



# LTE and 5G NR Overview

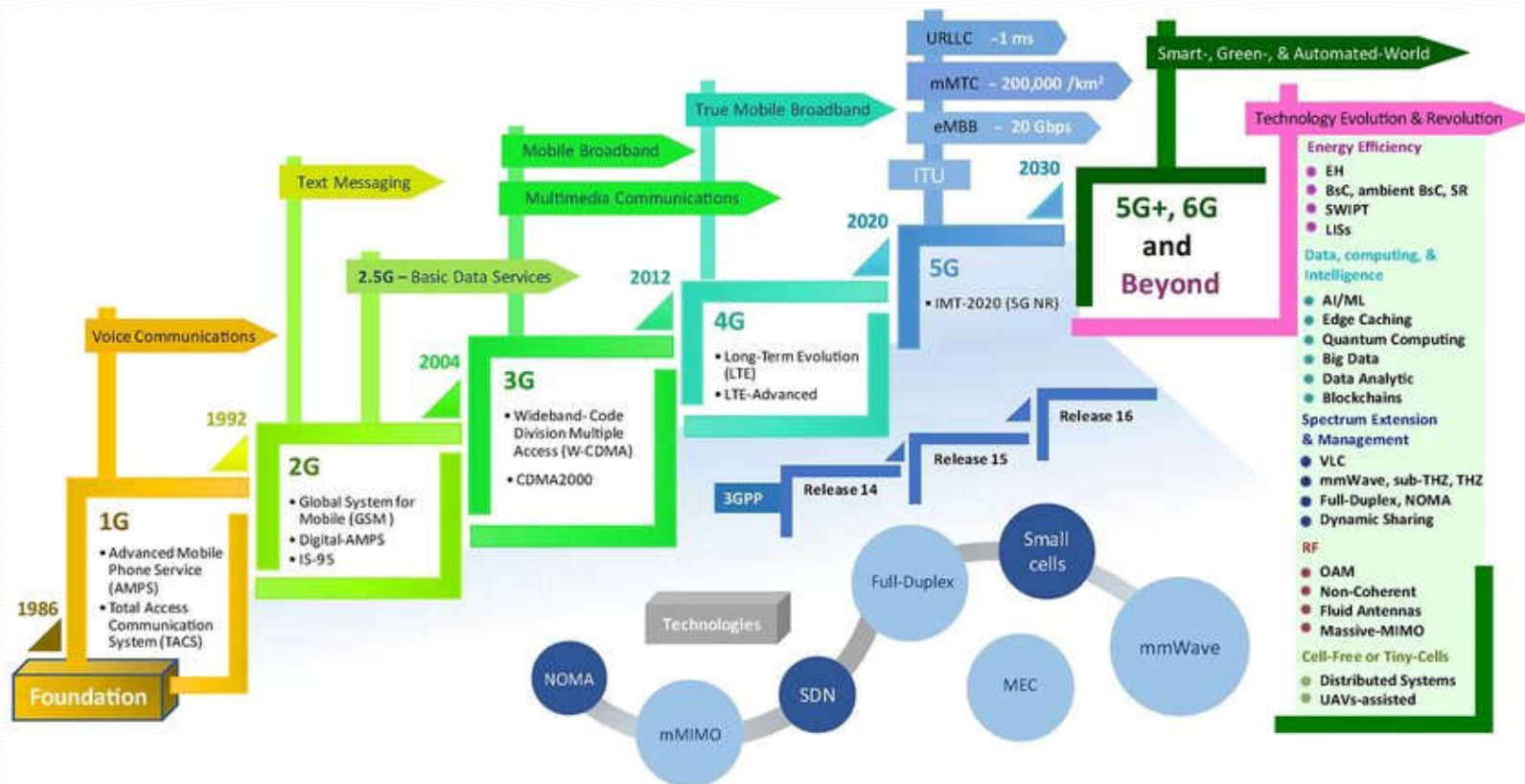
# Agenda

1. Evolution Of Cellular Networks
2. Overall Network Architecture of 4G/5G network
3. 4G/5G Base Stations (eNB & gNB)
4. 4G/5G Protocol Stacks
5. Call Flows



# Evolution Of Cellular Networks

# Cellular Network Generations



(source: ResearchGate)

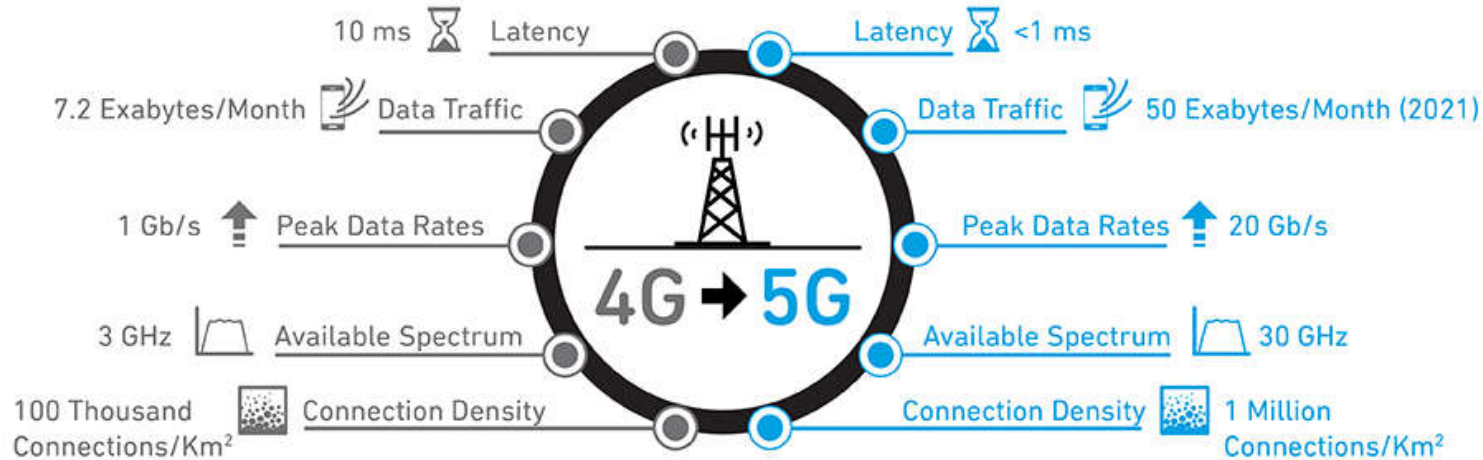


# From 1G to 5G – Evolution of Communication

- <https://www.youtube.com/watch?v=NUovkXWe15s>

# 5G vs. 4G

## Comparing 4G and 5G

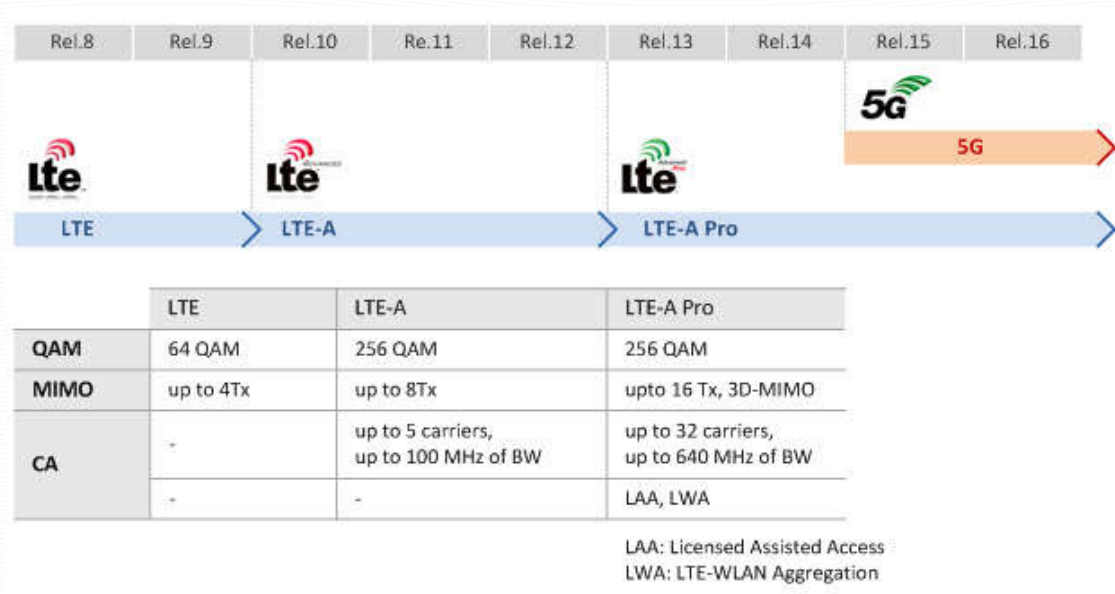


qorvo

©2017 Qorvo, Inc.

(source: qorvo)

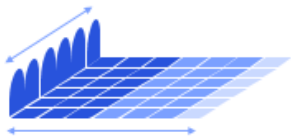
# 4G Key Technologies



(source: Netmanias)

# 5G Key Technologies

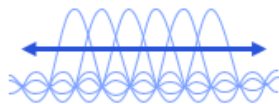
## Flexible slot-based framework



### Self-contained slot structure

Low latency, forward compatibility

## Scalable OFDM-based air interface



### Scalable OFDM numerology

Address diverse services, spectrum, deployments

## Advanced channel coding



### Multi-Edge LDPC and CRC-Aided Polar

More efficient delivery of multi-Gbps throughput

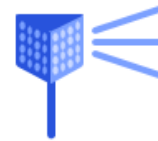
## Massive MIMO



### Reciprocity-based MU-MIMO

Increased network coverage and capacity

## Mobile mmWave



### Beamforming and beam-tracking

Extreme capacity and throughput

(source: Qualcomm)



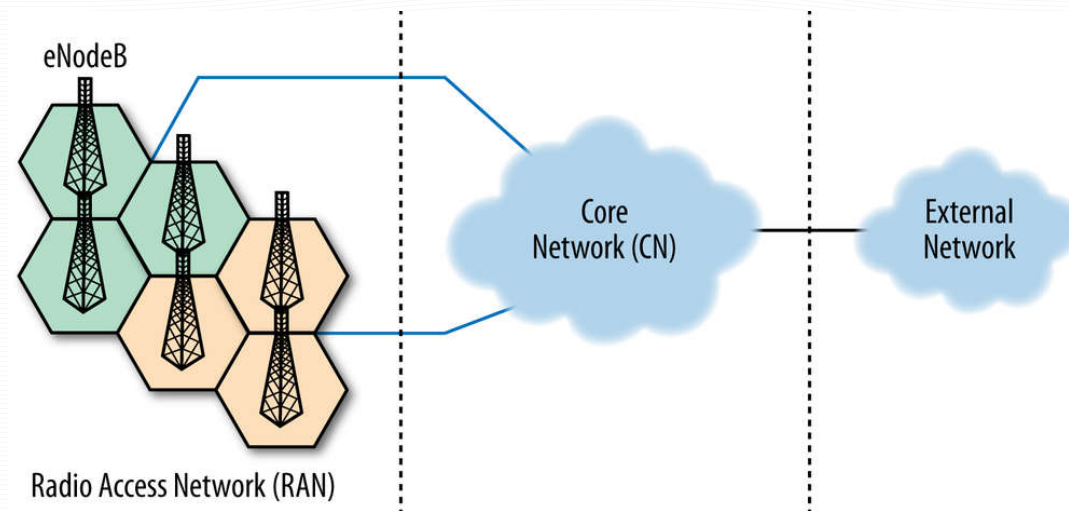


# 4G&5G Network Architecture

# Overall Cellular Network Architecture

In general, cellular network has 2 big logical components:

- Radio Access Network (RAN)
  - Providing radio access and coordinating the management of resources across the radio sites.
  - Including: Base station and UE
- Core Network (CN):
  - Authentication
  - Data routing
  - Accounting/Billing
  - Policy management

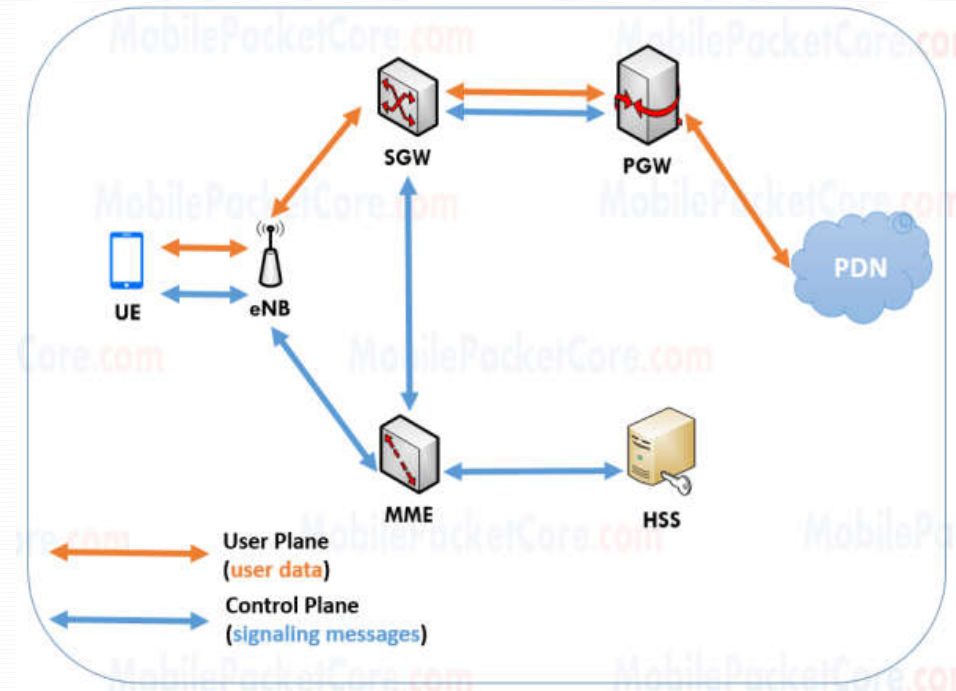


(source: Oreilly)

# 4G Network Architecture: Evolved Packet System (EPS)

EPS consists:

- RAN: LTE (Long-Term Evolution)
  - eNodeB
- Core Network (CN):
  - Mobility Management Entity (MME)
  - Serving Gateway (SGW)
  - PDN (Packet Data Network) Gateway (PGW)
  - Home Subscriber Server (HSS)



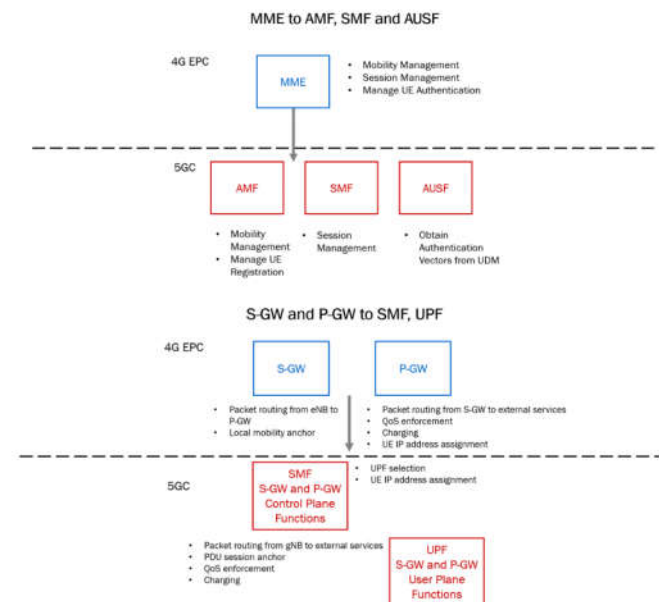
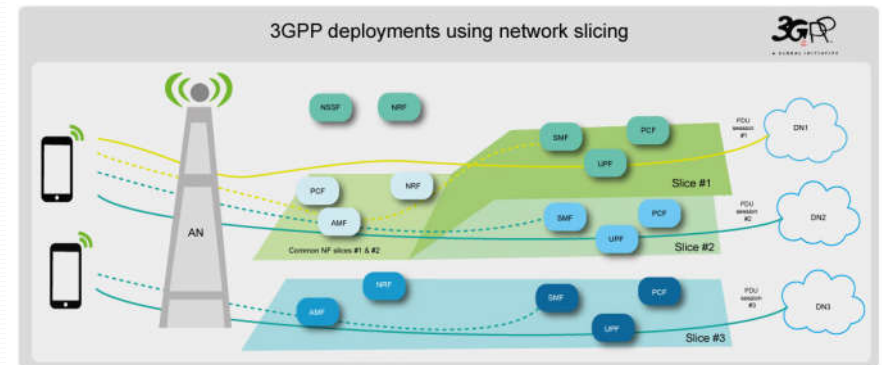
(source: mobilepacketcore)

# 5G Network Architecture: 5G System (5GS)

(source: 3GPP)

5GS consists:

- RAN: 5G NR
  - gNodeB
- Core Network (CN):
  - Access and Mobility Management Function (AMF)
  - Session Management Function (SMF)
  - Authentication Server Function (AUSF)
  - Session Management Function (SMF)
  - User Plane Function (UPF)



(source: medium.com)

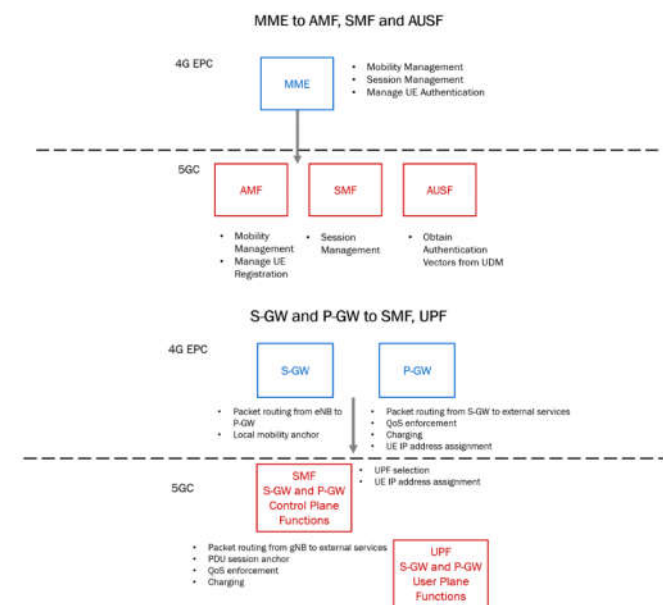
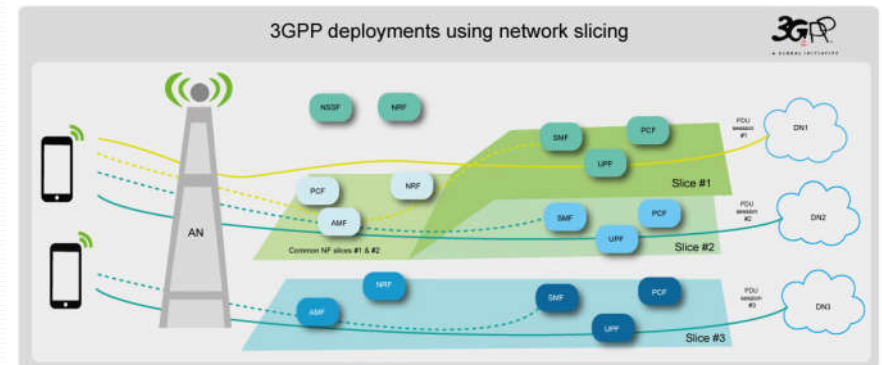


# 5G Network Architecture: 5G System (5GS)

(source: 3GPP)

5GS consists:

- RAN: 5G NR
  - gNodeB
- Core Network (CN):
  - Access and Mobility Management Function (AMF)
  - Session Management Function (SMF)
  - Authentication Server Function (AUSF)
  - Session Management Function (SMF)
  - User Plane Function (UPF)

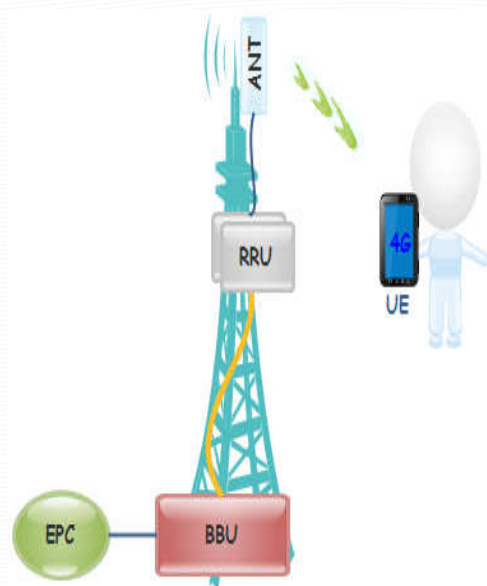


(source: medium.com)

# 4G/5G Base Stations (eNB & gNB)

# eNodeB Functional Architecture

Sơ đồ khối trạm gốc LTE



- **BBU (Baseband Unit)**
  - Baseband signal Processing (encode/decode, modulation, FFT...)
  - Protocols, algorithms

Sản phẩm eNB của VHT



- **RRU (Remote Radio Unit)**
  - Digital Front End (DFE): DPD, CFR
  - DAC/ADC
  - Mixer, PA, Filter
- **Antenna**
  - Electromagnetic Radiation

