Chapter 7
Wireless and Mobile Networks

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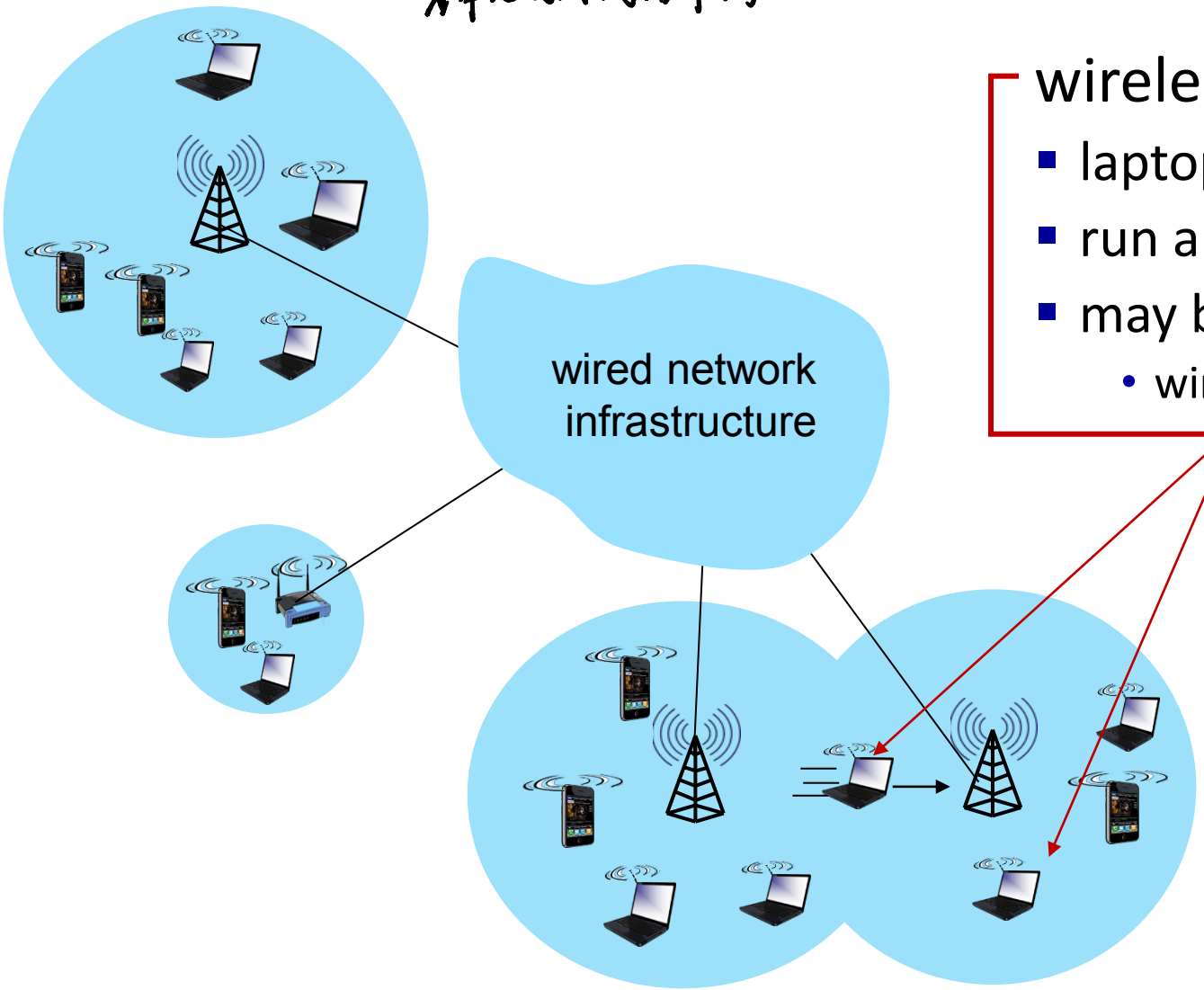
Wireless and Mobile Networks: context

- more wireless (mobile) phone subscribers than fixed (wired) phone subscribers (10-to-1 in 2019)!
- more mobile-broadband-connected devices than fixed-broadband-connected devices devices (5-1 in 2019)!
  - 4G/5G cellular networks now embracing Internet protocol stack, including SDN
- two important (but different) challenges
  - wireless: communication over wireless link
  - mobility: handling the mobile user who changes point of attachment to network

Elements of a wireless network

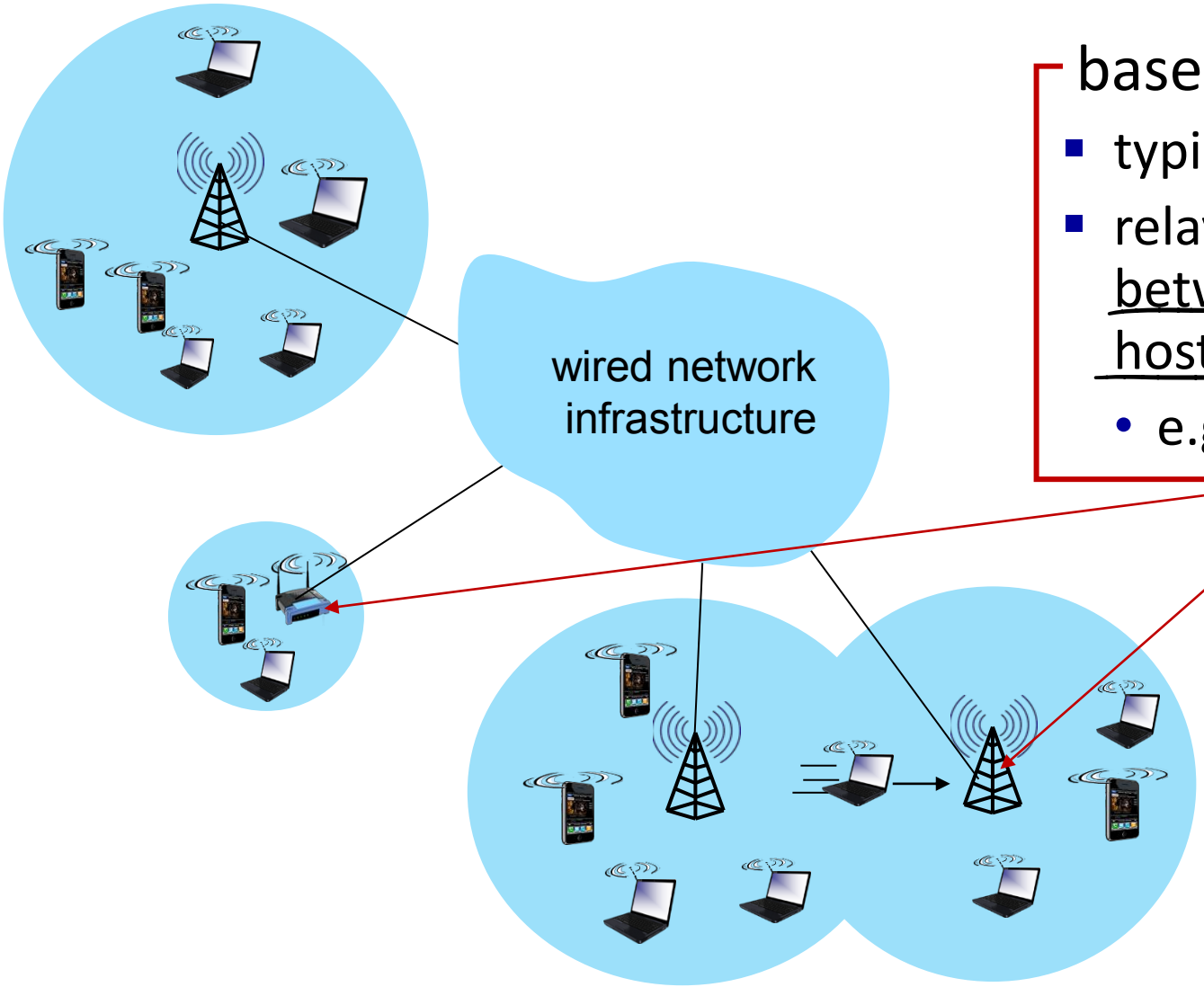
基本的无线网络架构.



