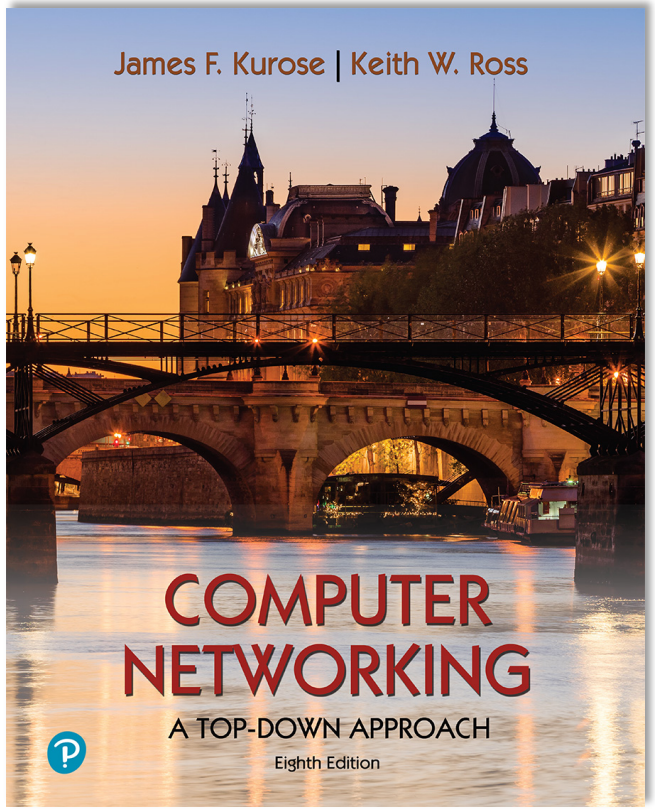
# Chapter 7
# Wireless and Mobile Networks




*Computer Networking: A Top-Down Approach*
8th edition
Jim Kurose, Keith Ross
Pearson, 2020

Acknowledgement: Based on the textbook's website:
https://gaia.cs.umass.edu/kurose_ross/index.php

# 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

# 4G/5G cellular networks

- *the* solution for wide-area mobile Internet
- widespread deployment/use:
  - more mobile-broadband-connected devices than fixed-broadband-connected devices 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)
  - wwww.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 protocols we've studied: HTTP, DNS, TCP, UDP, IP, NAT, separation of data/control planes, SDN, Ethernet, tunneling
- interconnected to wired Internet

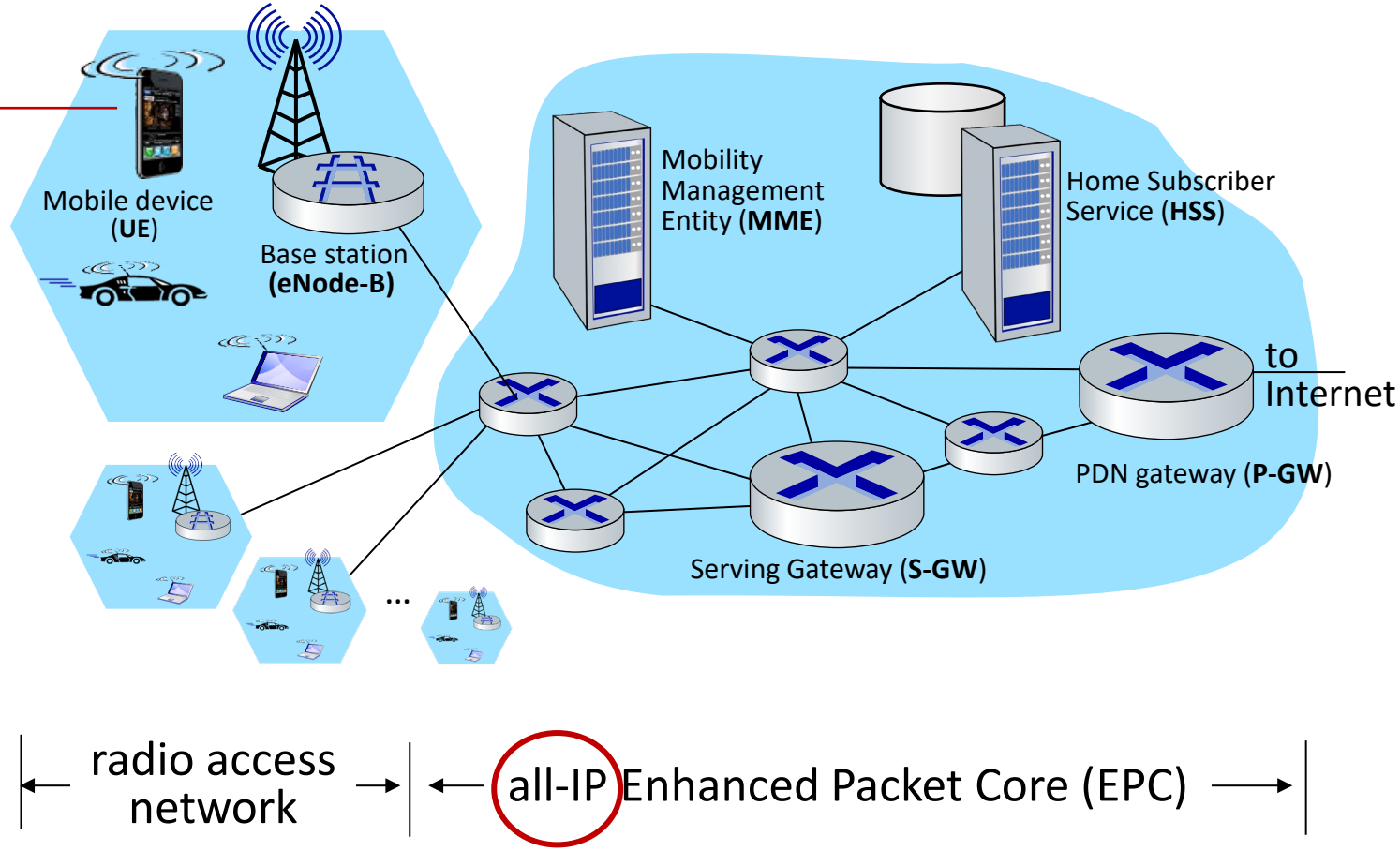
*differences* from wired Internet

- 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:

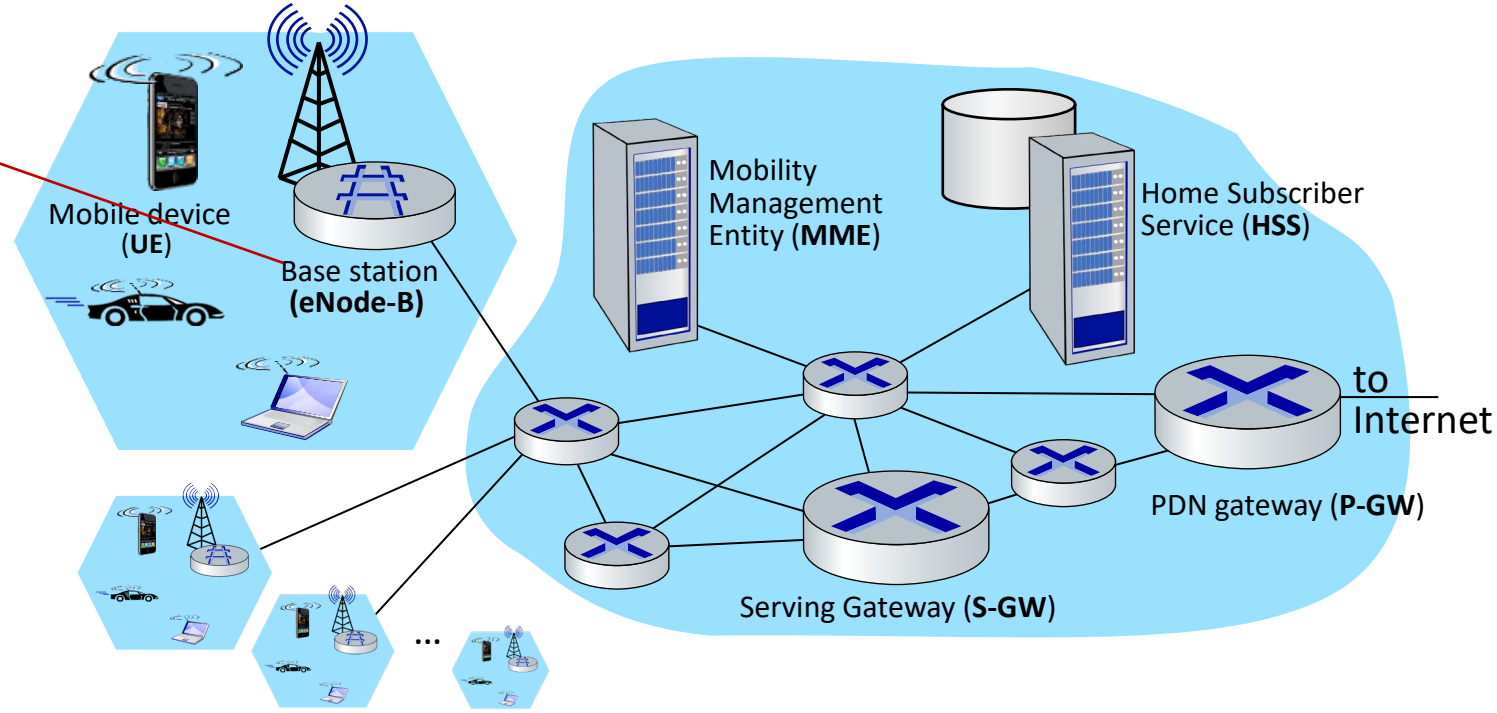
- smartphone, tablet, laptop, IoT, … with 4G LTE radio
- 64-bit International Mobile Subscriber Identity (IMSI), stored on SIM (Subscriber Identity Module) card
- LTE jargon: User Equipment (UE)