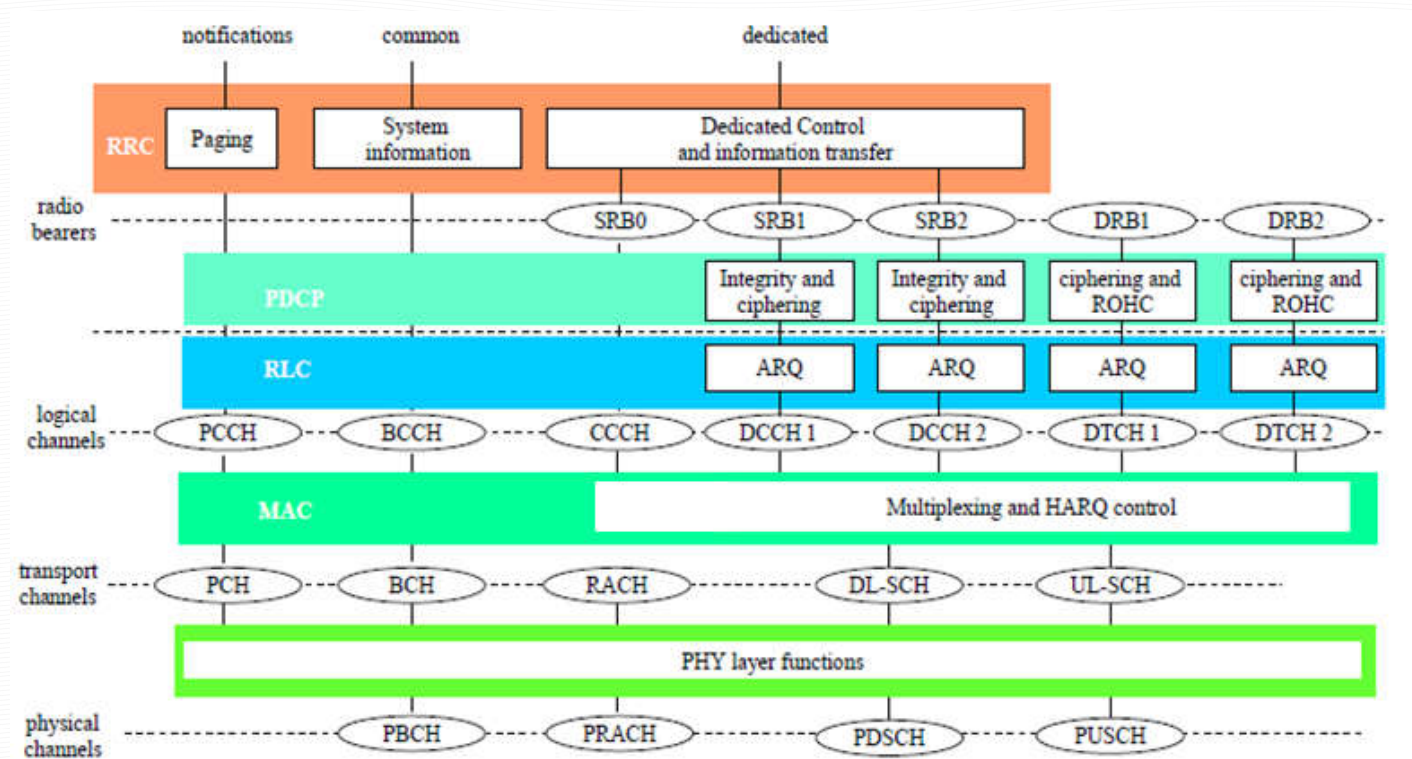
# 4G/5G Protocol Stacks



## Q&A

- What is Protocol?
- What is Protocol Stack?
- TCP/IP Protocol Stack: how many layers, functions of each layer?

# ENODEB PROTOCOL STACK



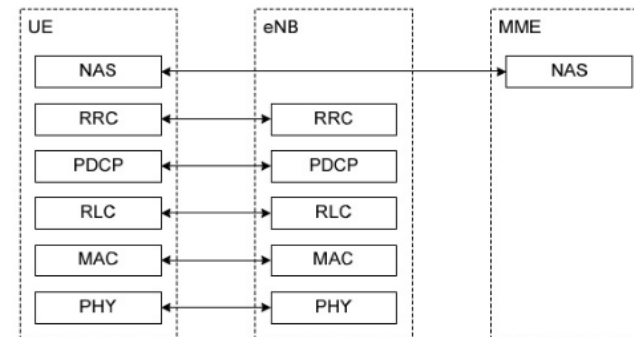
# RRC (RADIO RESOURCE CONTROL) LAYER



RRC (Radio Resource Control) protocol performs:

TS 36.331

- Broadcast of System Information related to NAS and AS;
- Establishment, maintenance and release of RRC connection;
- Establishment, configuration, maintenance and release of Signalling and Data Radio Bearers (SRBs and DRBs);
- Security functions including key management;
- Mobility functions including, e.g.:
  - Control of UE cell selection/reselection; Paging; UE measurement configuration and reporting; Handover;
- QoS management functions;
- UE measurement reporting and control of the reporting;
- Notification for ETWS, CMAS and MBMS;
- NAS direct message transfer between UE and NAS.



# RRC MESSAGES: SYSTEM INFORMATION

- 📶 System Information is provided by RRC, structured in MIB and SIBs
- 📶 MIB – transmitted in fixed location
  - Includes parameters essential to find SIB1 scheduled on DL-SCH (e.g., DL bandwidth and System Frame Number)
- 📶 SIB1 – scheduled in the frequency domain (fixed timing) on DL-SCH
  - Contains information relevant when evaluating if a UE is allowed to access a cell and defines the scheduling of other system information
- 📶 Other SIBs are multiplexed in *SystemInformationMessages*
  - Scheduled in time and frequency domains as defined by SIB1
  - SIB2
    - contains resource configuration information that is common for all UEs; needed before accessing a cell
  - SIB3, SIB4, ...
    - other system information grouped according to functionality



## RRC MESSAGES: SYSTEM INFORMATION

### **Secret codes for Field Test**

- Samsung: \*#0011#
- Iphone: \*3001#12345#\*
- Oppo: \*#803#
- Huawei: \*##6130##\*
- LG: \*#546368#\*873#
- ...


# RRC FUNCTIONS: CONNECTION MANAGEMENT

 Connection/session management is performed by:

- the RRC protocol between the UE and E-UTRAN
- the NAS protocol between the UE and CN

 The NAS protocol performs e.g.:

- authentication, registration, bearer context activation/ deactivation and location registration management

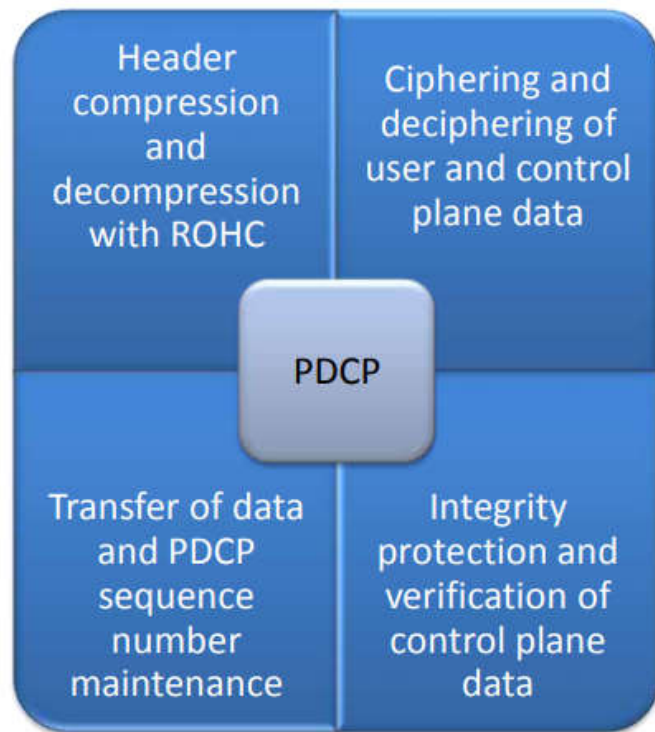
 RRC messages are used e.g., to:

- establish connection, configure the radio bearers and their corresponding attributes, and to control mobility

 The RRC protocol has two states:

- RRC\_IDLE and RRC\_CONNECTED

## PDCP (Packet Data Convergence Protocol) Layer

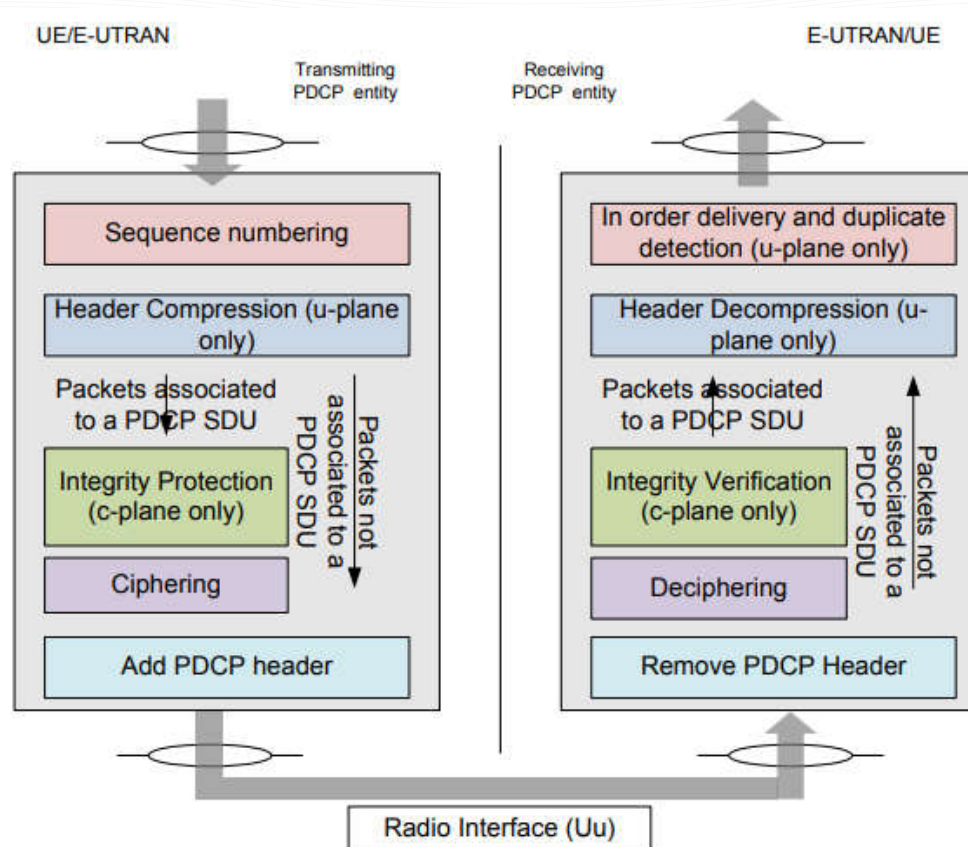


- Header compression and decompression of IP data flows using the ROHC protocol;
- Transfer of data (user plane or control plane);
- Maintenance of PDCP SNs;
- In-sequence delivery of upper layer PDUs at re-establishment of lower layers;
- Duplicate elimination of lower layer SDUs at re-establishment of lower layers for radio bearers mapped on RLC AM;
- Ciphering and deciphering of user plane data and control plane data;
- Integrity protection and integrity verification of control plane data
- Timer based discard
- Duplicate discarding

© 2009 EventHelix.com Inc.