wireless hosts

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

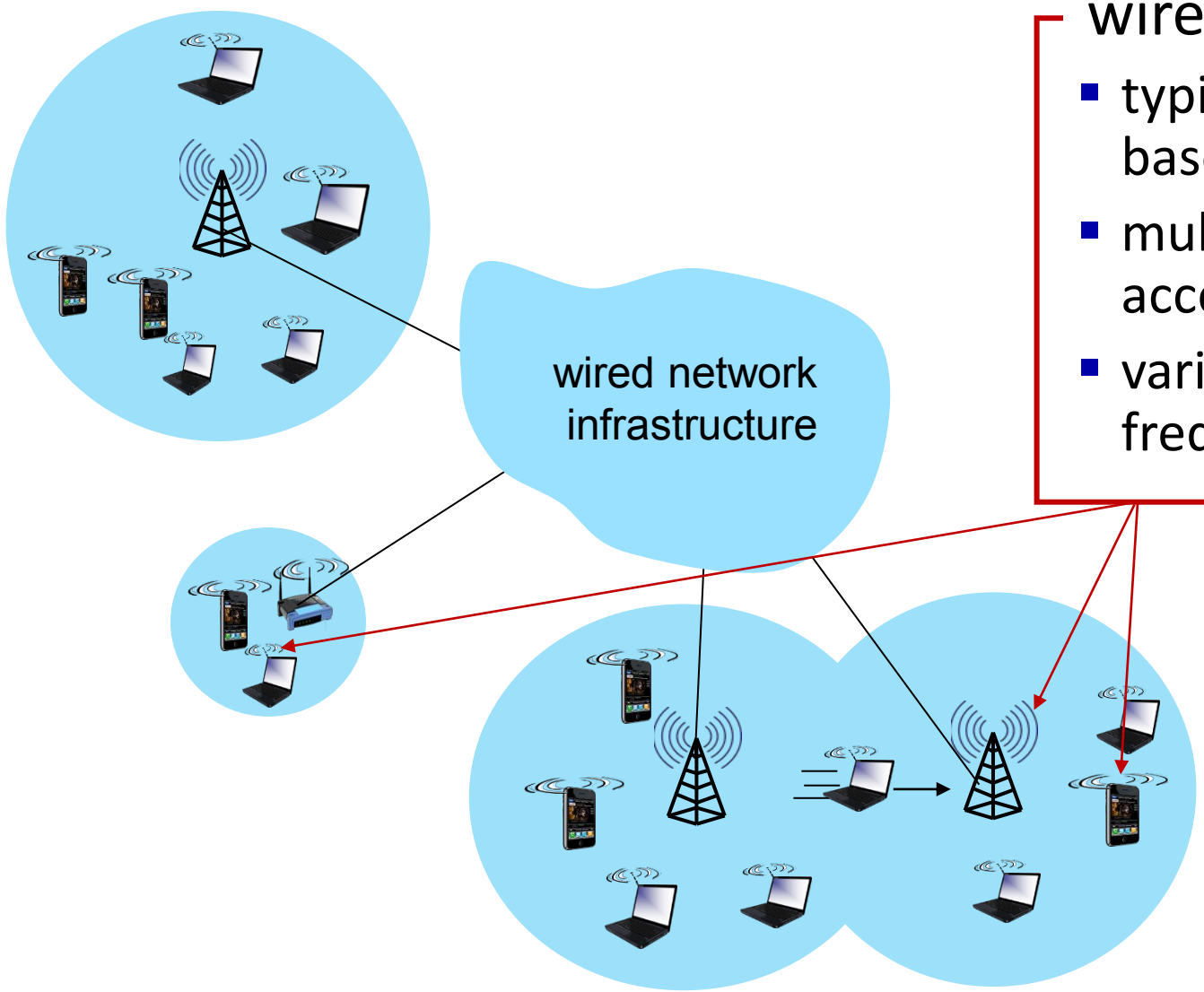
Elements of a wireless network



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

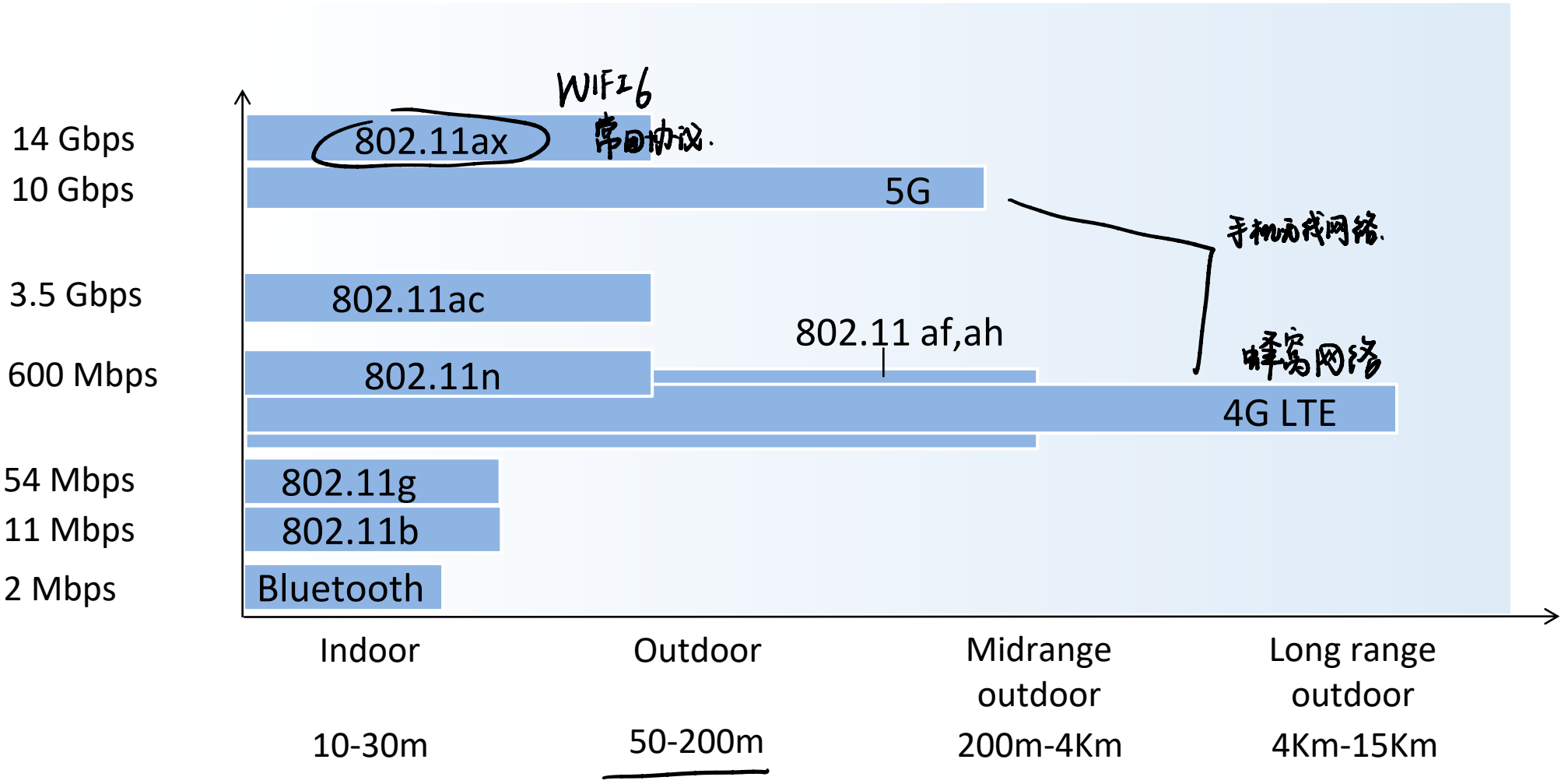
Elements of a wireless network



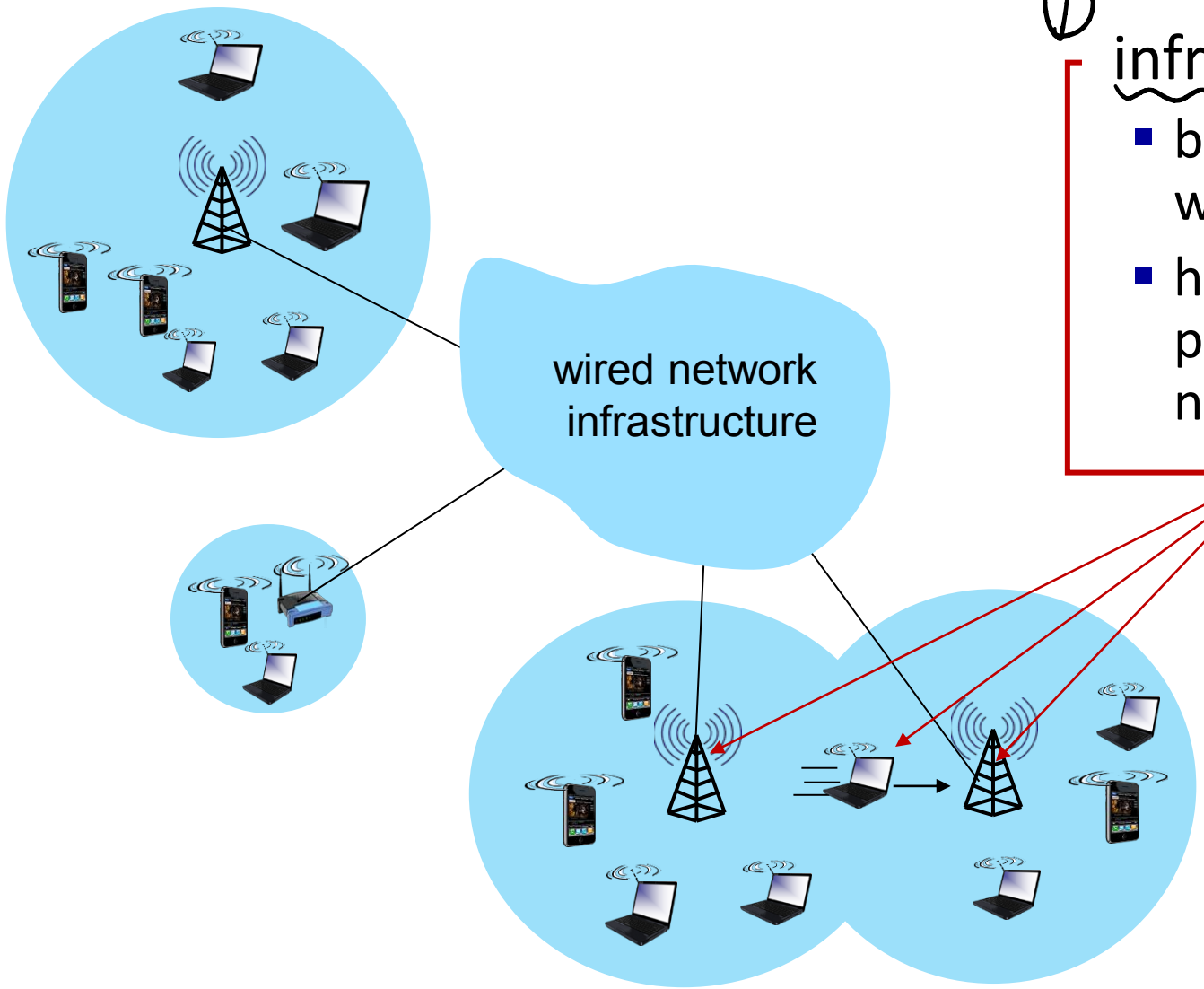
wireless link

- typically used to connect mobile(s) to base station, also used as backbone link
- multiple access protocol coordinates link access
- various transmission rates and distances, frequency bands

Characteristics of selected wireless links



Elements of a wireless network

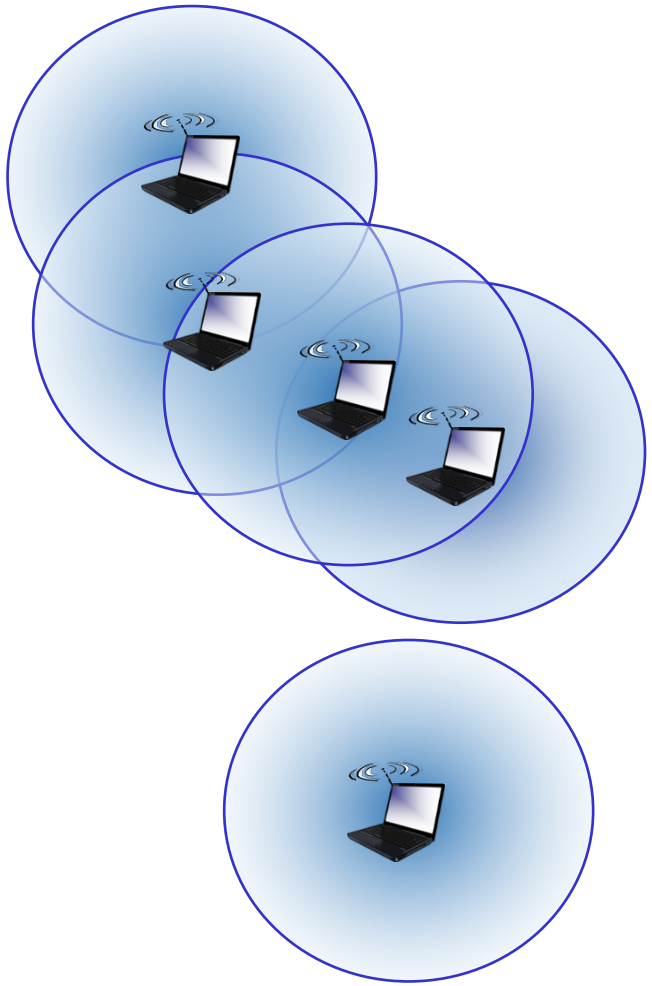


① infrastructure mode

以基站为基础的.

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

Elements of a wireless network



② ad hoc mode 自组织网络.

- 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

单跳即连基站.　　传感器网络　中间经过主机

	single hop	multiple hops
infrastructure (e.g., APs)	host connects to base station (WiFi, cellular) which connects to larger Internet	host may have to relay through several wireless nodes to connect to larger Internet: *mesh net*
no infrastructure ad hoc	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

车联网. relate 自动驾驶.
汽车之间也信息传递.

Chapter 7 outline

- Introduction

Wireless

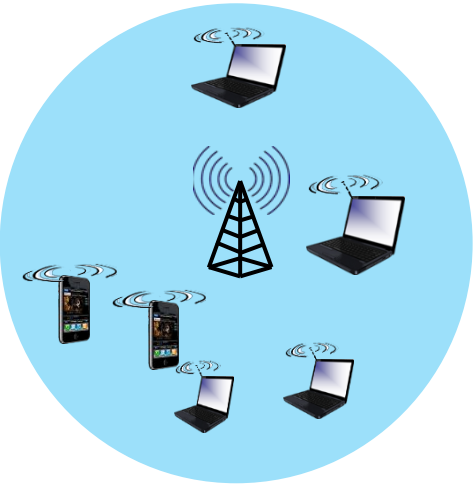
- Wireless links and network characteristics
- WiFi: 802.11 wireless LANs
- Cellular networks: 4G and 5G

Mobility

- Mobility management: principles
- Mobility management: practice
  - 4G/5G networks
  - Mobile IP
- Mobility: impact on higher-layer protocols

Wireless link characteristics (1)

important differences from wired link ….



- decreased signal strength: radio signal attenuates as it propagates through matter (path loss)
- interference from other sources: wireless network frequencies (e.g., 2.4 GHz) shared by many devices (e.g., WiFi, cellular, motors): interference

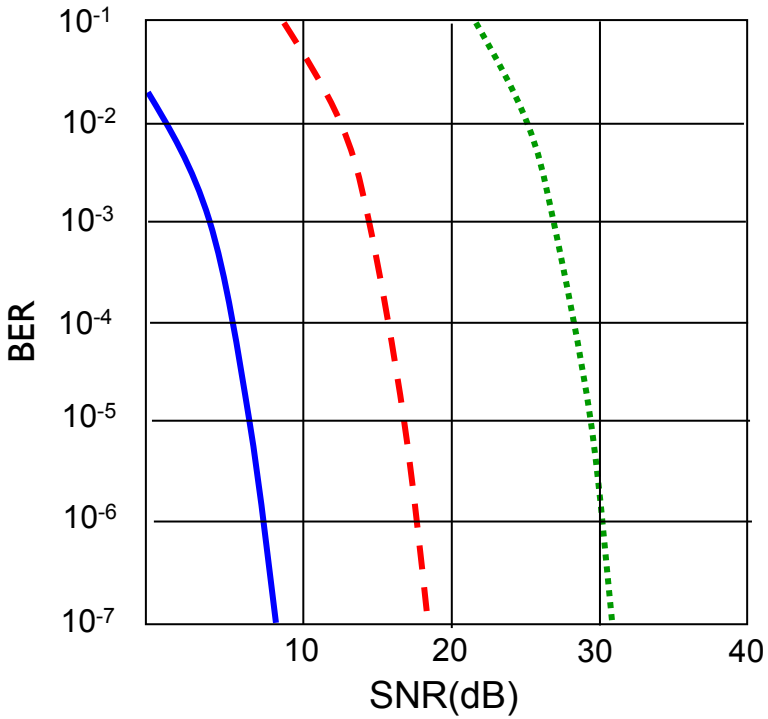
- multipath propagation: radio signal reflects off objects ground, arriving at destination at slightly different times 同样信号到达时间&强度不同

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

Wireless link characteristics (2)

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

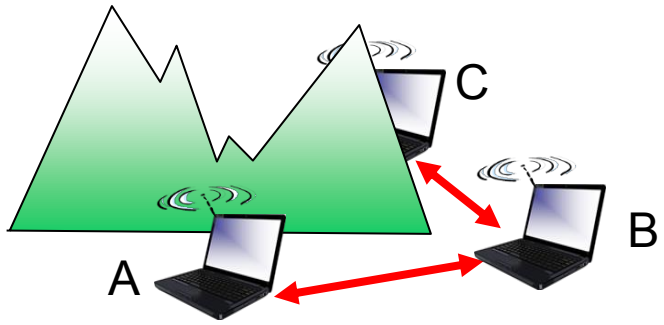
bit error rate.

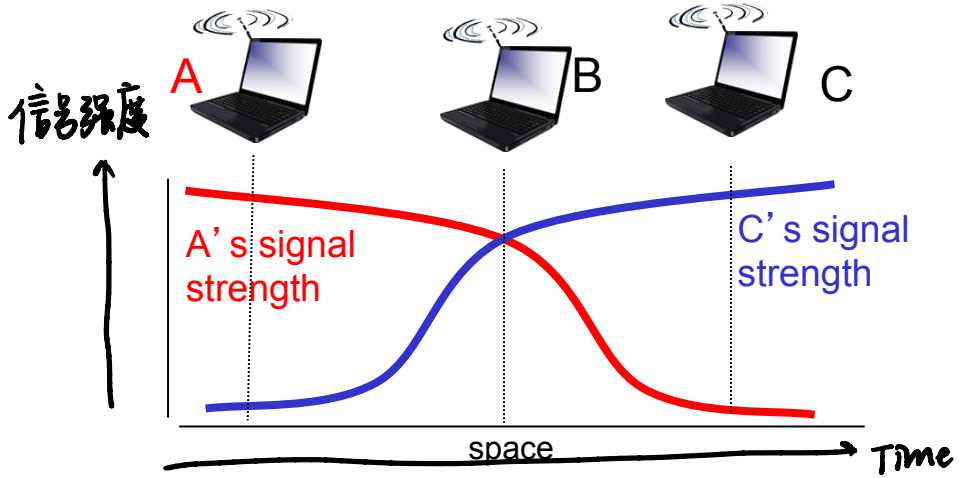


SNR — bandwidth ↗ BER ↗ 实际的吞吐量小 有损失 etc.