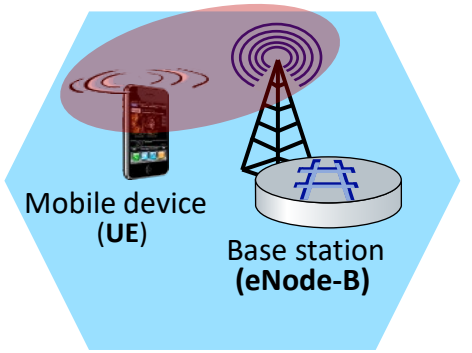
# Elements of 4G LTE architecture

## 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 nearly 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

Spectrum

# UNITED STATES FREQUENCY ALLOCATIONS

## THE RADIO SPECTRUM

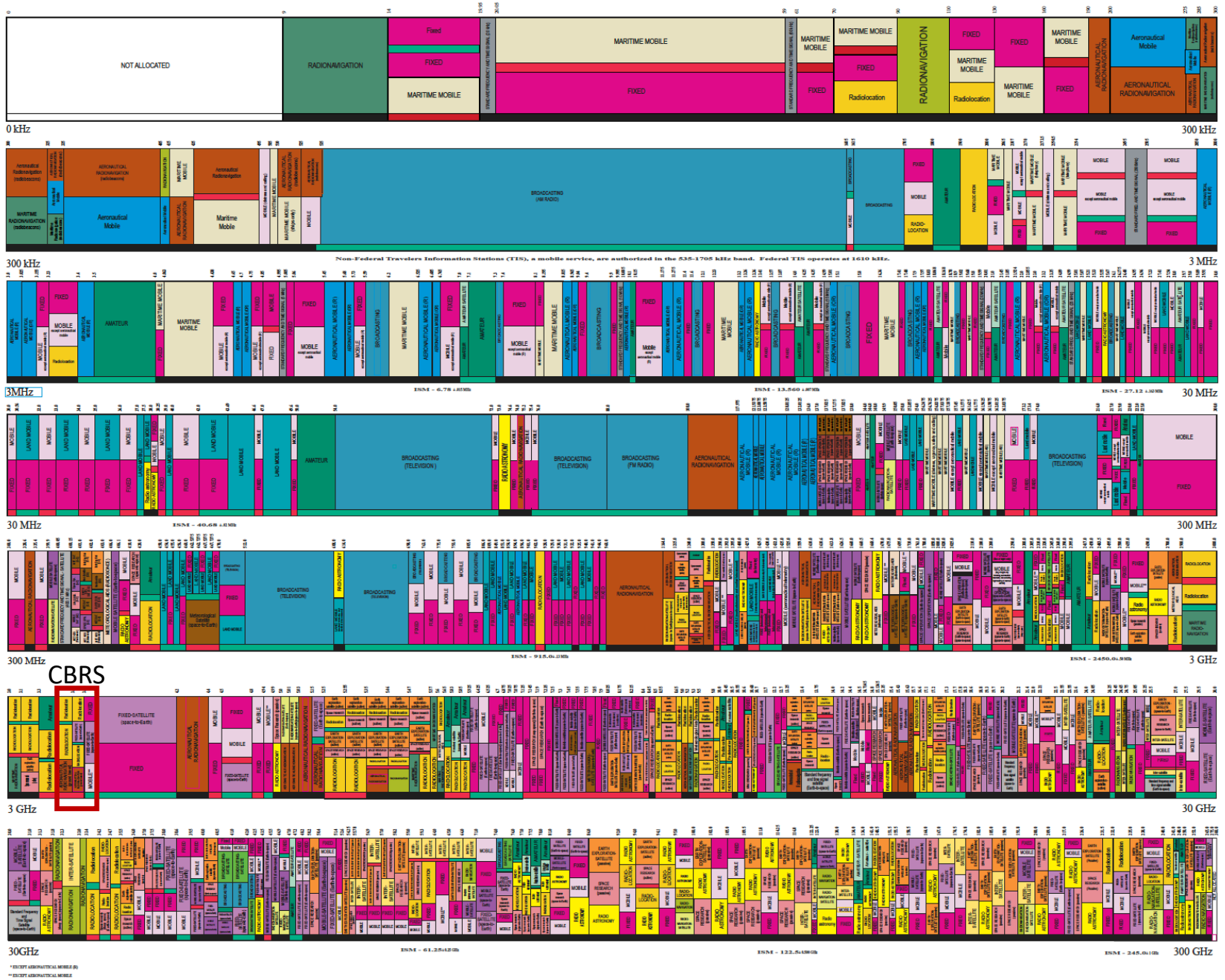

ALLOCATION USAGE DESIGNATION

| SERVICE | EXAMPLE | DESCRIPTION |
|---|---|---|
| Primary | FIXED | Capital Letters |
| Secondary | Mobile | 1st Capital with lower case letters |

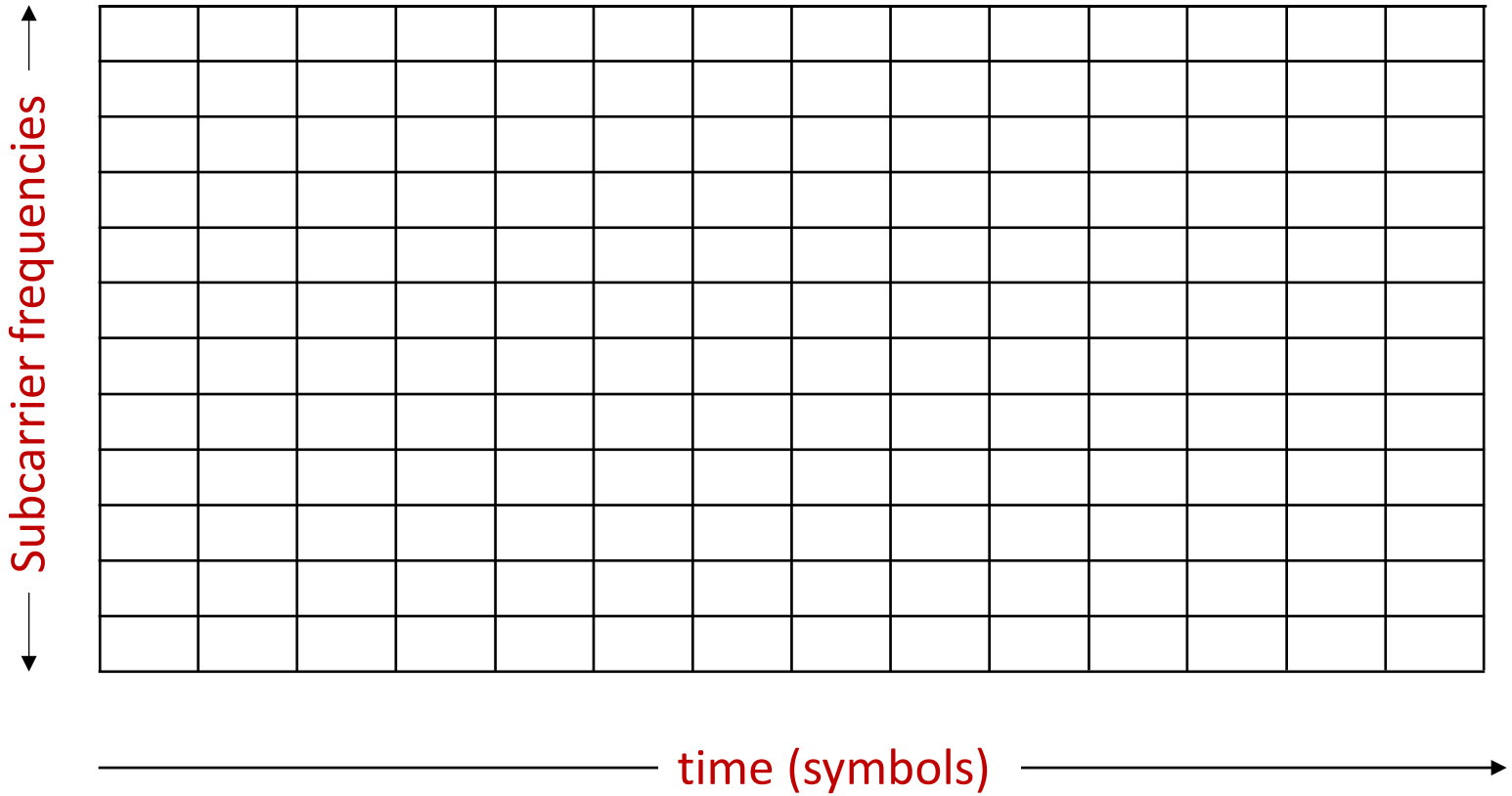
This chart is a graphic single-point-in-time portrayal of the Table of Frequency Allocations used by the FCC and NTIA. As such, it may not completely reflect all aspects, i.e. footnotes and recent changes made to the Table of Frequency Allocations. Therefore, for complete information, users should consult the Table to determine the current status of U.S. allocations.


U.S. DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Office of Spectrum Management

JANUARY 2016

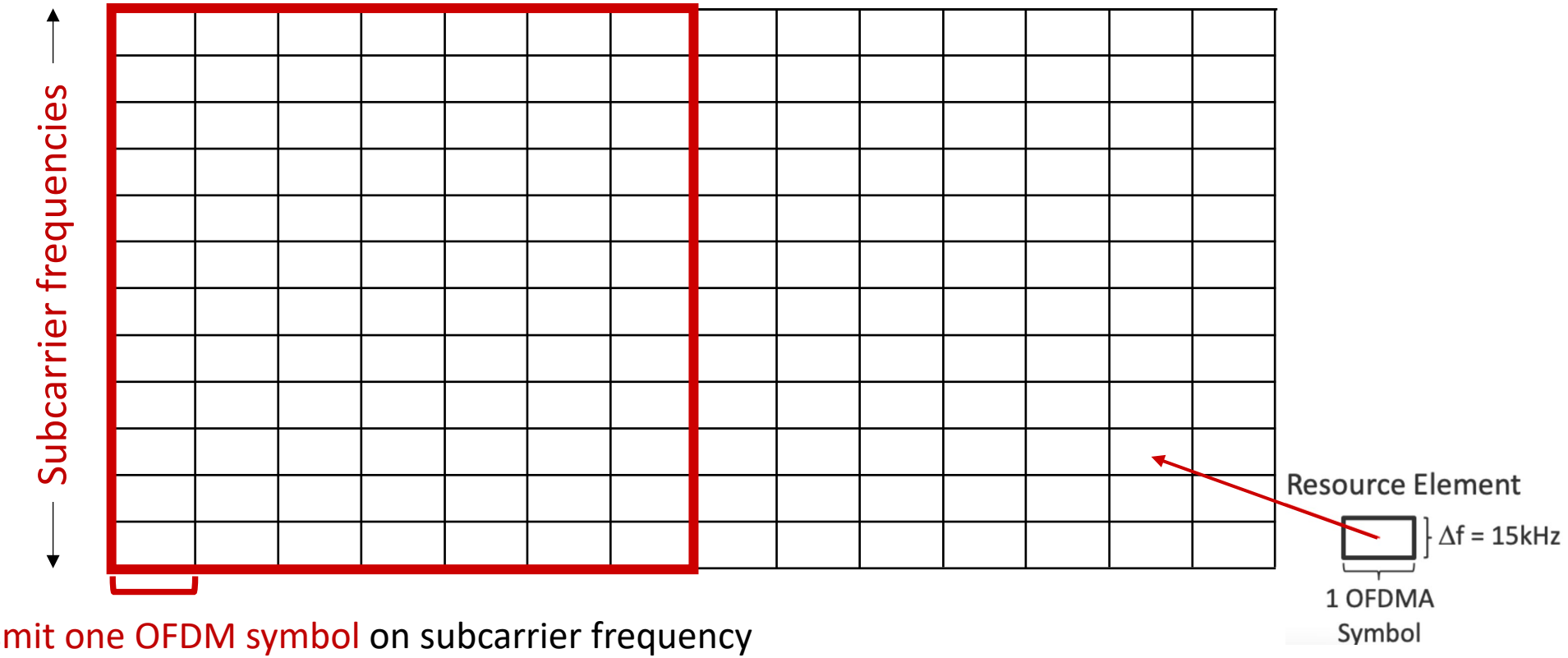
# OFDMA: time division (LTE)



