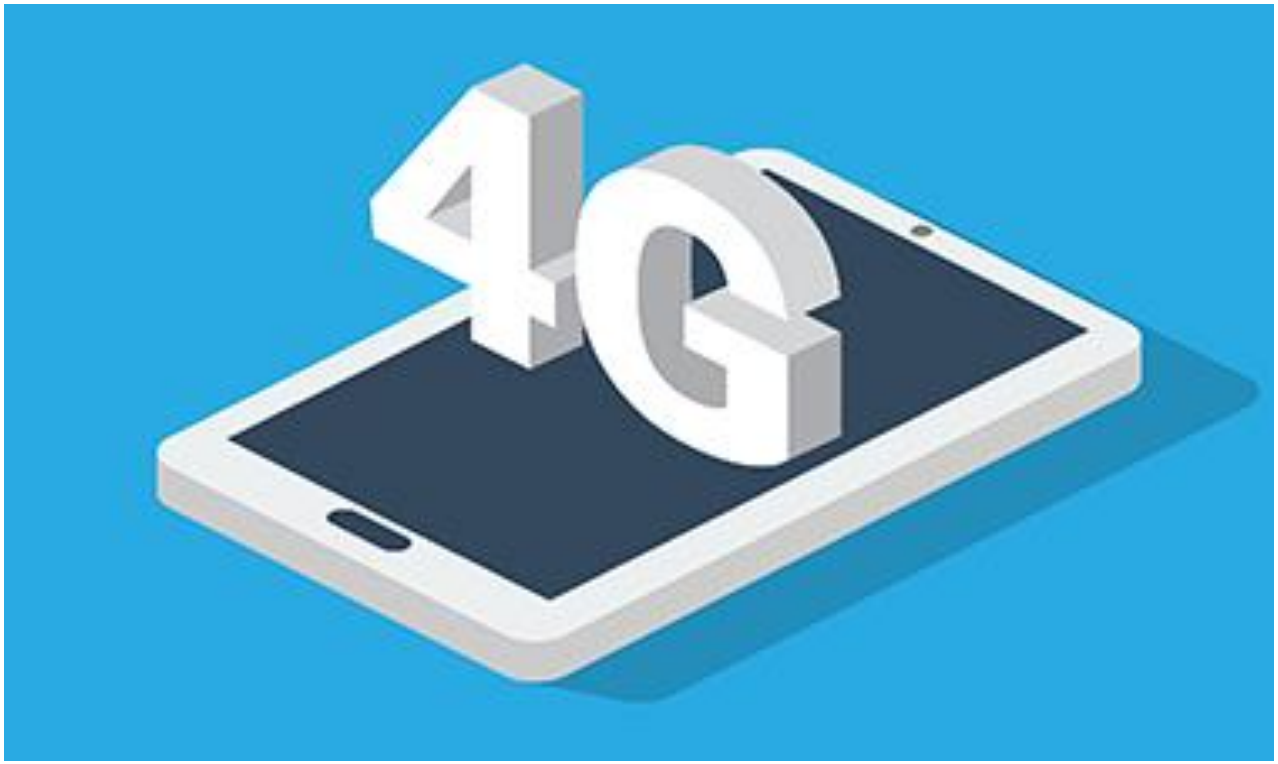


Long Term Evolution (LTE)
Long Term Evolution – Advanced (LTE-A)

IMT-Advanced

Item	IMT-Advanced
Peak Data Rate (DL)	1 Gbps
Peak Data Rate (UL)	500 Mbps
Spectrum Allocation	>40 MHz
Latency (User Plane)	10 ms
Latency (Control Plane)	100 ms
Peak Spectral Efficiency (DL)	15 bps/Hz (4 X 4)
Peak Spectral Efficiency (UL)	6.75 bps/Hz (2 X 4)
Average Spectral Efficiency (DL)	2.2 bps/Hz (4 X 2)
Average Spectral Efficiency (UL)	1.4 bps/Hz (2 X 4)
Cell-Edge Spectral Efficiency (DL)	0.06 bps/Hz (4 X 2)
Cell-Edge Spectral Efficiency (UL)	0.03 bps/Hz (2 X 4)
Mobility	Up to 350 km/h

Motivation for LTE

- Need for higher data rates and greater spectral efficiency
  - Can be achieved with HSDPA/HSUPA
  - and/or new air interface defined by 3GPP LTE
- Need for Packet Switched optimized system
  - Evolve UMTS towards packet only system
- Need for high quality of services
  - Use of licensed frequencies to guarantee quality of services
  - Always-on experience (reduce control plane latency significantly)
  - Reduce round trip delay
- Need for cheaper infrastructure
  - Simplify architecture, reduce number of network elements

Advantages of LTE

- High network throughput
- Low latency
- Plug & Play architecture
- Low Operating Costs
- All-IP network
- Simplified upgrade path from 3G networks

for Network Operators

- Faster data downloads/uploads
- Improved response for applications
- Improved end-user experience

for End Users

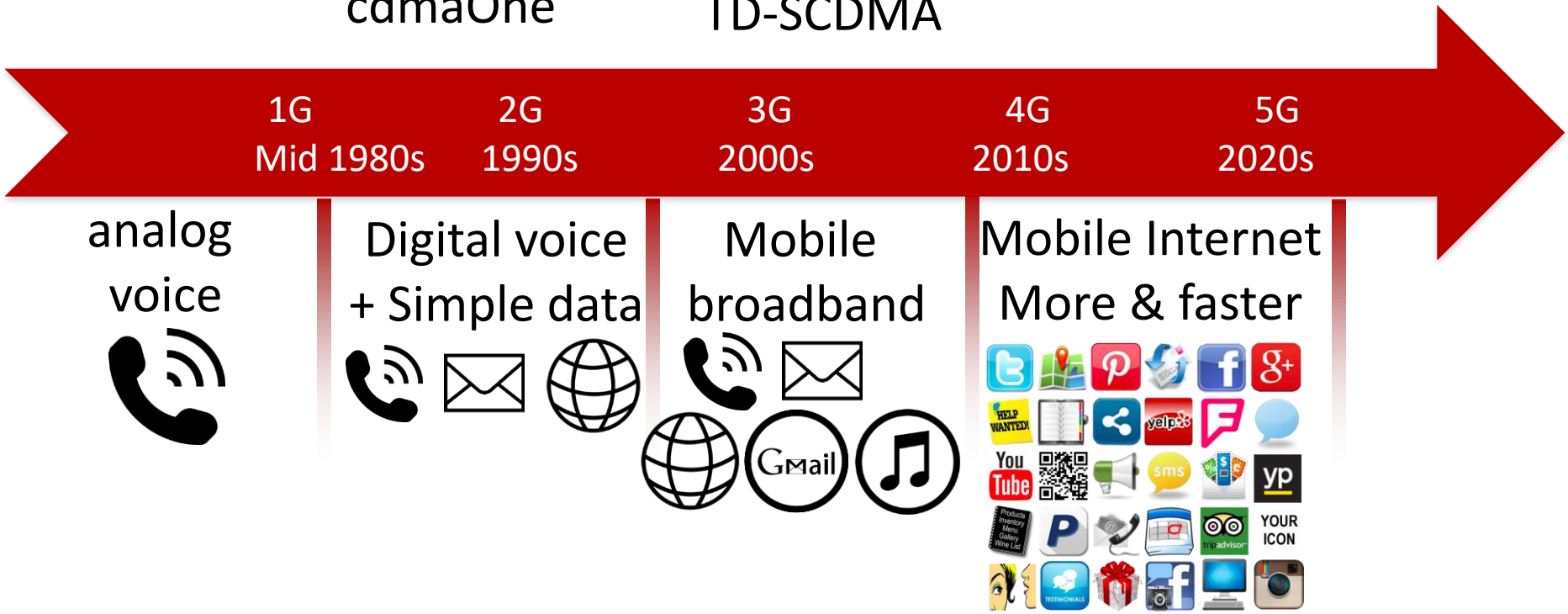
Mobile Network Evolution

1G
AMPS, NMT
TACS

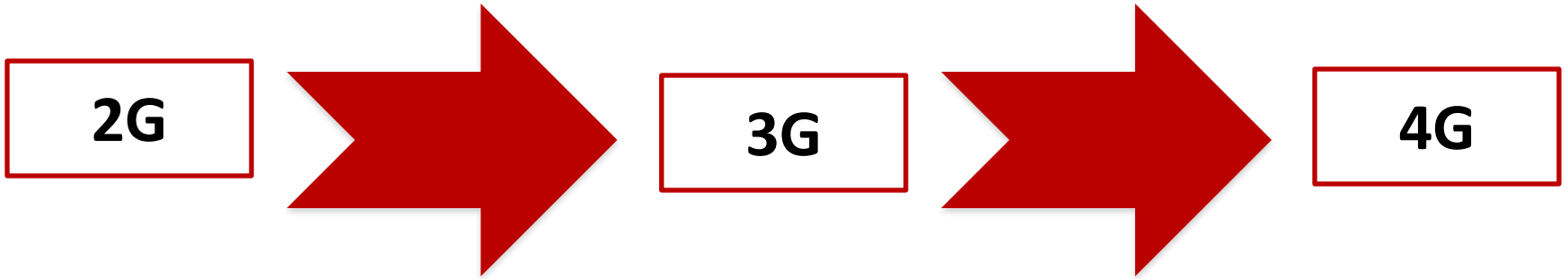
2G
GSM/GPRS/
EDGE
cdmaOne

3G
WCDMA/HSPA+
CDMA2000/EVDO
TD-SCDMA

4G
LTE
LTE-A



Network Architecture Evolution

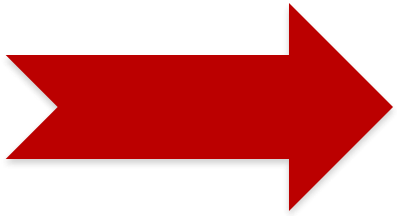


- Circuit-switching for voice

- Circuit-switching for voice
- Packet-switching for data

- Packet-switching for everything
- IP-based

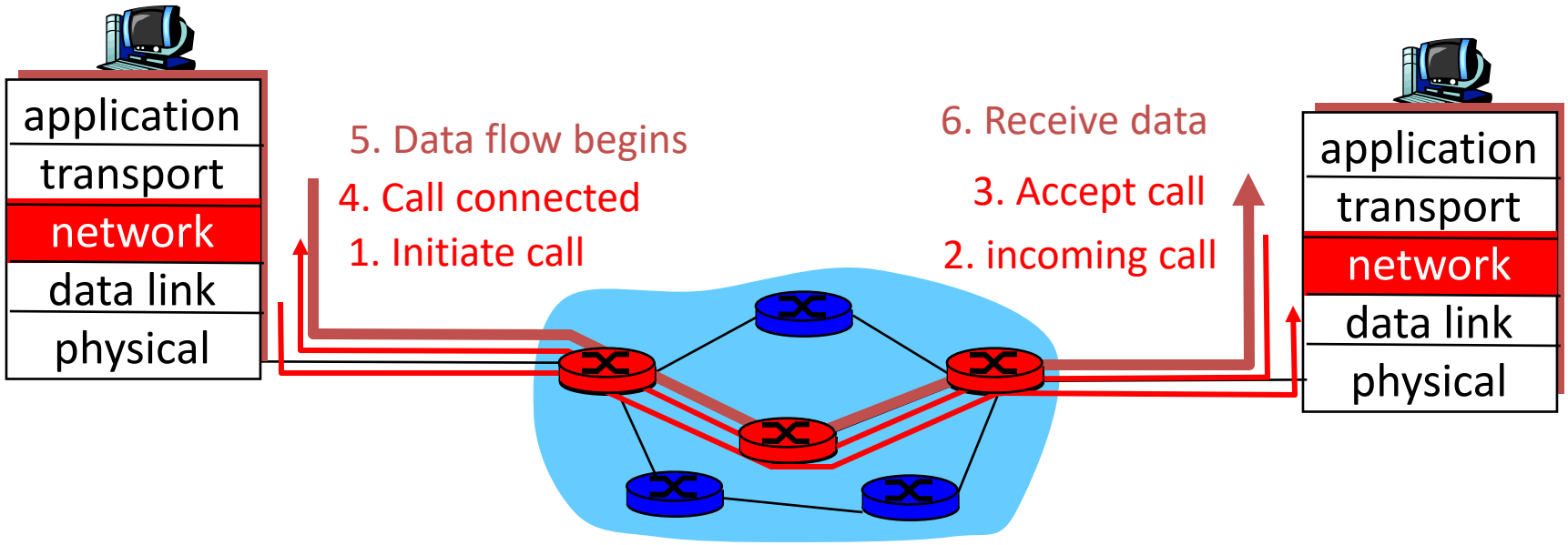
Telecomm Infrastructure



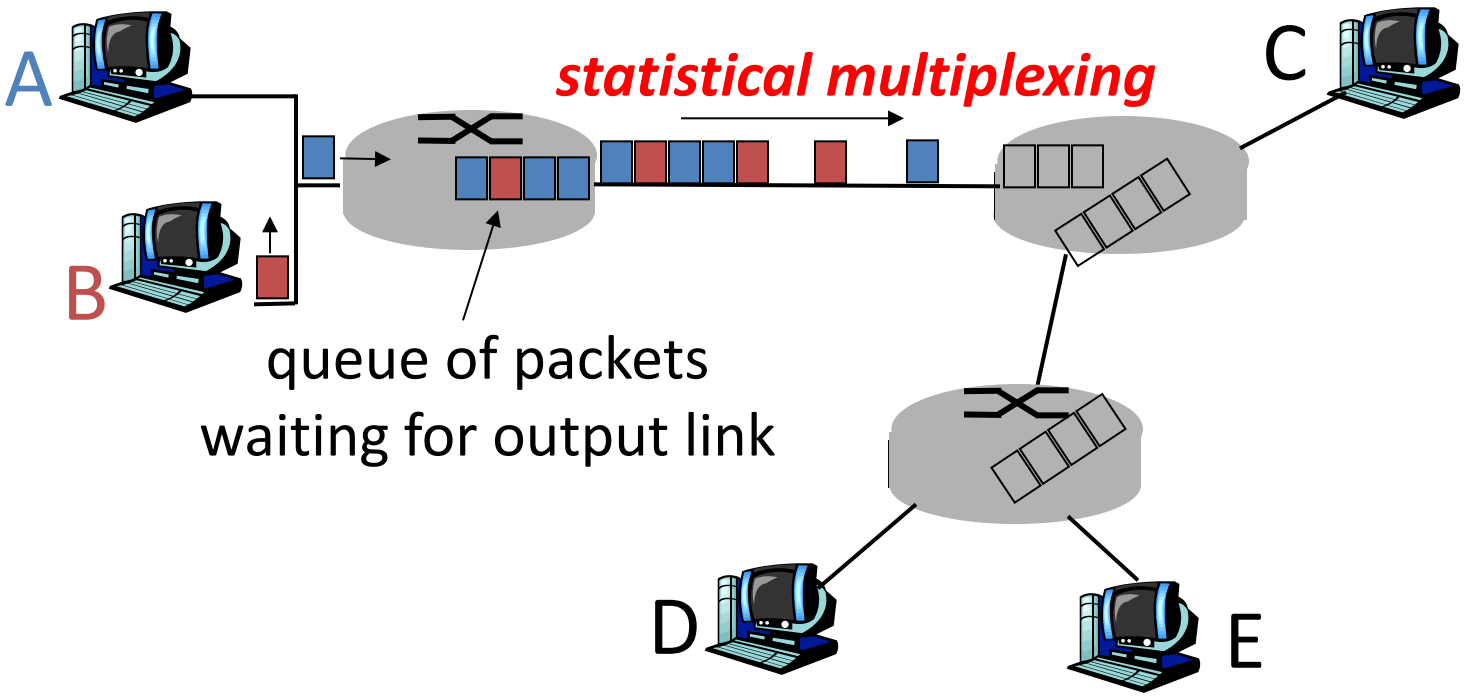
IP-based Internet

CS Signaling

- used to setup, maintain teardown VC
- used in 2G, as well as in 3G
- not used in today's Internet

