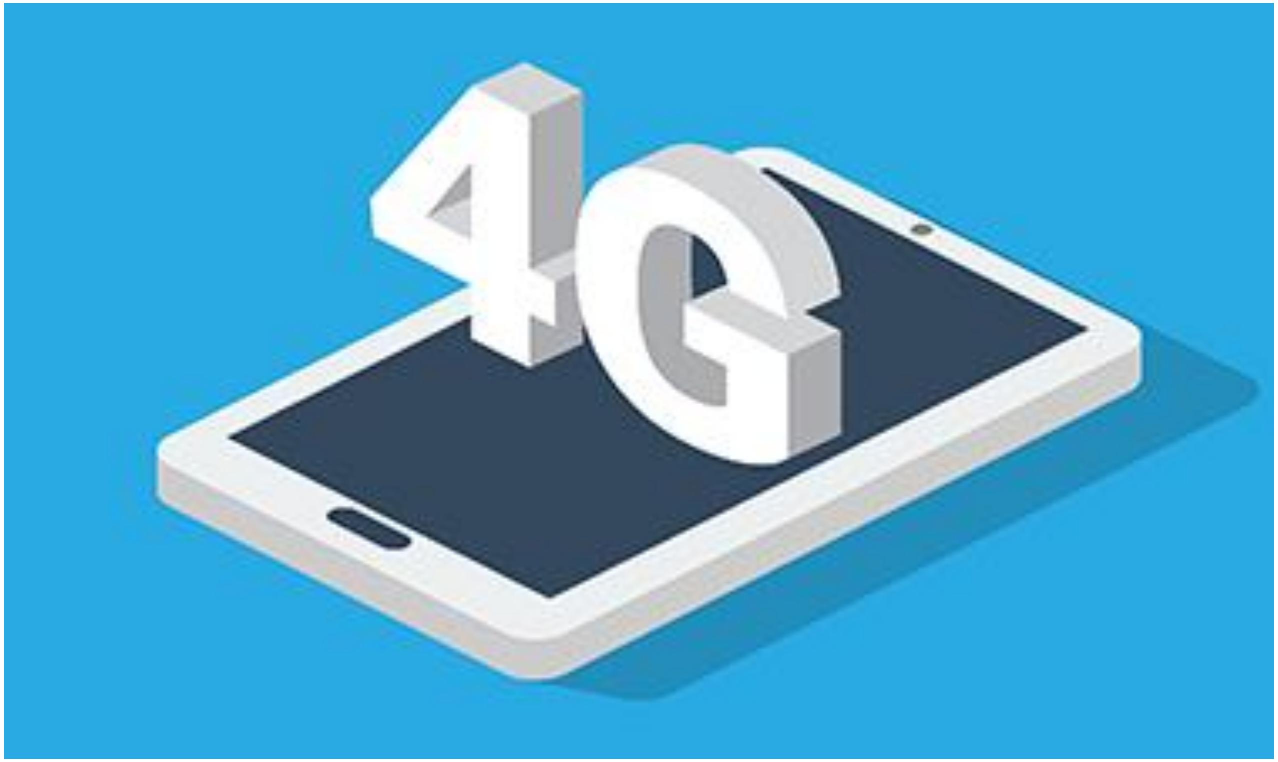


Long Term Evolution (LTE)
Long Term Evolution – Advanced (LTE-A)

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

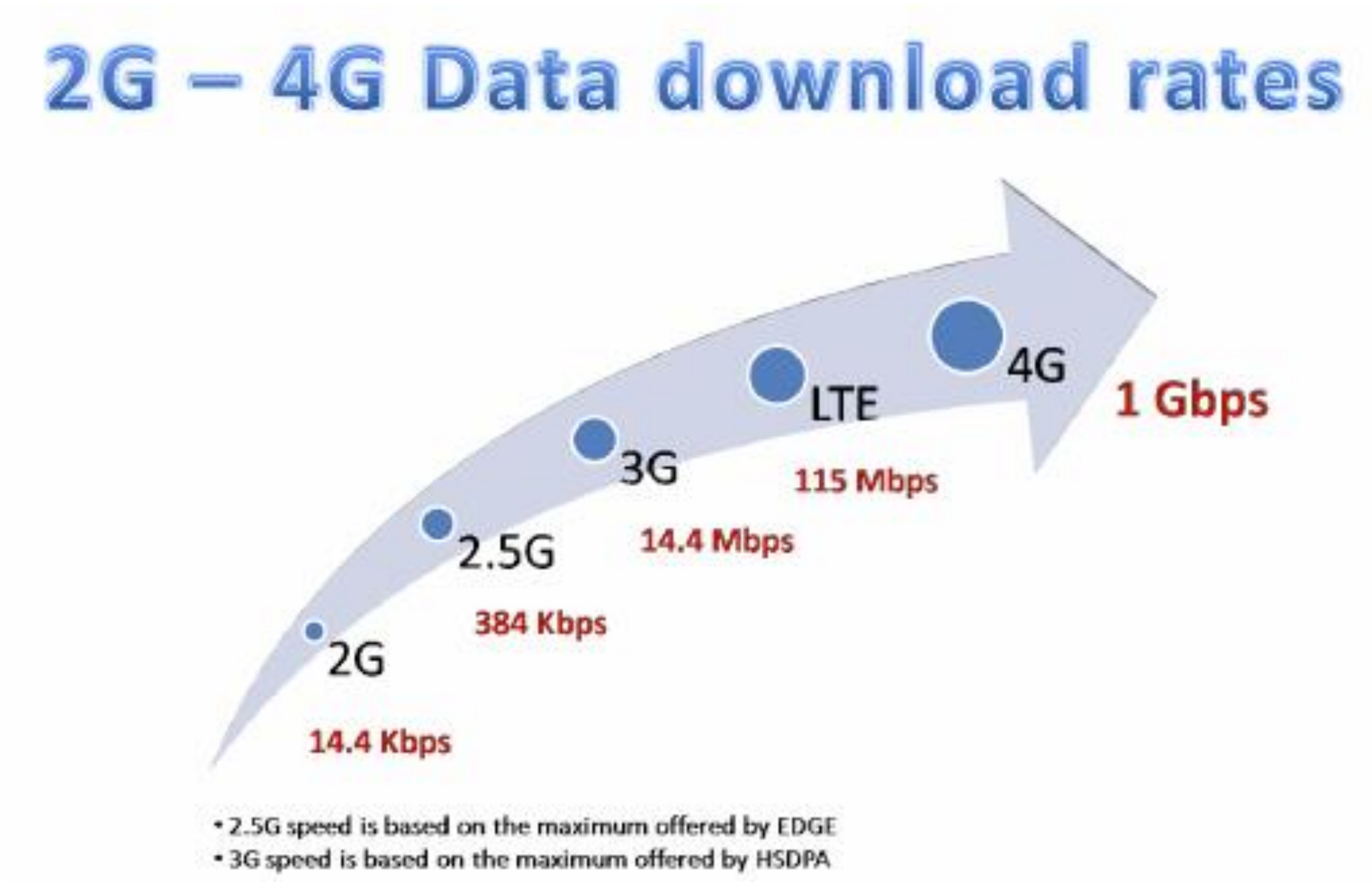
- High network throughput
- Low latency
- Plug & Play architecture
- Low Operating Costs
- All-IP network
- Simplified upgrade path from 3G networks

for Network Operators

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

for End Users

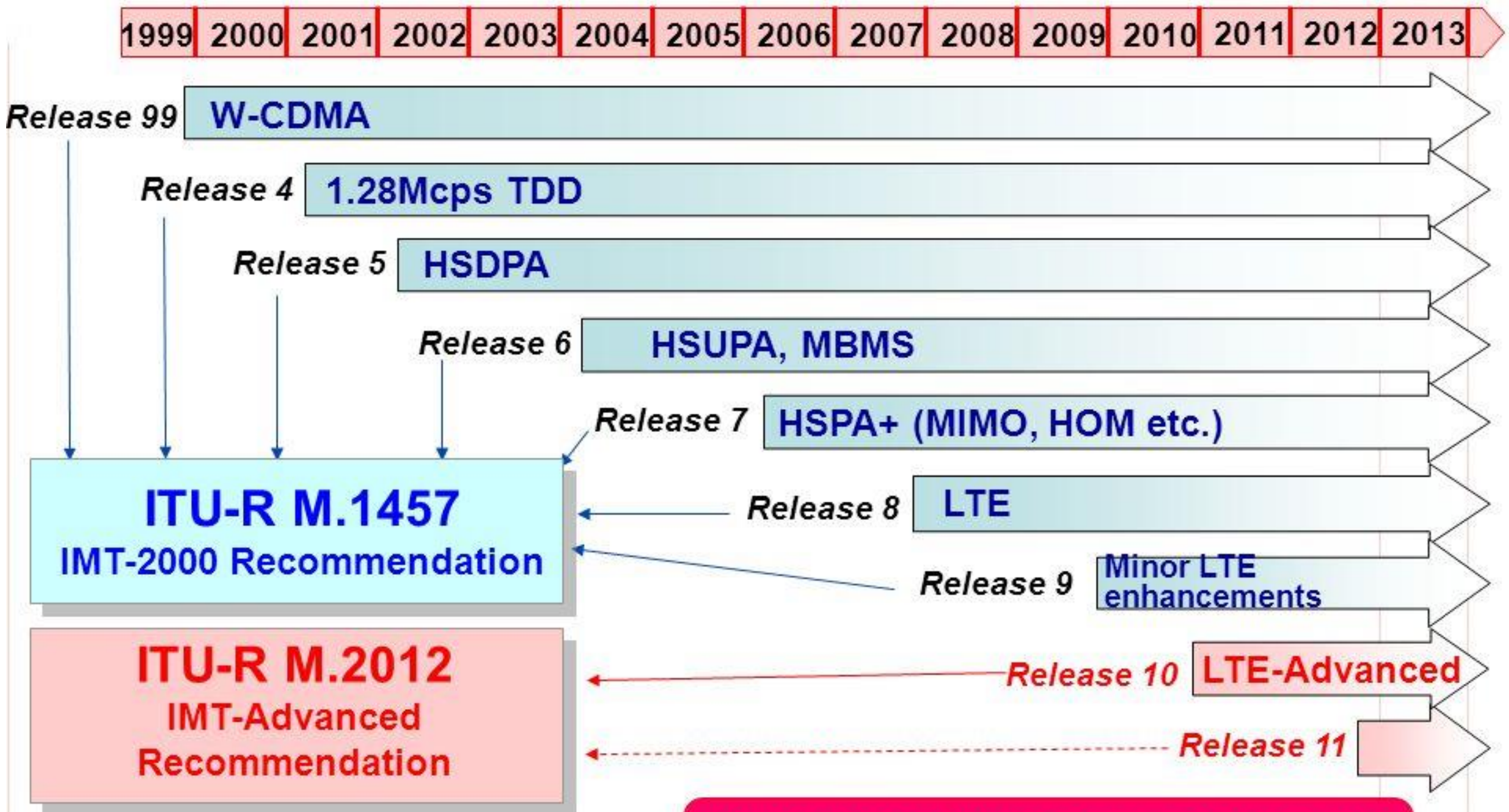
Comparison of LTE Speed



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



3GPP TSG-RAN Workshop on Release 12 onward held on June 11-12, 2012

	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)