# OFDMA: time division (LTE)

Physical Resource Block (PRB ): blocks of 7x12=84 resource elements

- unit of transmission scheduling



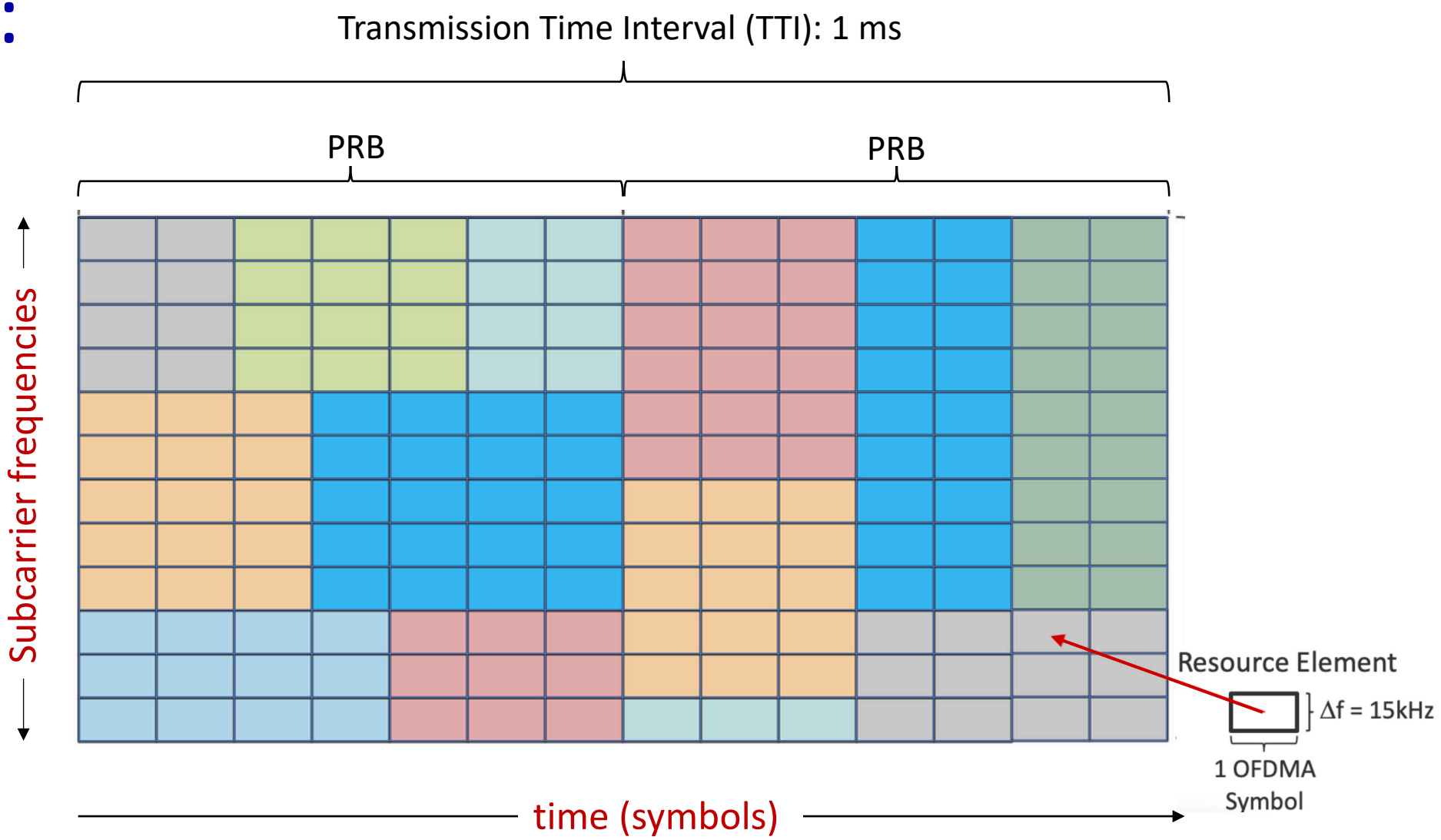

time to transmit one OFDM symbol on subcarrier frequency

# OFDMA:

## Transmission scheduling example:

- Send to 7 UEs in 7 blocks of REs in one PRB

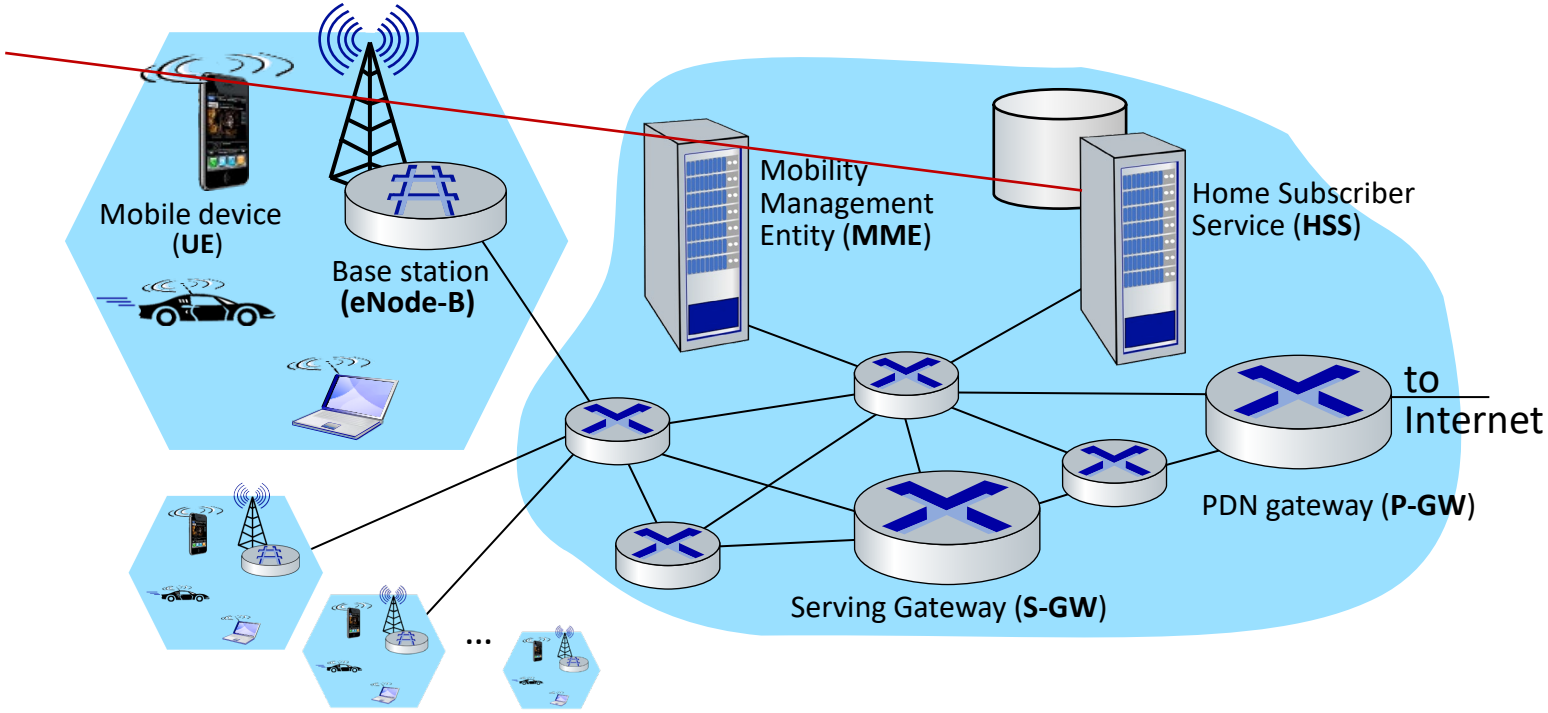
$UE_1$
$UE_2$
$UE_3$
$UE_4$
$UE_5$
$UE_6$
$UE_7$