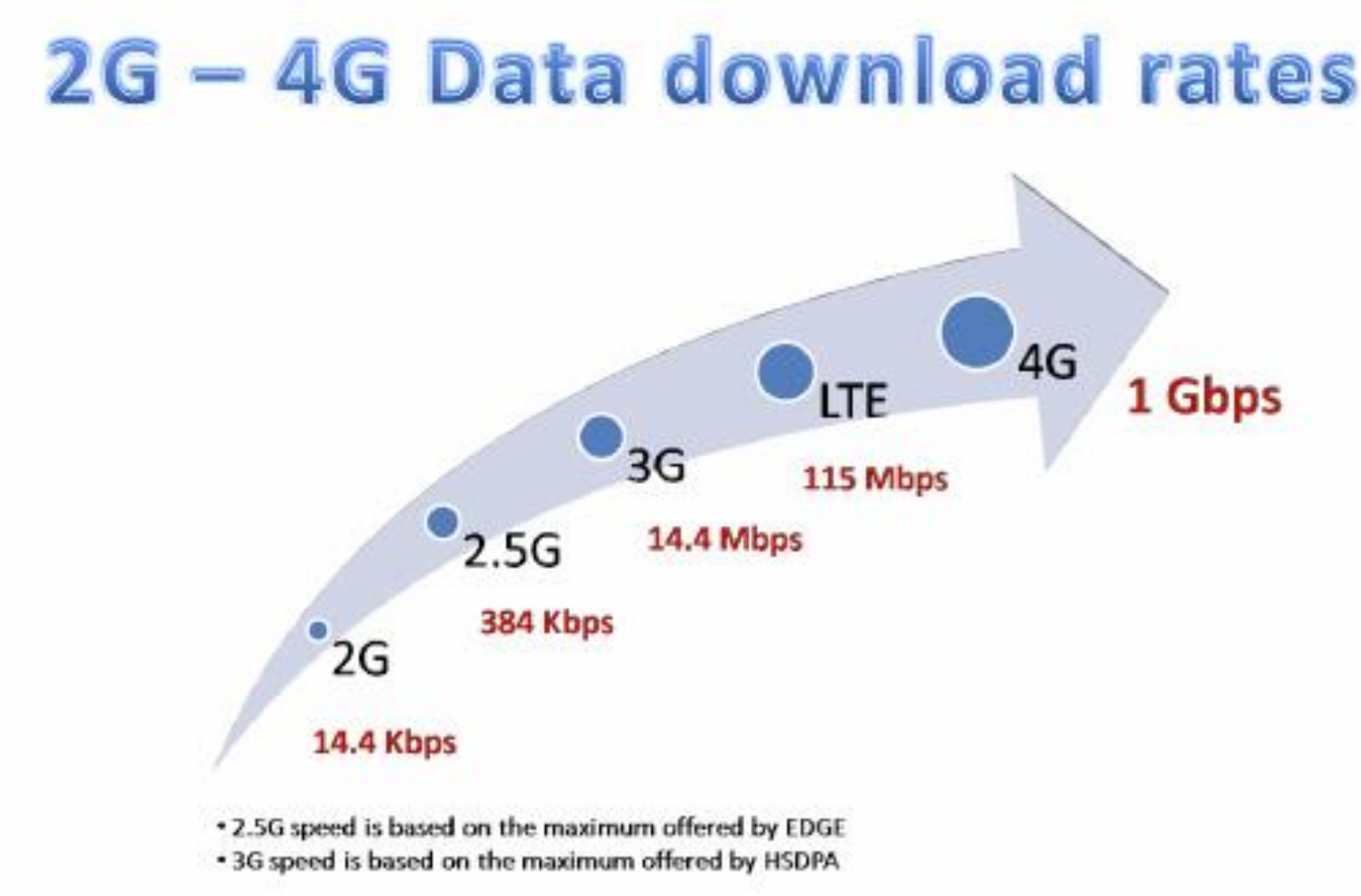


Packet Switching (PS)



- Sequence of A & B packets does not have fixed pattern, bandwidth shared on demand → statistical multiplexing
- Store-and-forward at intermediate routers
- Used by the Internet

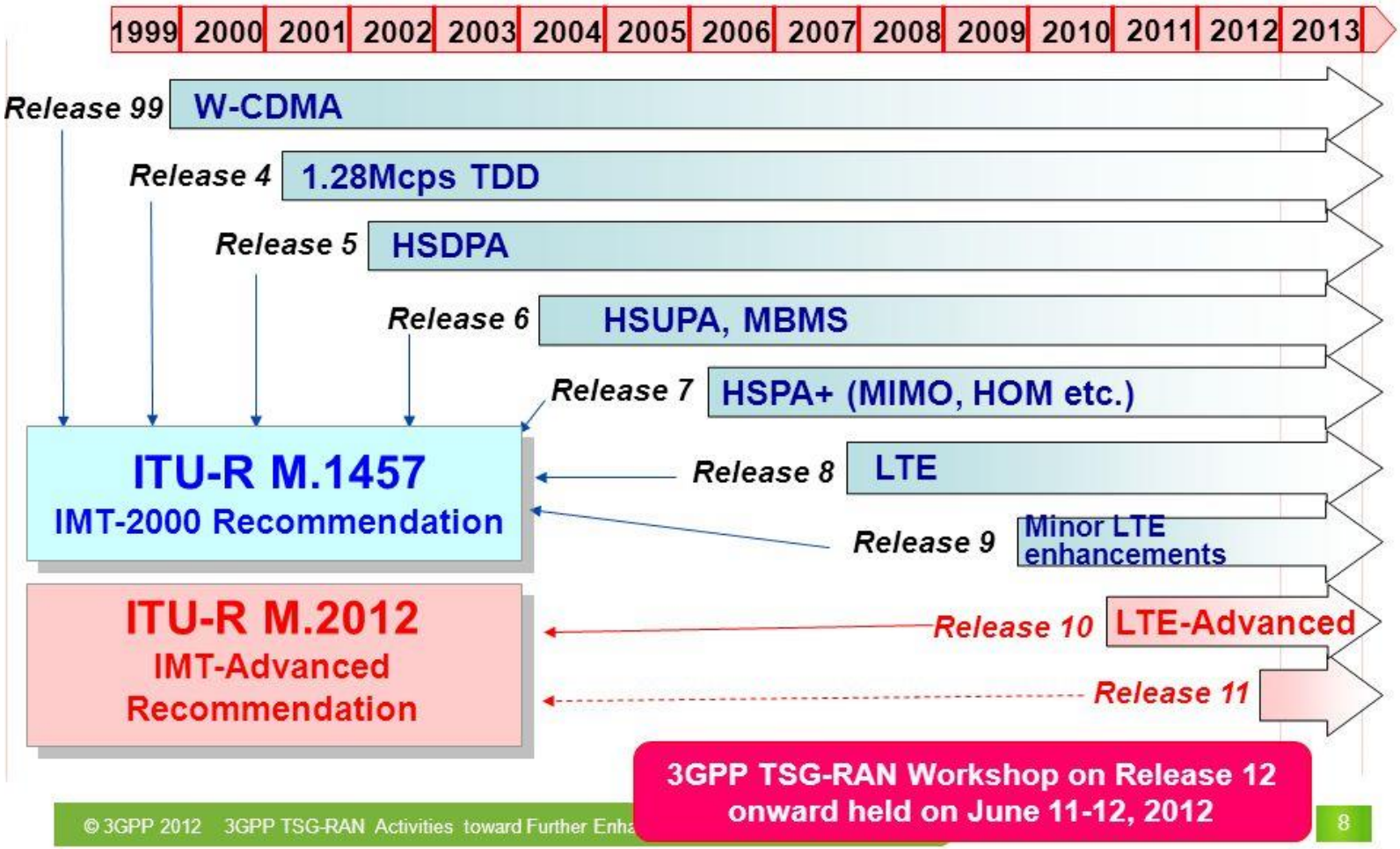
Comparison of LTE Speed



LTE Evolution

- Specification managed by 3GPP organization
  - 3rd Generation Partnership Project
  - UMTS (Universal Mobile Telephone System) Rel 99
  - HSDPA (High Speed Downlink Packet Access) Rel 5
  - HSUPA (High Speed Uplink Packet Access) Rel 6
  - HSPA+ Rel 7, enhancements in Rel 8-10
- New LTE specification in Release 8-9
- LTE-A in Release 10

Release of 3GPP specifications



	WCDMA (UMTS)	HSPA HSDPA / HSUPA	HSPA+	LTE	LTE ADVANCED (IMT ADVANCED)
Max downlink speed (bps)	384k	14 M	28 M	100 M	1 G
Max uplink speed (bps)	128 k	5.7 M	11 M	50 M	500 M
Latency round trip time (approx.)	150 ms	100 ms	50 ms (max)	~10 ms	Less than 5 ms
3GPP releases	Rel 99/4	Rel 5/6	Rel 7	Rel 8/9	Rel 10
Approx years of initial roll out	2003/4	2005/6 HSDPA 2007/8 HSUPA	2008/9	2009/10	
Access methodology	CDMA	CDMA	CDMA	OFDMA/SC-FDMA	OFDMA/SC-FDMA

LTE performance requirements

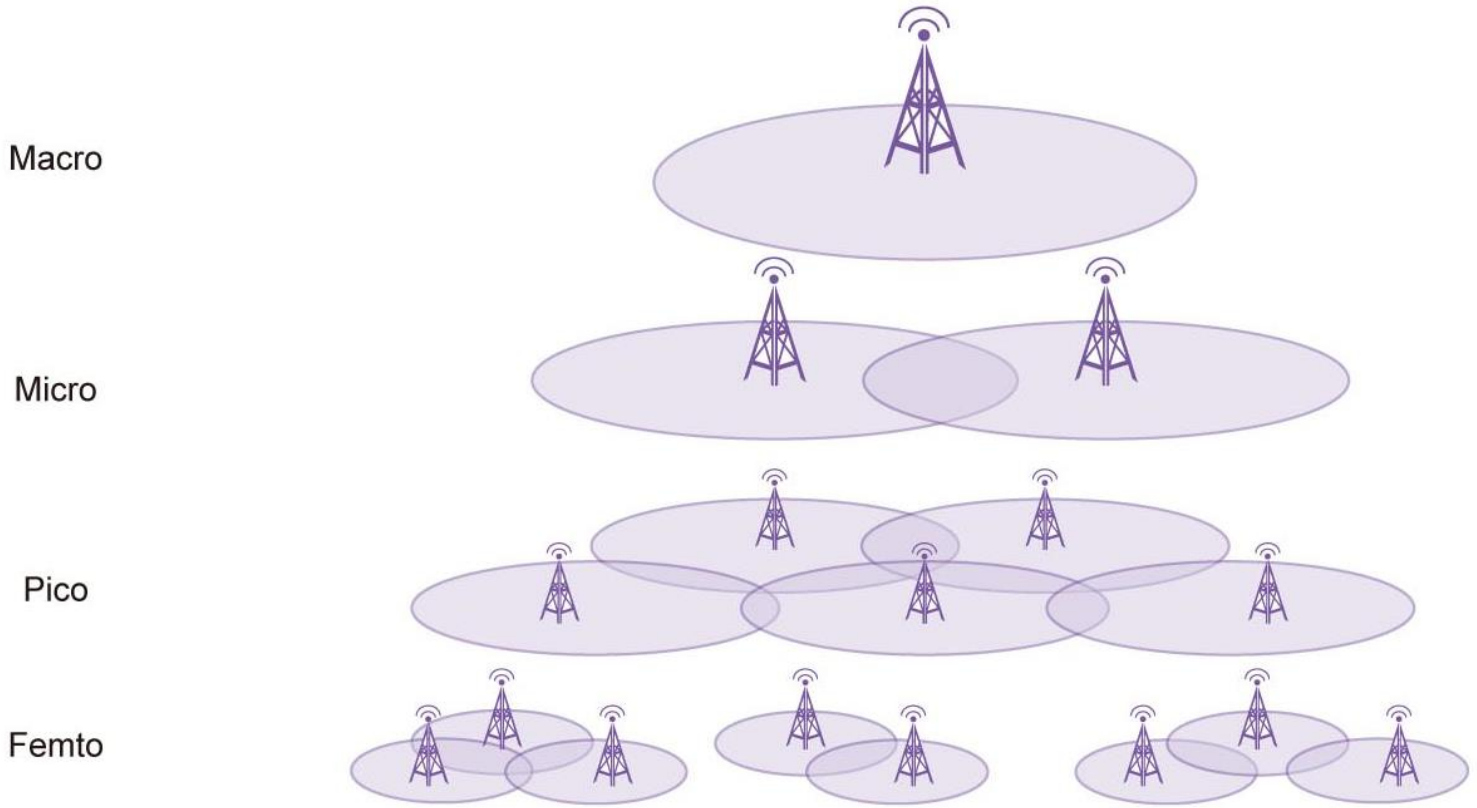
- Data Rate:
  - Instantaneous downlink peak data rate of 100Mbit/s in a 20MHz downlink spectrum (i.e. 5 bit/s/Hz)
  - Instantaneous uplink peak data rate of 50Mbit/s in a 20MHz uplink spectrum (i.e. 2.5 bit/s/Hz)
- Cell range
  - 5 km - optimal size
  - 30km sizes with reasonable performance
  - up to 100 km cell sizes supported with acceptable performance
- Cell capacity
  - up to 200 active users per cell(5 MHz) (i.e., 200 active data clients)

Key parameters of LTE

Frequency Range	**UMTS FDD bands and UMTS TDD bands**					
Channel bandwidth 1 Resource Block (RB) =180 kHz	**1.4 MHz**	**3 MHz**	**5 MHz**	**10 MHz**	**15 MHz**	**20 MHz**
	6 RB	15 RB	25 RB	50 RB	75 RB	100 RB
Modulation Schemes	**Downlink**	QPSK, 16QAM, 64QAM				
	Uplink	QPSK, 16QAM, 64QAM (⇨ optional for handset)				
Multiple Access	**Downlink**	OFDMA (Orthogonal Frequency Division Multiple Access)				
	Uplink	SC-FDMA (Single Carrier Frequency Division Multiple Access)				
MIMO technology	**Downlink**	Wide choice of MIMO configuration options for transmit diversity, spatial multiplexing, and cyclic delay diversity (max. 4 antennas at base station and handset)				
	Uplink	Multi-user collaborative MIMO				
Peak Data Rate	**Downlink**	150 Mbps (UE category 4, 2x2 MIMO, 20 MHz) 300 Mbps (UE category 5, 4x4 MIMO, 20 MHz)				
	Uplink	75 Mbps (20 MHz)				

