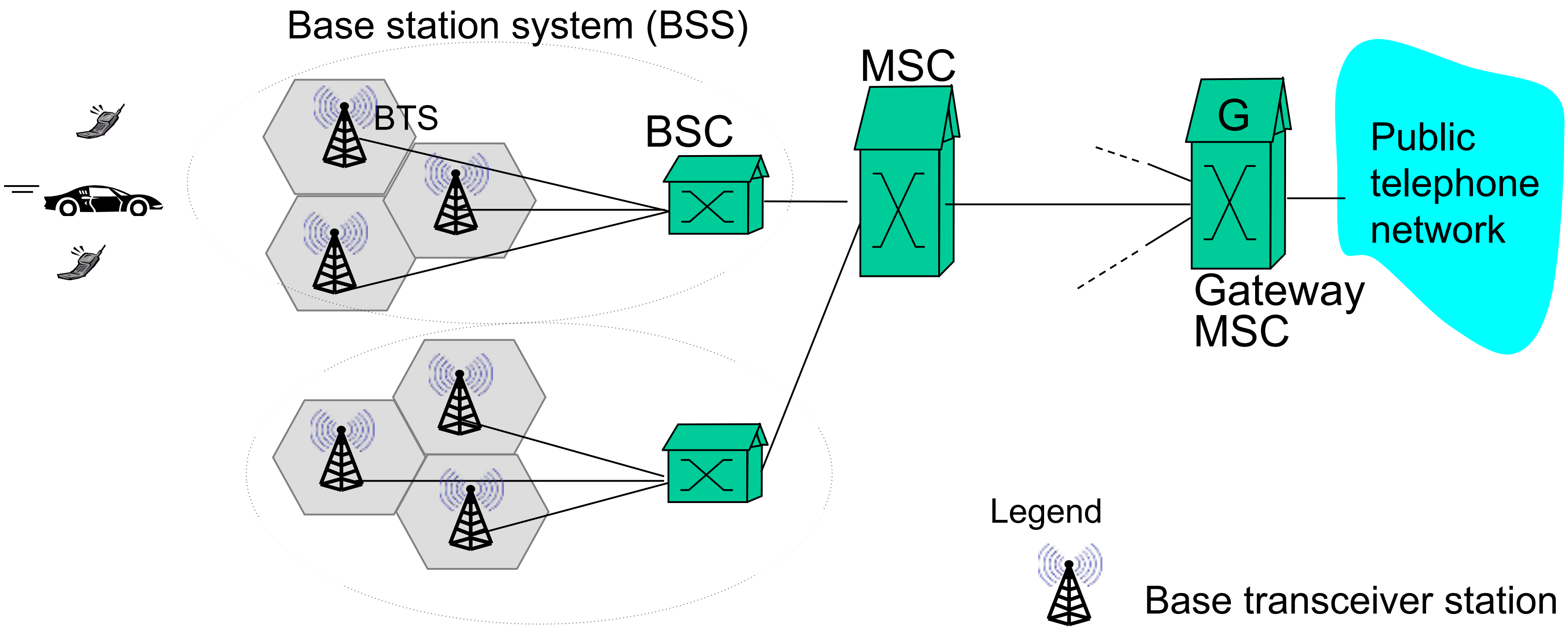
Two techniques for sharing mobile-to-BS radio spectrum

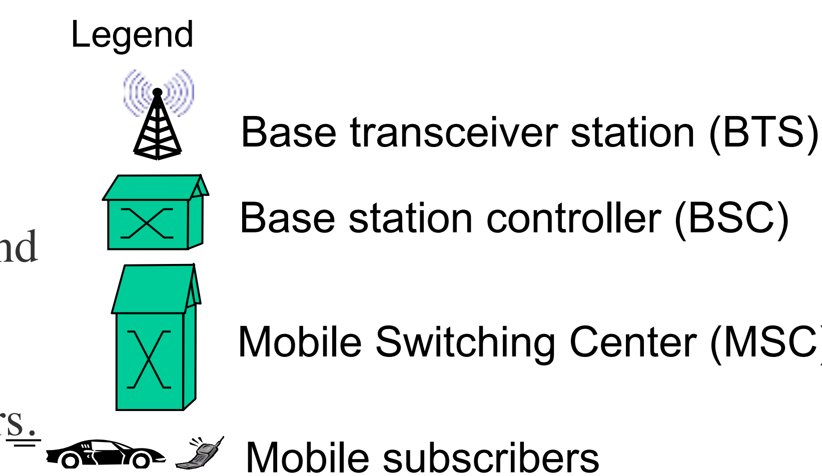
- combined FDMA/TDMA: divide spectrum in frequency channels, divide each channel into time slots
- CDMA: code division multiple access