# Elements of 4G LTE architecture

## Home Subscriber Service

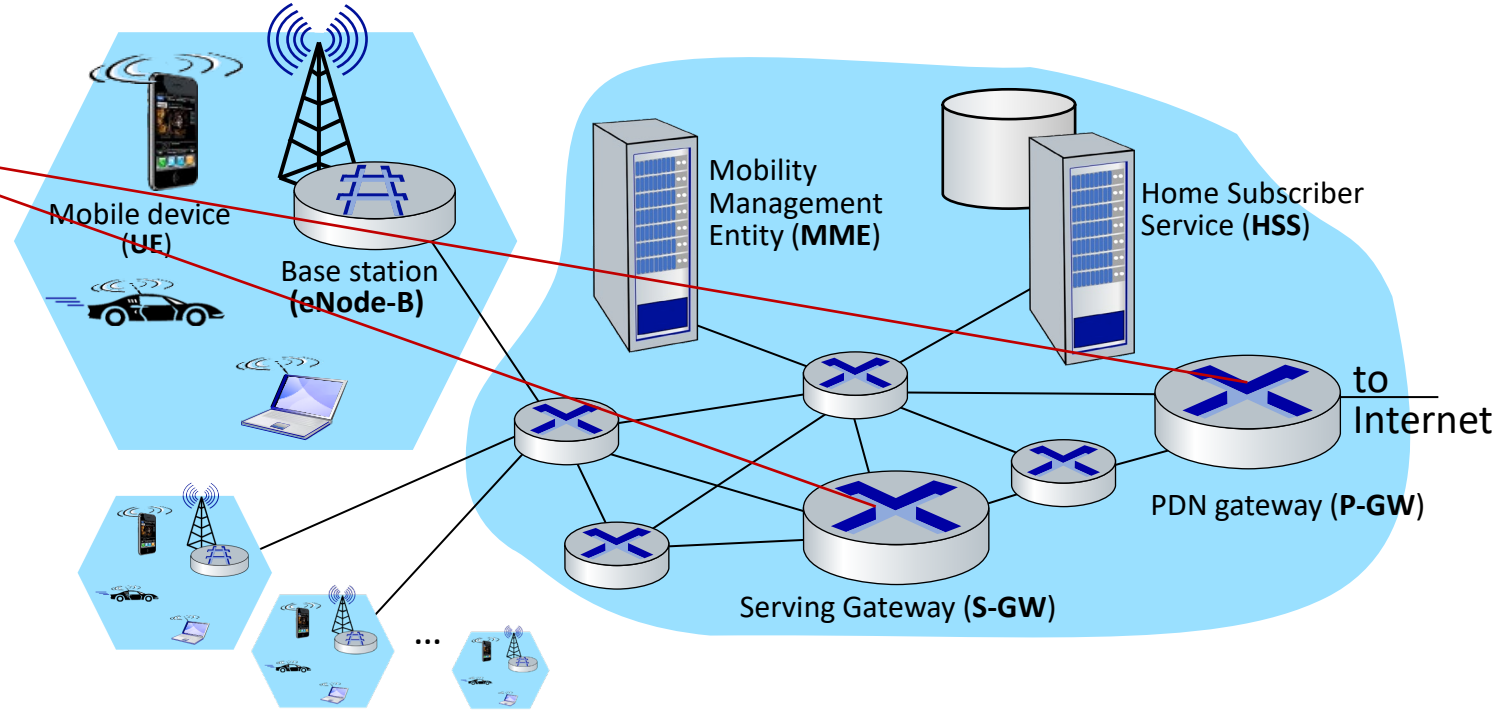
- stores info about mobile devices for which the HSS's network is their "home network"
- works with MME in device authentication



# Elements of 4G LTE architecture

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

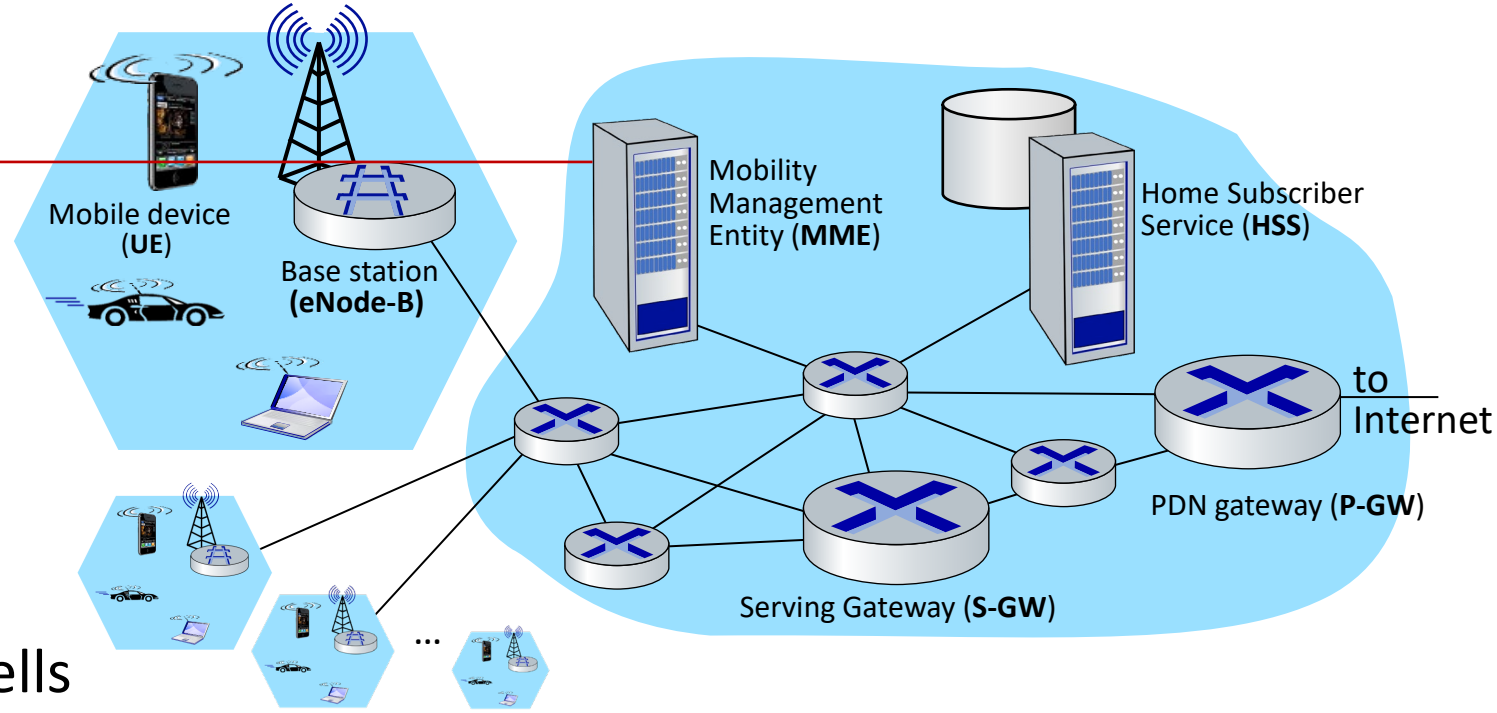
- lie on data path from mobile to/from Internet
- P-GW
  - gateway to mobile cellular network
  - Looks like nay other internet gateway router
  - provides NAT services
- other routers:
  - extensive use of tunneling