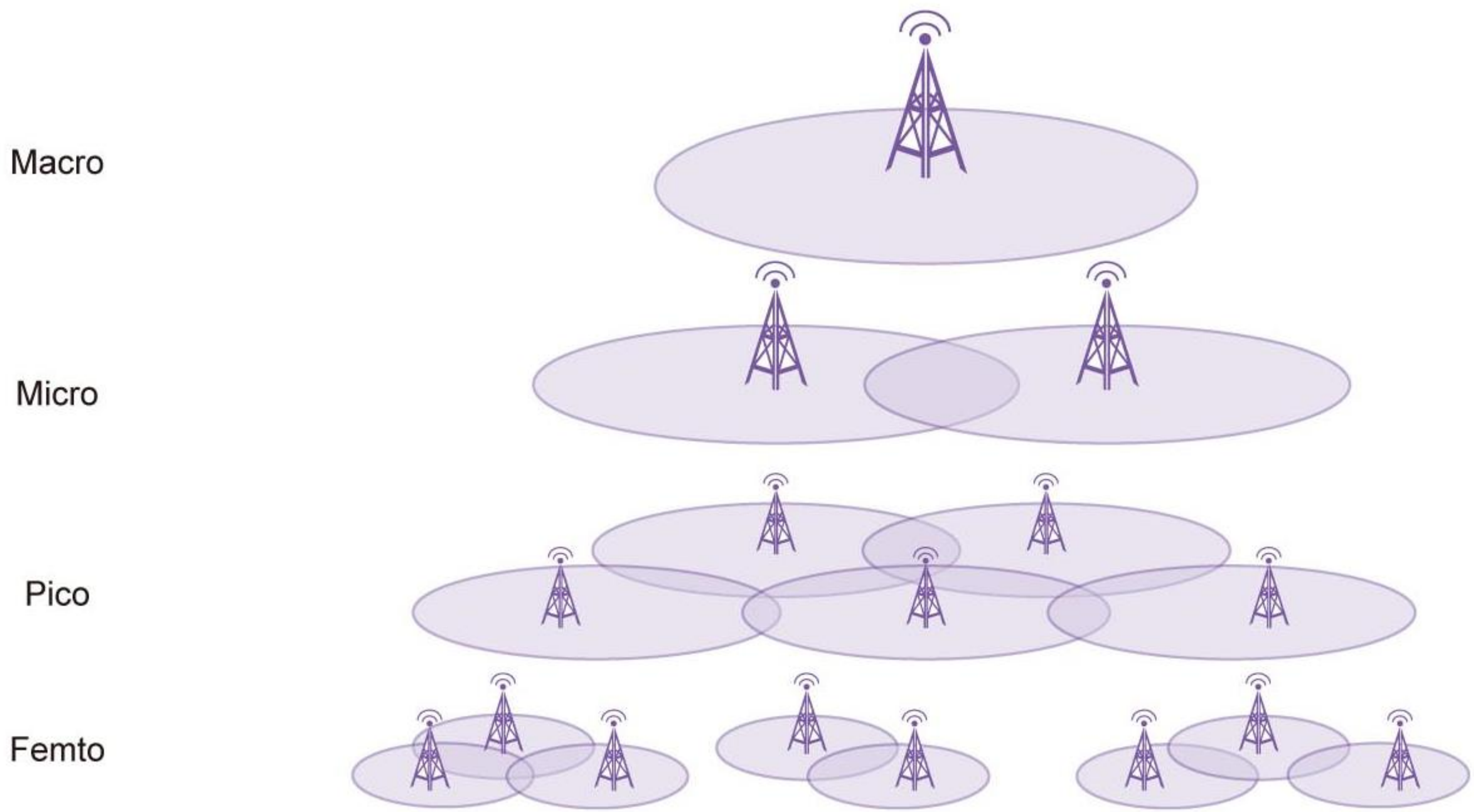
LTE performance requirements

- Mobility
  - Optimized for low mobility(0-15km/h) but supports high speed
- Latency
  - user plane   < 5ms
  - control plane < 50 ms
- Improved spectrum efficiency
- Improved broadcasting
- IP-optimized
- Scalable bandwidth of 20, 15, 10, 5, 3 and 1.4MHz
- Co-existence with legacy standards

Key parameters of LTE

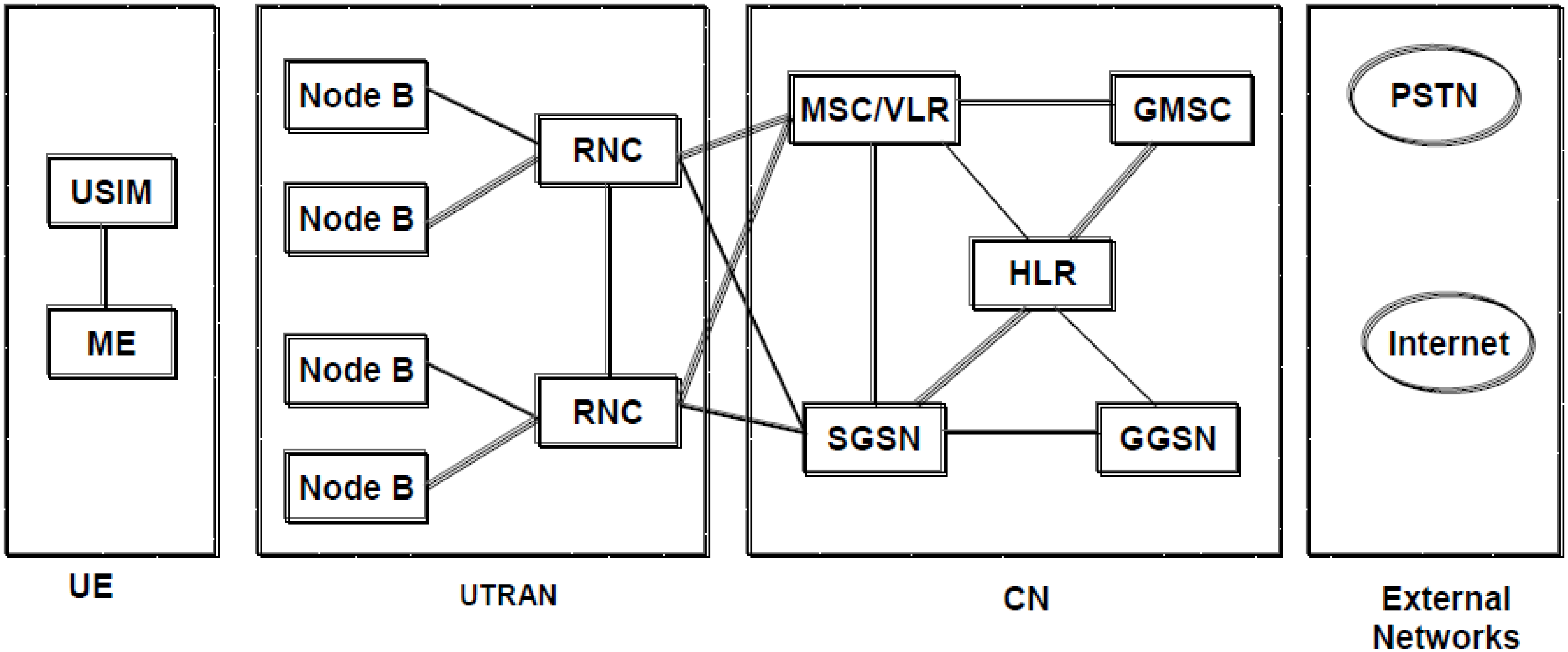
Frequency Range	**UMTS FDD bands and UMTS TDD bands**					
Channel bandwidth	**1.4 MHz**	**3 MHz**	**5 MHz**	**10 MHz**	**15 MHz**	**20 MHz**
1 Resource Block (RB) =180 kHz	6 RB	15 RB	25 RB	50 RB	75 RB	100 RB
Modulation Schemes	**Downlink**	QPSK, 16QAM, 64QAM				
	Uplink	QPSK, 16QAM, 64QAM (⇨ optional 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



LTE frequency bands

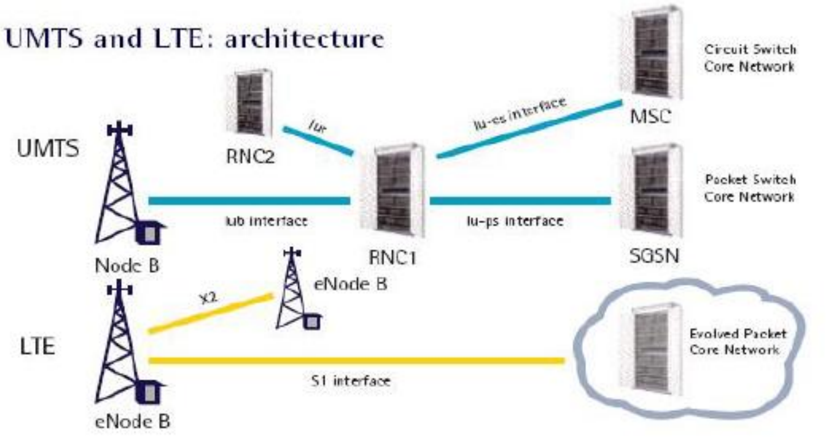
UMTS Architecture

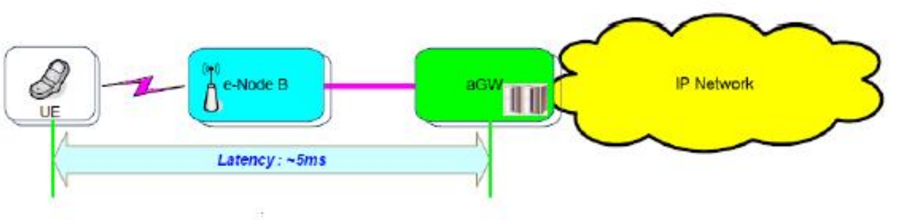


- UE (User Equipment) that interfaces with the user
- UTRAN (UMTS Terrestrial Radio Access Network) handles all radio related functionality – WCDMA is radio interface standard here.
- CN (Core Network) is responsible for transport functions such as switching and routing calls and data, tracking users