# PDCP (Packet Data Convergence Protocol) Layer

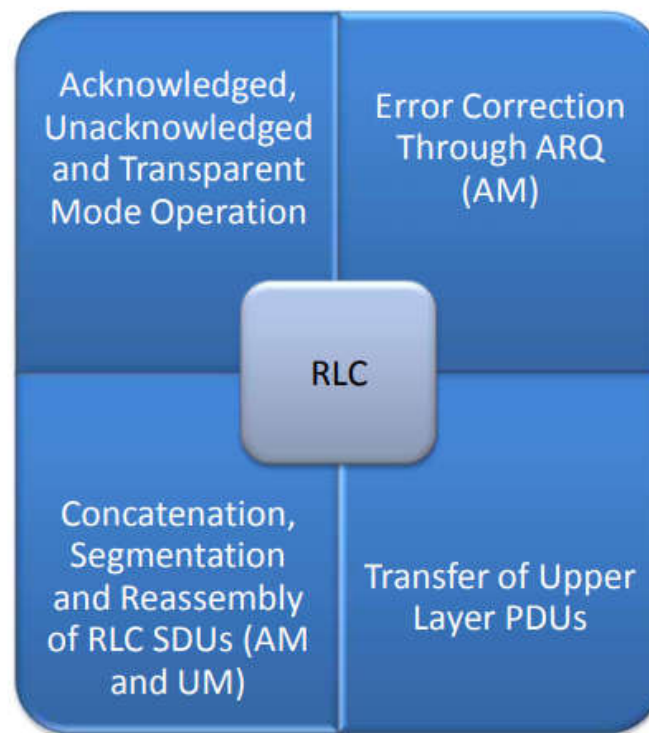


© 2009 EventHelix.com Inc.



# RLC (Radio Link Control) Layer

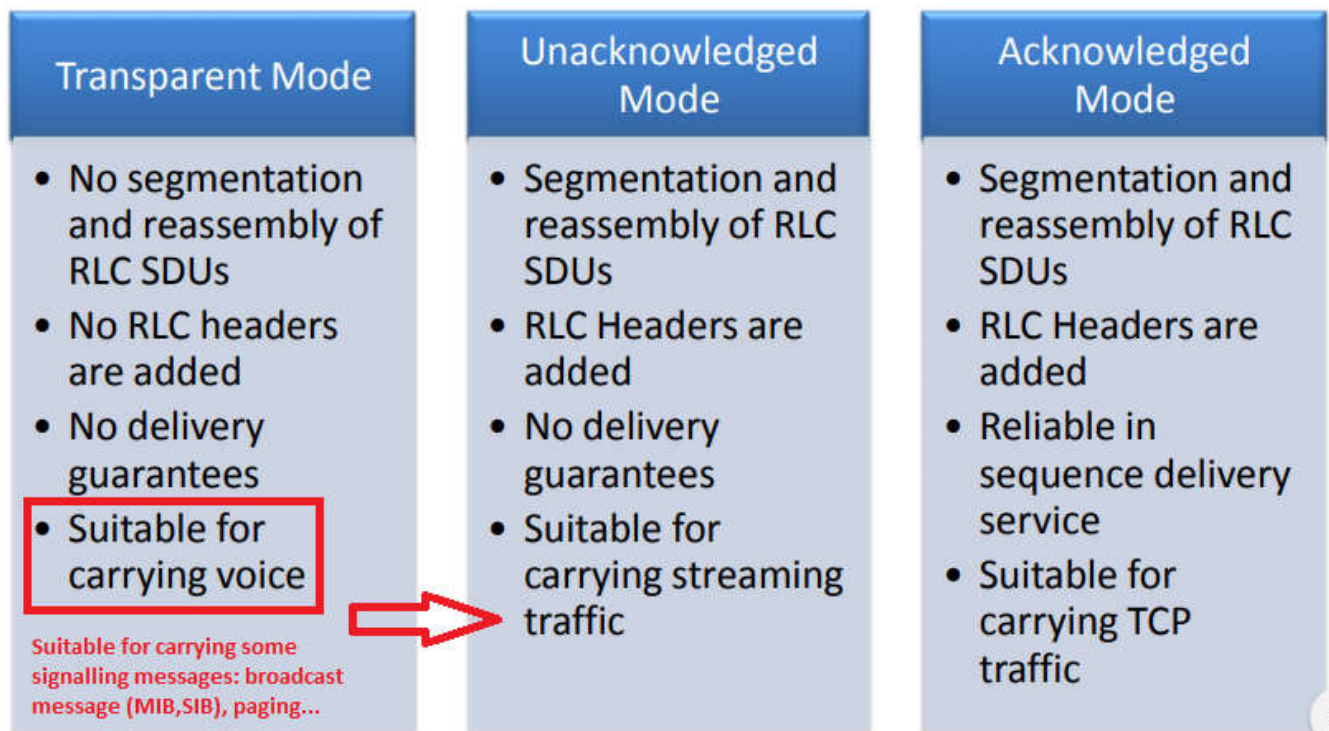
## RLC Functions:



- Transfer of upper layer PDUs;
- Error correction through ARQ (only for AM data transfer)
- Concatenation, segmentation and reassembly of RLC SDUs (UM and AM)
- Re-segmentation of RLC data PDUs (AM)
- Reordering of RLC data PDUs (UM and AM);
- Duplicate detection (UM and AM);
- RLC SDU discard (UM and AM)
- RLC re-establishment
- Protocol error detection and recovery

# RLC (Radio Link Control) Layer

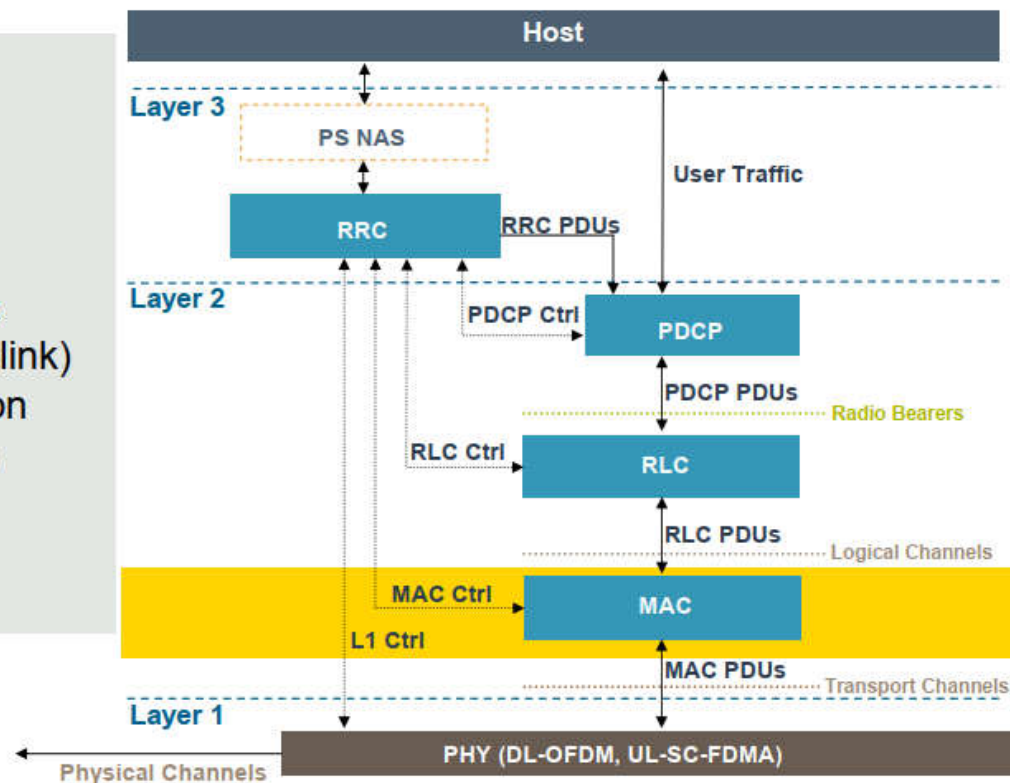
## RLC Modes:



# MAC (Medium Access Control) Layer

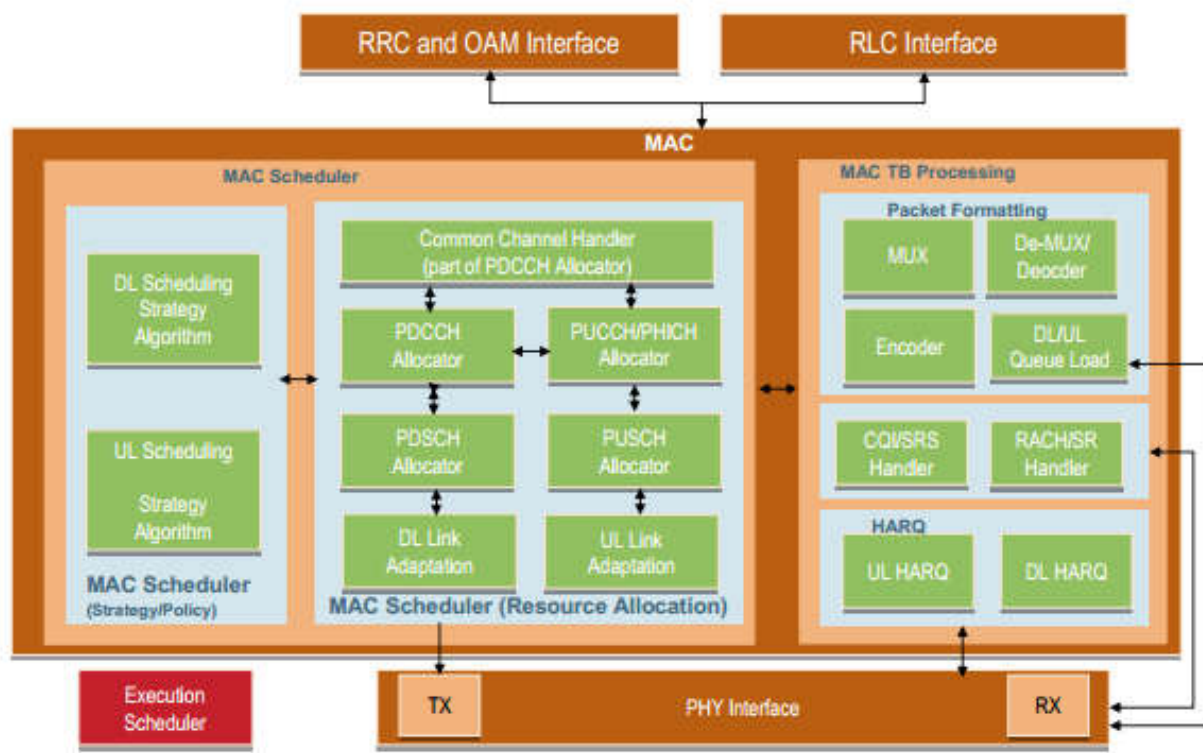
## ► MAC Functions

- Hybrid ARQ
- Mapping
  - Transport ⇔ Logical
  - Mux / DeMux
- Scheduling (uplink)
- Format selection
- Measurements (RRC)





## MAC Architecture – Functional View





# MAC (Medium Access Control) Layer

## MAC - Downlink - Hybrid ARQ

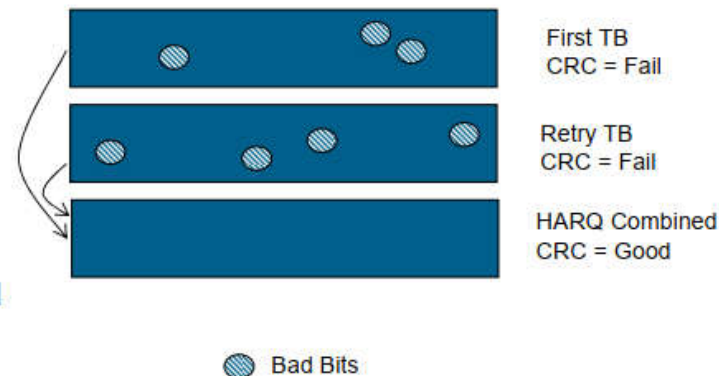
### ► Retransmission of Transport blocks for error recovery