Wireless link characteristics (3)

Multiple wireless senders, 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:

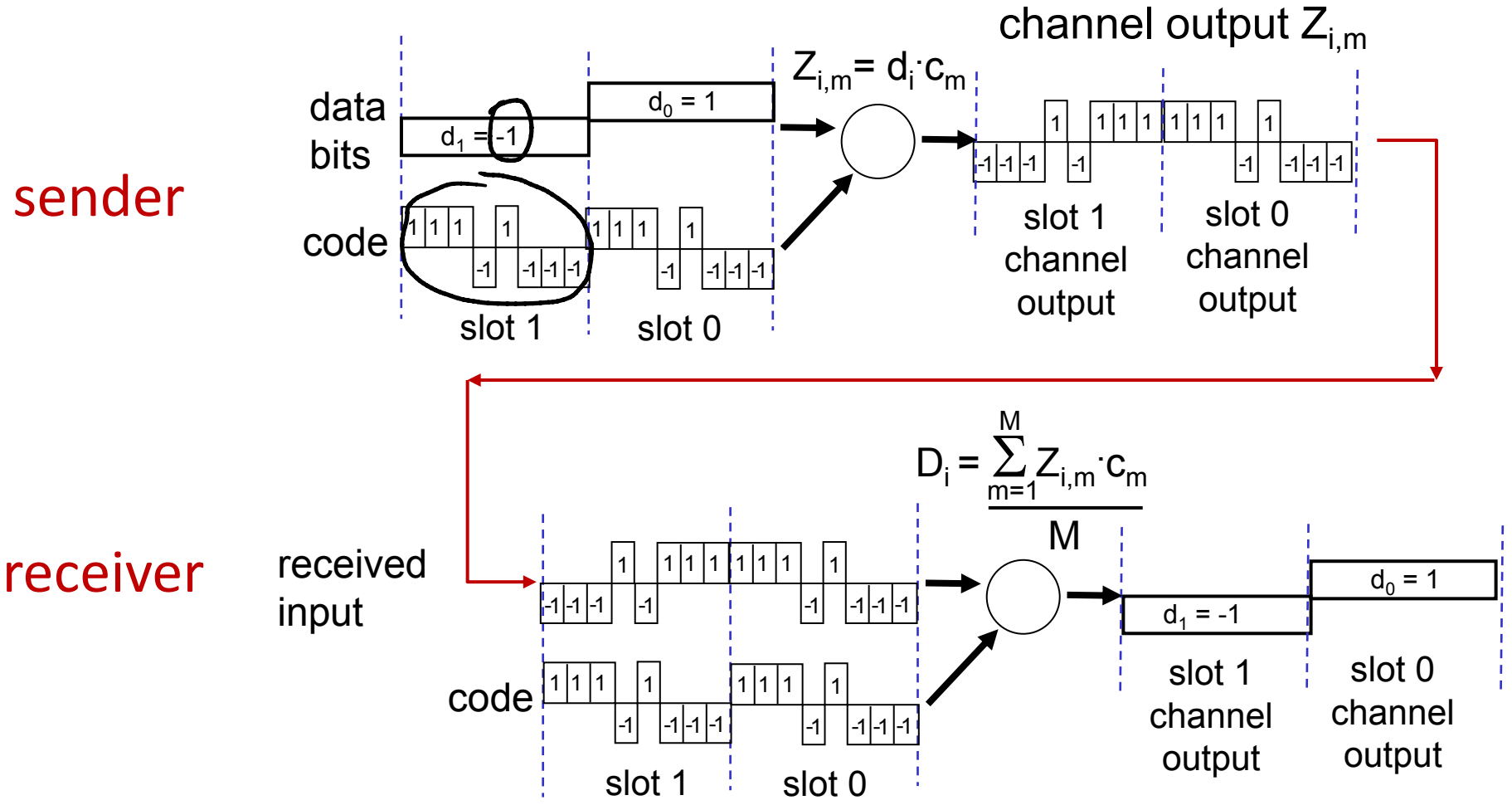
- B, A hear each other
- B, C hear each other
- A, C can not hear each other interfering at B

A不能sense到C→B的通信.
但可能同时发送成colision

Code Division Multiple Access (CDMA)

- unique "code" assigned to each user; i.e., code set partitioning
  - all users share same frequency, but each user has own "chipping" sequence (i.e., code) to encode data （chipping rate, 码片率）
  - allows multiple users to "coexist" and transmit simultaneously with minimal interference (if codes are "orthogonal")
- encoding: inner product: (original data) X (chipping sequence)
- decoding: summed inner-product: (encoded data) X (chipping sequence)

CDMA encode/decode



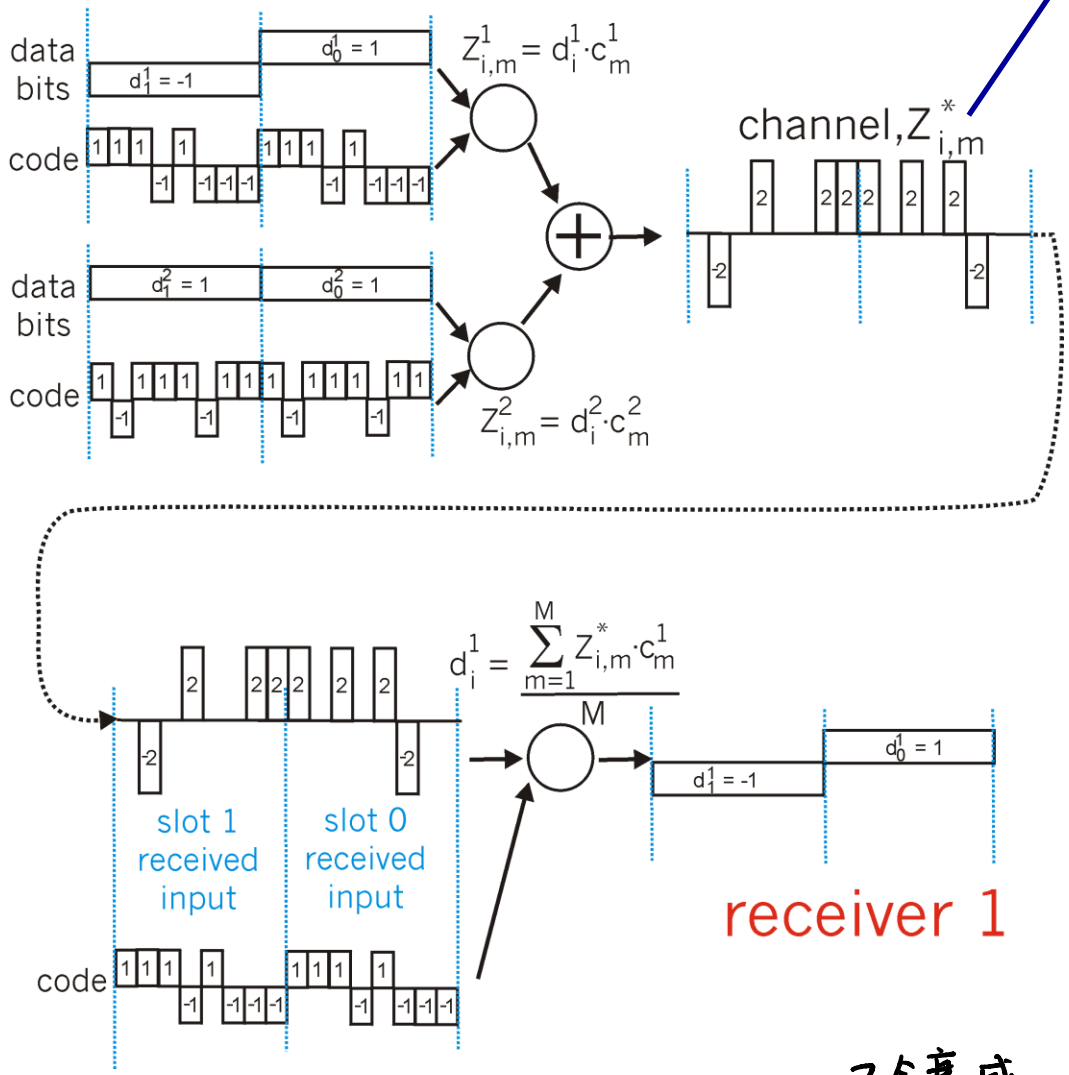
… but this isn't really useful yet!

CDMA: two-sender interference

C1,C2是正交的

Sender 1

Sender 2



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!

… now *that's* useful!

又会衰减.

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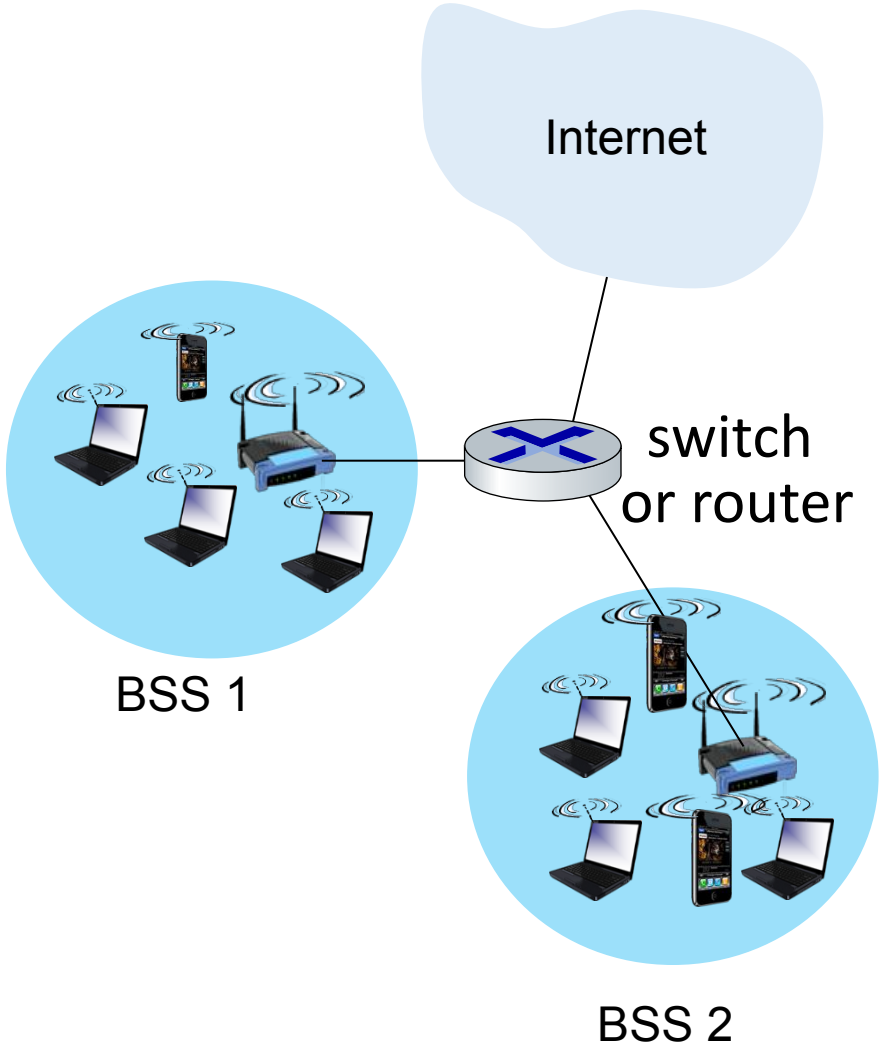
IEEE 802.11 Wireless LAN

IEEE 802.11 standard	Year	Max data rate	Range	Frequency
802.11b	1999	11 Mbps	30 m	2.4 Ghz
802.11g	2003	54 Mbps	30m	2.4 Ghz
802.11n (WiFi 4)	2009	600	70m	2.4, 5 Ghz
802.11ac (WiFi 5)	2013	3.47Gpbs	70m	5 Ghz
802.11ax (WiFi 6)	2020 (exp.)	14 Gbps	70m	2.4, 5 Ghz
802.11af	2014	35 – 560 Mbps	1 Km	unused TV bands (54-790 MHz)
802.11ah	2017	347Mbps	1 Km	900 Mhz

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

以太网 CSMA/CD

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

一定频率上的分割.

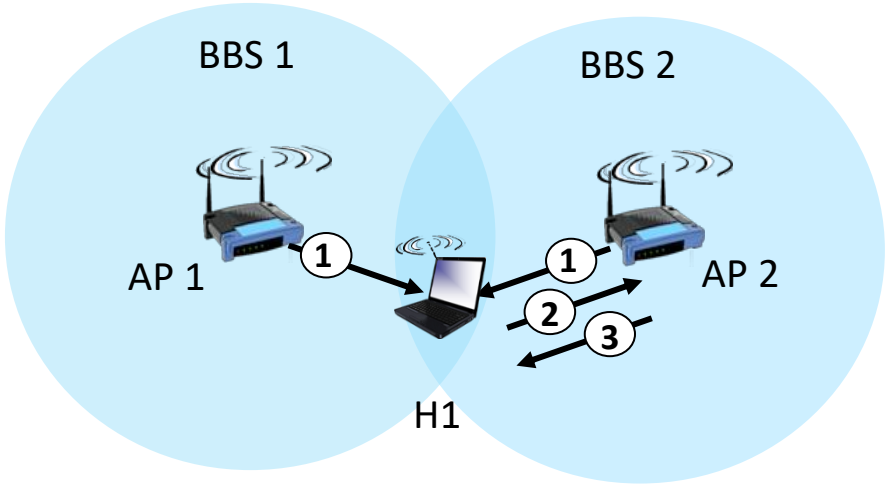
- spectrum divided into channels at different frequencies
  - AP admin chooses frequency for AP
  - interference possible: channel can be same as that chosen by neighboring AP!
- arriving host: must associate with an AP
  - scans channels, listening for *beacon frames* 信标帧 containing AP's name (SSID) and MAC address
  - selects AP to associate with
  - then may perform authentication [Chapter 8]
  - then typically run DHCP to get IP address in AP's subnet

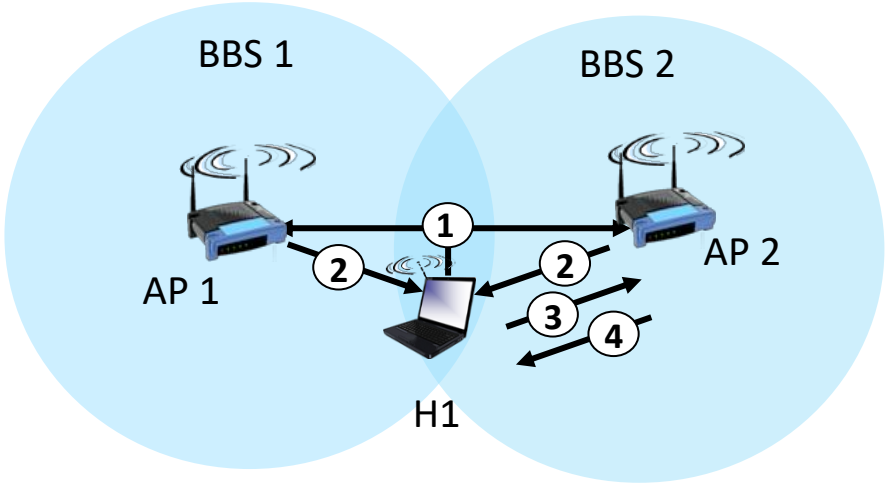
BSS

SSID: SUSTech-wifi-5G

802.11: passive/active scanning

信标帧由谁发送
主机发 passive





passive scanning:

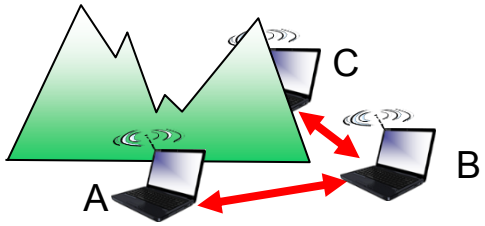
(1) beacon frames sent from APs
(2) association Request frame sent: H1 to selected AP
(3) association Response frame sent from selected AP to H1