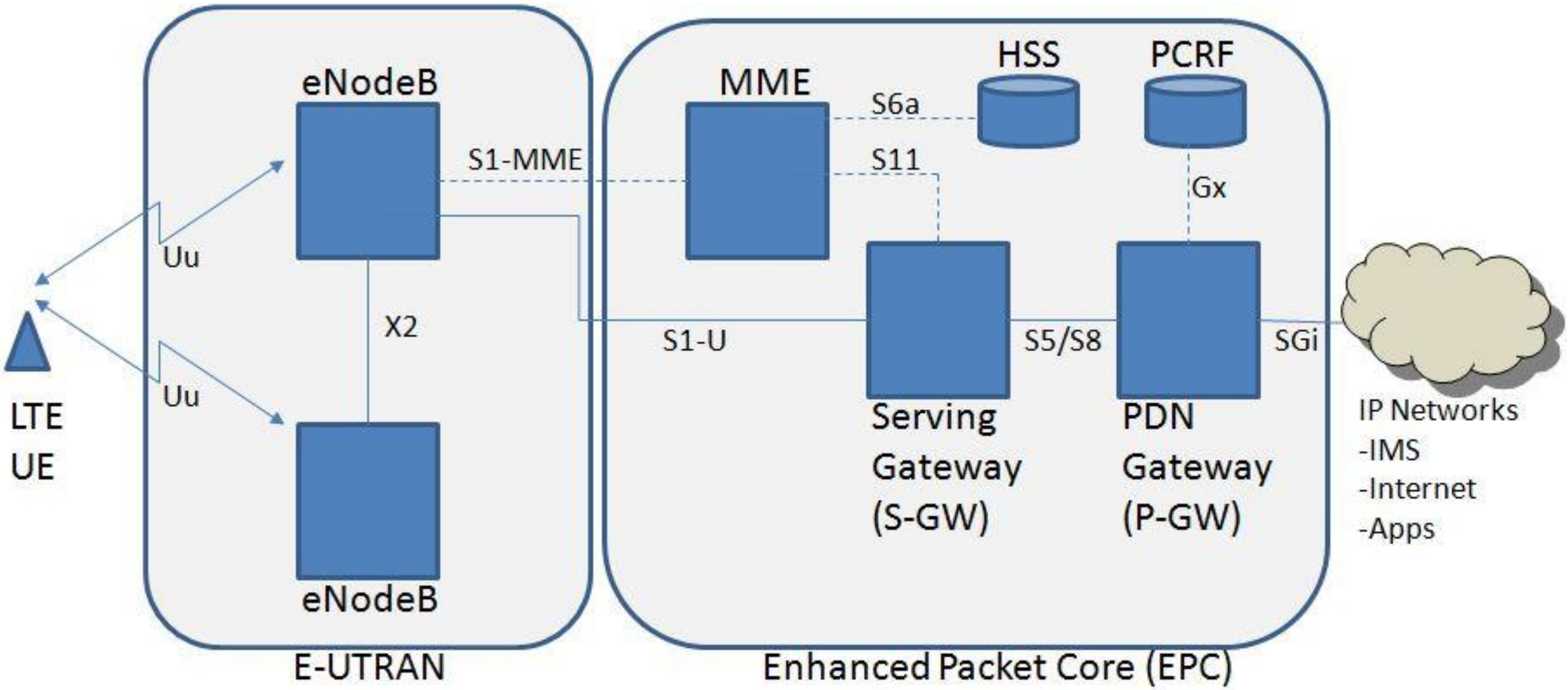
UMTS->LTE Migration

- 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

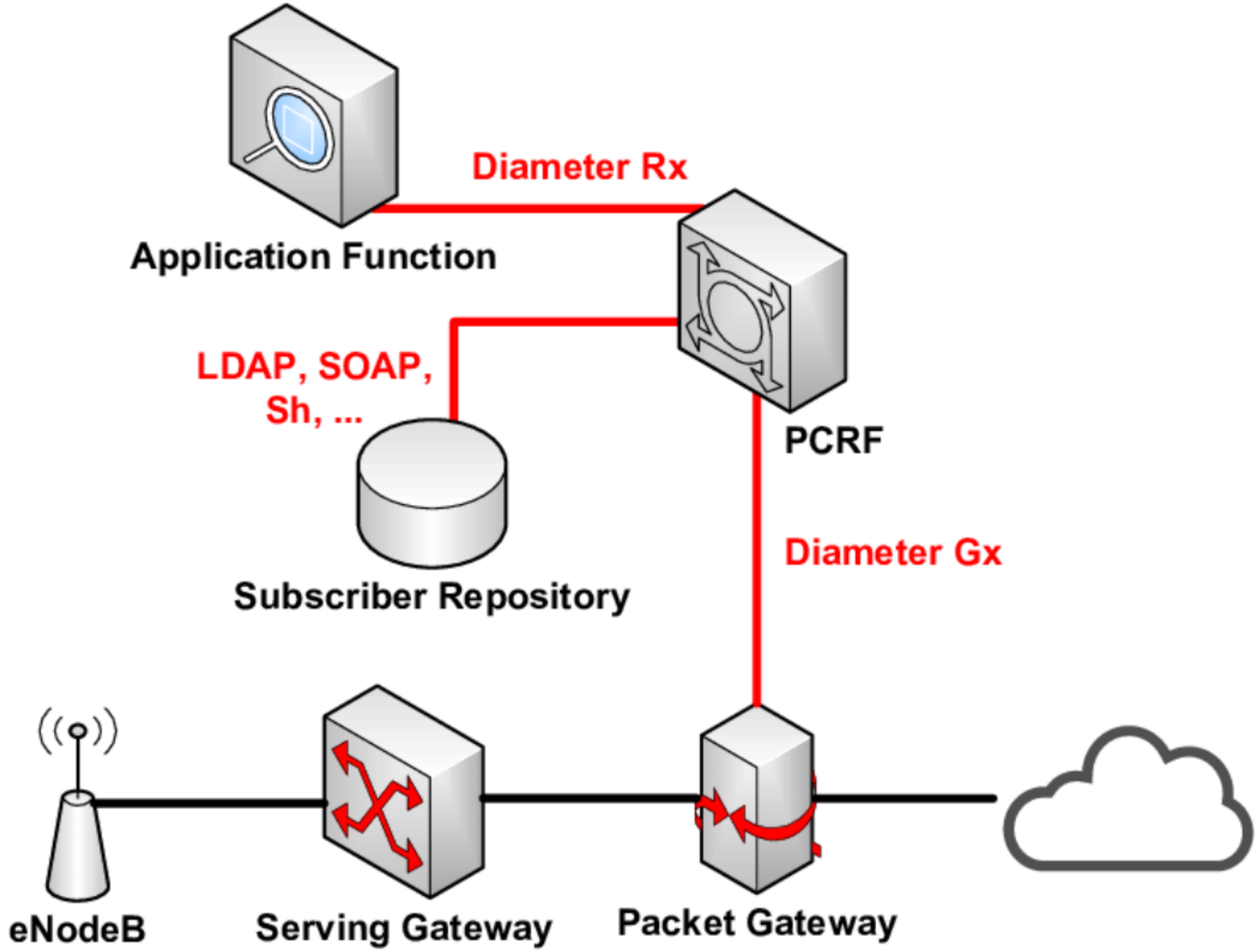




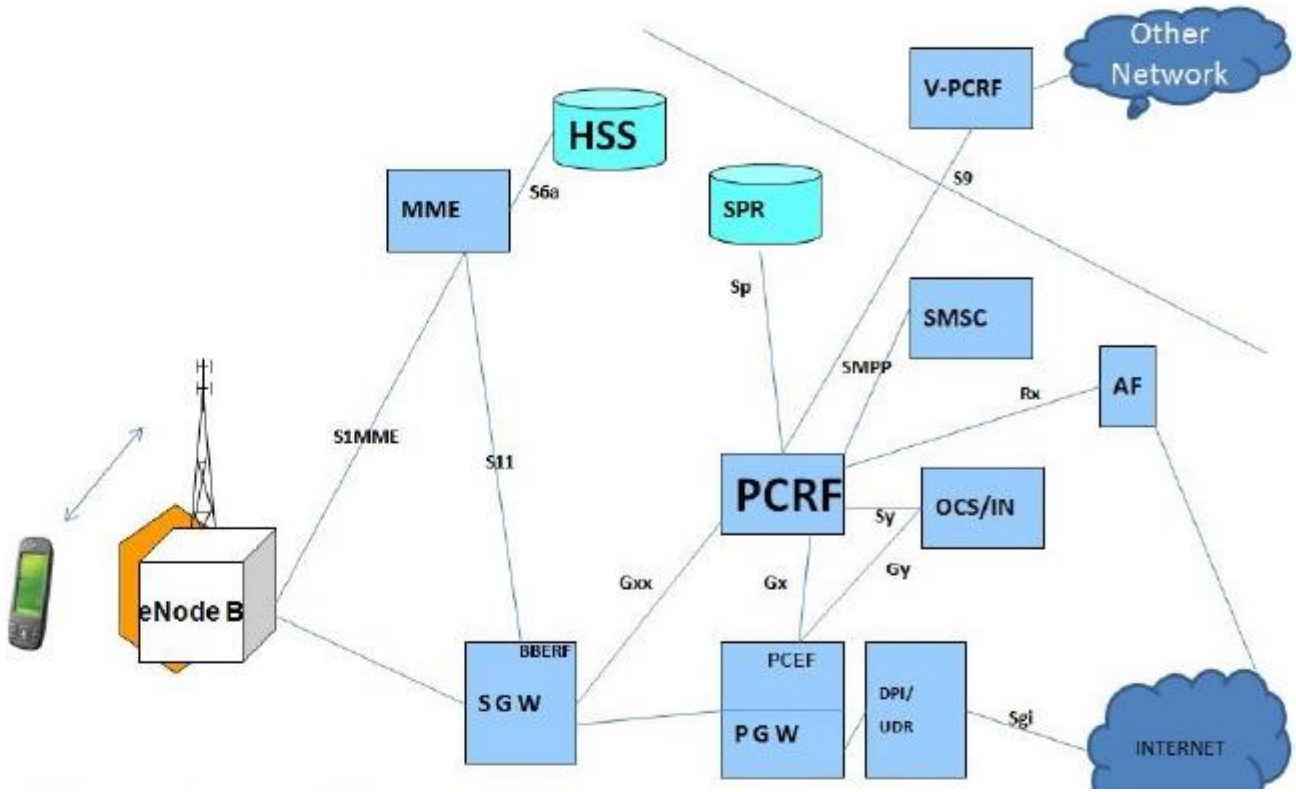
LTE Architecture



LTE Architecture



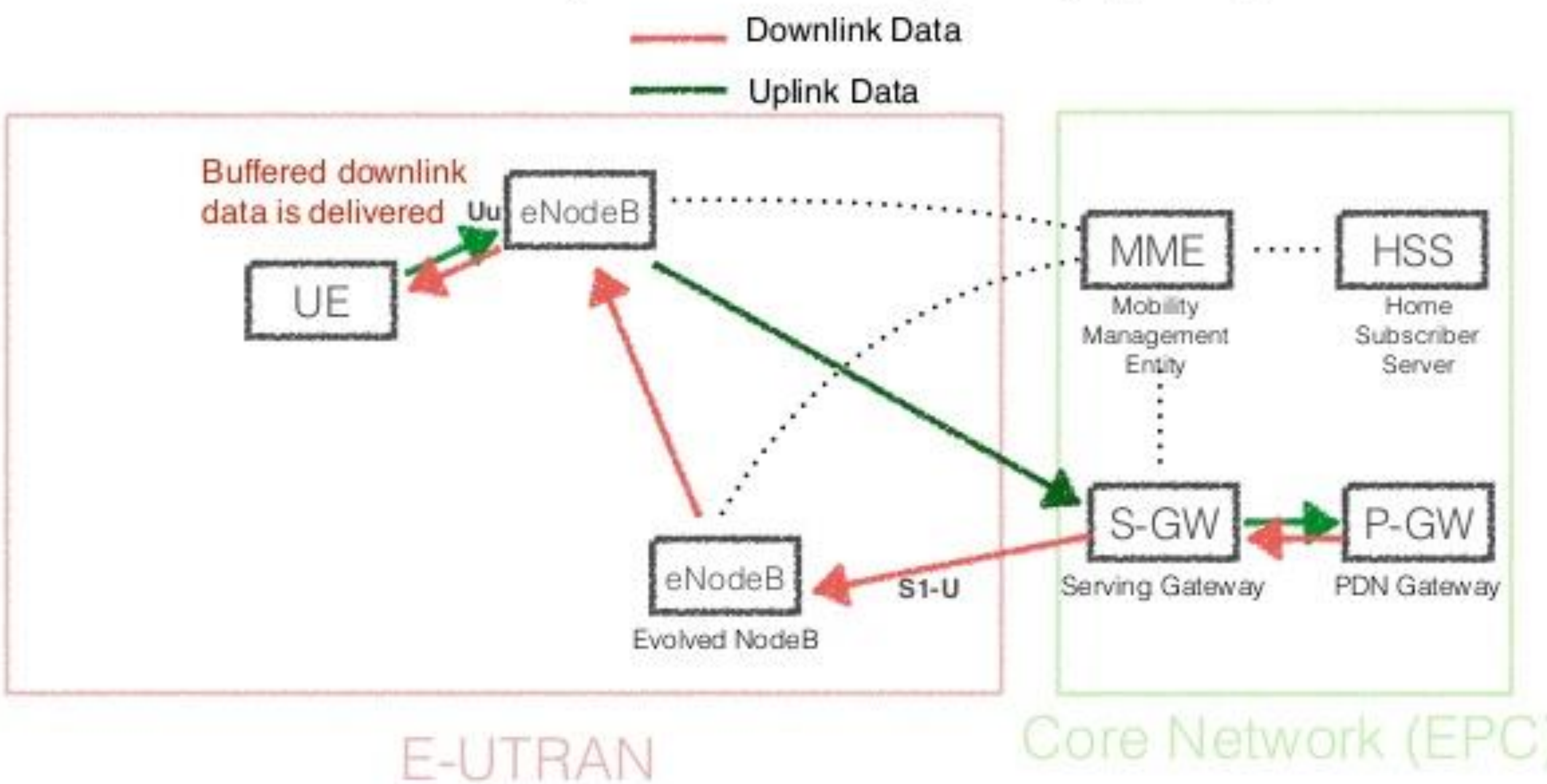
LTE Architecture

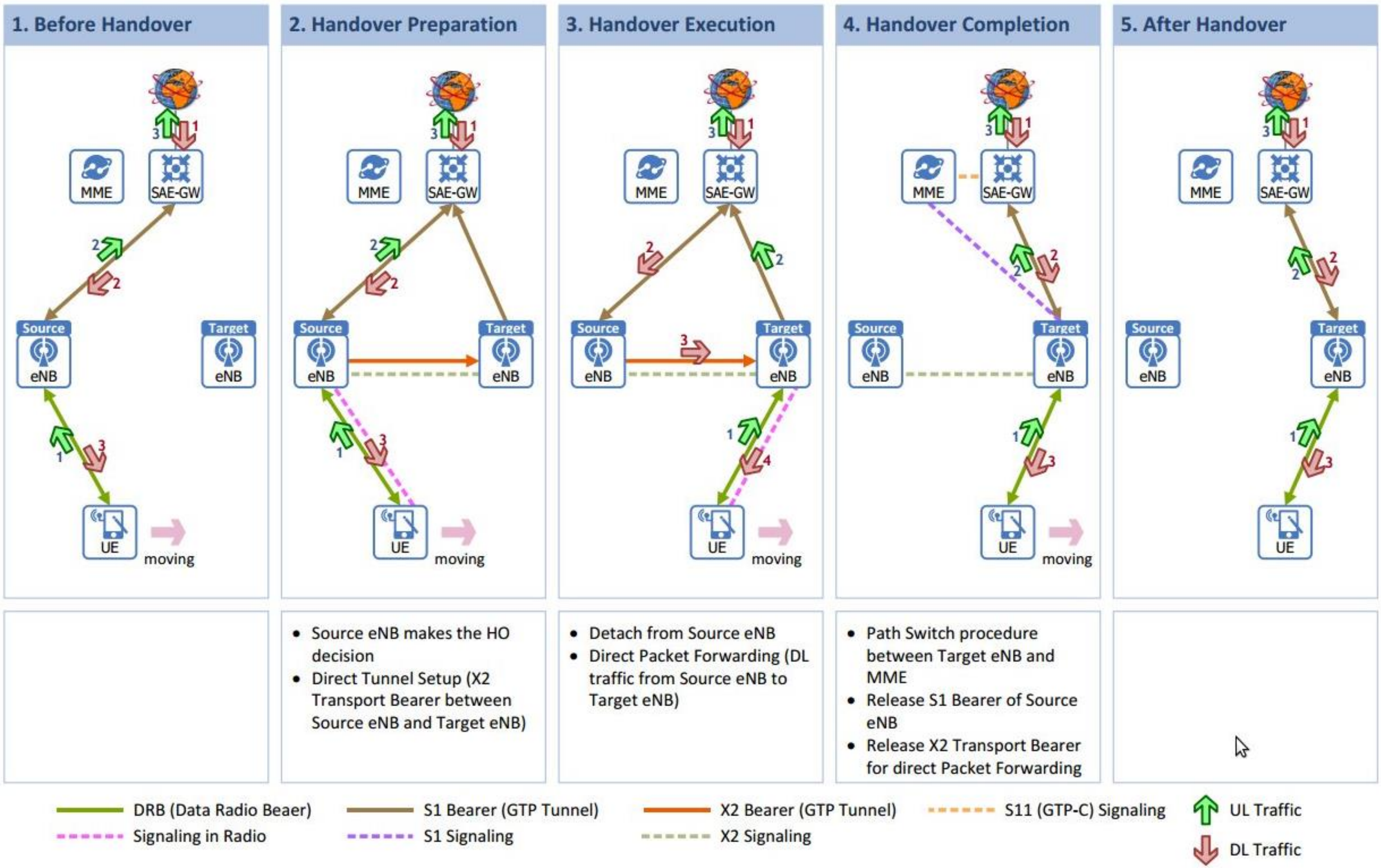


Decision → Request → Preparation → Path Switch → Complete

X2 Handover

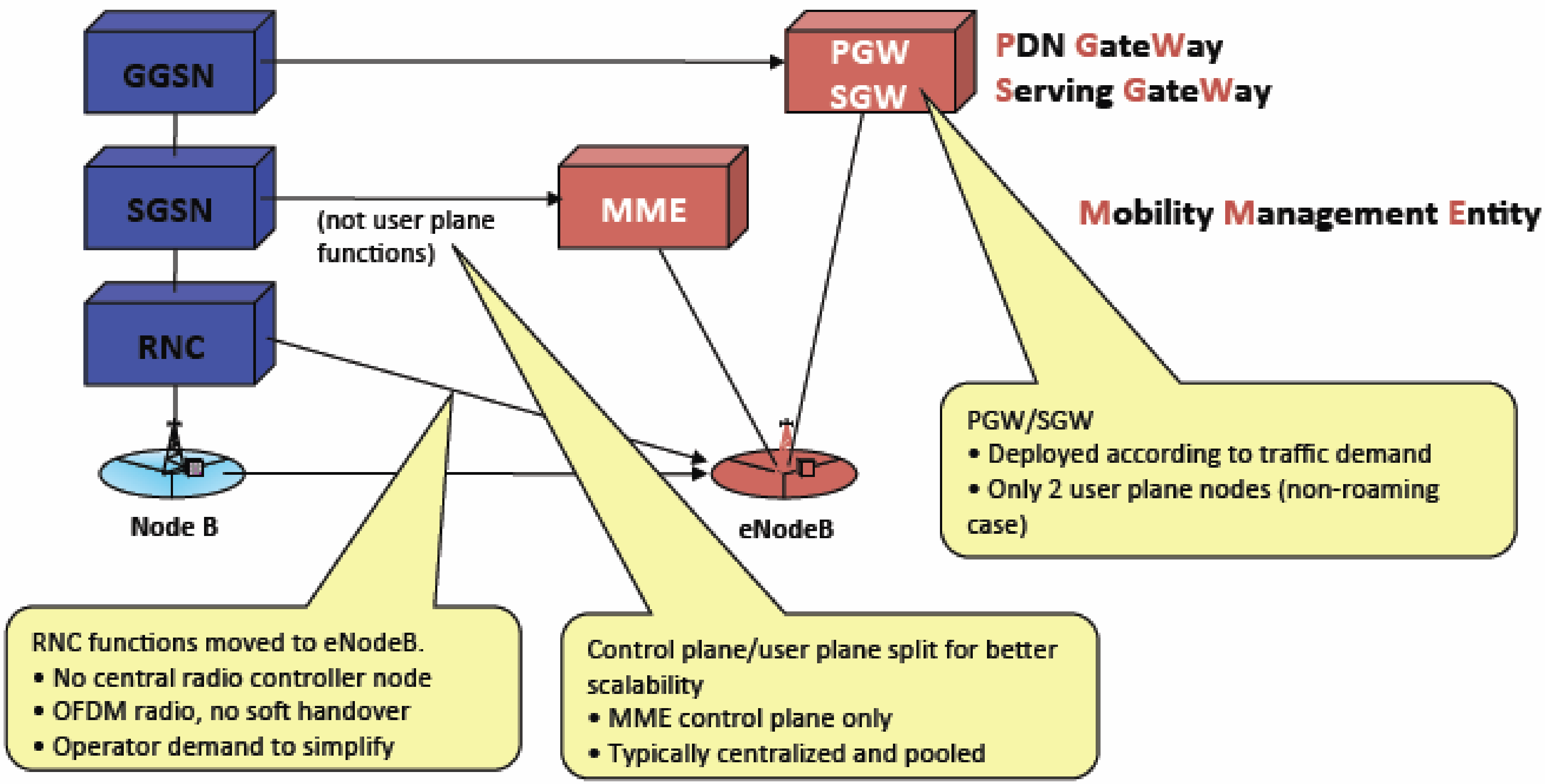
Data flow during handover execution (after ho preparation):



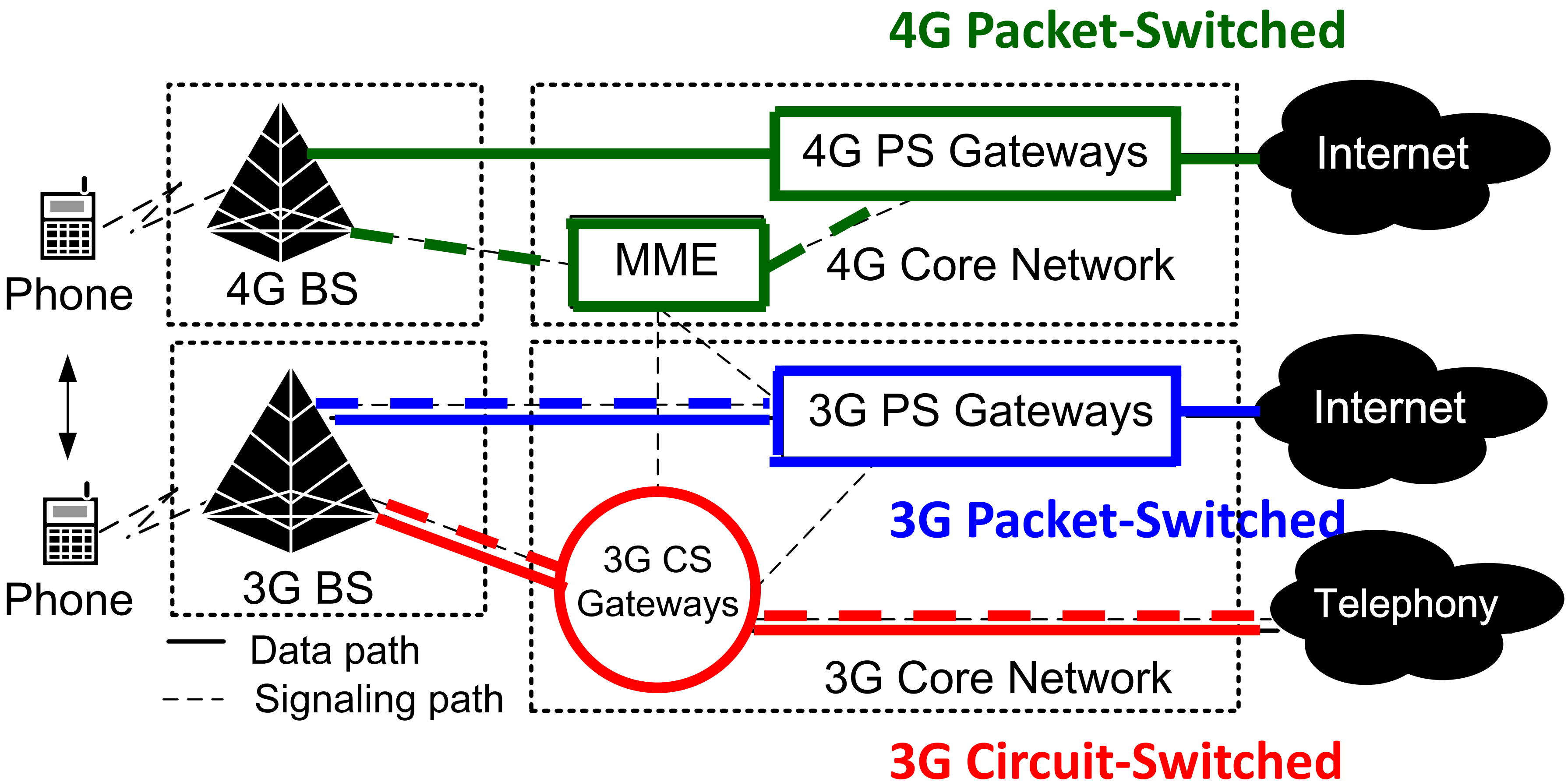

1. Before Handover
2. Handover Preparation
3. Handover Execution
4. Handover Completion
5. After Handover
MME
SAE-GW
Source
