RAN Course

10/02/2022

Agenda

Contents:

- PRB resources allocation
- LTE Radio Channels
- Signaling Flow for basic 4G procedures
- CSFB vs VoLTE
- CSFB Signaling Flow
- VoLTE architecture
- RRC and RAB Signaling Flow
- Handover

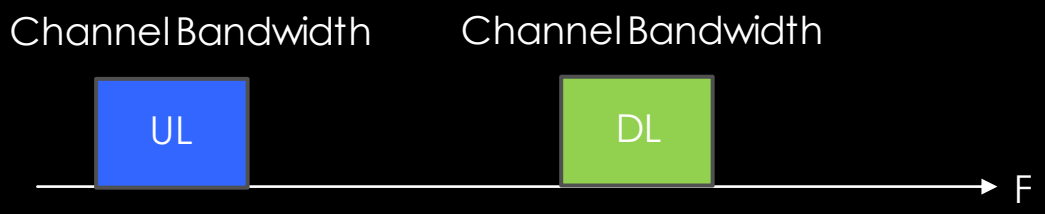
LTE Resource Allocation

10/02/2022

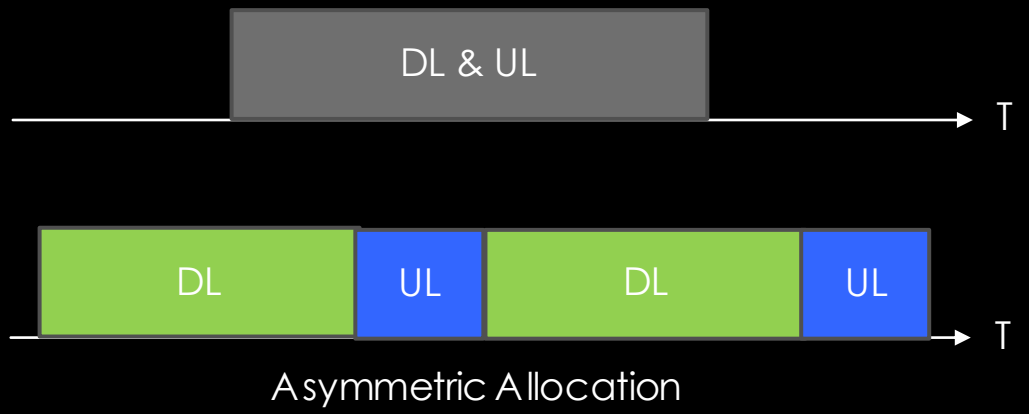
Division Multiplex Technology

TRANSMISSION MODE

Frequency Division Duplex (FDD):
Distinguish uplink and downlink according to frequencies.



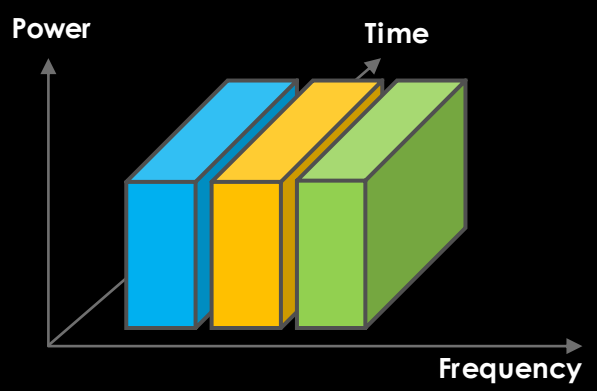
Time division duplex (TDD):
Distinguish uplink and downlink according to timeslots.



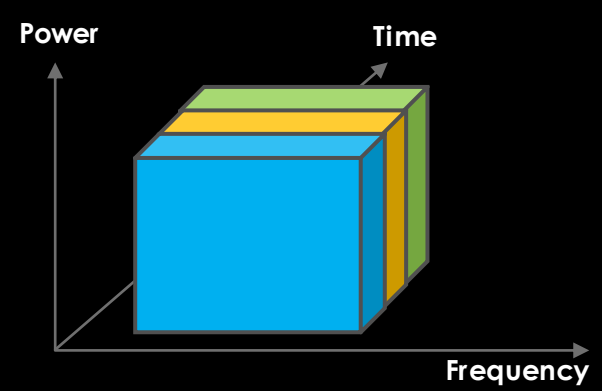
Asymmetric Allocation

MULTIPLE ACCESS TECHNOLOGY

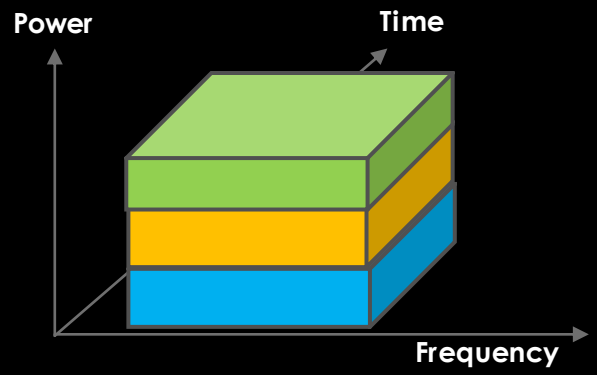
FDMA



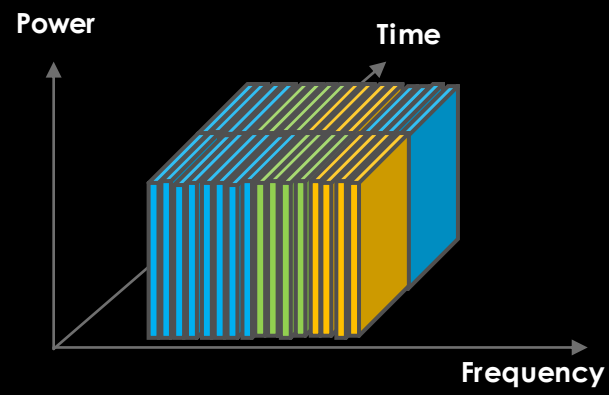
TDMA



CDMA

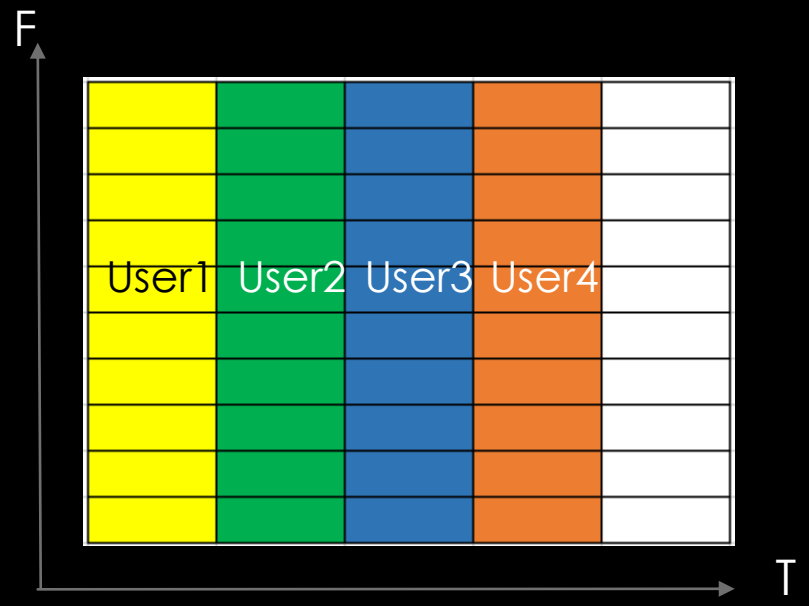


OFDMA



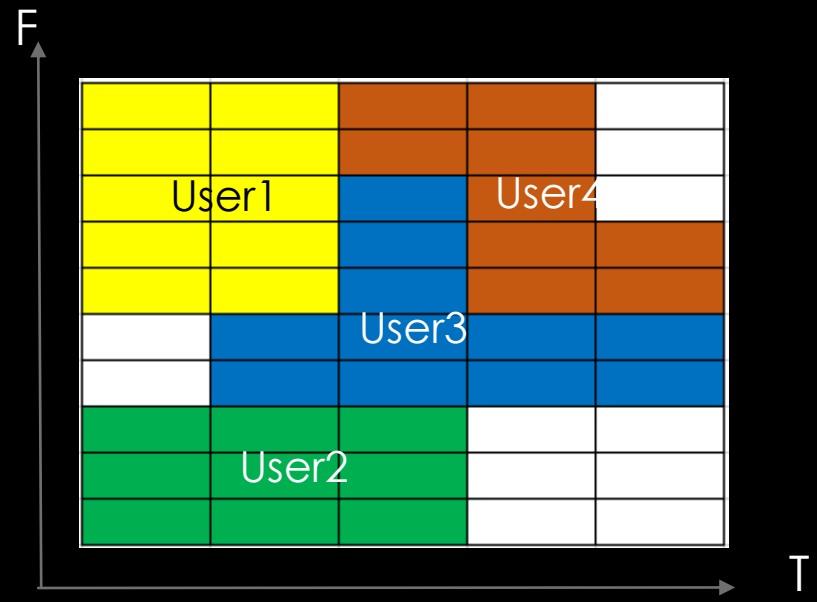
OFDM and OFDMA

In OFDM all sub carriers of the symbol are used for providing data to a specific user.



OFDM

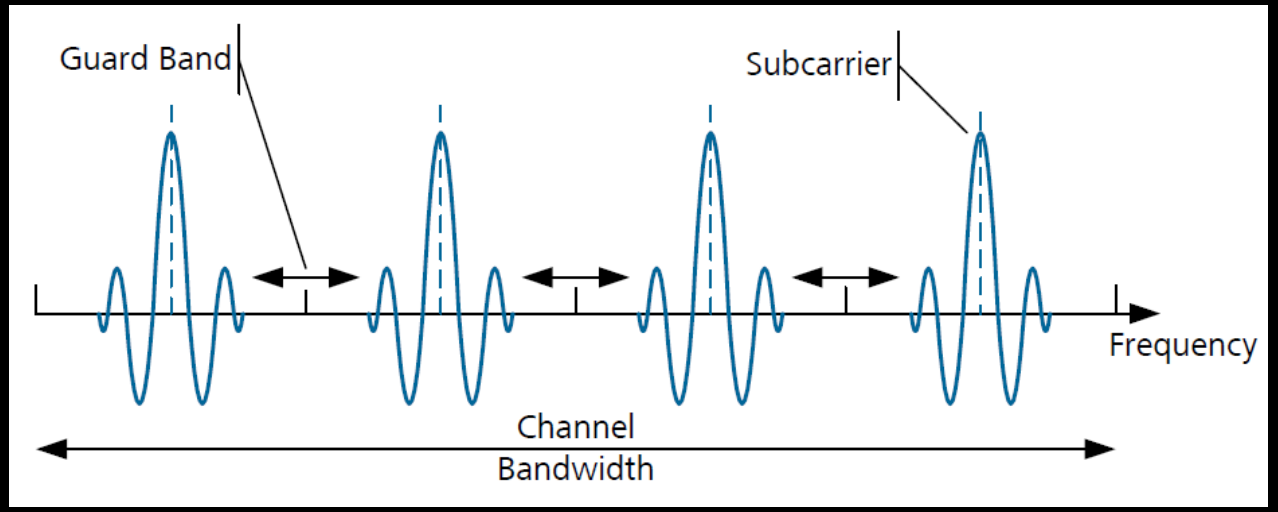
In OFDMA the sub carriers of each symbol may be divided between multiple users thus enabling better use of the radio resources.



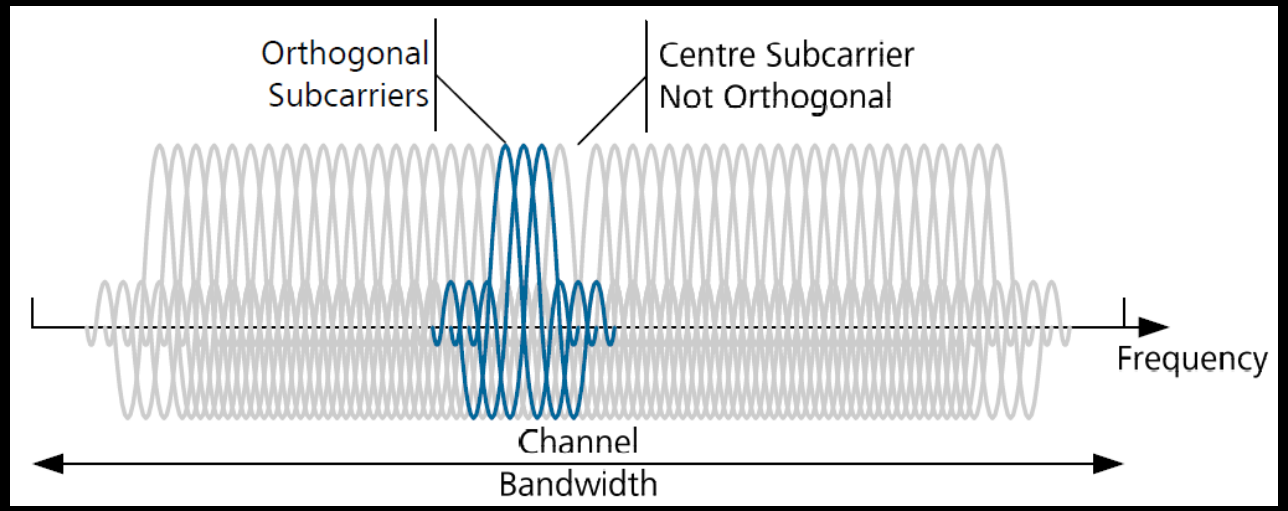
OFDMA

Principles of OFDM

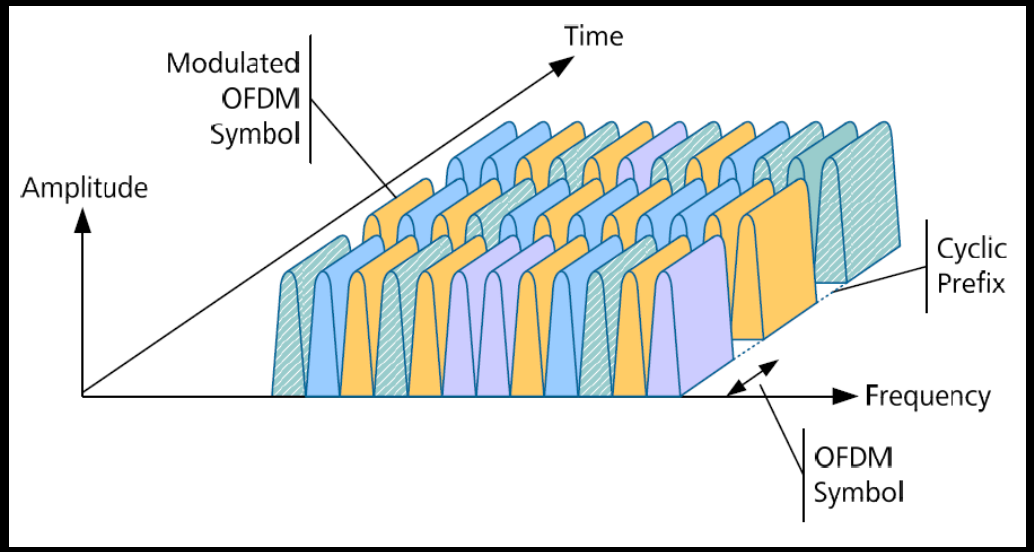
Frequency Division Multiplexing



OFDM Subcarriers



OFDM Symbol Mapping



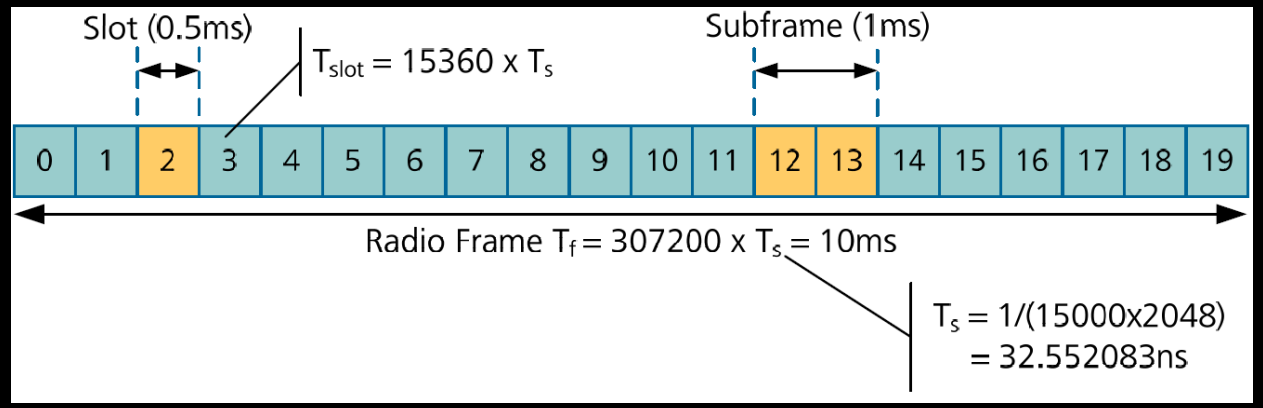
Resource Block

Radio Frame Structures Supported by LTE:

- Type 1, applicable to FDD
- Type 2, applicable to TDD

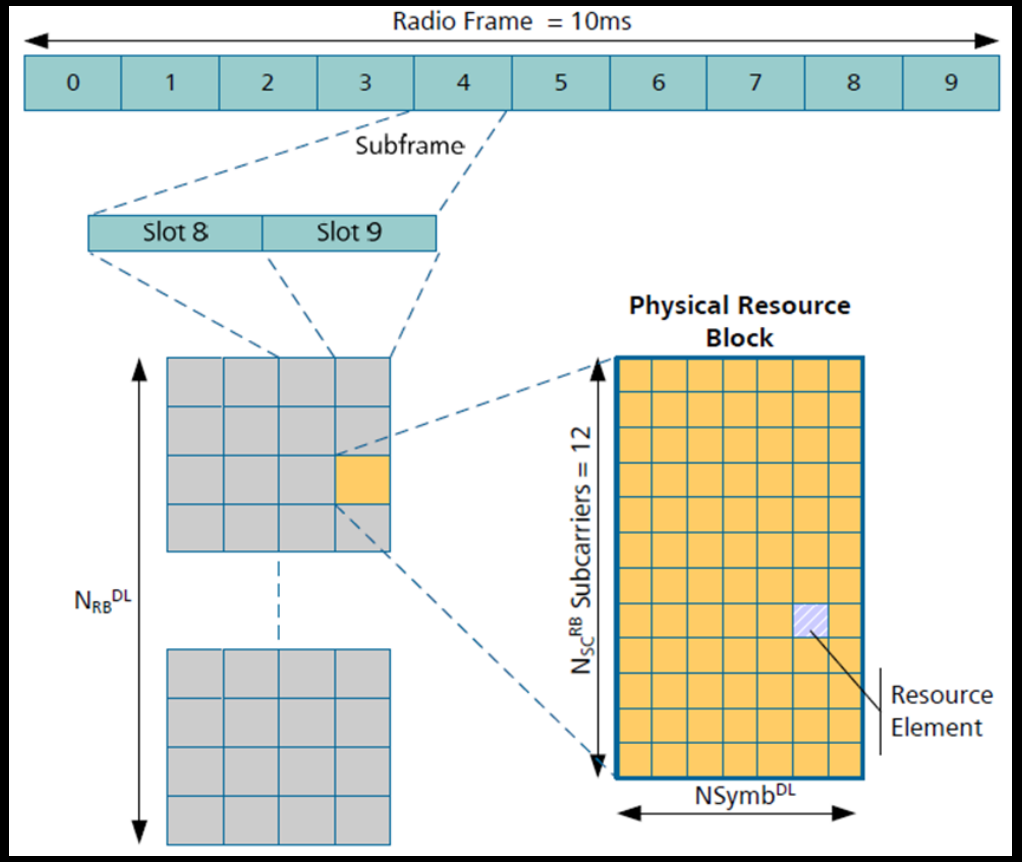
FDD Radio Frame Structure:

- LTE applies OFDM technology, with subcarrier spacing f=15kHz and 2048-order IFFT. The time unit in frame structure is Ts=1/(2048* 15000) second
- FDD radio frame is 10ms shown as below, divided into 20 slots which are 0.5ms. One slot consists of 7 consecutive OFDM Symbols under Normal CP configuration



Concept of Resource Block:

- LTE consists of time domain and frequency domain resources. The minimum unit for schedule is RB (Resource Block), which compose of RE (Resource Element)
- RE has 2-dimension structure: symbol of time domain and subcarrier of frequency domain
- One RB consists of 1 slot and 12 consecutive subcarriers under Normal CP configuration

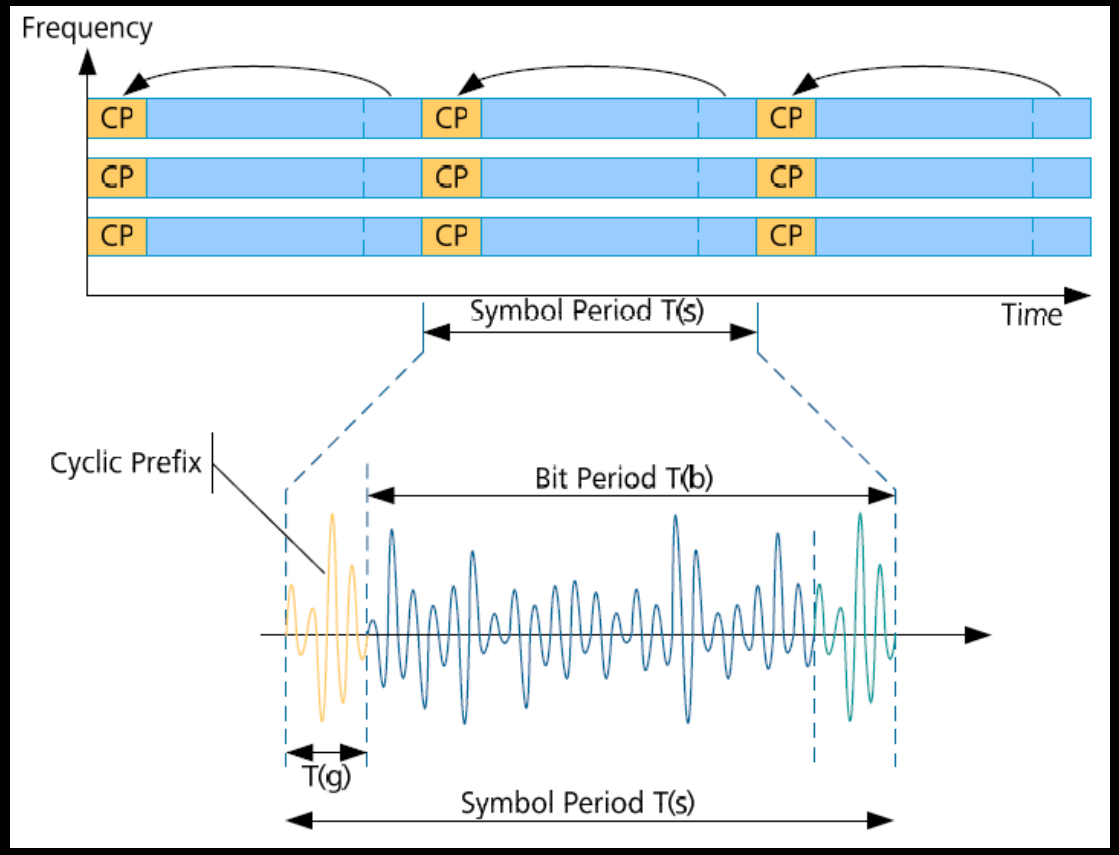


Cyclic Prefix : CP

CP Length Configuration:

- Cyclic Prefix is applied to eliminate ISI of OFDM.
- CP length is related with coverage radius. Normal CP can fulfill the requirement of common scenarios. Extended CP is for wide coverage scenario.
- Longer CP, higher overheading.

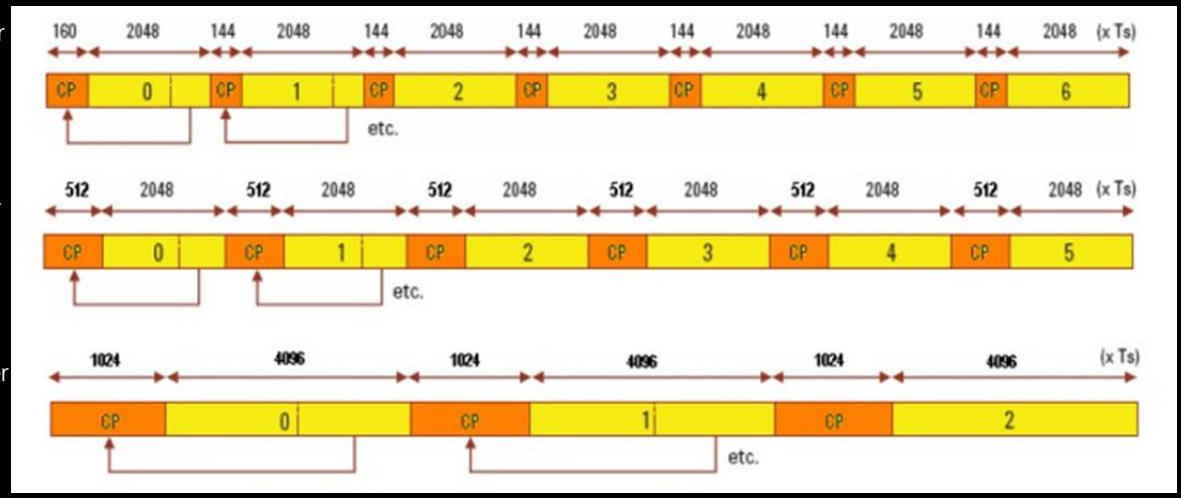
Configuration		DL OFDM CP Length	UL SC-FDMA CP Length	Sub-carrier of each RB	Symbol of each slot
Normal CP	f=15kHz	160 for slot #0 144 for slot #1~#6	160 for slot #0 144 for slot #1~#6	12	7
Extended CP	f=15kHz	512 for slot #0~#5	512 for slot #0~#5		6
	f=7.5kHz	1024 for slot #0~#2	NULL	24 (DL only)	3 (DL only)



Slot structure Under Normal CP configuration (Δf=15kHz)

Slot structure Under Extended CP configuration (Δf=15kHz)

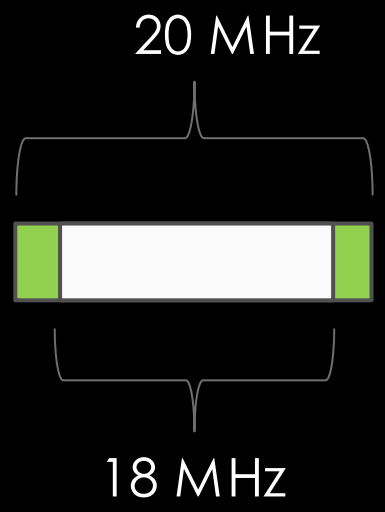
Slot structure Under Extended CP configuration (Δf=7.5kHz)



Characteristics of Bandwidth

- The number of sub-carriers is dependent on the bandwidth of the radio channel
- The width of the bandwidth, is made up of sub-carriers with a 15 kHz step.

Radio CH BW	1.4 MHz	3 MHz	5 MHz	10 MHz	15 MHz	20 MHz
BW used	1.08 MHz	2.7 MHz	4.5 MHz	9 MHz	13.5 MHz	18 MHz
Number of sub-carriers	72	180	300	600	900	1200
Number of RB	6	15	25	50	75	100