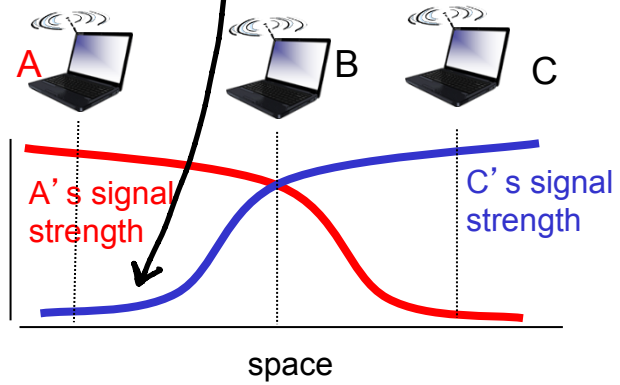
active scanning:

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

IEEE 802.11: multiple access

- avoid collisions: 2+ nodes transmitting at same time
- 802.11: CSMA - sense before transmitting
  - don't collide with detected ongoing transmission by another node
- 802.11: *no* collision detection!
  - difficult to sense collisions: high transmitting signal, weak received signal due to fading
  - can't sense all collisions in any case: hidden terminal, fading
  - goal: *avoid collisions:* CSMA/CollisionAvoidance





IEEE 802.11 MAC Protocol: CSMA/CA

802.11 sender

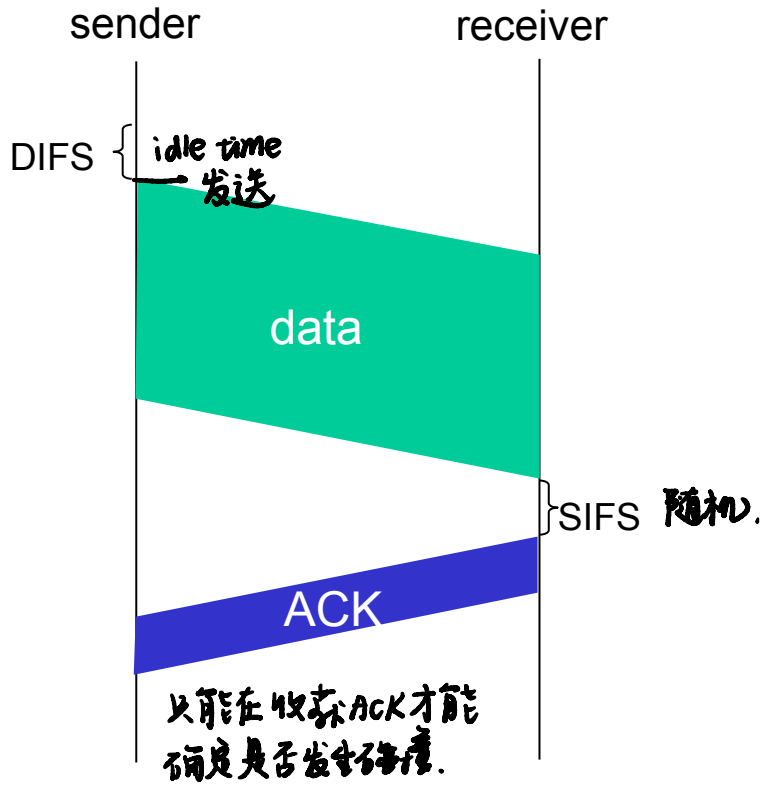
随机等待一个时间

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)

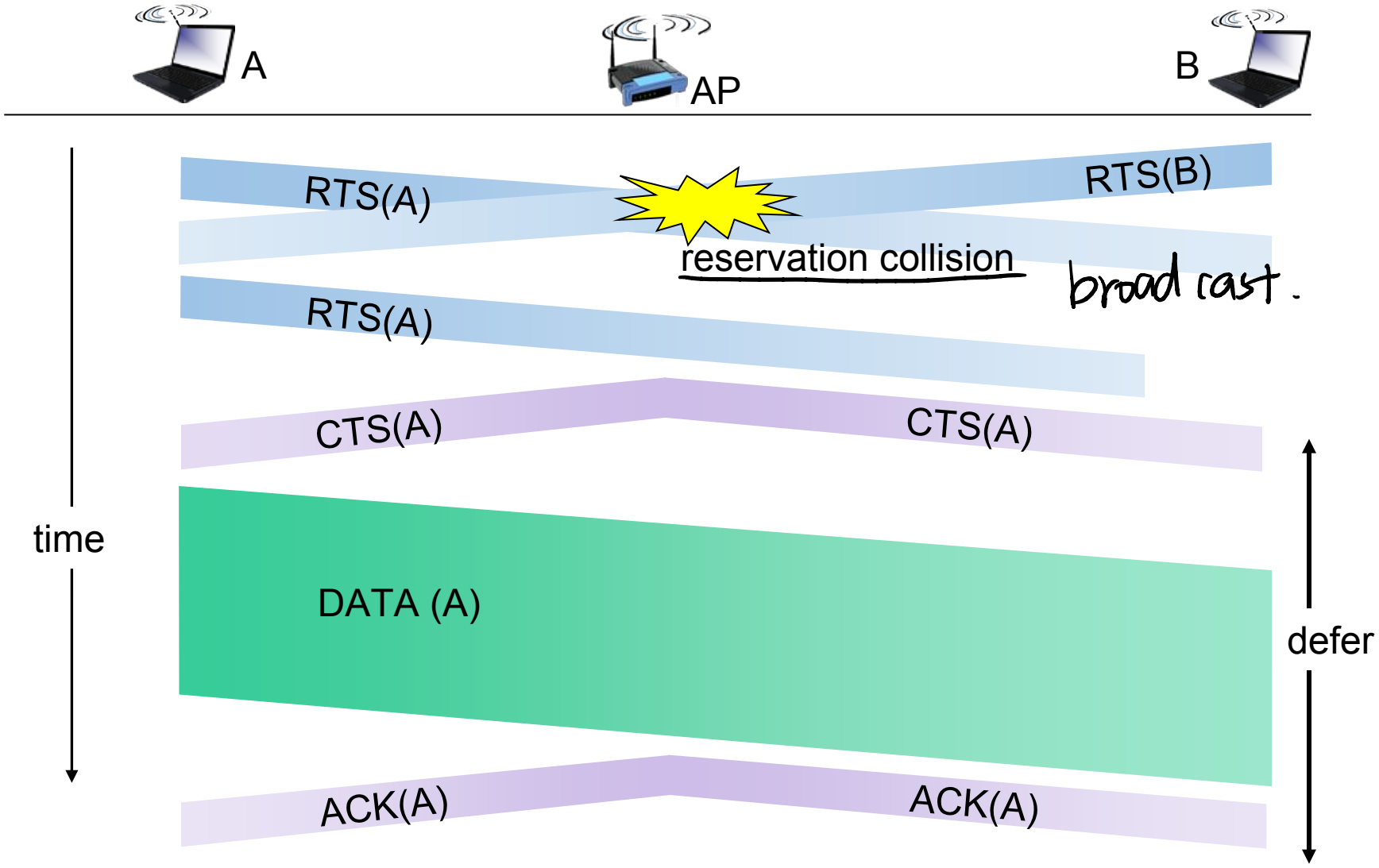


Avoiding collisions (more)

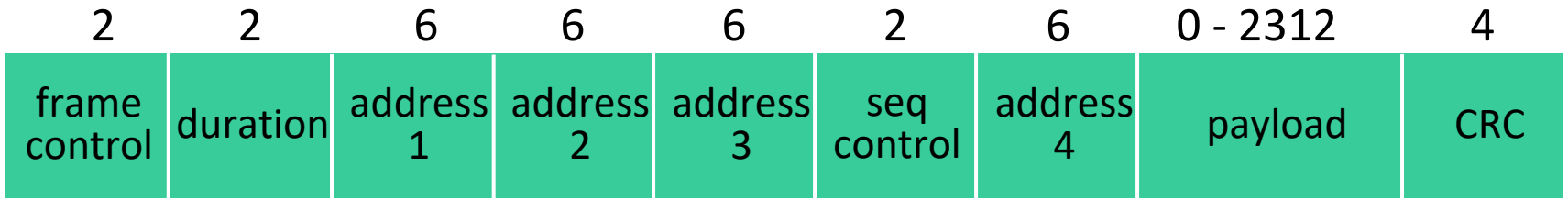
idea: sender "reserves" channel use for data frames using small reservation packets

- sender first transmits *small* request-to-send (RTS) packet 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 哪段时间可以发送.
  - sender transmits data frame
  - other stations defer transmissions

Collision Avoidance: RTS-CTS exchange



802.11 frame: addressing



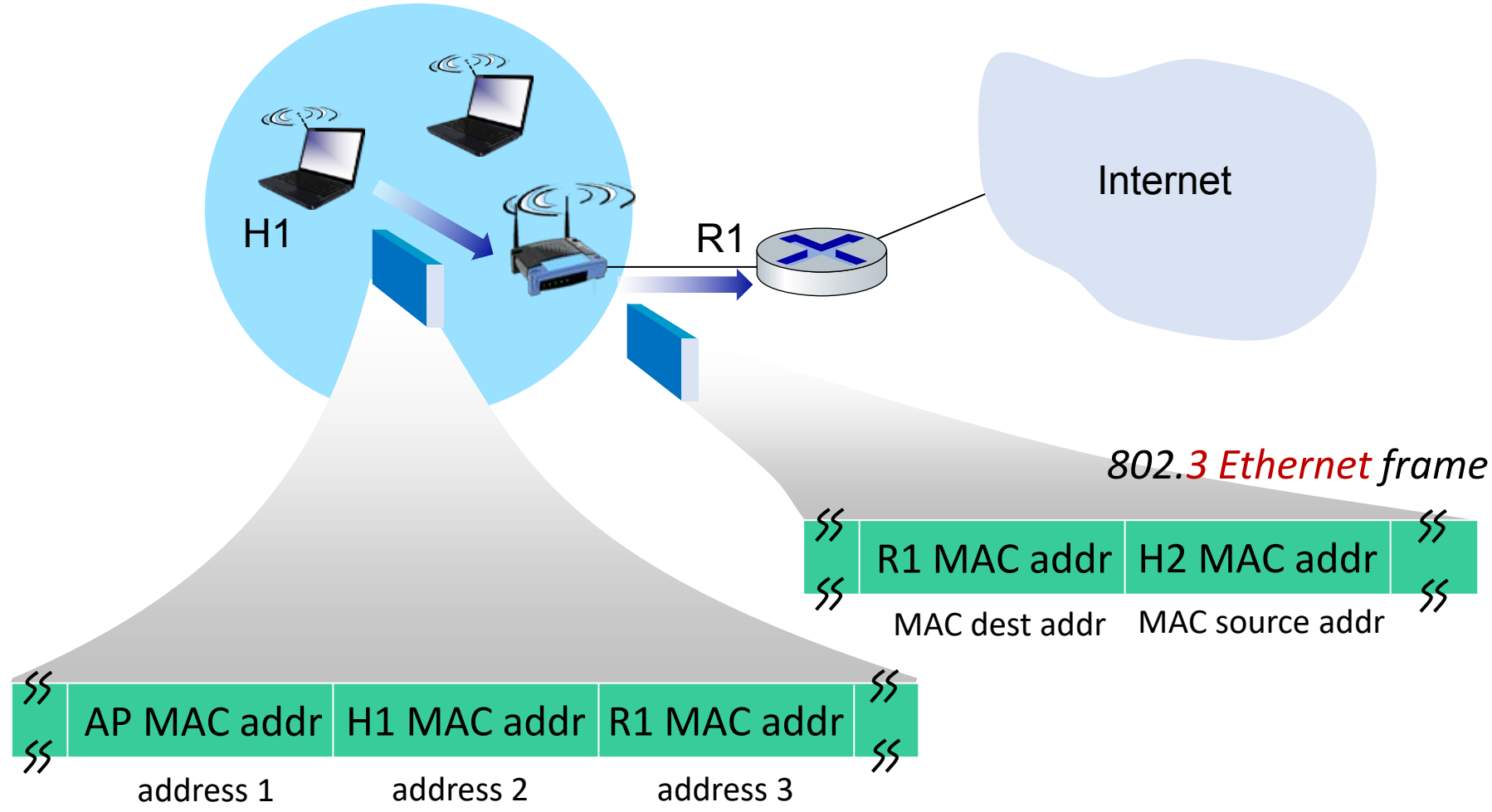
Address 1: MAC address of wireless host or AP to receive this frame

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

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

Address 4: used only in ad hoc mode

802.11 frame: addressing



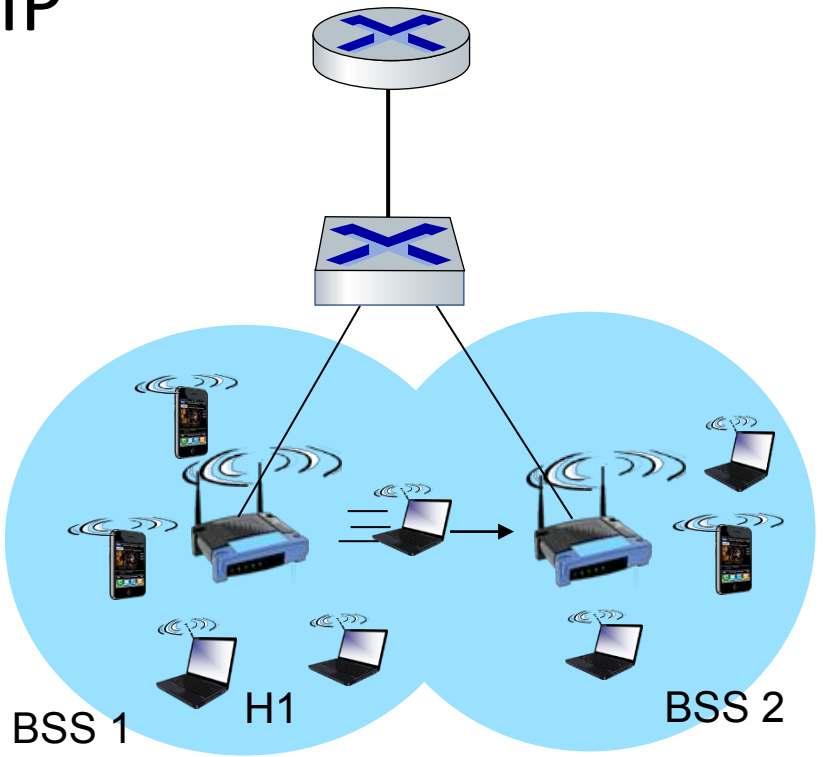
802.11: mobility within same subnet

无线网络进行切换

- H1 remains in same IP subnet: IP address can remain same

切换需要inform switch 依赖于switch自能习

- switch: which AP is associated with H1?
  - self-learning (Ch. 6): switch will see frame from H1 and "remember" which switch port can be used to reach H1



切换后第一次发送data帧自学习.