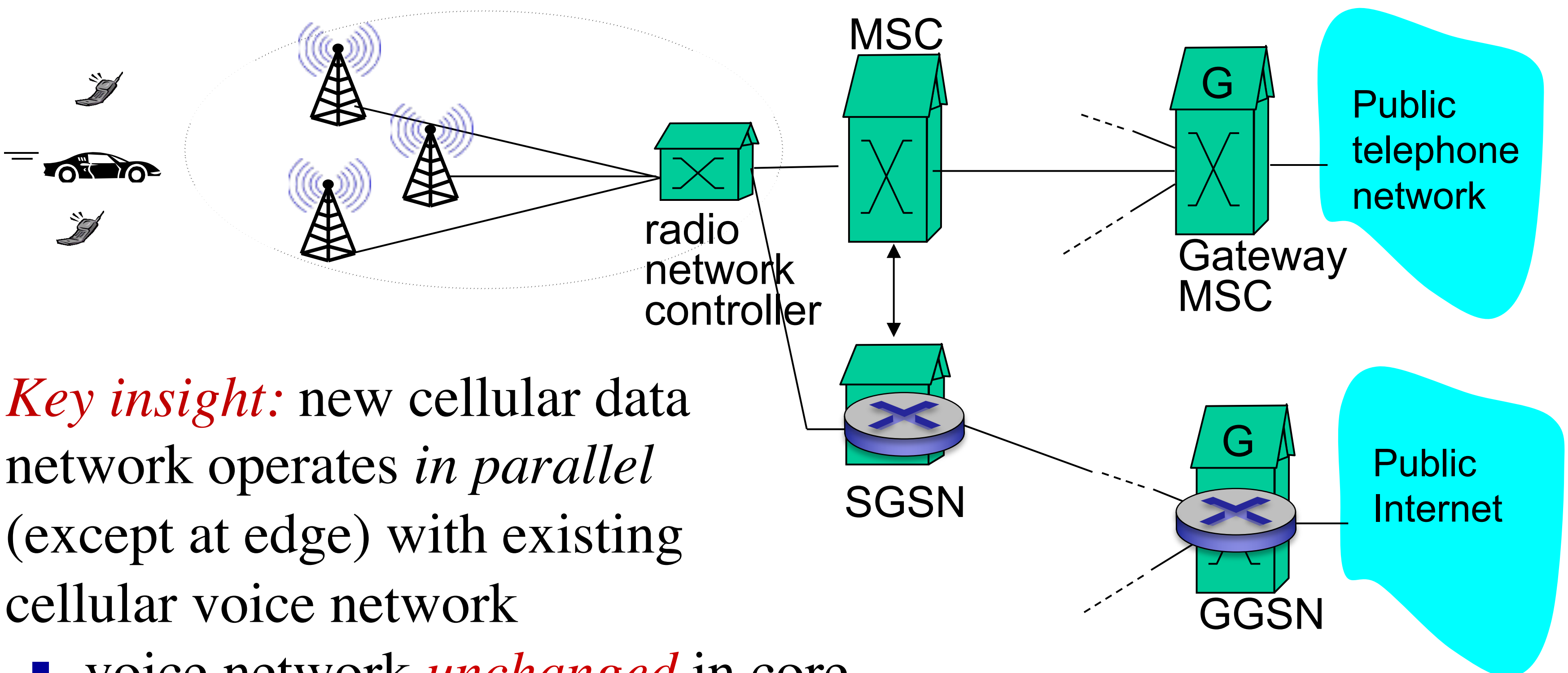
2G (voice) network architecture





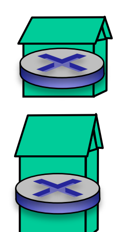
Base transceiver station (BTS): transmits signals to and receives signals from the mobile stations in its cell.
Base station controller (BSC): allocate BTS radio channels, paging, and perform handoff of mobile users.
Mobile switching center (MSC): user authorization and accounting, call establishment and teardown, and handoff.

3G (voice+data) network architecture



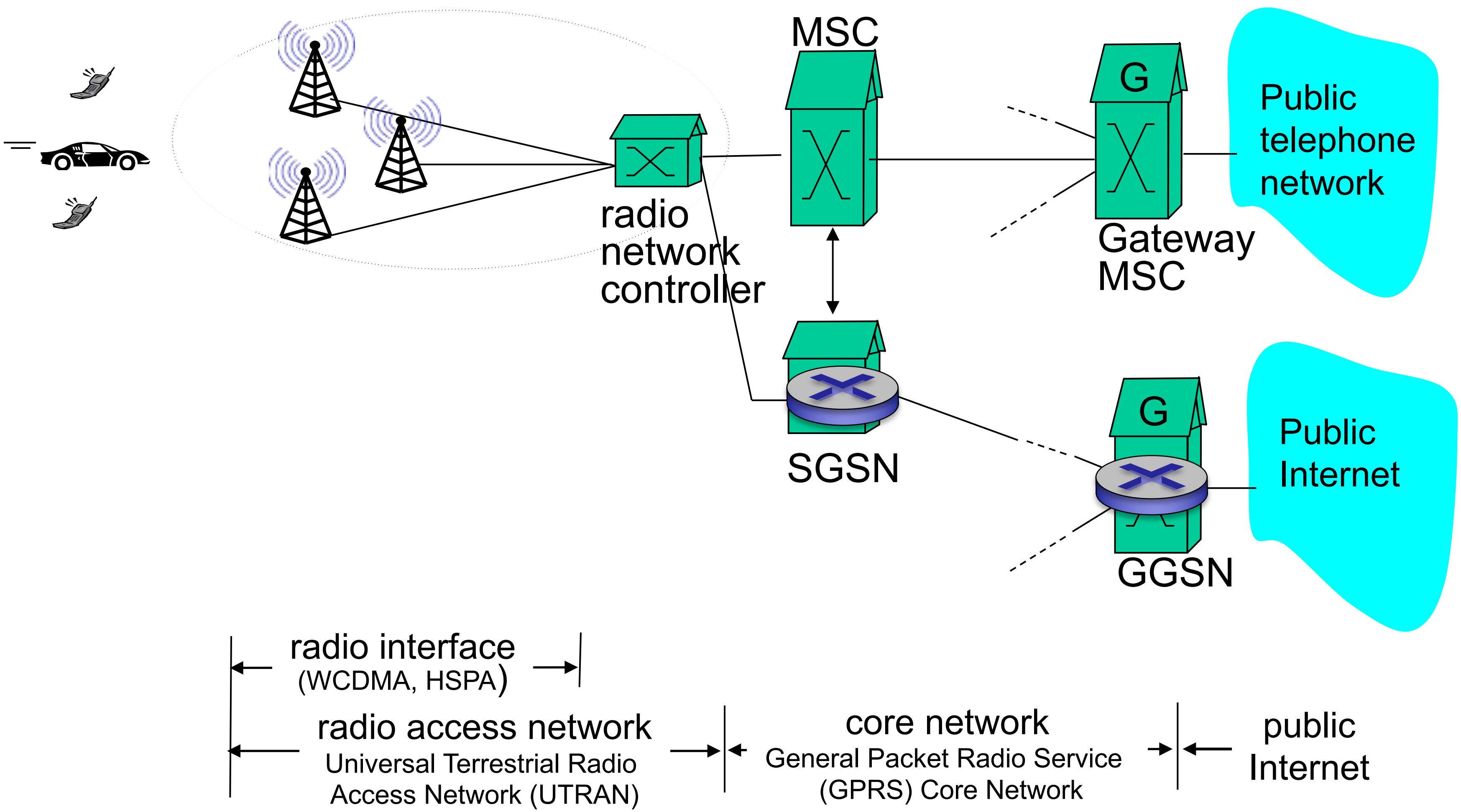
Key insight: new cellular data network operates *in parallel* (except at edge) with existing cellular voice network