Target
eNB
UE
moving
• Source eNB makes the HO decision
• Direct Tunnel Setup (X2 Transport Bearer between Source eNB and Target eNB)
• Detach from Source eNB
• Direct Packet Forwarding (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

LTE vs UMTS

- Functional changes compared to the UMTS architecture



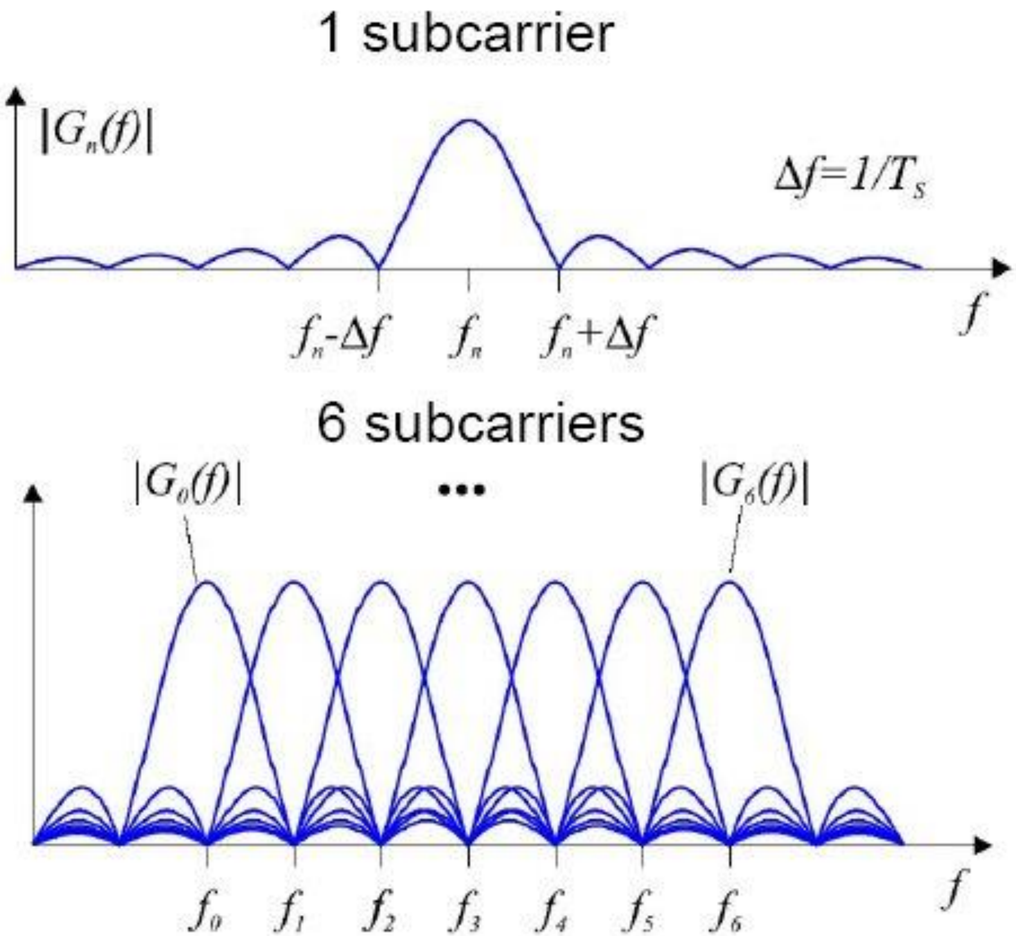
LTE vs UMTS


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

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)



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

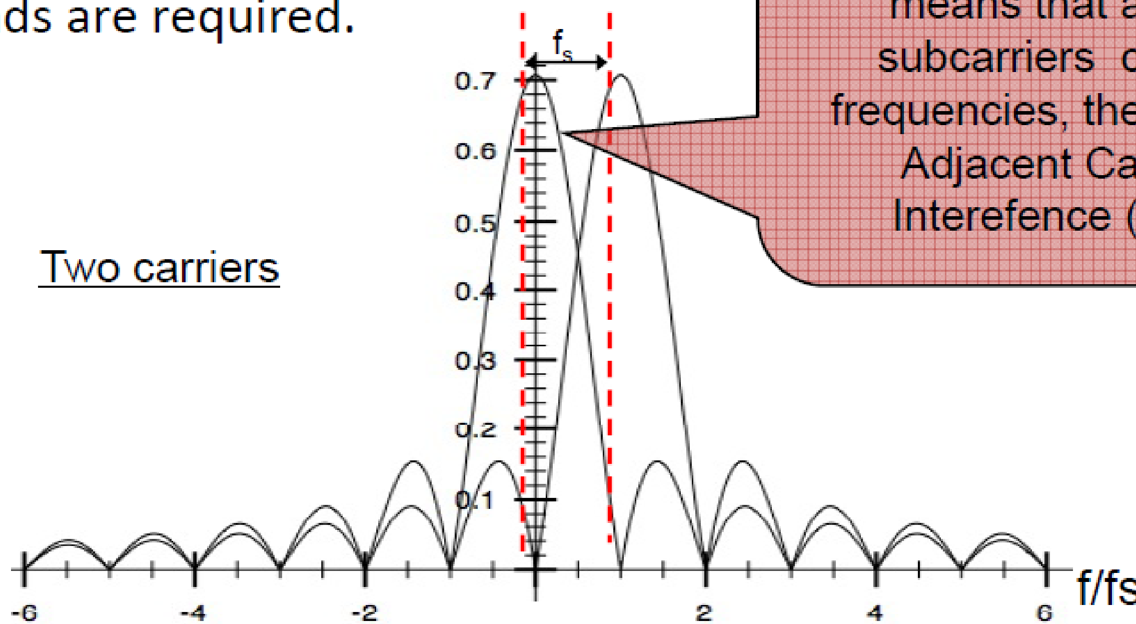
OFDM: Orthogonal Frequency Division Multi-Carrier

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.