802.11: advanced capabilities

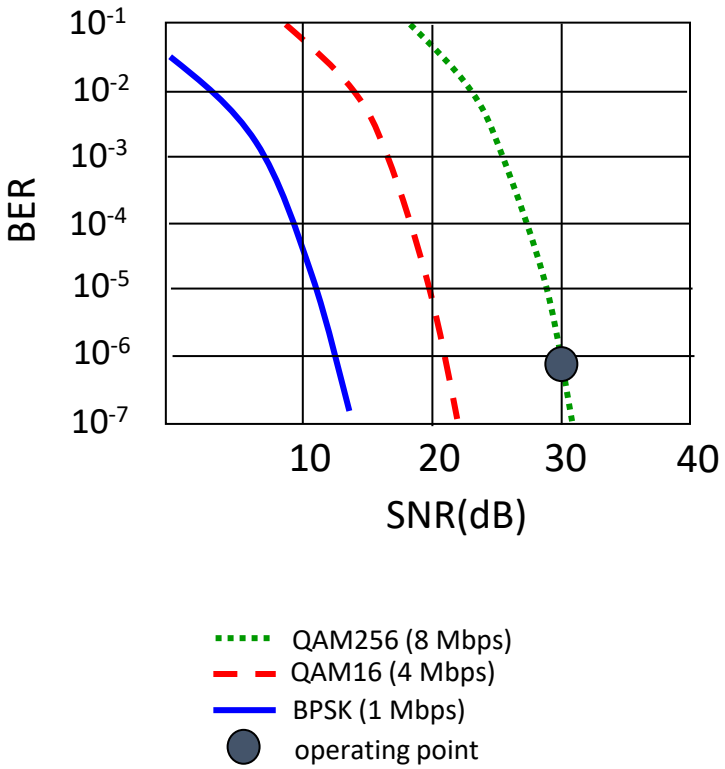
Rate adaptation

自动调整带宽使吞吐量↑

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

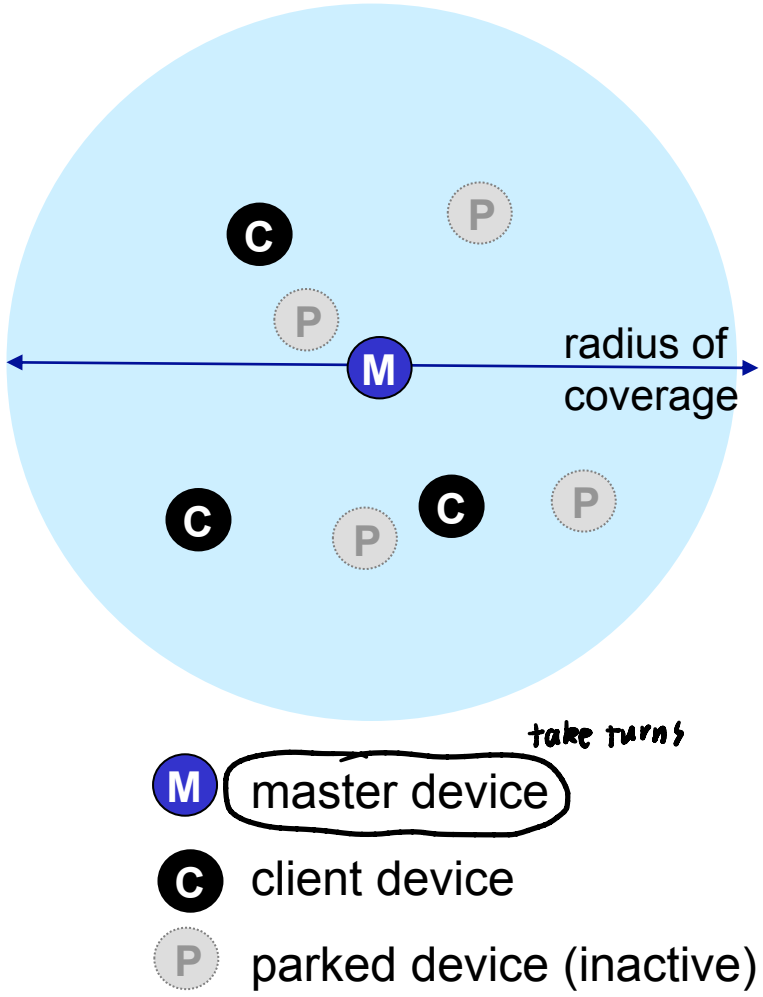
1. SNR decreases, BER increase as node moves away from base station

2. When BER becomes too high, switch to lower transmission rate but with lower BER



Personal area networks: Bluetooth

- less than 10 m diameter
- replacement for cables (mouse, keyboard, headphones)
- ad hoc: no infrastructure
- 2.4-2.5 GHz ISM radio band, up to 3 Mbps
- master controller / clients devices:
  - master polls clients, grants requests for client transmissions

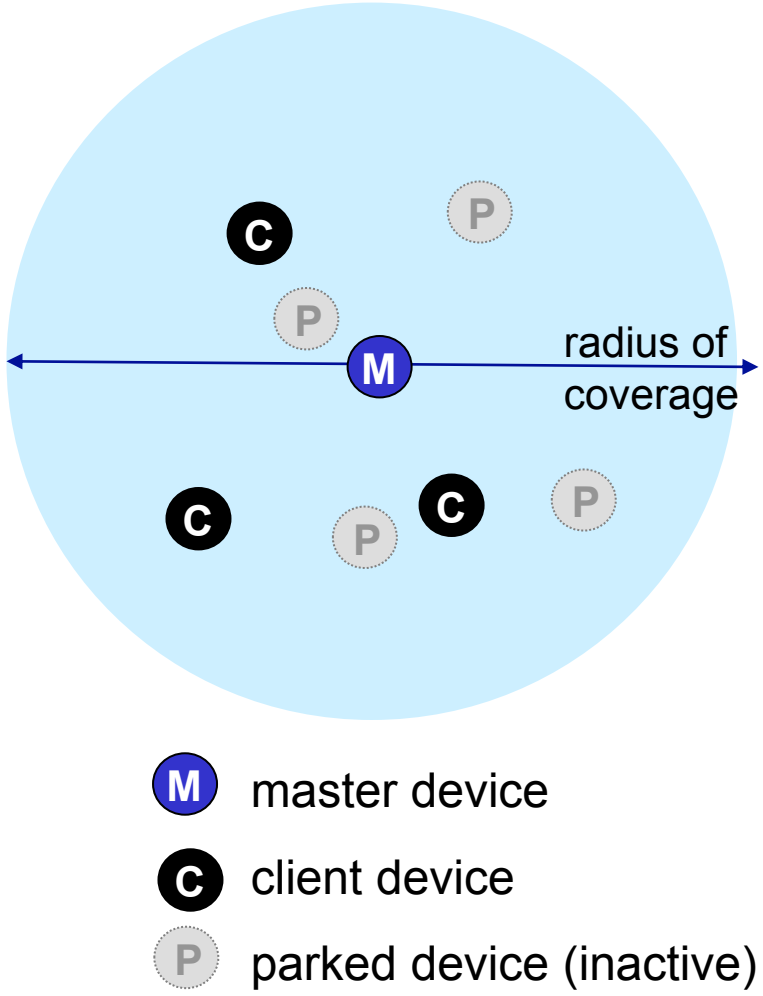


Personal area networks: Bluetooth

- TDM, 625 μsec sec. slot
- FDM: sender uses 79 frequency channels in known, pseudo-random order slot-to-slot (spread spectrum)
  - other devices/equipment not in piconet only interfere in some slots

自休眠：降低功耗

- parked mode: clients can "go to sleep" (park) and later wakeup (to preserve battery)



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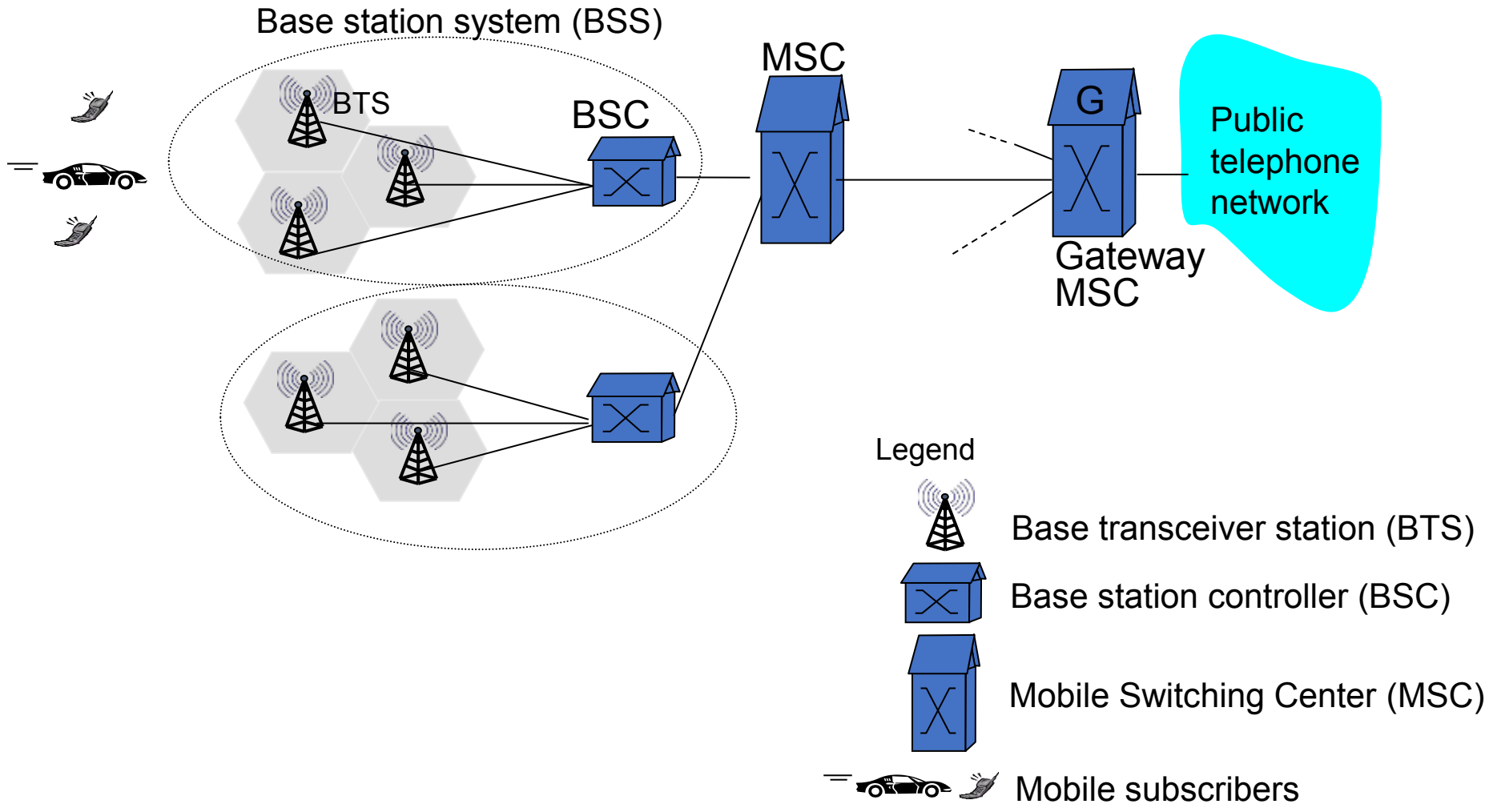
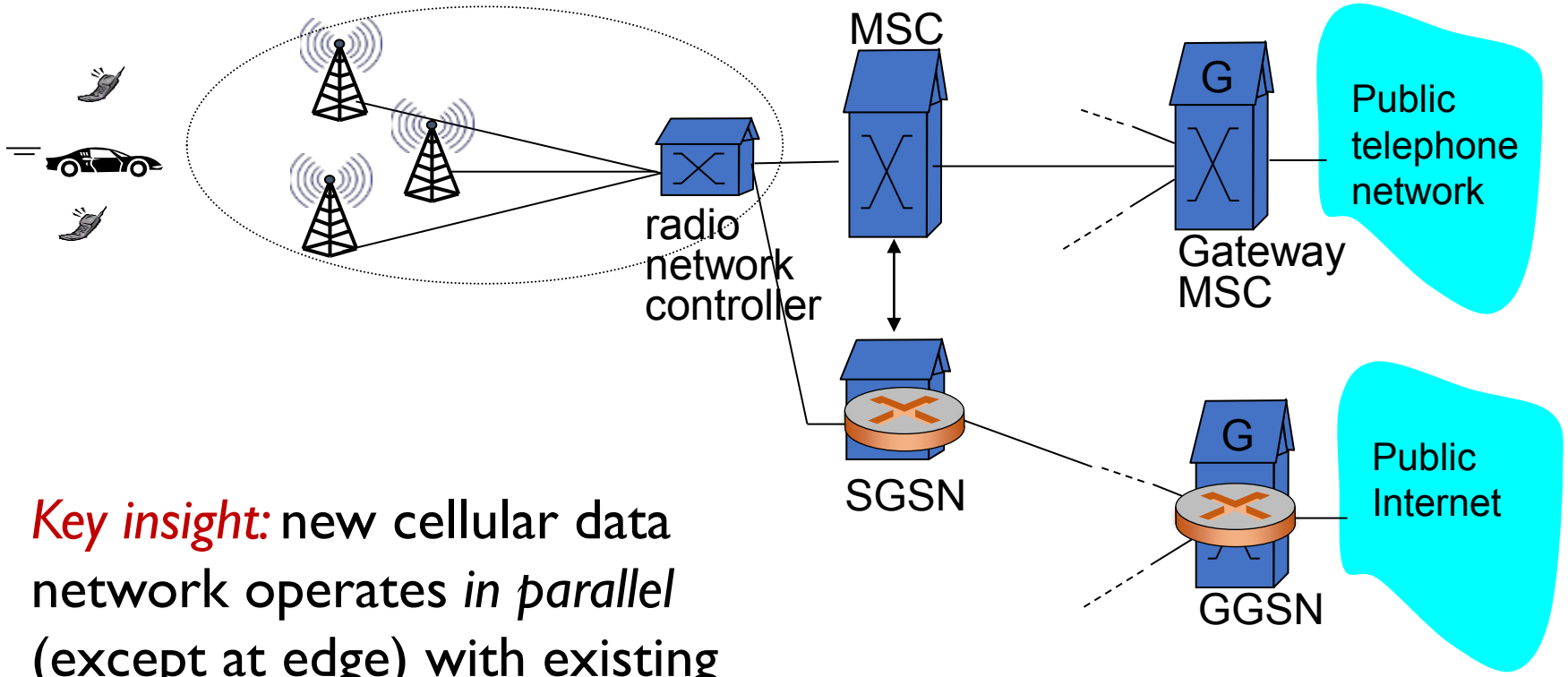
- Mobility: impact on higher-layer protocols

