

Διαχείριση Edge και Cloud δικτύων βασισμένων στο λογισμικό (CSIS109)

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Chapter 7

Wireless and Mobile Networks

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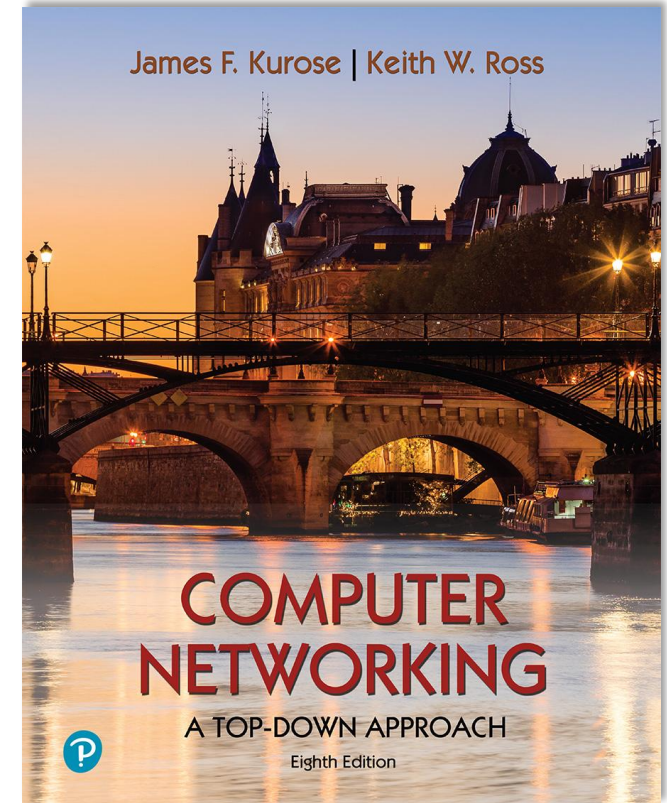
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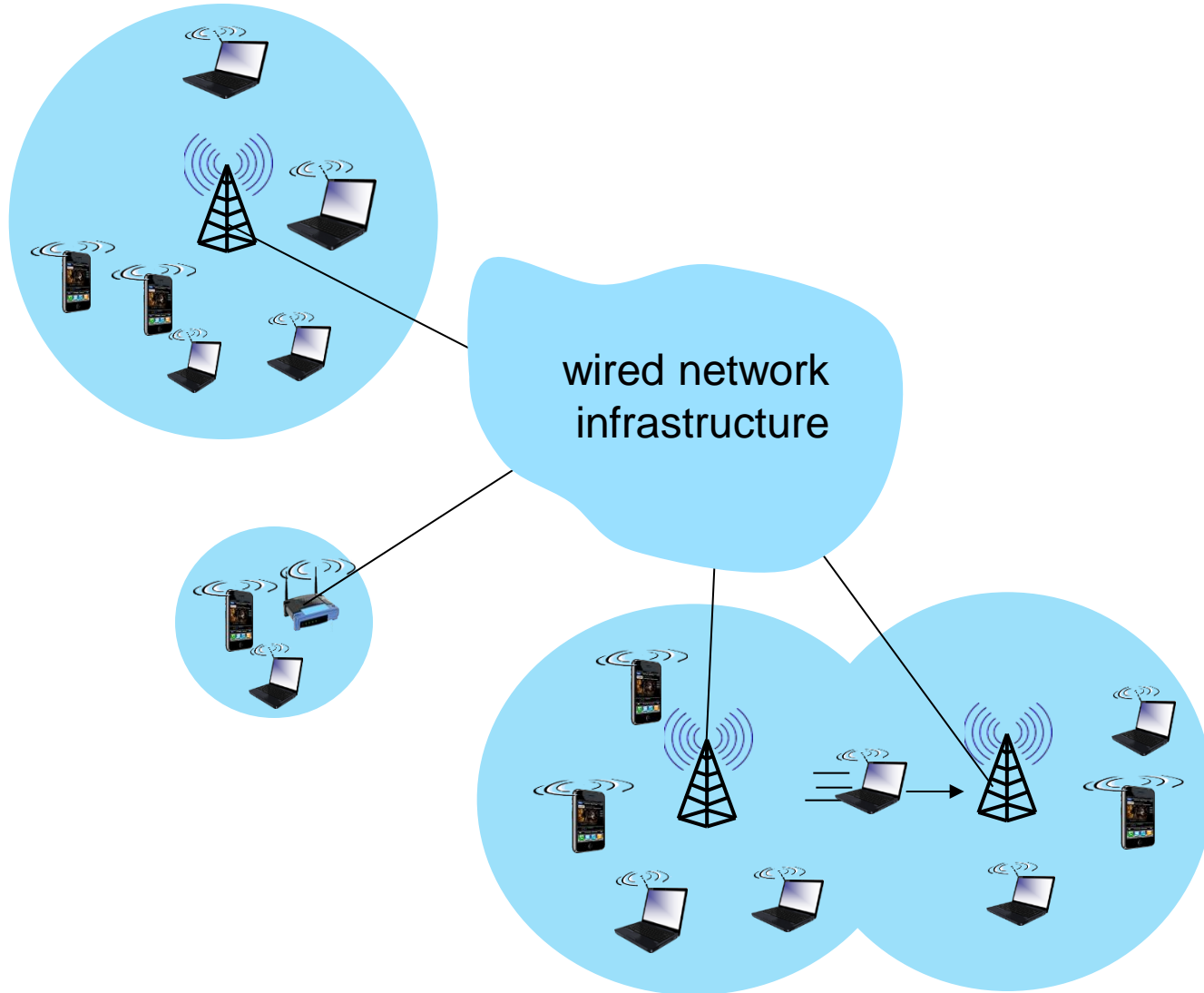