- MAC sends “NACK” message when TB fails CRC
- Transport Blocks with errors are retained
- PHY retransmits with different puncturing code
- Retransmission combined with saved transport block(s)
- When correct transport block is decoded, MAC signals “ACK”
- Multiple HARQ processes run in parallel – retry several TBs

### ► Hybrid ARQ function involves both MAC and PHY

- PHY performs retention and re-combination (incremental redundancy)
- MAC controls signaling

### Simplified HARQ Operation



# MAC (Medium Access Control) Layer

## MAC channels

- ▶ Logical Channels exist at the top of the MAC
  - Represent data transfer services offered by the MAC
  - They are defined by what type of information they carry
- ▶ Types of Logical Channels
  - Control channels (for control plane data)
  - Traffic channels (for user plane data)
- ▶ Transport Channels exist at the bottom of the MAC
  - Represent data transfer services offered by the PHY
  - They are defined by how the information is carried



# MAC (Medium Access Control) Layer

## MAC – Downlink Mapping

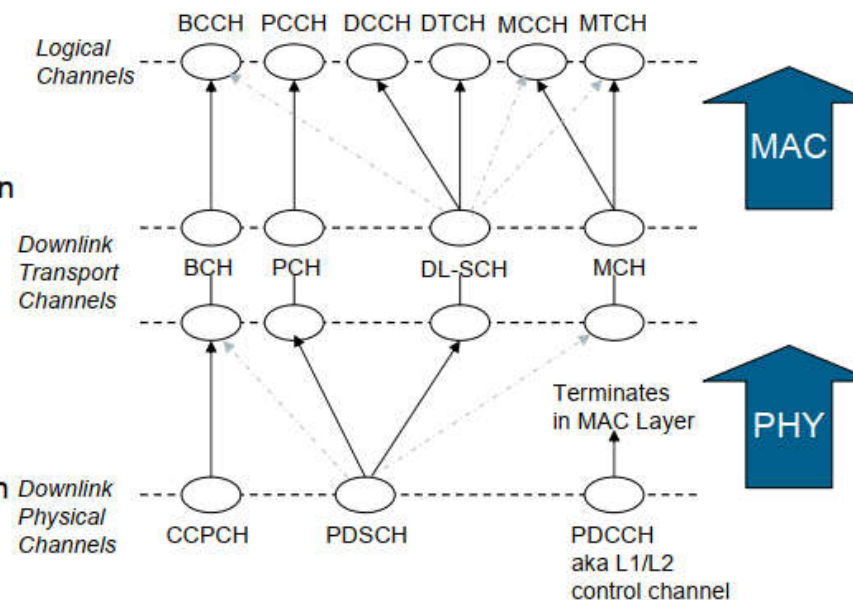
- ▶ A valid Transport block is available from the HARQ process
- ▶ Next, the transport channels are mapped to logical channels

### ▶ Logical Channels

- PCCH: Paging Control Chan
- BCCH: Broadcast Ctrl Chan
- DCCH: Dedicated Ctrl Chan
- DTCH: Dedicated Traffic Chan
- MCCH: Multicast Ctrl Chan
- MTCH: Multicast Traffic Chan

### ▶ Transport Channels

- PCH: Paging Channel
- BCH: Broadcast Channel
- DL-SCH: Downlink Shared Ch
- MCH: Multicast Channel





# MAC (Medium Access Control) Layer

## MAC – Format selection, measurements

- ▶ The MAC sets the transport format on downlink
  - The eNB includes information in each transport block that specifies the format (MCS: Modulation Coding Scheme) for the **next** Transport Block
  - The MAC configures the PHY for the next TB
- ▶ The MAC coordinates measurements
  - From local PHY to RRC regarding local
    - RRC reports back to eNB via control messages
  - From eNB to RRC
    - RRC controls local PHY modulation and configuration settings
- ▶ MAC measurements support downlink scheduling
  - Rates and radio conditions at the UE are used by the eNB
  - If the rate is high, fewer time slots are needed to send data



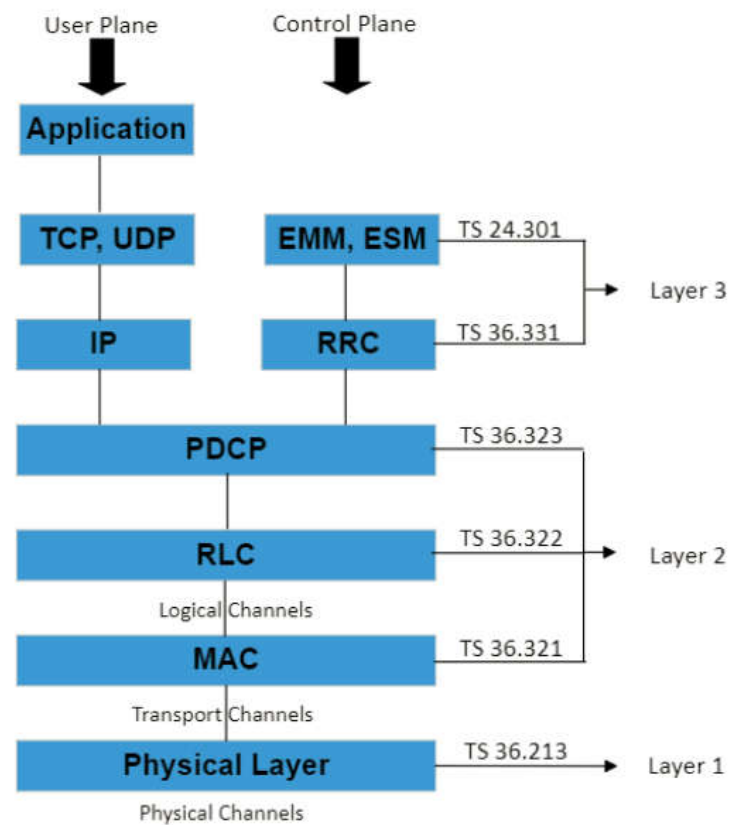
## 3GPP STANDARDS FOR LTE RAN

TS 36.104	Base station RF requirement
TS 36.201-36.214	Physical Layer Specification
TS 36.321-36.323	RRC, PDCP, RLC, MAC Specification
TS 36.410-36.414	S1 Specification (Signaling)
TS 36.420-36.425	X2 interface specification
TS 29.281	General Packet Radio System (GPRS) Tunneling Protocol User Plane

<https://www.3gpp.org/DynaReport/36-series.htm>

# 3GPP STANDARDS FOR LTE RAN

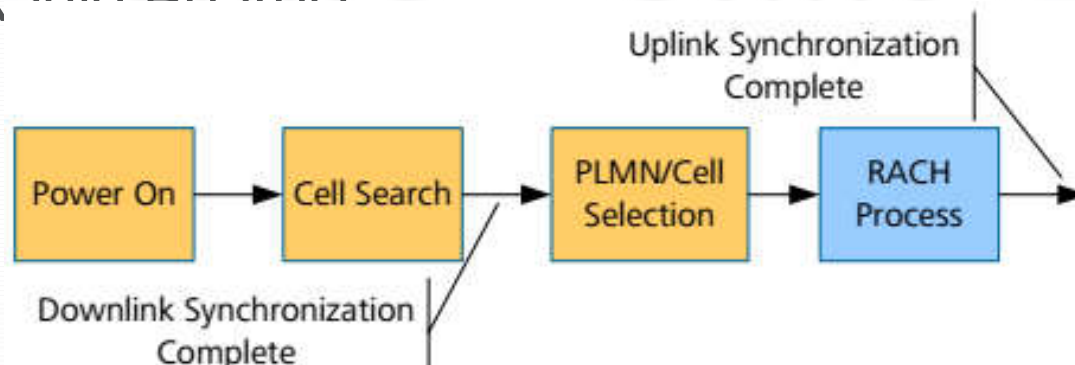
## Architecture of air interface Protocol Stack



# Call Flows

## LTE Cell Search Procedure

- In order to access a cell the device must find and synchronize to the cell.
- It is then able to decode the System Information messages and perform PLMN and Cell Selection.
- Once this has been completed, the device is in a position to access the cell and establish a RRC connection, i.e. a SRB (Signaling Radio Bearer)

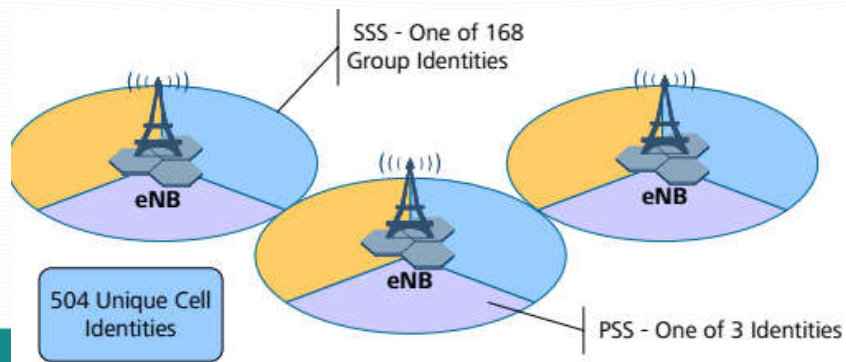
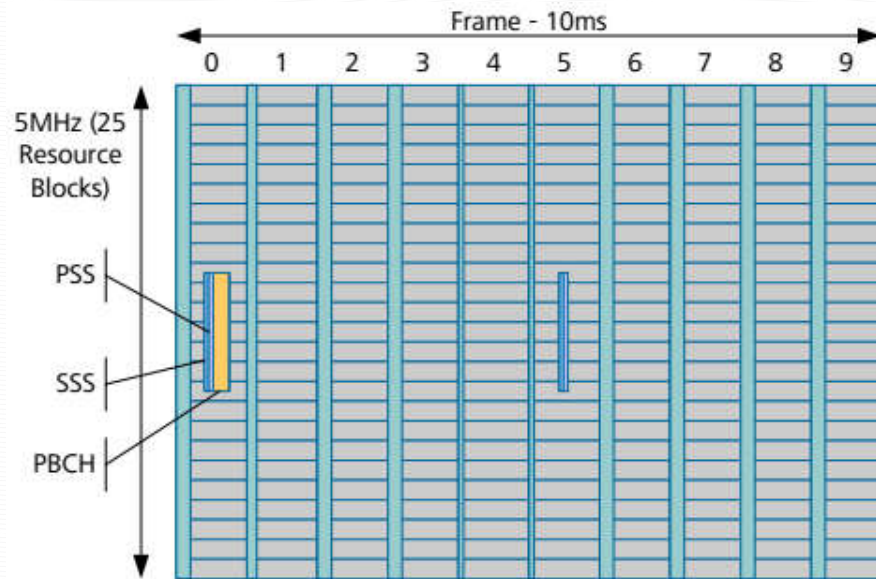