2G (voice) network architecture



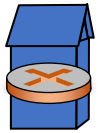
3G (voice+data) network architecture



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

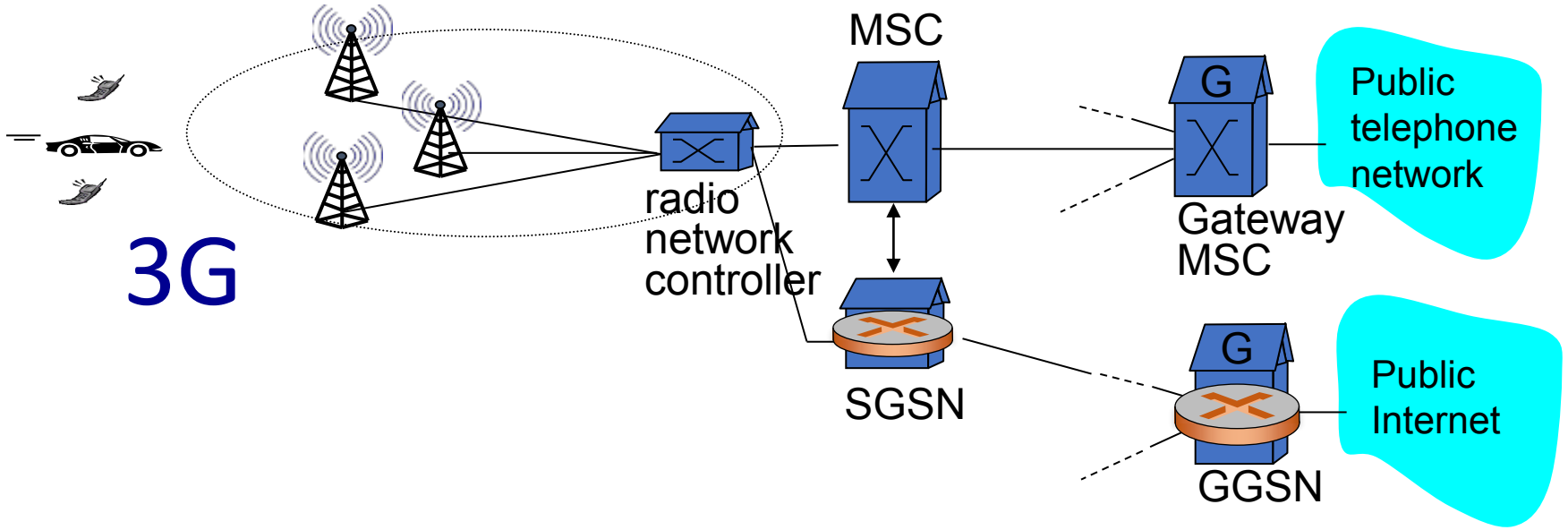
- voice network *unchanged* in core
- data network operates in parallel

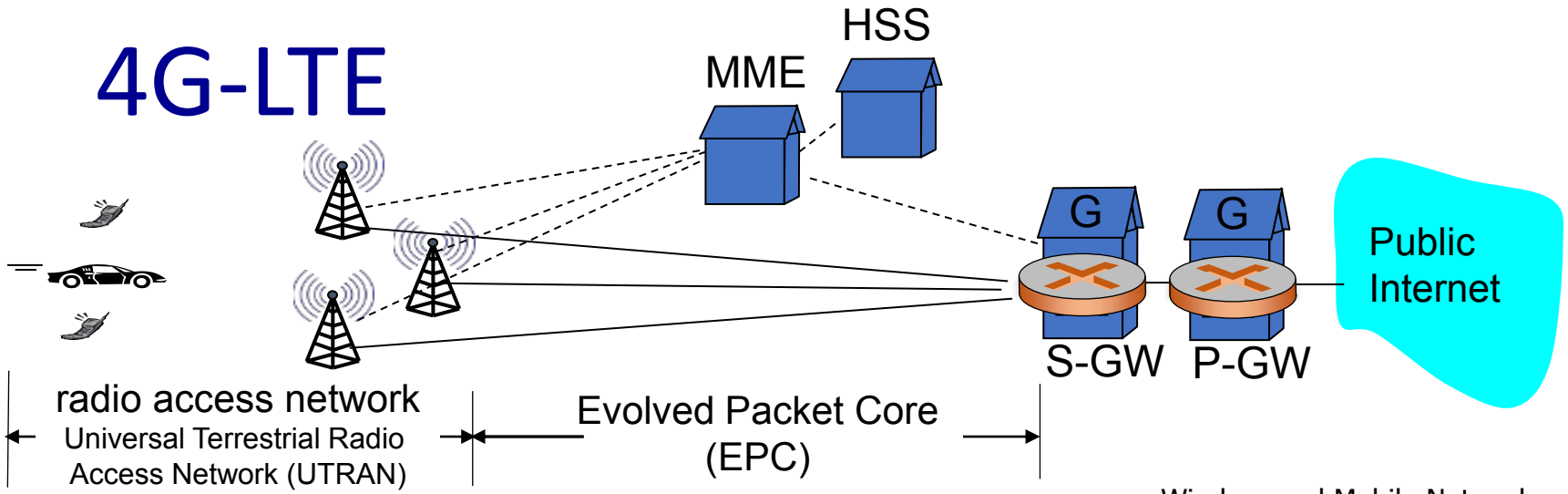
Serving GPRS Support Node (SGSN)



Gateway GPRS Support Node (GGSN)

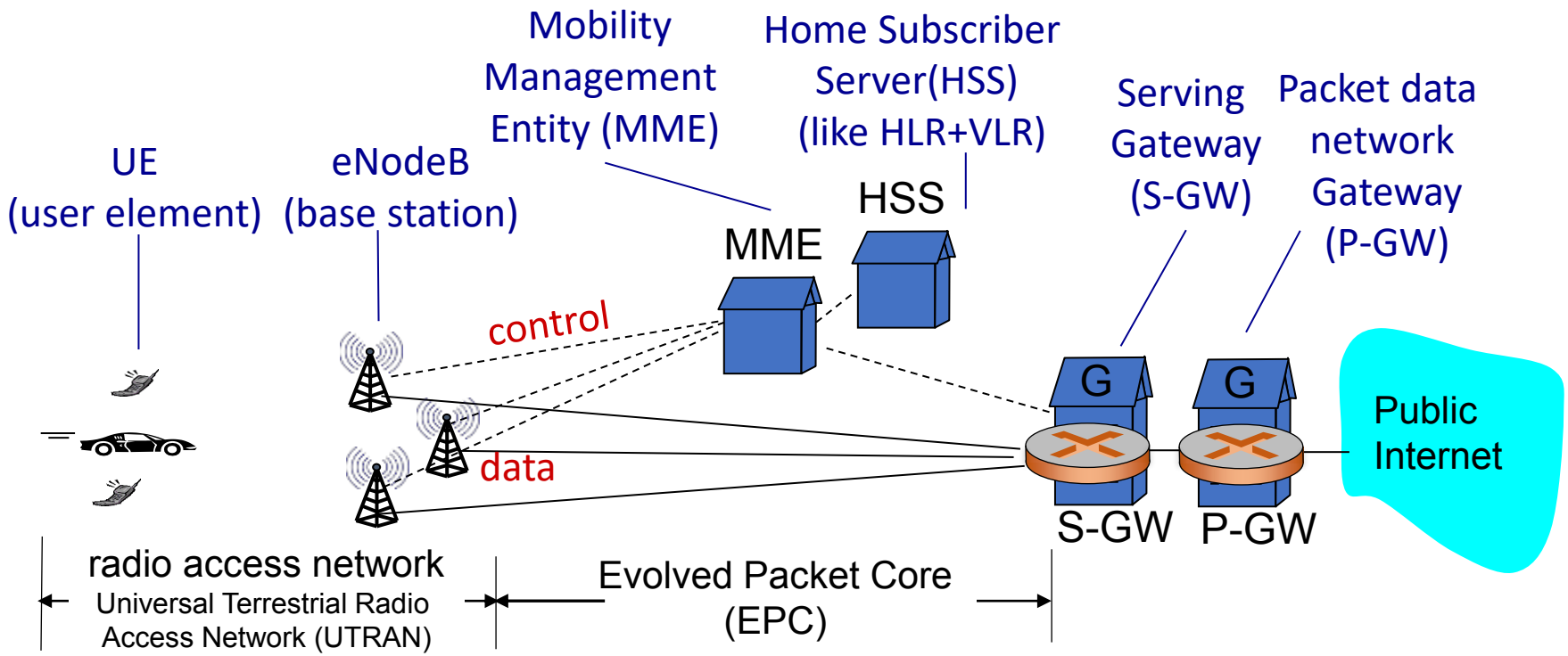
3G versus 4G LTE network architecture





4G: differences from 3G

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



On to 5G!

- goal: 10x increase in peak bitrate, 10x decrease in latency, 100x increase in traffic capacity over 4G
- 5G NR (new radio):
  - two frequency bands: FR1 (450 MHz–6 GHz) and FR2 (24 GHz–52 GHz): millimeter wave frequencies
  - not backwards-compatible with 4G
  - MIMO: multiple directional antennae
- millimeter wave frequencies: much higher data rates, but over shorter distances
  - pico-cells: cells diameters: 10-100 m
  - massive, dense deployment of new base stations required

On to 5G!

频率范围	波段	波长范围
≤ 3 赫兹（≤3Hz）		≥ 100,000 千米
3-30 赫兹（3Hz–30Hz）	极长波	100,000千米 – 10,000千米
30–300 赫兹（30Hz–300Hz）	超长波	10,000千米 – 1,000千米
300–3000 赫兹（300Hz–3KHz）	特长波	1,000千米 – 100千米
3–30 千赫（3KHz–30KHz）	甚长波	100千米 – 10千米
30–300 千赫（30KHz–300KHz）	长波	10千米 – 1千米
300–3000 千赫（300KHz–3MHz）	中波	1千米 – 100米
3–30 兆赫（3MHz–30MHz）	短波	100米 – 10米
30–300 兆赫（30MHz–300MHz）	米波	10米 – 1米
300–3000 兆赫（300MHz–3GHz）	分米波	1米 – 100毫米
3–30 吉赫（3GHz–30GHz）	厘米波	100毫米 – 10毫米
30–300 吉赫（30GHz–300GHz）	毫米波	10毫米 – 1毫米

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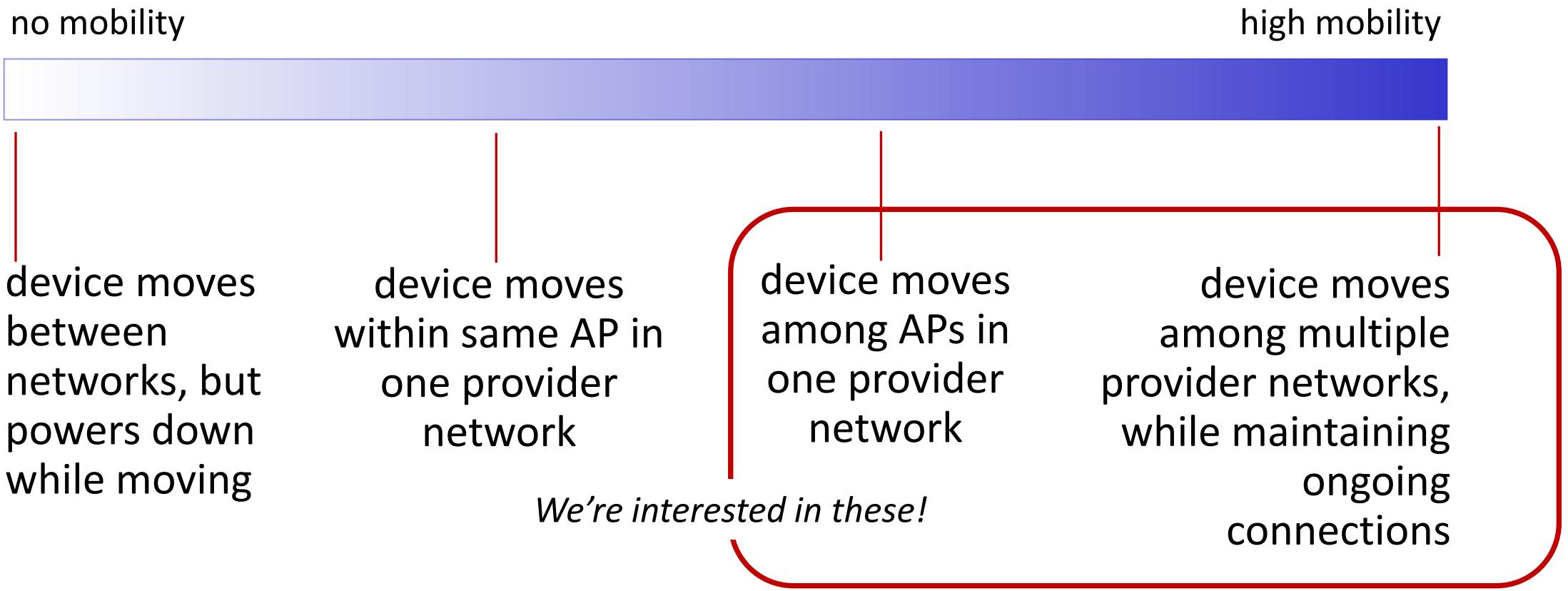
What is mobility?

- spectrum of mobility, from the network perspective:



Mobility approaches

- let network (routers) handle it:
  - routers advertise well-known name, address (e.g., permanent 32-bit IP address), or number (e.g., cell #) of visiting mobile node via usual routing table exchange
  - Internet routing could do this already *with no* changes! Routing tables indicate where each mobile located via longest prefix match!

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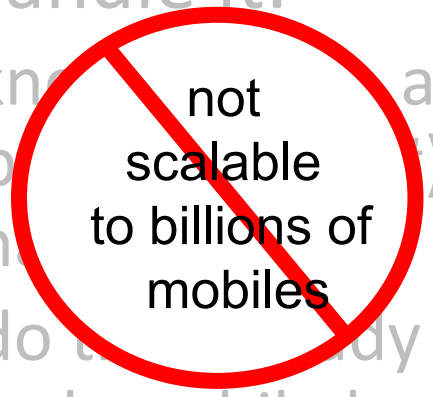
  - routers advertise well-kn address (e.g., permanent 32-bit IP address), or numb) of visiting mobile node via usual routing table exch
  - Internet routing could do t dy *with no* changes! Routing tables indicate where each mobile located via longest prefix match!