*Computer Networking: A
Top-Down Approach*

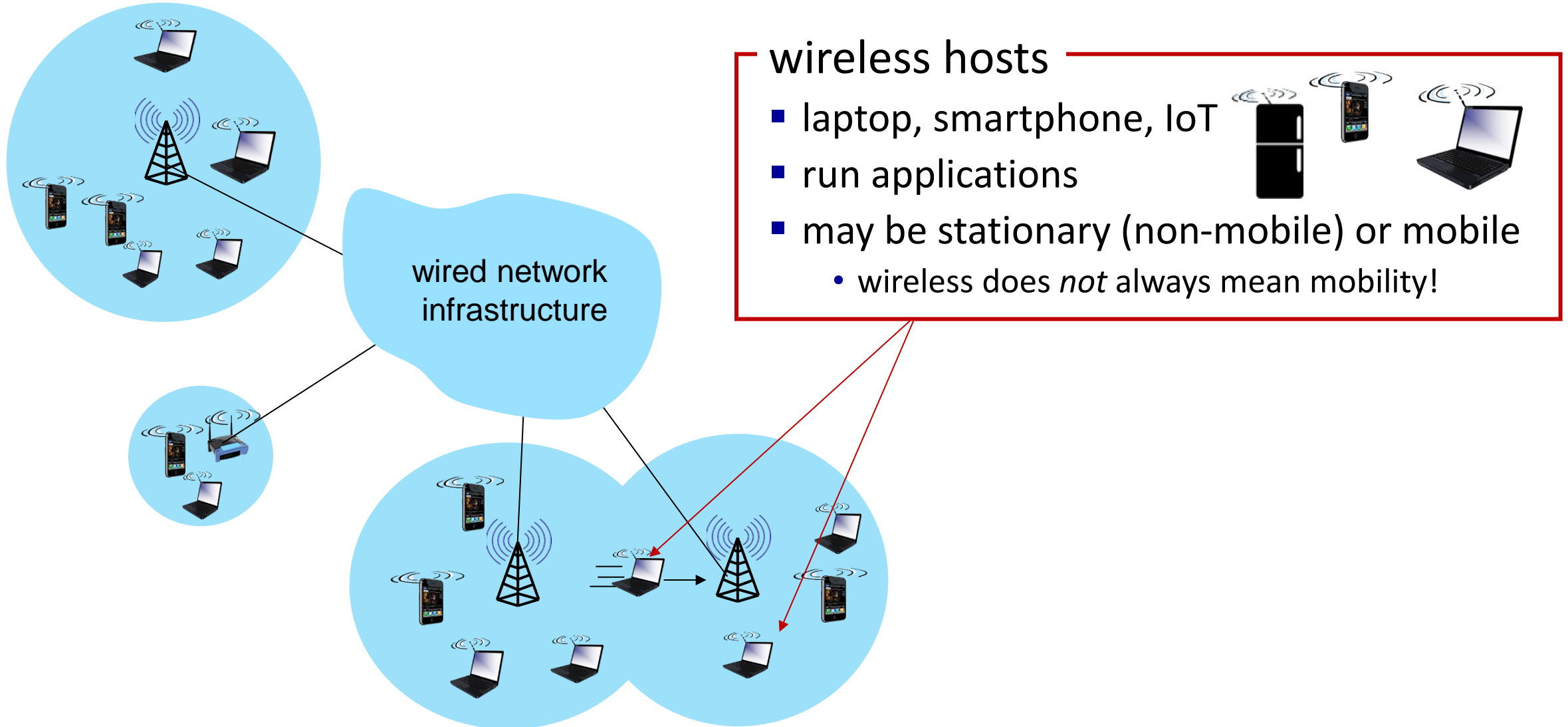
8th edition

Jim Kurose, Keith Ross
Pearson, 2020

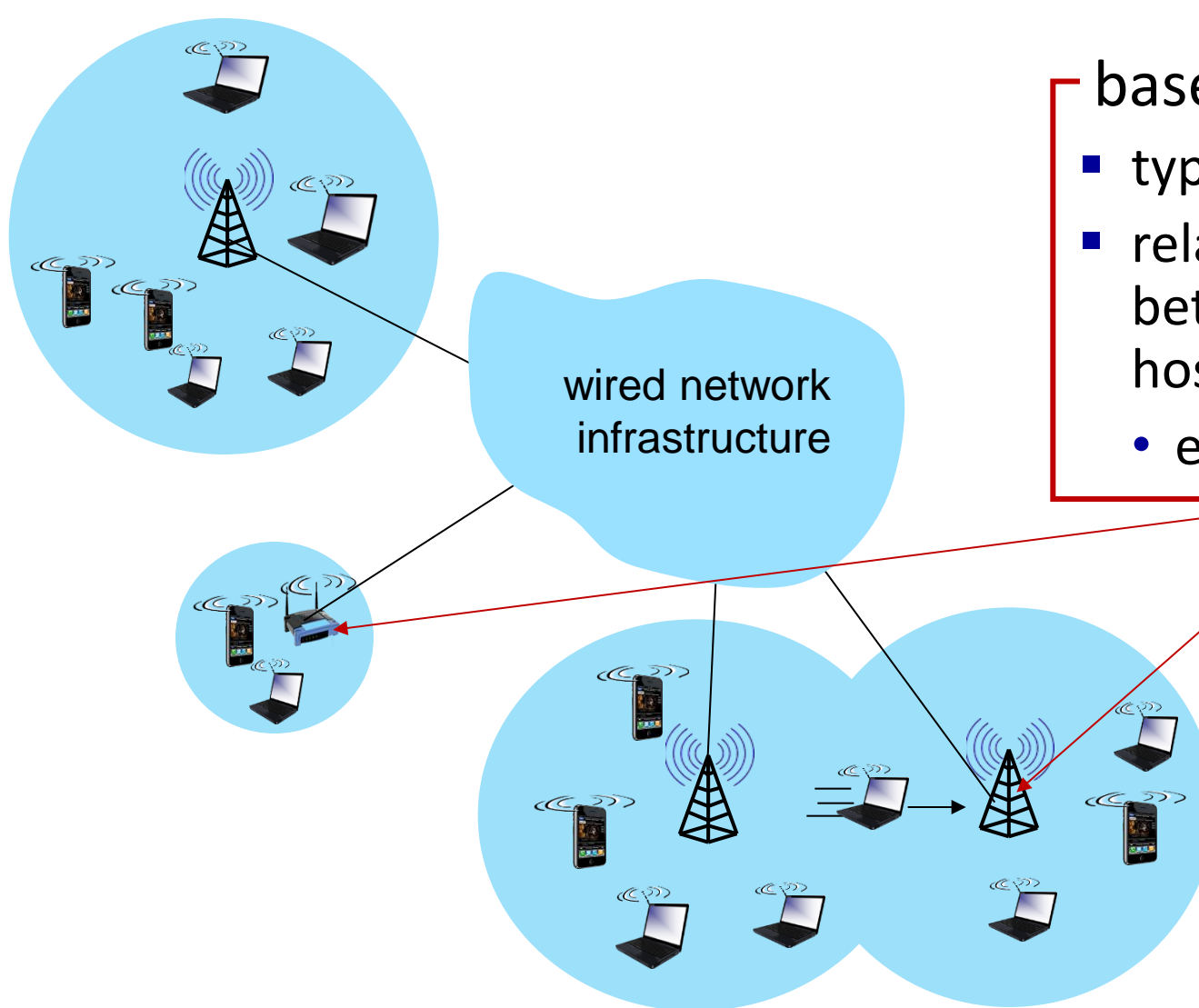
Elements of a wireless network



Elements of a wireless network



Elements of a wireless network

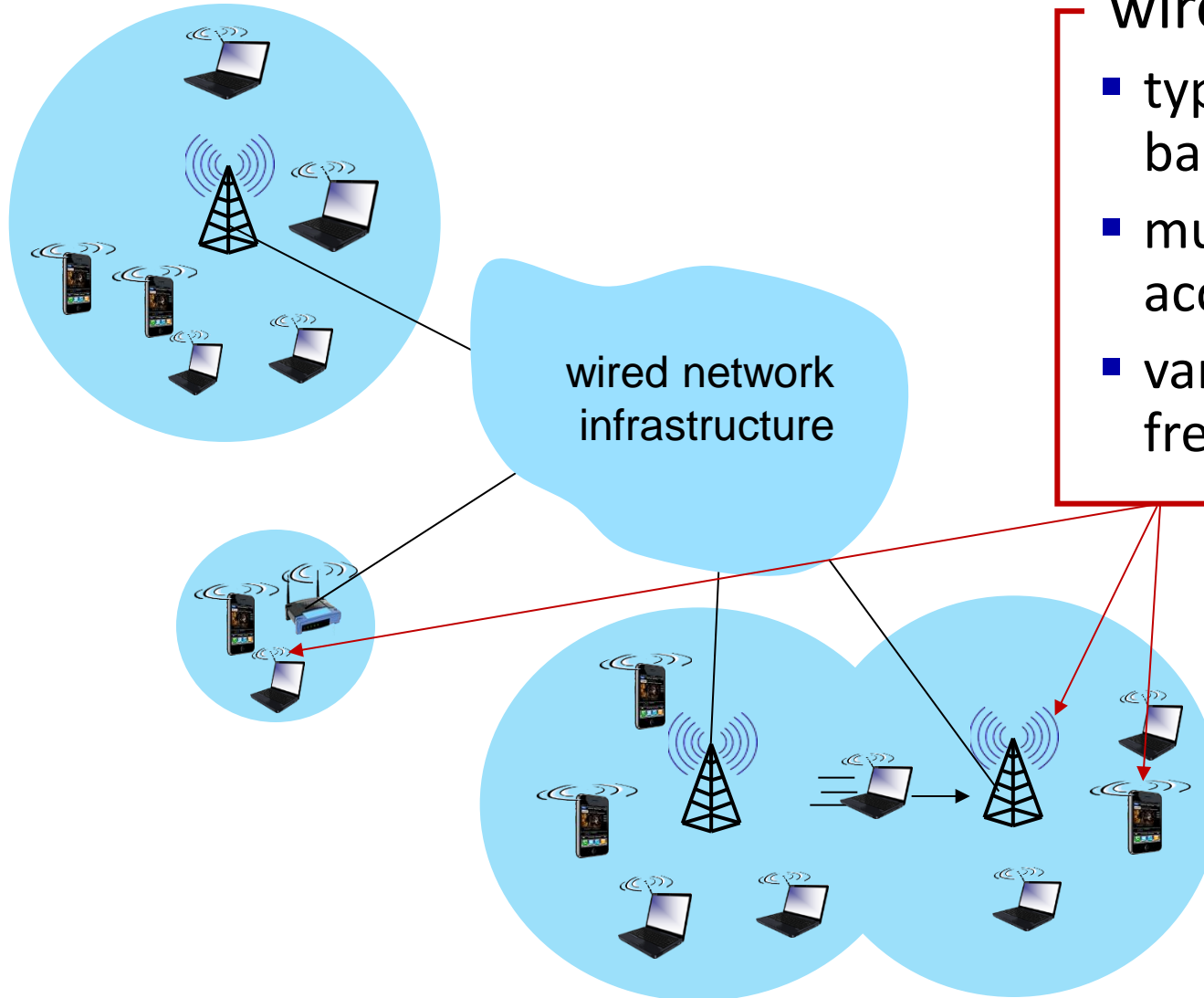


base station



- 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

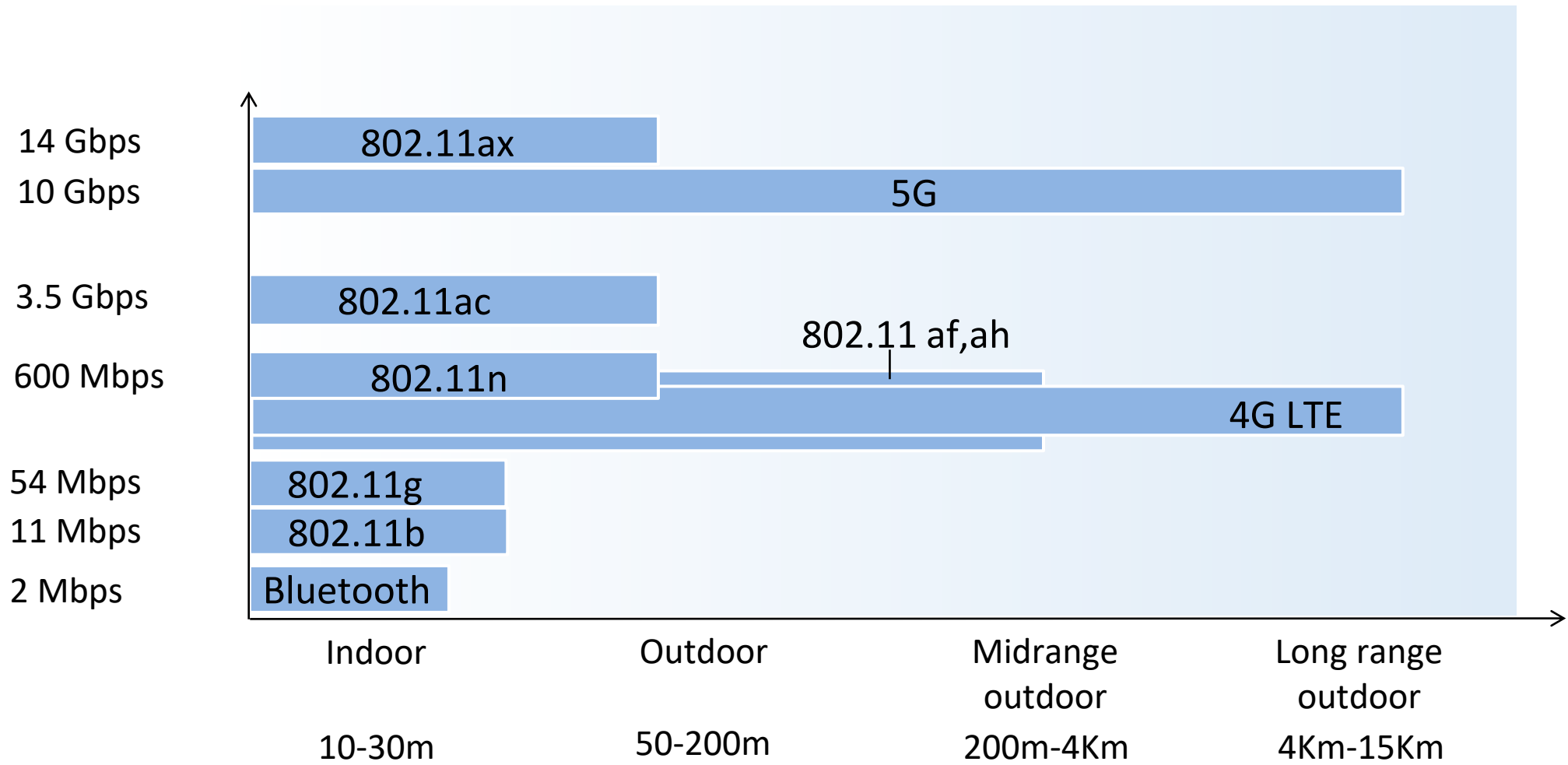


wireless link

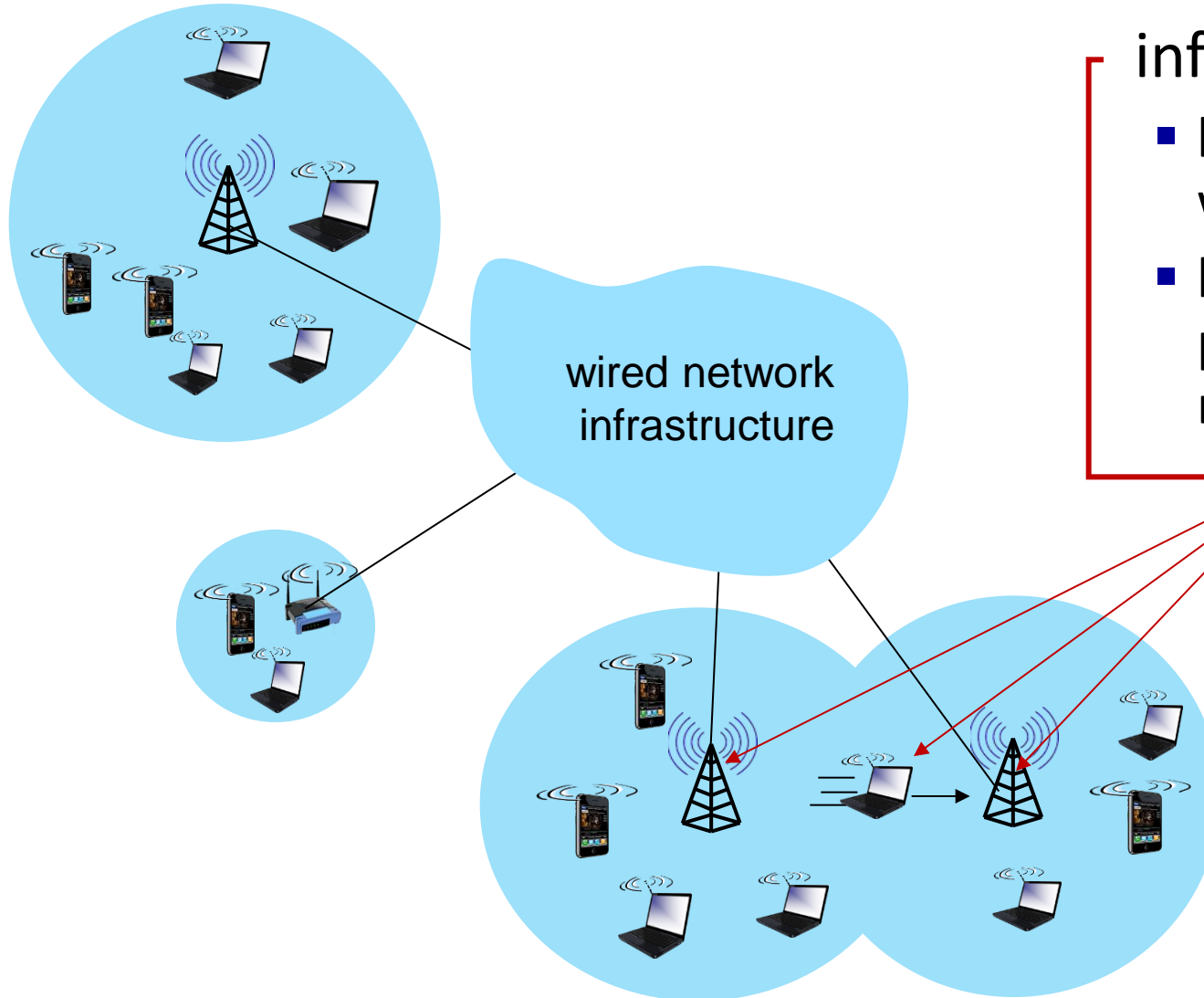


- typically used to connect mobile(s) to base station, also used as backbone link
- multiple access protocol coordinates link access
- various transmission rates and distances, frequency bands

Characteristics of selected wireless links



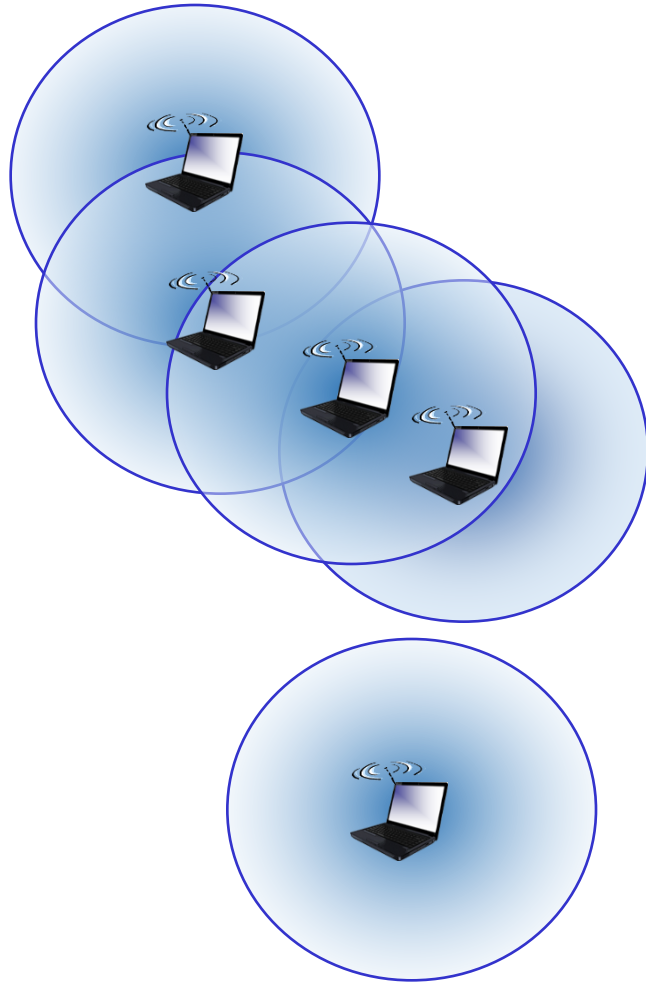
Elements of a wireless network



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

4G/5G cellular networks

- *the* solution for wide-area mobile Internet
- widespread deployment/use:
 - more mobile-broadband-connected devices than fixed-broadband-connected devices (5-1 in 2019)!
 - 4G availability: 97% of time in Korea (90% in US)
- transmission rates up to 100's Mbps
- technical standards: 3rd Generation Partnership Project (3GPP)
 - www.3gpp.org
 - 4G: Long-Term Evolution (LTE) standard

4G/5G cellular networks

similarities to wired Internet

- edge/core distinction, but both belong to same carrier
- global cellular network: a network of networks
- widespread use of well-known protocols: HTTP, DNS, TCP, UDP, IP, NAT, separation of data/control planes, SDN, Ethernet, tunneling
- interconnected to wired Internet

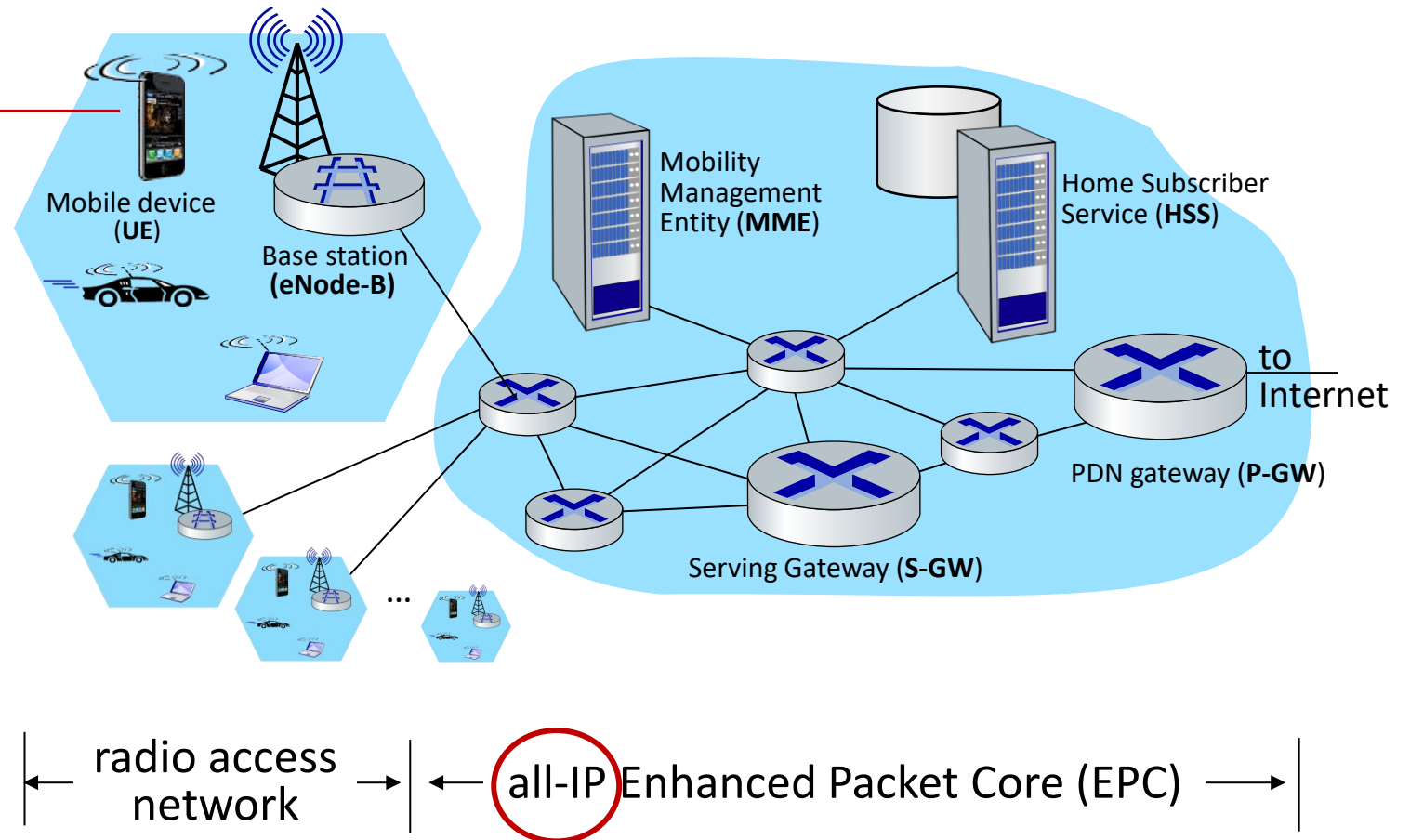
differences from wired Internet

- different wireless link layer
- mobility as a 1st class service
- user “identity” (via SIM card)
- business model: users subscribe to a cellular provider
 - strong notion of “home network” versus roaming on visited nets
 - global access, with authentication infrastructure, and inter-carrier settlements

Elements of 4G LTE architecture

Mobile device:

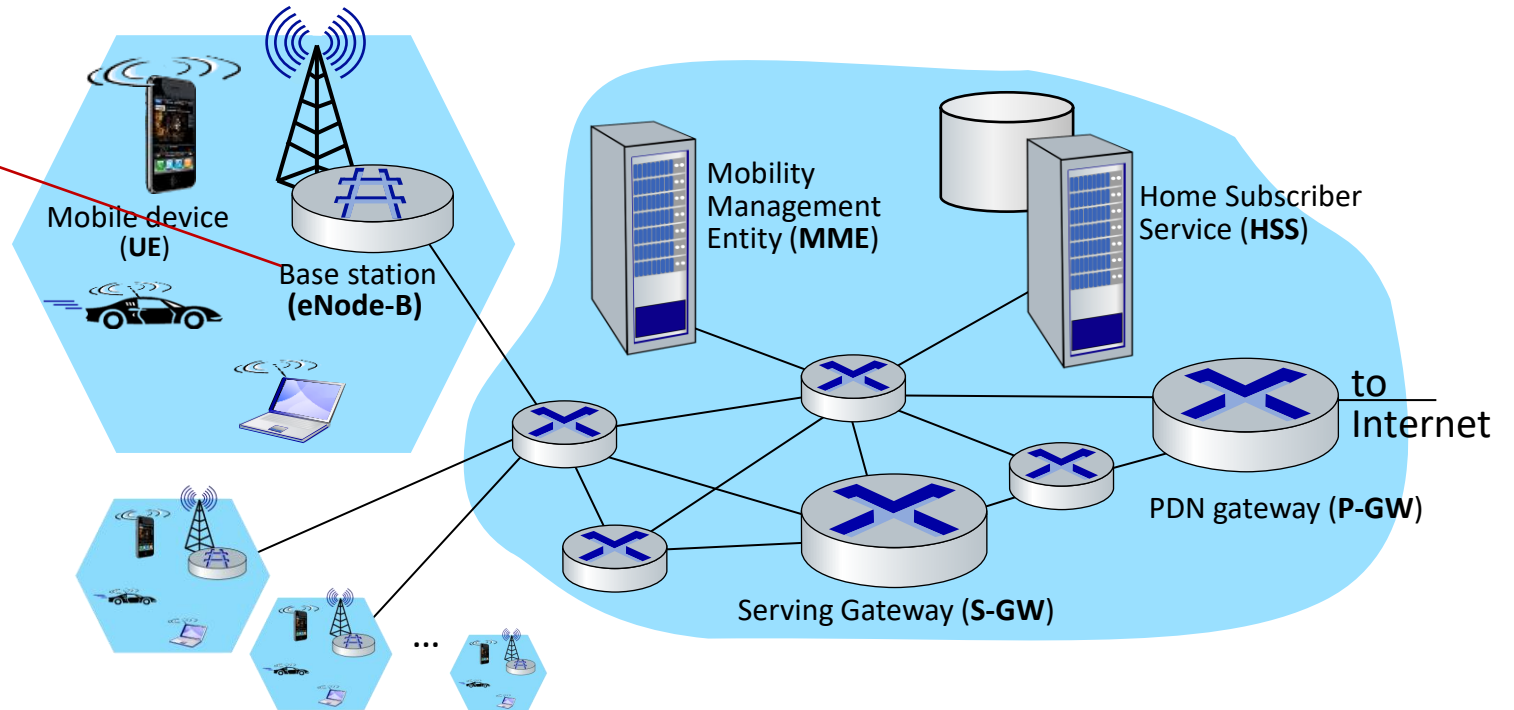
- smartphone, tablet, laptop, IoT, ... with 4G LTE radio
- 64-bit International Mobile Subscriber Identity (IMSI), stored on SIM (Subscriber Identity Module) card
- LTE jargon: User Equipment (UE)