Frequency bandwidth vs Throughput

L2100

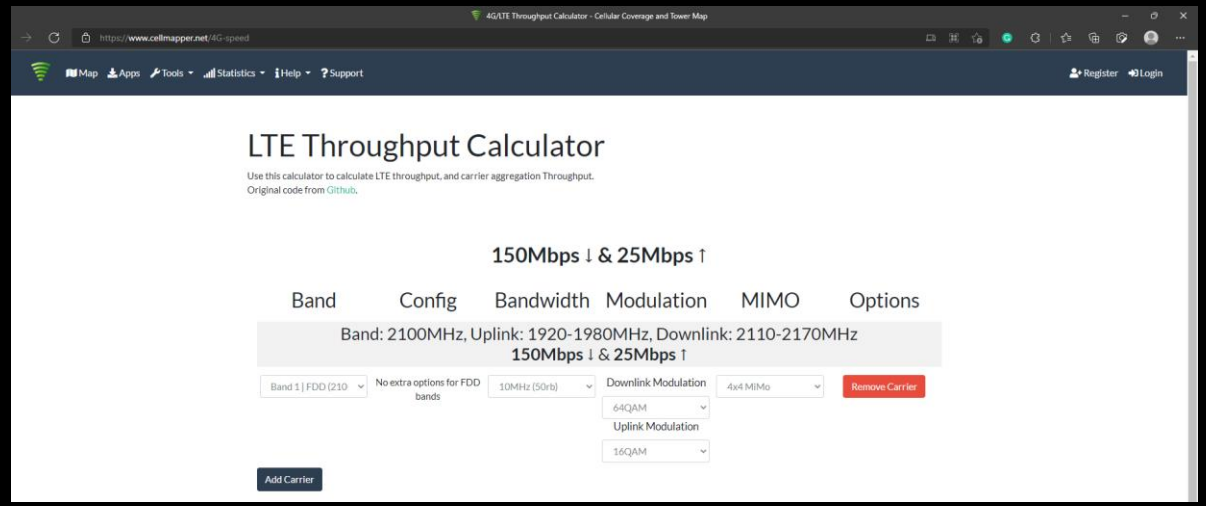
10 MHz → 50 PRB

- 1 TX → 37.5 Mbps
- 2 TX → 75 Mbps
- 4 TX → 150 Mbps

L1800

20 MHz → 100 PRB

- 1 TX → 75 Mbps
- 2 TX → 150 Mbps
- 4 TX → 300 Mbps



https://www.cellmapper.net/4G-speed

Frequency Band vs Priority

Priority

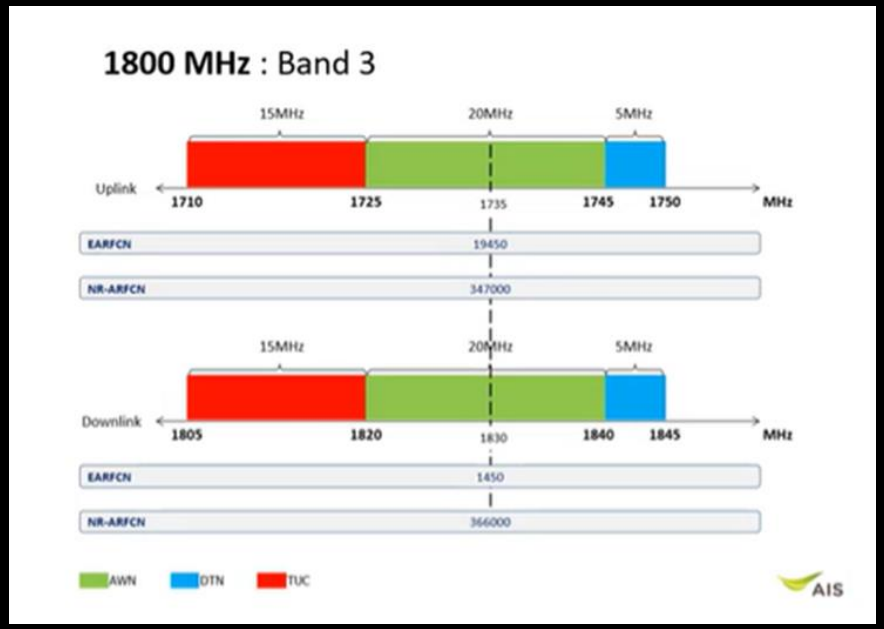
L1800
Priority 7

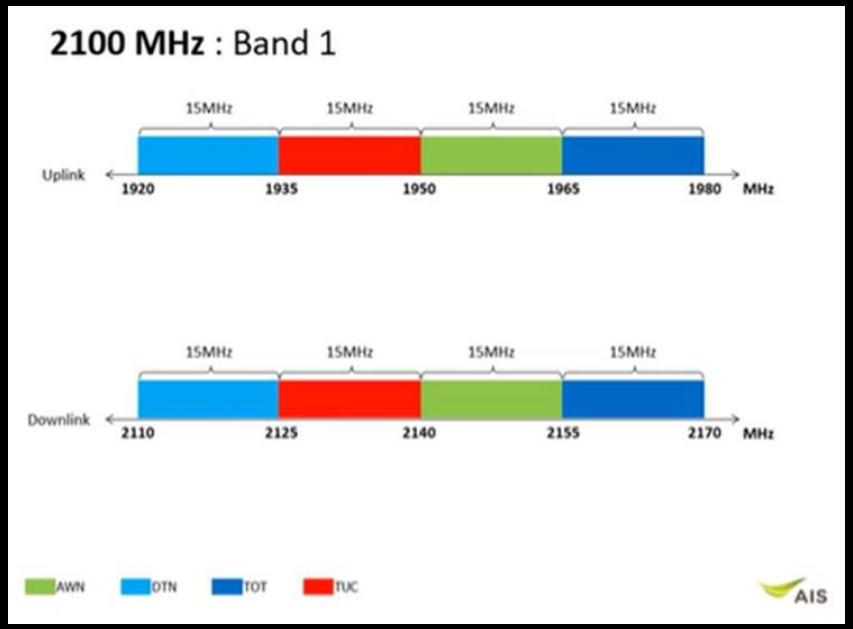
L2100
Priority 6

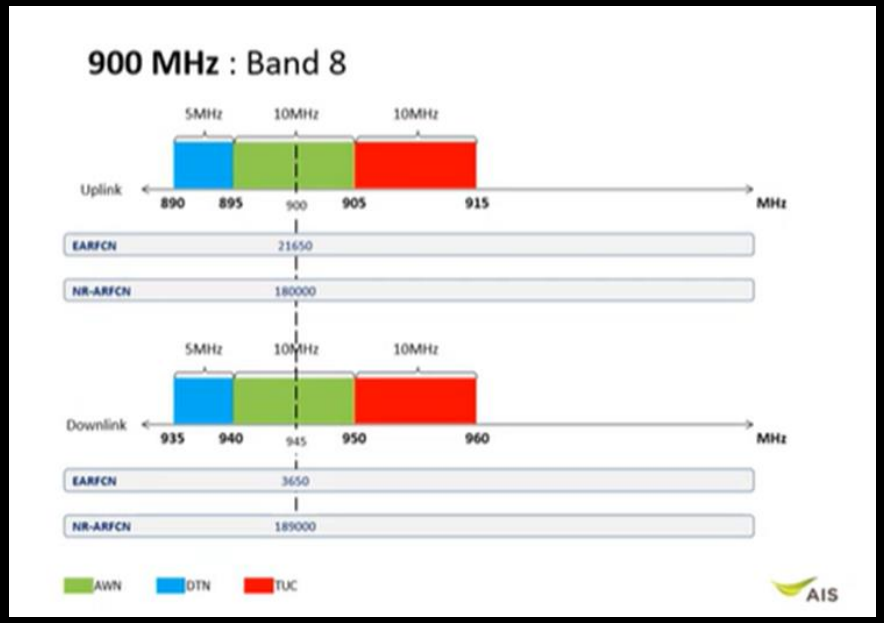
L900
Priority 5

L2300
Priority 4

U2100
Priority 2







Frequency Band vs Coverage

Priority

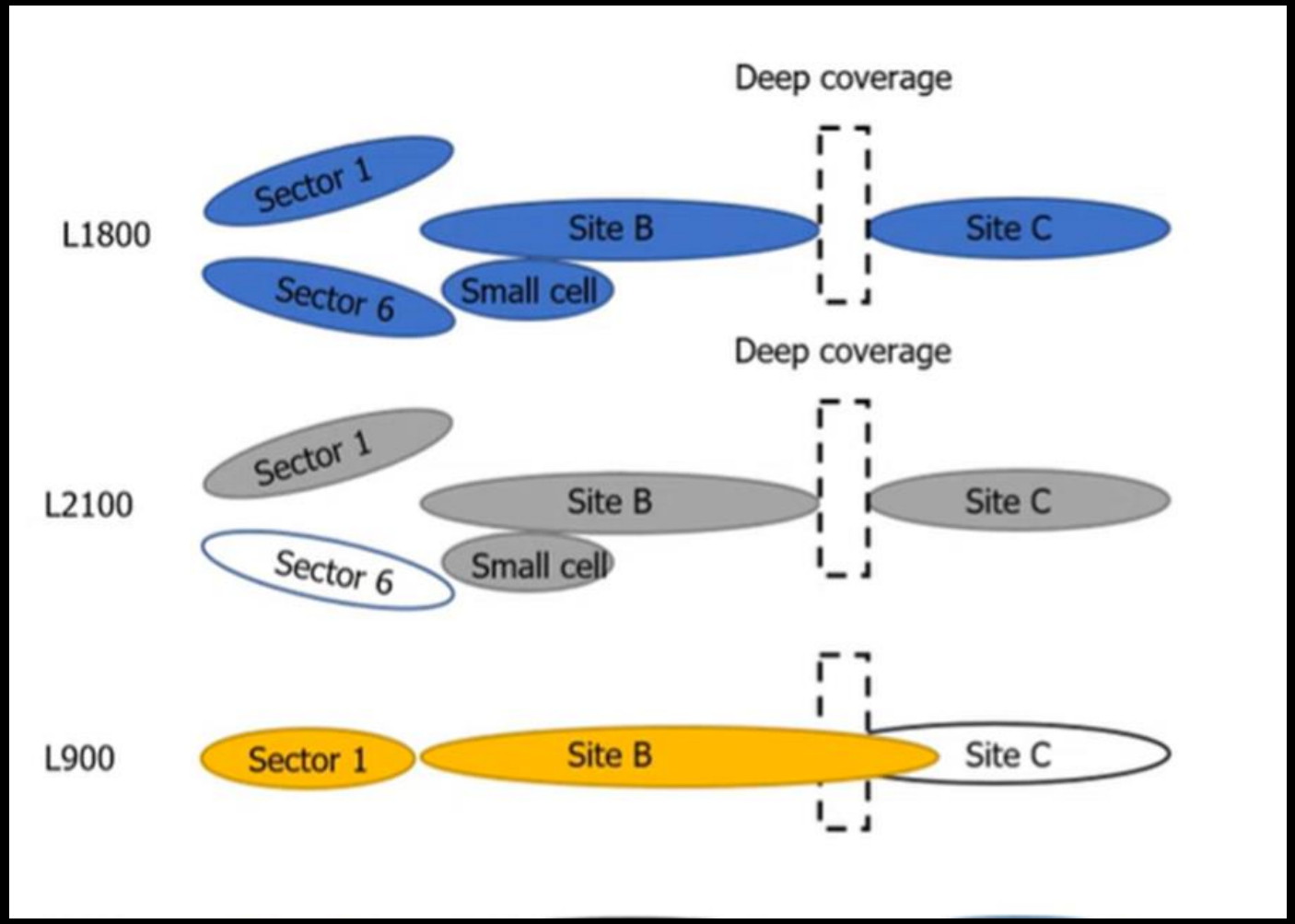
L1800
Priority 7

L2100
Priority 6

L900
Priority 5

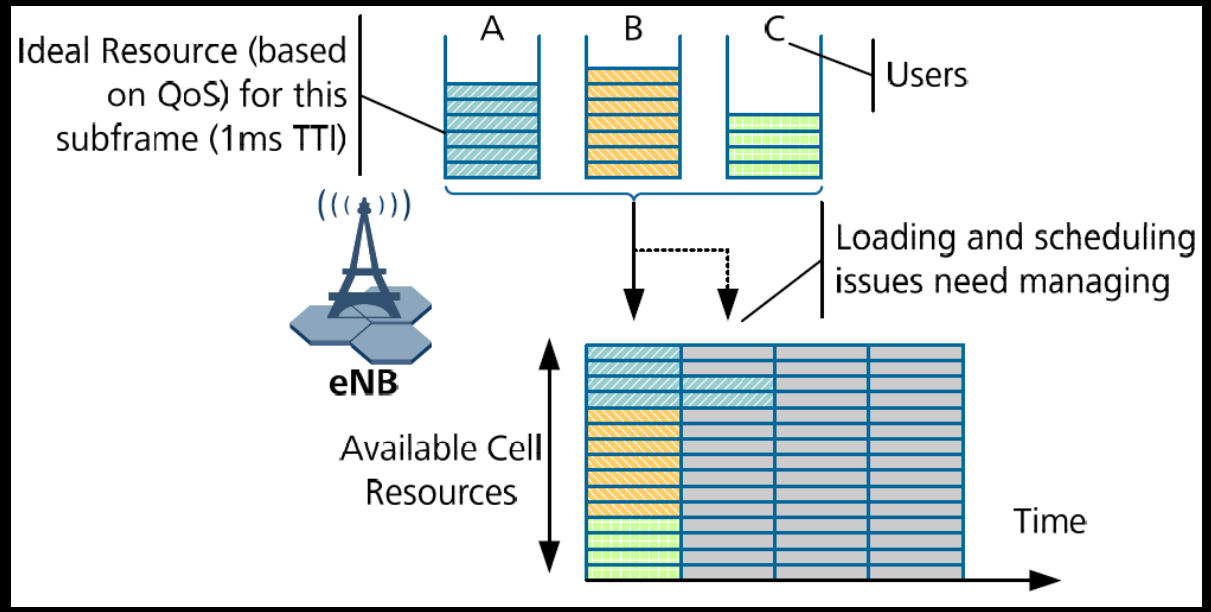
L2300
Priority 4

U2100
Priority 2

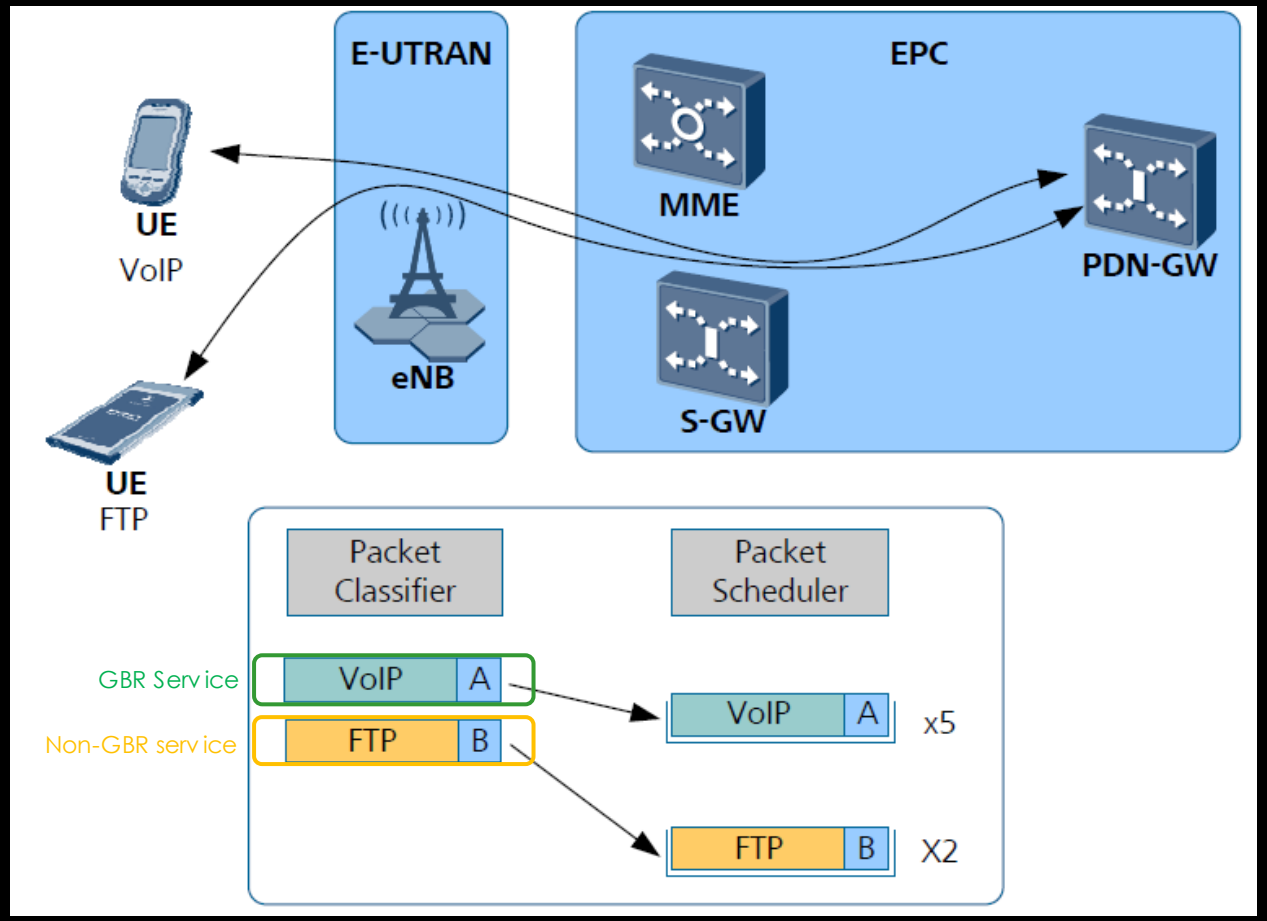


Basic Scheduling in a Cell

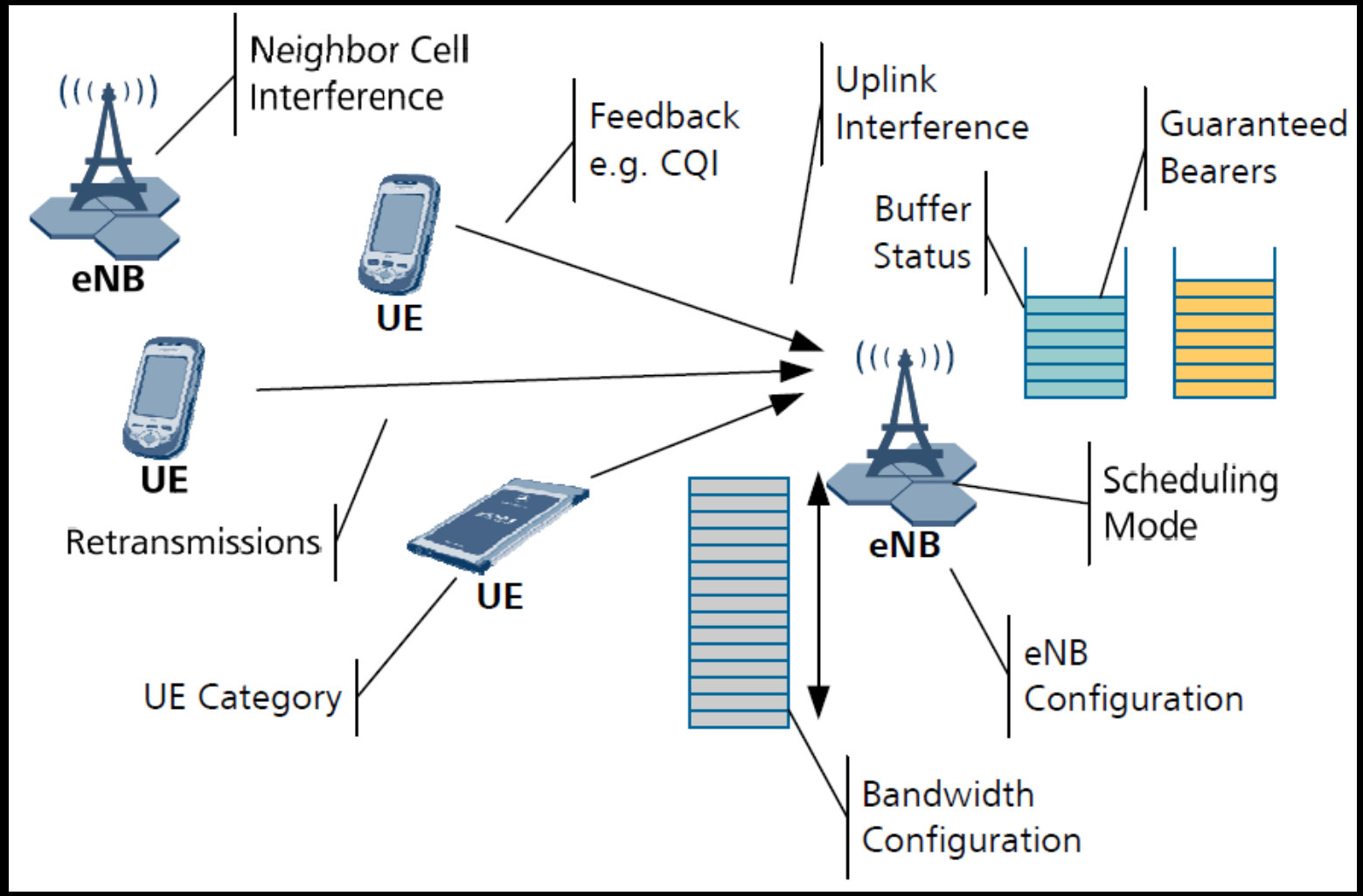
Basic Scheduling in a Cell



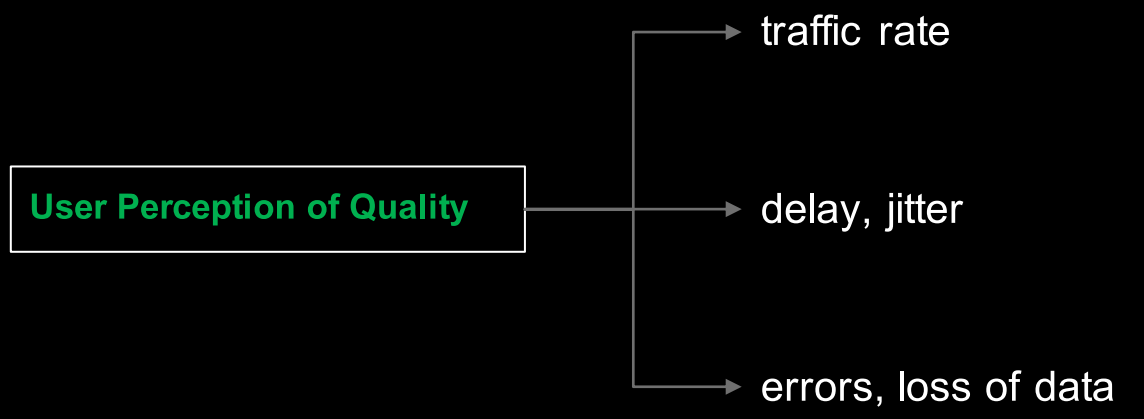
QoS in Packet Switched Networks Packet Schedulers and Classifiers

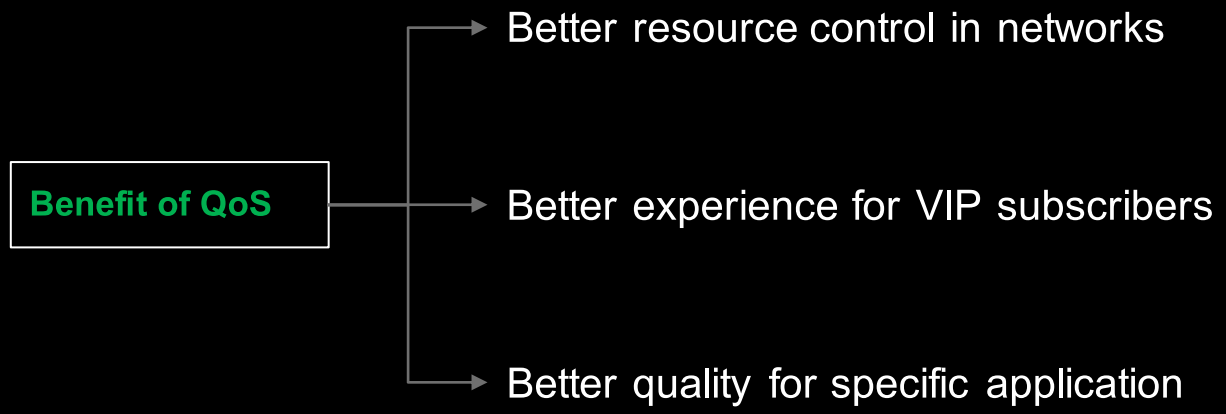


Key Factors Influencing Scheduling



What is QoS (Quality of Service)





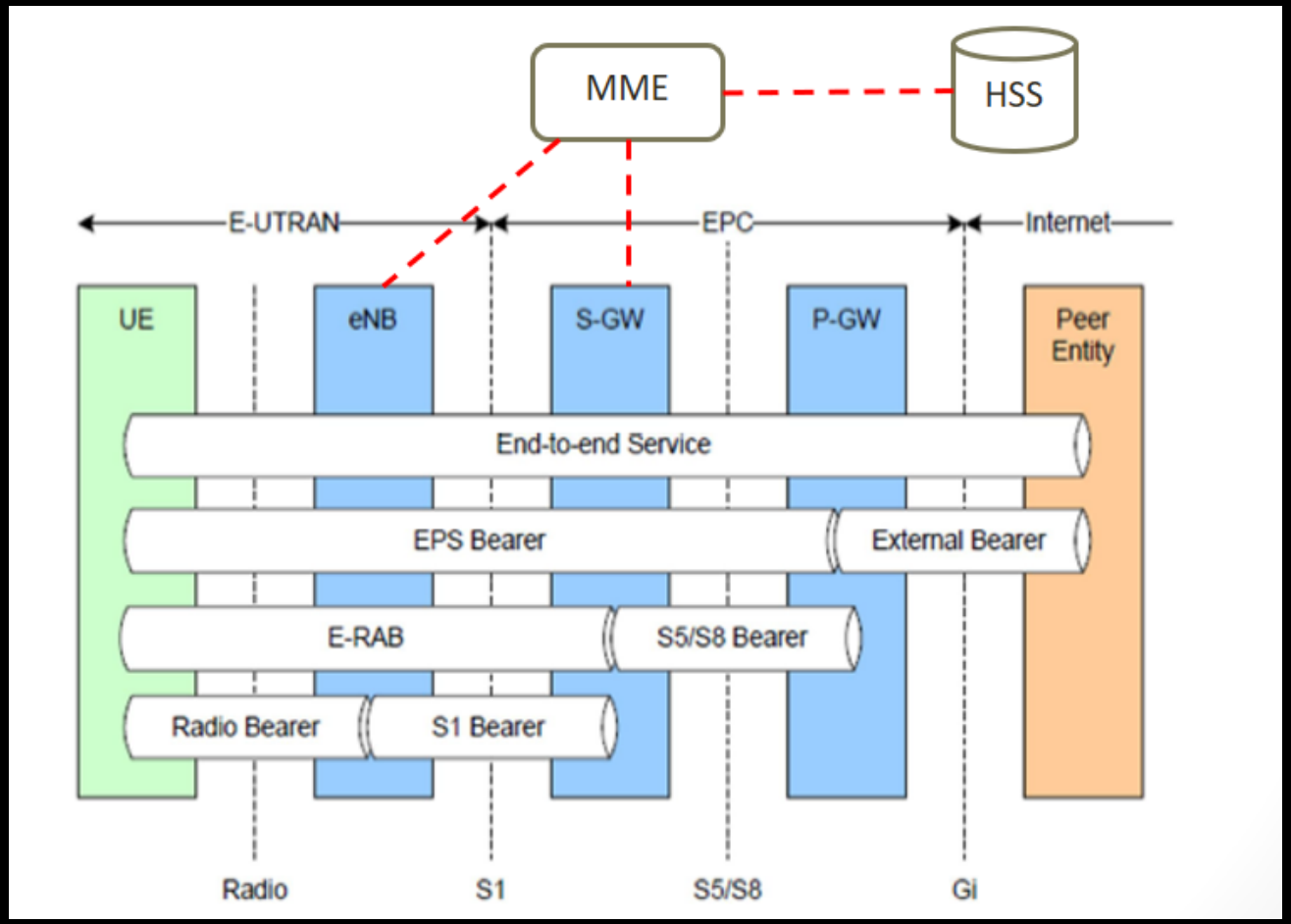
QoS Subscription

QoS = { _ , _ , _, _ , … }

Pre-EPS
- QoS is subscribed in HLR

EPS
- QoS is subscribed in HSS(Default Bearer) and PCRF(Dedicated Bearer)