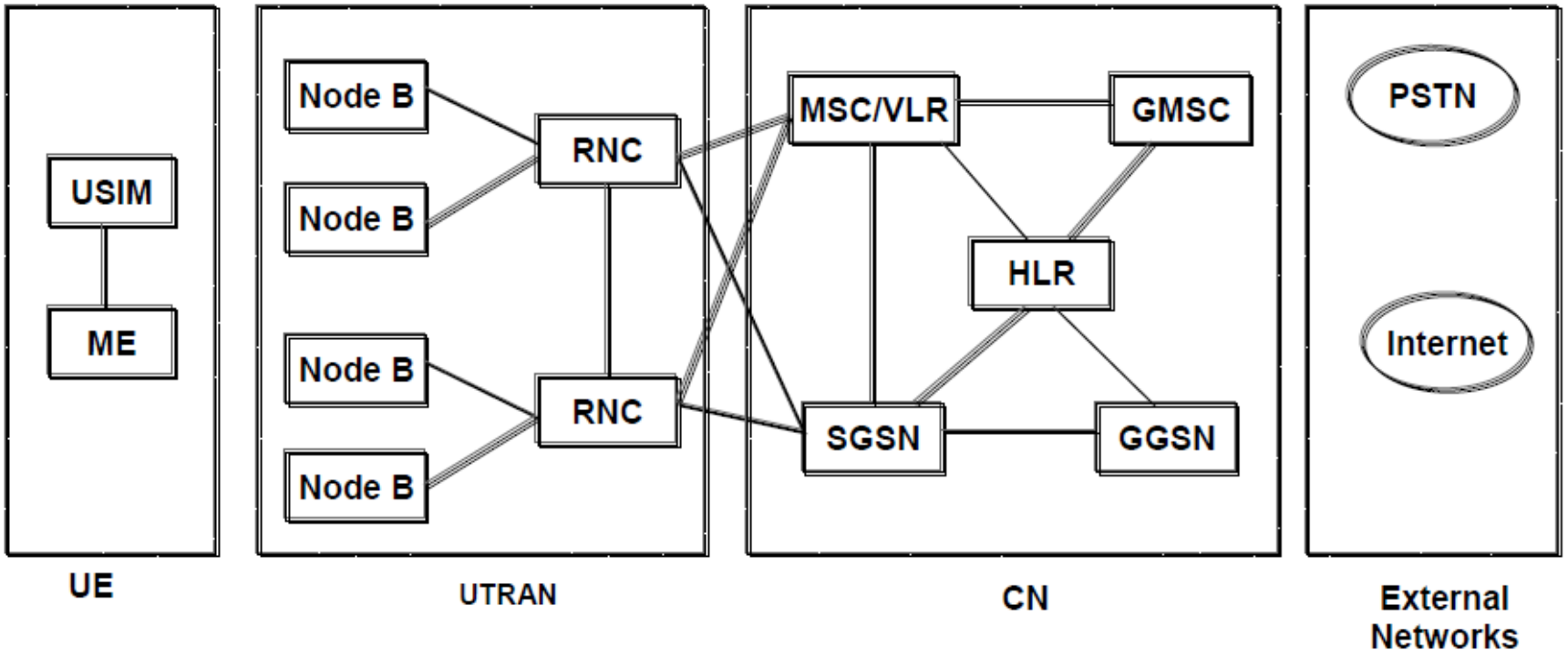
Multi-tier Architecture

One technology



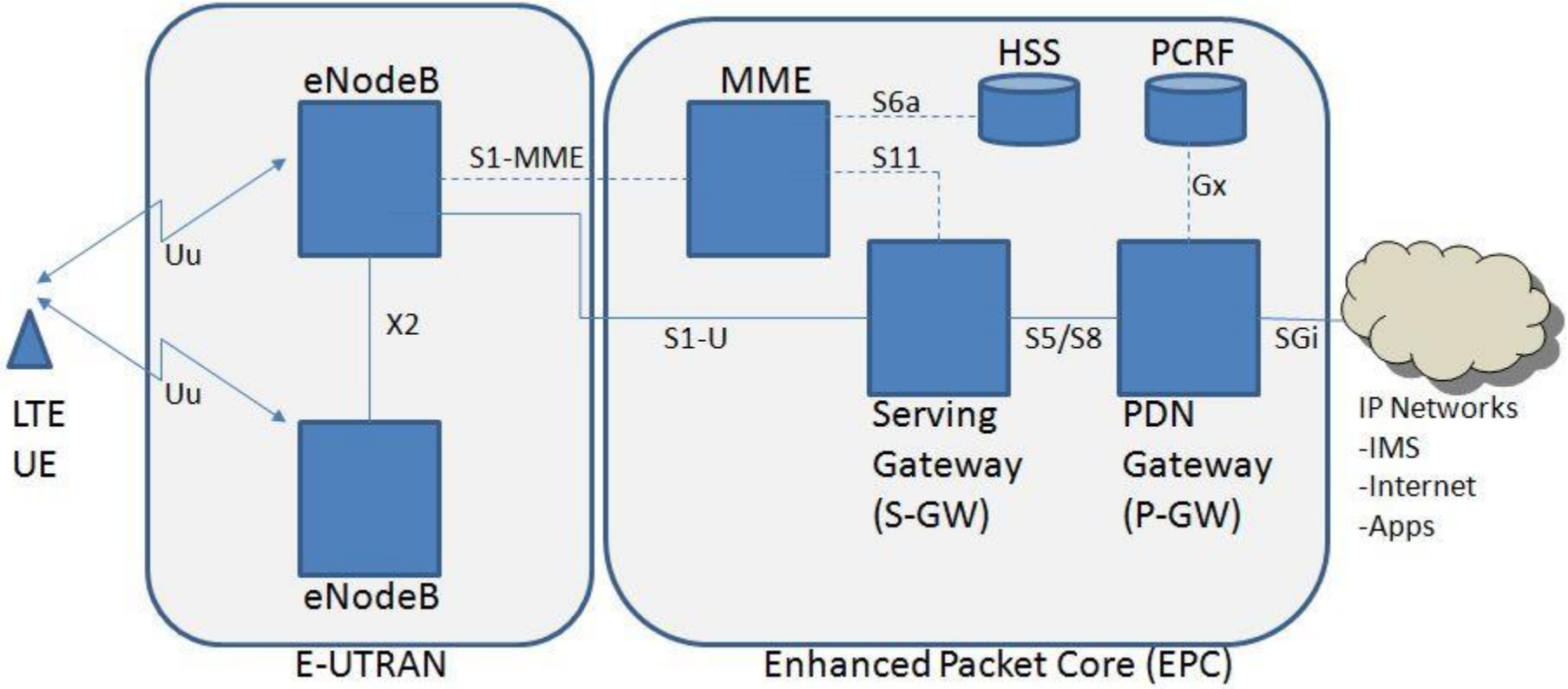
LTE frequency bands

UMTS Architecture

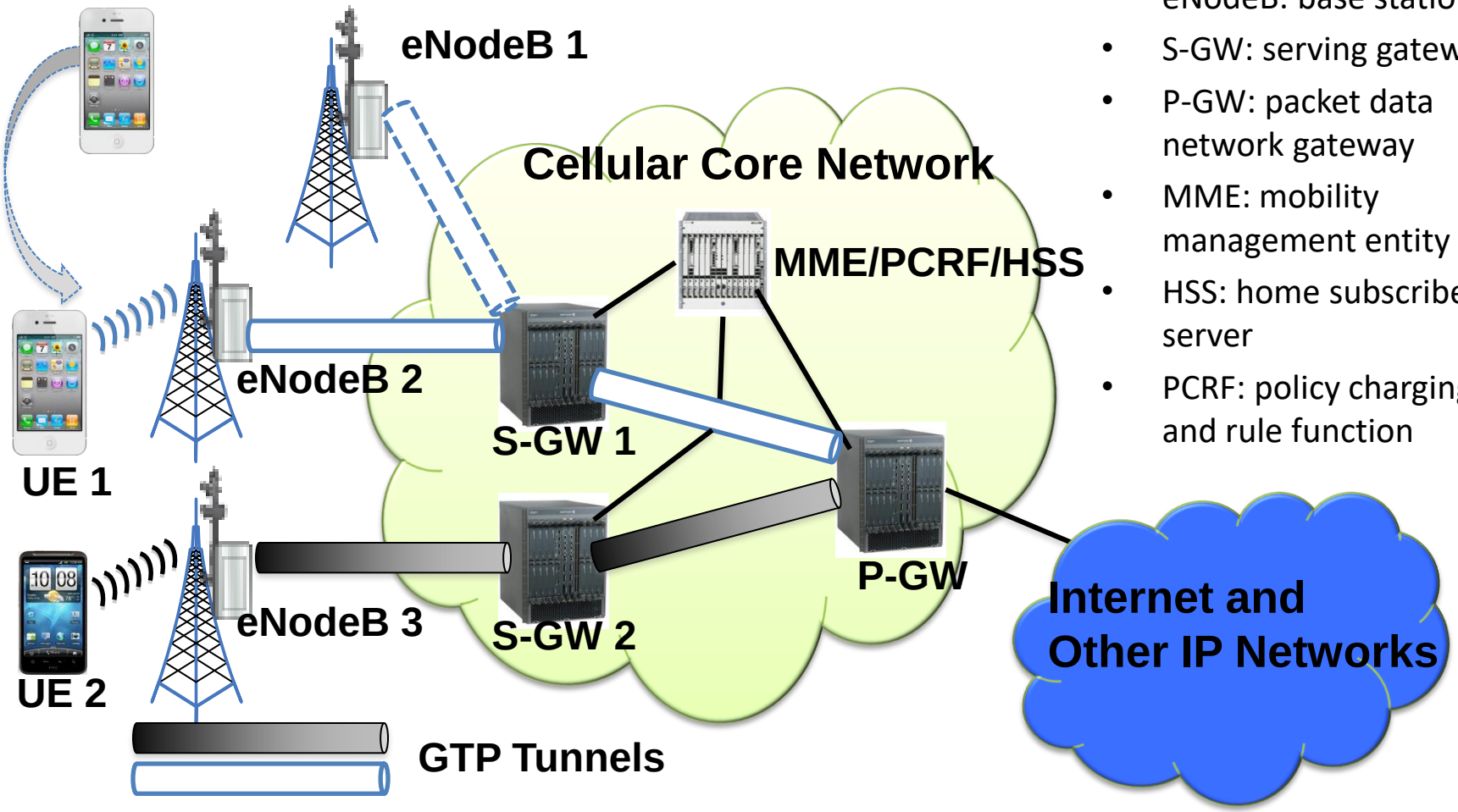


- UE (User Equipment) that interfaces with the user
- UTRAN (UMTS Terrestrial Radio Access Network) handles all radio related functionality – WCDMA is radio interface standard here.
- CN (Core Network) is responsible for transport functions such as switching and routing calls and data, tracking users

LTE Architecture

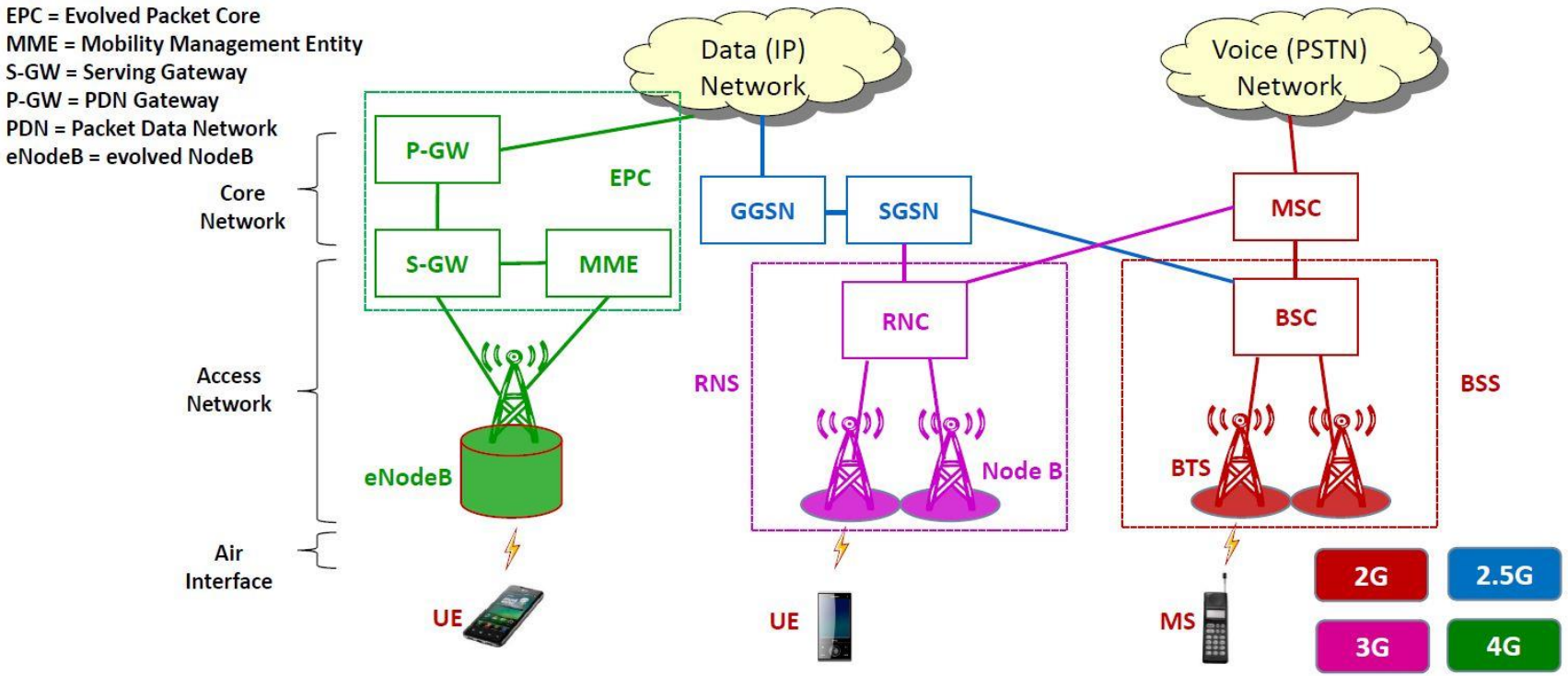


LTE Infrastructure



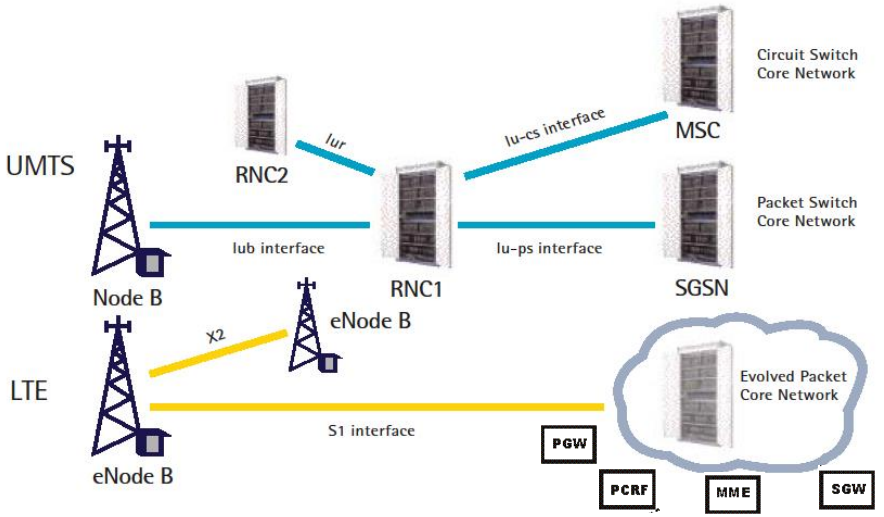
- UE: user equipment
- eNodeB: base station
- S-GW: serving gateway
- P-GW: packet data network gateway
- MME: mobility management entity
- HSS: home subscriber server
- PCRF: policy charging and rule function

Architectural evolution



UMTS->LTE Migration

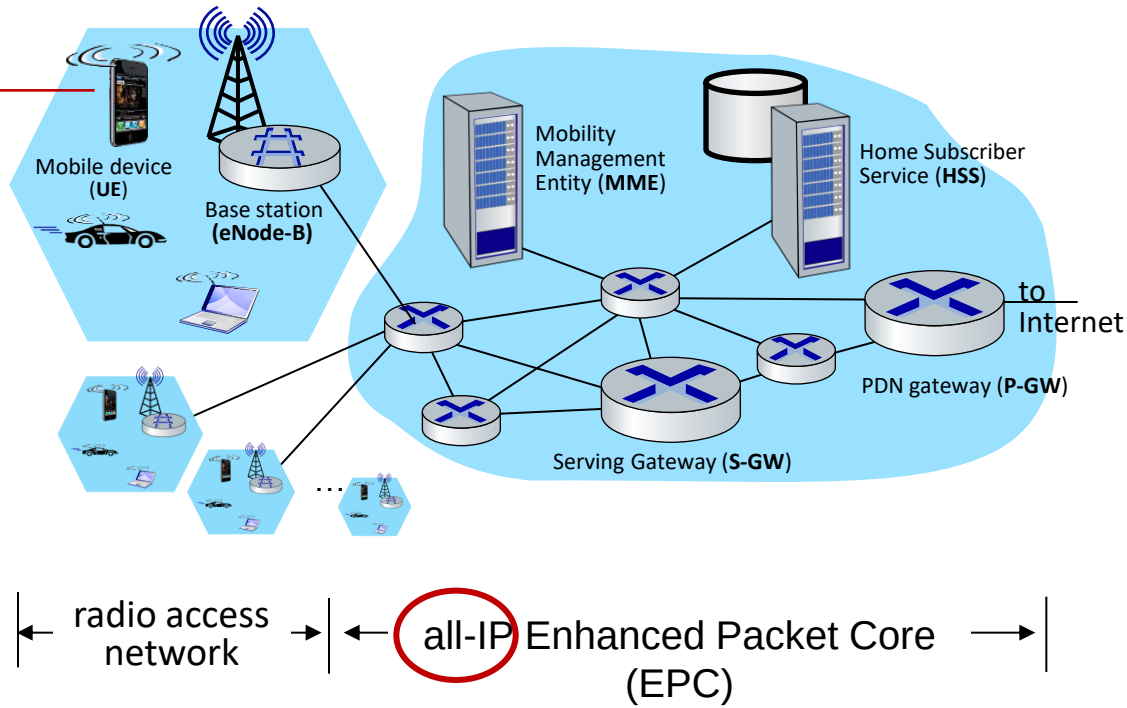
- LTE RAN agreed on the following
  - Packet bearer support
    - Real Time
    - Conversational
  - Reduce the number of the new interfaces
    - NO RNC
    - NO CS-CN
  - Reduce the single point of failure
    - NO RNC
  - Separate the treatment of different types of traffic (O&M, Control and Data) to utilize the BW
  - Reduce the variable delay and Jitter (TCP/IP)
  - Agreed QOS between Transmitting end and receiving end
  - No SHO or Macro diversity
  - MIMO and Tx diversity techniques used