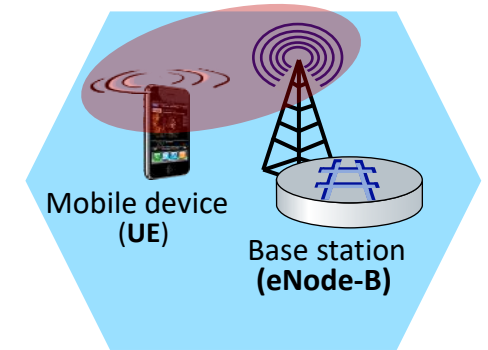
Elements of 4G LTE architecture

Base station:

- at “edge” of carrier’s network
- manages wireless radio resources, mobile devices in its coverage area (“cell”)
- coordinates device authentication with other elements
- similar to WiFi AP but:
 - active role in user mobility
 - coordinates with nearby base stations to optimize radio use
- LTE jargon: eNode-B



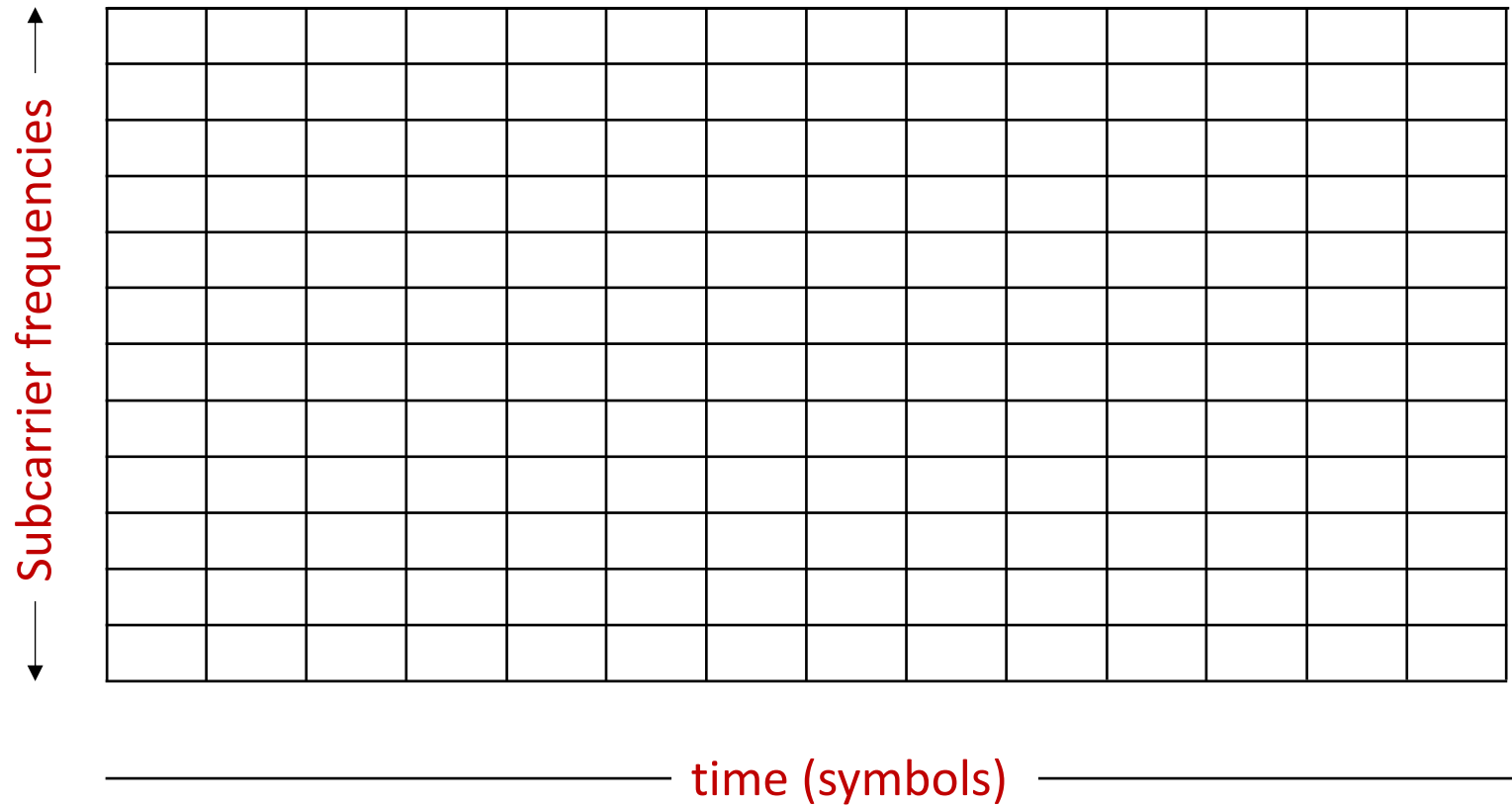
Radio Access Network: 4G radio



- connects device (UE) to a base station (eNode-B)
 - multiple devices connected to each base station
- many different possible frequencies bands, multiple channels in each band
 - popular bands: 600, 700, 850, 1500, 1700, 1900, 2100, 2600, 3500 MHz
 - separate upstream and downstream channels
- sharing 4G radio channel among users:
 - **OFDM**: Orthogonal Frequency Division Multiplexing
 - combination of FDM, TDM
- 100's Mbps possible per user/device

PLEASE NOTE: THE SPACING ALLOTTED THE SERVICES IN THE SPECTRUM

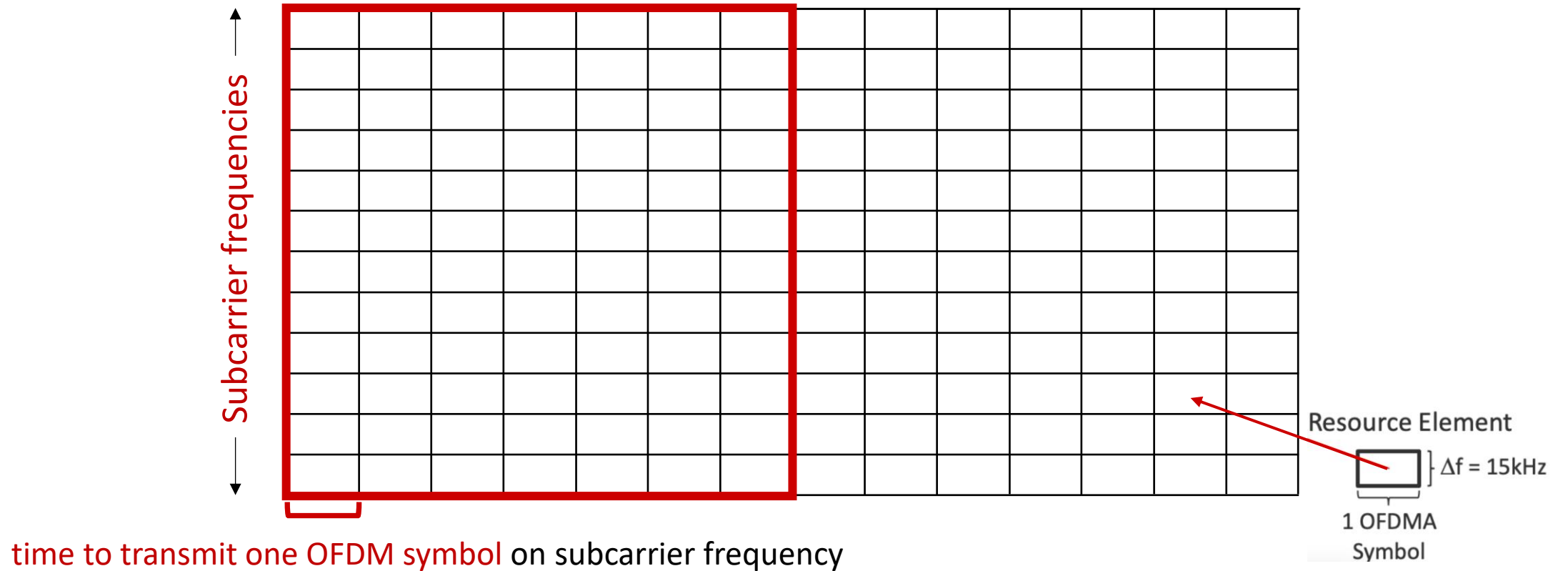
OFDMA: time division (LTE)



OFDMA: time division (LTE)

Physical Resource Block (PRB): blocks of $7 \times 12 = 84$ resource elements

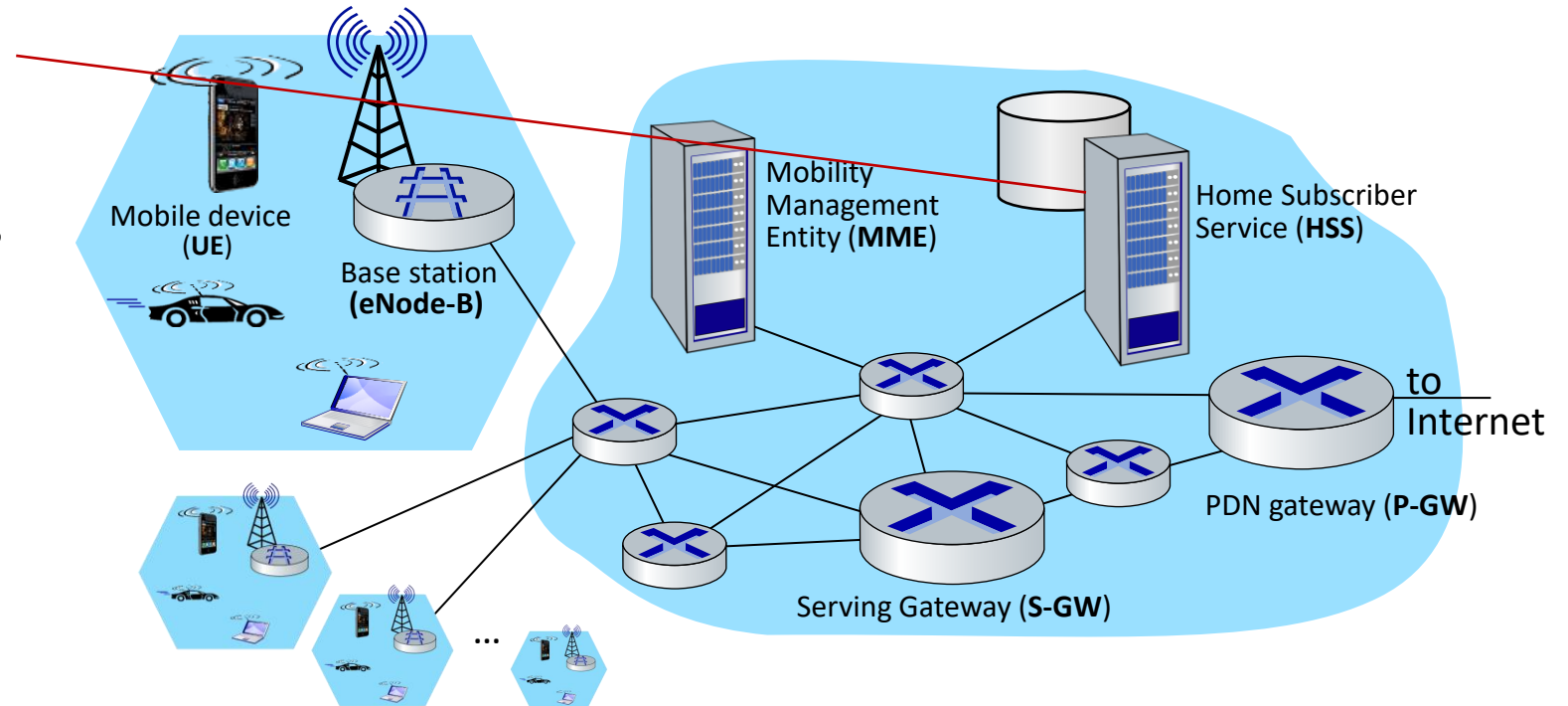
- unit of transmission scheduling



Elements of 4G LTE architecture

Home Subscriber Service

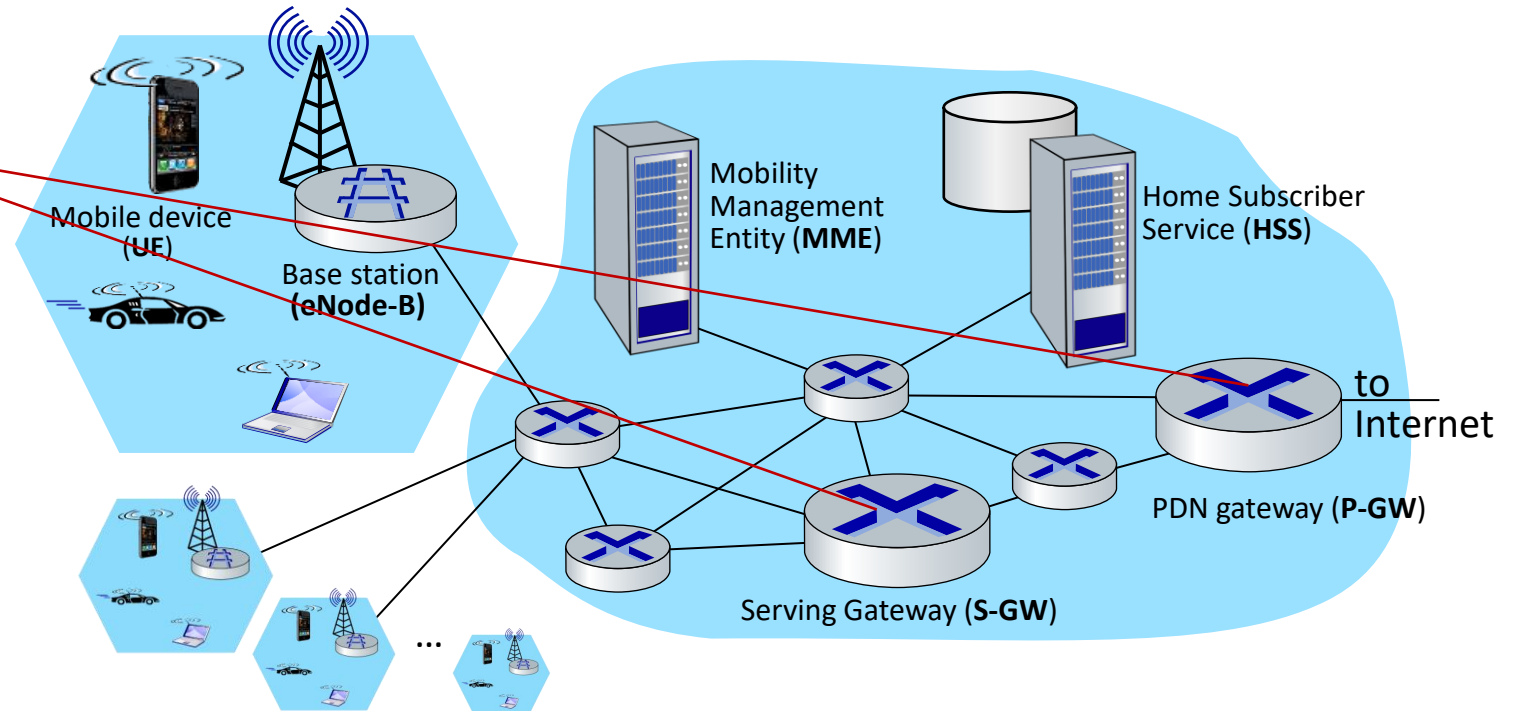
- stores info about mobile devices for which the HSS's network is their “home network”
- works with MME in device authentication



Elements of 4G LTE architecture

Serving Gateway (S-GW), PDN Gateway (P-GW)