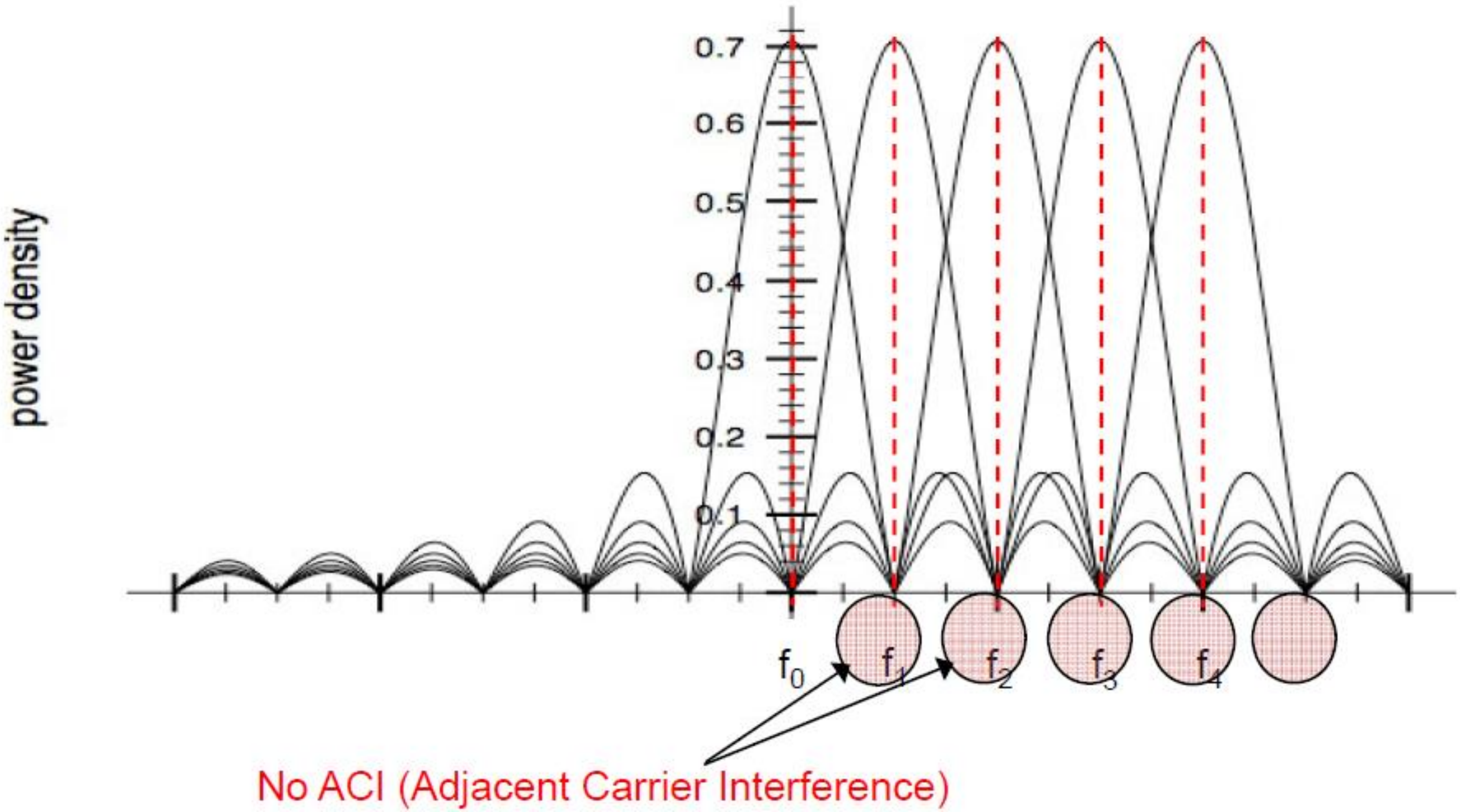
Two carriers



Orthogonal Subcarriers: it means that at the subcarriers center frequencies, there is no Adjacent Carrier Interefence (ACI)

Spectrum Overlapping of multiple OFDM carriers

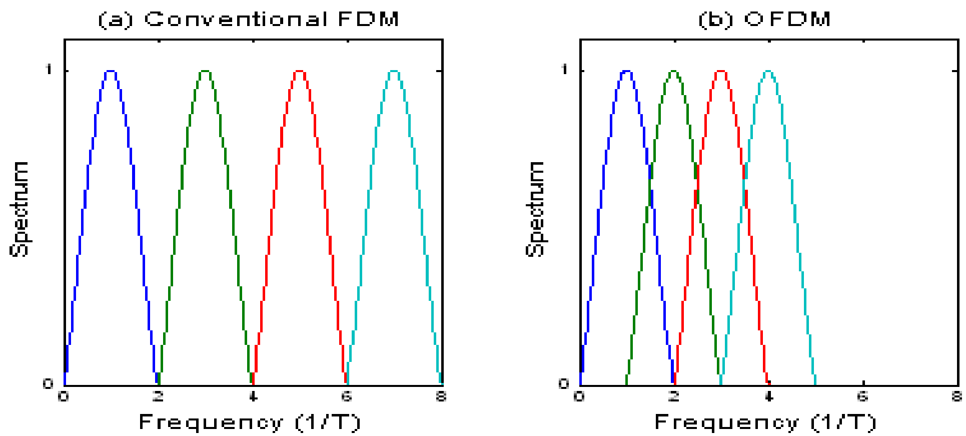
$$f_n = f_0 + nf_s = f_0 + n\frac{1}{T_s} \qquad n = \ldots -1, 0, 1, 2 \ldots$$



OFDM pros and cons

Pros

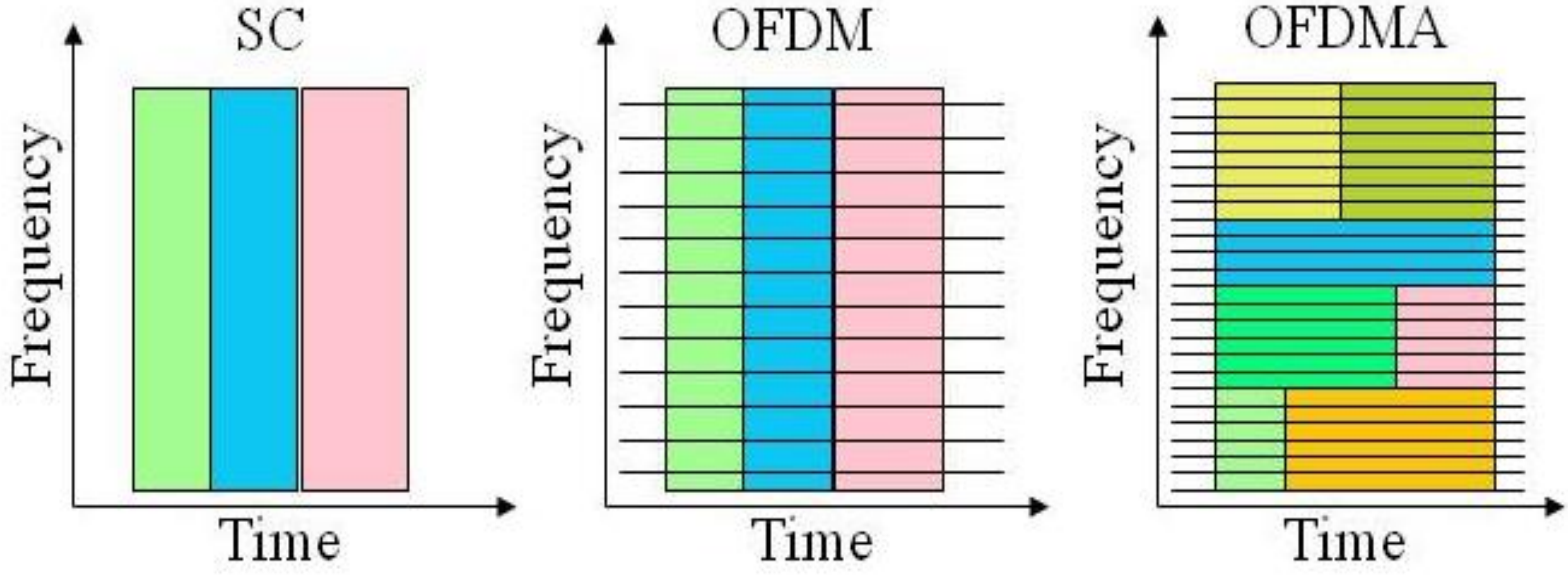
- Spectral efficiency
- Robust against narrow-band co-channel interference
- Higher throughput in the same frequency band (more subcarriers)



Cons

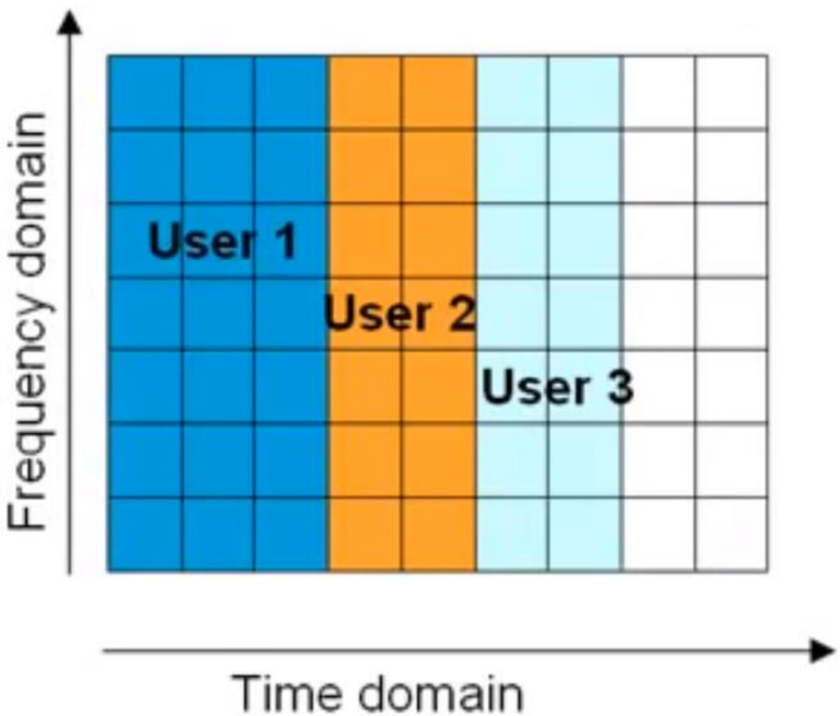
- It is more sensitive to carrier frequency offsets
- More energy requirements due to high peak-to-average power ratio (PAPR)