Elements of 4G LTE architecture

Mobile device:

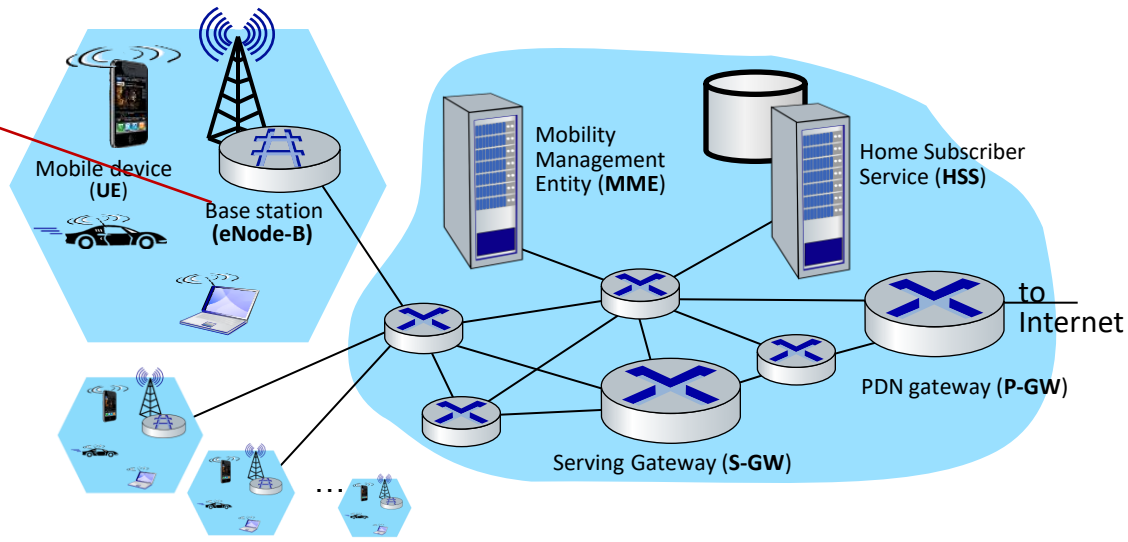
- smartphone, tablet, laptop, IoT, ... with 4G LTE radio
- 64-bit International Mobile Subscriber Identity (IMSI), stored on SIM (Subscriber Identity Module) card
- LTE jargon: User Equipment (UE)



Elements of 4G LTE architecture

Base station:

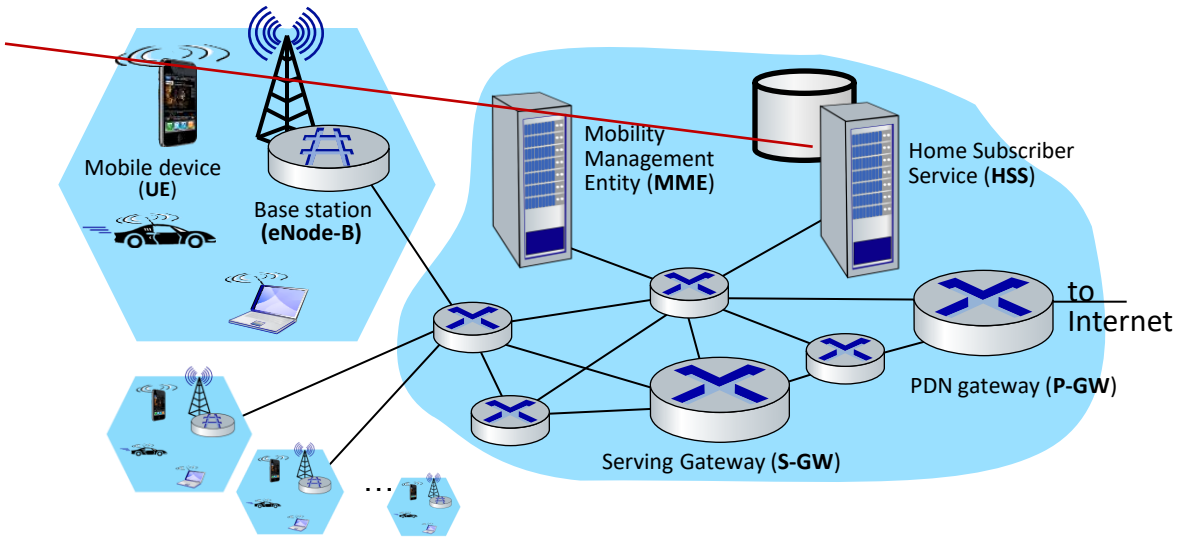
- at “edge” of carrier’s network
- manages wireless radio resources, mobile devices in its coverage area (“cell”)
- coordinates device authentication with other elements
- similar to WiFi AP but:
  - active role in user mobility
  - coordinates with nearly base stations to optimize radio use
- LTE jargon: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



Elements of 4G LTE architecture

Home Subscriber Service

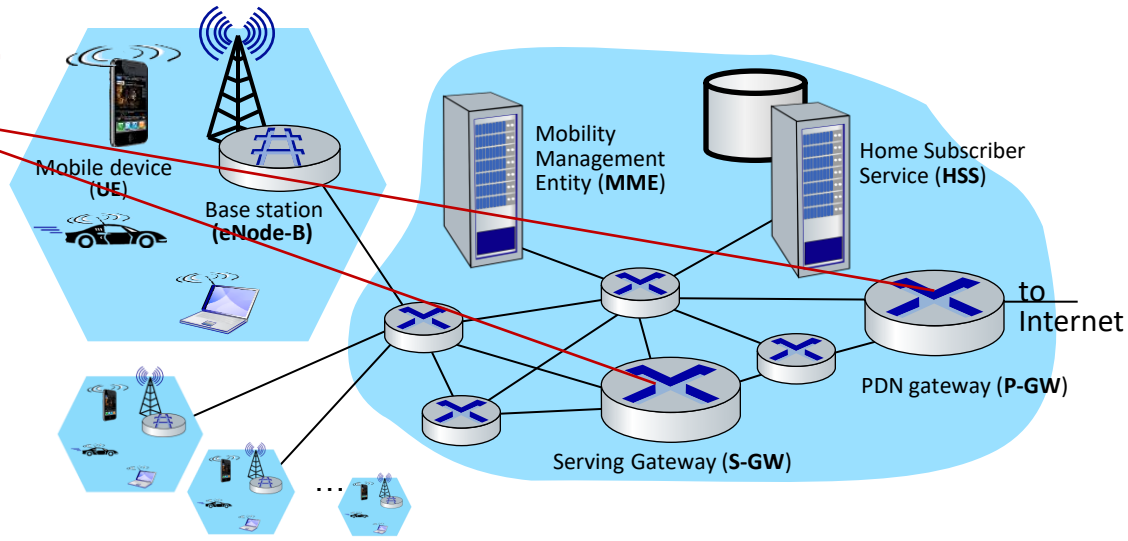
- stores info about mobile devices for which the HSS's network is their "home network"
- works with MME in device authentication



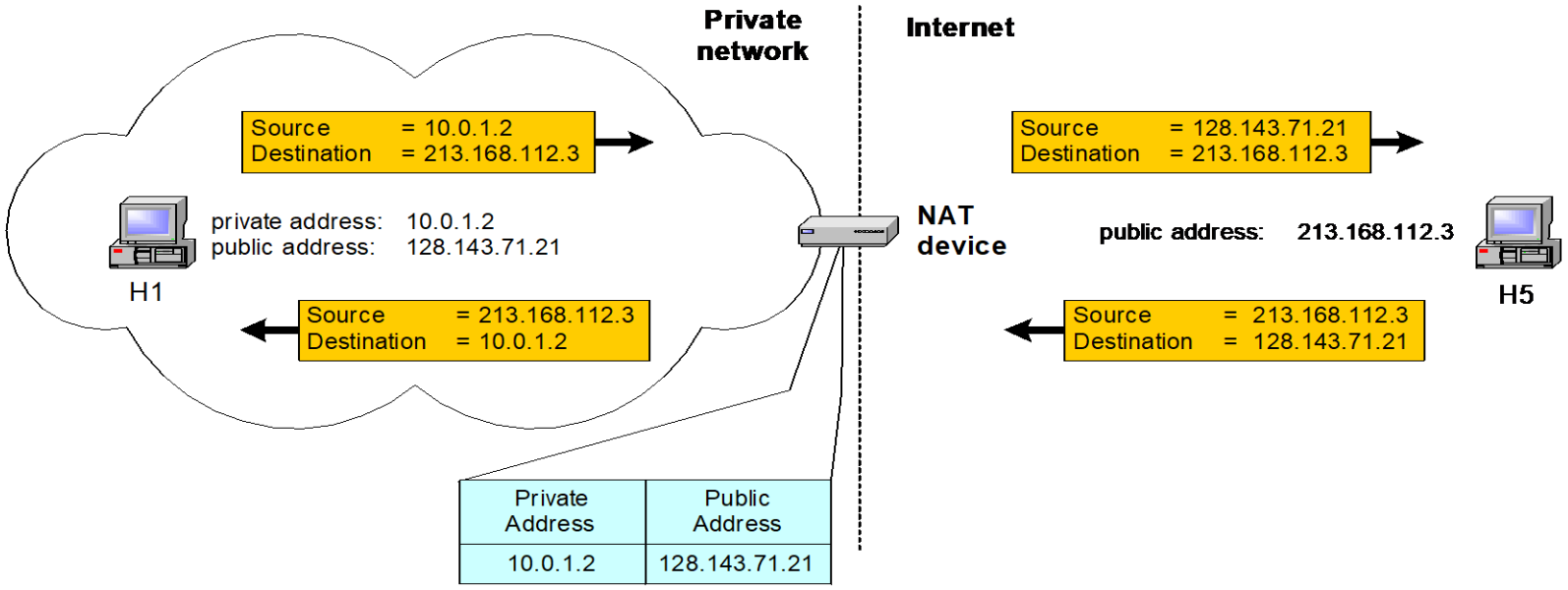
Elements of 4G LTE architecture

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



Basic operation of NAT (Network Address Translation)

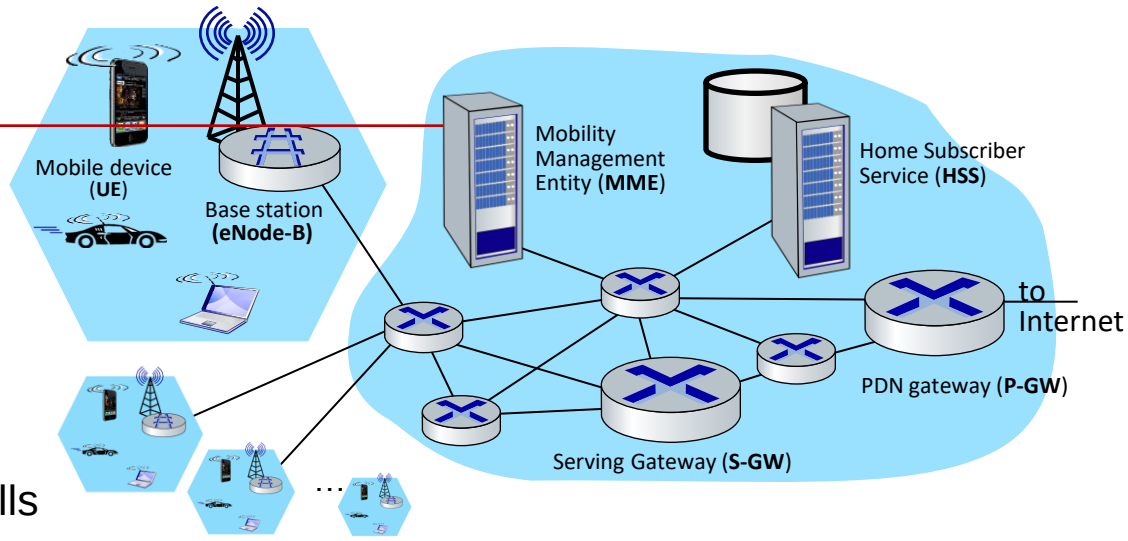


- NAT device has address translation table

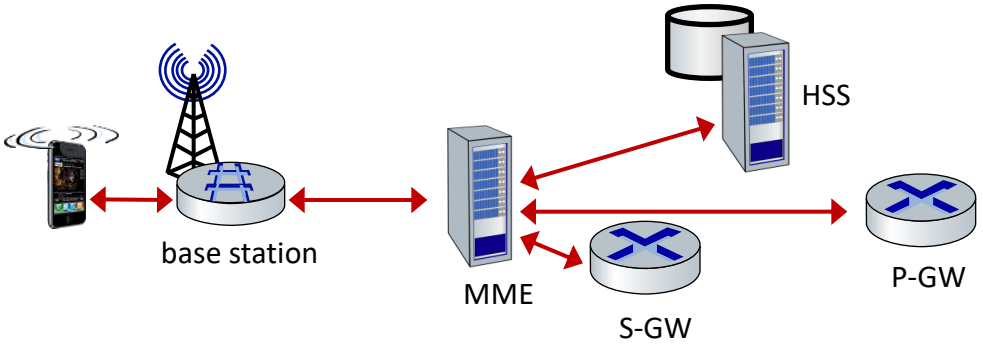
Elements of 4G LTE architecture

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

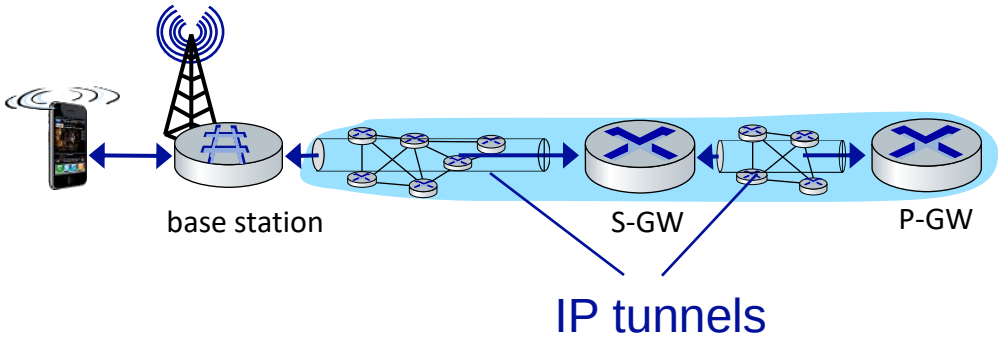


LTE: data plane control plane separation



control plane

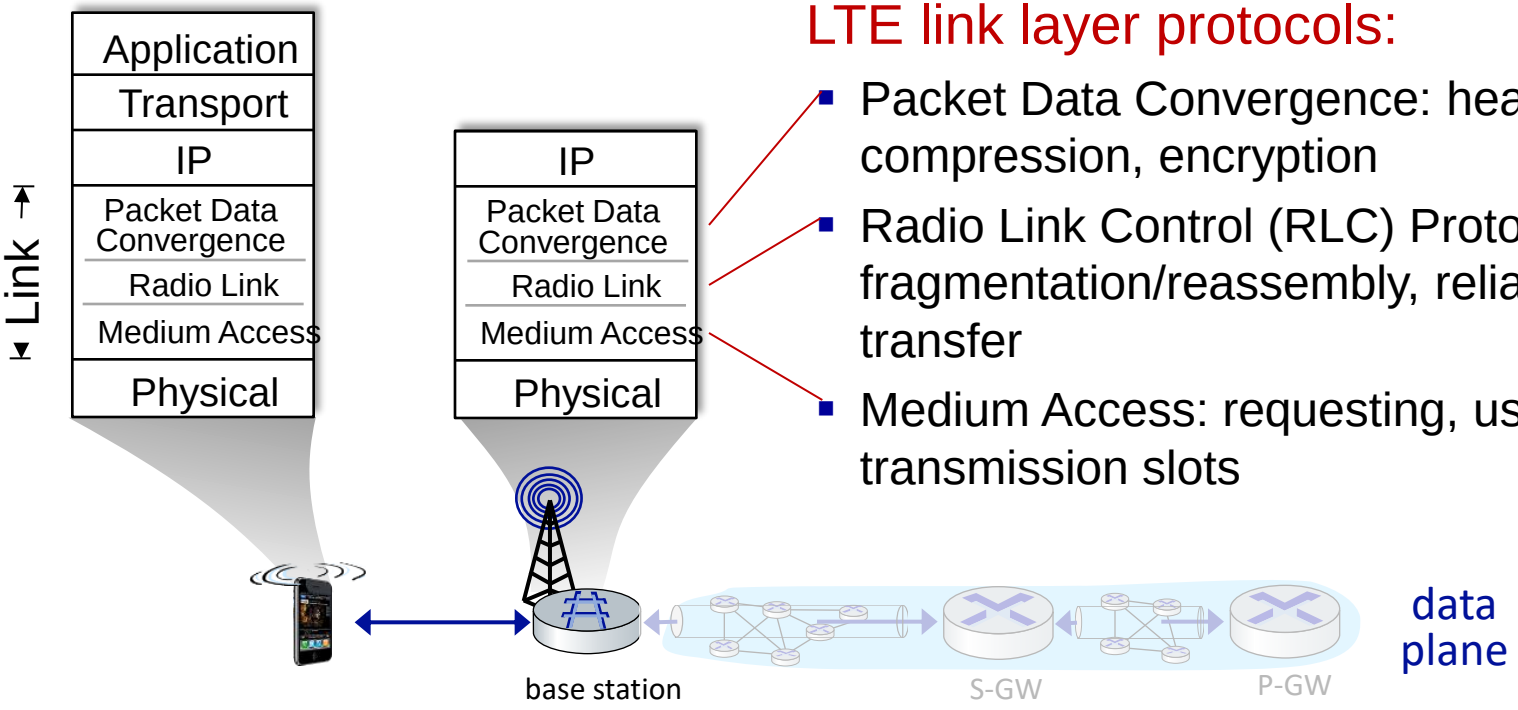
- new protocols for mobility management , security, authentication