3GPP definition for QoS



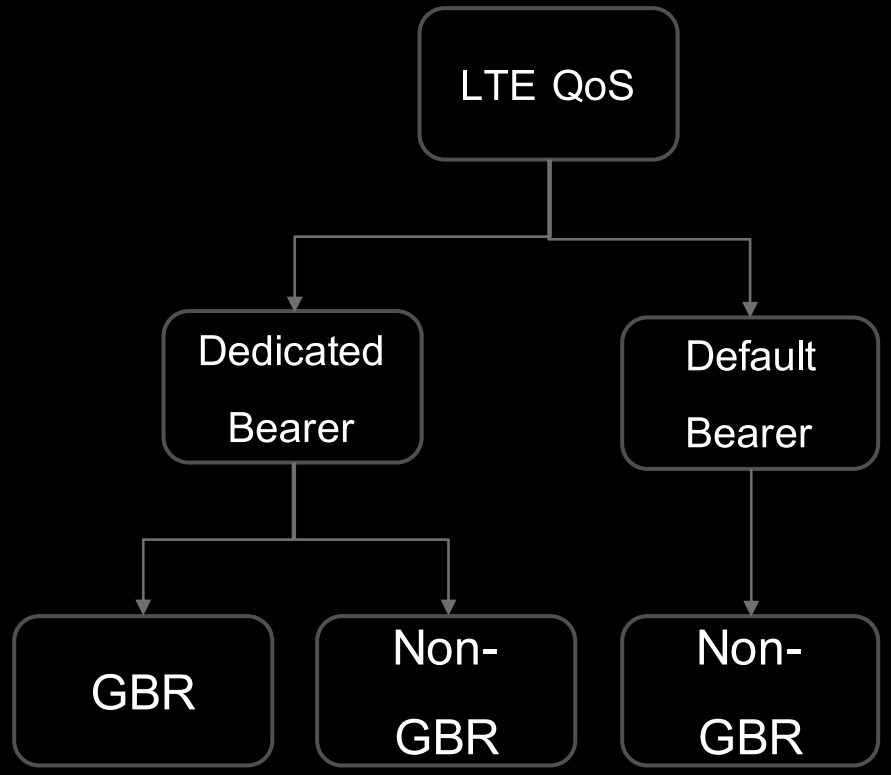
EPS Bearer

3GPP definition for QoS

QoS is implemented between UE and PGW

QoS is applied on Radio bearer, S1-U bearer and S5/S8 bearer, called as EPS bearer

Default and Dedicated Bearer Map To Non-GBR and GBR Type



Non-GBR vs. GBR Type

Non-GBR: Non-Guaranteed bit rate

- bearer does not provide guaranteed bit rate
  - A-AMBR: APN Aggregate maximum bit rate is the maximum allowed total non-GBR throughput to specific APN.
  - UE -AMBR: UE Aggregate maximum bit rate is the maximum allowed total non-GBR throughput among all APN to a specific UE.
- For non-real time service

GBR: Guaranteed bit rate

- GBR provides guaranteed bit rate
  - GBR: The minimum guaranteed bit rate per EPS bearer
  - MBR: The maximum guaranteed bit rate per EPS bearer
- For real time service

Standardized QCIs for LTE

QCI	Resource Type	Priority	Priority Packet Delay Budget	Packet Error Loss Rate	Service Type (Examples)
1	GBR	2	100 ms	1/100	VoLTE - Conversational Video
2		4	150 ms	1/1 000	ViLTE - Live Video Streaming
3		3	50 ms	1/1 000	Real time Gaming
4		5	300 ms	1/1 000 000	Non-conversational Video (buffered Streaming)
5	Non-GBR	1	100 ms	1/1 000 000	IMS Signaling
6		6	300 ms	1/1 000 000	TCP based - www, email, chat, ftp
7		7	100 ms	1/1 000	Voice, Video (live streaming) Interactive Gaming
8		8	300 ms	1/1 000 000	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p, filesharing, progressive video, etc.)
9		9			

QoS of Default Bearer = { QCI(5-9), A-AMBR, UE-AMBR, ARP }.
QoS of Dedicated Bearer = { QCI(1-9), GBR, MBR, ARP }.

EX. QCI for user

apn = internet (for Data service)

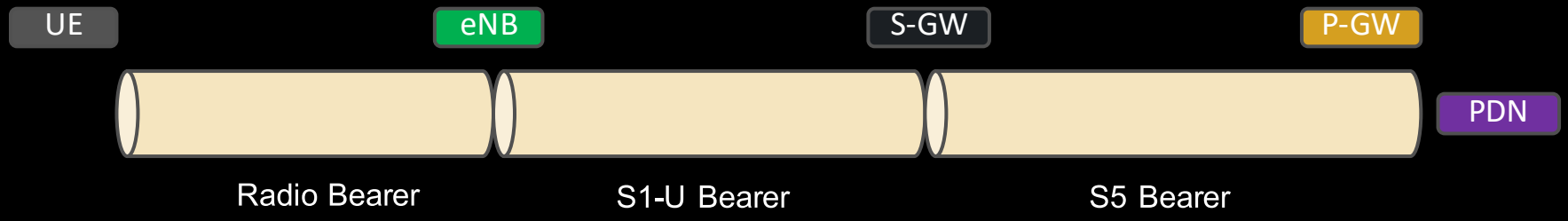
QCI = 8 ; be defined in HSS per user subscription

apn = ims (for VoLTE, ViLTE)

QCI = 5 ; be defined in HSS per user subscription (IMS signalling)

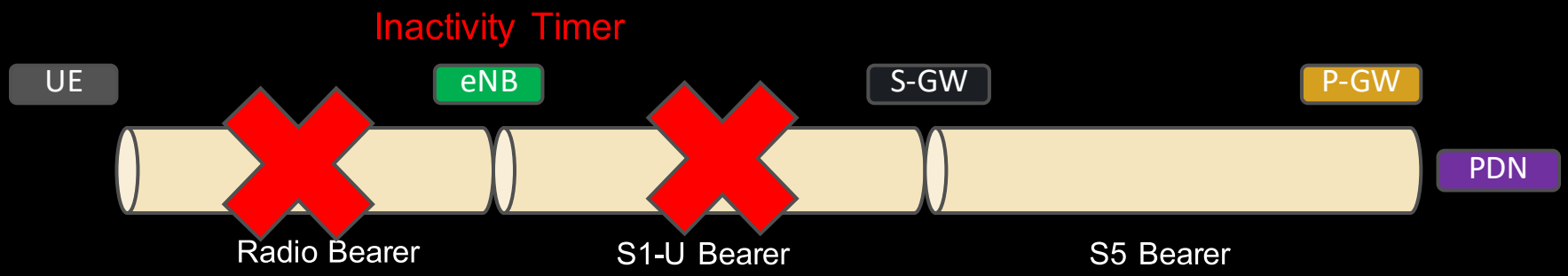
QCI = 1 ; be defined in PCRF when set up Dedicated bearer

Default Bearer



UE is in Connected mode

Default Bearer Detachment



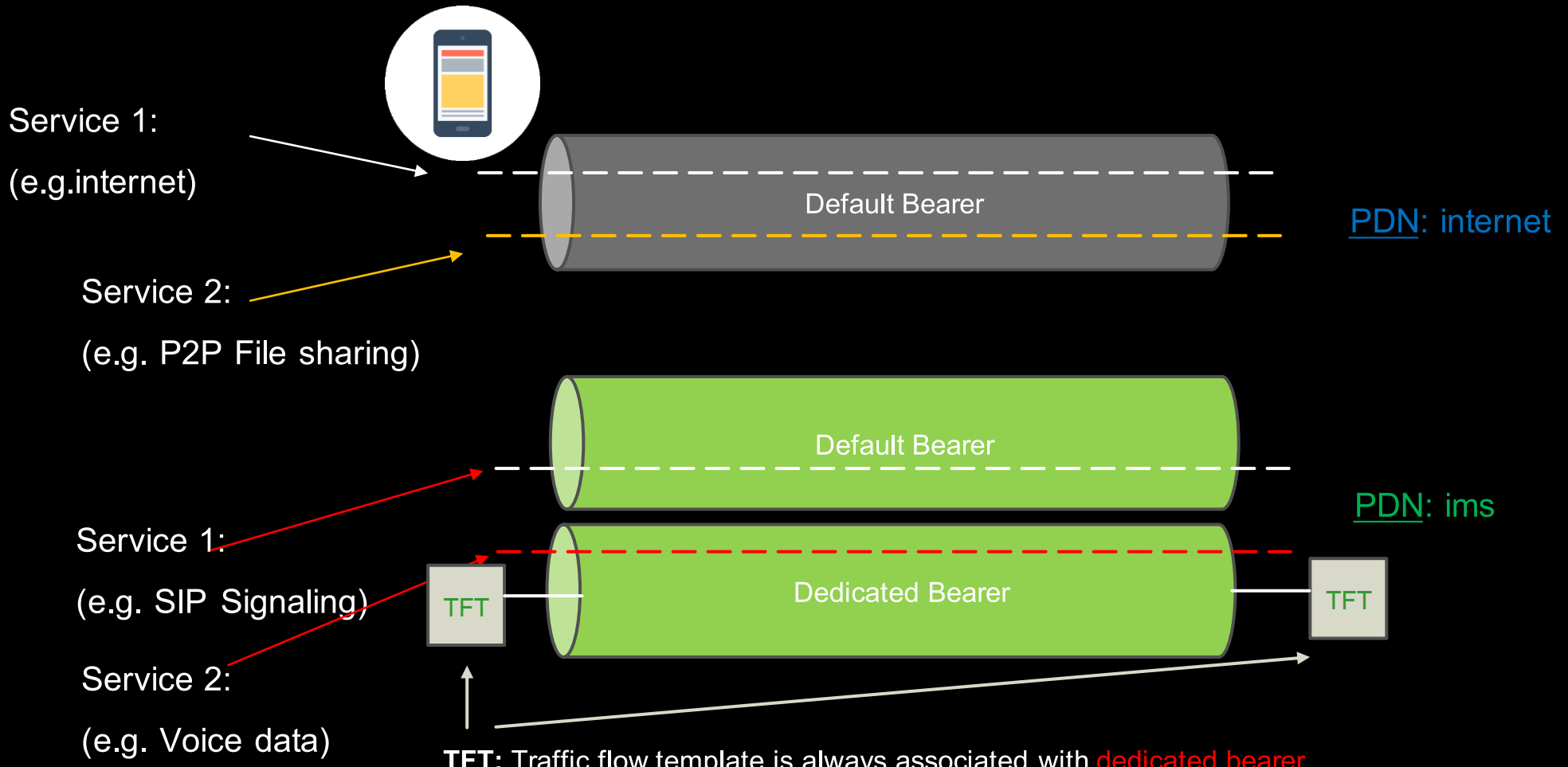
~~UE is in Connected mode~~

UE is in Idle mode

Detachment

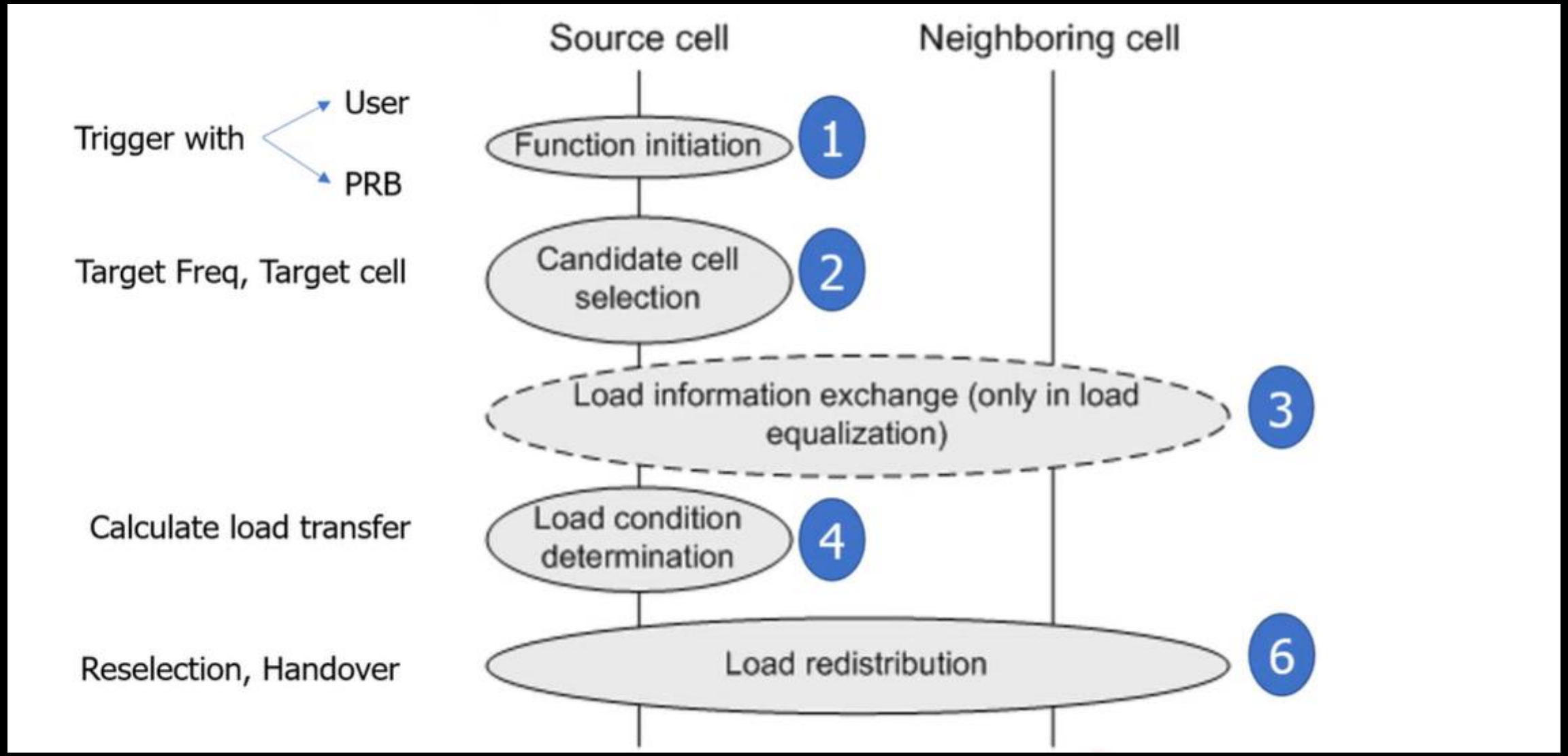
1. UE initiates – UE power off, UE is in Airplane mode On
2. Network initiates

Default Bearer and Dedicated Bearer

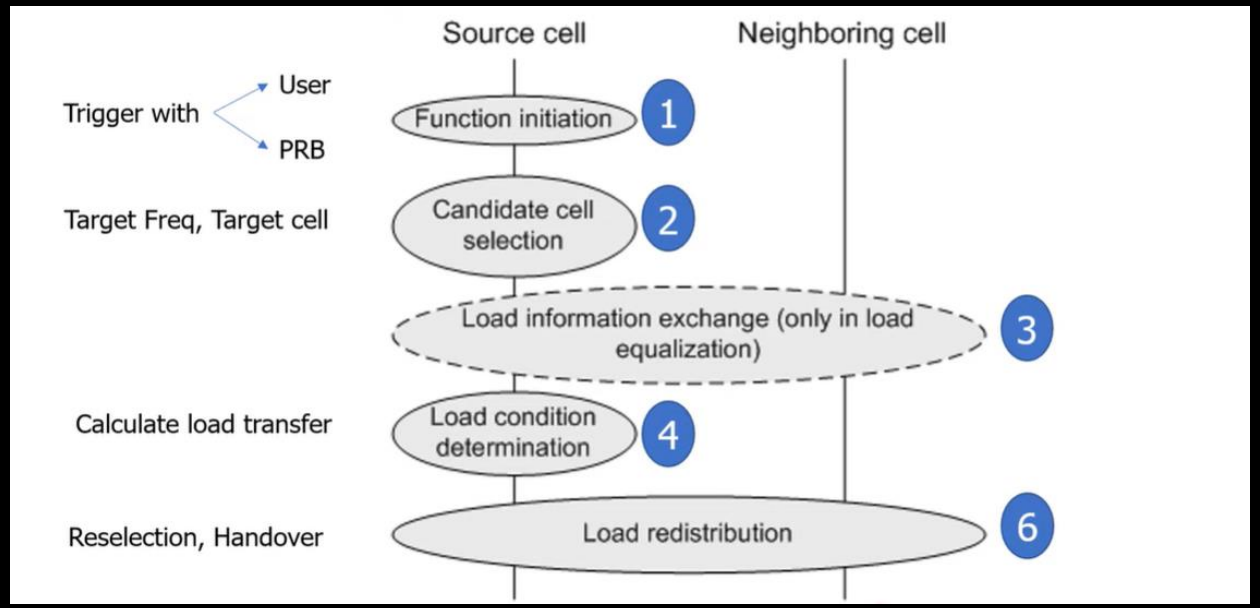


TFT: Traffic flow template is always associated with dedicated bearer and defines rules so that UE and Network knows which IP packet should be sent on particular dedicated bearer

MLB mechanism



MLB mechanism



MLB by transferring UEs in Idle Mode

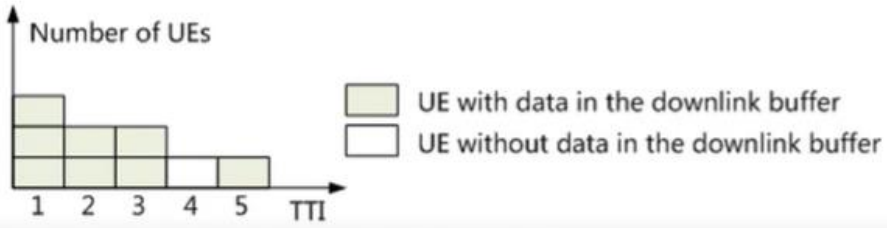
User-number-based MLB transfer by idle mode not affect abrupt change in UE data but a UE-movement-included slow change in the load.