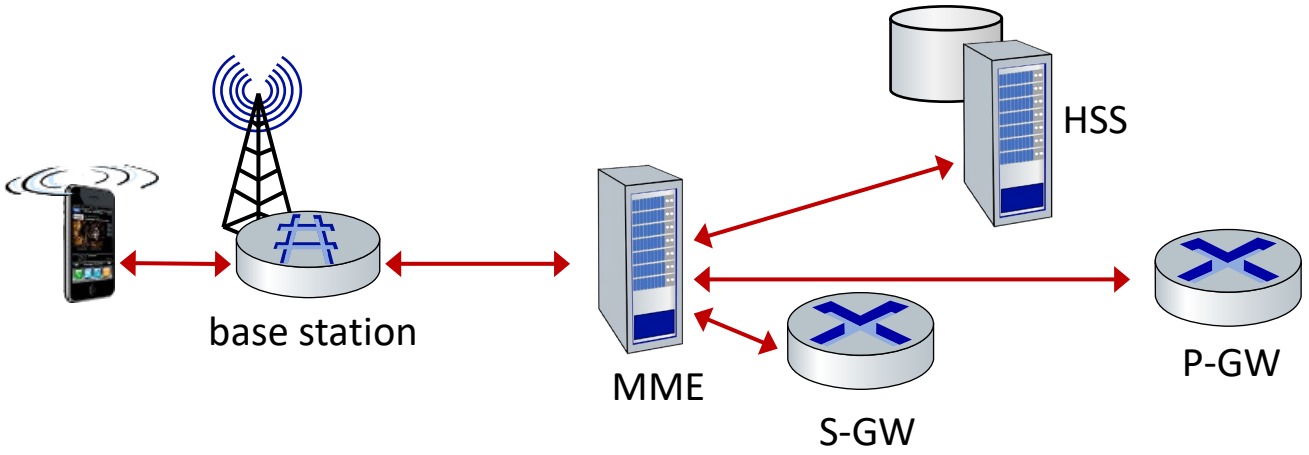
# Elements of 4G LTE architecture

## 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

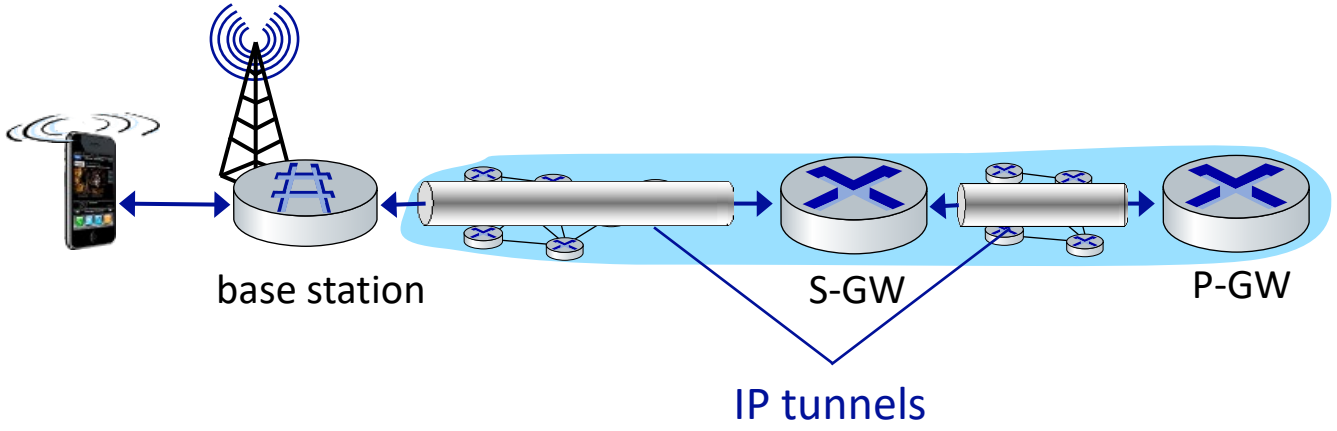


# LTE: data plane control plane separation




control plane

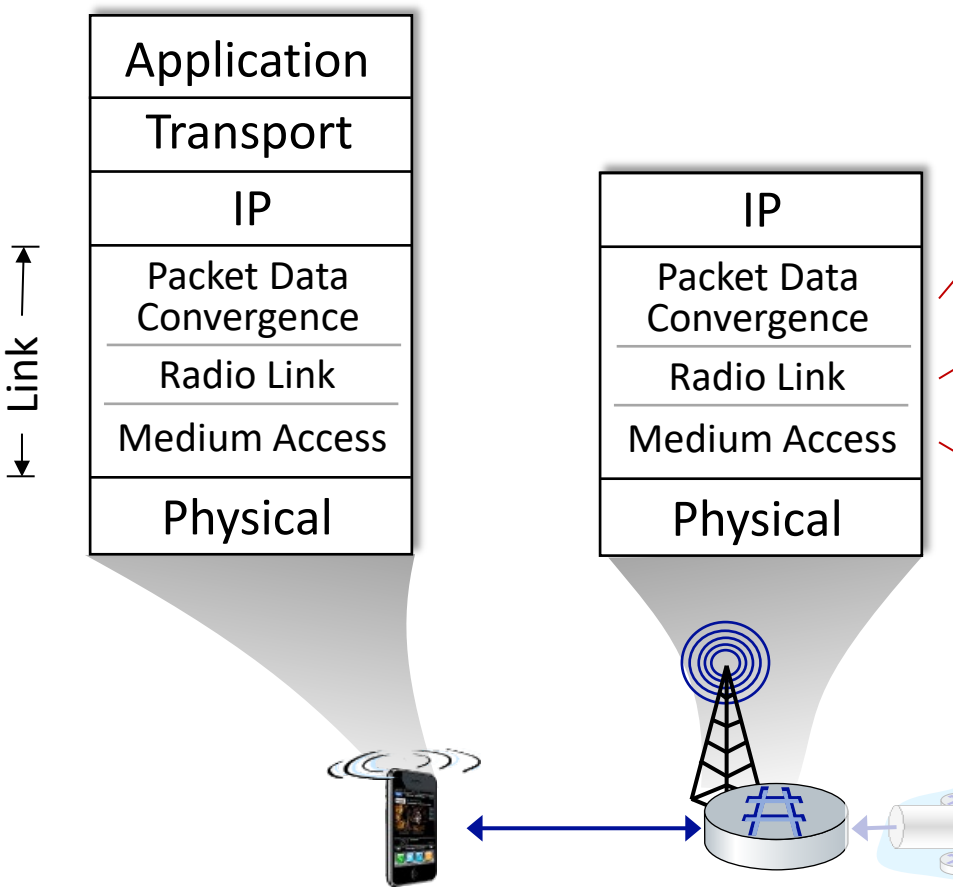
- new protocols for mobility management , security, authentication (later)




data plane

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

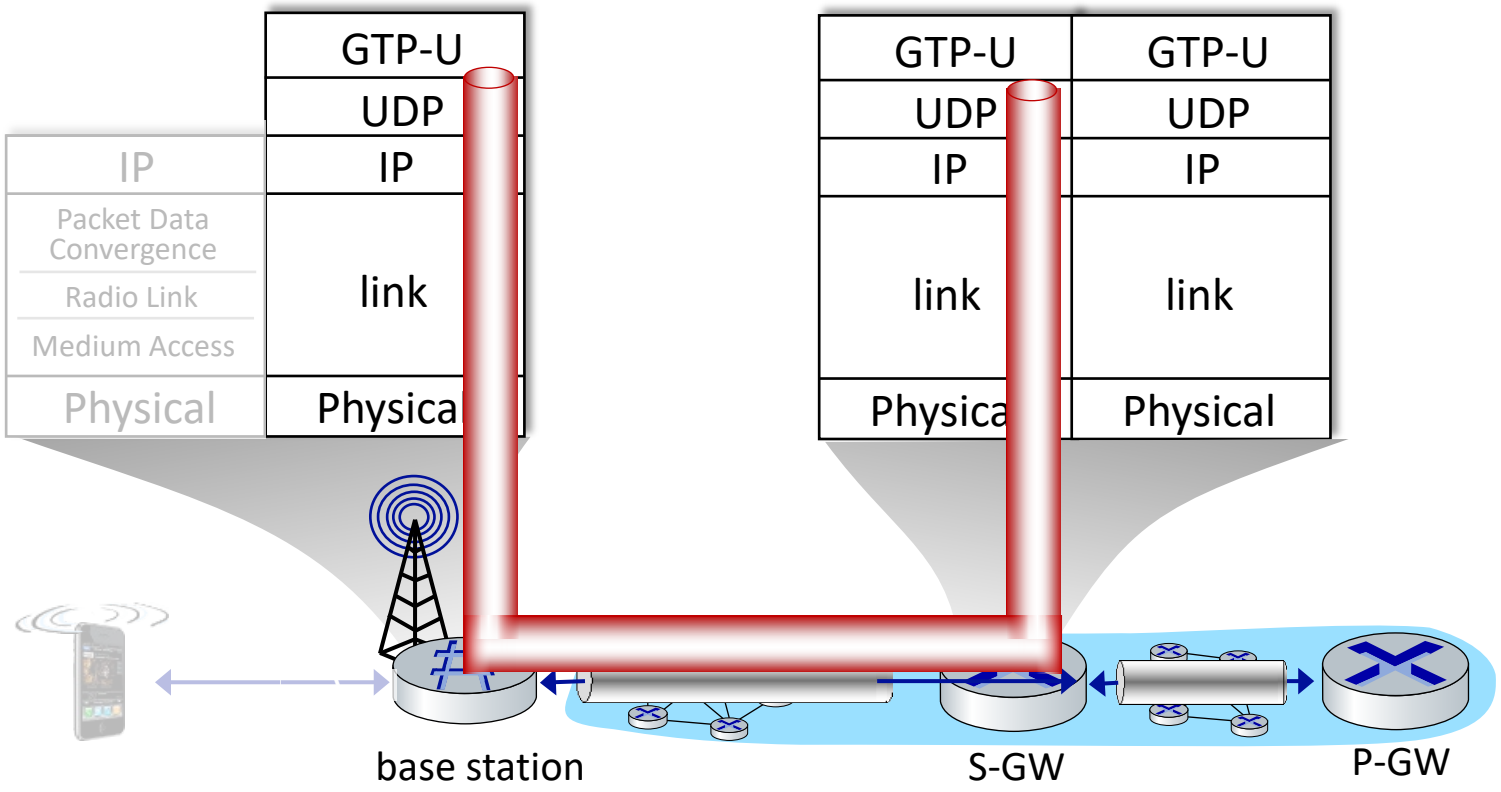
# LTE data plane protocol stack: first hop




## LTE link layer protocols:

- Packet Data Convergence: header compression, encryption
- Radio Link Control (RLC) Protocol: fragmentation/reassembly, reliable data transfer
- Medium Access: requesting, use of radio transmission slots (OFDM)

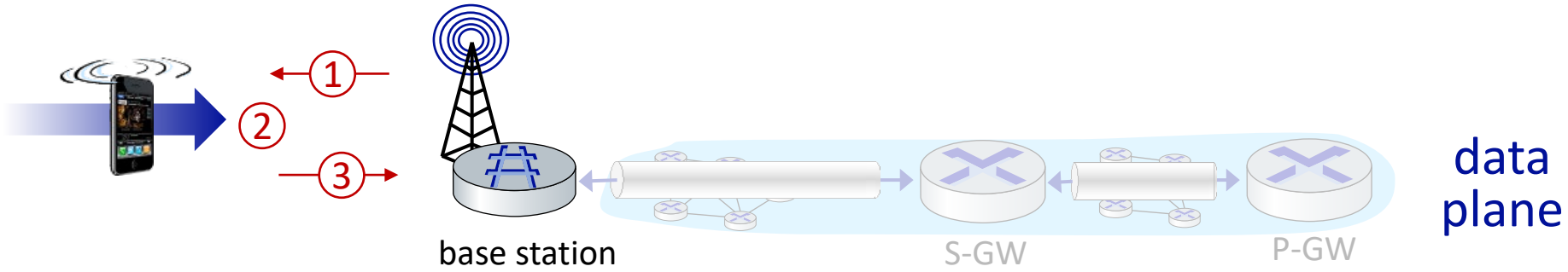
# LTE data plane protocol stack: packet core




tunneling:

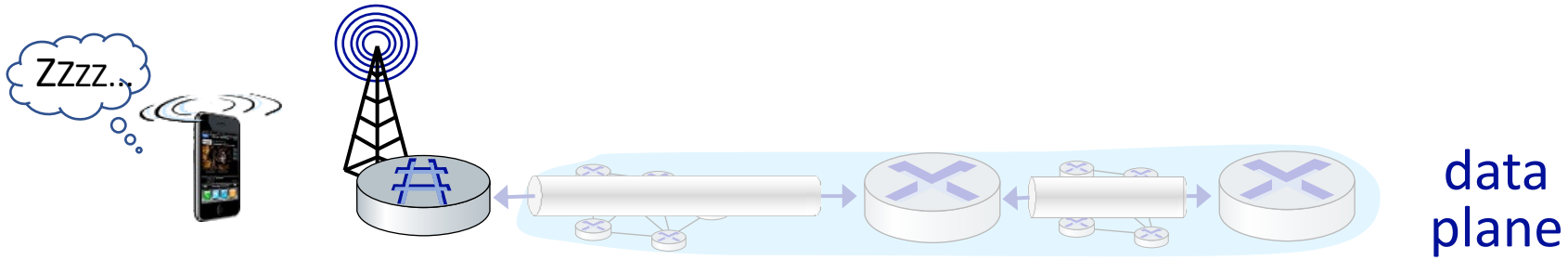
- mobile datagram encapsulated using GPRS Tunneling Protocol (GTP), sent inside UDP datagram to S-GW
- S-GW re-tunnels datagrams to P-GW
- supporting mobility: only tunneling endpoints change when mobile user moves