SC/OFDM/OFDMA

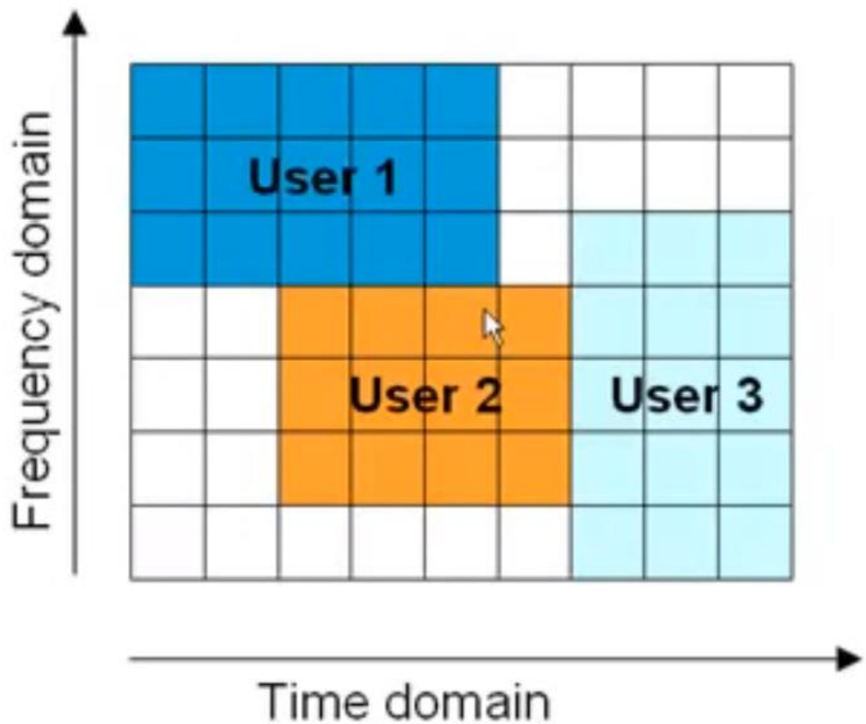


OFDMA allocation

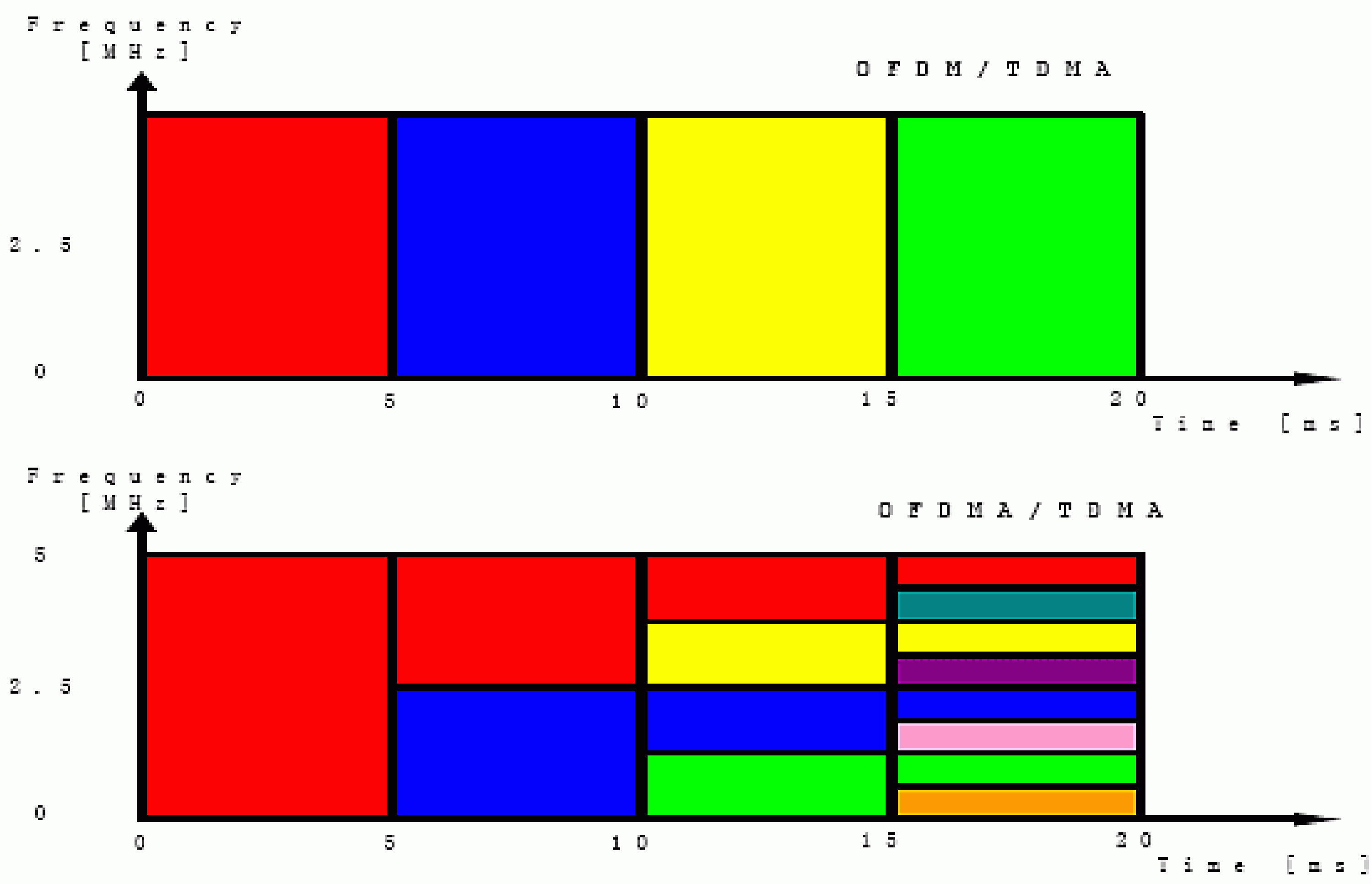
- OFDM allocates users in time domain only



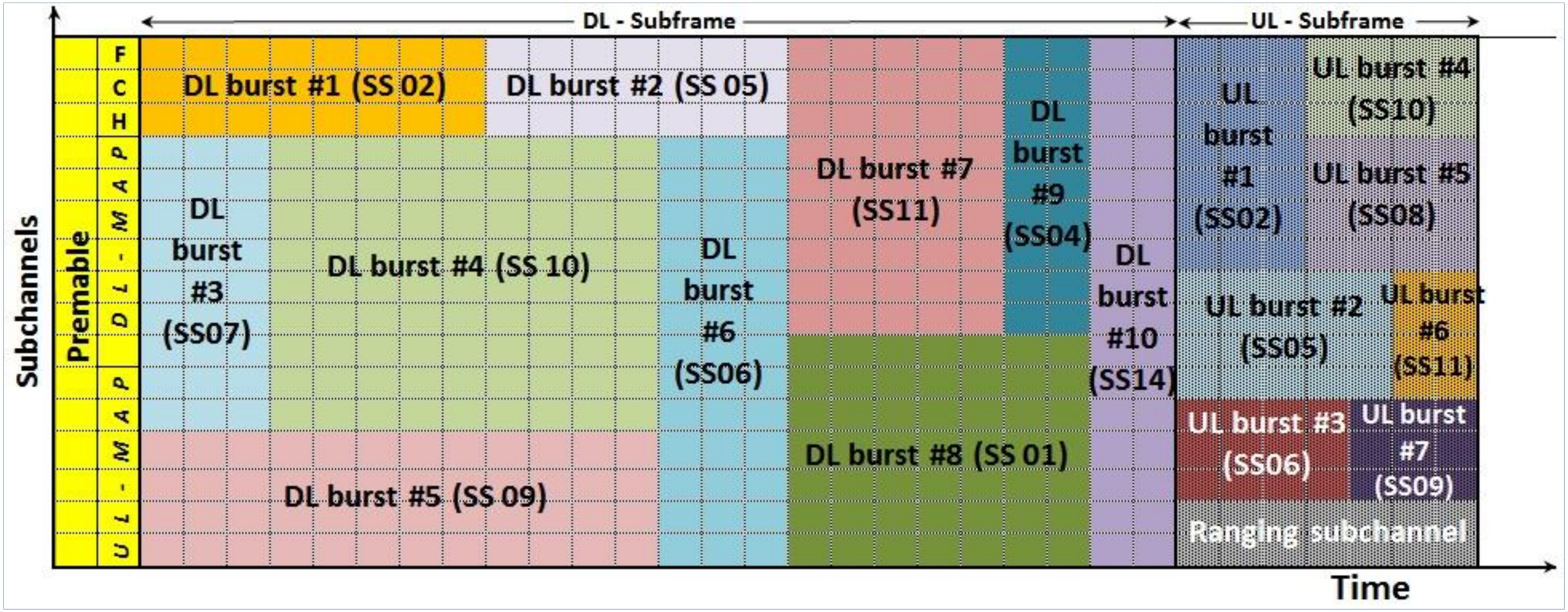
- OFDMA allocates users in time and frequency domain