# LTE Cell Search Procedure

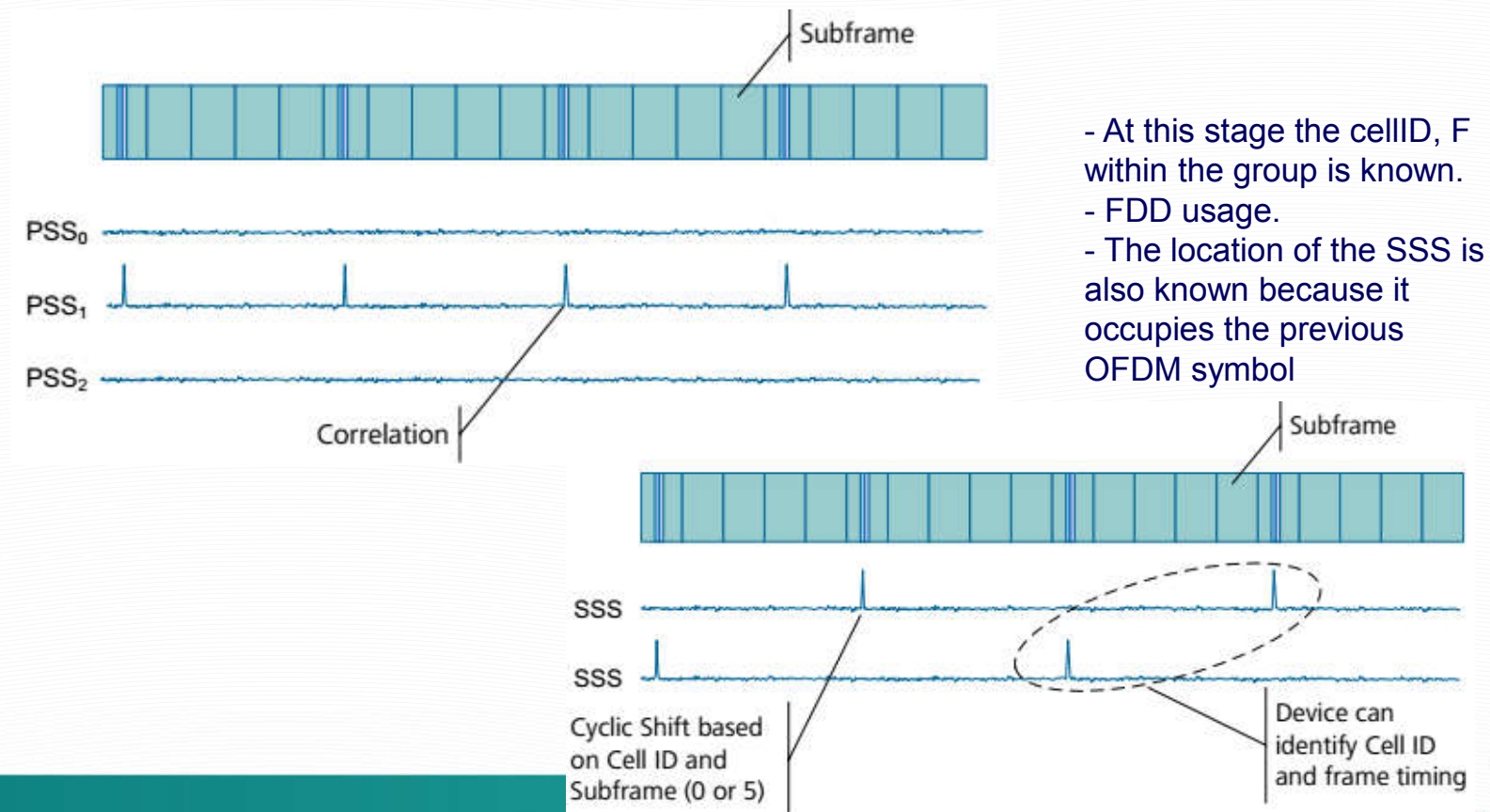
## ■ Cell Search

- Subframe 0, 5 utilize the same PSS sequence



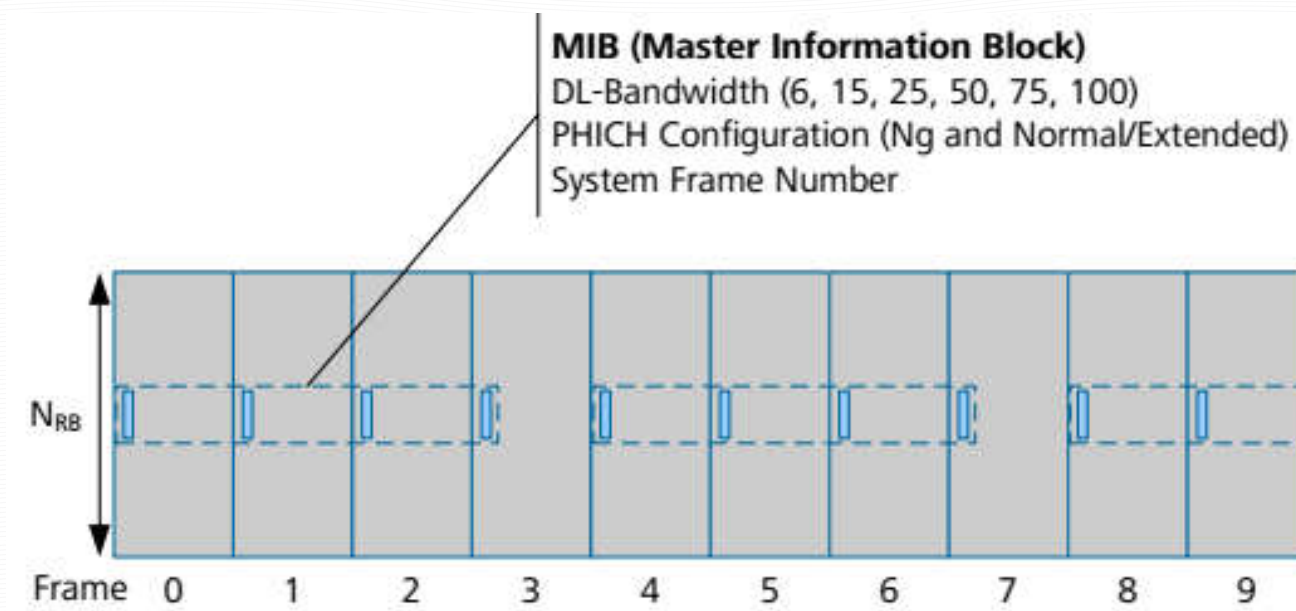
# LTE Cell Search Procedure

## ■ Cell Search



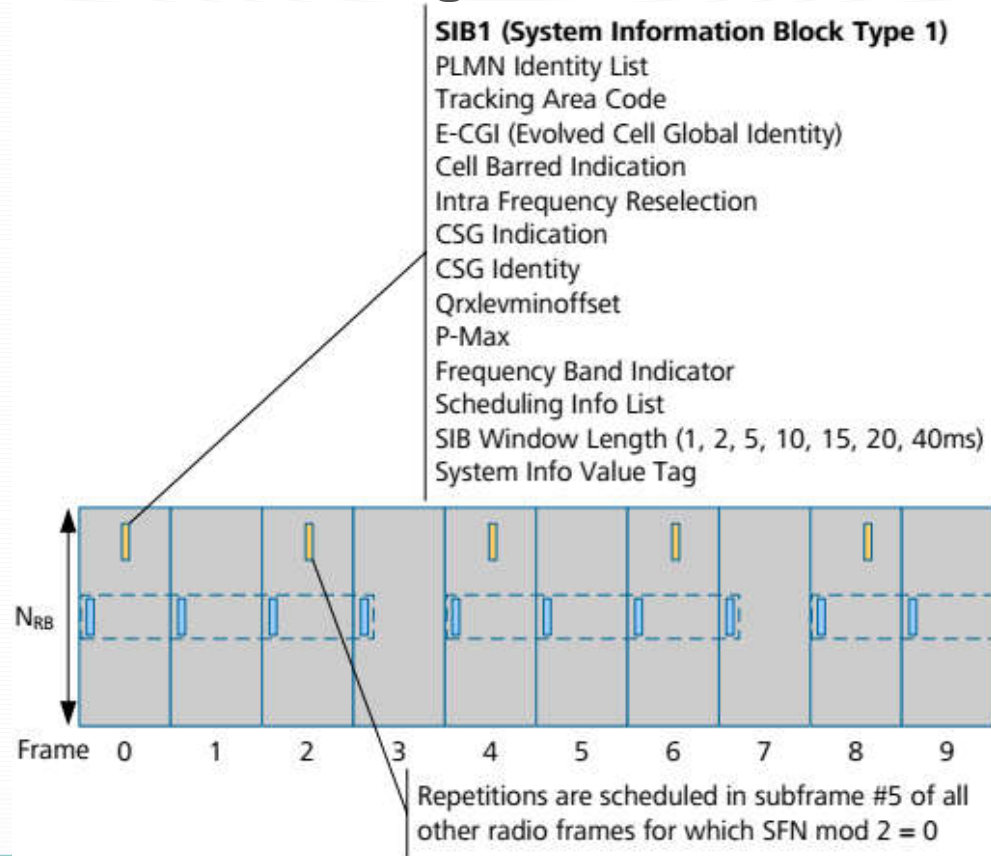
# LTE Cell Search Procedure

- Master Information Block



# LTE Cell Search Procedure

## ■ System Information Messages





# LTE Cell Search Procedure

## ■ System Information Messages

### **SIB2 (System Information Block Type 2)**

Access Class Information  
Uplink Carrier Frequency  
UL Bandwidth  
MBSFN Configuration Information

### **SIB4 (System Information Block Type 4)**

Intra Freq Neighbour Cell List  
q-OffsetCell  
Intra Freq Black Cell List  
CSG Physical Cell Id Range

### **SIB3 (System Information Block Type 3)**

Cell Reselection Information  
Q-Hyst  
Speed State Reselection Parameters  
Q-Hyst Speed SF (Scaling Factor)  
Treseselection EUTRA  
Treseselection EUTRA SF  
S Intra Search  
Cell Reselection Serving Freq Info  
S-Non-Intra Search Info  
Threshold Serving Low Value  
Intra Freq Cell Reselection Info  
p-Max  
Allowed Measurement Bandwidth

### **SIB5 (System Information Block Type 5)**

Inter Frequency Carrier Freq List  
Inter Frequency Carrier Freq Info  
Inter Frequency Neighbour Cell List  
Inter Frequency Neighbour Cell Info  
Inter Frequency Black Cell List  
Inter Frequency Black Cell Info