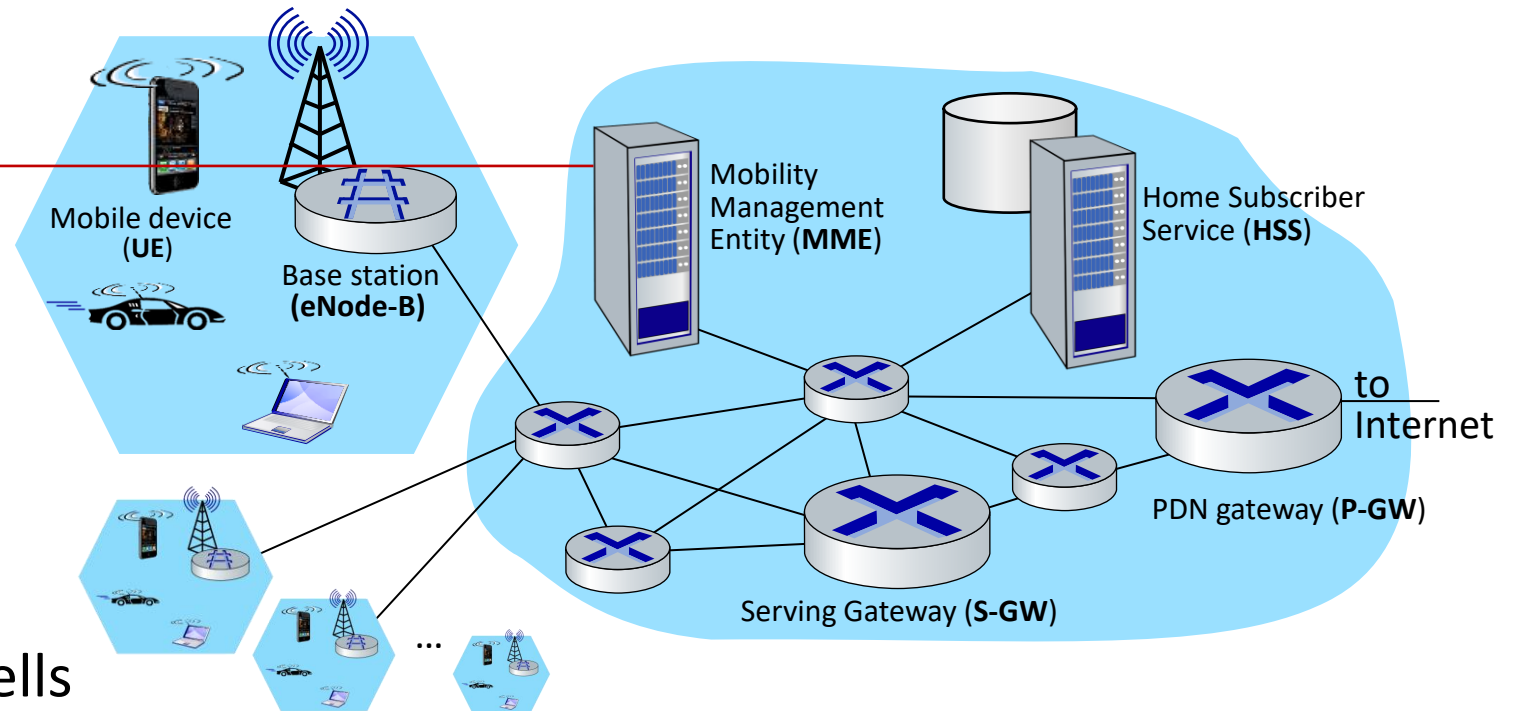
- lie on data path from mobile to/from Internet
- P-GW
 - gateway to mobile cellular network
 - Looks like any other internet gateway router
 - provides NAT services
- other routers:
 - extensive use of tunneling



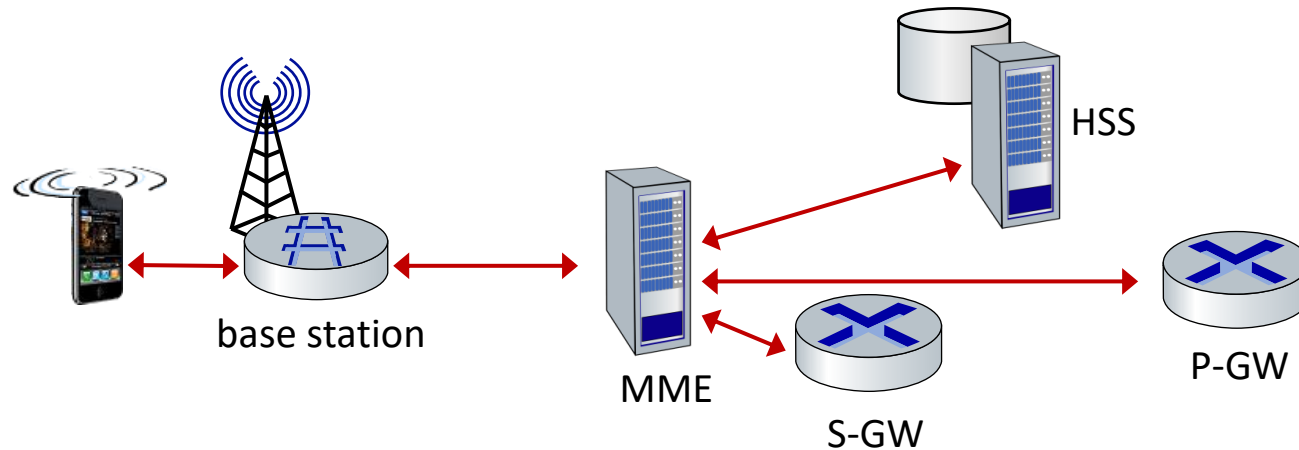
Elements of 4G LTE architecture

Mobility Management Entity

- device authentication (device-to-network, network-to-device) coordinated with mobile home network HSS
- mobile device management:
 - device handover between cells
 - tracking/paging device location
- path (tunneling) setup from mobile device to P-GW

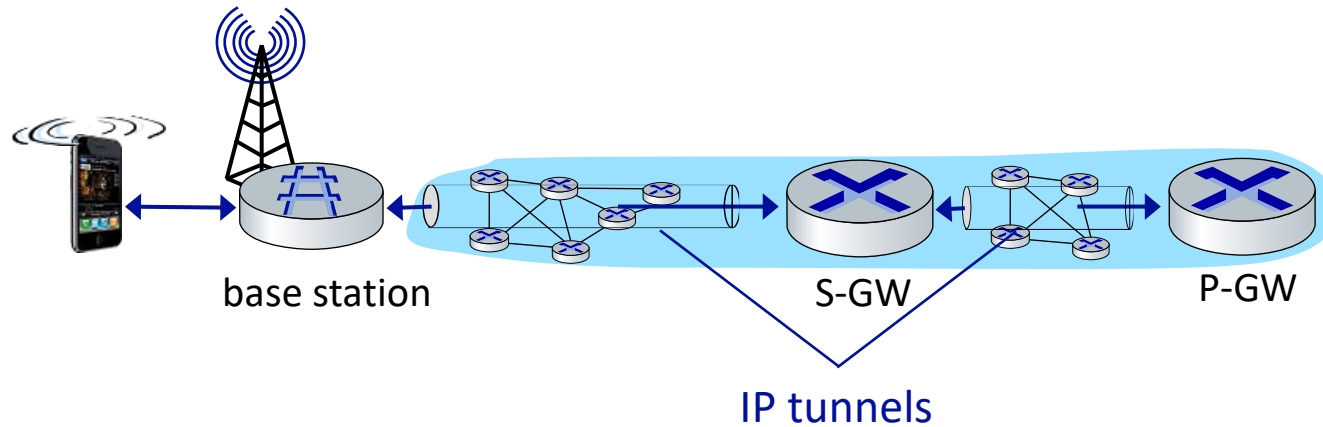


LTE: data plane control plane separation



control plane

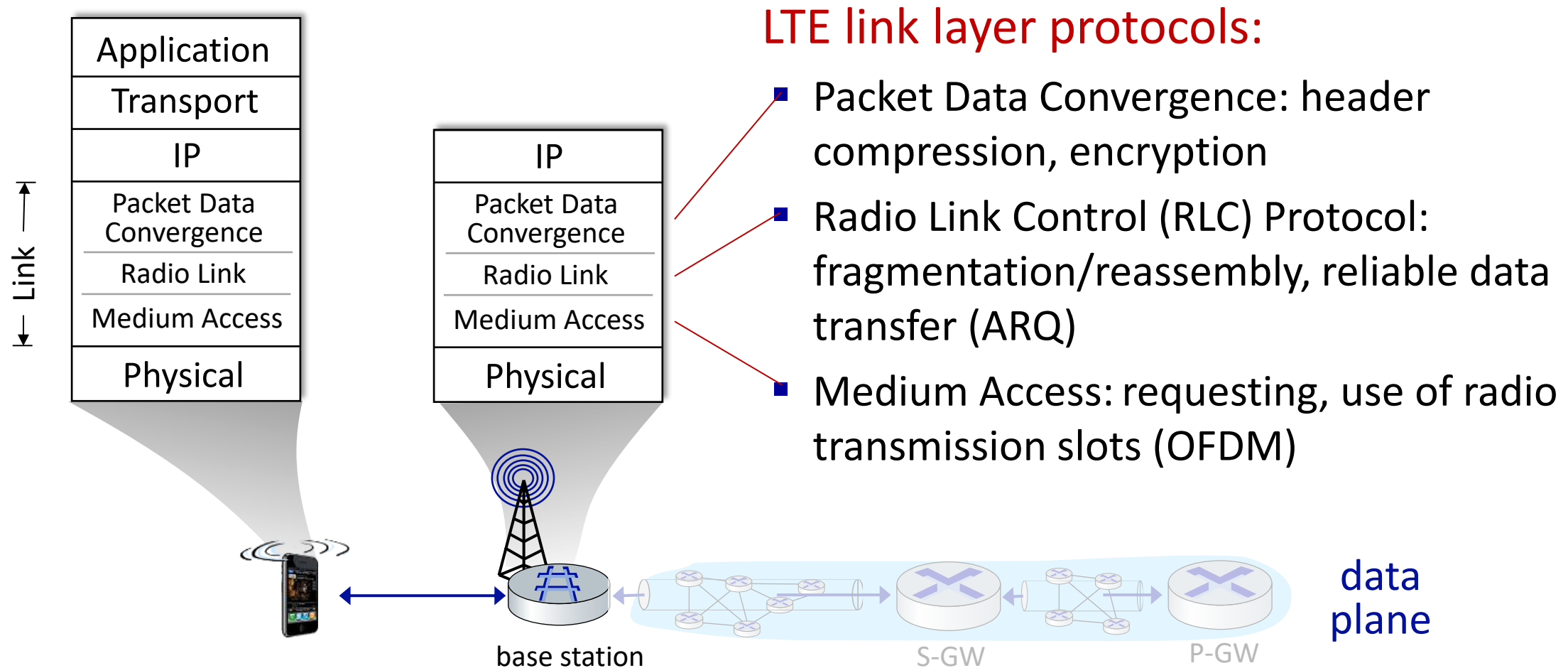
- new protocols for mobility management, security, authentication



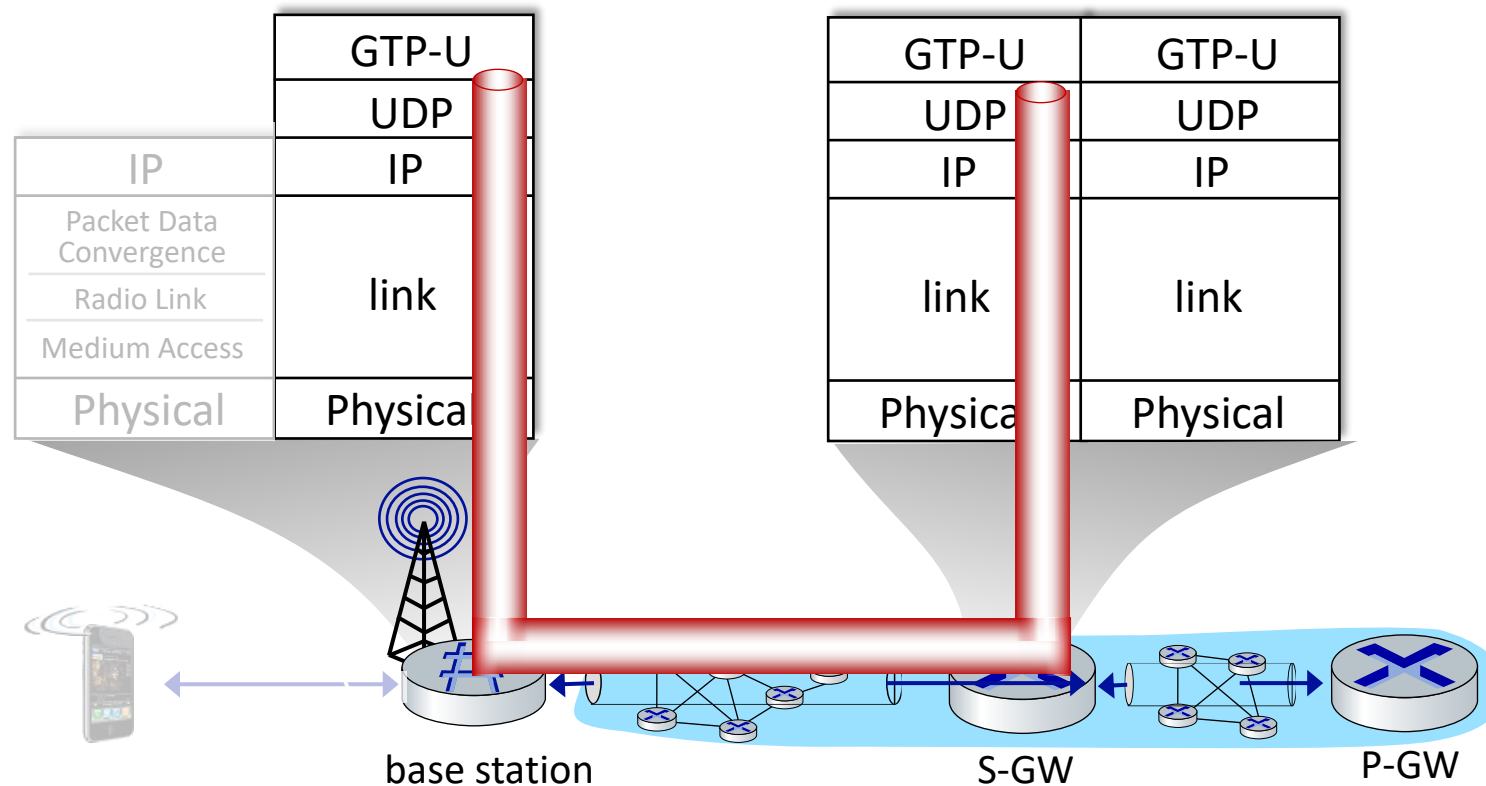
data plane

- new protocols at link, physical layers
- extensive use of tunneling to facilitate mobility

LTE data plane protocol stack: first hop



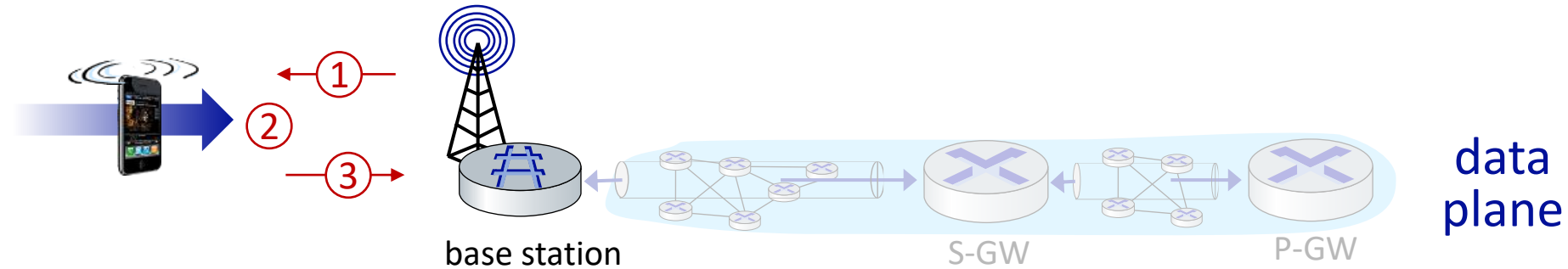
LTE data plane protocol stack: packet core



tunneling:

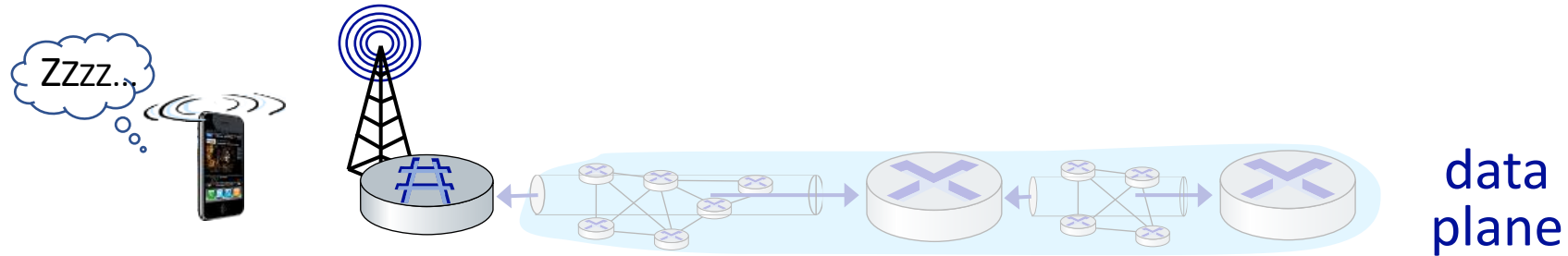
- mobile datagram encapsulated using GPRS Tunneling Protocol (GTP), sent inside UDP datagram to S-GW
- S-GW re-tunnels datagrams to P-GW
- supporting mobility: only tunneling endpoints change when mobile user moves

LTE data plane: associating with a BS



- ① BS broadcasts primary synch signal every 5 ms on all frequencies
 - BSs from multiple carriers may be broadcasting synch signals
- ② mobile finds a primary synch signal, then locates 2nd synch signal on this freq.
 - mobile then finds info broadcast by BS: channel bandwidth, configurations; BS's cellular carrier info
 - mobile may get info from multiple base stations, multiple cellular networks
- ③ mobile selects which BS to associate with (*e.g.*, preference for home carrier)
- ④ more steps still needed to authenticate, establish state, set up data plane