# 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

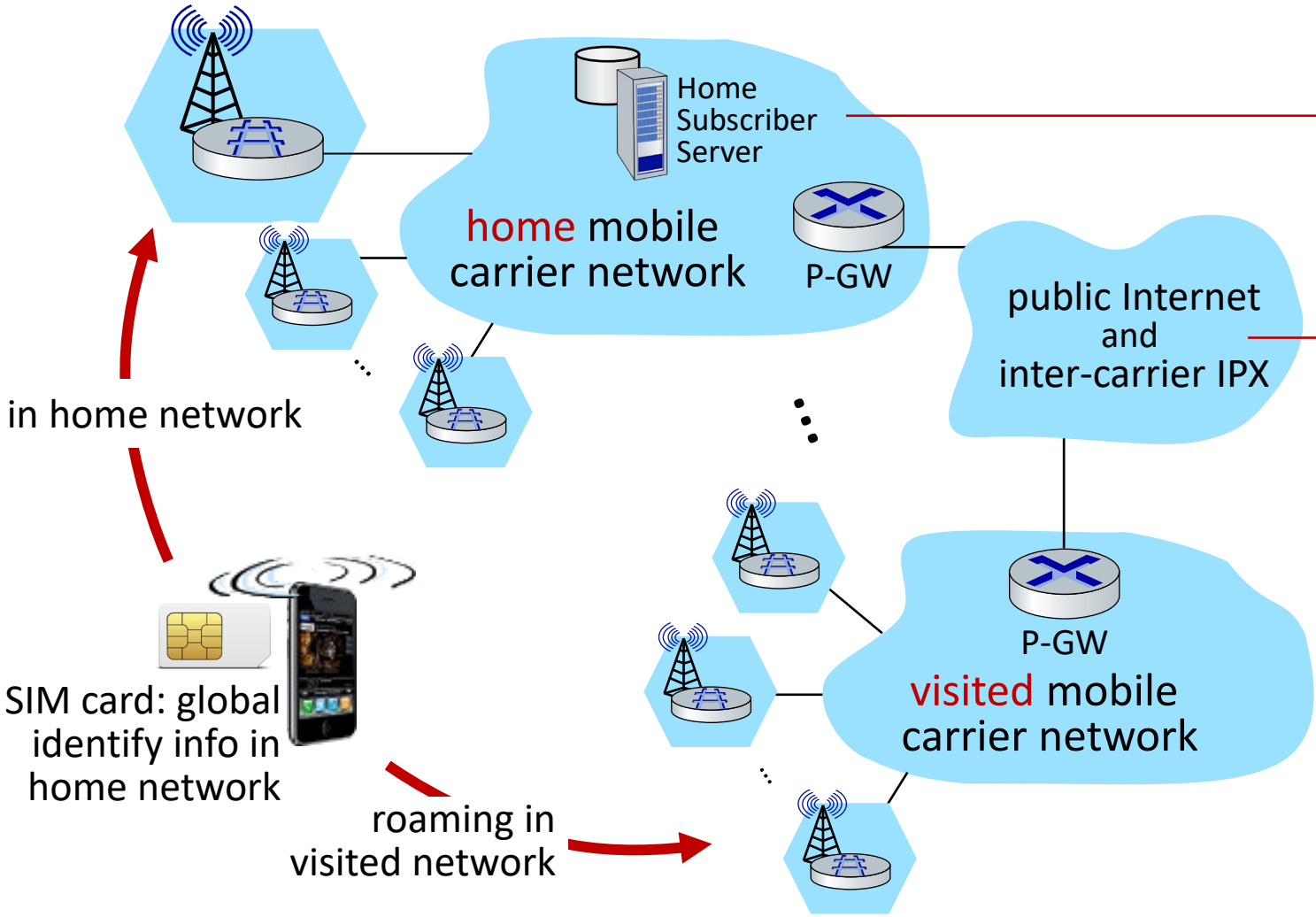
# LTE mobiles: sleep modes




as in WiFi, Bluetooth: 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



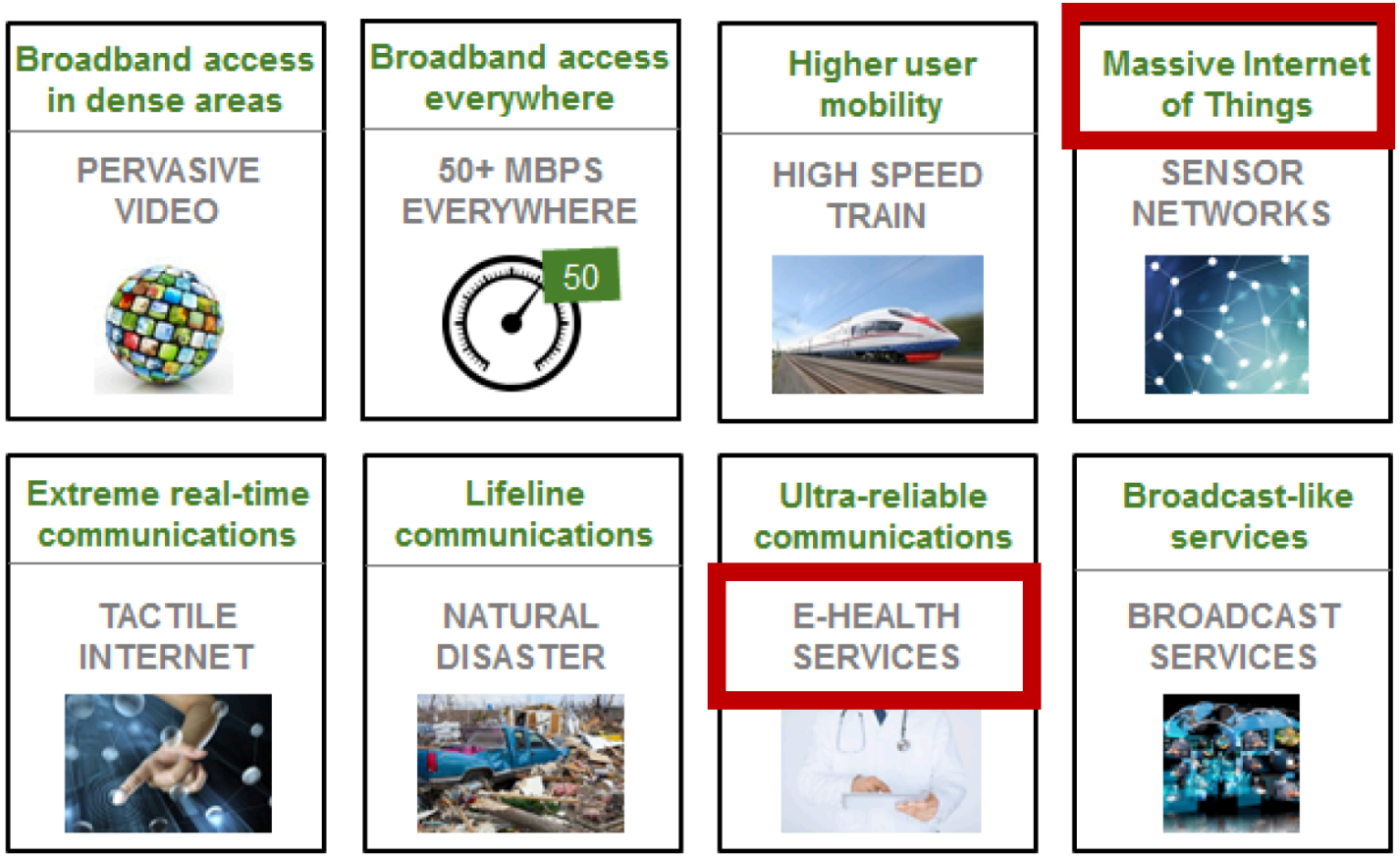

## home network HSS:

- 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