data plane

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

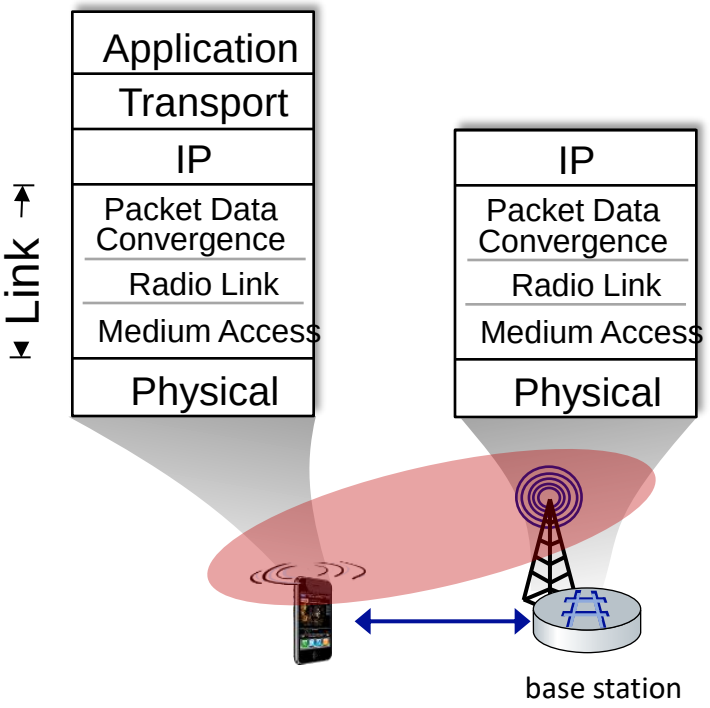
LTE data plane protocol stack: first hop



LTE 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

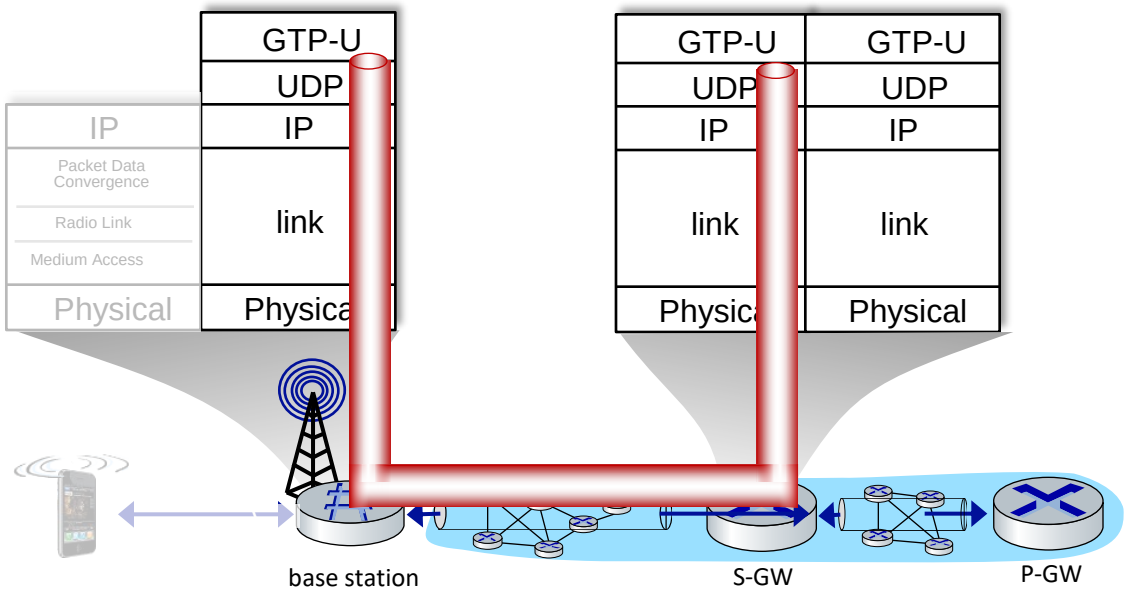
LTE data plane protocol stack: first hop



LTE radio access network:

- downstream channel: FDM, TDM within frequency channel (OFDM - orthogonal frequency division multiplexing)
  - "orthogonal": minimal interference between channels
  - upstream: FDM, TDM similar to OFDM
- each active mobile device allocated two or more 0.5 ms time slots over 12 frequencies
  - scheduling algorithm not standardized – up to operator
  - 100's Mbps per device possible

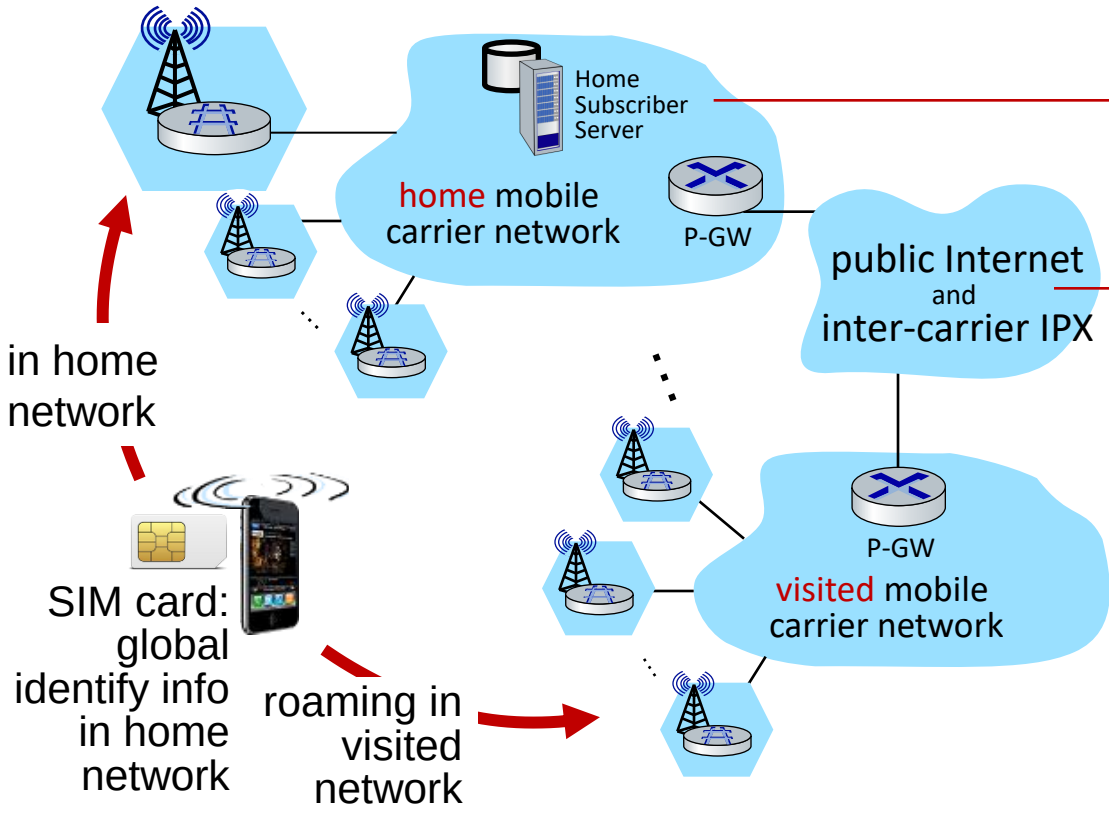
LTE data plane protocol stack: packet core



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

Global cellular network: a network of IP networks



home network HSS:

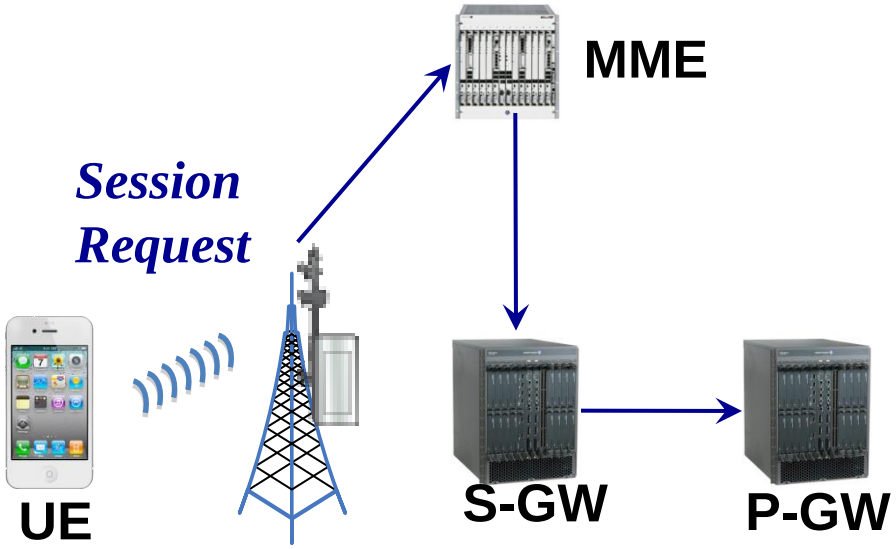
- identify & services info, while in home network and roaming

all IP:

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

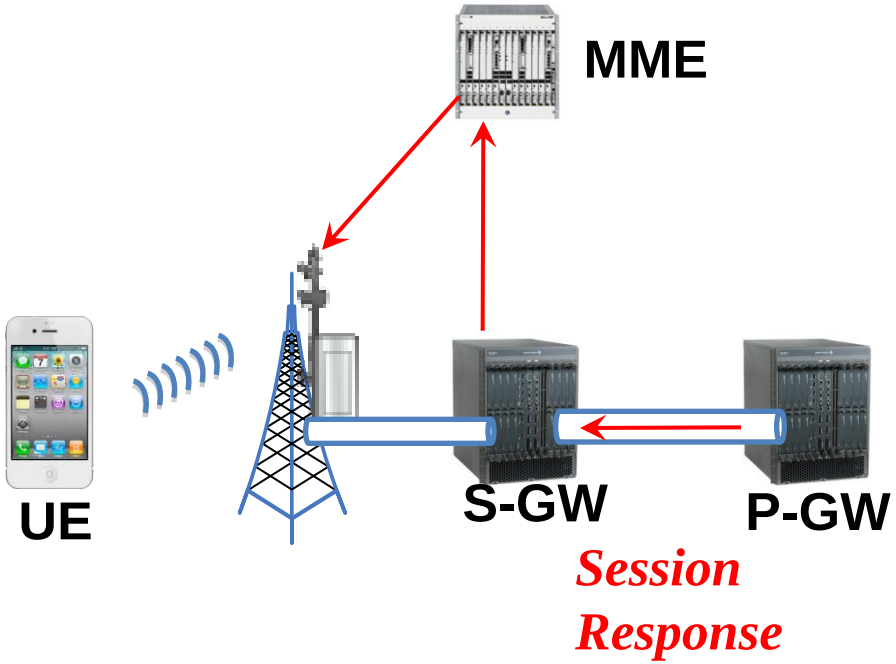
Connection Setup

- Session Requests
  - UE to base station
  - Base station to MME
    - MME obtains subscriber info from HSS, selects S-GW and P-GW
  - S-GW sends to P-GW
    - P-GW obtains policy from PCRF



Connection Setup (Cont'd)

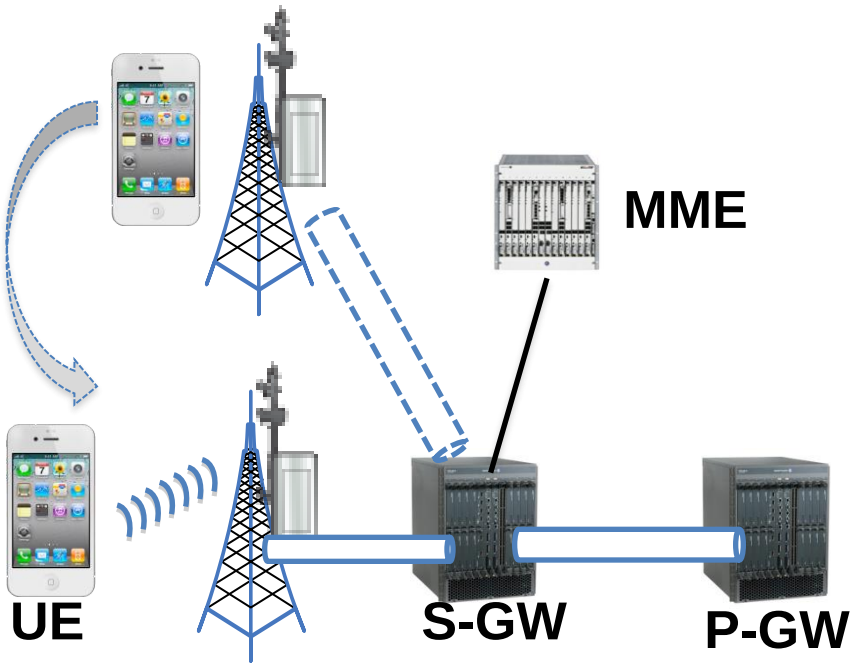
- Session Response
  - Establishes GPRS Tunnels (GTP) between S-GW and P-GW, between S-GW and UE
  - Base station allocates radio resources to UE