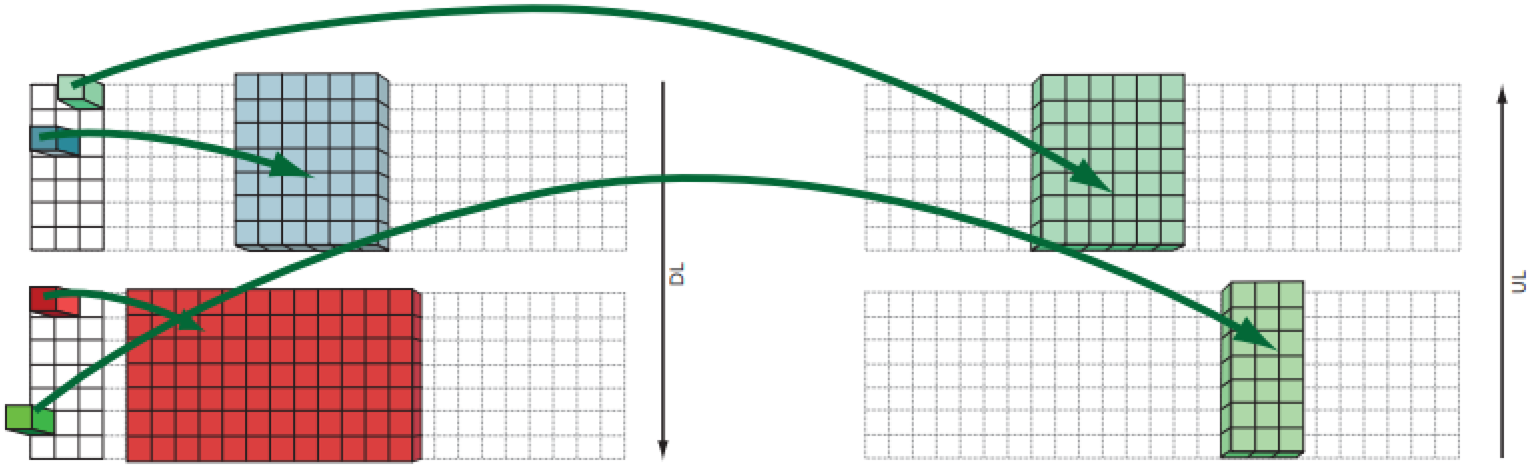
OFDMA allocation



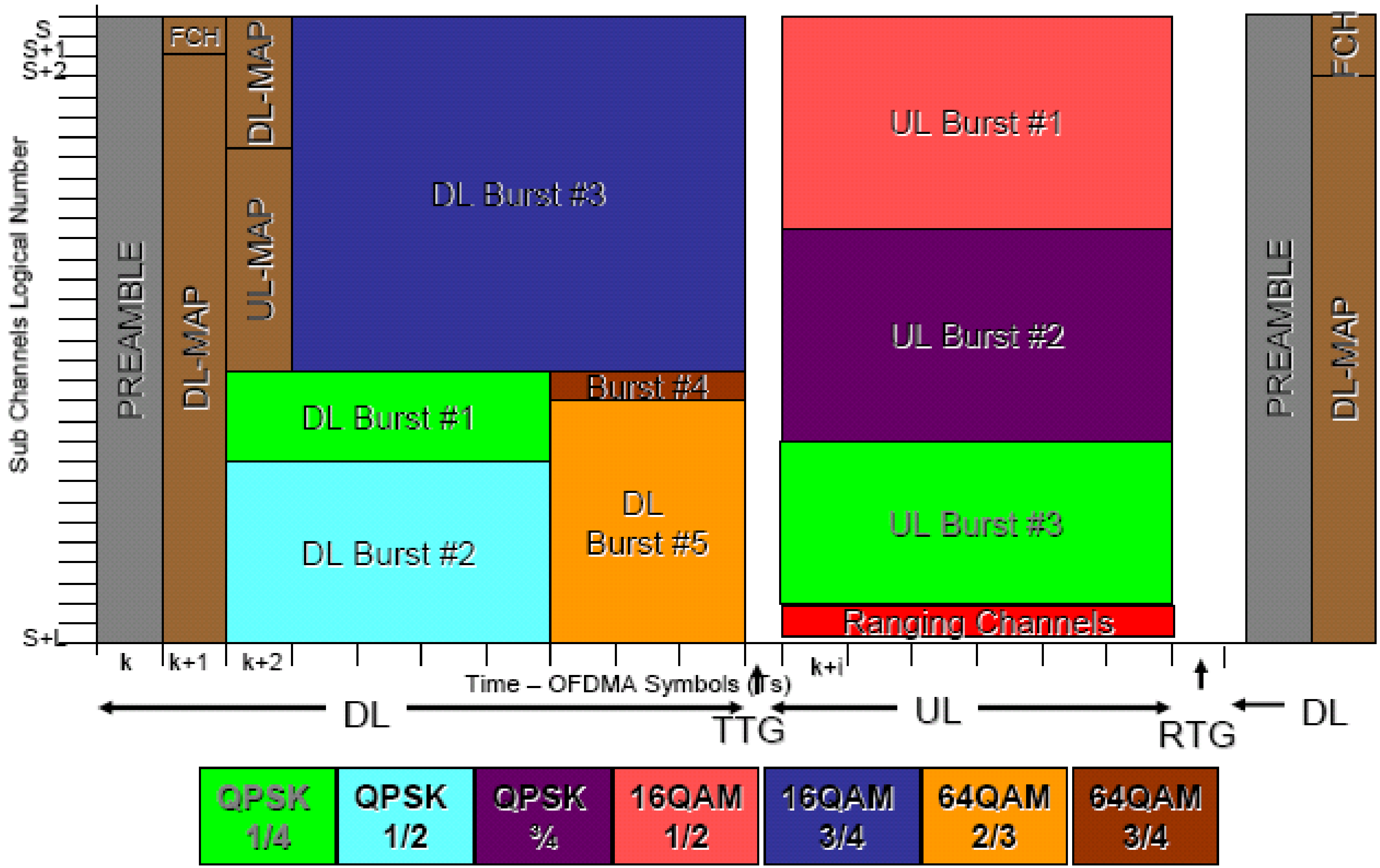
OFDMA/TDD structure



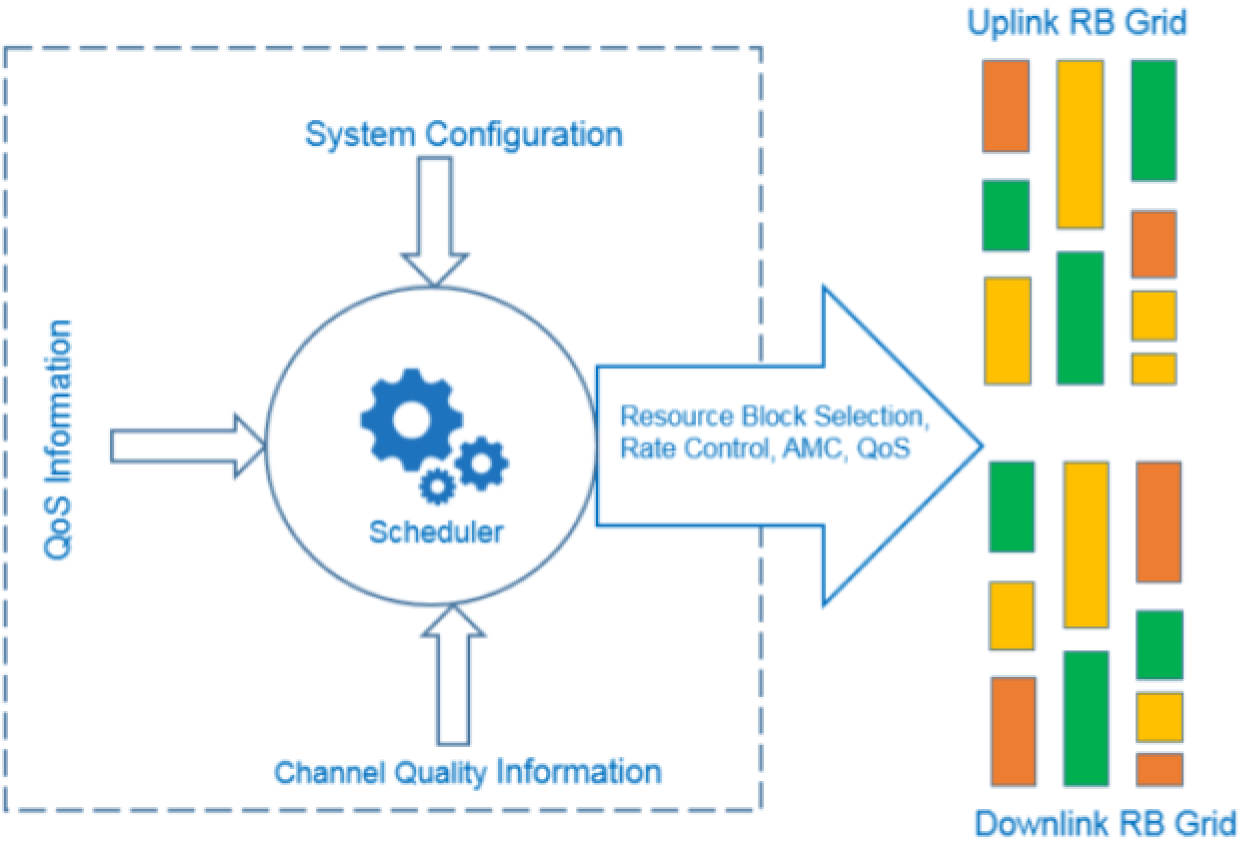
OFDMA/TDD structure



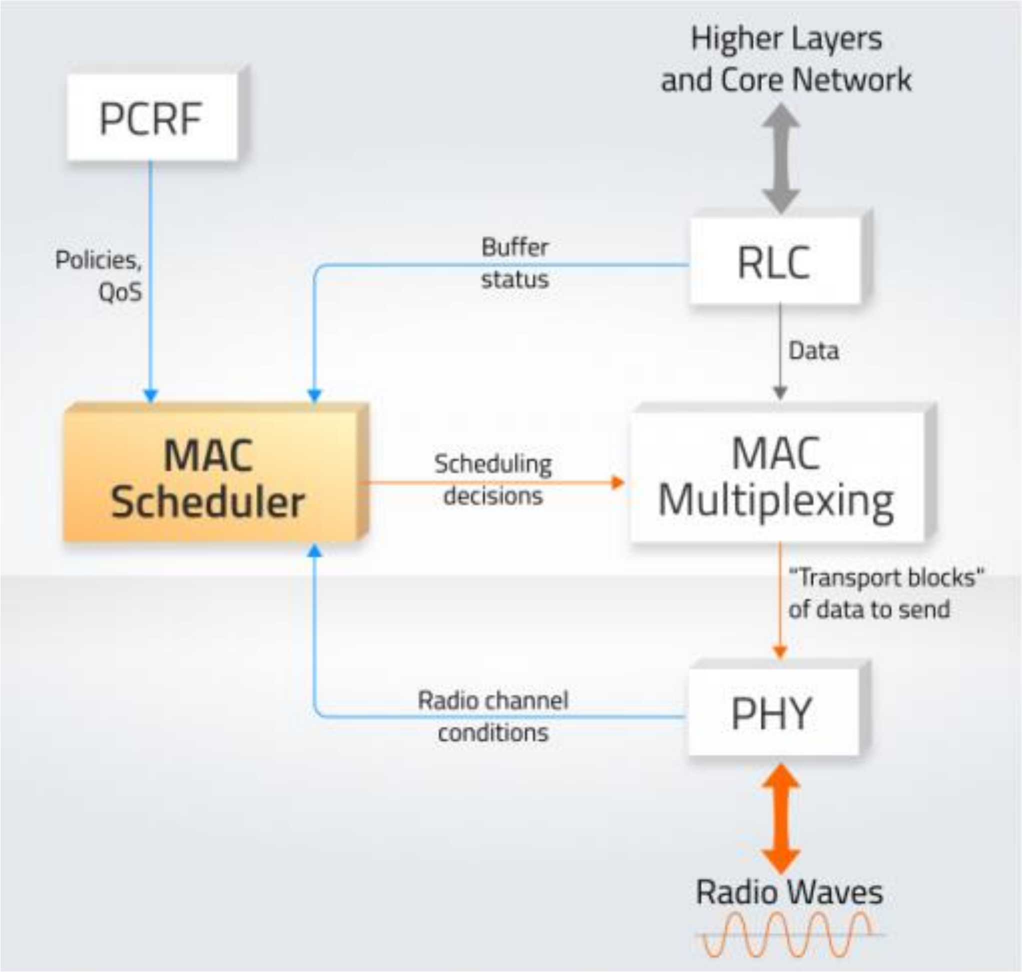
OFDMA/TDD structure



Traffic Scheduling

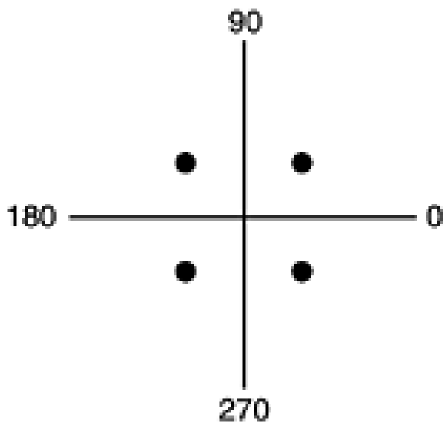


Traffic Scheduling

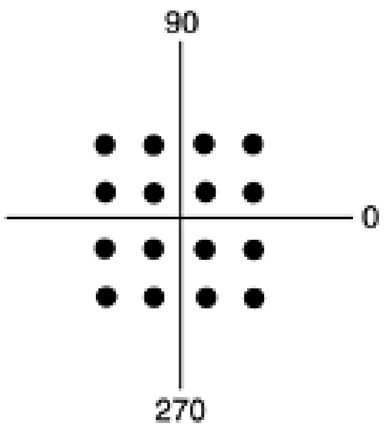


Multiple modulations

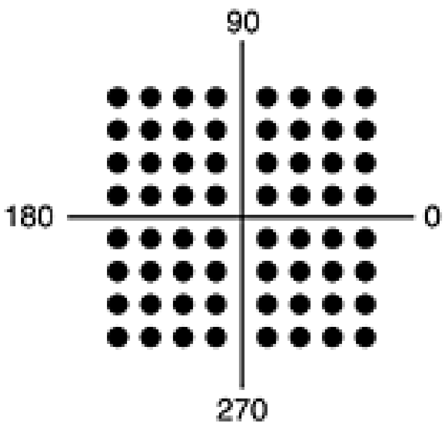
- QPSK (Quadrature Phase Shift Keying) = 4 phase shifts, 1 amplitude level, 2 bits/symbol
- QAM-16 = 4 phase shifts, 4 amplitude levels, 4 bits/symbol
- QAM-64 = 4 phase shifts, 16 amplitude levels, 6 bits/symbol



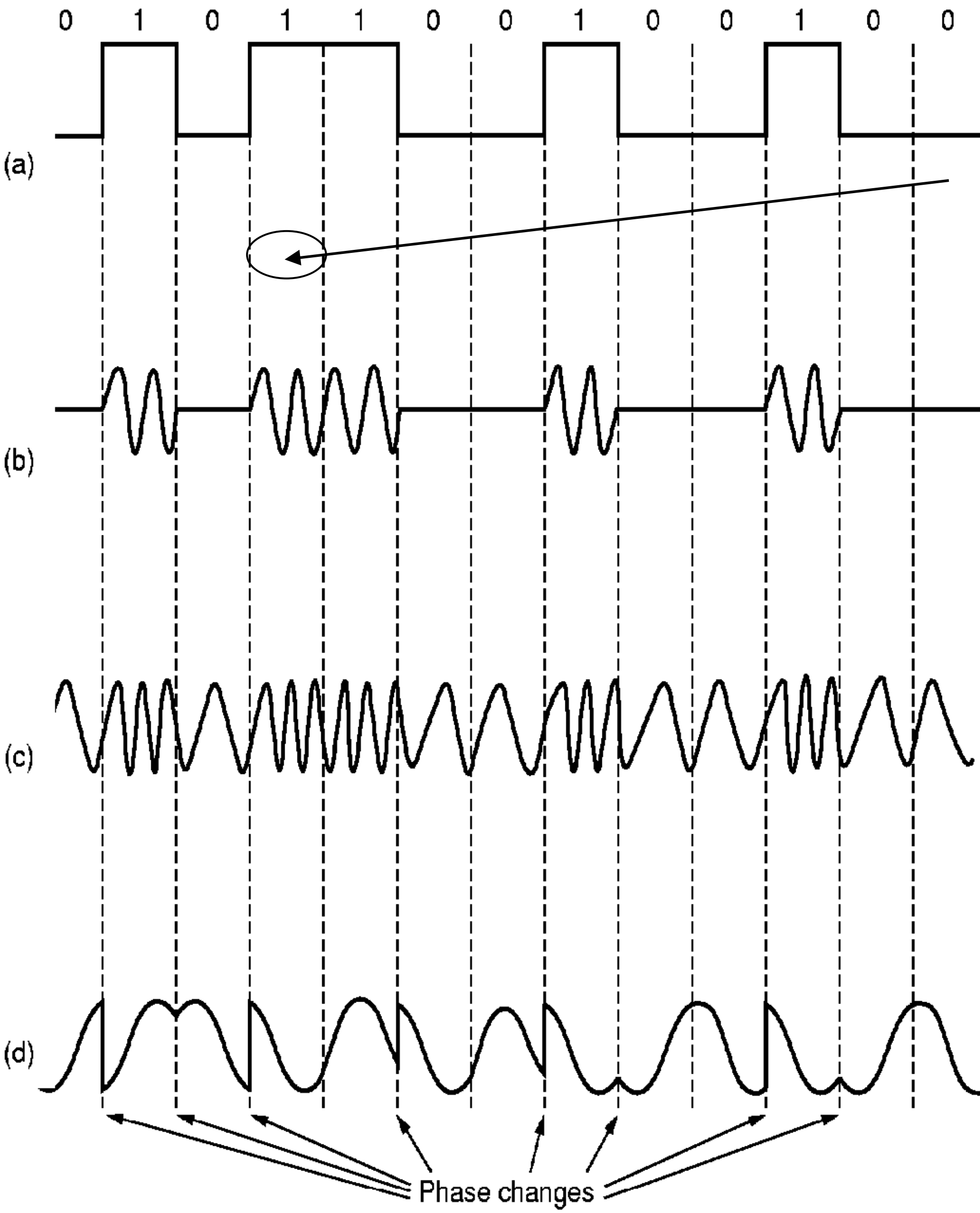
QPSK



QAM-16



QAM-64



Sample
Sample Rate=Samples/sec (Baud Rate)
During one Sample one **“symbol”** is sent
Symbol=piece of information=level of voltage