- let end-systems handle it: functionality at the "edge"
  - *indirect routing:* communication from correspondent to mobile goes through home network, then forwarded to remote mobile
  - *direct routing:* correspondent gets foreign address of mobile, send directly to mobile

Contacting a mobile friend:

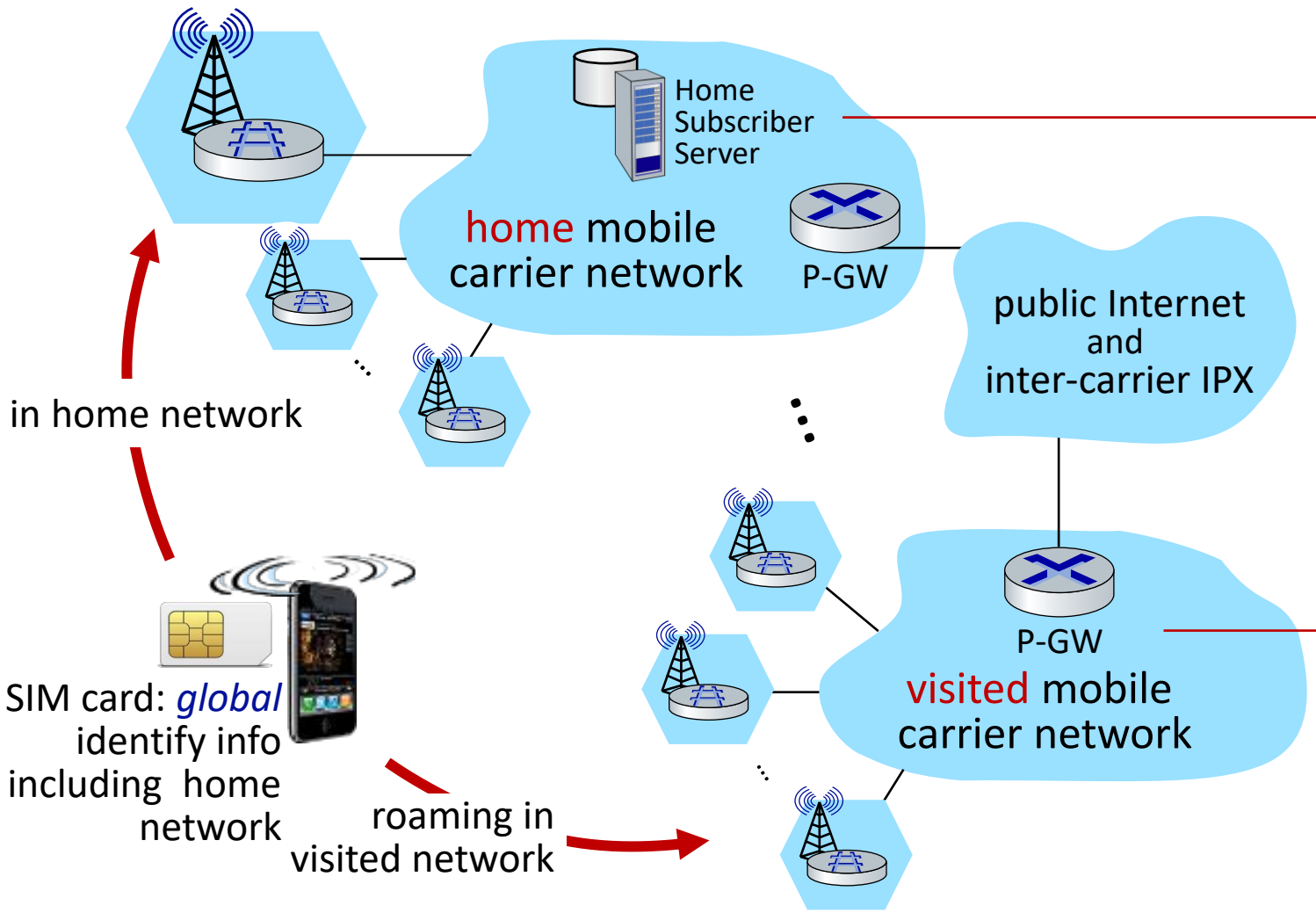
Consider friend frequently changing locations, how do you find him/her?

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

The importance of having a “home”:

- a definitive source of information about you
- a place where people can find out where you are

Home network, visited network: 4G/5G



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home network:

- (paid) service plan with cellular provider, e.g., Verizon, Orange
- home network HSS stores identify & services info

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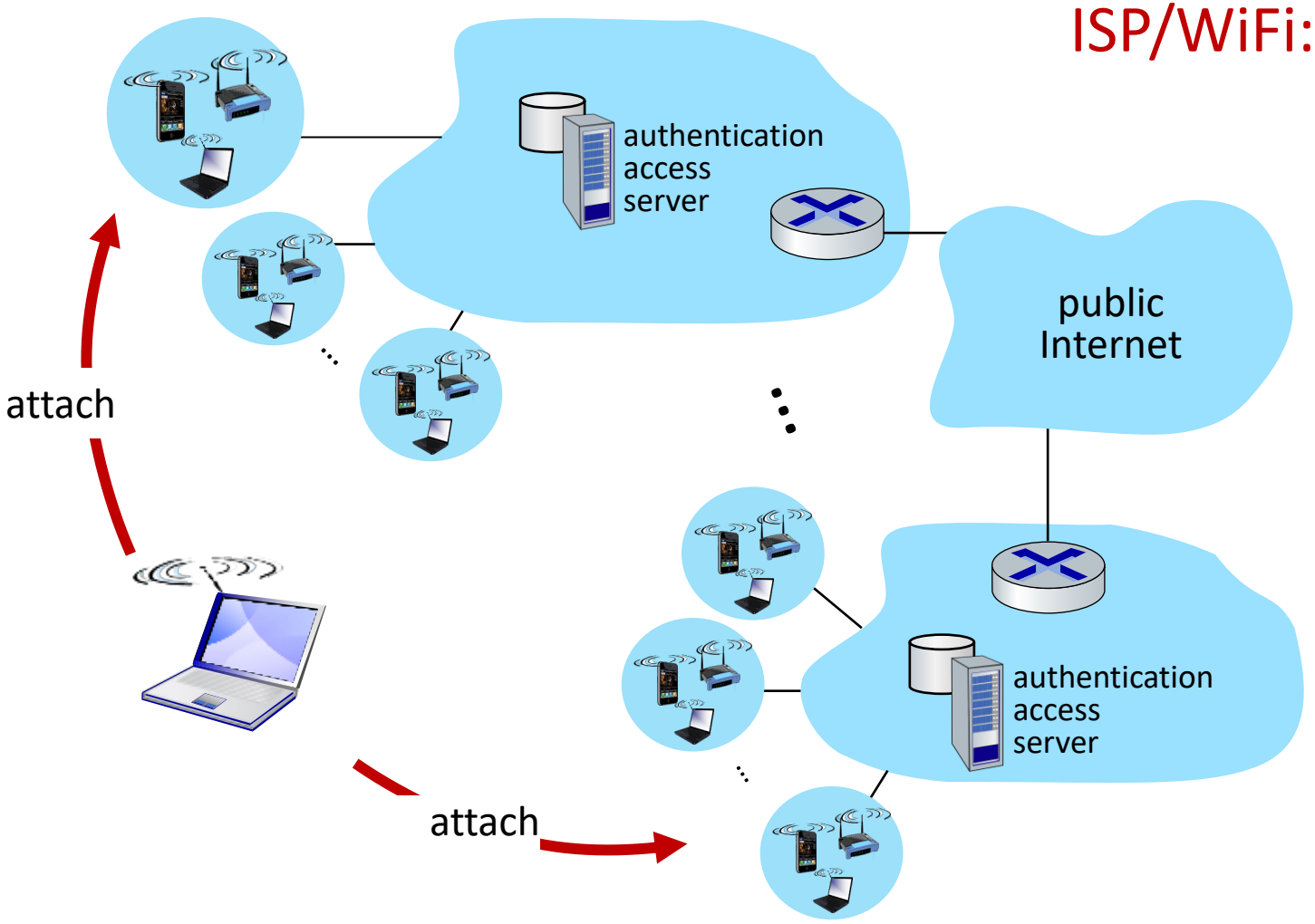
visited network:

- any network other than your home network
- service agreement with other networks: to provide access to visiting mobile

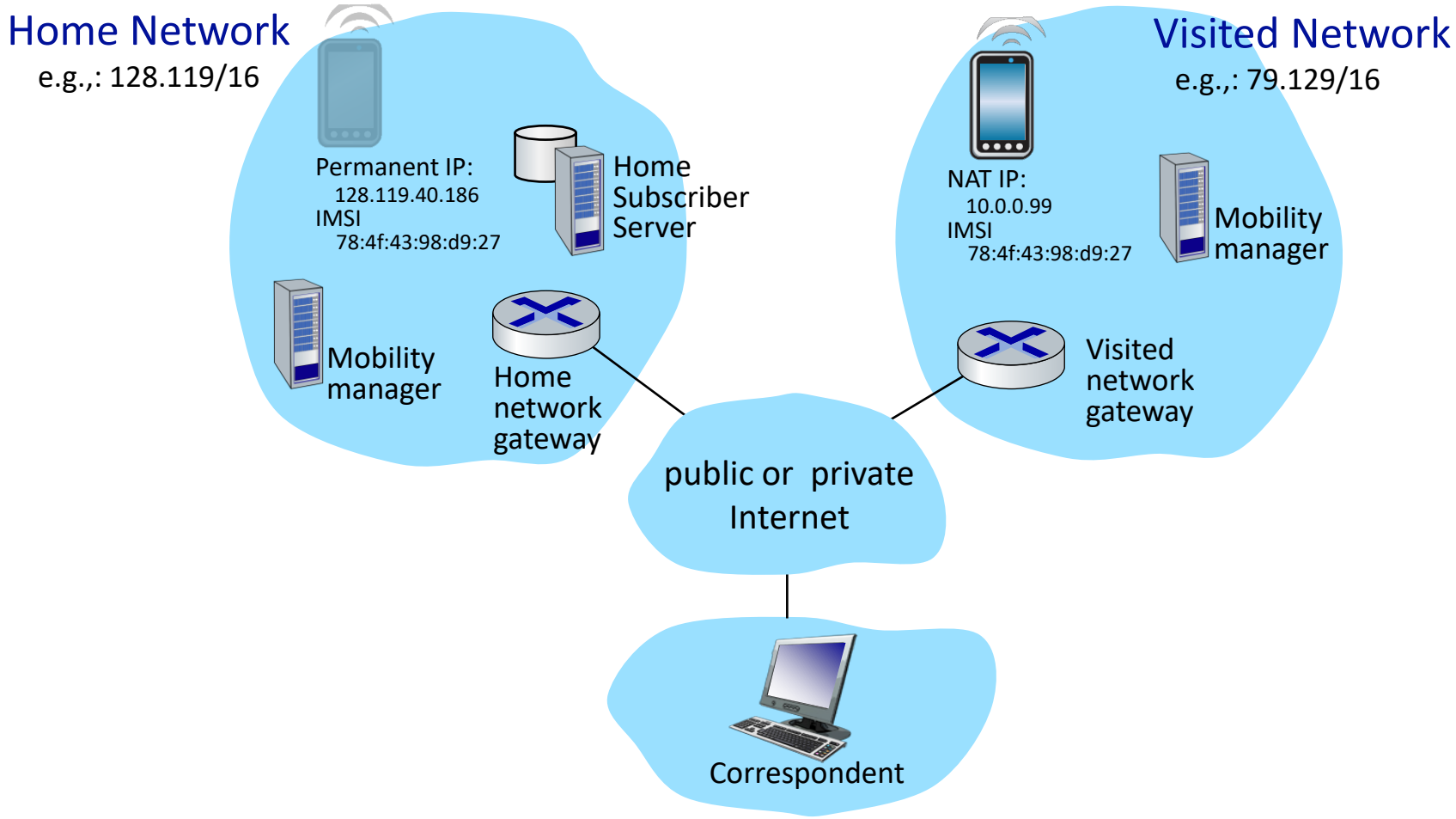
Home network, visited network: ISP/WiFi



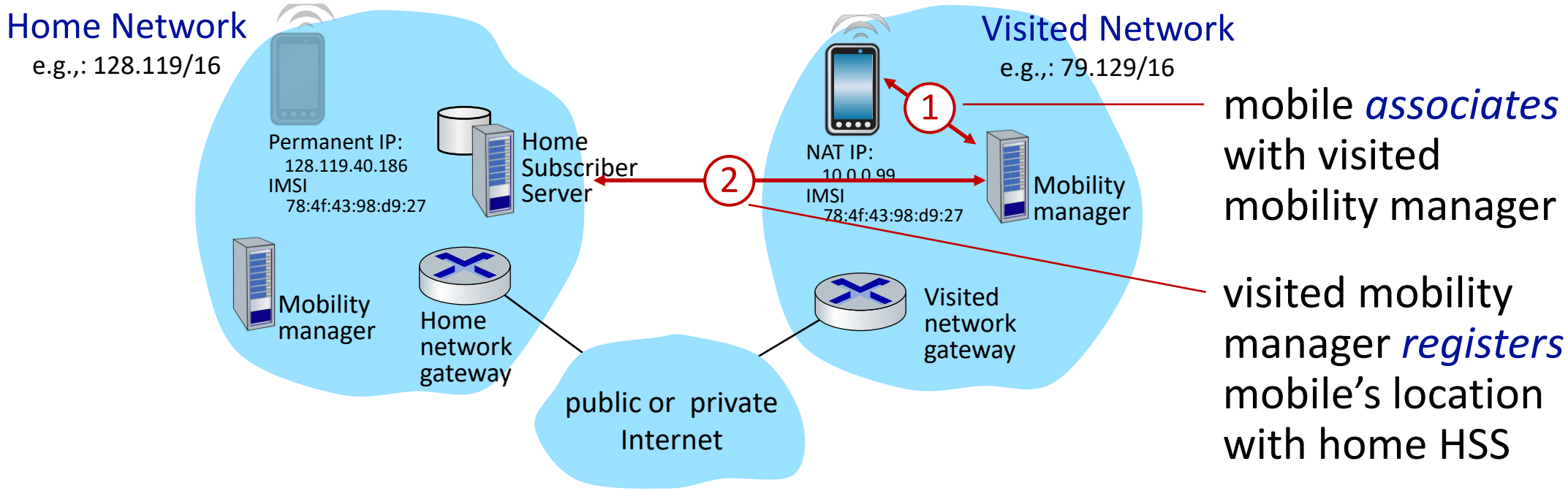
ISP/WiFi: no notion of global "home"