Mobility Management

Handoff

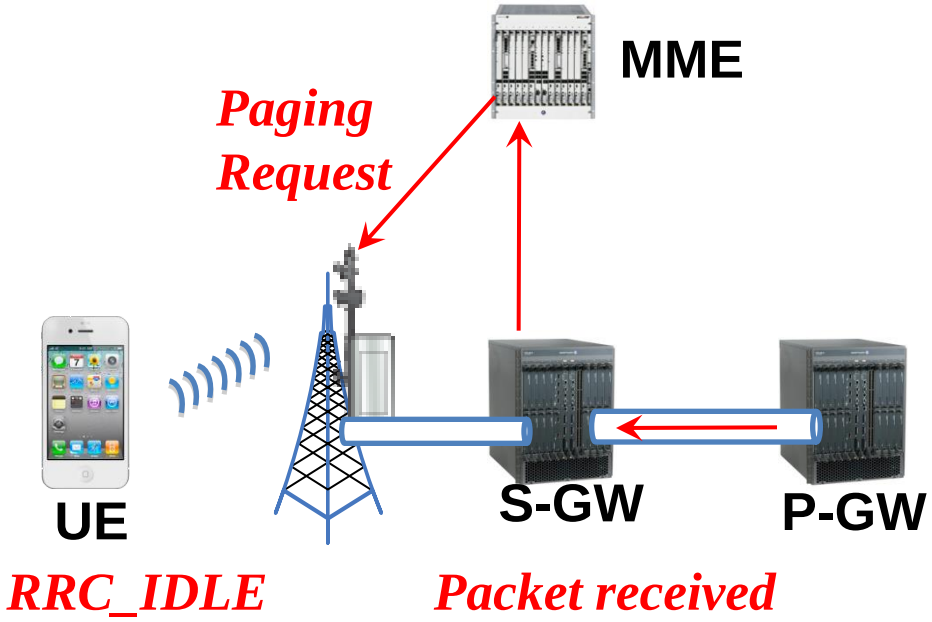
- Handoff without change of S-GW
  - No change at P-GW
- Handoff with change of S-GW or MME
- Inter-technology handoff (LTE to 3G)



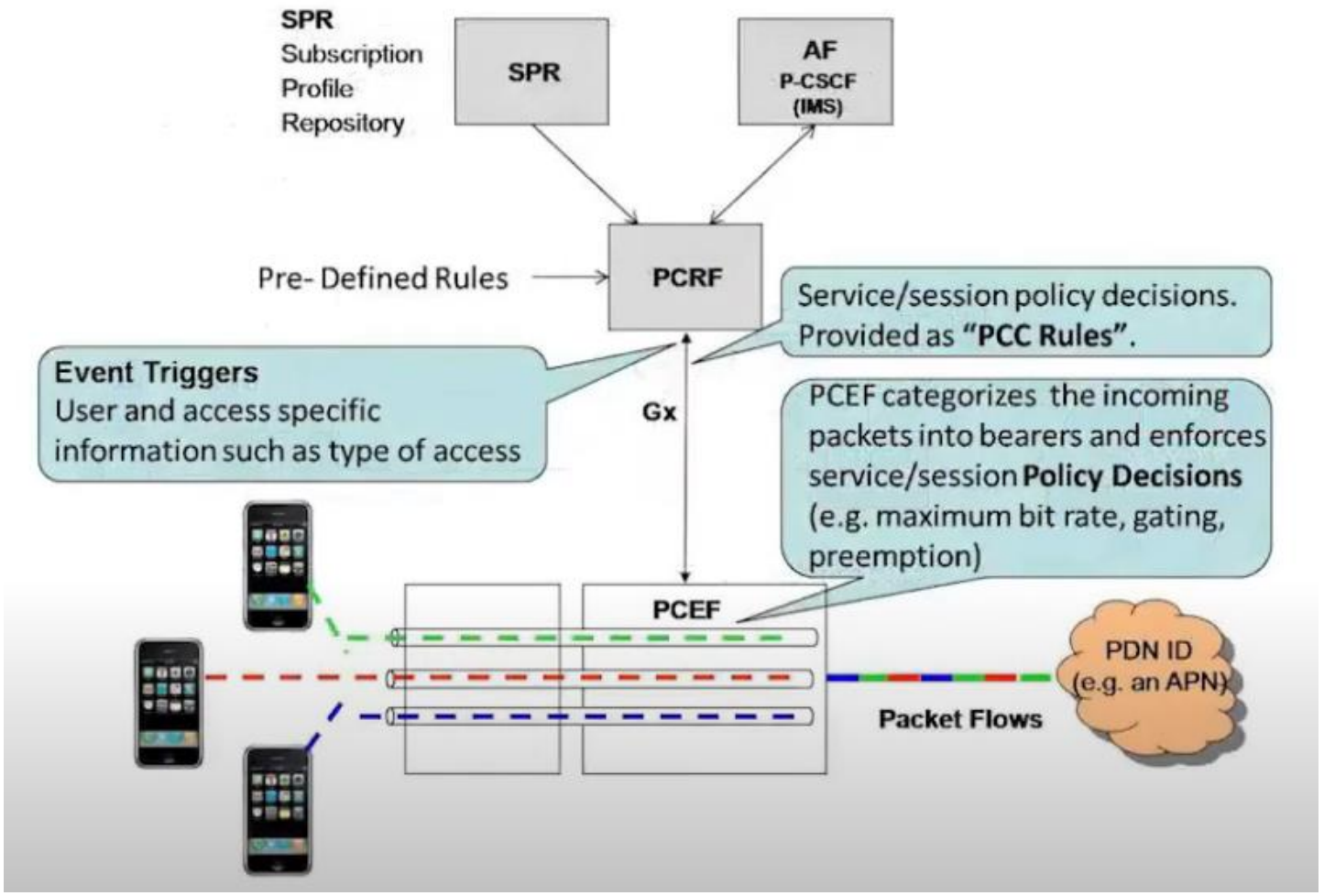
Mobility Management (Cont'd)

Paging

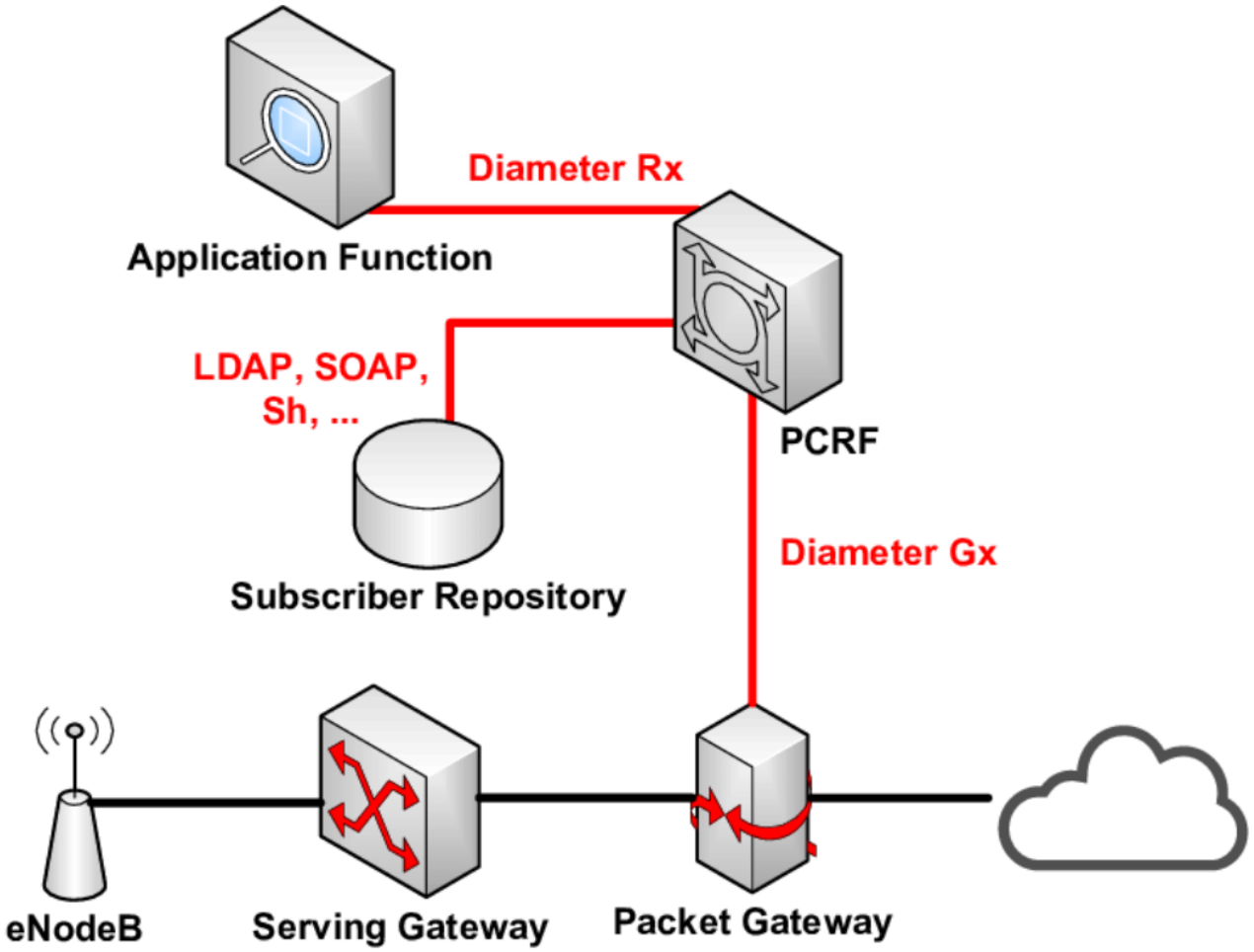
- If S-GW receives a packet to a UE in IDLE state, inform MME
- MME pages UE through base station



Policy and Charging Rules Function (PCRF)

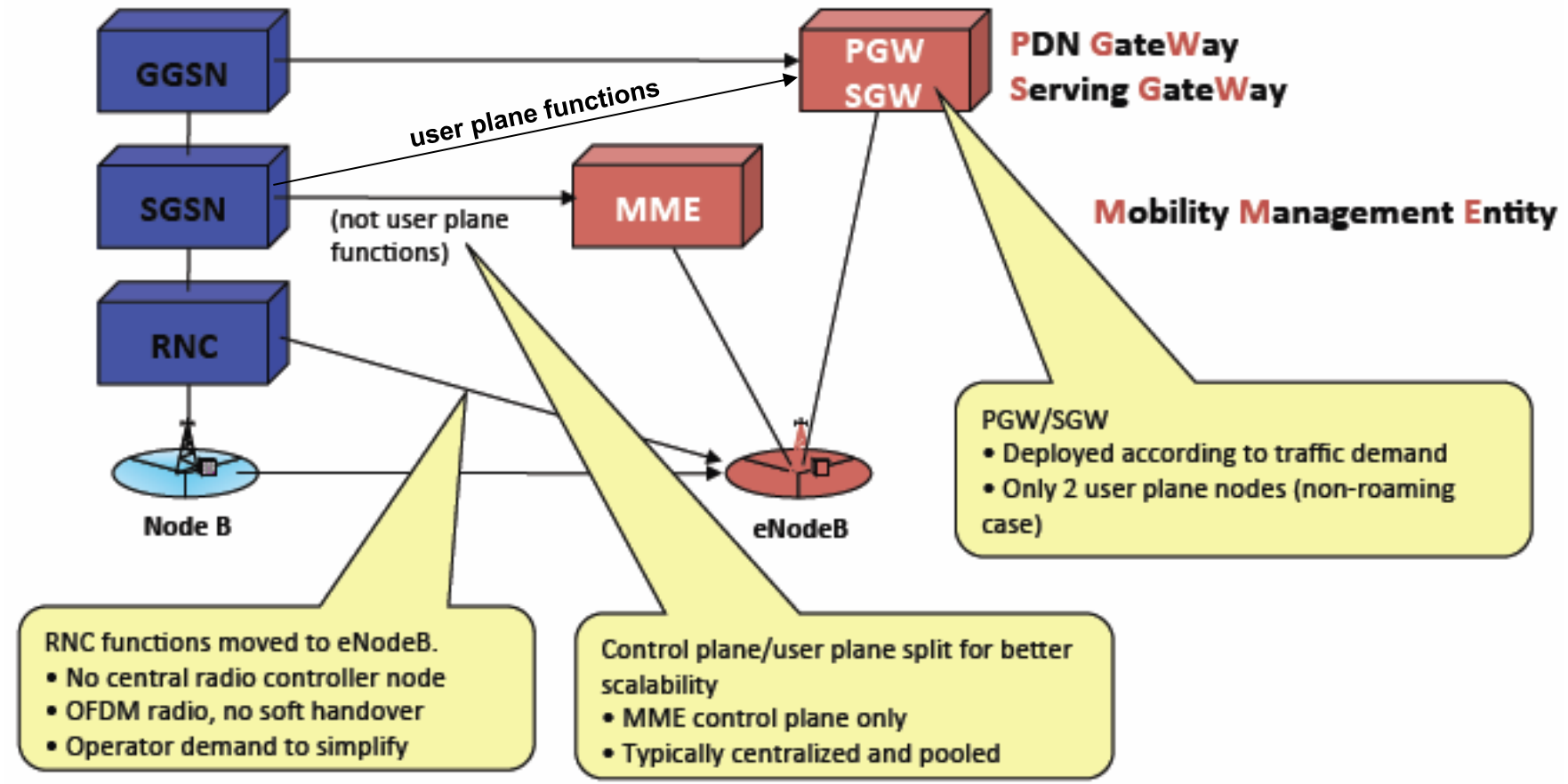


Policy and Charging Rules Function (PCRF)