### **SIB6 (System Information Block Type 6)**

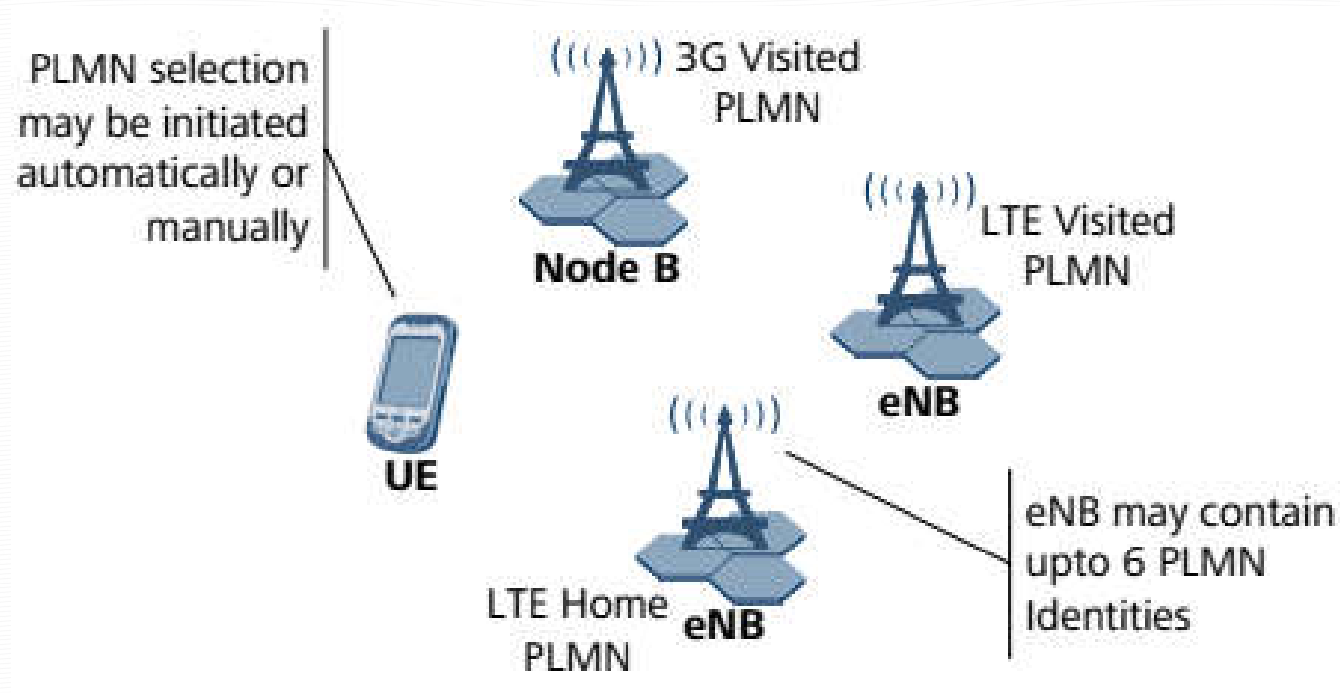
Carrier Frequency List UTRA  
UTRA Reselection Information

### **SIB7 (System Information Block Type 7)**

Carrier Frequency List GERAN  
GERAN Reselection Information

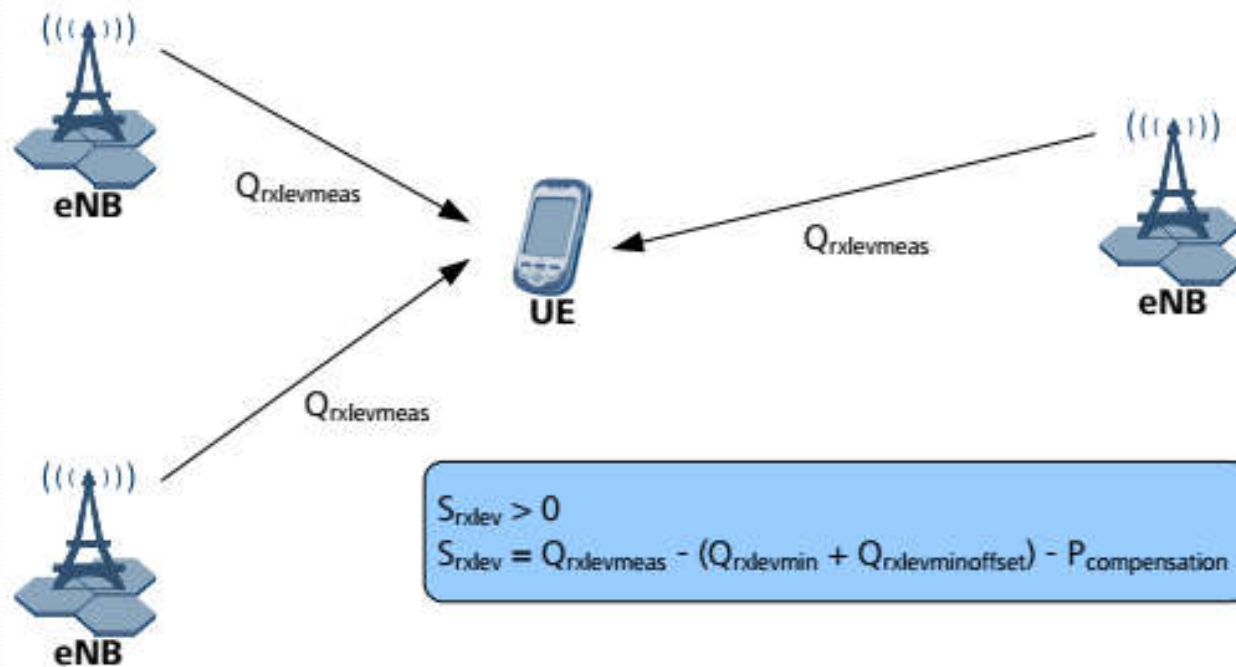
# LTE Cell Search Procedure

- **PLMN Selection**



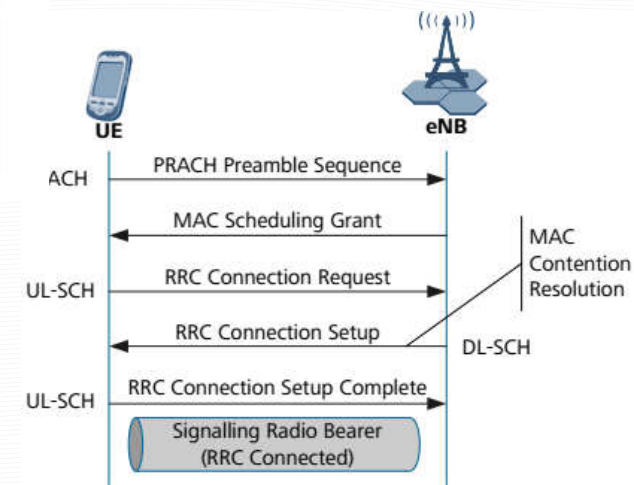
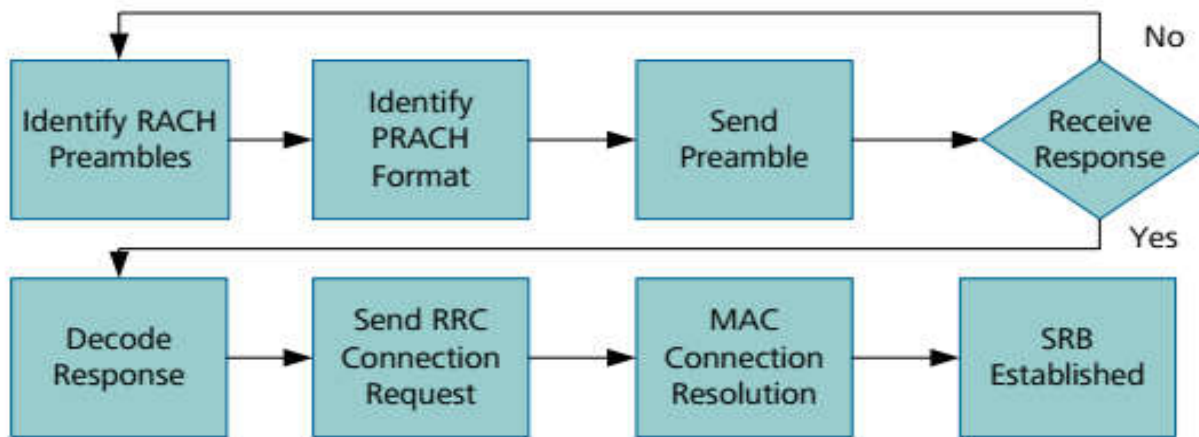
# LTE Cell Search Procedure