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

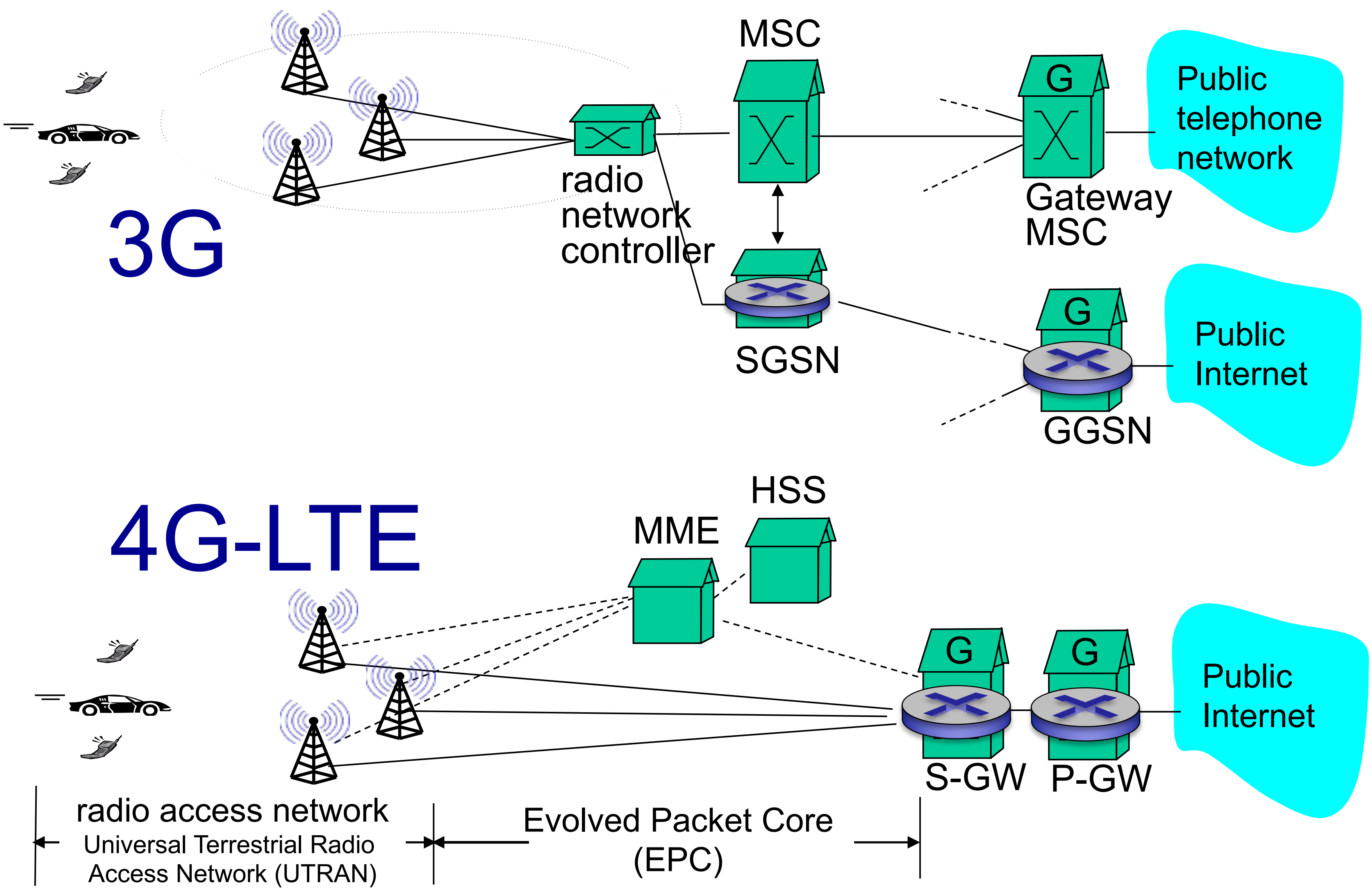


SGSN: delivering datagrams to/from the mobile nodes
GGSN: gateway, connecting multiple SGSNs into the larger Internet

3G (voice+data) network architecture

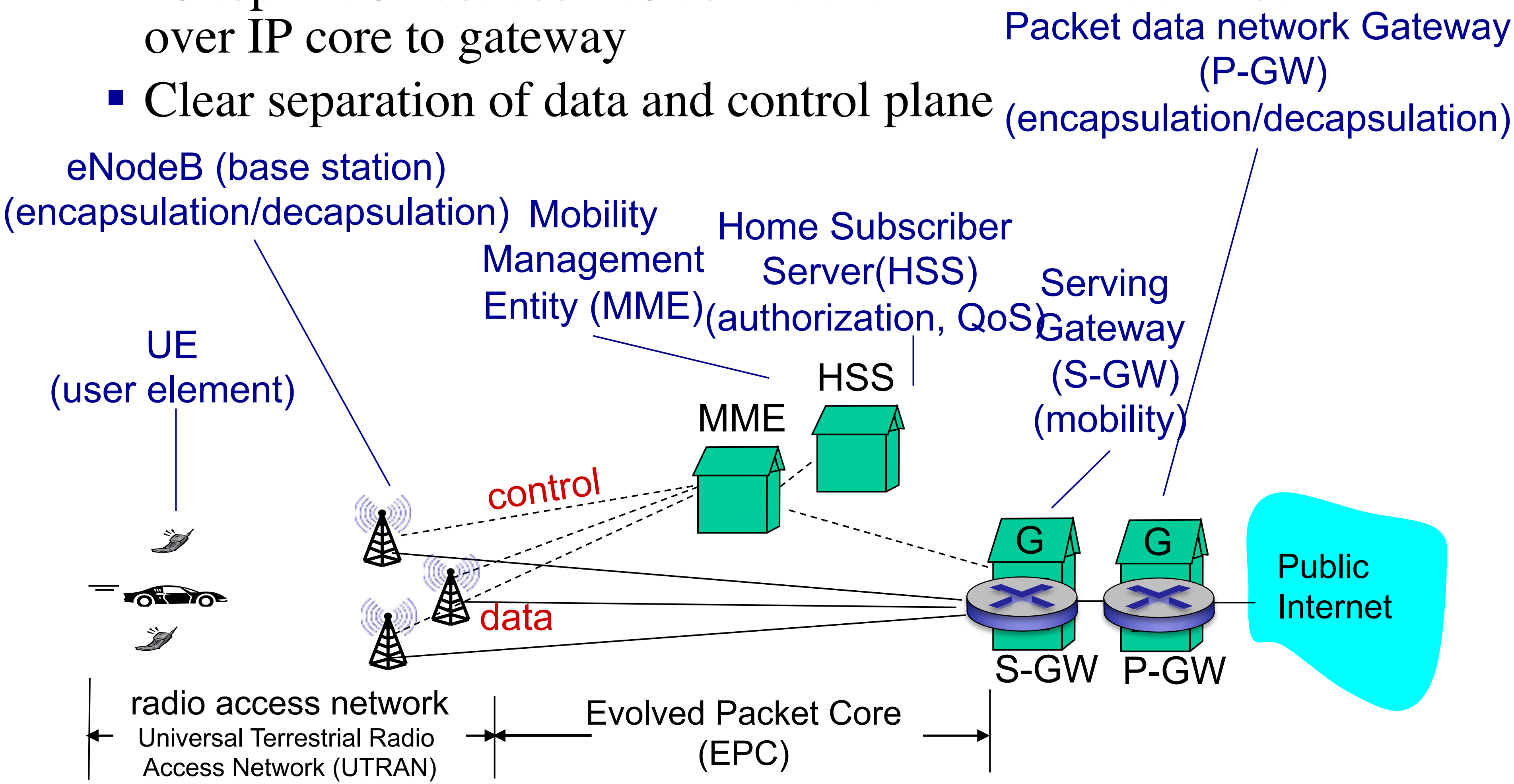


3G versus 4G LTE network architecture



4G: differences from 3G

- no separation between voice and data – all traffic carried over IP core to gateway
- Clear separation of data and control plane