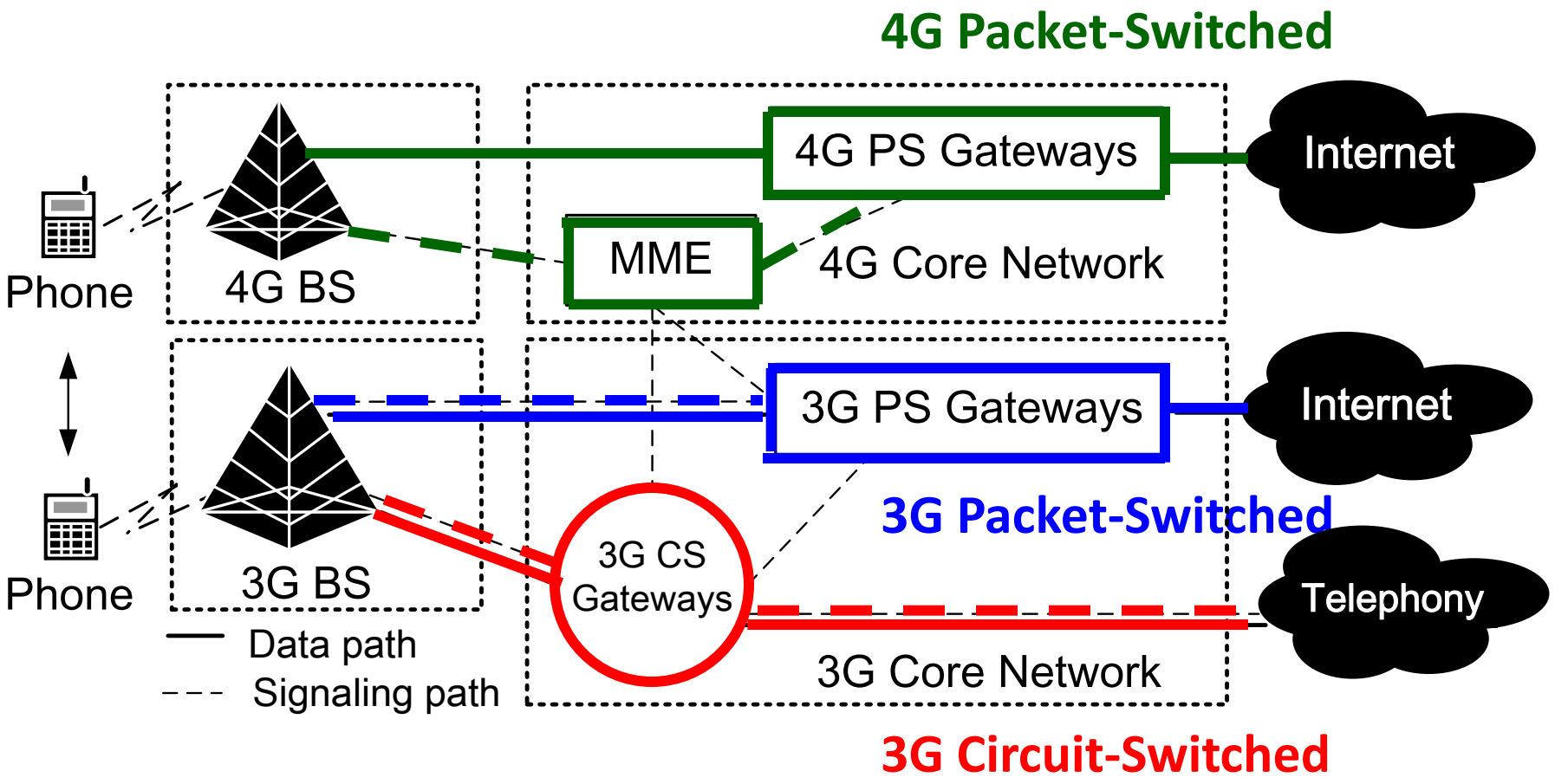


LTE vs UMTS

- Functional changes compared to the UMTS architecture

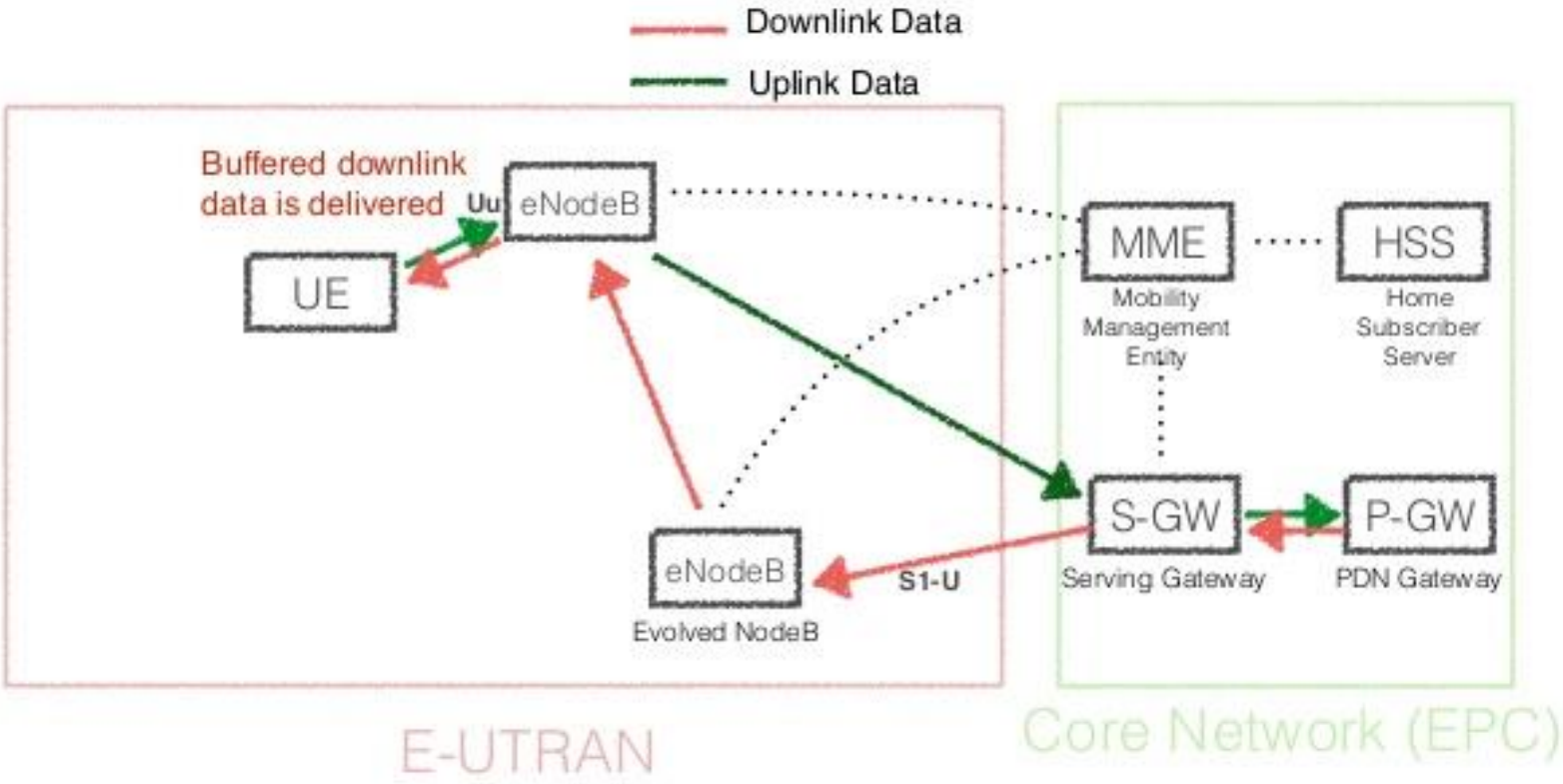


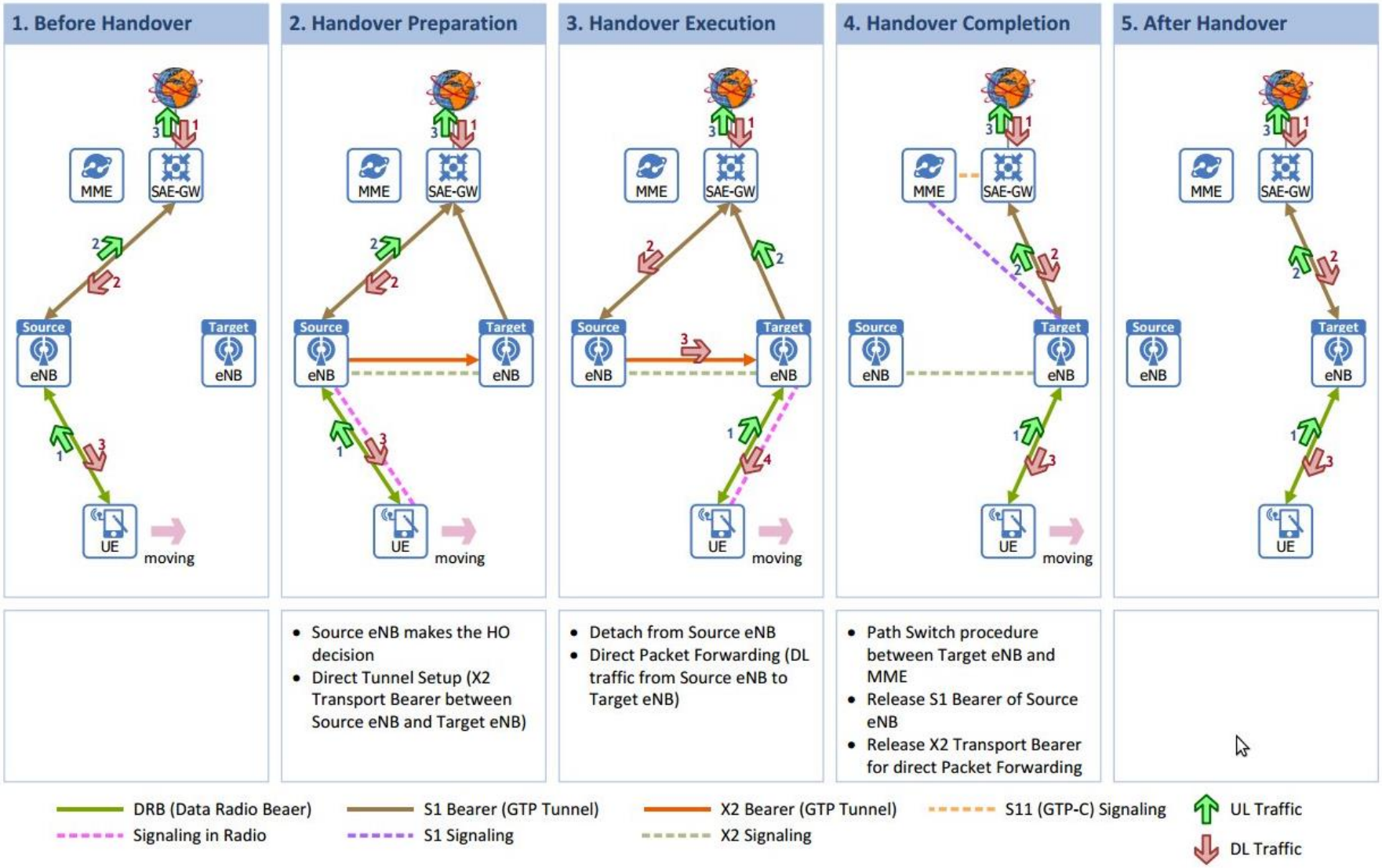
LTE vs UMTS


4G Packet-Switched
4G PS Gateways
Internet
MME
4G Core Network
Phone
4G BS
3G PS Gateways
Internet
3G Packet-Switched
3G CS
Gateways
Telephony
Phone
3G BS
Data path
Signaling path
3G Core Network
3G Circuit-Switched

X2 Handover

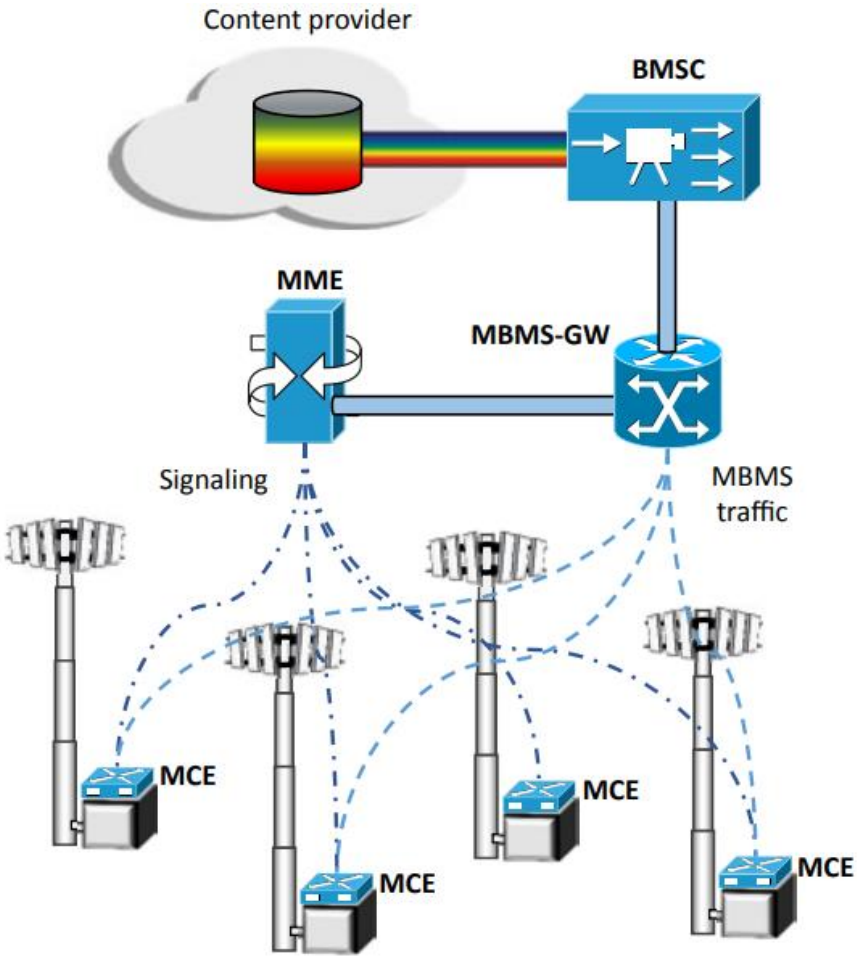
Data flow during handover execution (after ho preparation):




1. Before Handover
2. Handover Preparation
3. Handover Execution
4. Handover Completion
5. After Handover
MME
SAE-GW
Source
eNB
Target
eNB
UE
moving
• Source eNB makes the HO decision
• Direct Tunnel Setup (X2 Transport Bearer between Source eNB and Target eNB)
• Detach from Source eNB
• Direct Packet Forwarding (DL traffic from Source eNB to Target eNB)
• Path Switch procedure between Target eNB and MME
• Release S1 Bearer of Source eNB
• Release X2 Transport Bearer for direct Packet Forwarding
DRB (Data Radio Beaer)
Signaling in Radio
S1 Bearer (GTP Tunnel)
S1 Signaling
X2 Bearer (GTP Tunnel)
X2 Signaling
S11 (GTP-C) Signaling
UL Traffic
DL Traffic

Evolved Multimedia Broadcast Multicast Services (eMBMS)

Evolved Multimedia Broadcast Multicast Services (eMBMS)



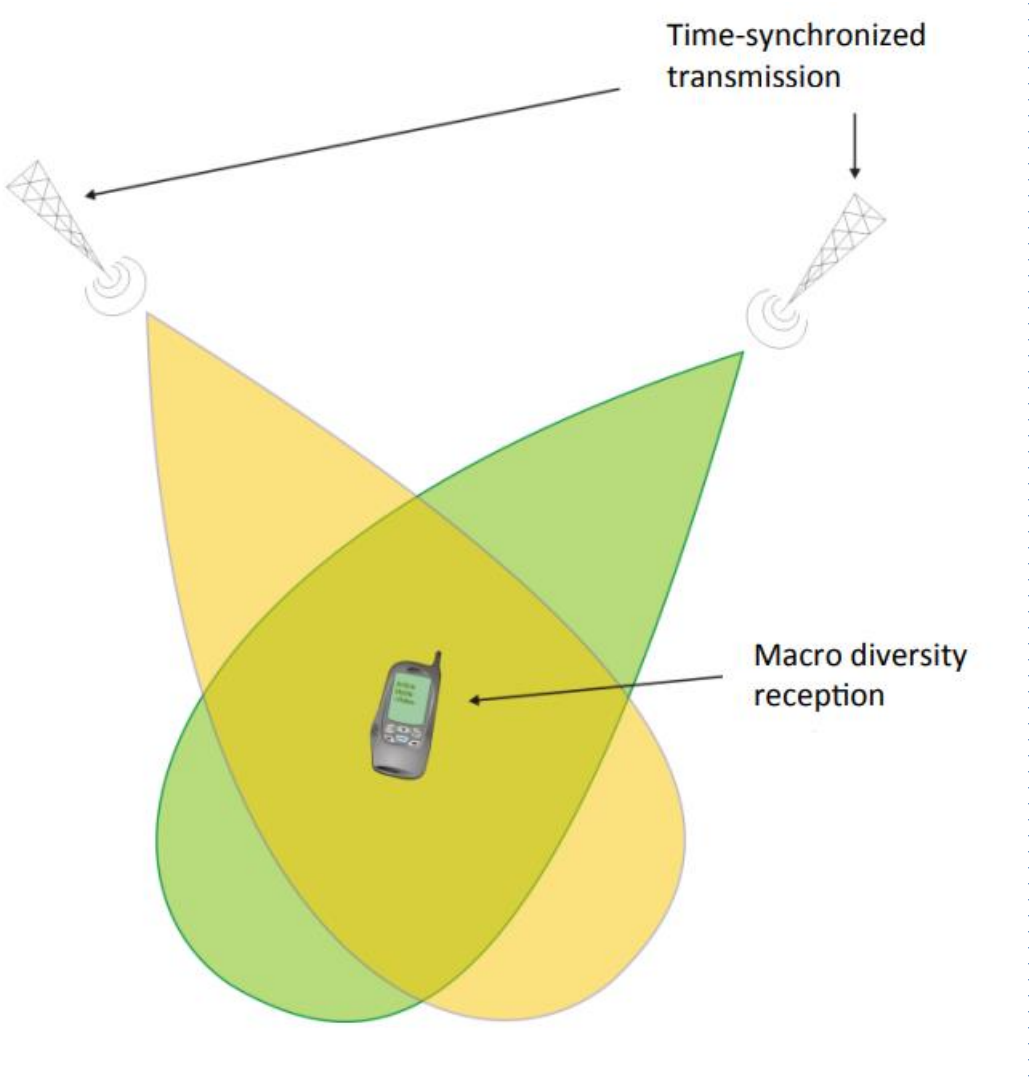
Broadcast Multicast Service Center (BMSC)
Interface with content providers including billing and the content to be transmitted.