- Cell Selection



# LTE Random Access Procedure

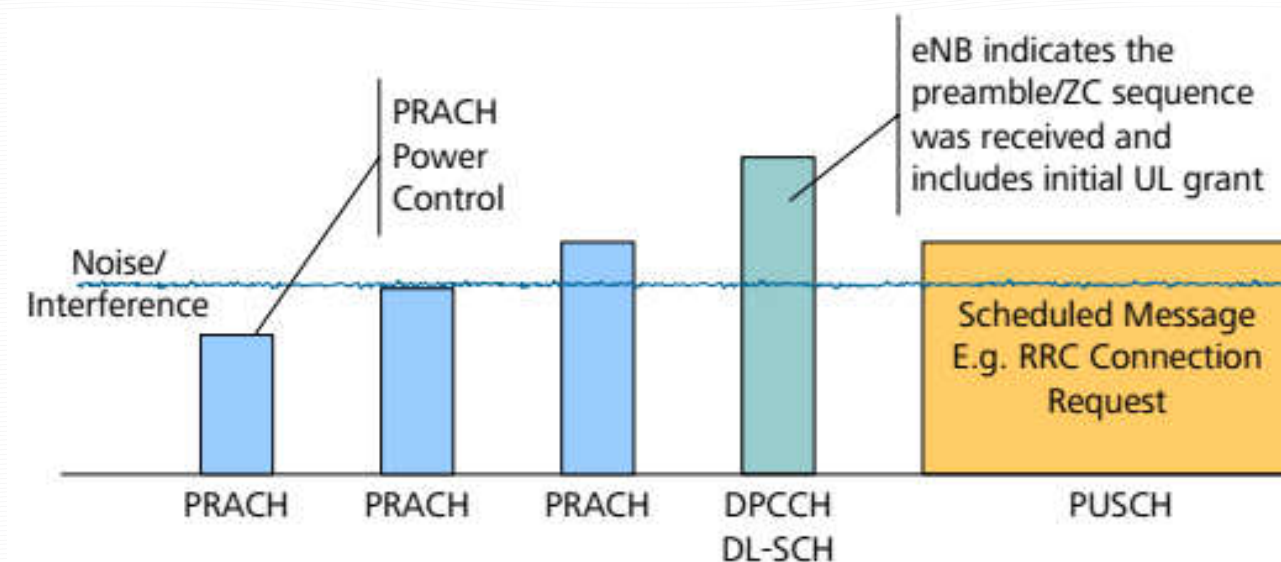
## Overall Random Access Procedure





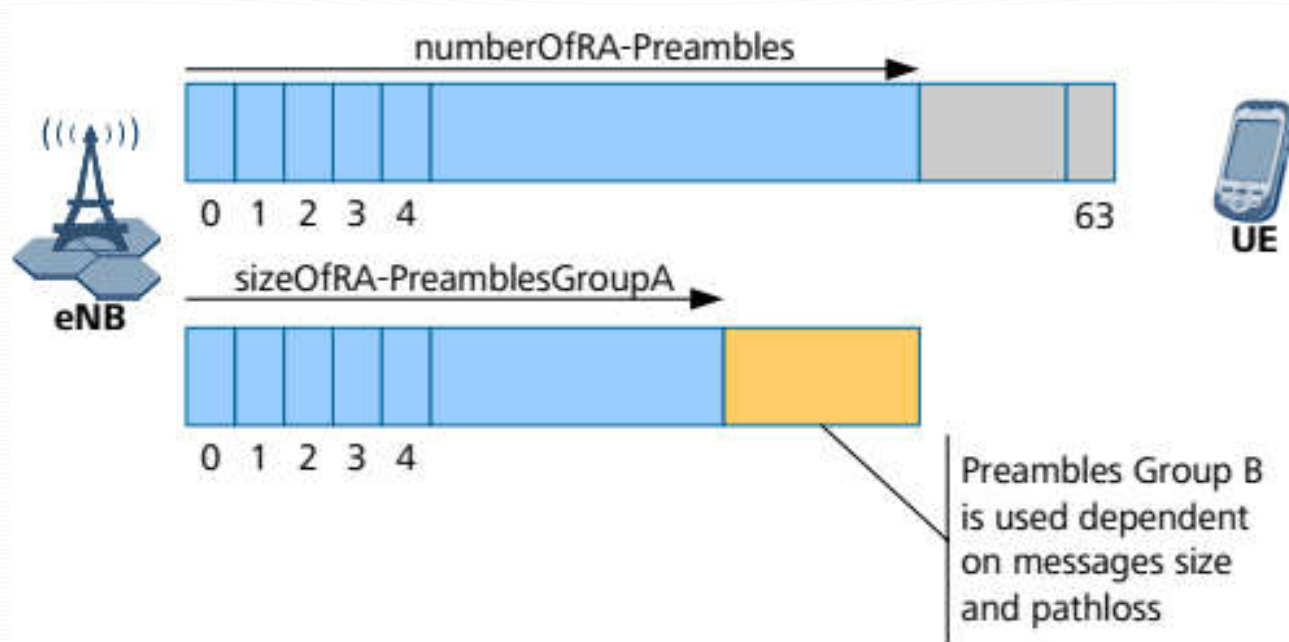
# LTE Random Access Procedure

- PRACH Preambles



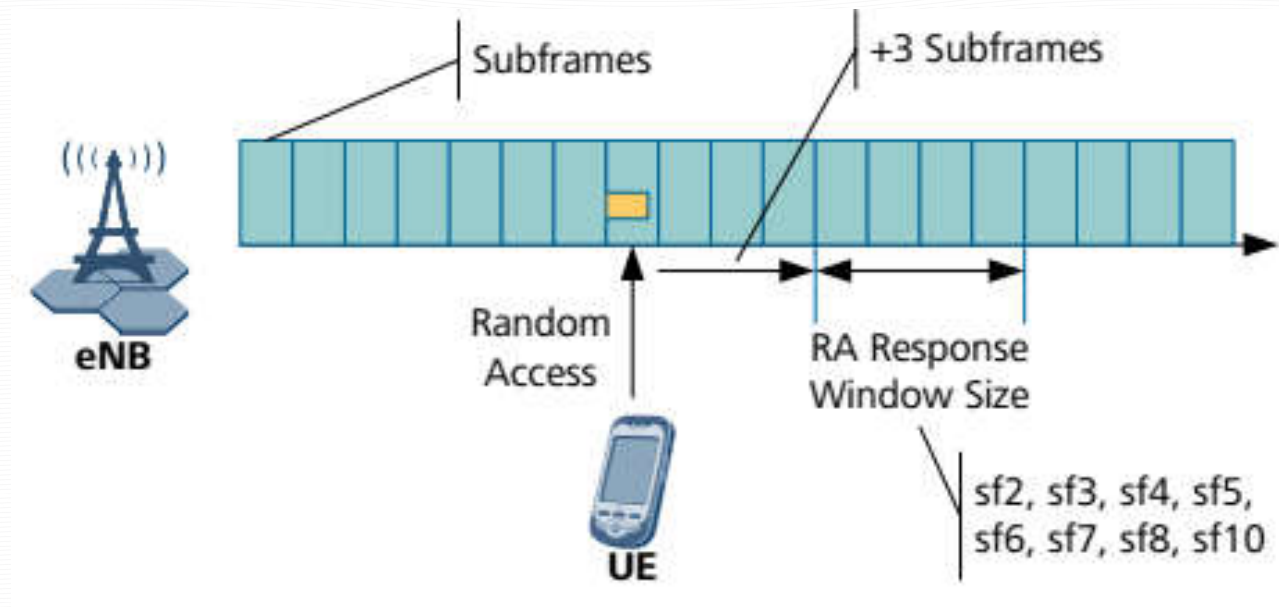
# LTE Random Access Procedure

- Allocation of Preamble Groups



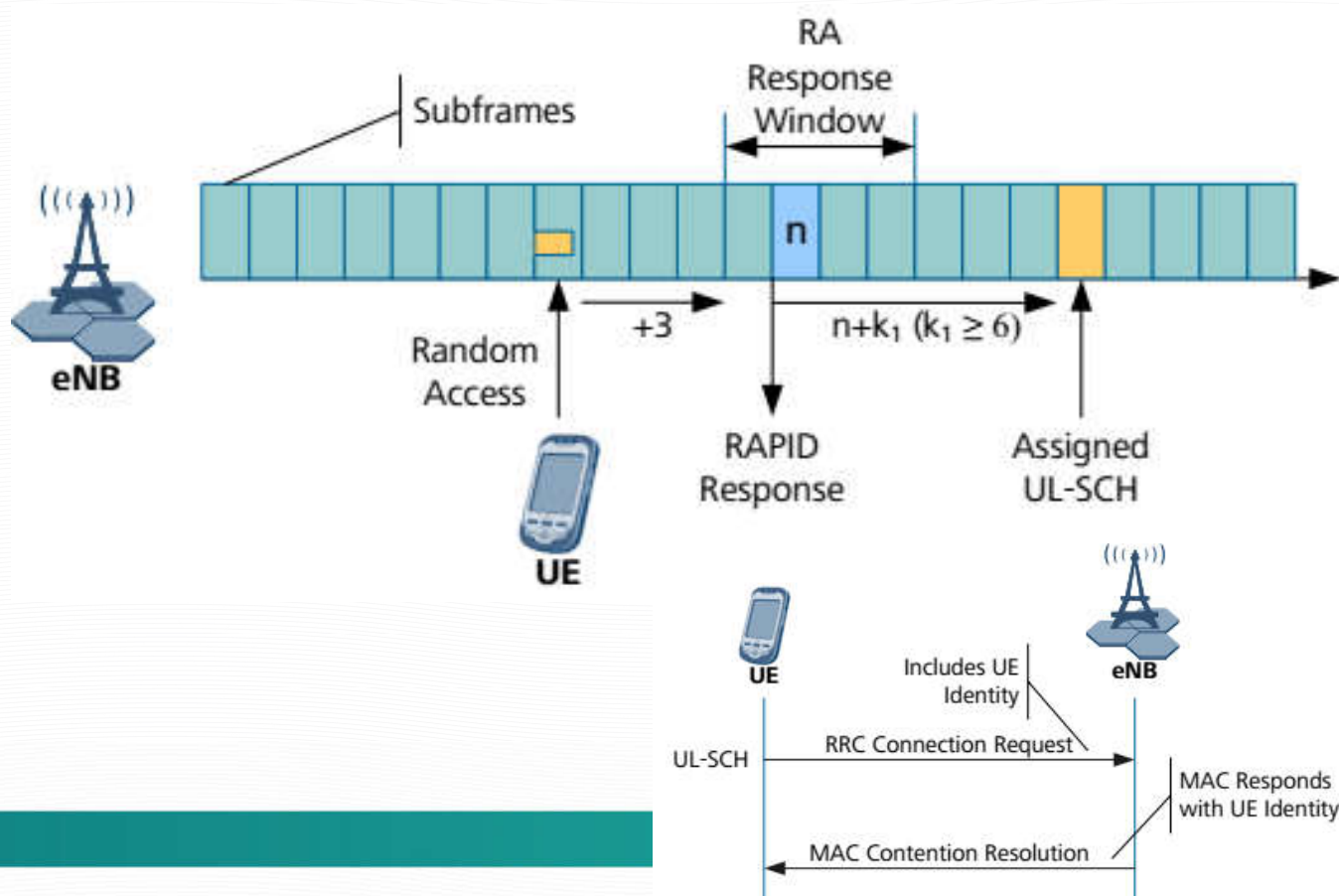
# LTE Random Access Procedure

- Random Access Response Window



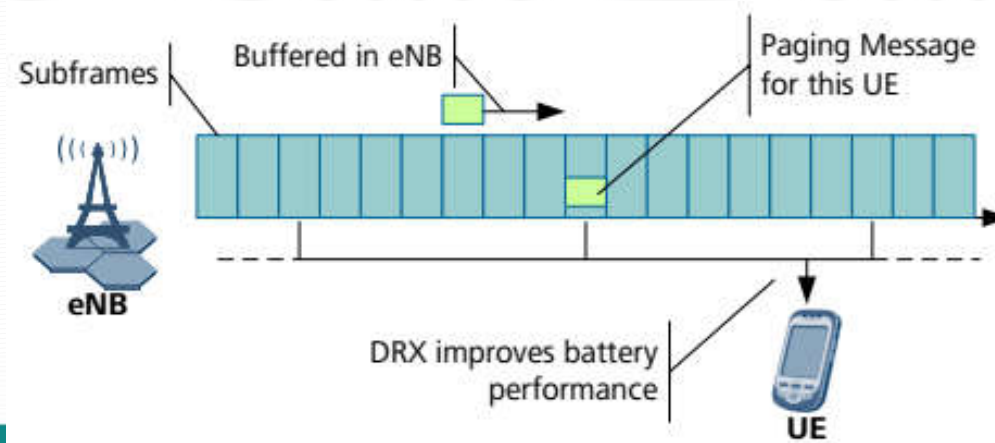
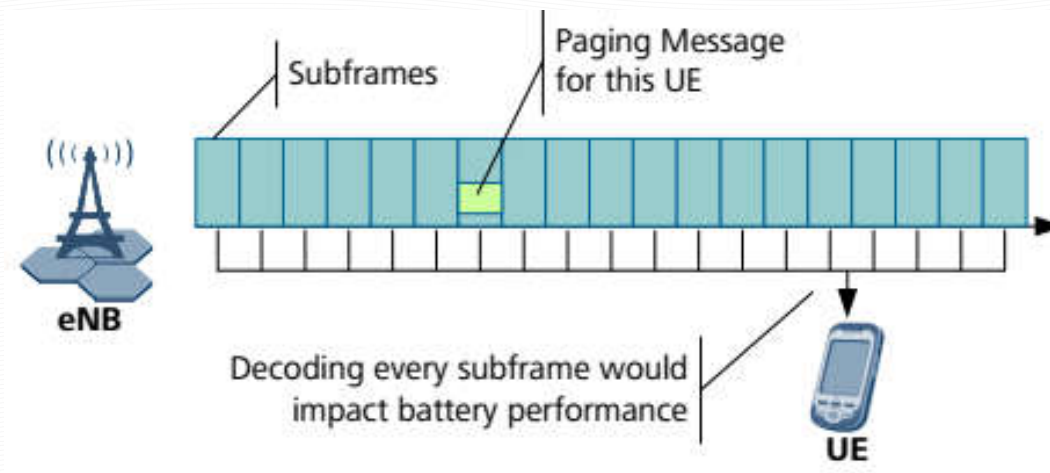
# LTE Random Access Procedure

## ■ Uplink Transmission





# Paging Procedure



# Attach Procedure