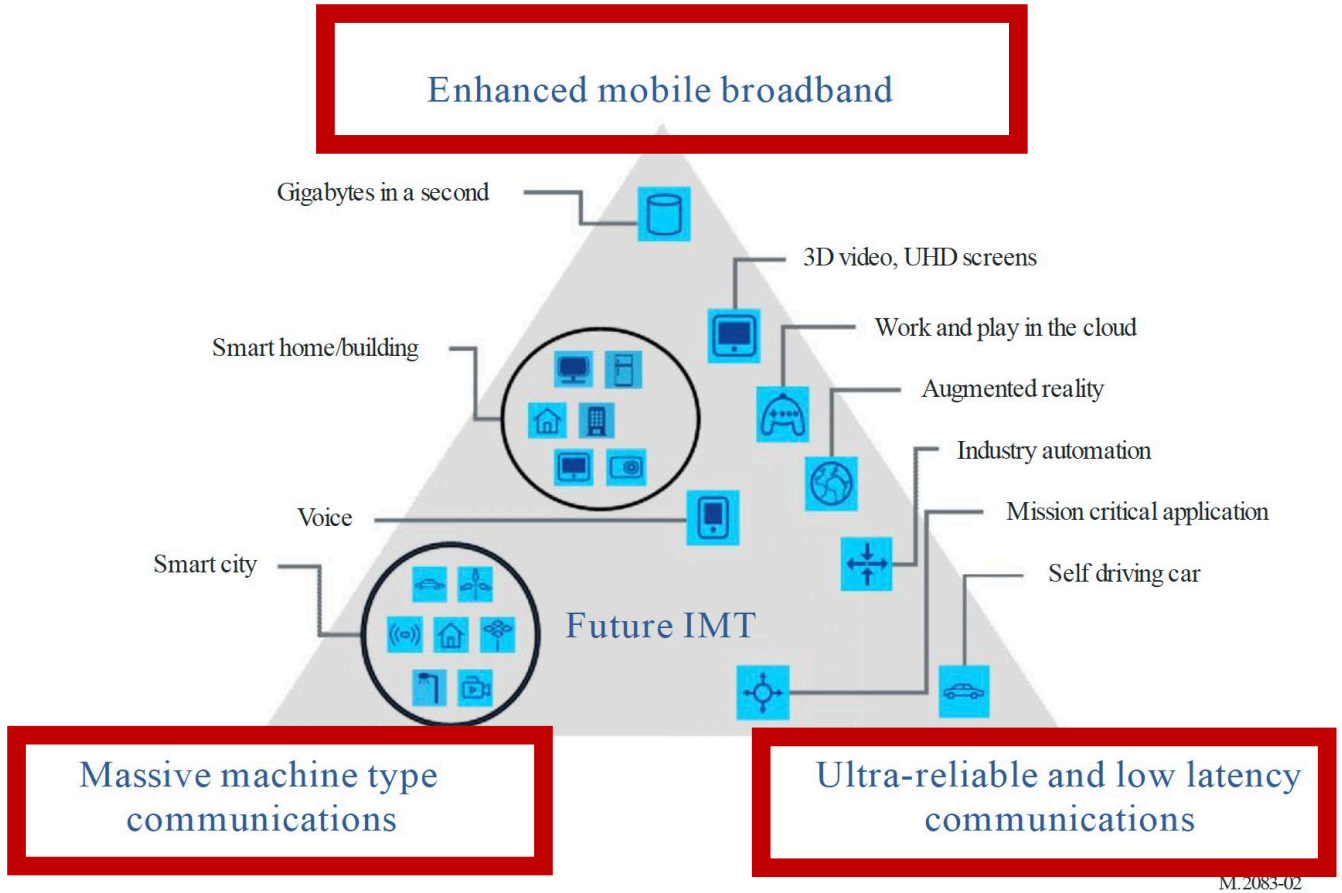
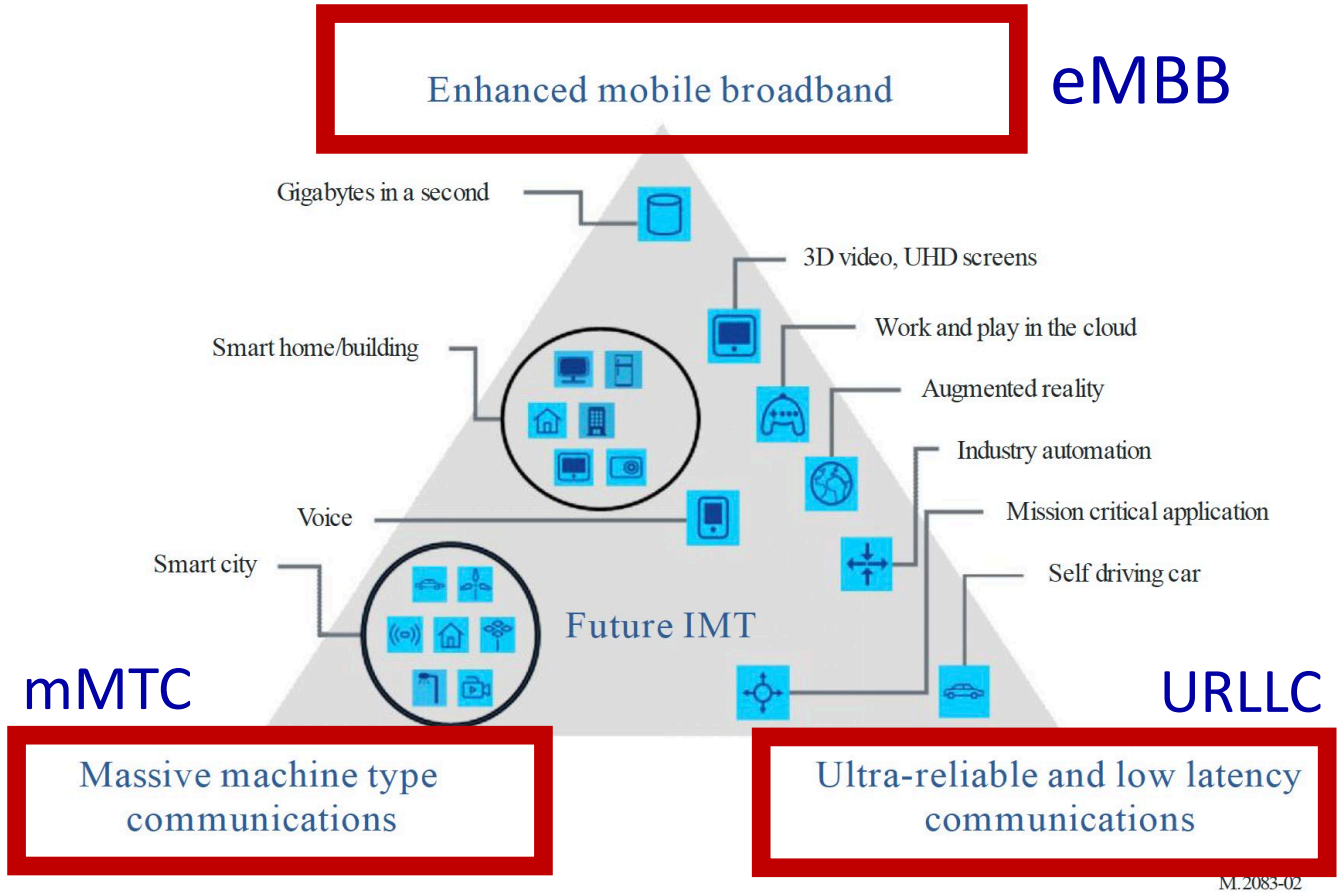



Figure: from Recommendation ITU-R M.2083-0 (2015)

"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:

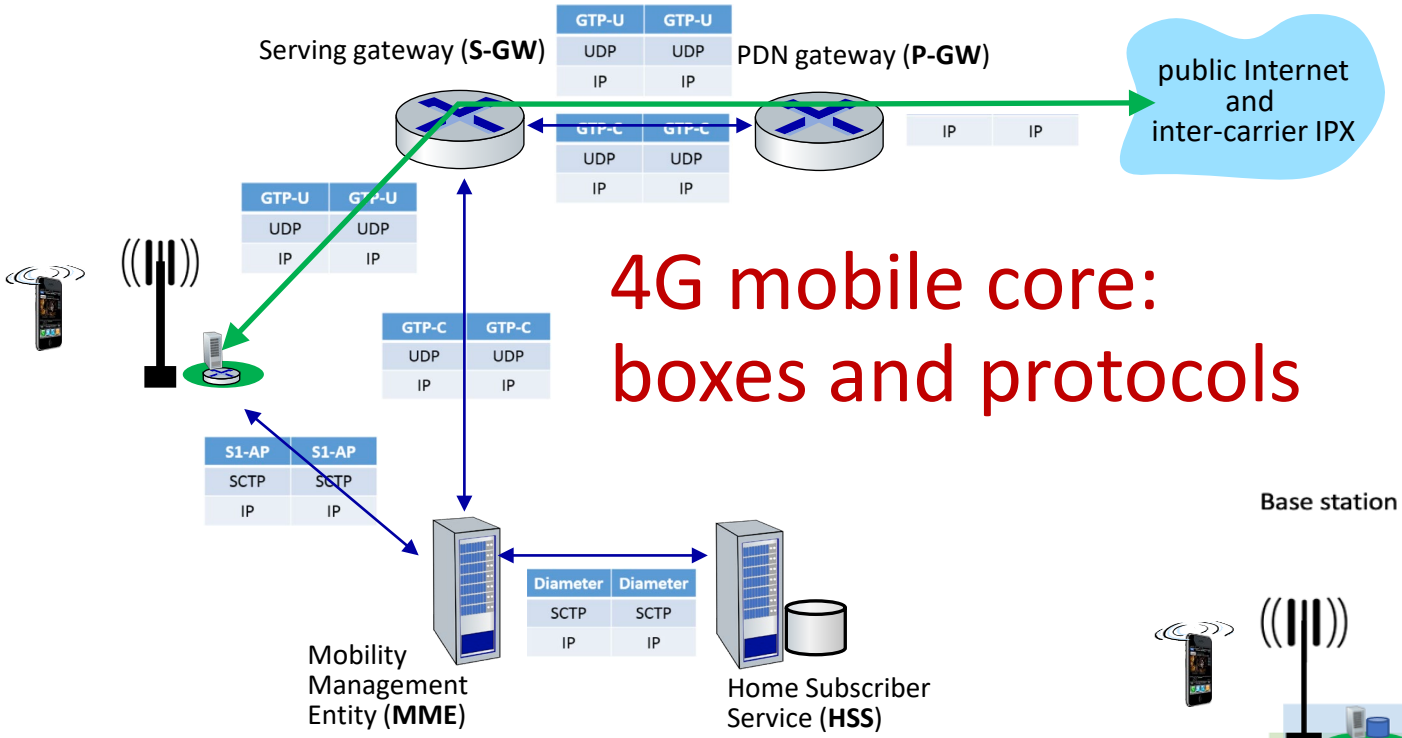
- Manufacturing
- Constructions
- Transport
- Health
- Smart communities
- Education
- Tourism
- Agriculture
- Finance