MBMS Gateway (MBMS-GW)
Delivers MBMS traffic using IP-multicast reaching multiple cells

Multi-cell/multicast Coordination Entity (MCE)
Administration of radio resources for MBMS

Mobility Management Entity (MME)
Session control signaling (start, update, and stop, QoS)

MBMS single-frequency network (MBSFN)

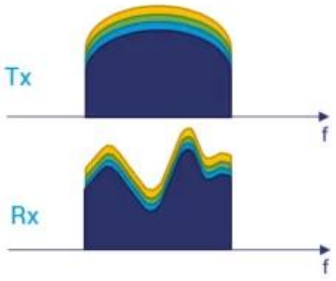


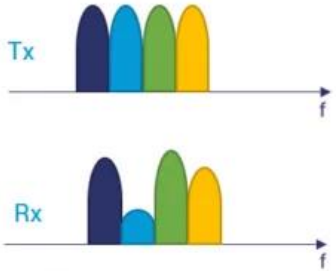
LTE Transmission Techniques

- LTE employs Orthogonal Frequency Division Multiple Access (OFDMA) for downlink data transmission and Single Carrier FDMA (SC-FDMA) for uplink transmission

LTE-Downlink (OFDM)

2 options for transmitting the data





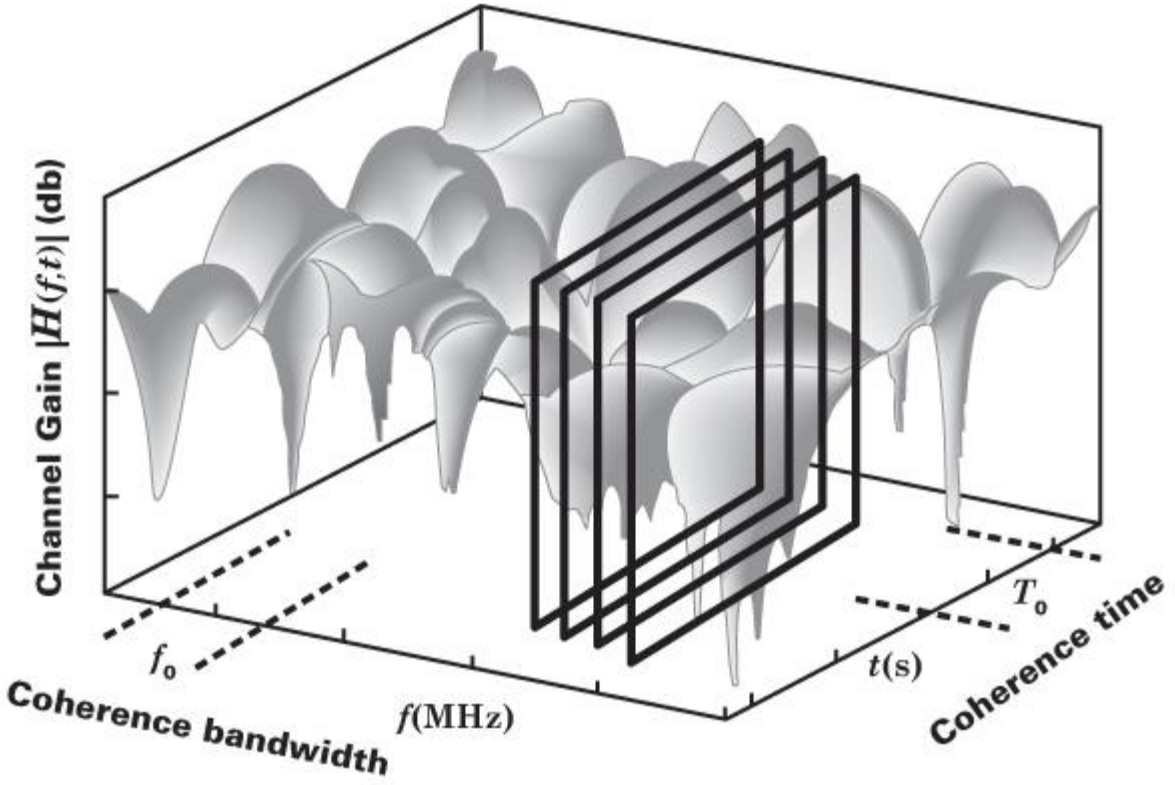
Both cary the same date but a deep fade damages only 1/4 of data

2 options for shipment goods via a truck

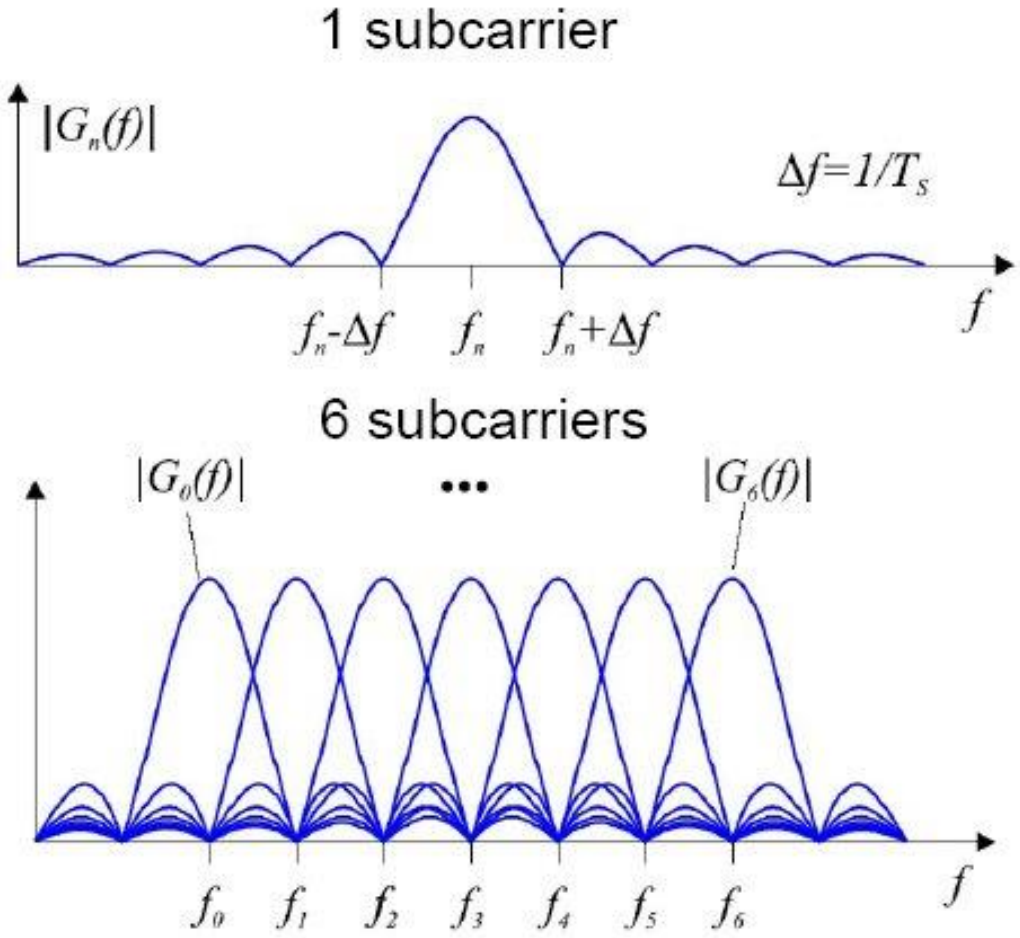
Both carry the same goods, but an accident damages only 1/4 of goods

GRANDMETRIC WATCH!

LTE-Downlink (OFDM)



LTE-Downlink (OFDM)



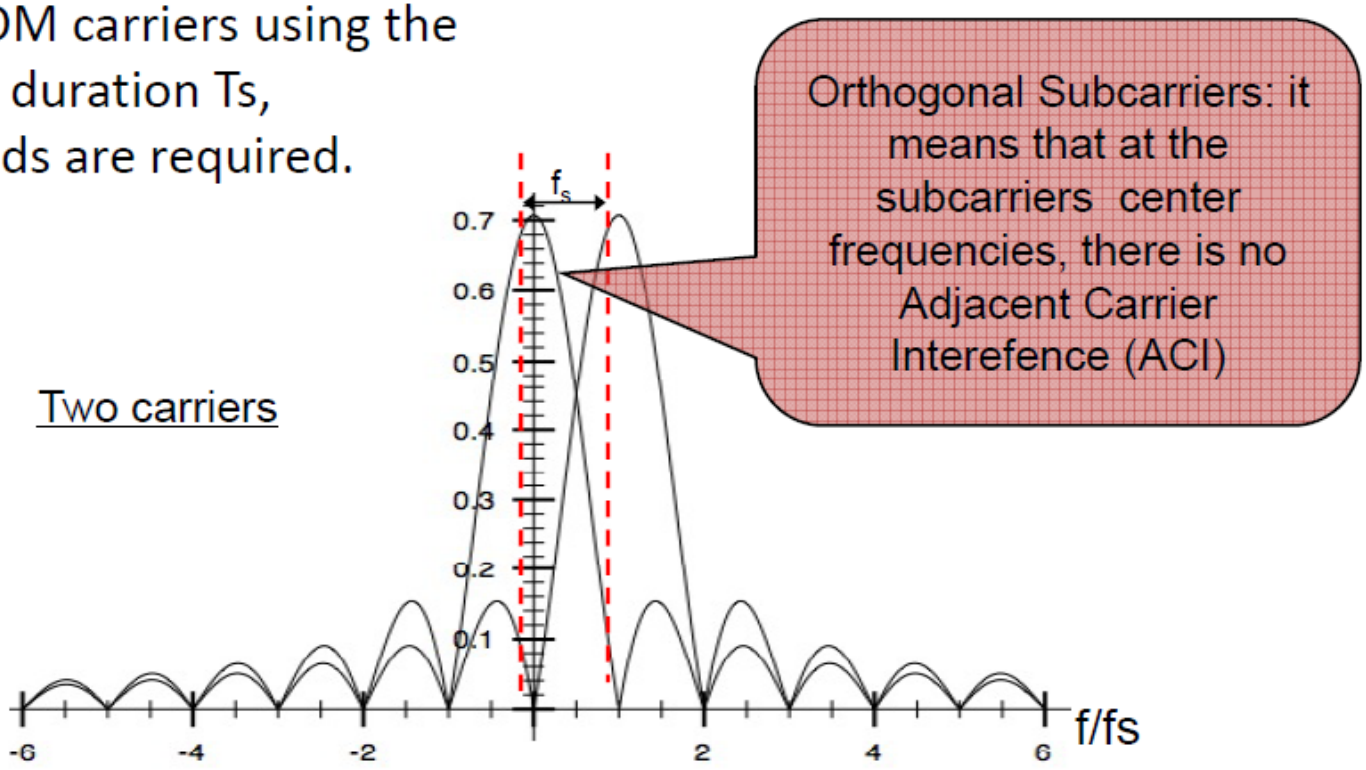
- Improved spectral efficiency
- Reduce ISI effect by multipath
- Against frequency selective fading

OFDM: Orthogonal Frequency Division Multi-Carrier

Thus OFDM simply places the next carrier exactly in the first null point of the previous one.

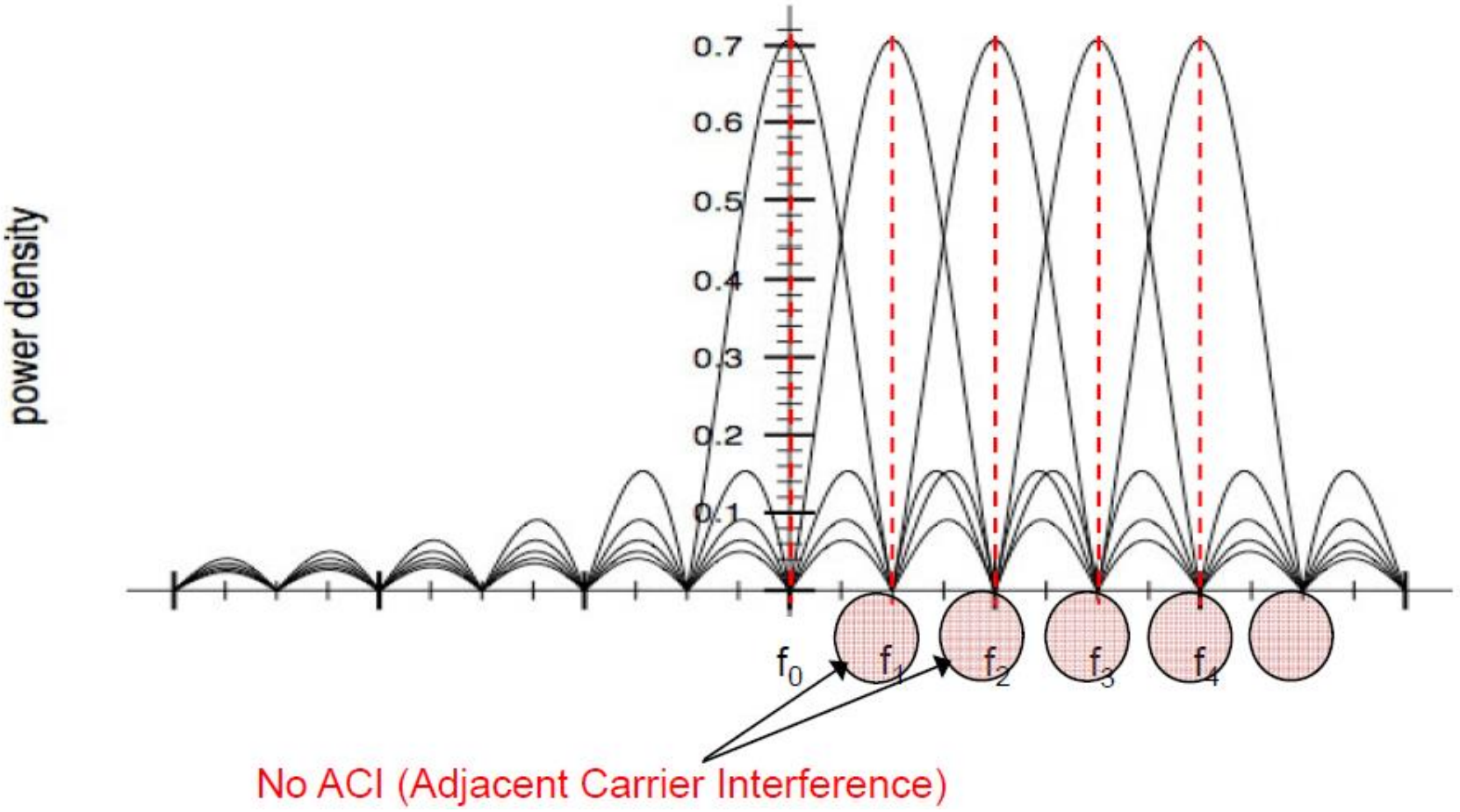
With this we don't need any pulse-shaping.

Between OFDM carriers using the same symbol duration Ts, no guard bands are required.



Spectrum Overlapping of multiple OFDM carriers

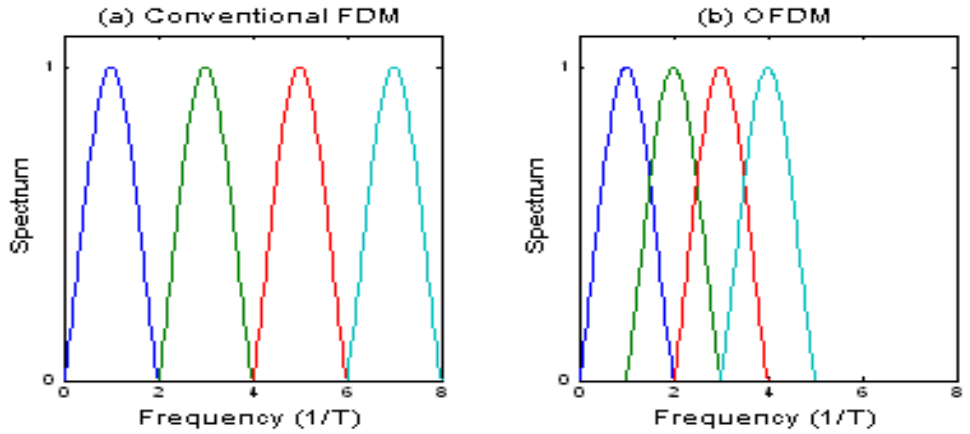
$$f_n = f_0 + nf_s = f_0 + n\frac{1}{T_s} \qquad n = \ldots -1, 0, 1, 2 \ldots.$$



OFDM pros and cons

Pros

- Spectral efficiency
- Robust against narrow-band co-channel interference
- Higher throughput in the same frequency band (more subcarriers)



Cons

- It is more sensitive to carrier frequency offsets
- More energy requirements due to high peak-to-average power ratio (PAPR)

SC/OFDM/OFDMA