- credentials from ISP (e.g., username, password) stored on device or with user
- ISPs may have national, international presence
- different networks: different credentials
  - some exceptions (e.g., eduroam)
  - architectures exist (mobile IP) for 4G-like mobility, but not used

Home network, visited network: generic



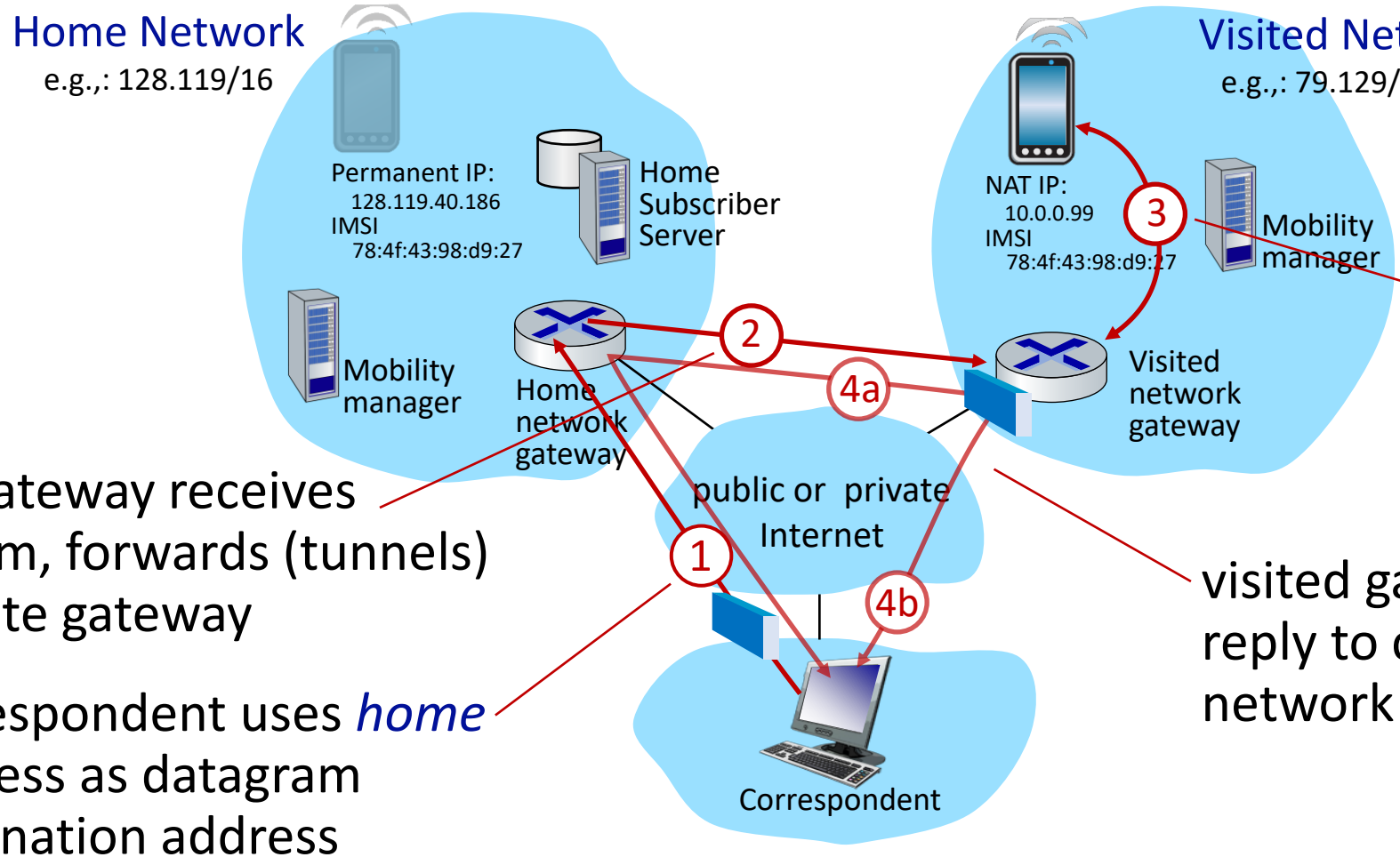
Registration: home needs to know where you are!



end result:

- visited mobility manager knows about mobile
- home HSS knows location of mobile

Mobility with indirect routing



visited gateway router forwards to mobile

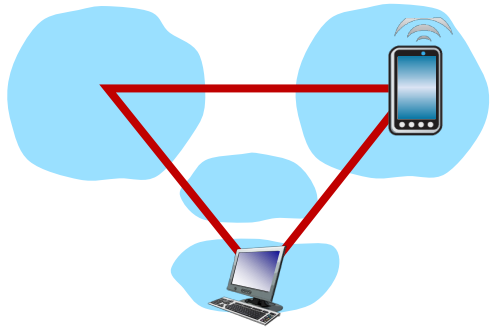
home gateway receives datagram, forwards (tunnels) to remote gateway

correspondent uses *home* address as datagram destination address

visited gateway router forwards reply to correspondent via home network (4a) or directly (4b)

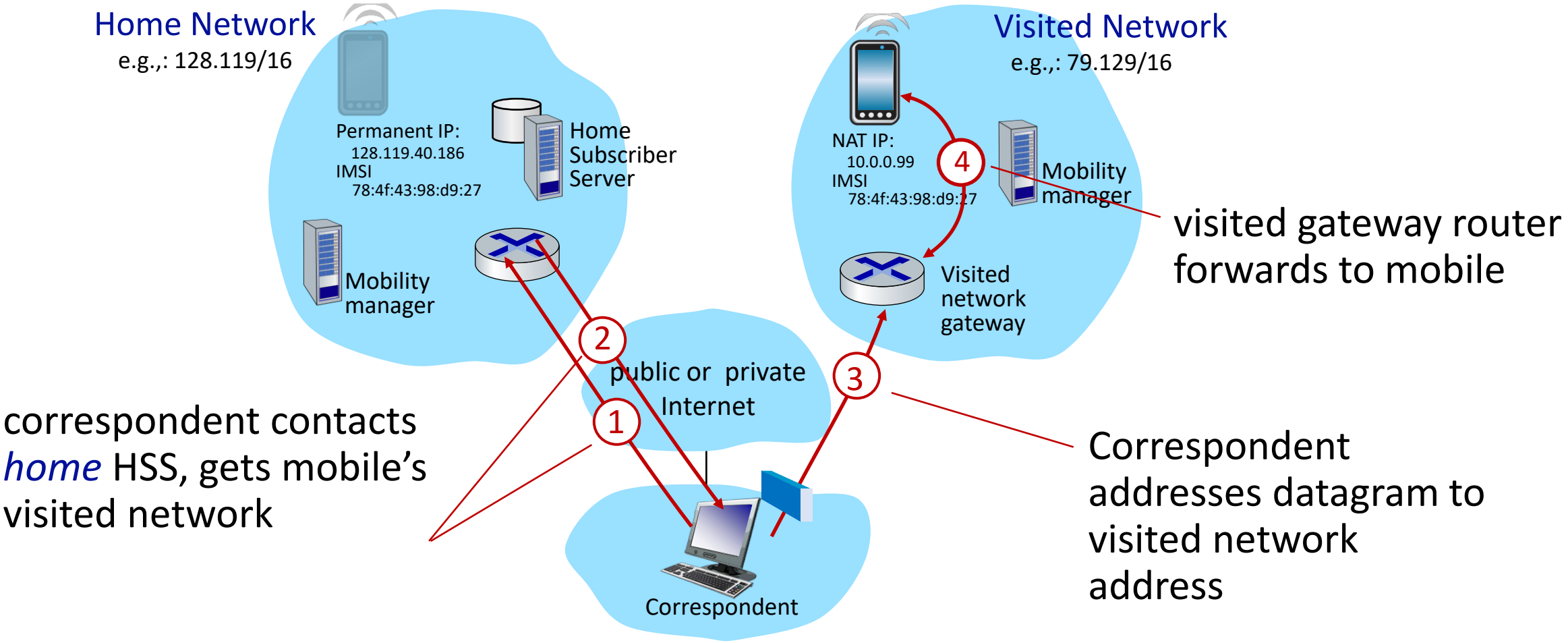
Mobility with indirect routing: comments

- triangle routing:
  - inefficient when correspondent and mobile are in same network



- mobile moves among visited networks: transparent to correspondent!
  - registers in new visited network
  - new visited network registers with home HSS
  - datagrams continue to be forwarded from home network to mobile in new network
  - *on-going (e.g., TCP) connections between correspondent and mobile can be maintained!*

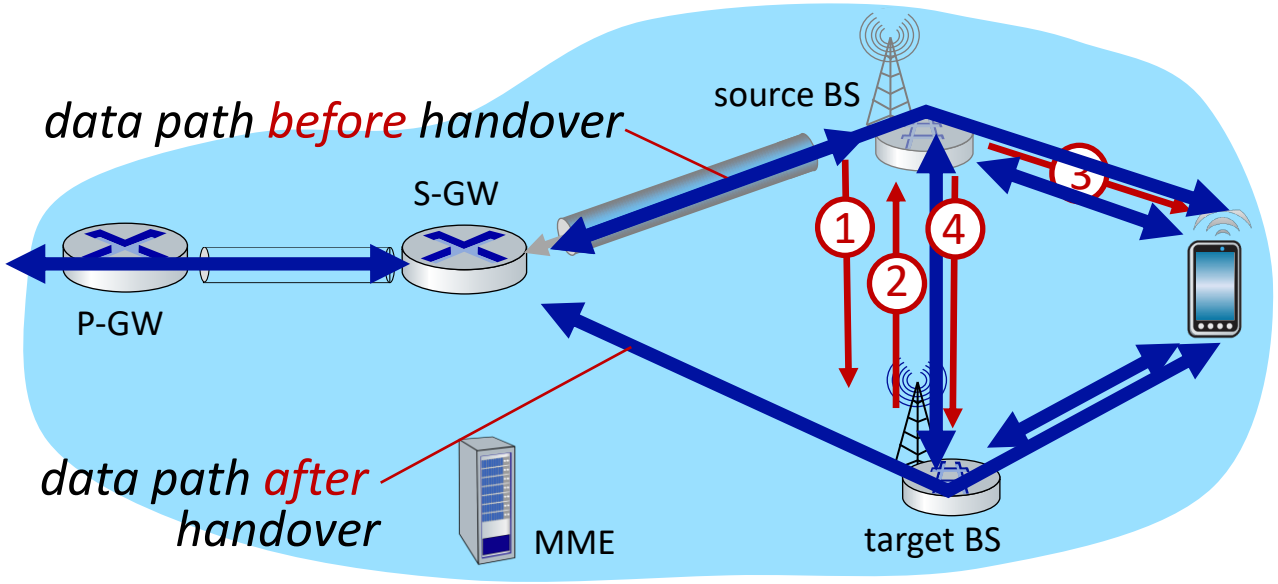
Mobility with direct routing



Mobility with direct routing: comments

- overcomes triangle routing inefficiencies
- *non-transparent to correspondent:* correspondent must get care-of-address from home agent
- what if mobile changes visited network?
  - can be handled, but with additional complexity

Handover between BSs in same cellular network



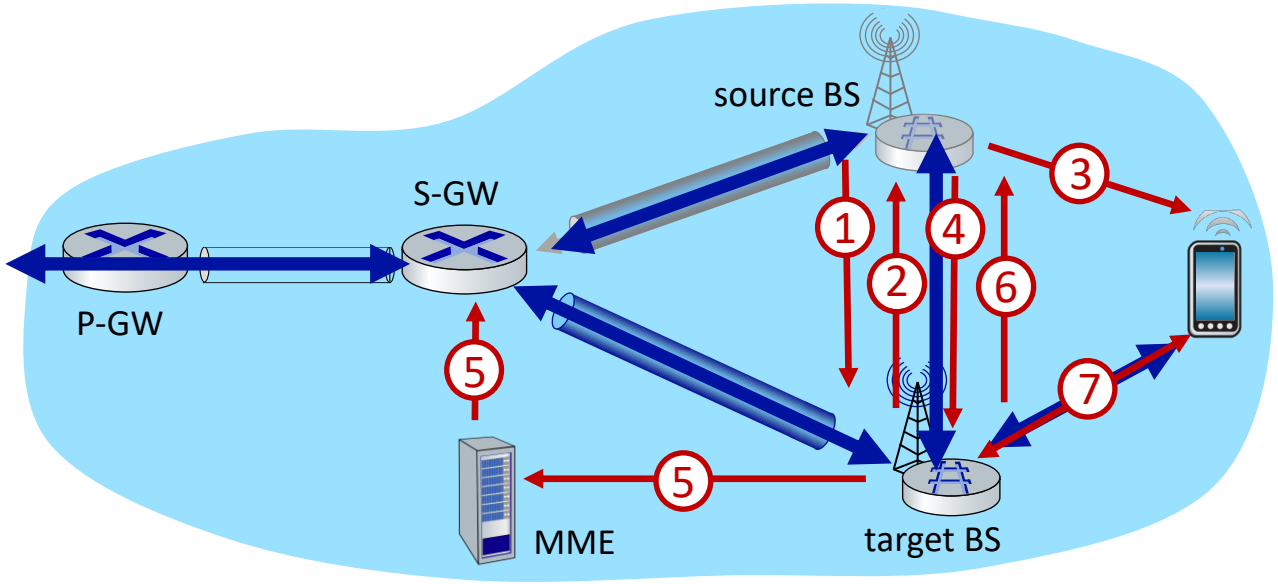
1. current (source) BS selects target BS, sends *Handover Request message* to target BS

2. target BS pre-allocates radio time slots, responds with HR ACK with info for mobile

3. source BS informs mobile of new BS
   - mobile can now send via new BS - handover *looks* complete to mobile

4. source BS stops sending datagrams to mobile, instead forwards to new BS (who forwards to mobile over radio channel)

Handover between BSs in same cellular network



5 target BS informs MME that it is new BS for mobile
- MME instructs S-GW to change tunnel endpoint to be (new) target BS

6 target BS ACKs back to source BS: handover complete, source BS can release resources

7 mobile's datagrams now flow through new tunnel from target BS to S-GW

Chapter 7 summary

Wireless

- Wireless Links and network characteristics
- WiFi: 802.11 wireless LANs
- Cellular networks: 4G and 5G

Mobility

- Mobility management: principles
- Mobility management: practice
  - 4G/5G networks
  - Mobile IP
- Mobility: impact on higher-layer protocols

Thank you!

Please finish the evaluation online