Parameter ID	Option
CellAlgoSwitch.*MlbAlgoSwitch*	InterFreqMlbSwitch
CellMLB.*MlbTriggerMode*	UE_NUMBER_ONLY
CellMLB.*InterFreqUeTrsfType*	IdleUE

Number of UEs in a Cell

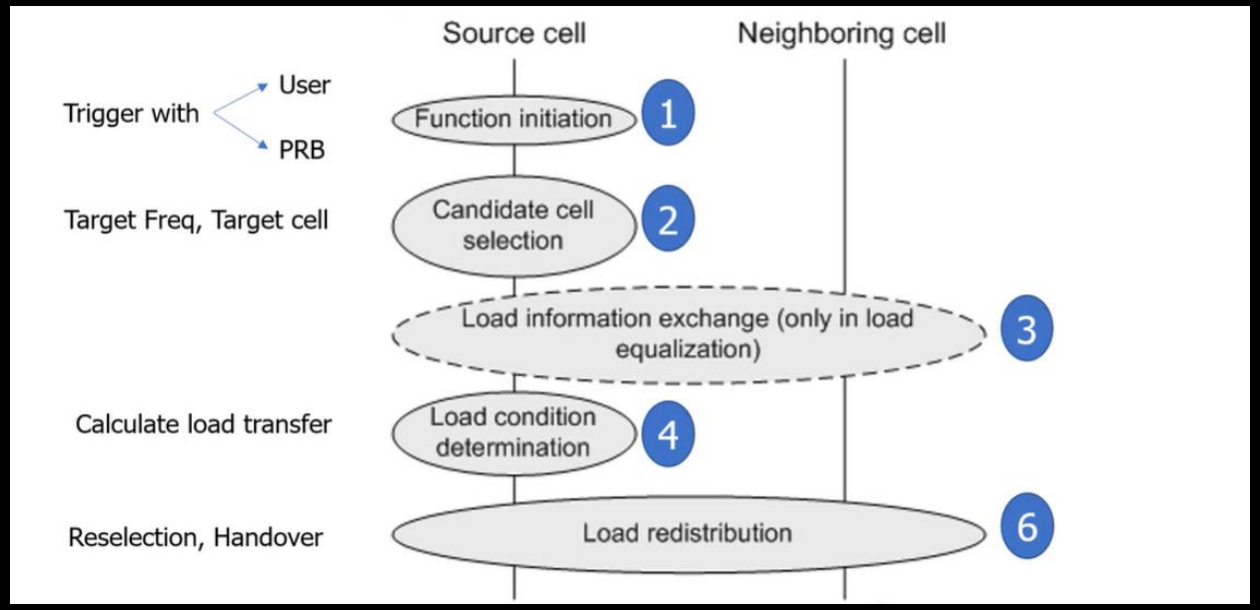
CellAlgoSwitch.EnhancedMlbAlgoSwitch .ActiveUeBasedLoadEvalSw

- ***Select (1)*** the number of active Ue
- ***Deselect (0)*** go to ....



Number of active UEs = (3 + 2 + 2 + 1)/4 = 2

MLB mechanism



MLB by PRB-Usage-based Idle Mode Load Equalization

eNodeB calculates the following type of PRB usages of a cell:

- Uplink GBR PRB usage
- Uplink Non-GBR PRB usage
- Uplink total PRB usage
- Downlink GBR PRB usage
- Downlink Non-GBR PRB usage
- Downlink total PRB usage

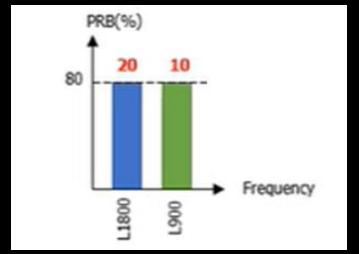
Load Difference

PRB-usage-based idle mode load equalization varies with the setting of the LoadTransferEnhSw option of the CellAlgoSwitch.EnchancedMlbAlgoSwitch parameter

If this option is selected
Load difference = PRB usage of the serving cell – PRB usage of a candidate cell

If this option is deselected
Load difference = PRB usage of the serving cell – PRB unused a candidate cell / Number of available PRBs in the smaller-bandwidth

Parameter ID	Option
CellAlgoSwitch.*MlbAlgoSwitch*	InterFreqMlbSwitch
CellMLB.*MlbTriggerMode*	PRB_ONLY
CellMLB.*PrbLoadCalcMethod*	PRB_USAGE
CellMLB.*InterFreqUeTrsfType*	PrbMlbIdleUE



MLB mechanism

Load Condition Evaluation [User based]

L1800 — 100 user

L2100 — 10 User

$$\frac{\text{(Air interface load in the serving cell – Air interface load in a candidate cell)}}{\text{Air interface load in the serving cell}} \geq \text{Load difference}$$

Load difference = 15%

The air interface load of a cell is defined as N/C

- *N* denotes the number of UEs in the cell.
- *C* denotes the air interface capability of the cell.

Cell Air Interface Capability

CellAlgoSwitch.EnhancedMlbAlgoSwitch. SpectralEffBasedLoadEvalSw

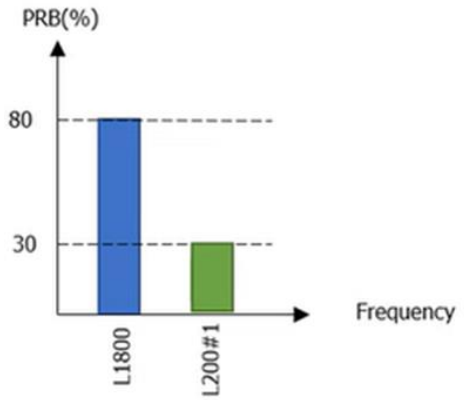
- ***Select(1)*** = P x SF x SE - G
- ***Deselect(0)*** = P x SF

P = DL PRB Available in cell
SF = CellMLB.CellCapacityScaleFactor

*SE = converted spectral efficiency in the unit of bit/RB
*G = required bandwidth for GBR services in the cell.

Air interface serving cell = 100/(100x10) = 0.1
Air interface target cell = 10/(50x7) = 0.028
Load difference = (0.1-0.028)/0.1 = 0.72

Load Condition Evaluation [PRB-Usage-based]



L1800 User = 50 user
L2100#1 User = 10 User

PRB usage serving cell = 80%
PRB usage target cell cell = 30%
Load difference = 80% -30% = 50%

MLB mechanism

Load Redistribution [User based]

L1800 — 100 user

L2100 — 10 User

Number of UEs to Be Transferred

$$\frac{C_t \times N_s - C_s \times N_t}{C_t + C_s}$$

L1800 = 100 UE
L2100#1 = 10 UE
Cs = PRB x SF = 100x10
Ct = PRB x SF = 50x7

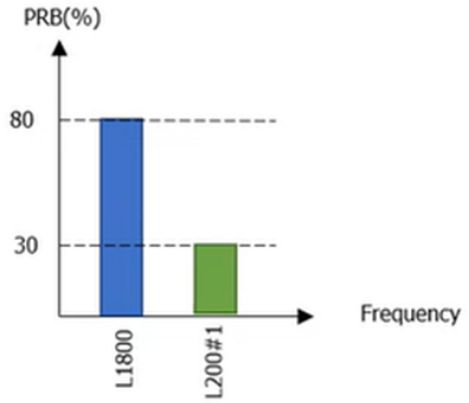
$$\frac{(350x100) - (1000x10)}{(350+1000)}$$ = 25,000 / 1,350 = Round down(18.51)

Final user

L1800 — 82 user

L2100#1 — 28 User

Load Redistribution [PRB-Usage-based]



L1800 User = 50 user
L2100#1 User = 10 user

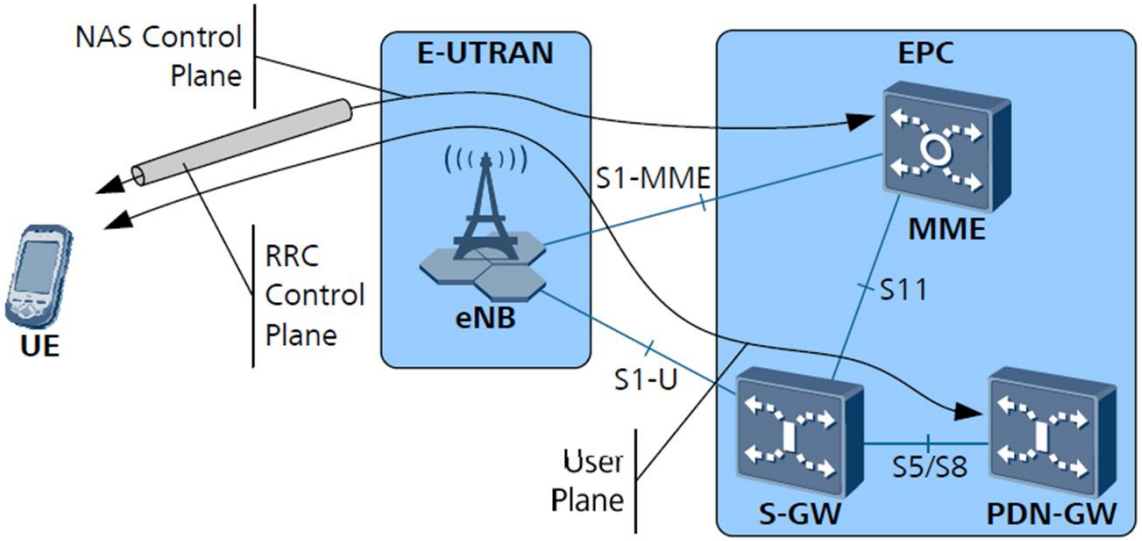
Number of UEs to Be Transferred
1. User per PRB usage per user = 80%/50 = 1.6 % per 1 user
2. How many user transfer to target load equalizer
- Target load equalizer (80+30)/2 = 55%
- Serving cell RB to transfer 80 – 55 = 25 %
Target user to transfer = 25 /1.6 = Round down(15.6)

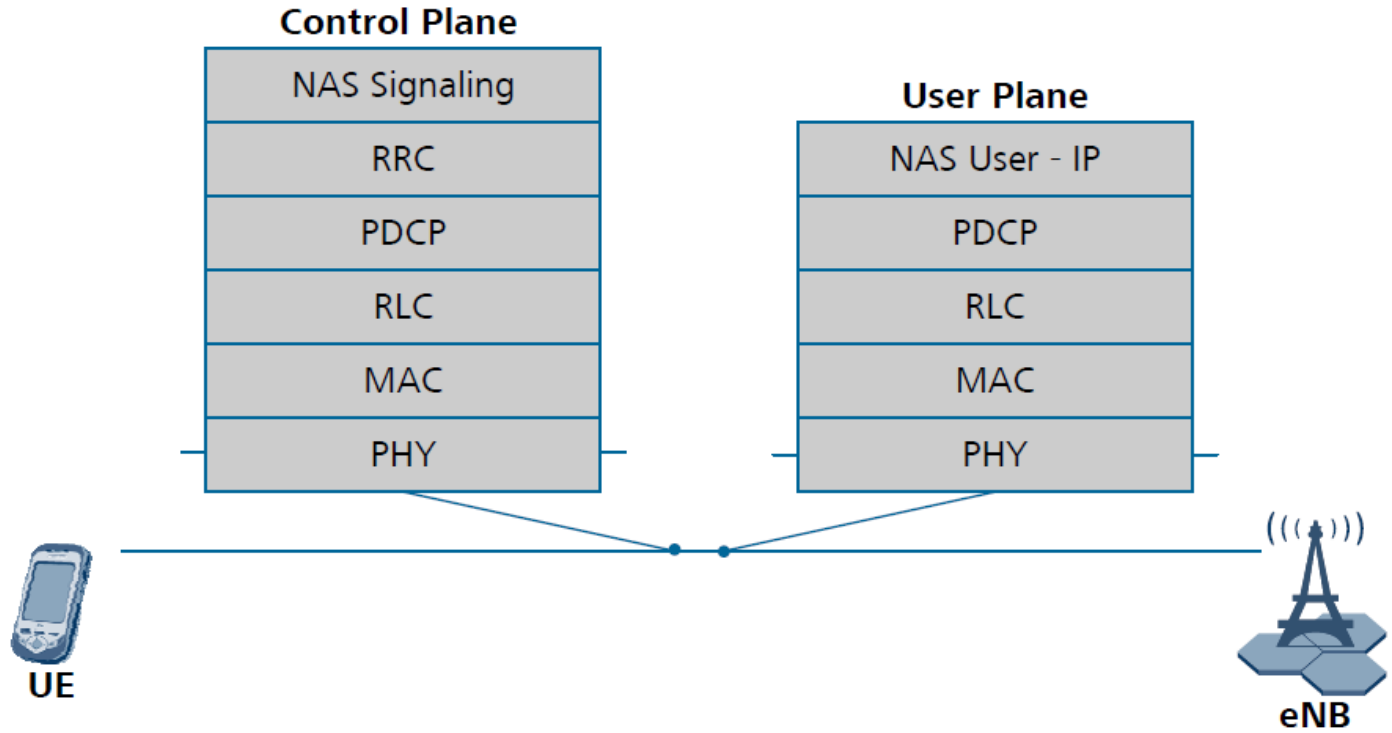
Final PRB usage
Serving cell -> 80 % – 25 % = 55%
Target cell -> 30%+ 25% = 55%

LTE Radio Channel

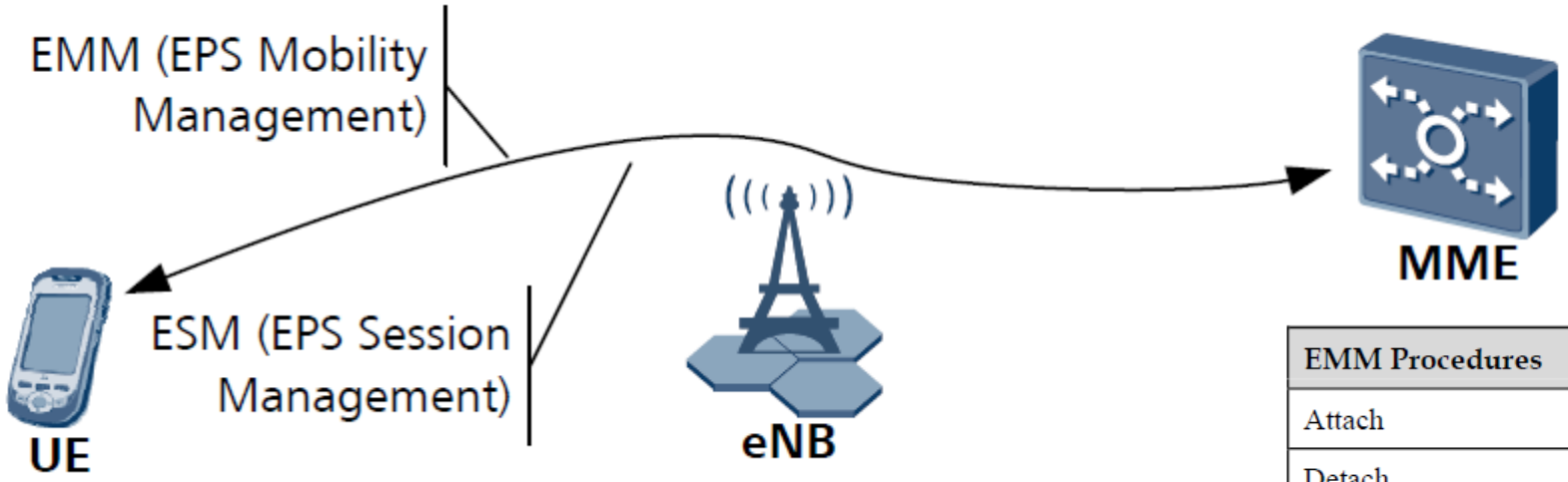
10/02/2022

LTE Control Plane and User Plane





NAS Signaling

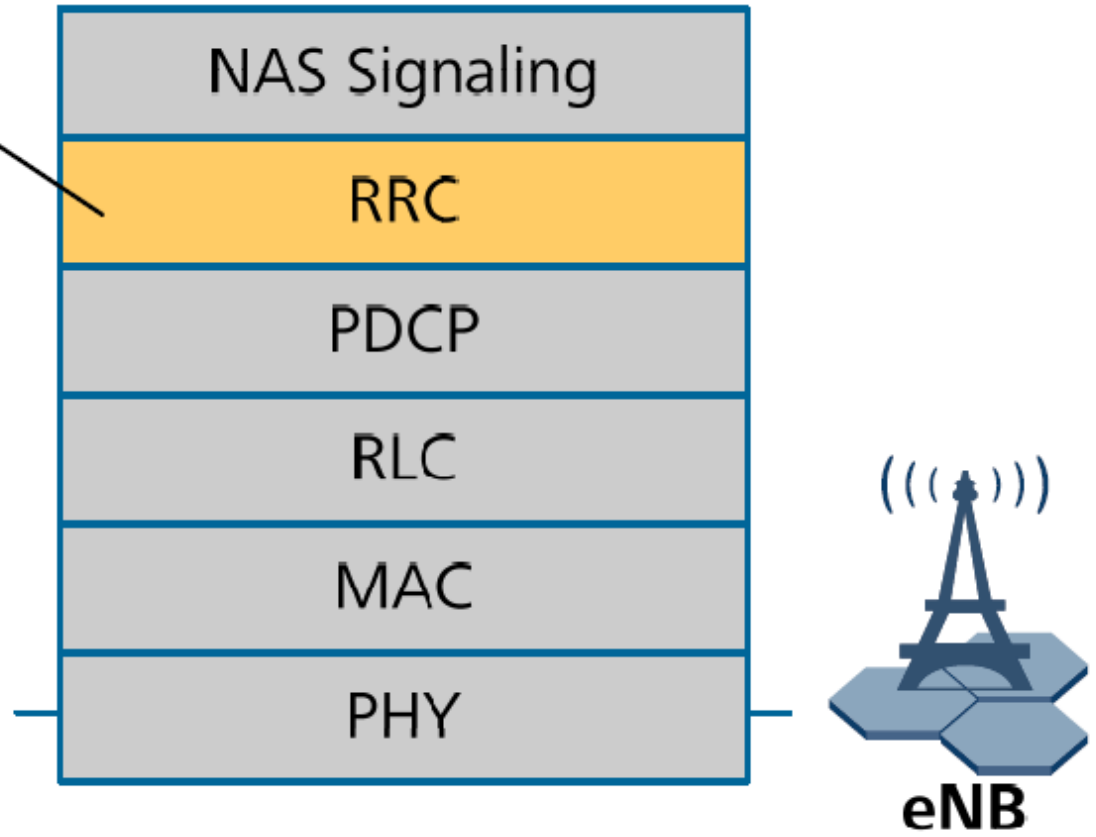


Non-access stratum (NAS) is that it is a protocol for messages passed between the User Equipment, also known as mobiles, and Core Nodes (e.g. Mobile Switching Center, Serving GPRS Support Node, or Mobility Management Entity) that is passed transparently through the radio network.