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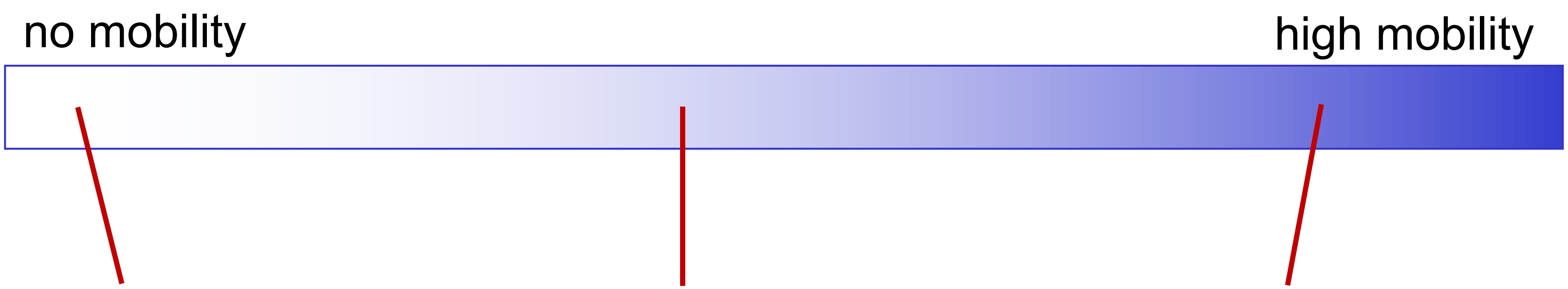
What is mobility?

Spectrum of mobility, from the *network* perspective:



mobile wireless user, using same access point

mobile user, connecting/ disconnecting from network using DHCP.

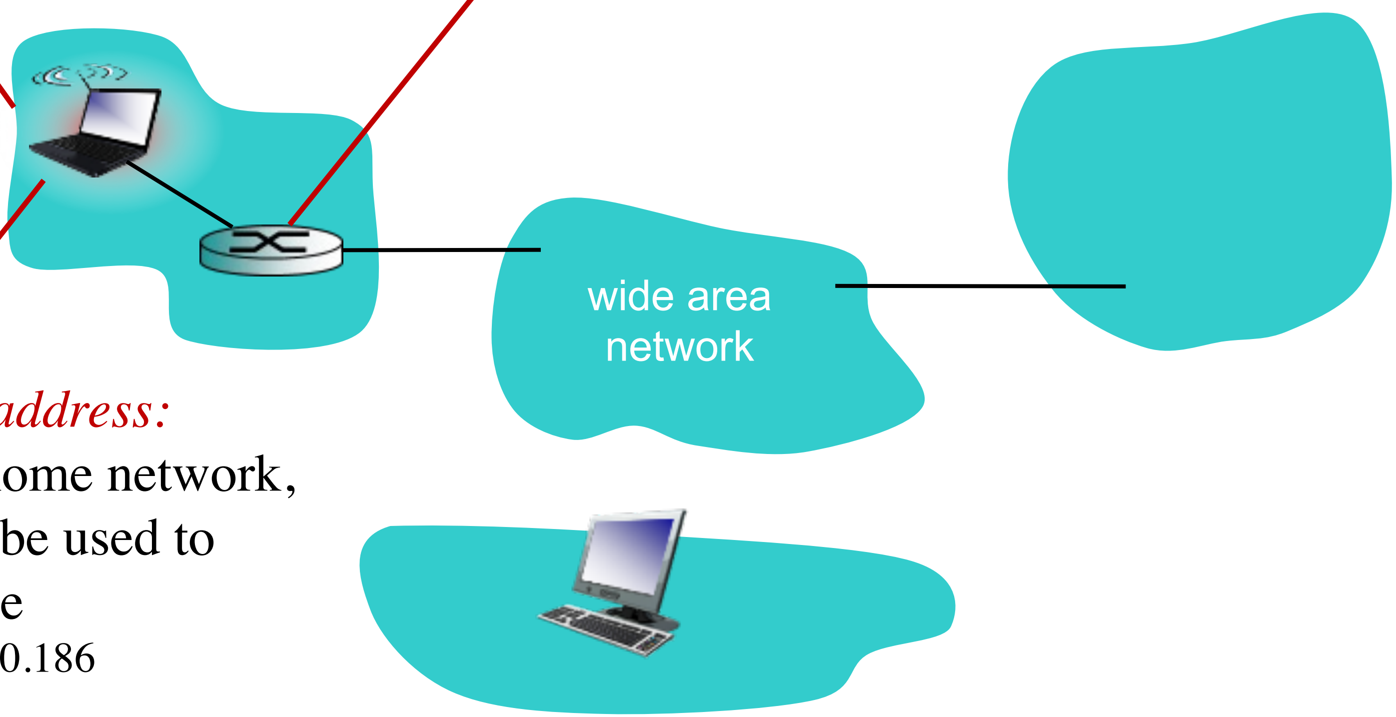
That is, shutting down while moving between networks.