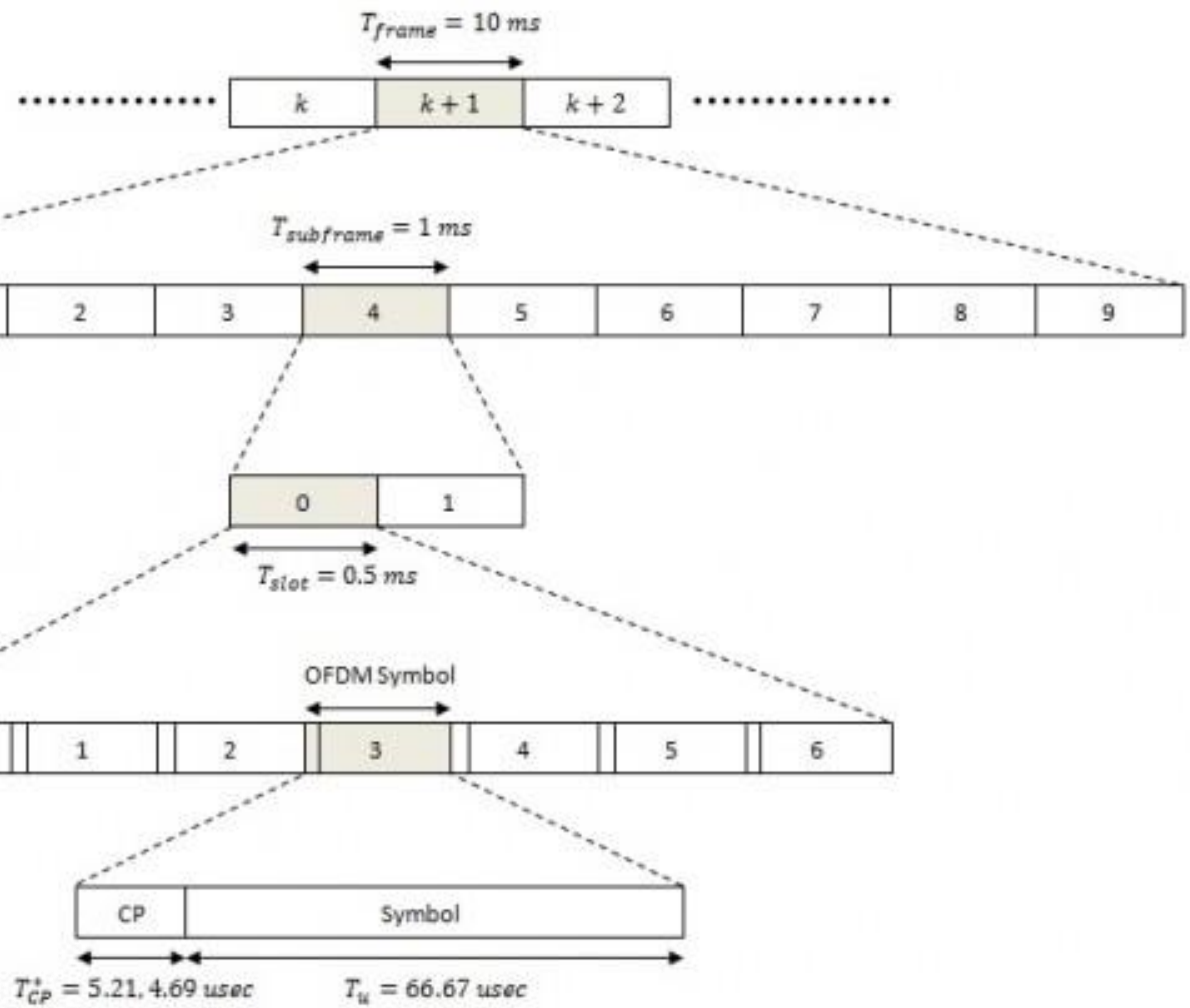
Στην απλούστερη περίπτωση:
1 symbol = 1 bit (0/1) = voltage/no voltage

Για να αυξήσουμε την ταχύτητα μετάδοσης δε μπορούμε να μειώνουμε το sample επ’ άπειρον.

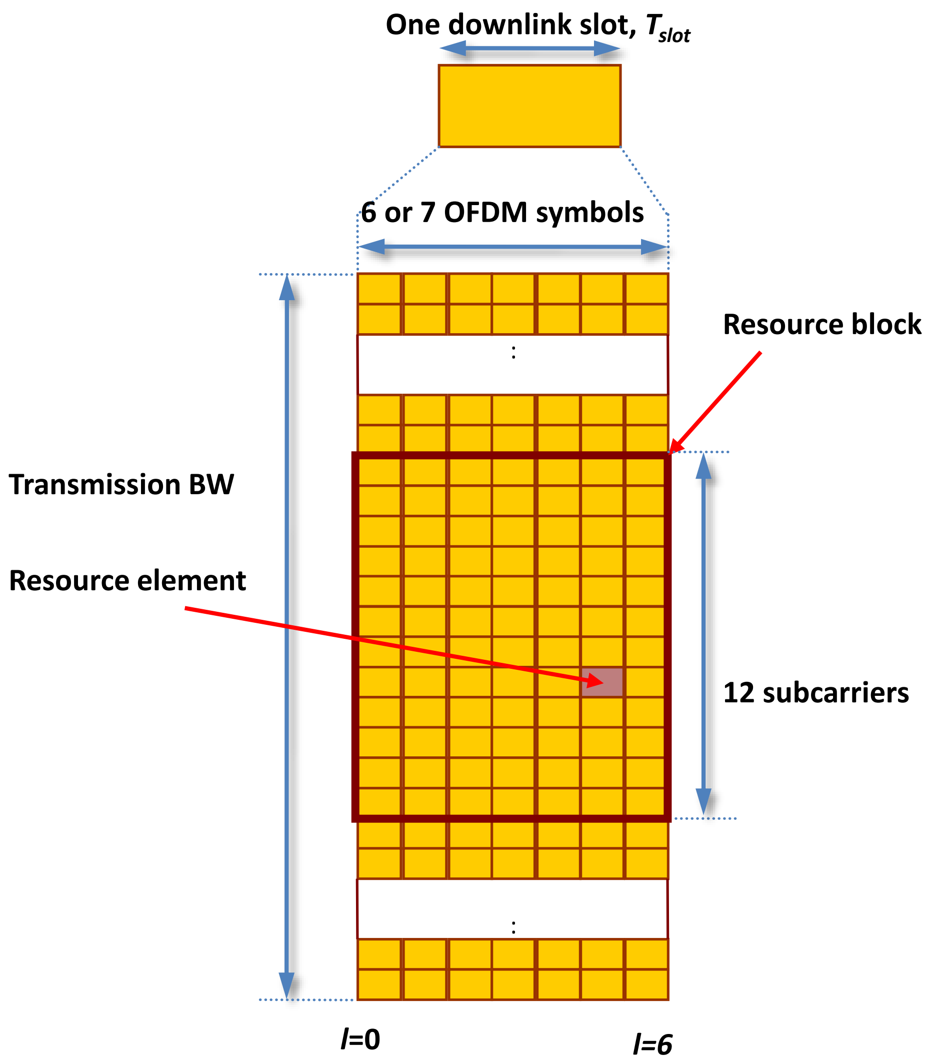
Μπορούμε όμως να αυξάνουμε τον αριθμό των πιθανών symbols (επιπέδων έντασης μετάδοσης, δηλαδή εύρους σήματος)

Συνηθέστερος συνδυασμός της τεχνικής αυτής με PSK.

Generic Frame Structure

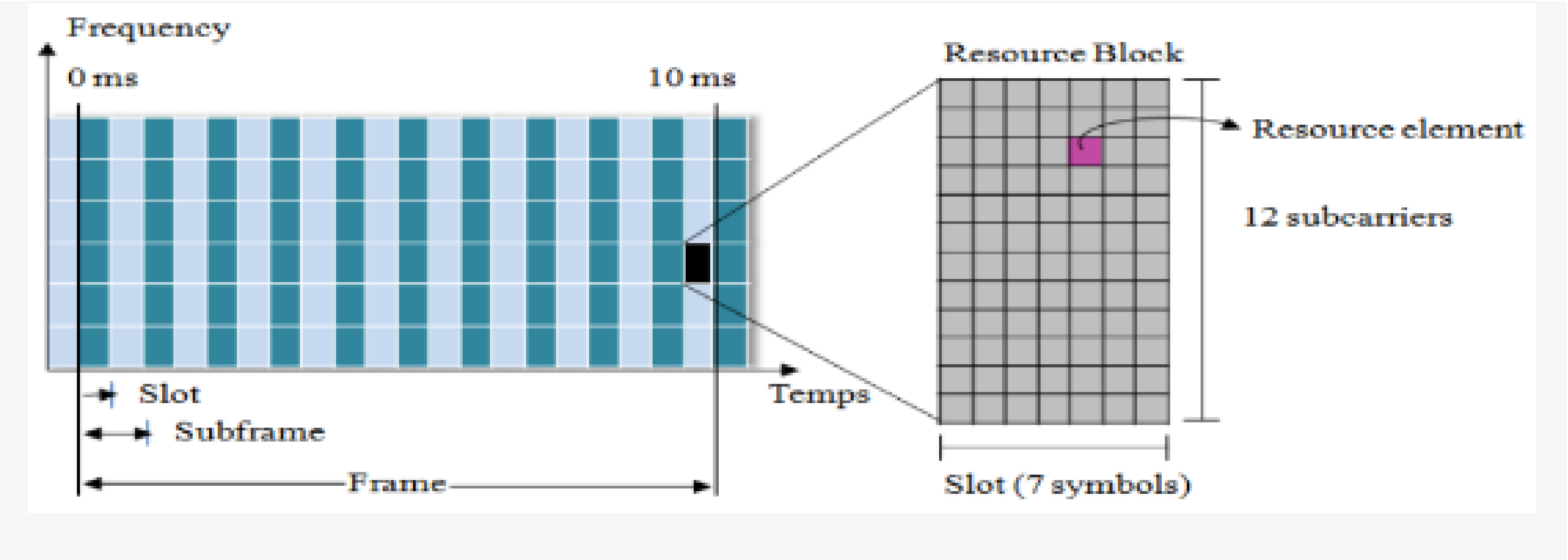


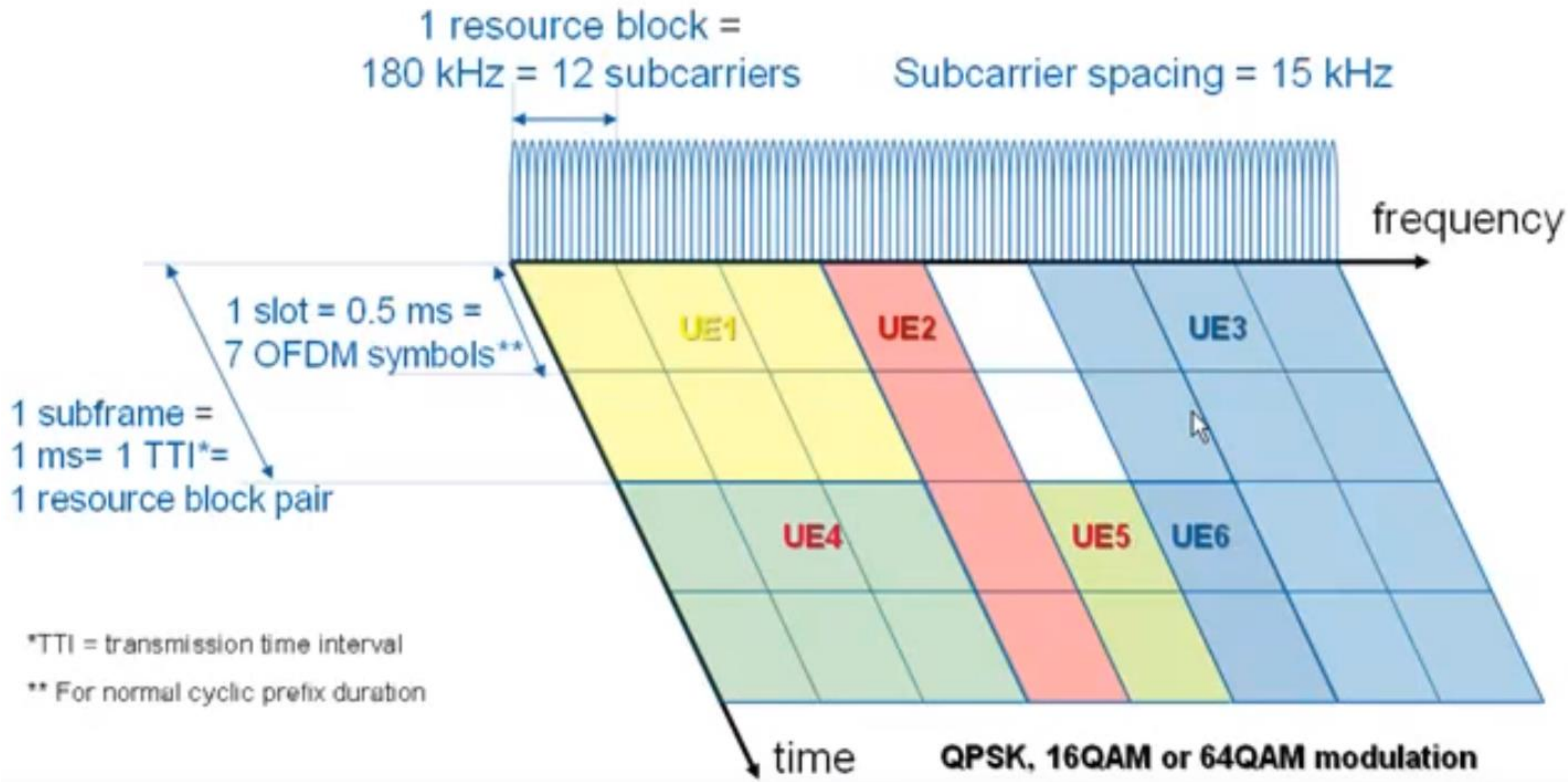
Resource Grid



- 6 or 7 OFDM symbols in 1 slot
- Subcarrier spacing = 15 kHz
- Block of 12 SCs in 1 slot = 1 RB
  - *0.5 ms x 180 kHz*
  - Smallest unit of allocation

Resource Grid




1 resource block =
180 kHz = 12 subcarriers
Subcarrier spacing = 15 kHz
frequency
1 slot = 0.5 ms =
7 OFDM symbols**
1 subframe =
1 ms= 1 TTI*=
1 resource block pair
UE1
UE2
UE3
UE4
UE5
UE6
*TTI = transmission time interval
** For normal cyclic prefix duration
time
QPSK, 16QAM or 64QAM modulation

Adaptive modulation