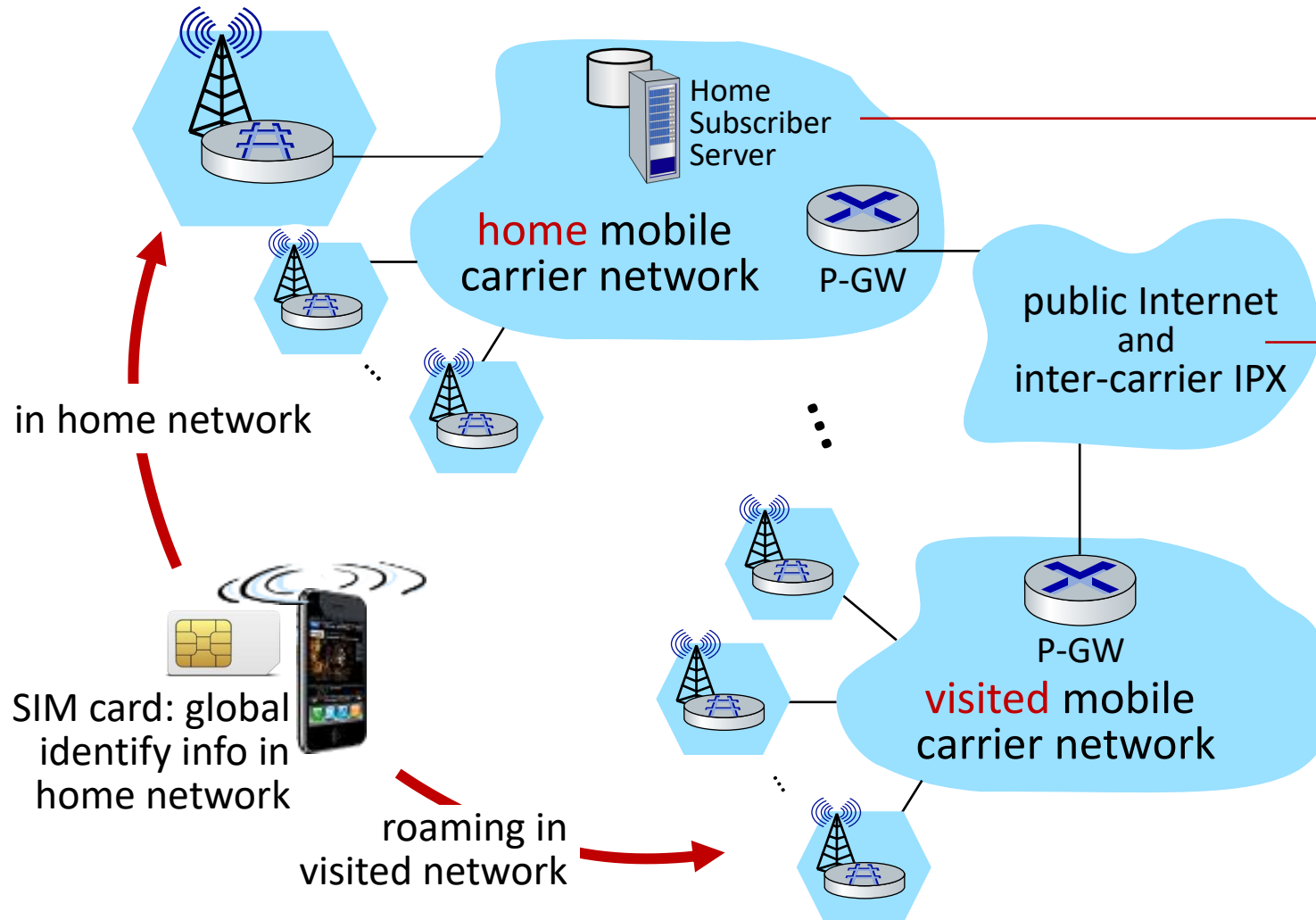
LTE mobiles: sleep modes



LTE mobile may put radio to “sleep” to conserve battery:

- **light sleep:** after 100's msec of inactivity
 - wake up periodically (100's msec) to check for downstream transmissions
- **deep sleep:** after 5-10 secs of inactivity
 - mobile may change cells while deep sleeping – need to re-establish association

Global cellular network: a network of IP networks



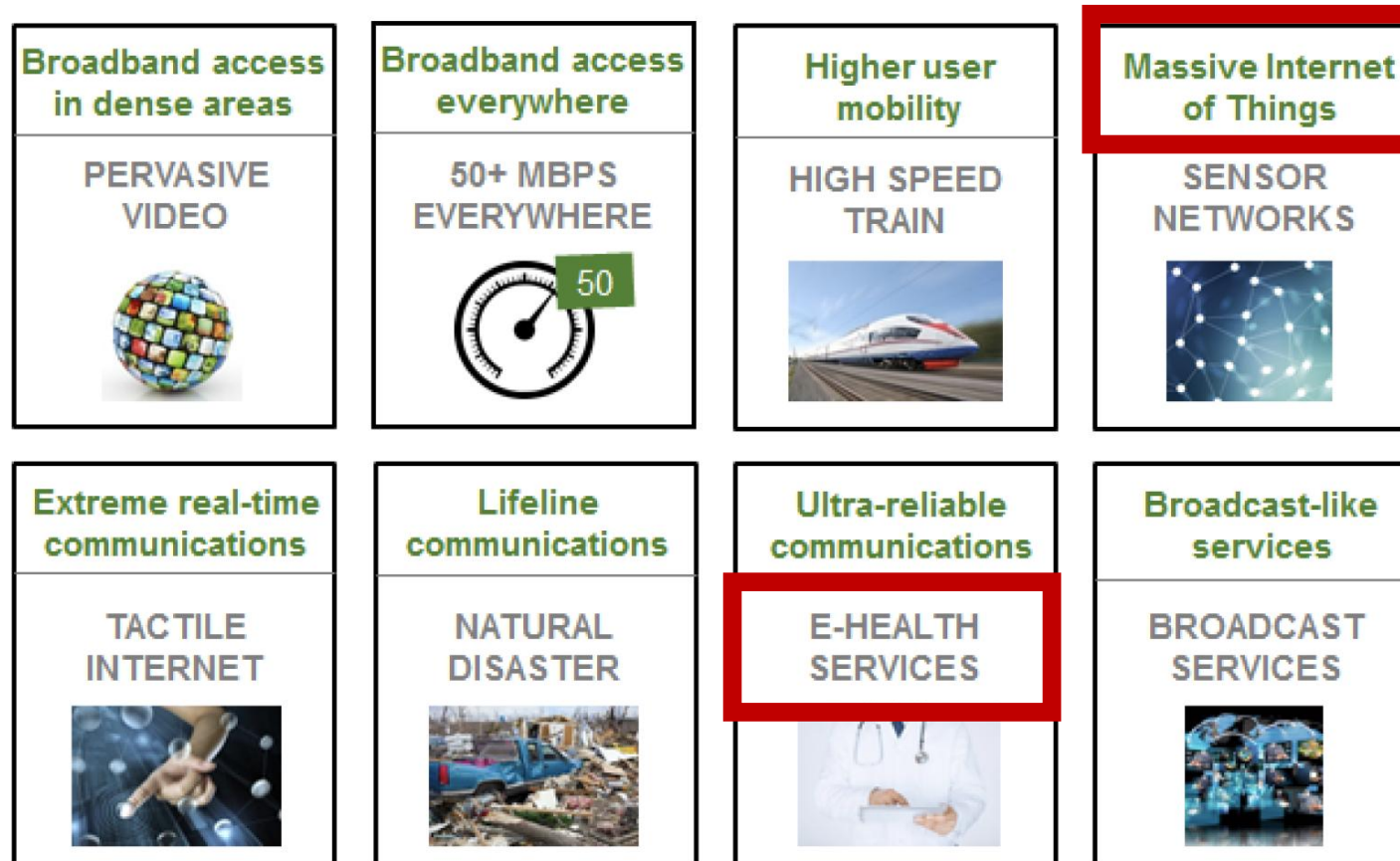
home network HSS:

- identify & services info, while in home network and roaming

all IP:

- carriers interconnect with each other, and public internet at exchange points
- legacy 2G, 3G: not all IP, handled otherwise

On to 5G: motivation



From Next Generation Mobile Networks (NGMS) alliance: 2020 white paper

Hype/wishes need to be separated from reality or likely nearer-term reality

On to 5G: motivation

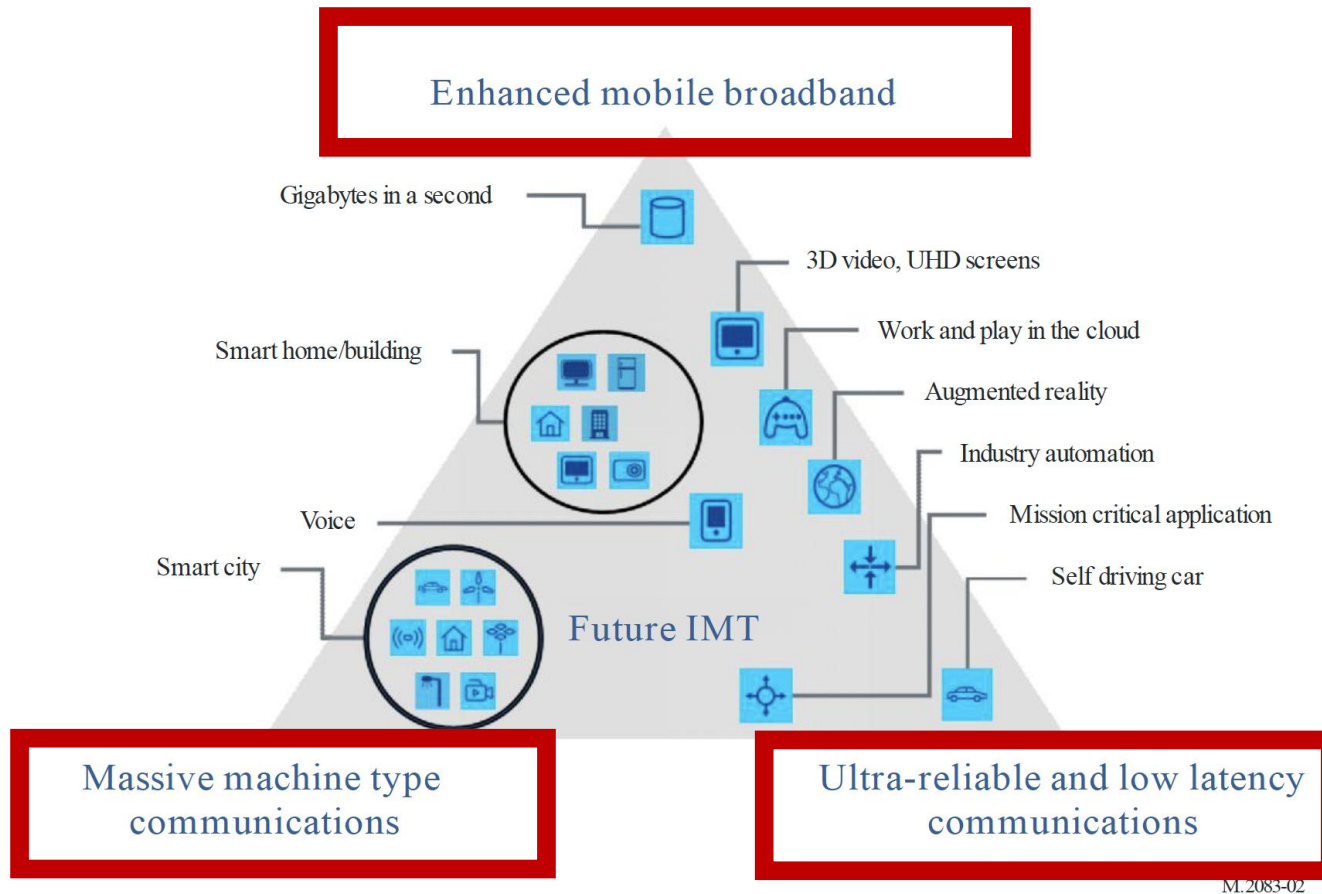
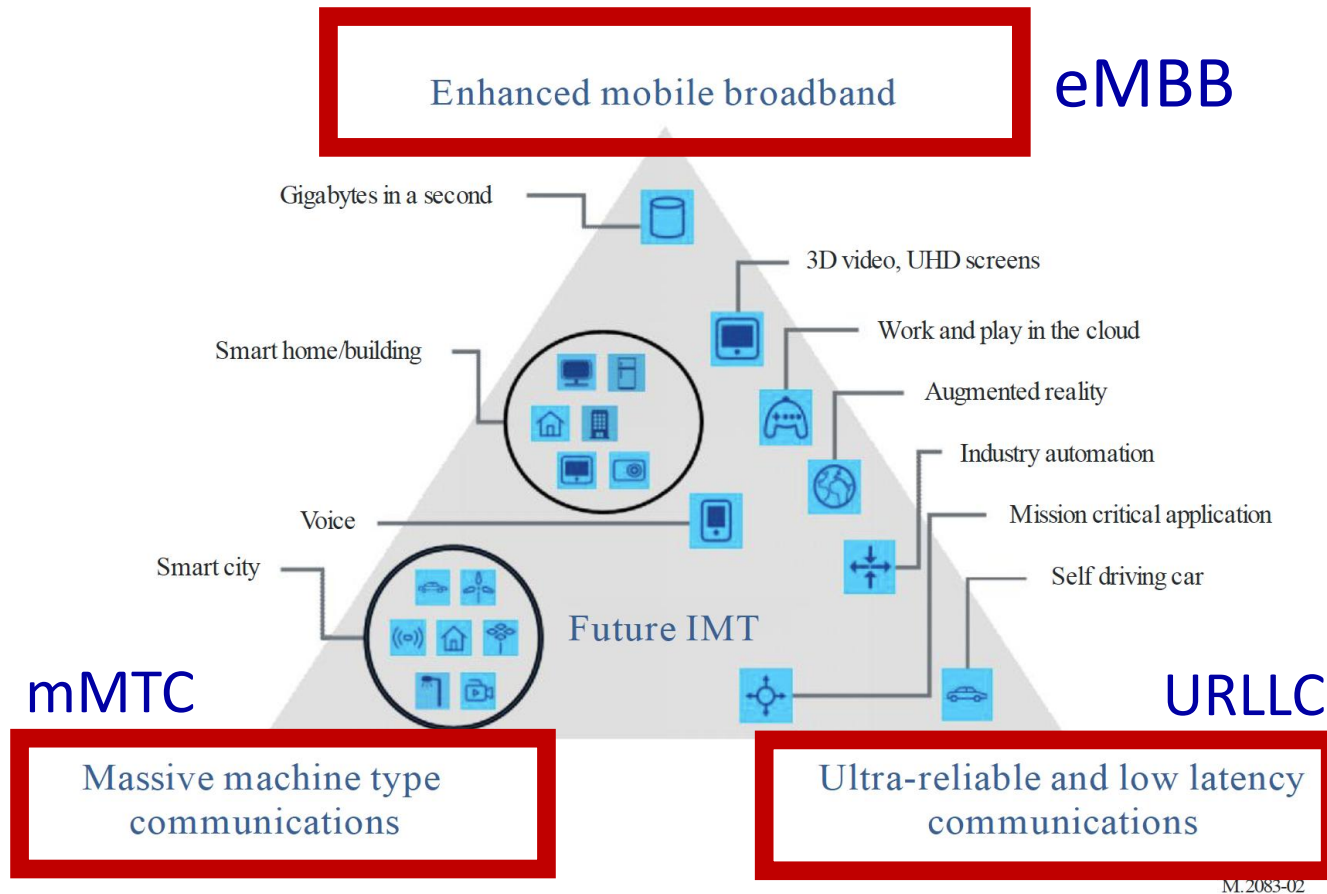


Figure: from Recommendation ITU-R M.2083-0 (2015)

“initial standards and launches have mostly focused on **enhanced Mobile Broadband**, 5G is expected to increasingly enable new business models and countless new use cases, in particular those of **massive Machine Type Communications** and **Ultra-reliable and Low Latency Communications**.”