EMM Procedures	ESM Procedures
Attach	Default EPS Bearer Context Activation
Detach	Dedicated EPS Bearer Context Activation
Tracking Area Update	EPS Bearer Context Modification
Service Request	EPS Bearer Context Deactivation
Extended Service Request	UE Requested PDN Connectivity
GUTI Reallocation	UE Requested PDN Disconnect
Authentication	UE Requested Bearer Resource Allocation
Identification	UE Requested Bearer Resource Modification
Security Mode Control	ESM Information Request
EMM Status	ESM Status
EMM Information	
NAS Transport	
Paging	

Radio Resource Control

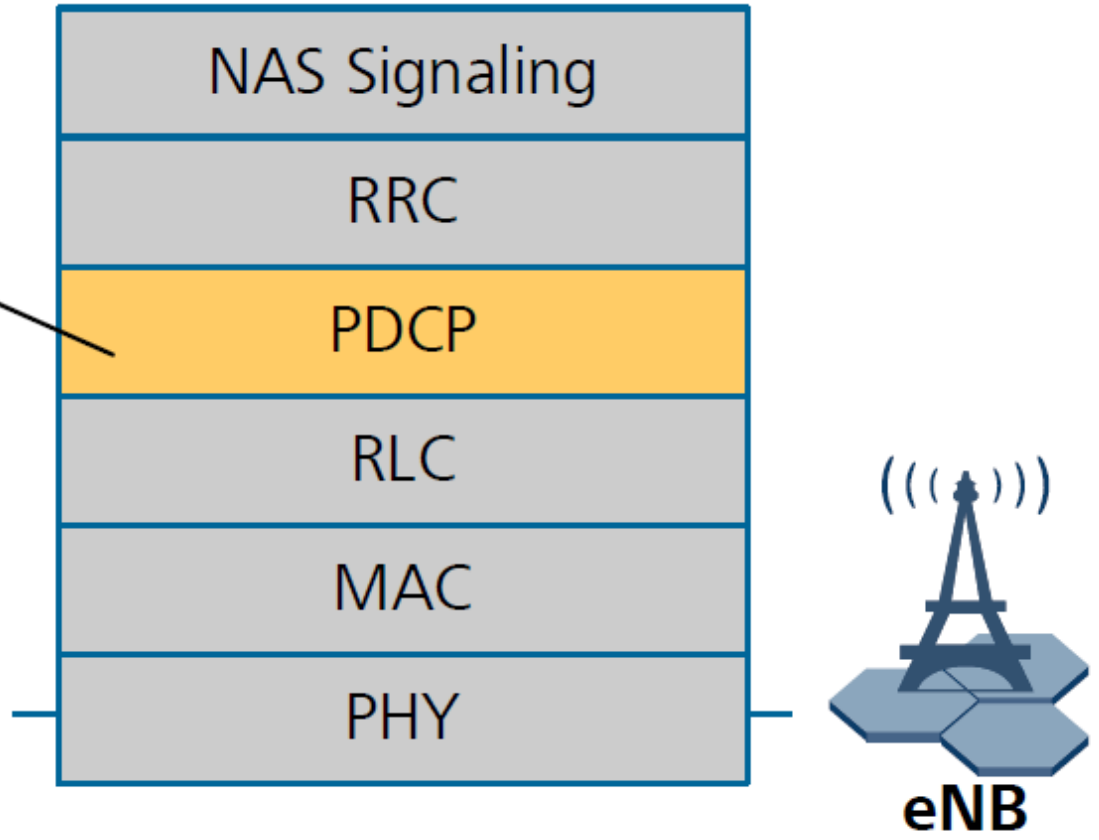
System Information
PLMN and Cell Selection
Admission Control
Security Management
Cell Reselection
Measurement Reports
Handovers and Mobility
NAS Transport
Radio Resource Management



Packet Data Convergence Protocol

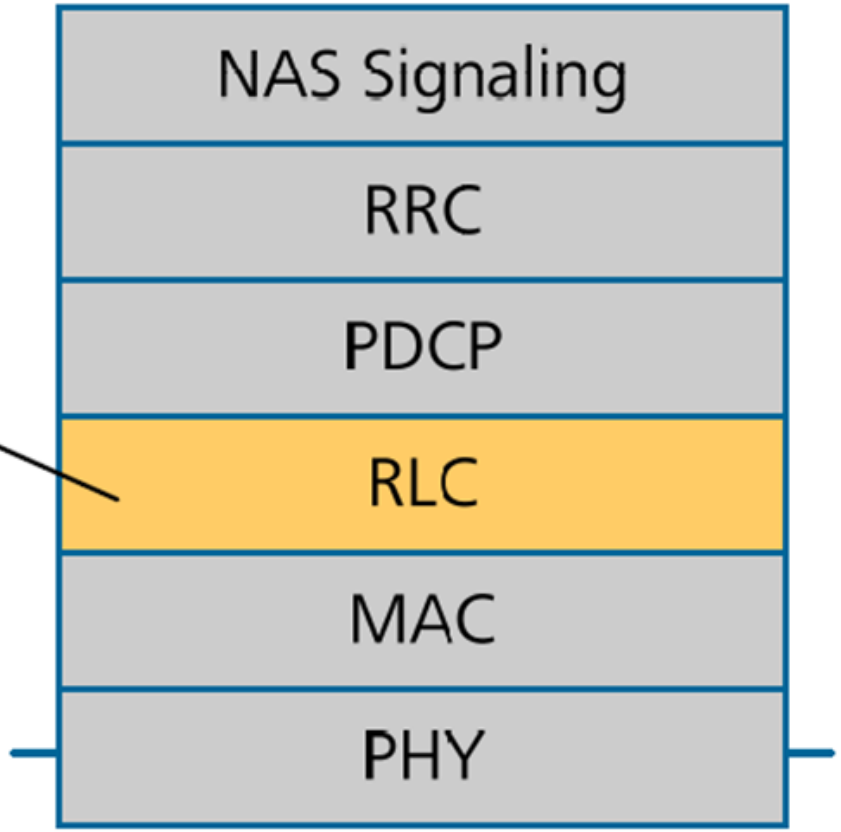
Control Plane
Encryption
Integrity Checking

User Plane
IP Header Compression
Encryption
Sequencing and Duplicate Detection

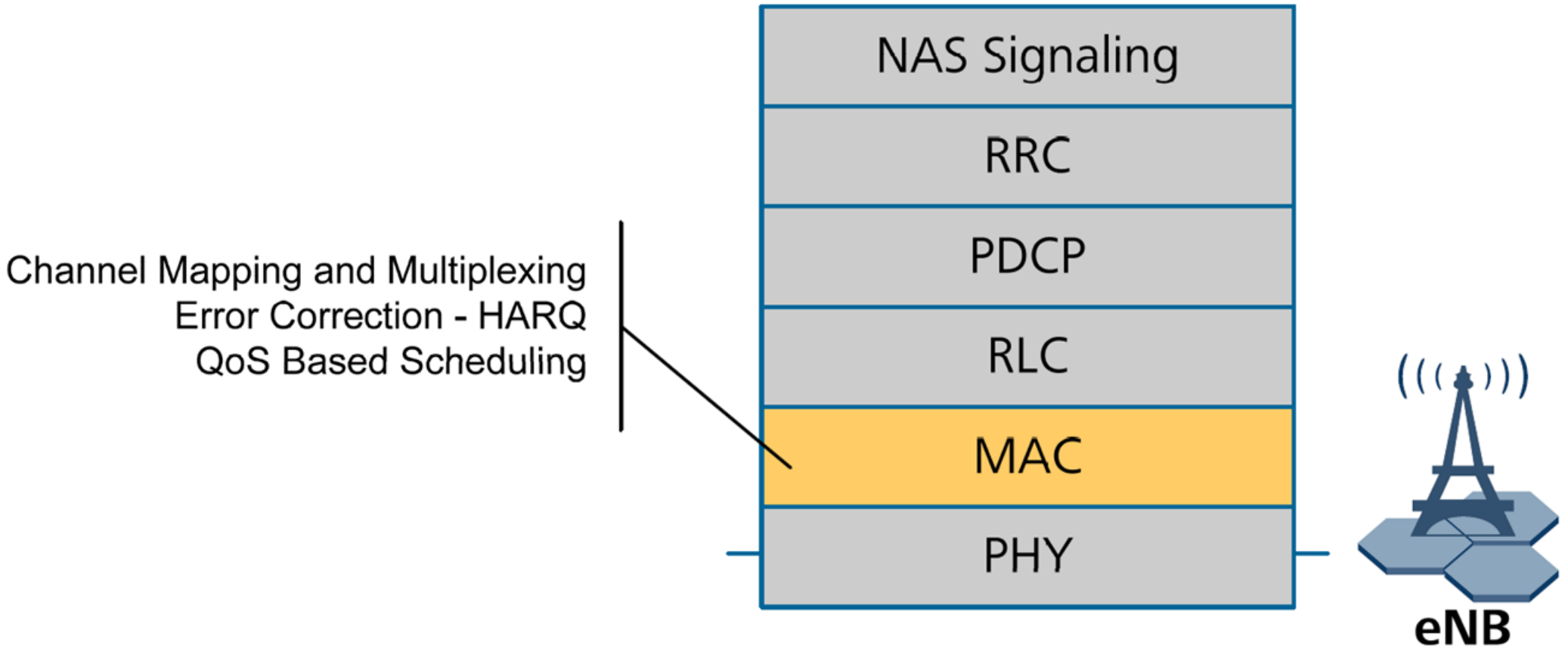


Radio Link Control

TM (Transparent Mode)
UM (Unacknowledged Mode)
AM (Acknowledged Mode)
Segmentation and Re-assembly
Concatenation
Error Correction

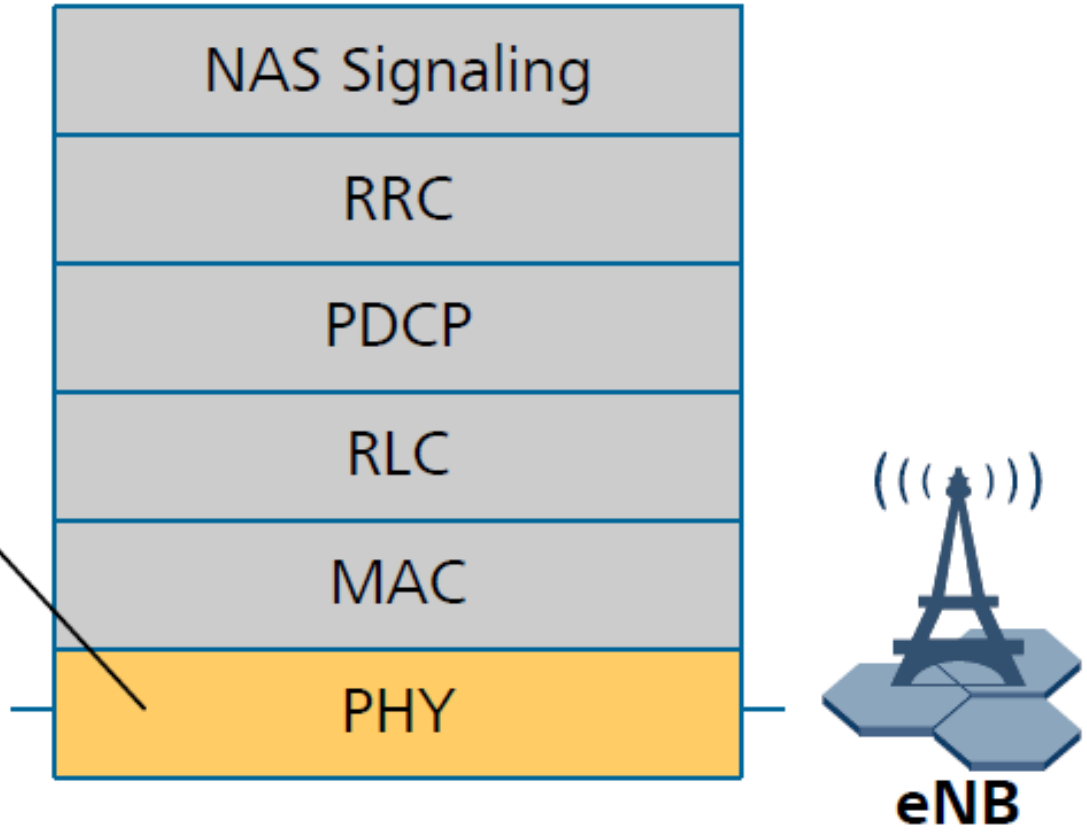


Medium Access Control

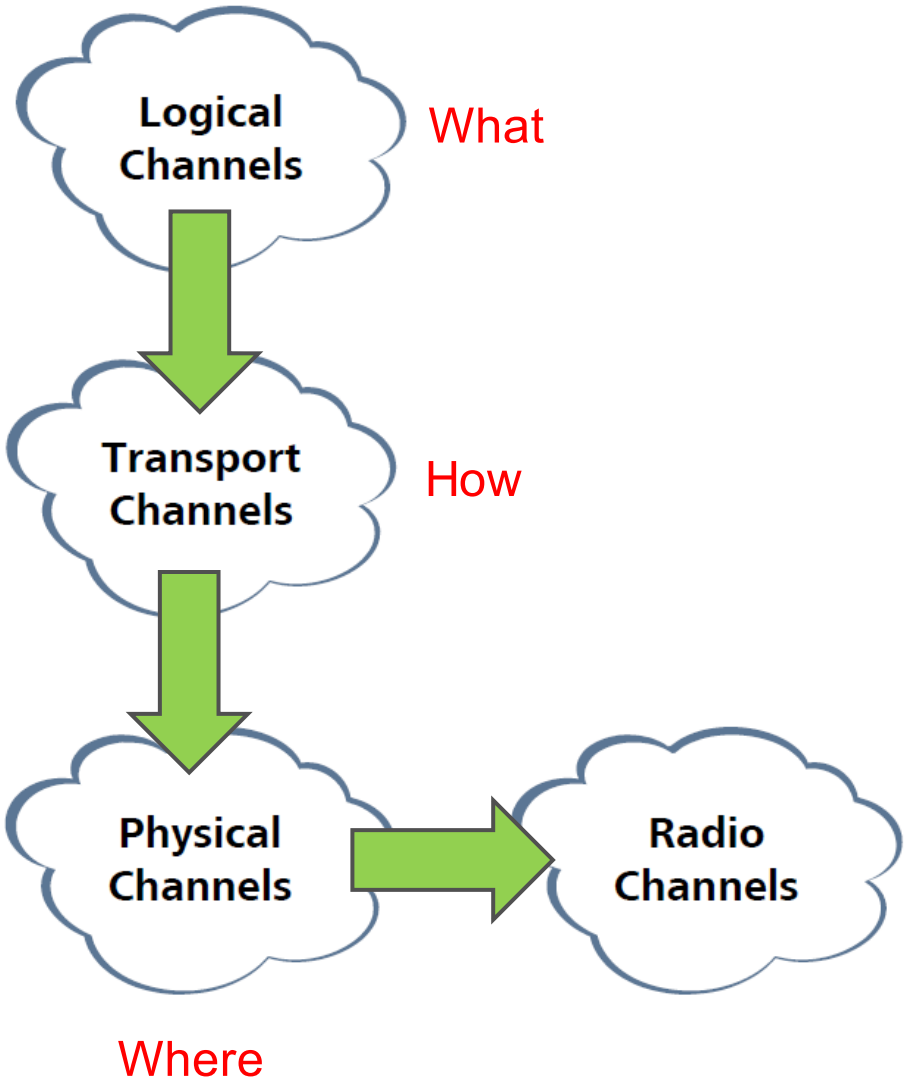


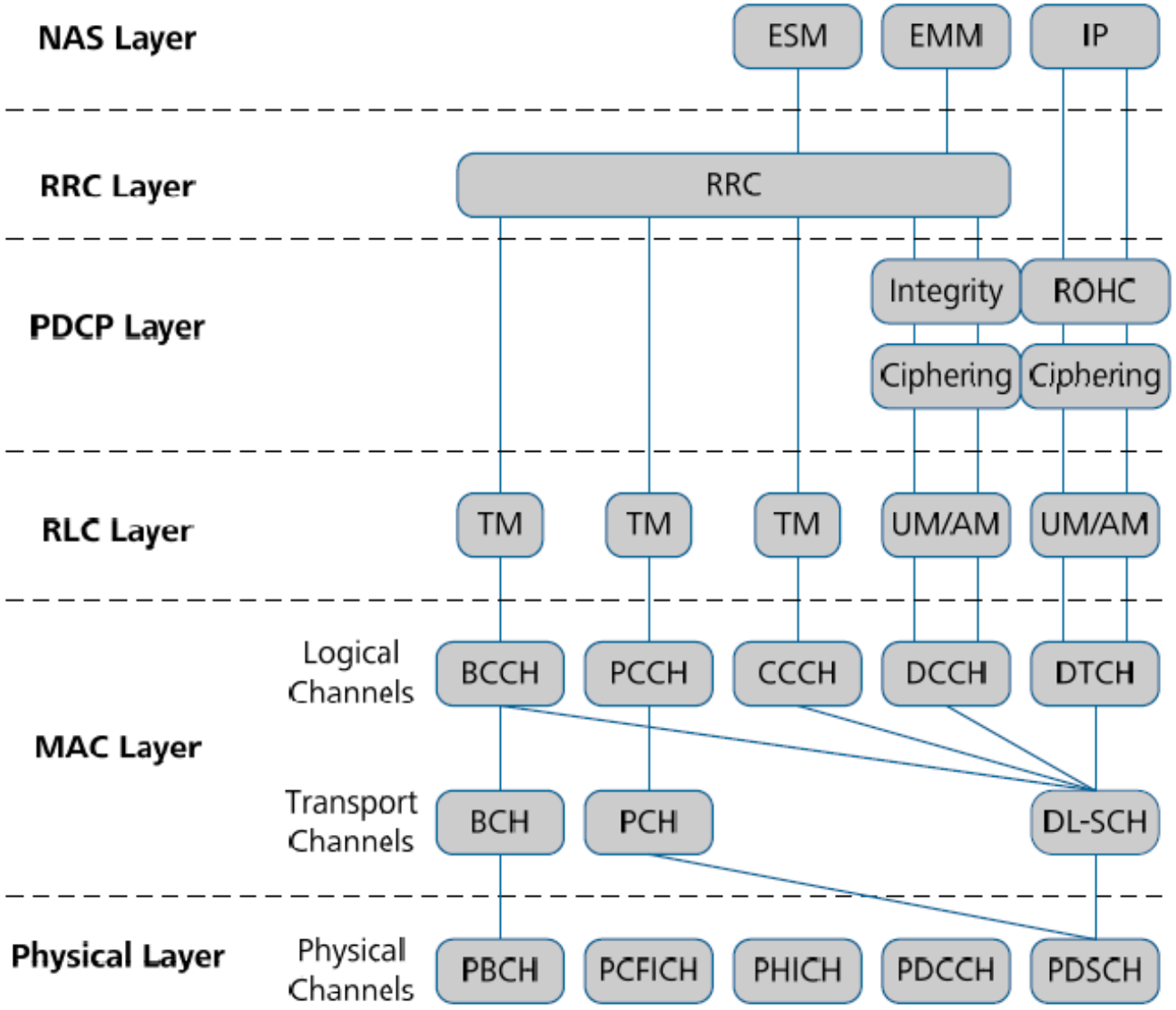
Physical Control Layer

Error Detection
FEC Encoding/Decoding
Rate Matching
Mapping of Physical Channels
Power Weighting
Modulation and Demodulation
Frequency and Time Synchronization
Radio Measurements
MIMO Processing
Transmit Diversity
Beamforming
RF Processing