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



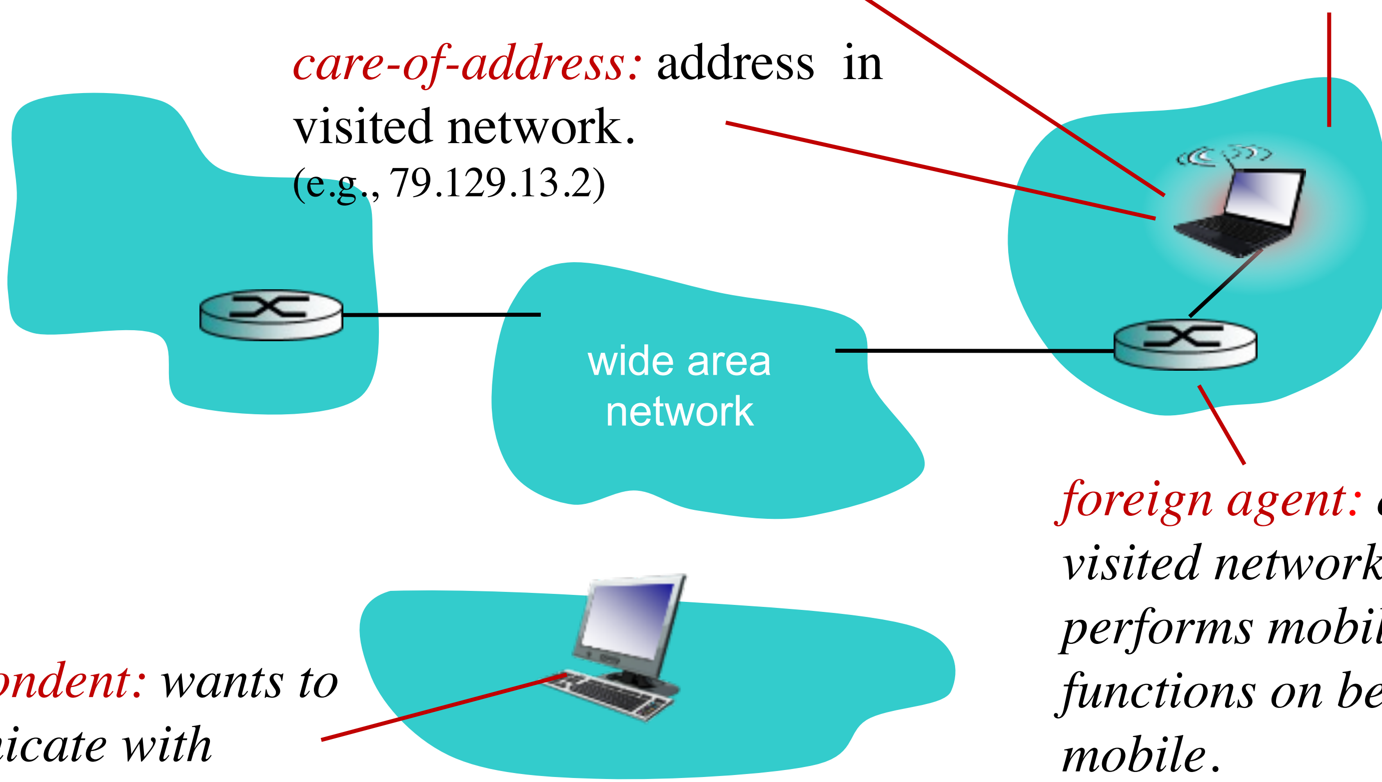
permanent address:
address in home network, *can always* be used to reach mobile
e.g., 128.119.40.186

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)



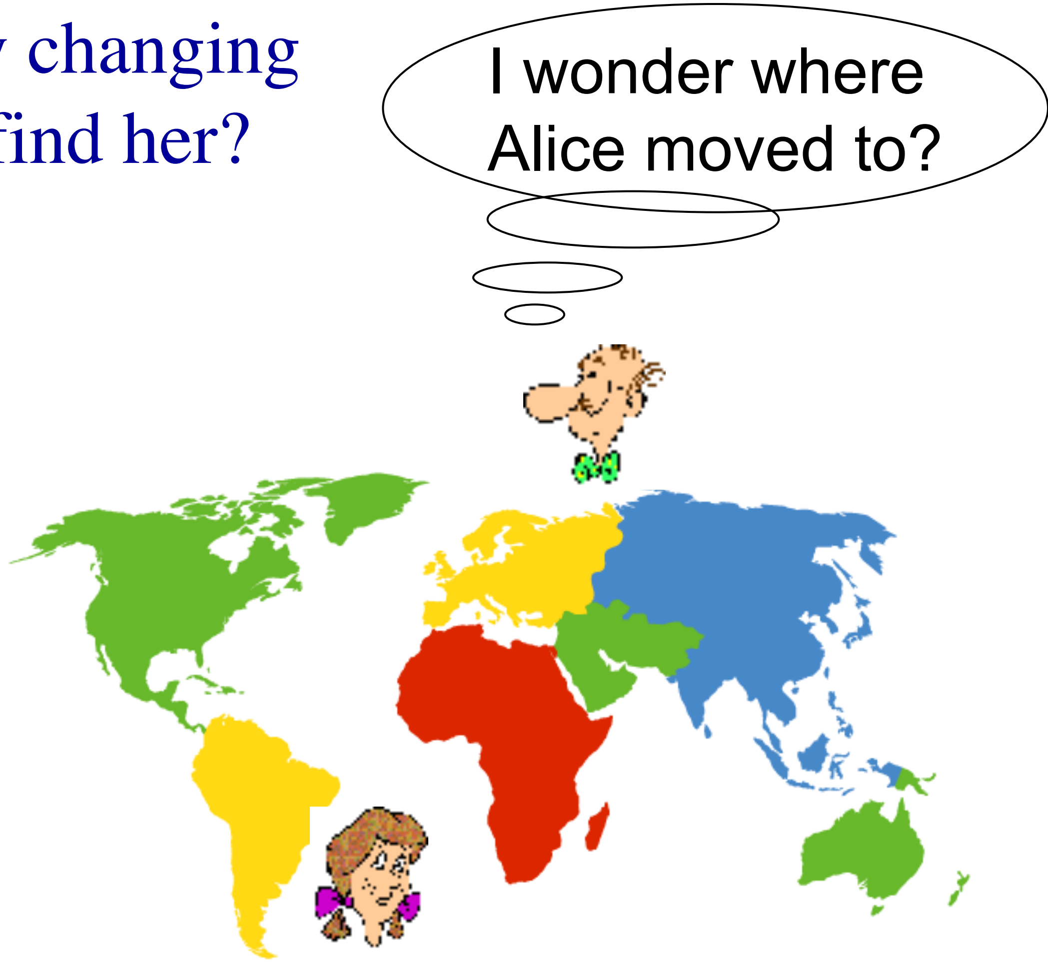
foreign agent: entity in visited network that performs mobility functions on behalf of mobile.

correspondent: wants to communicate with mobile

How do *you* contact a mobile friend?