On to 5G: motivation



Industry verticals:

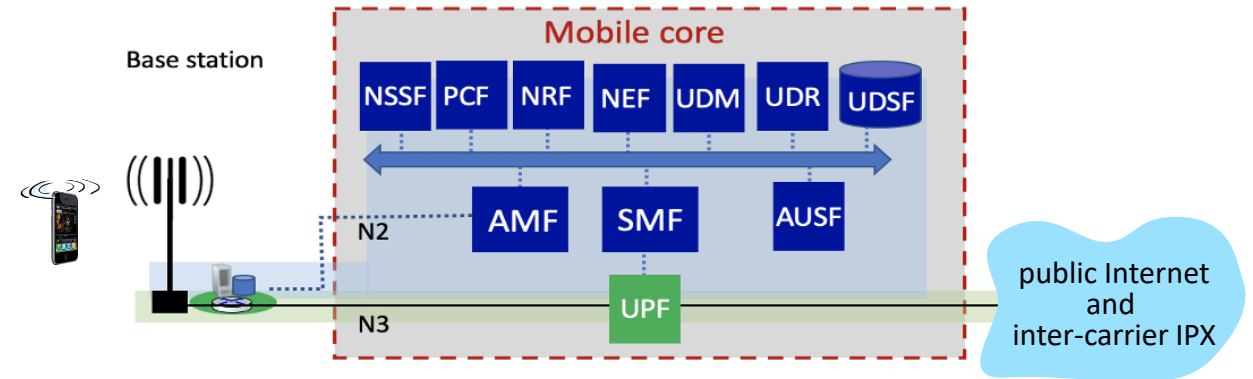
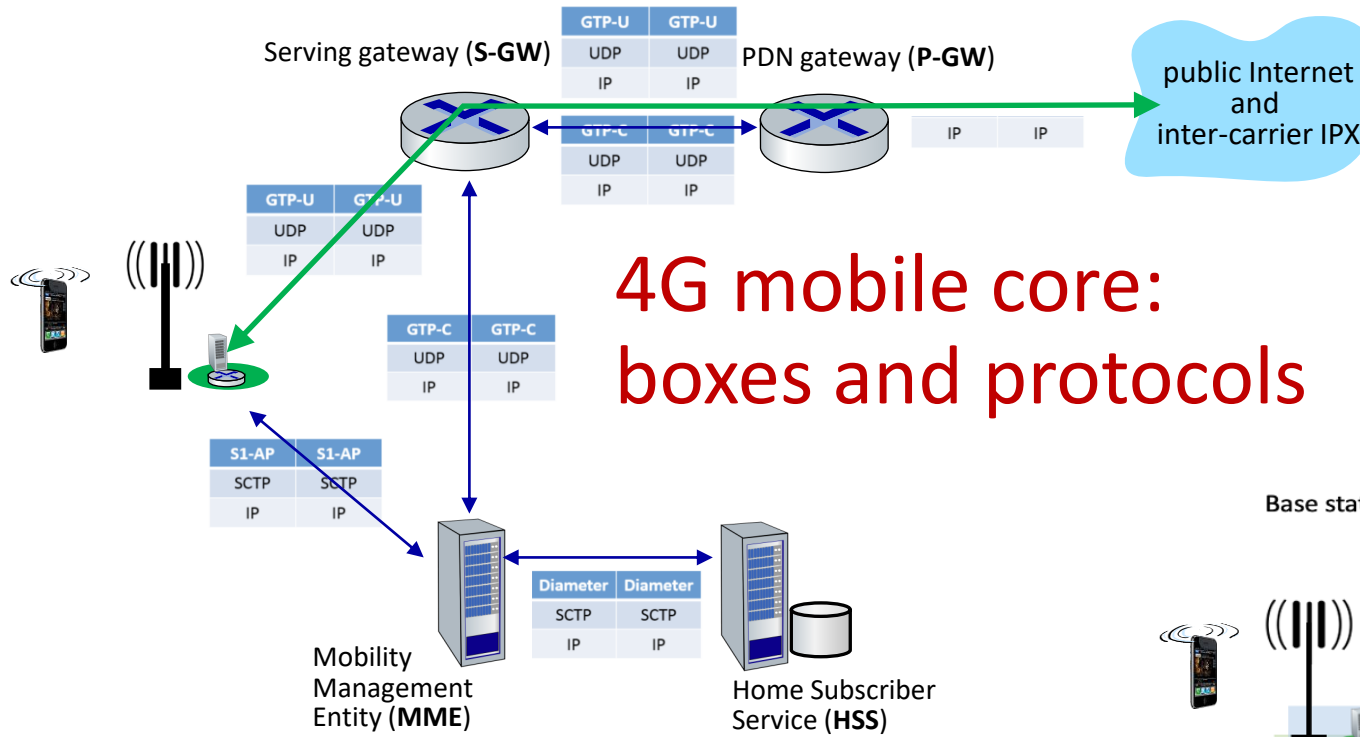
- Manufacturing
- Constructions
- Transport
- Health
- Smart communities
- Education
- Tourism
- Agriculture
- Finance

K. Schwab, "The Fourth Industrial Revolution," World Economic Forum.

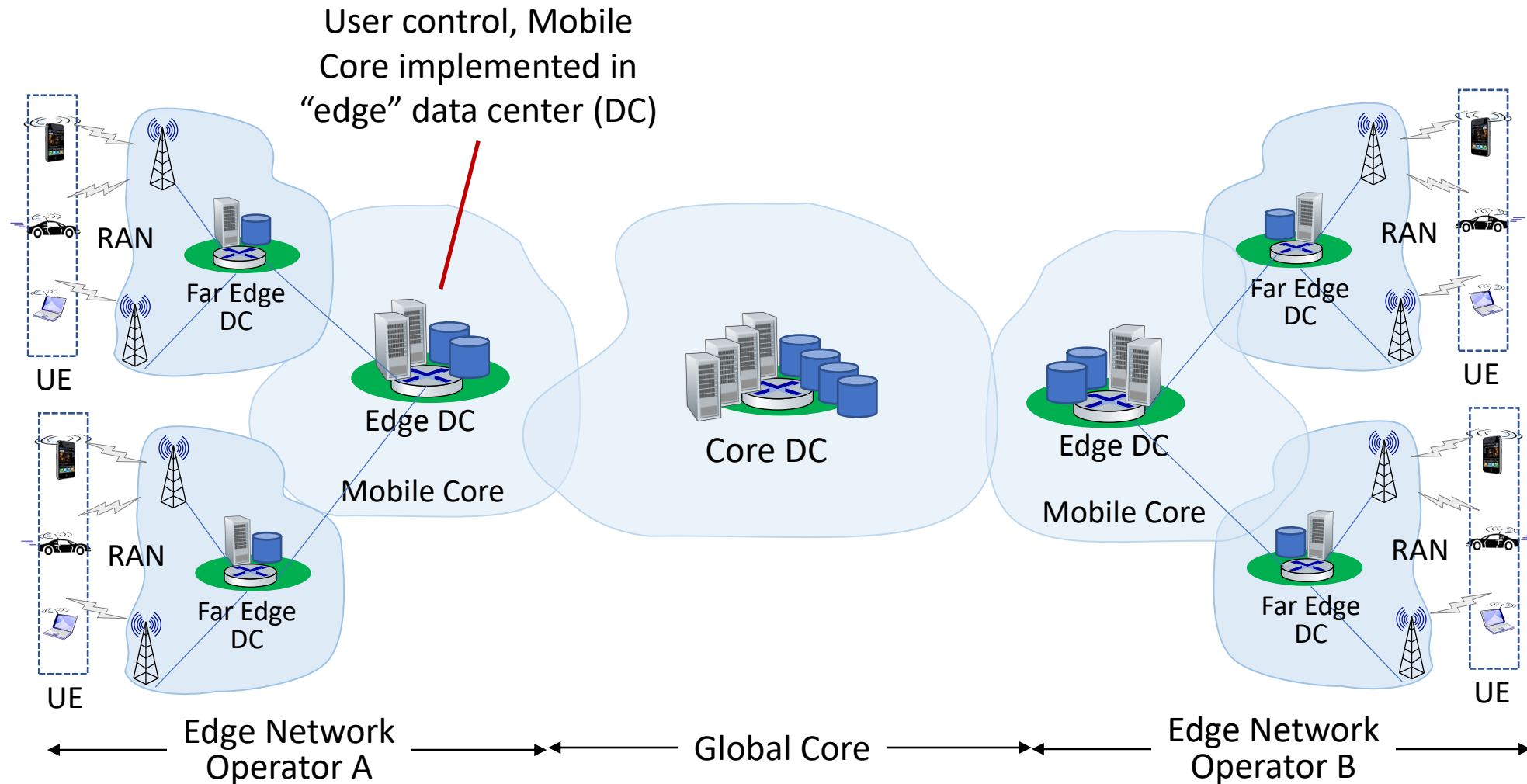
On to 5G: Radio

- **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

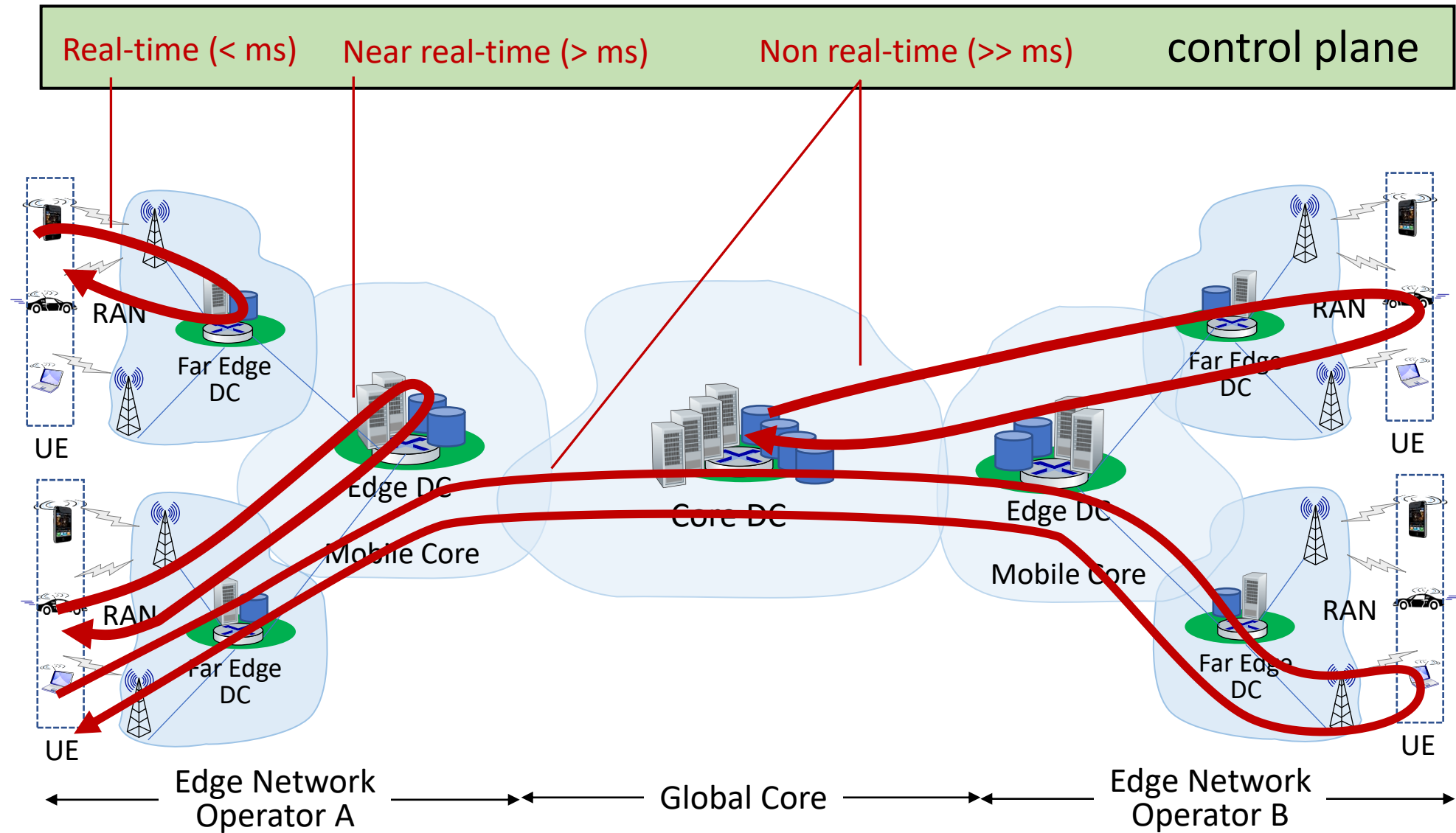
On to 5G: SDN-like architecture



Functional elements: communication, computation, data

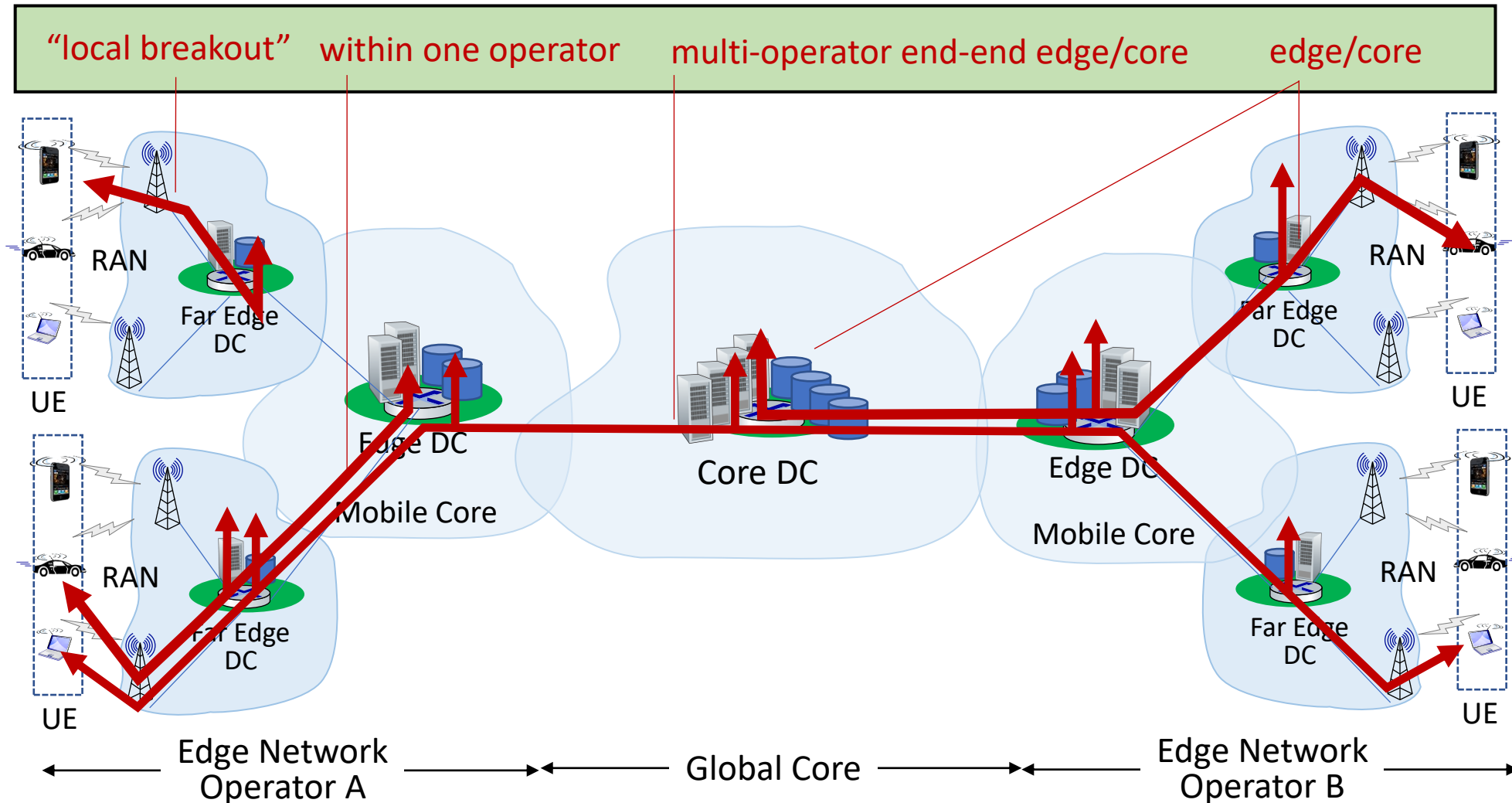


Control plane: resource control



User plane: resources, as used by users (application)

User plane



On beyond 5G?

- “6G” “NextG” and “Beyond 5G”
- 5G on an evolutionary path (like the Internet)
 - **agility**: cloud technologies (SDN) mean new features can be introduced rapidly, deployed continuously
 - **customization**: change can be introduced bottom-up (e.g., by enterprises and edge cloud partners with Private 5G)
 - No need to wait for standardization
 - No need to reach agreement (among all incumbent stakeholders)

What is mobility?

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

no mobility

high mobility



device moves
between
networks, but
powers down
while moving

device moves
within same AP in
one provider
network

device moves
among APs in
one provider
network

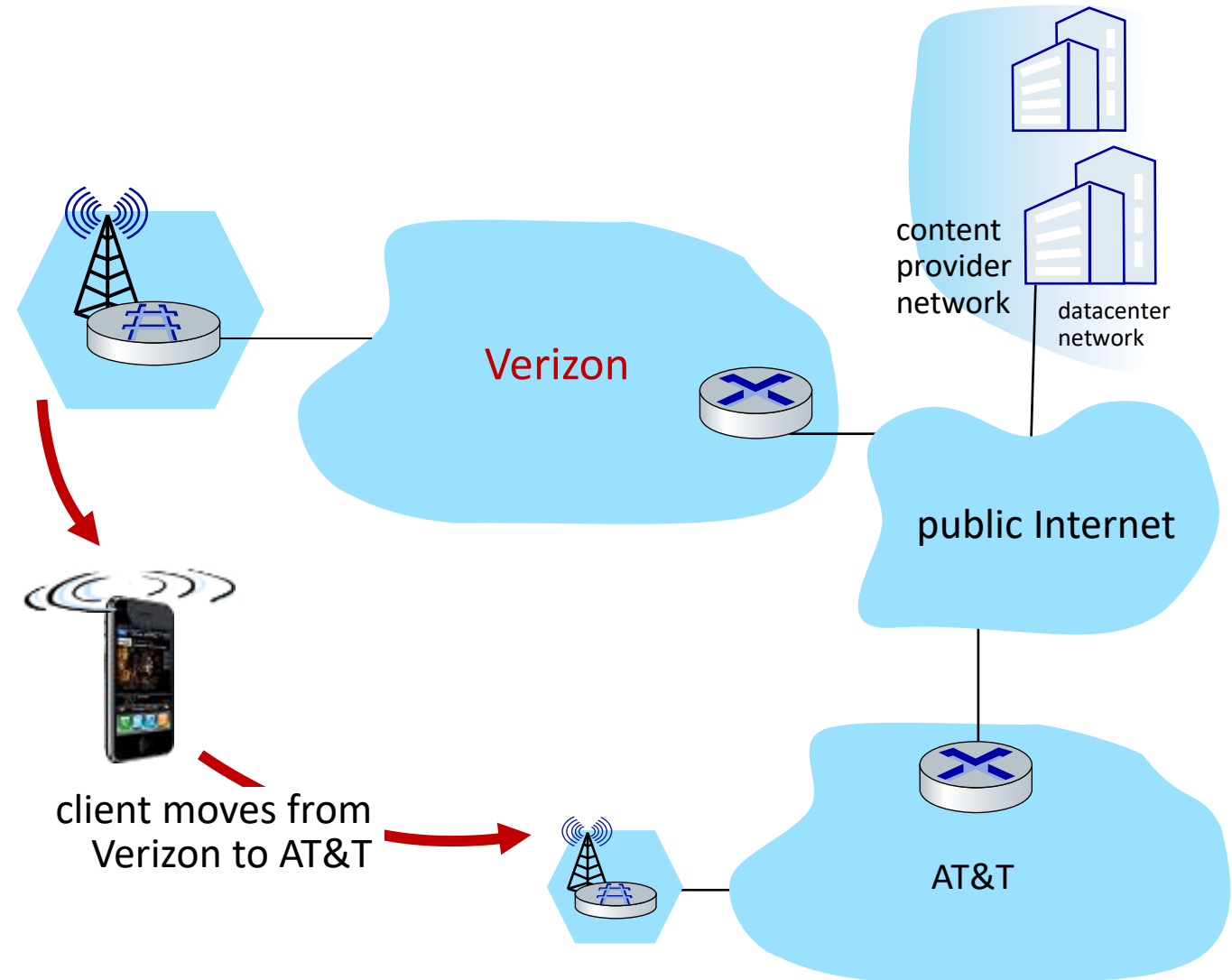
device moves
among multiple
provider networks,
while maintaining
ongoing
connections

We're interested in these!