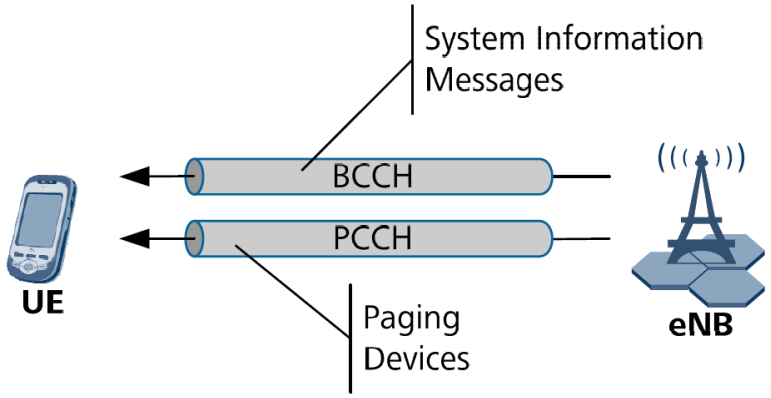
LTE Downlink Channel Mapping



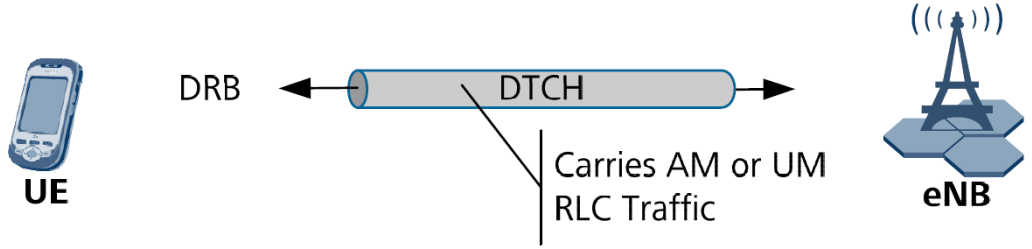


LTE Downlink Channel Mapping

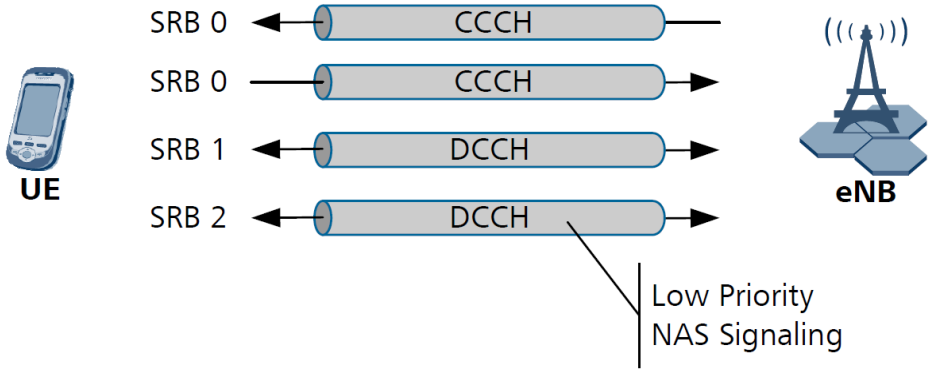
Control Logical Channels



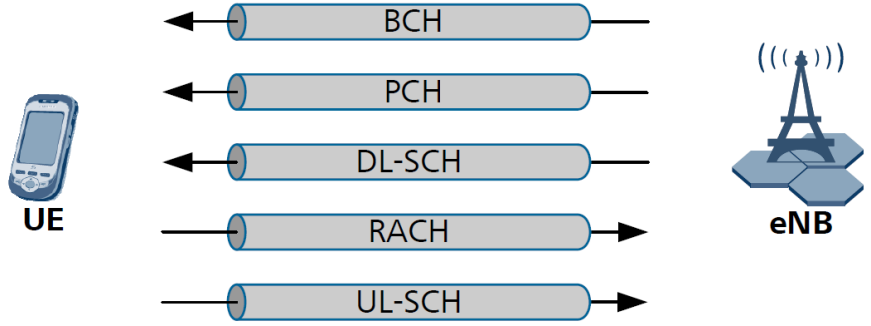
Traffic Logical Channels



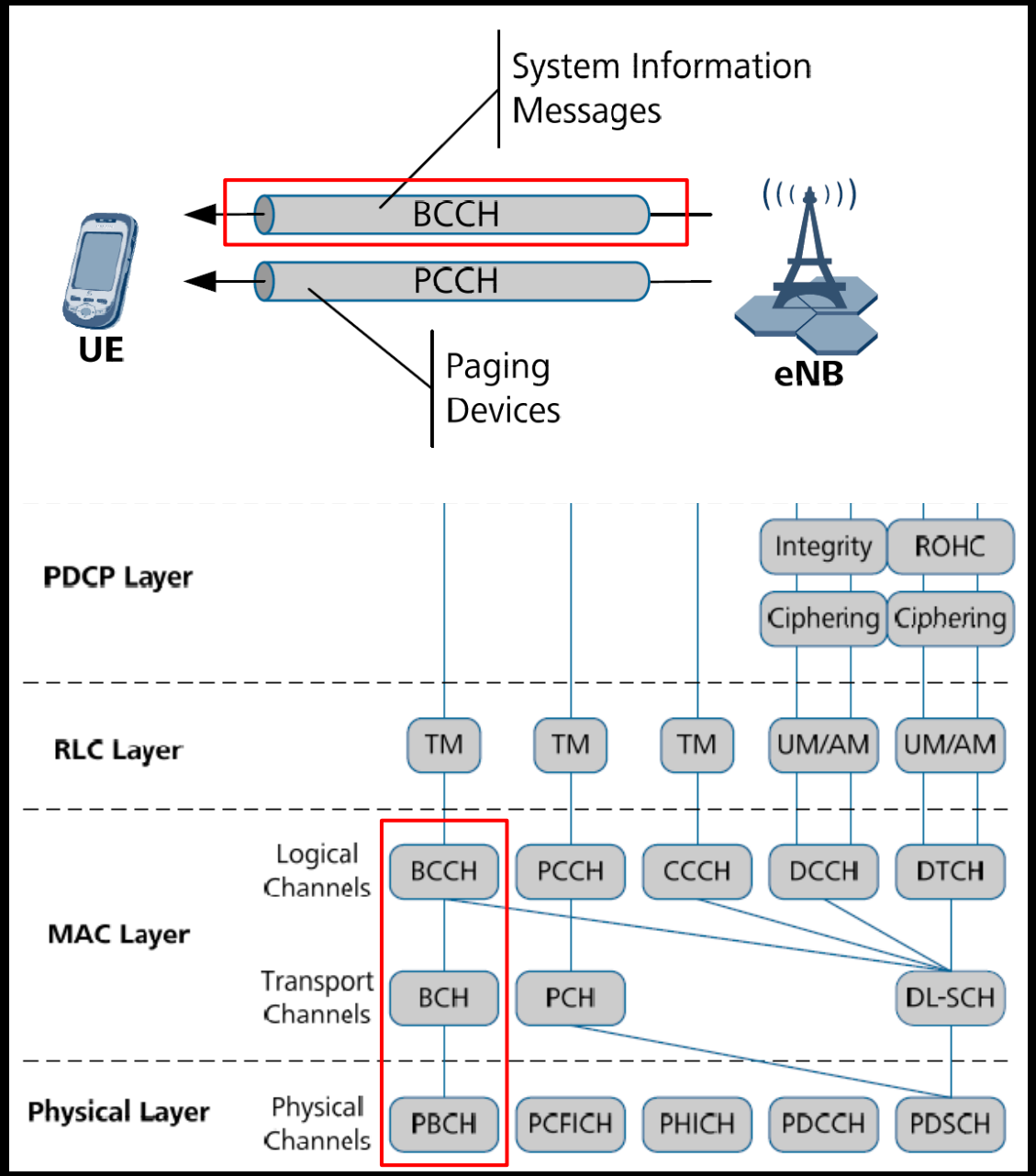
CCCH and DCCH Signaling



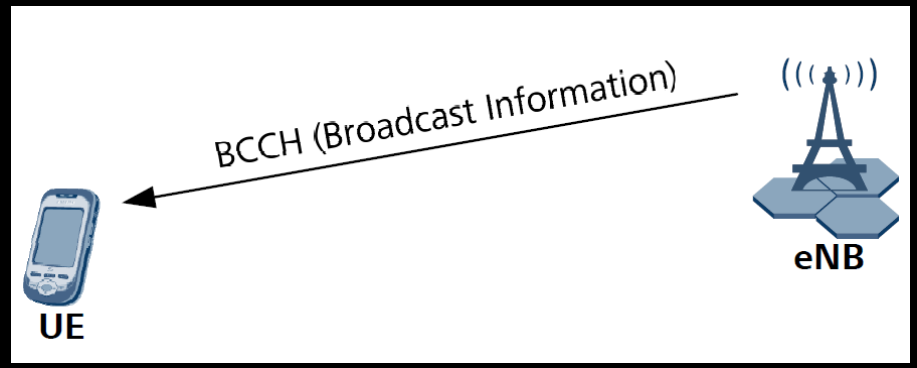
LTE Release 8 Transport Channels



BCCH (Broadcast Control Channel)



BCCH (Broadcast Control Channel): Use to send "System Information" to UEs. Send on Broadcast Channel (**BCH**)



System Information

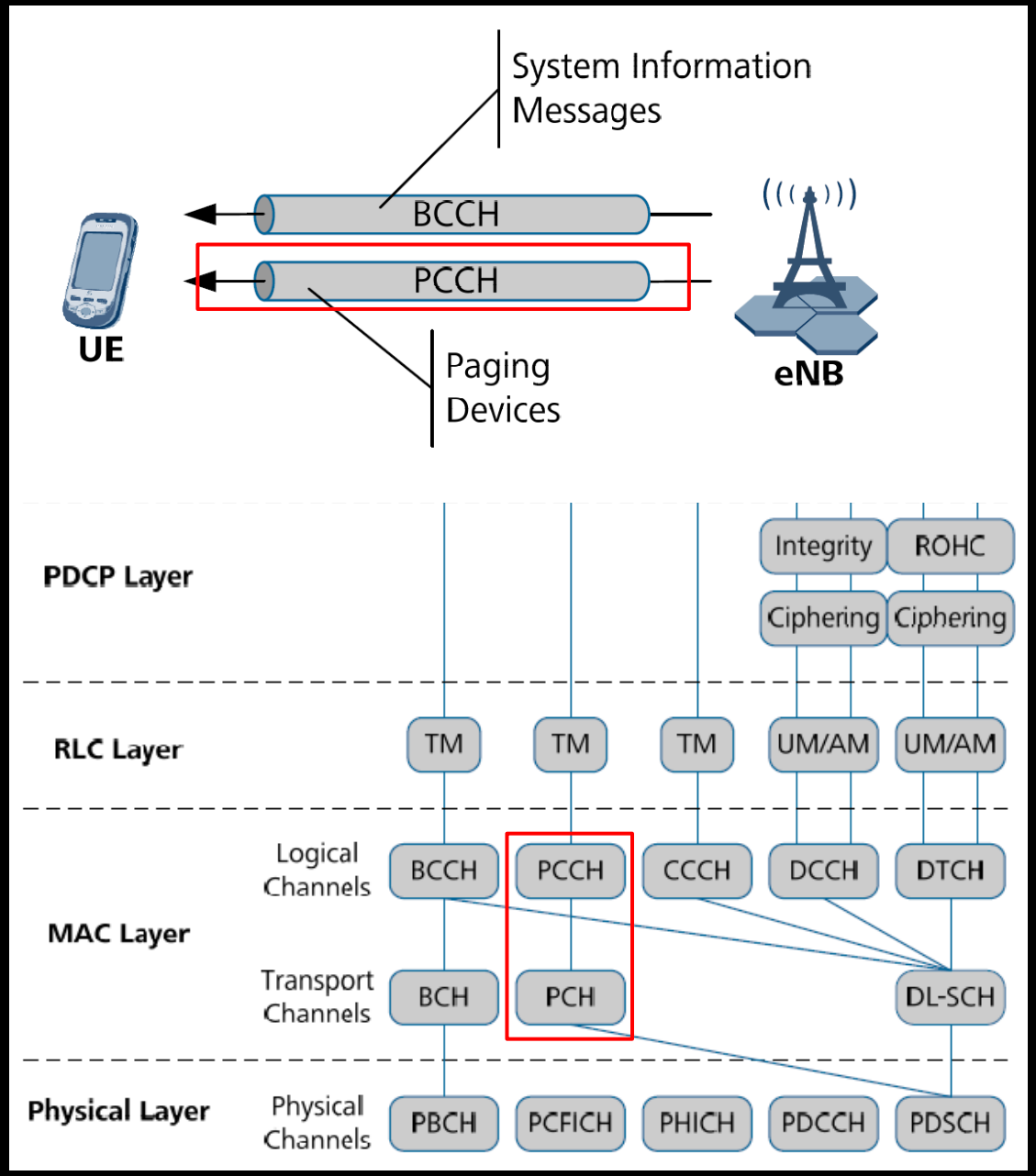
MIB (Master Information Block)

SIBs (System Information Block)
Ex. SIB1,SIB2,SIB3,….etc.

PBCH (Physical Broadcast Channel): Use to send MIB to UE.

Source: Book-LTE The UMTS Long Term Evolution

PCCH (Paging Control Channel)



PCCH (Paging Control Channel): Use to send paging information to UEs. Send on PCH (Paging Channel)

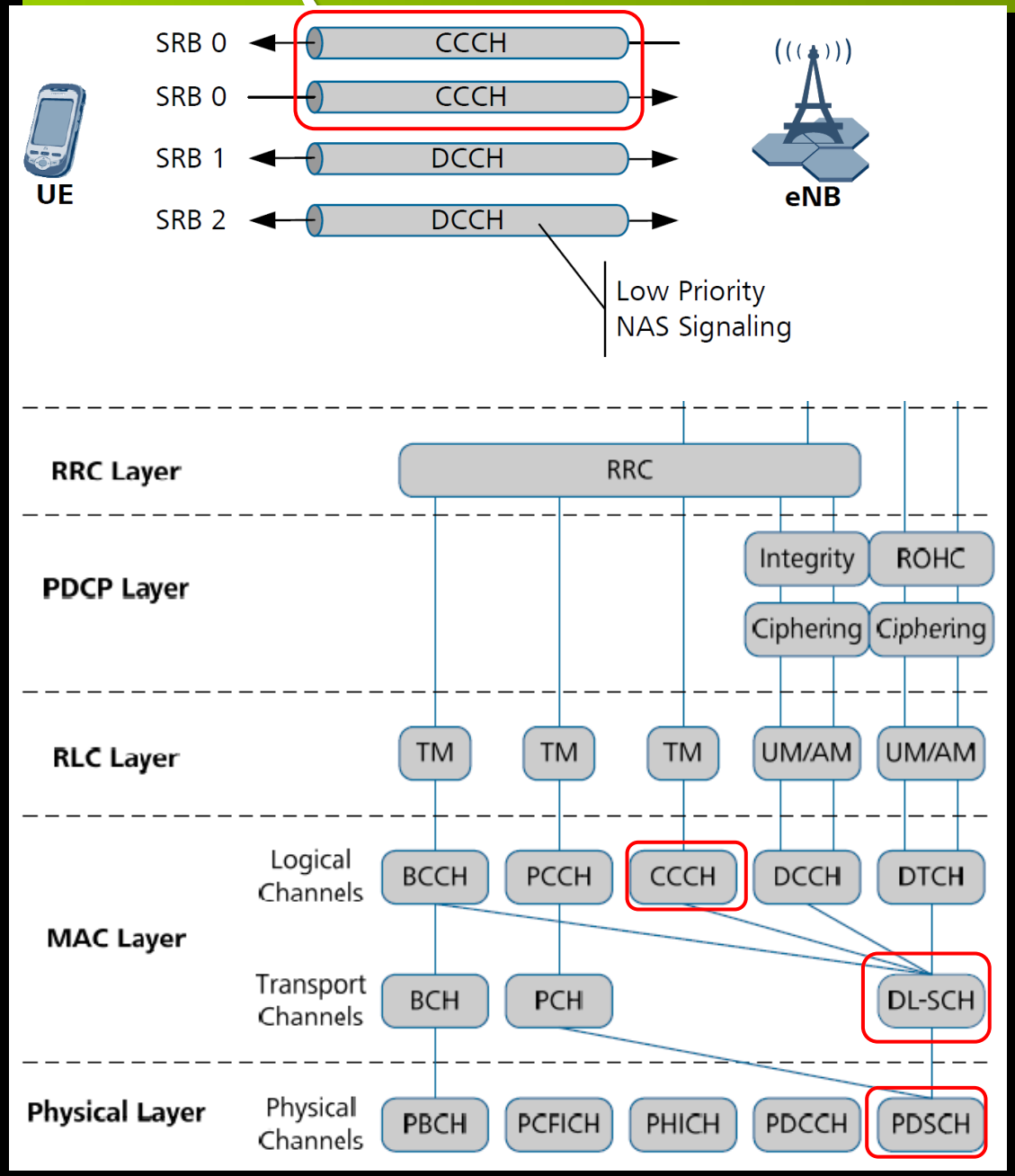
PCCH (Paging Control Channel)