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

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



Mobility: approaches

- *let routing handle it:* foreign agent advertises 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

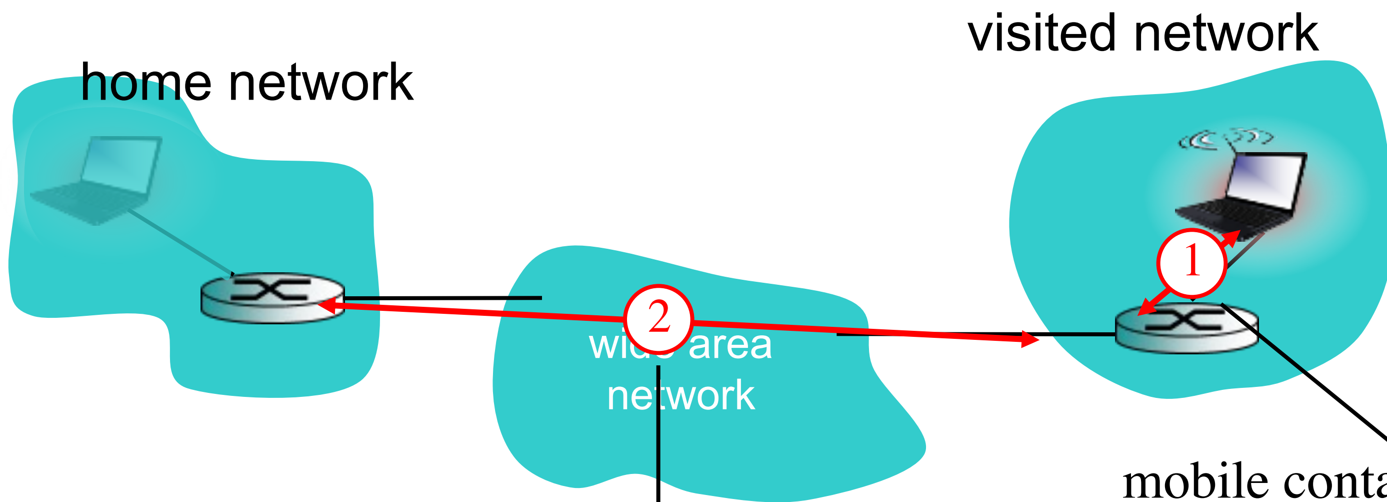
Mobility: approaches

- *let routing handle it:* routers advertise permanent address of mobile ... -residence via usual routing table ex...
  - routing table ... ere each mobile located
  - no changes to e... ms

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



foreign agent contacts home agent home: "this mobile is resident in my network"

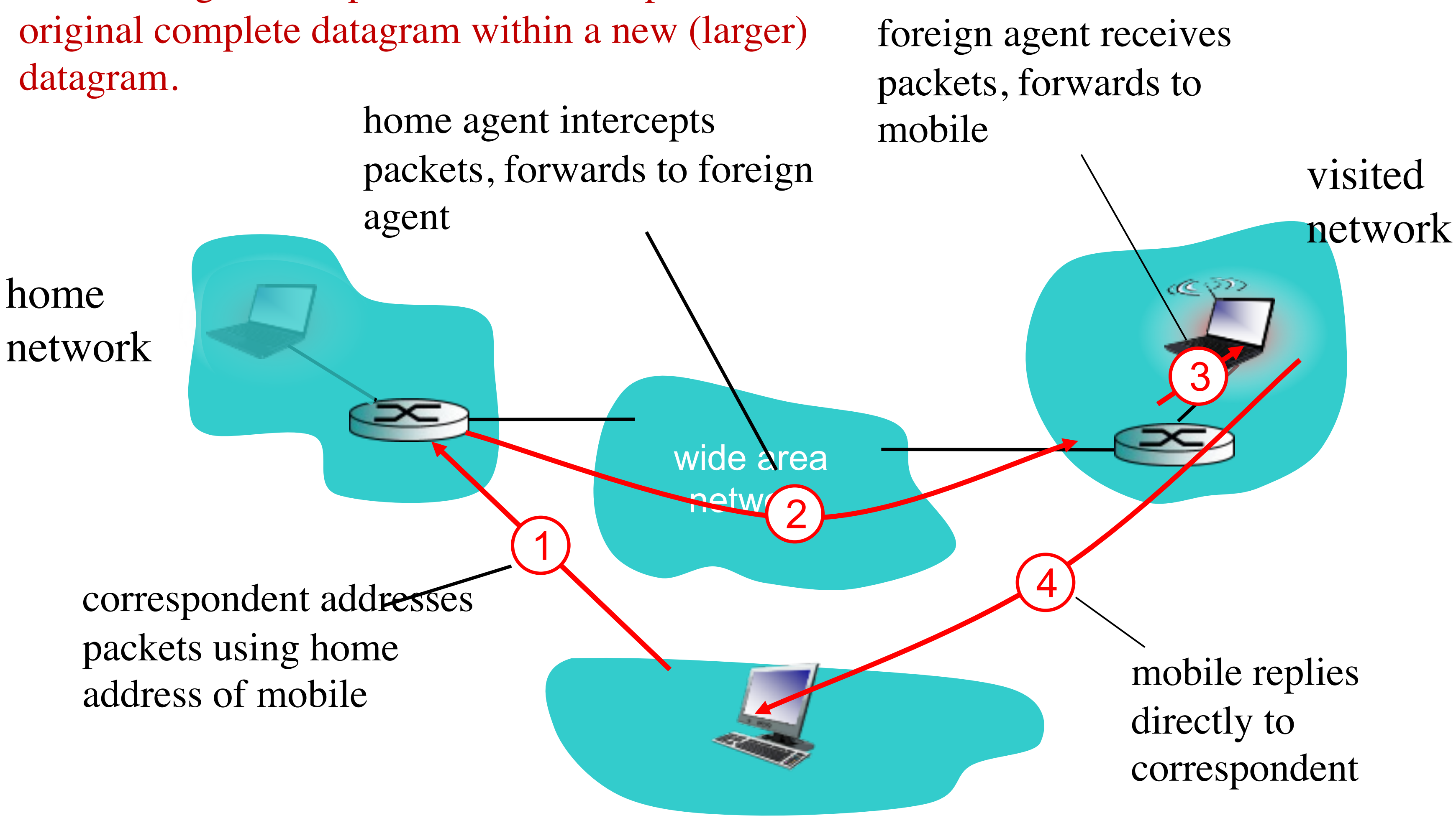
mobile contacts foreign agent on entering visited network

end result:

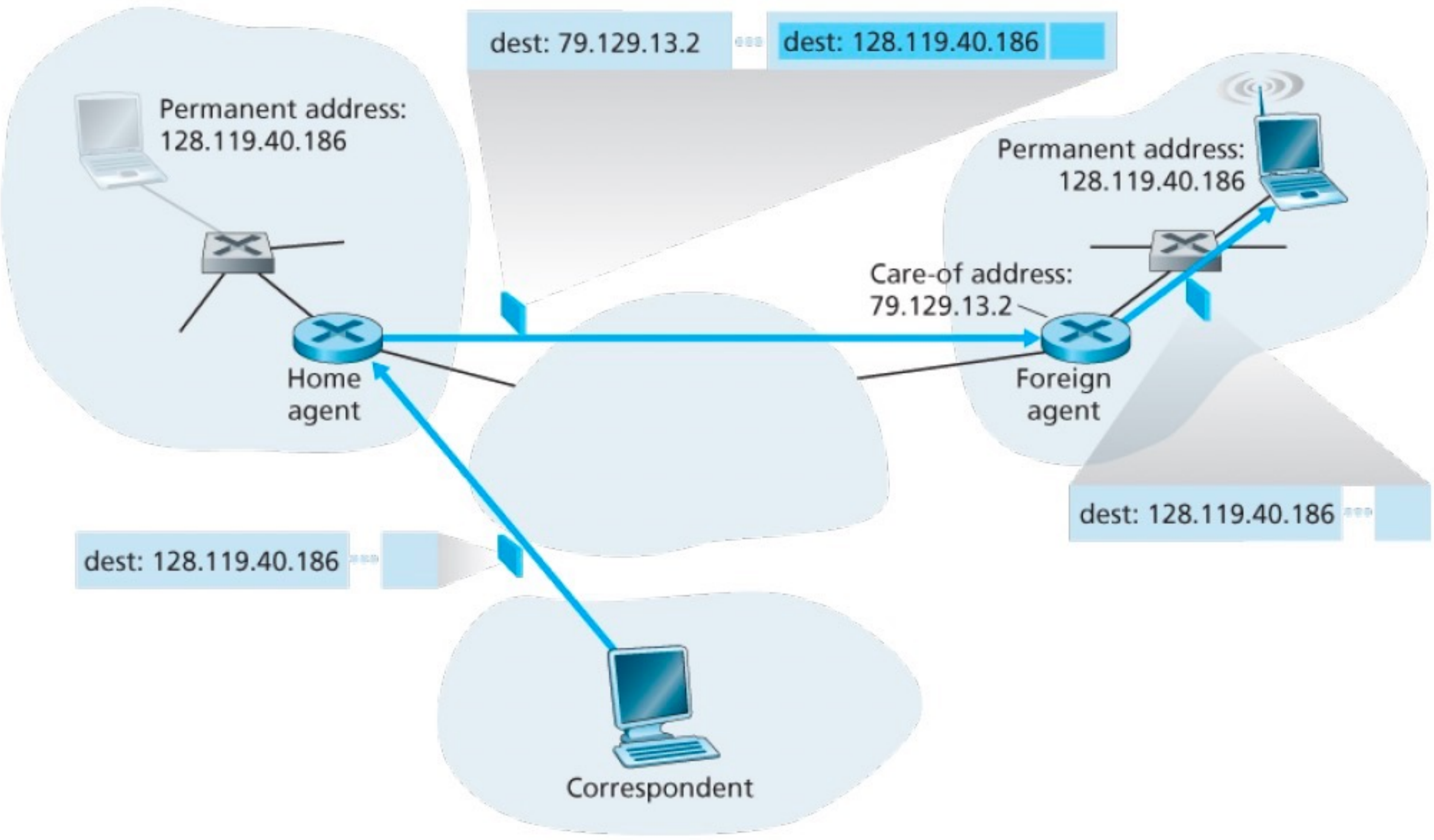
- foreign agent knows about mobile
- home agent knows location of mobile

Mobility via indirect routing

the home agent encapsulates the correspondent's original complete datagram within a new (larger) datagram.

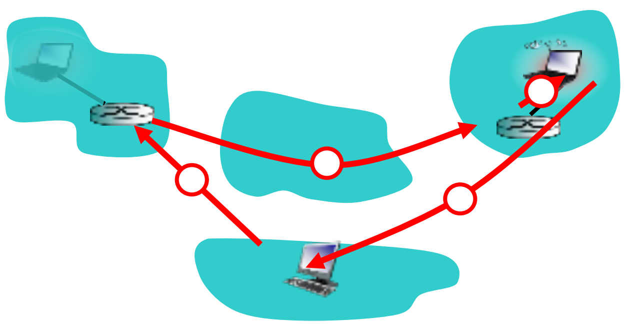


Mobility via indirect routing



Indirect Routing: comments

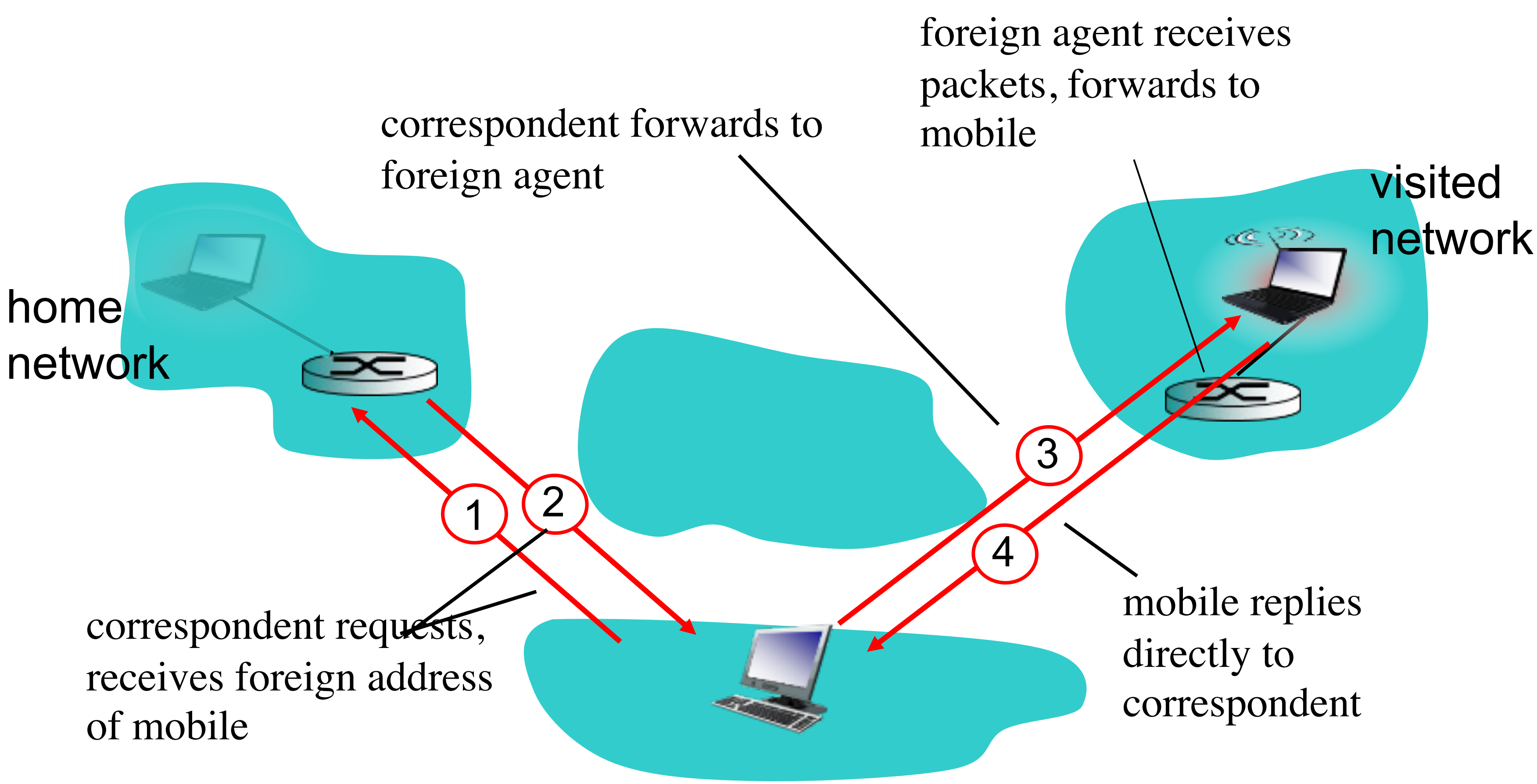
- mobile uses two addresses:
  - permanent address: used by correspondent (hence mobile location is *transparent* to correspondent)
  - care-of-address: used by home agent to forward datagrams to mobile
- foreign agent functions may be done by mobile itself
- triangle routing: correspondent-home-network-mobile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