Mobility challenge:

If a device moves from one network another:

- How will the “network” know to forward packets to the *new* network?



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!

Mobility approaches

- let network (routers) handle it:
 - routers advertise well-known address (e.g., permanent 32-bit IP address), or number of visiting mobile node via usual routing table exchange
 - Internet routing could do it *very easily 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

not
scalable
to billions of
mobiles

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?

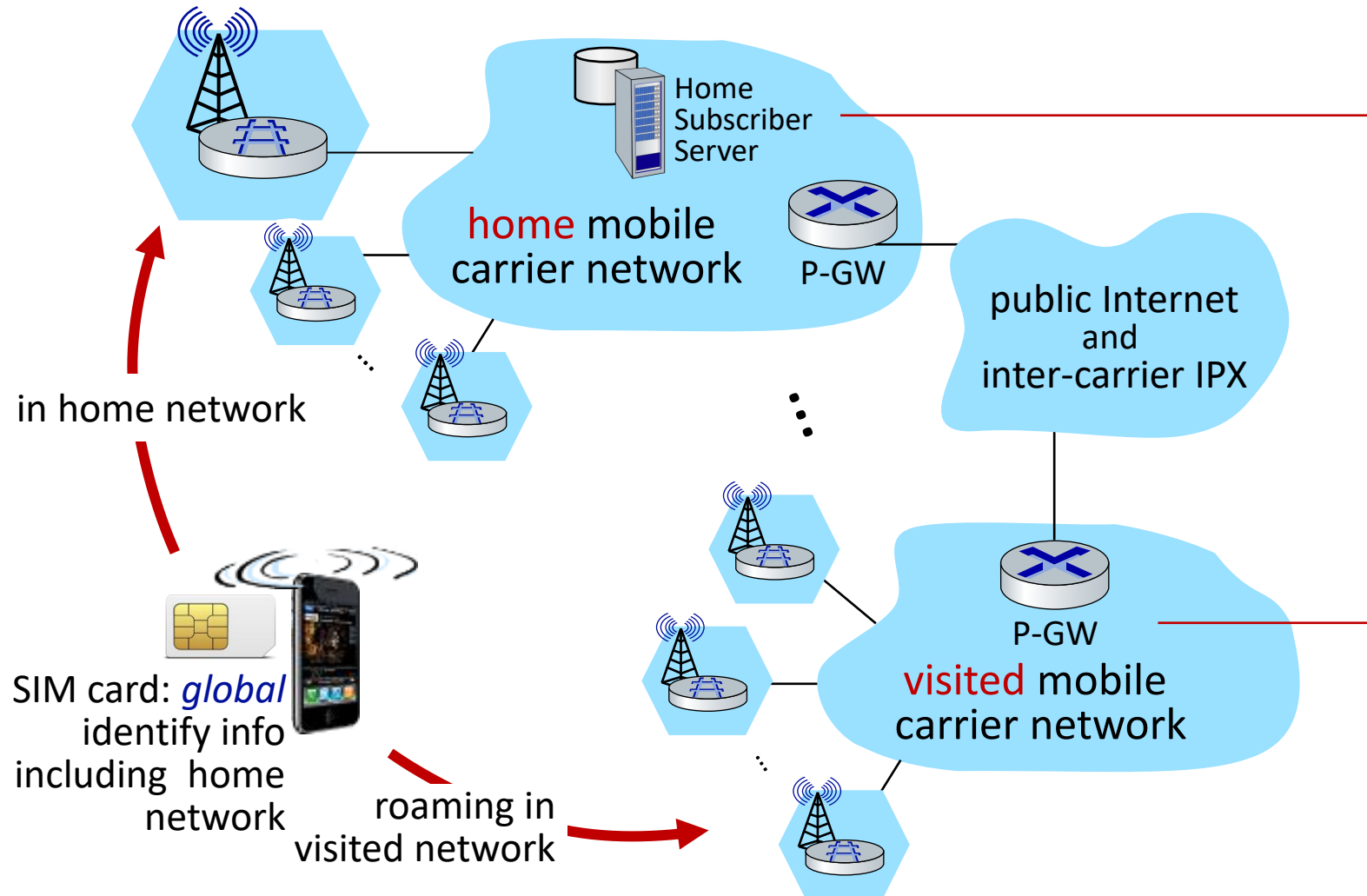
- call his/her parents?
- Facebook!

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



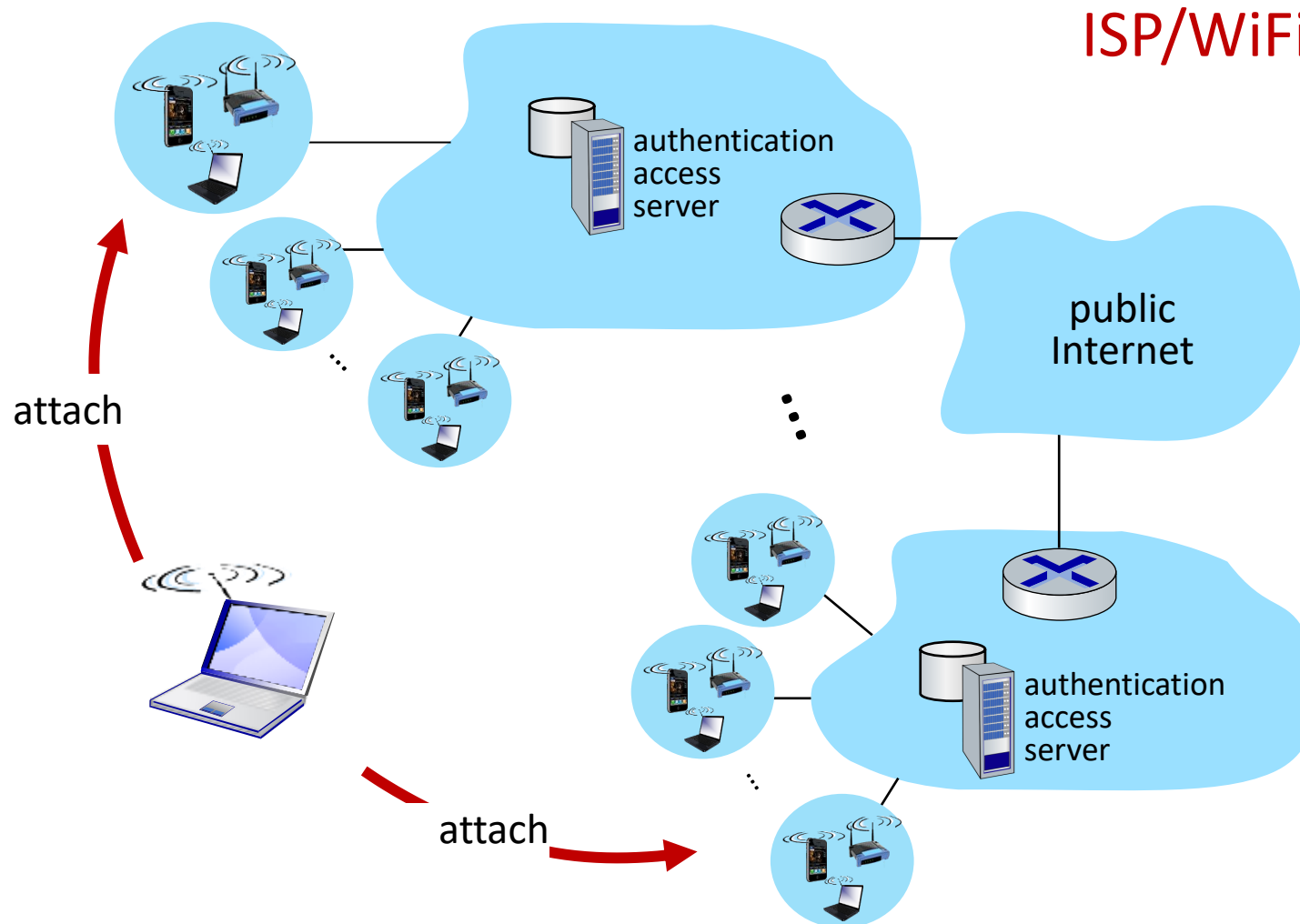
home network:

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

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



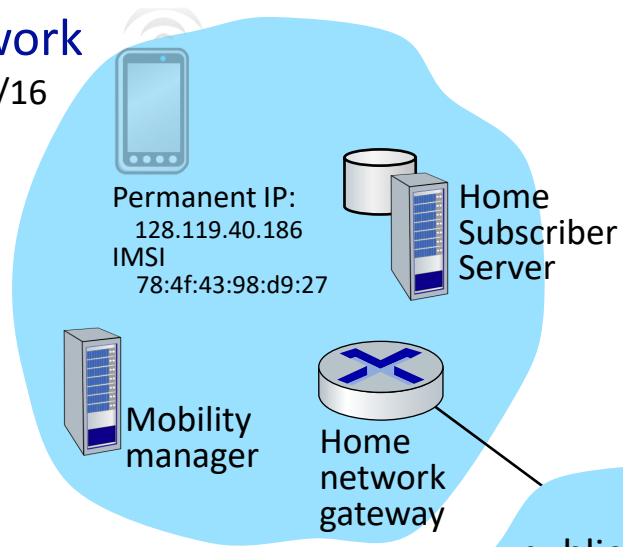
ISP/WiFi: no notion of global “home”

- 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

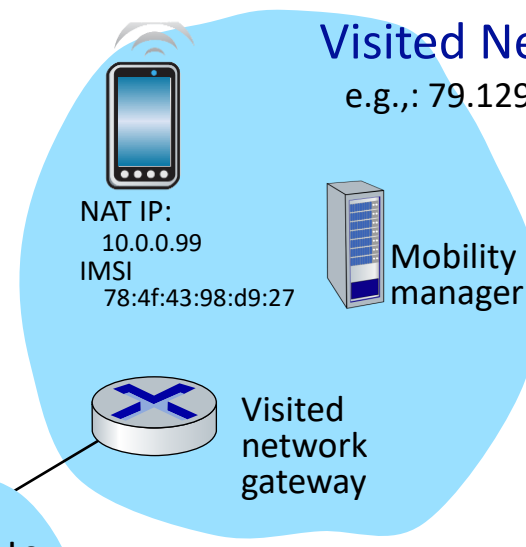
Home Network

e.g.,: 128.119/16



Visited Network

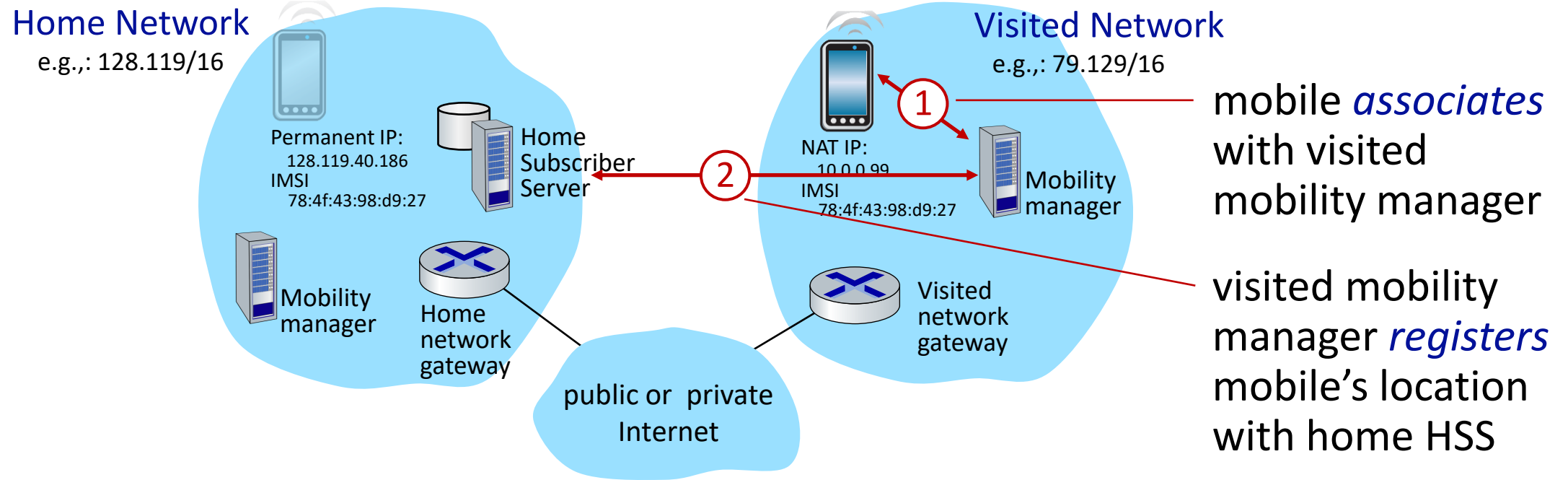
e.g.,: 79.129/16



public or private
Internet

Correspondent

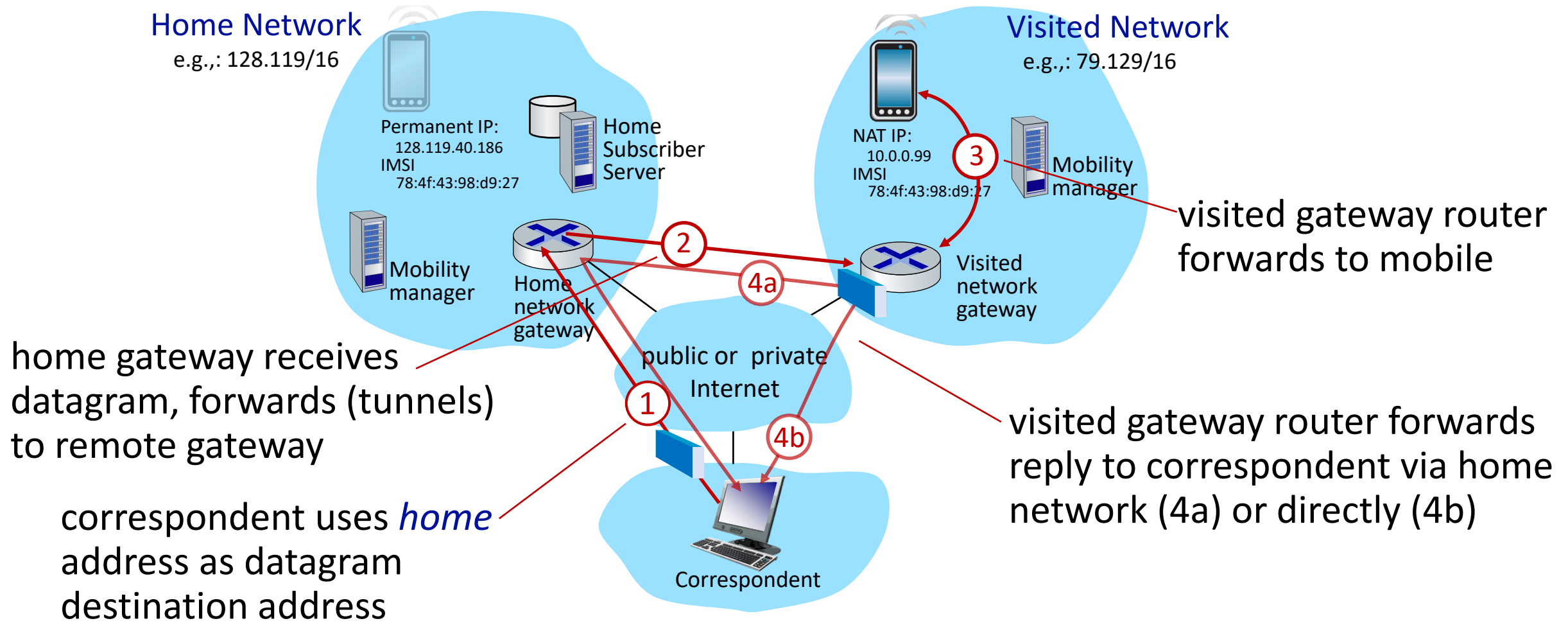
Registration: home needs to know where you are!



end result:

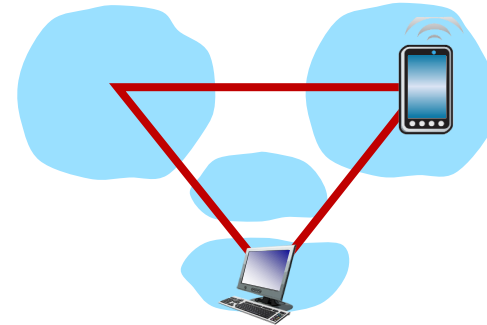
- visited mobility manager knows about mobile
- home HSS knows location of mobile