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

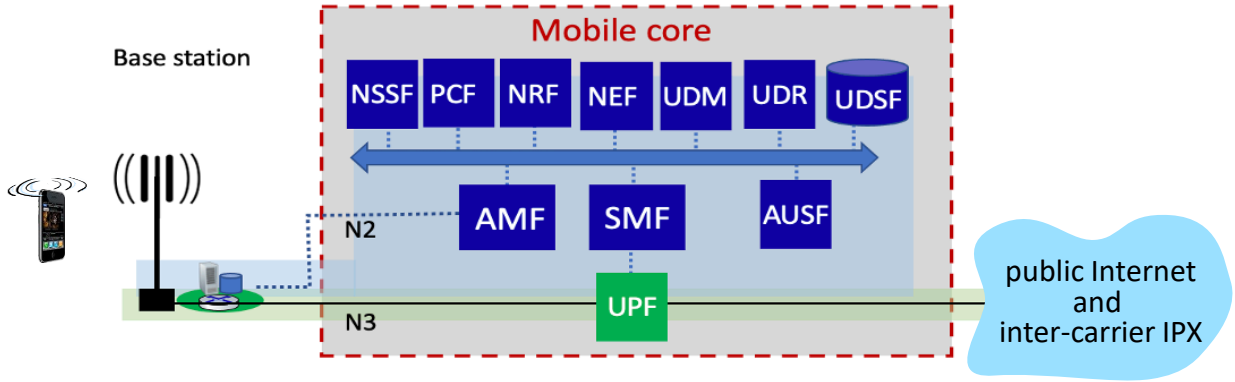
# On to 5G: Radio

- 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

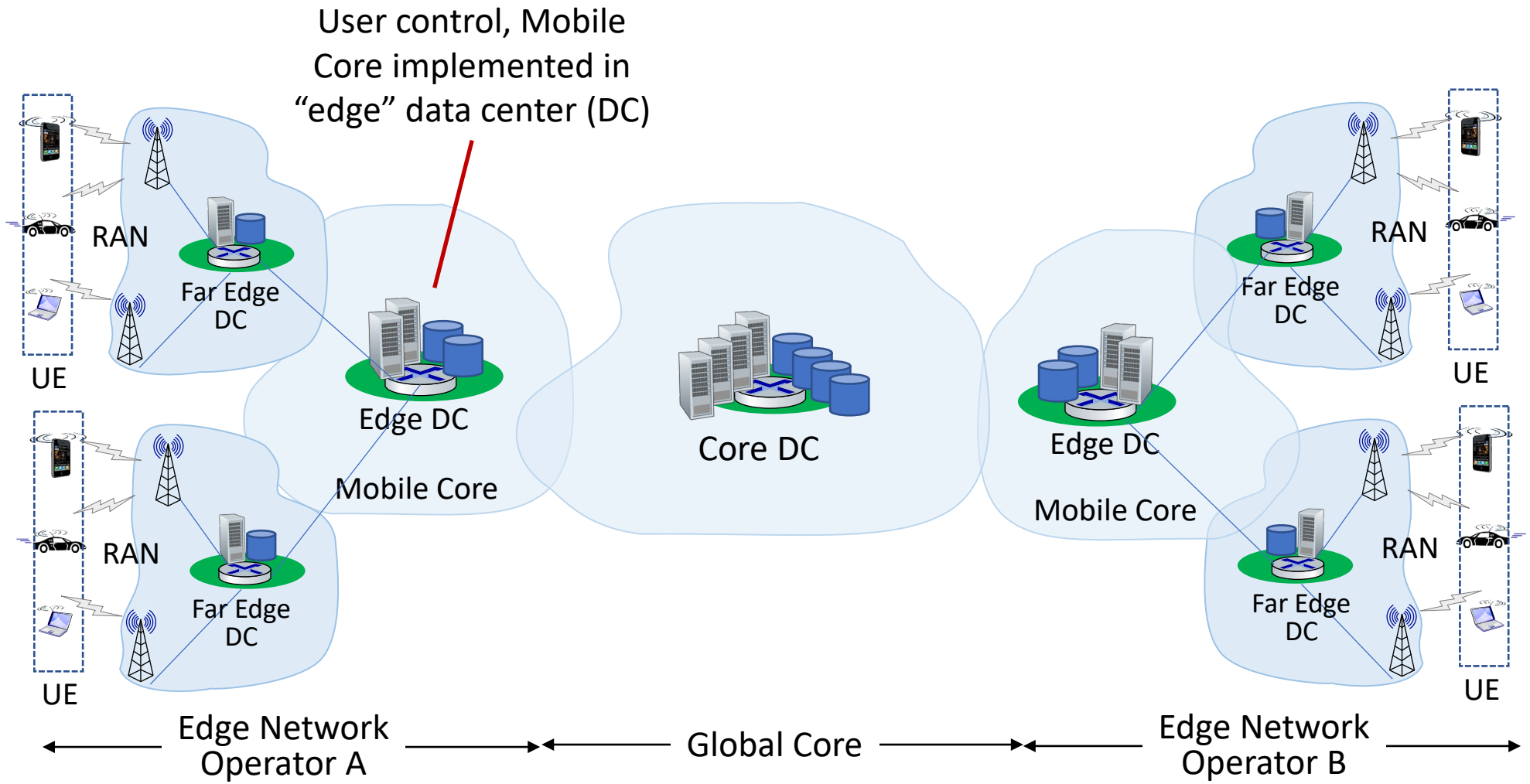



4G mobile core: boxes and protocols

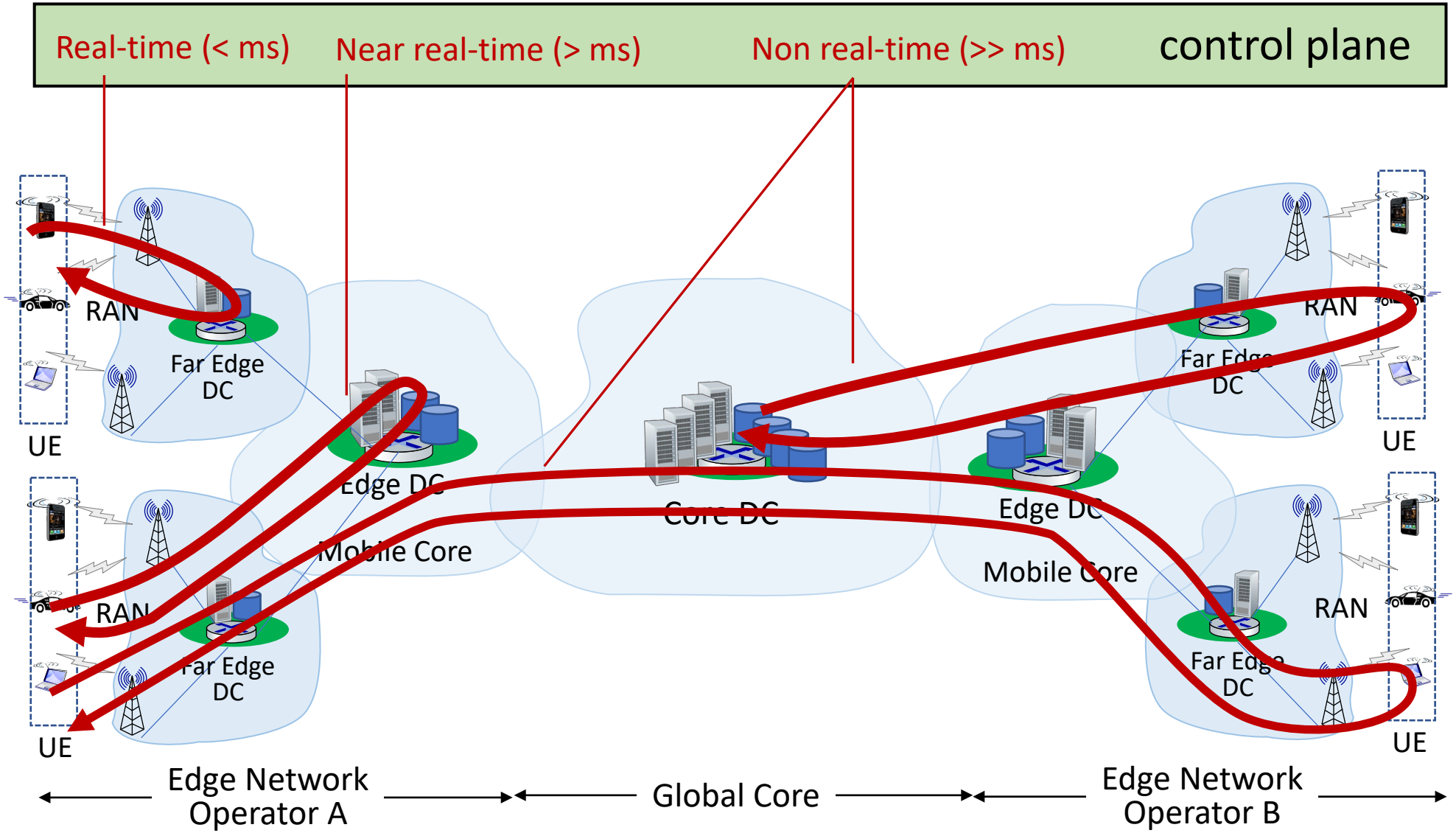



5G: microservice-like architecture

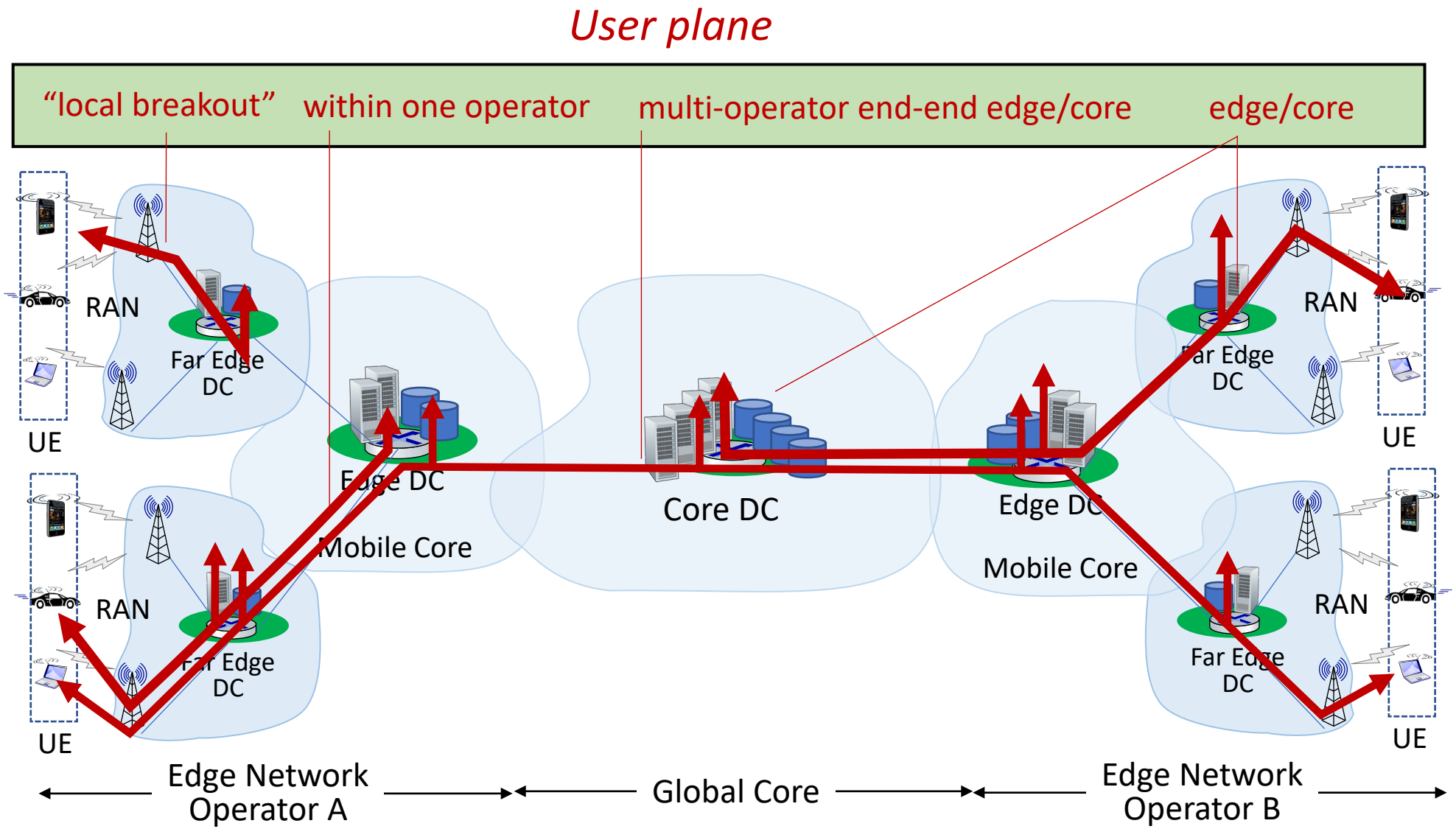
# Functional elements: communication, computation, data



# Control plane: resource control



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



# On beyond 5G?

- "6G" not obviously next: "NextG" and "Beyond 5G" heard more often than "6G"
- 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)