Indirect routing: moving between networks

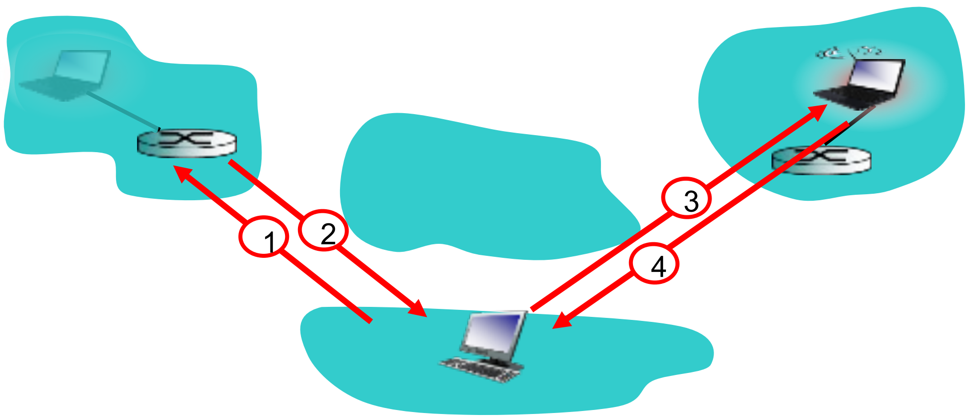
- suppose mobile user moves to another network
  - registers with new foreign agent
  - new foreign agent registers with home agent
  - home agent update care-of-address for mobile
  - packets continue to be forwarded to mobile (but with new care-of-address)
- mobility, changing foreign networks transparent: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

Mobility via direct routing



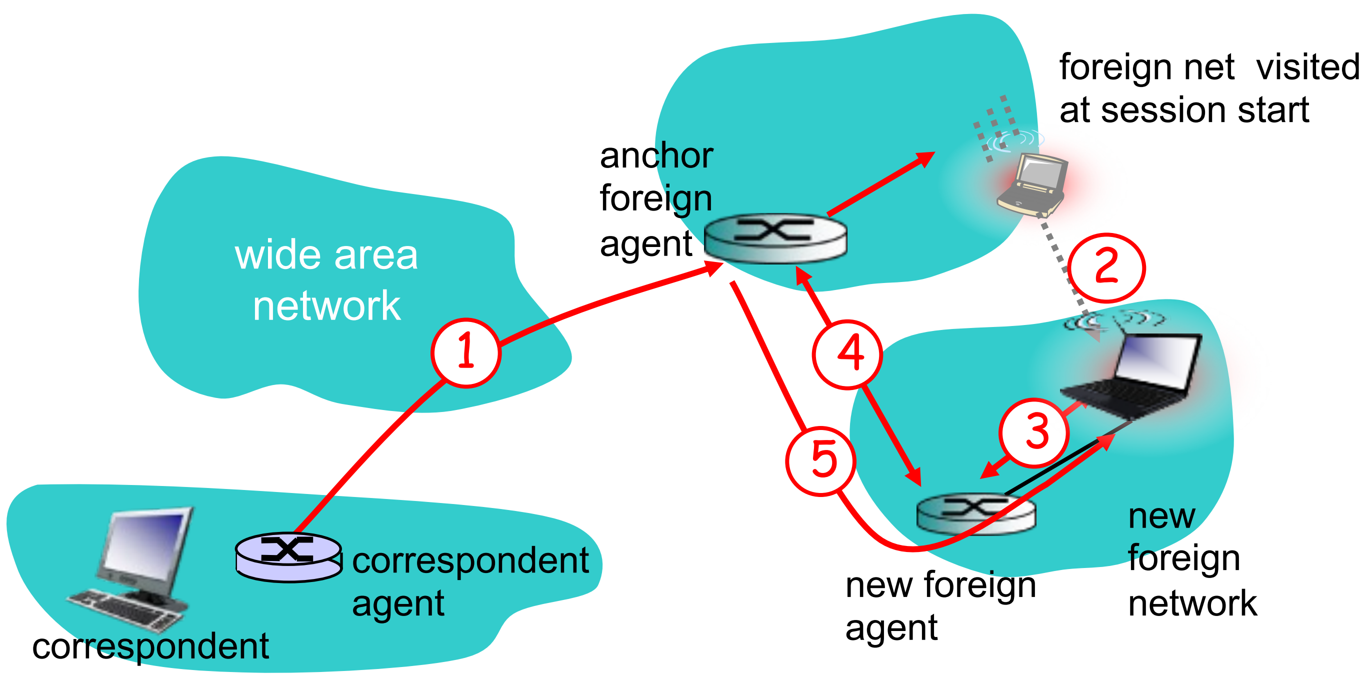
Mobility via direct routing: comments

- 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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