Mobility with indirect routing

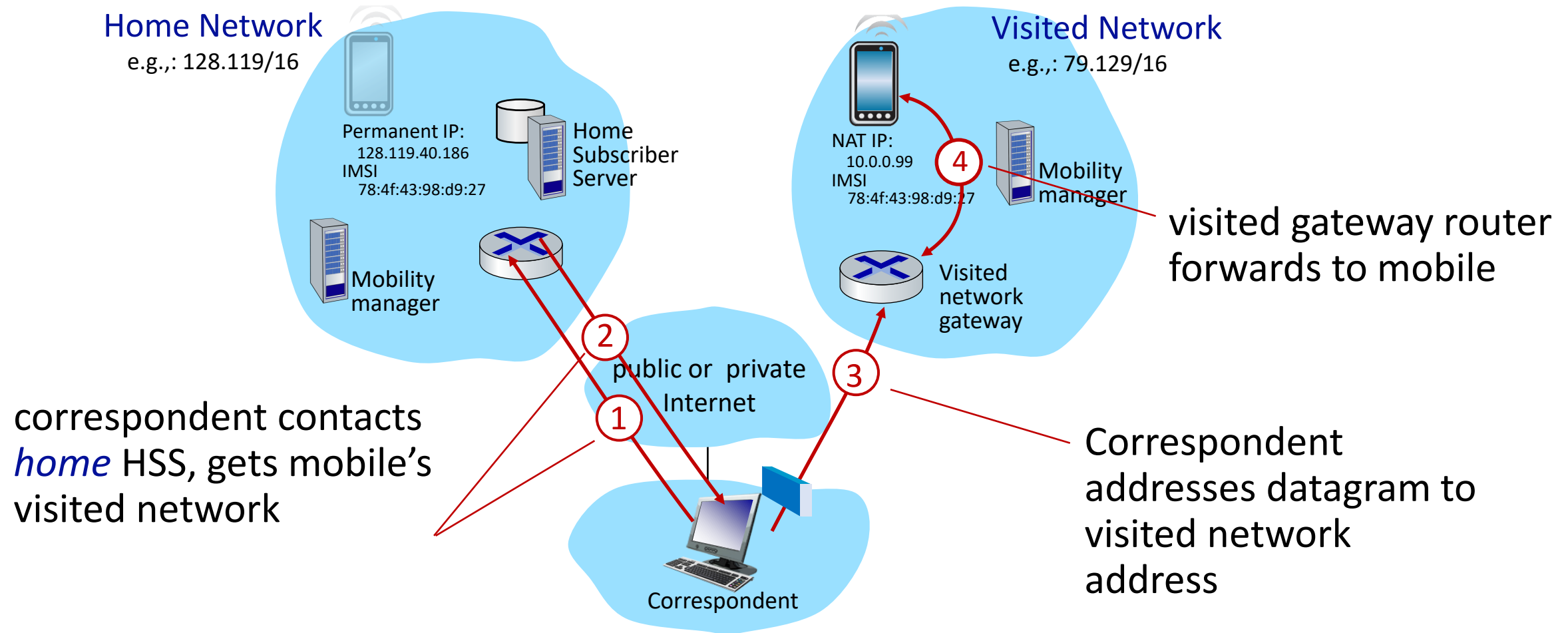


Mobility with indirect routing: comments

- triangle routing:
 - inefficient when correspondent and mobile are in same area
- 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!*



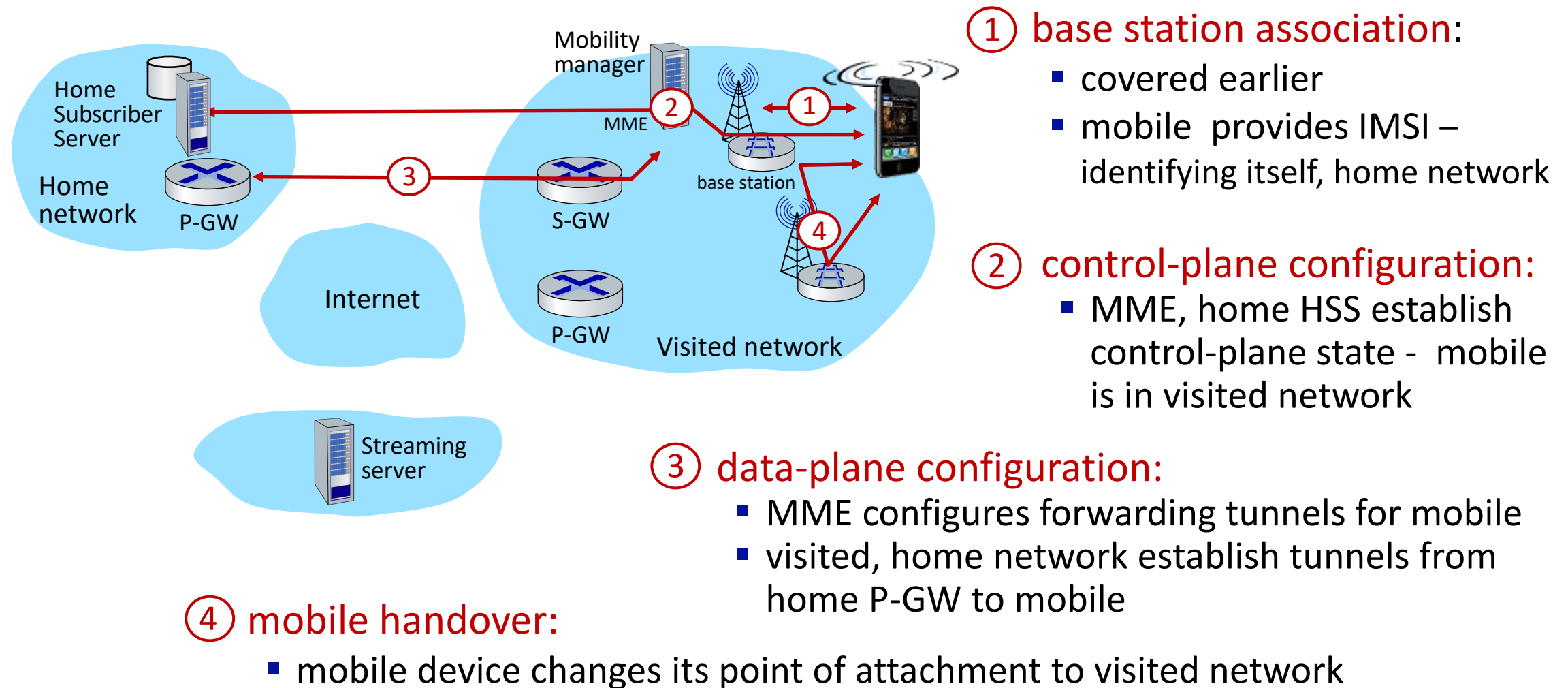
Mobility with direct routing



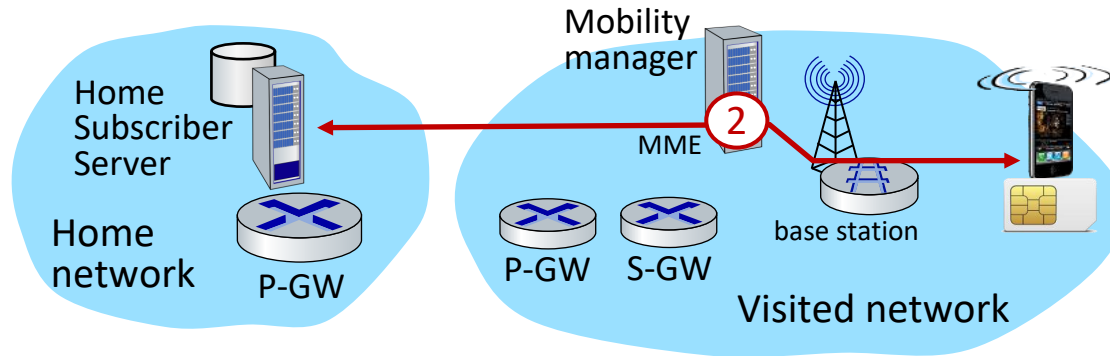
Mobility with direct routing: comments

- 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

Mobility in 4G networks: major mobility tasks



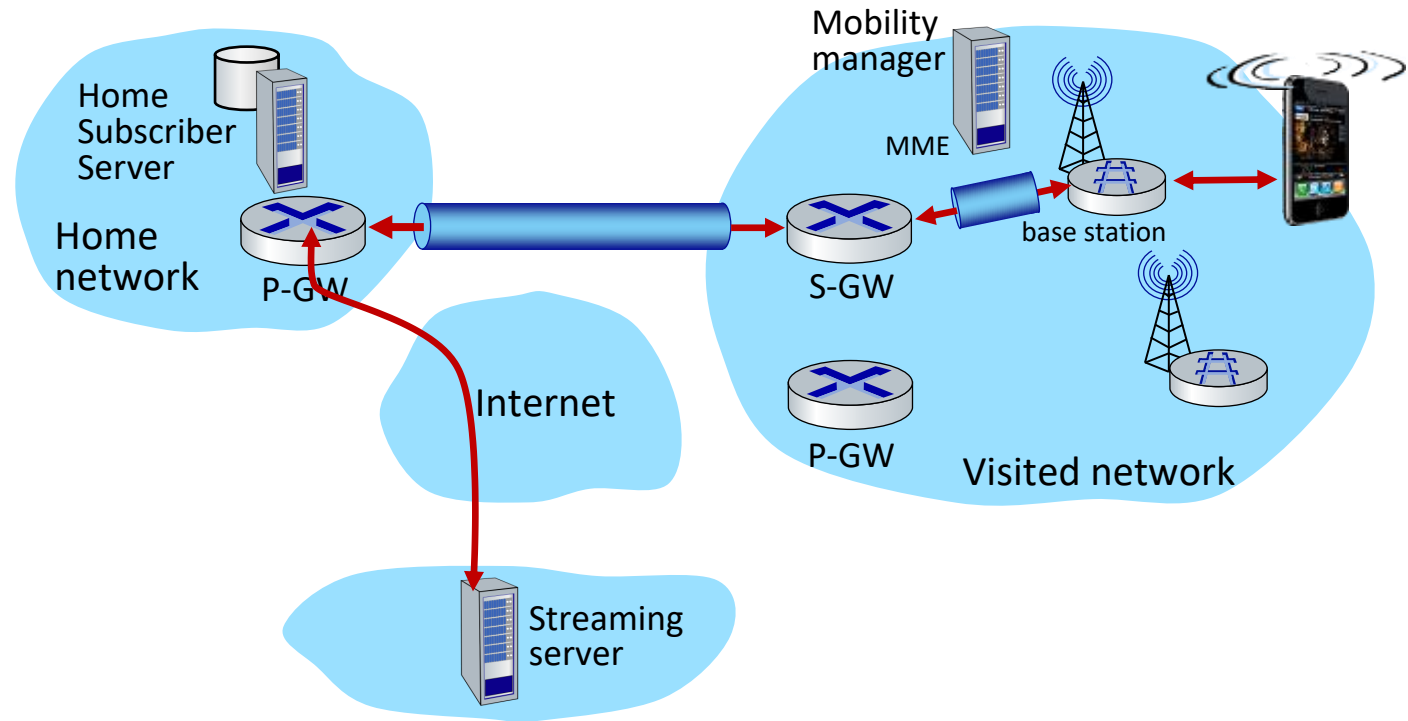
Configuring LTE control-plane elements



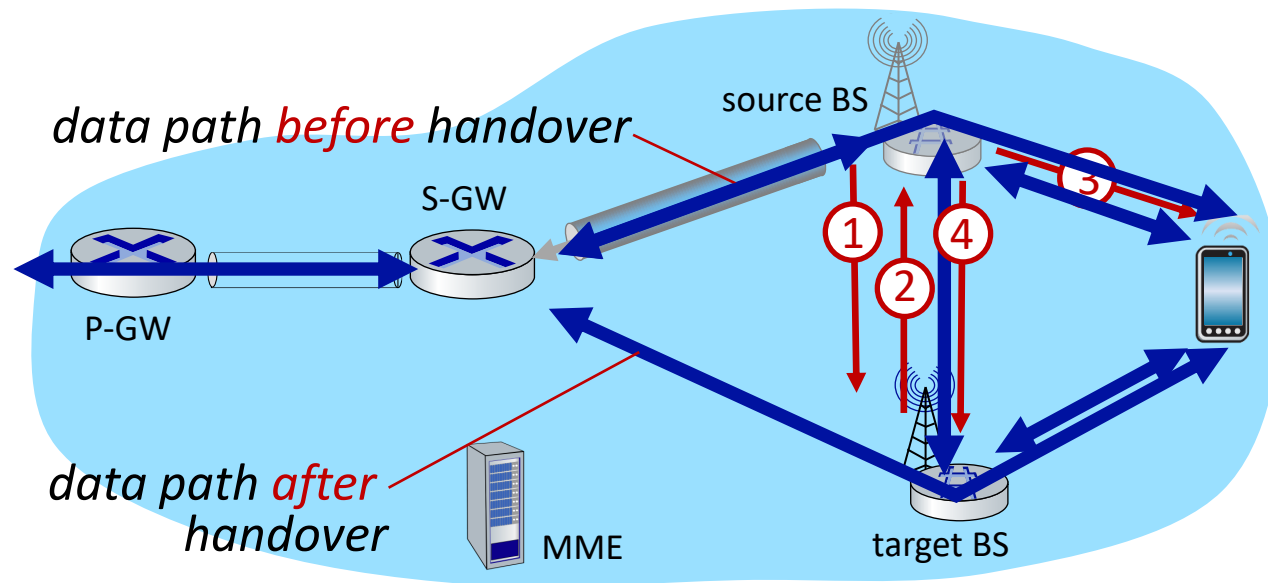
- Mobile communicates with local MME via BS control-plane channel
- MME uses mobile's IMSI info to contact mobile's home HSS
 - retrieve authentication, encryption, network service information
 - home HSS knows mobile now resident in visited network
- BS, mobile select parameters for BS-mobile data-plane radio channel

Configuring data-plane tunnels for mobile

- **S-GW to BS tunnel:** when mobile changes base stations, simply change endpoint IP address of tunnel
- **S-GW to home P-GW tunnel:** implementation of indirect routing
- **tunneling via GTP** (GPRS tunneling protocol): mobile's datagram to streaming server encapsulated using GTP inside UDP, inside datagram



Handover between BSs in same cellular network



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

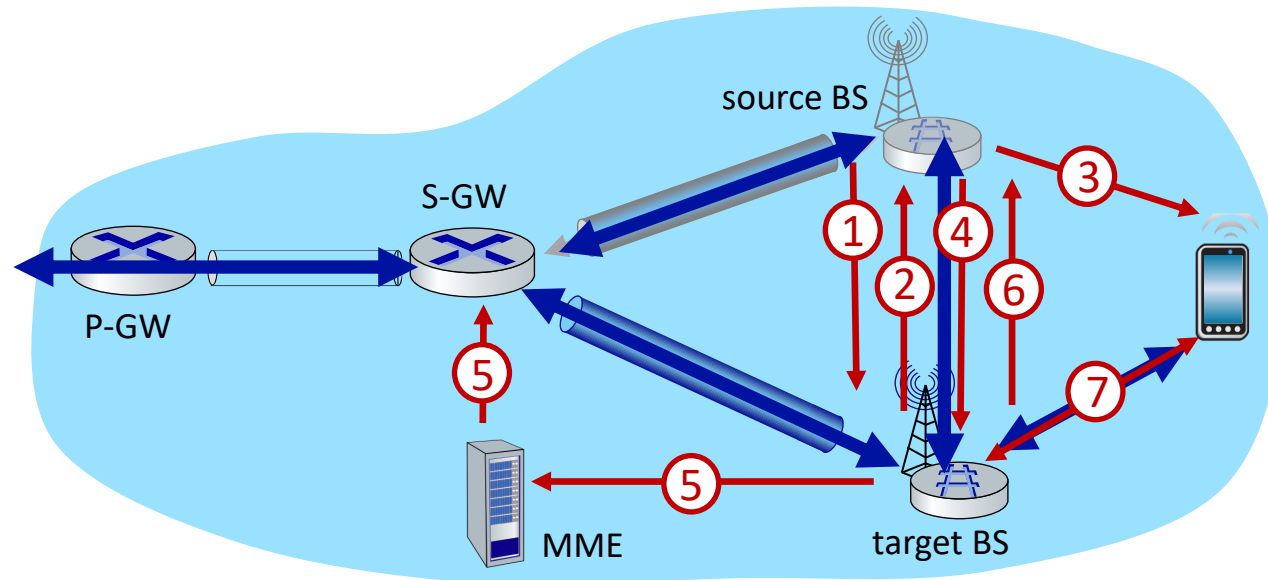
② target BS pre-allocates radio time slots, responds with HR ACK with info for mobile

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

Mobile IP

- mobile IP architecture standardized ~20 years ago [RFC 5944]
 - long before ubiquitous smartphones, 4G support for Internet protocols
 - did not see wide deployment/use
 - perhaps WiFi for Internet, and 2G/3G phones for voice were “good enough” at the time
- mobile IP architecture:
 - indirect routing to node (via home network) using tunnels
 - mobile IP home agent: combined roles of 4G HSS and home P-GW
 - mobile IP foreign agent: combined roles of 4G MME and S-GW
 - protocols for agent discovery in visited network, registration of visited location in home network via ICMP extensions

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 handover loss
 - TCP interprets loss as congestion, will decrease congestion window unnecessarily
 - delay impairments for real-time traffic
 - bandwidth a scarce resource for wireless links