↓

Point-to-Multi Points

Source: Book-LTE The UMTS Long Term Evolution

CCCH (Common Control Channel)



CCCH: Use to send other signaling information

CCCH (Common Control Channel)

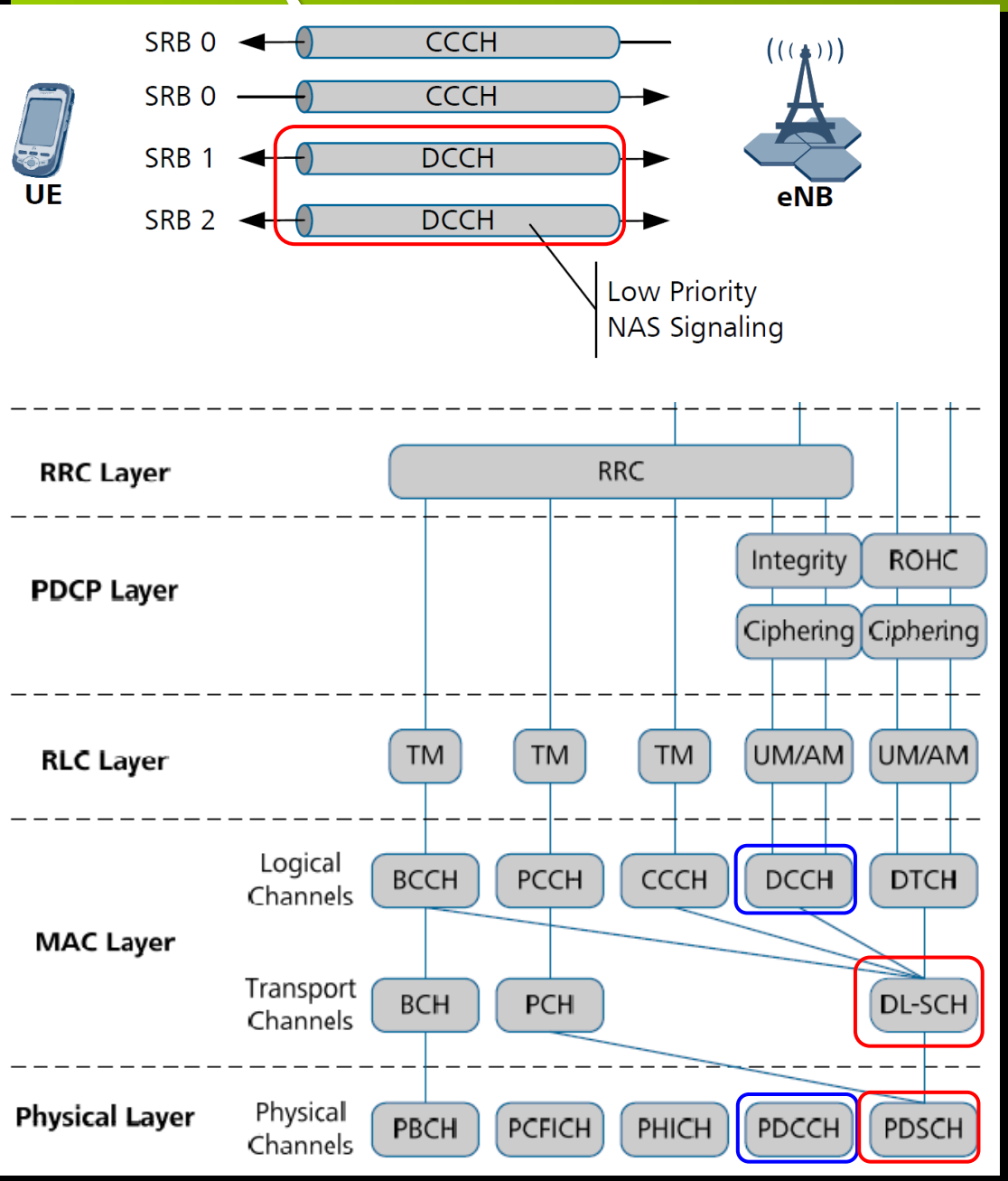
↓

Point-to-Multi Points

PDSCH: Use to receive some signaling and user traffic from eNB for downlink side.

Source: Book-LTE The UMTS Long Term Evolution

DCCH (Dedicated Control Channel)



DCCH: Use to send other signaling information

DCCH (Dedicated Control Channel)

Point-to-Point

PDCCH: Use to allocate radio resources to UE.

Radio Resources

PDSCH : DL

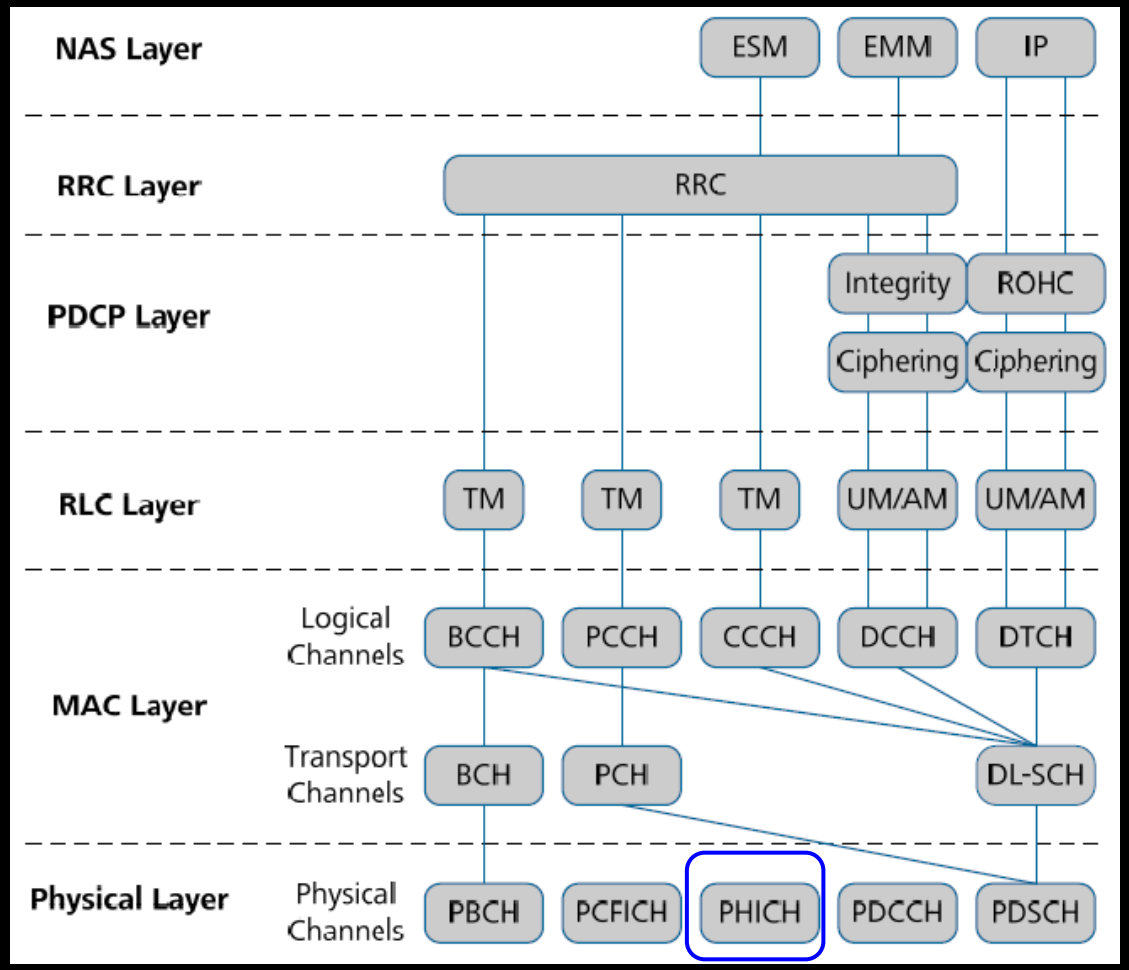
PUSCH : UL

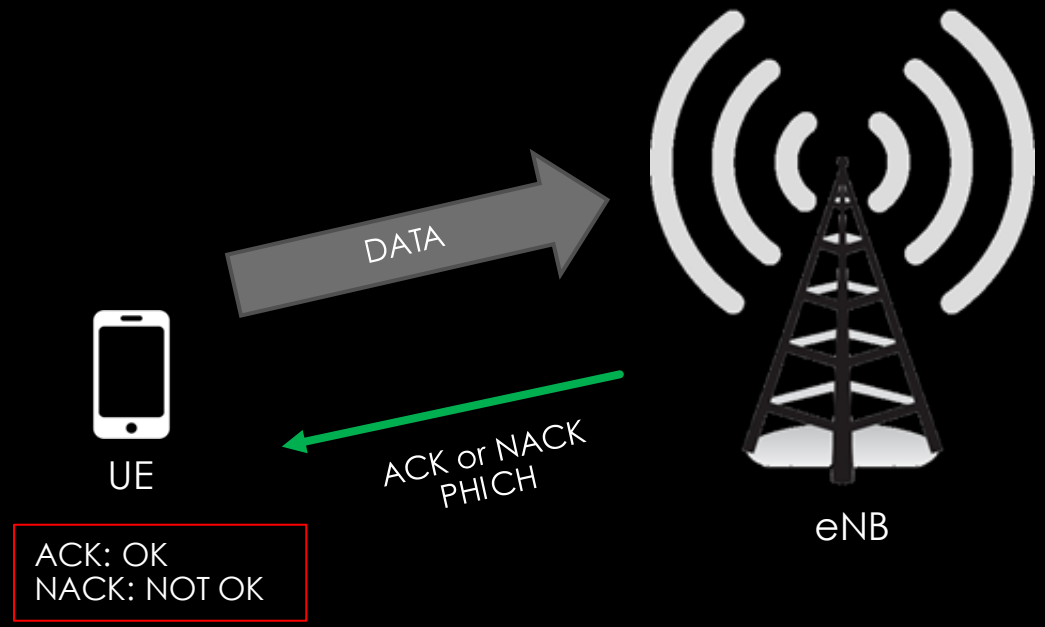
Source: Book-LTE The UMTS Long Term Evolution

PHICH (Physical Hybrid ARQ Indicator Channel)

PHICH (Physical Hybrid ARQ Indicator Channel)

- Use to send HARQ Indicator from eNB.
- HARQ is a mechanism to be used for Retransmission.

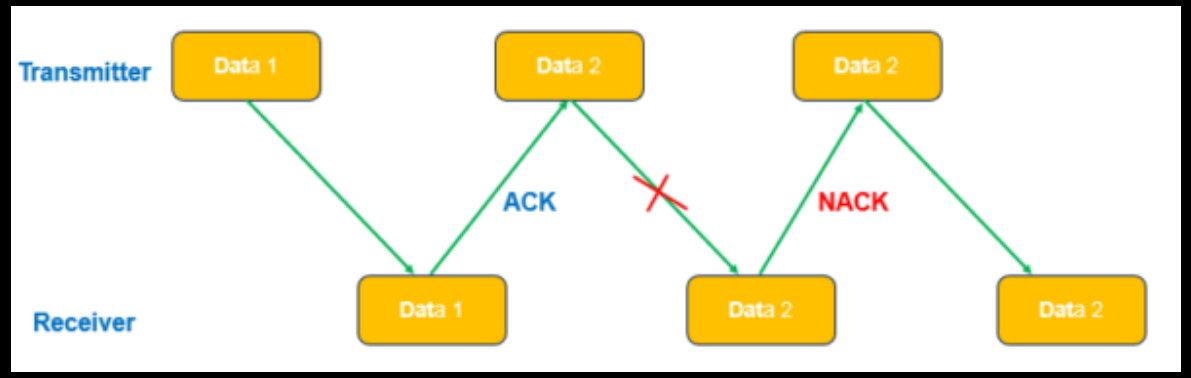




Source: Book-LTE The UMTS Long Term Evolution

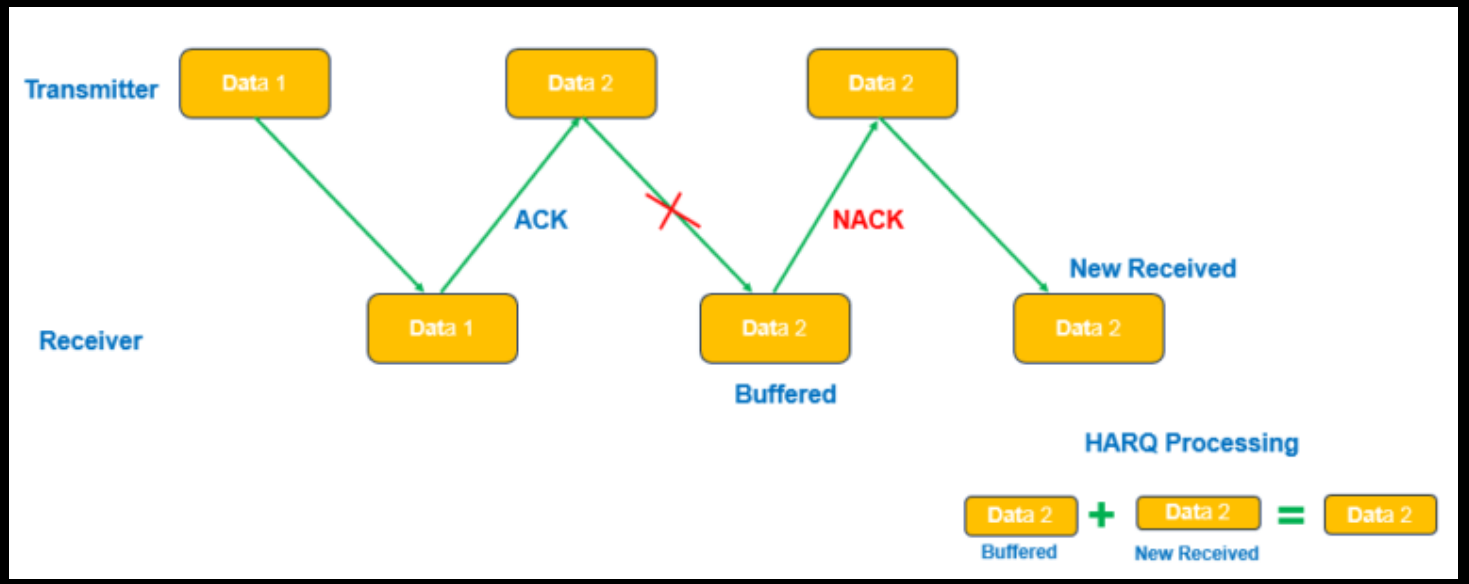
Hybrid Automatic Repeat Request (HARQ)

Automatic Repeat Request (ARQ)



ARQ refers to Automatic Repeat Request i.e. if sender doesn't receive Acknowledgement (ACK) before timeout, the receiver discards the bad packet and sender shall re-transmits the packet.

Hybrid Automatic Repeat Request (HARQ)



HARQ stands for Hybrid Automatic Repeat Request. HARQ = ARQ + FEC (Forward Error Correction)/Soft Combining

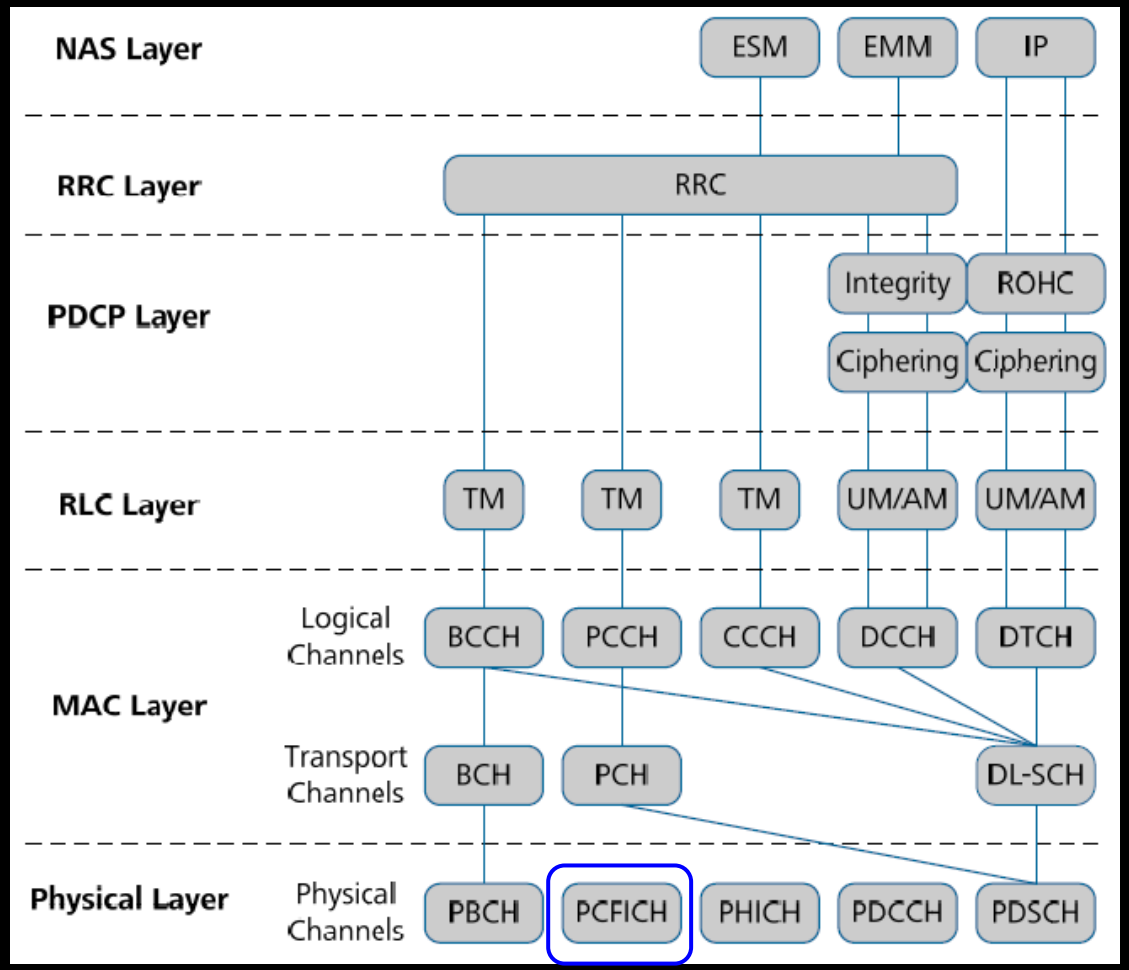
Soft Combining is an error correction technique in which the bad packets are not discarded but stored in a buffer. The basic idea is that 2 or more packets received with insufficient information can be combined together in such a way that total signal can be decoded. HARQ procedure is as follows

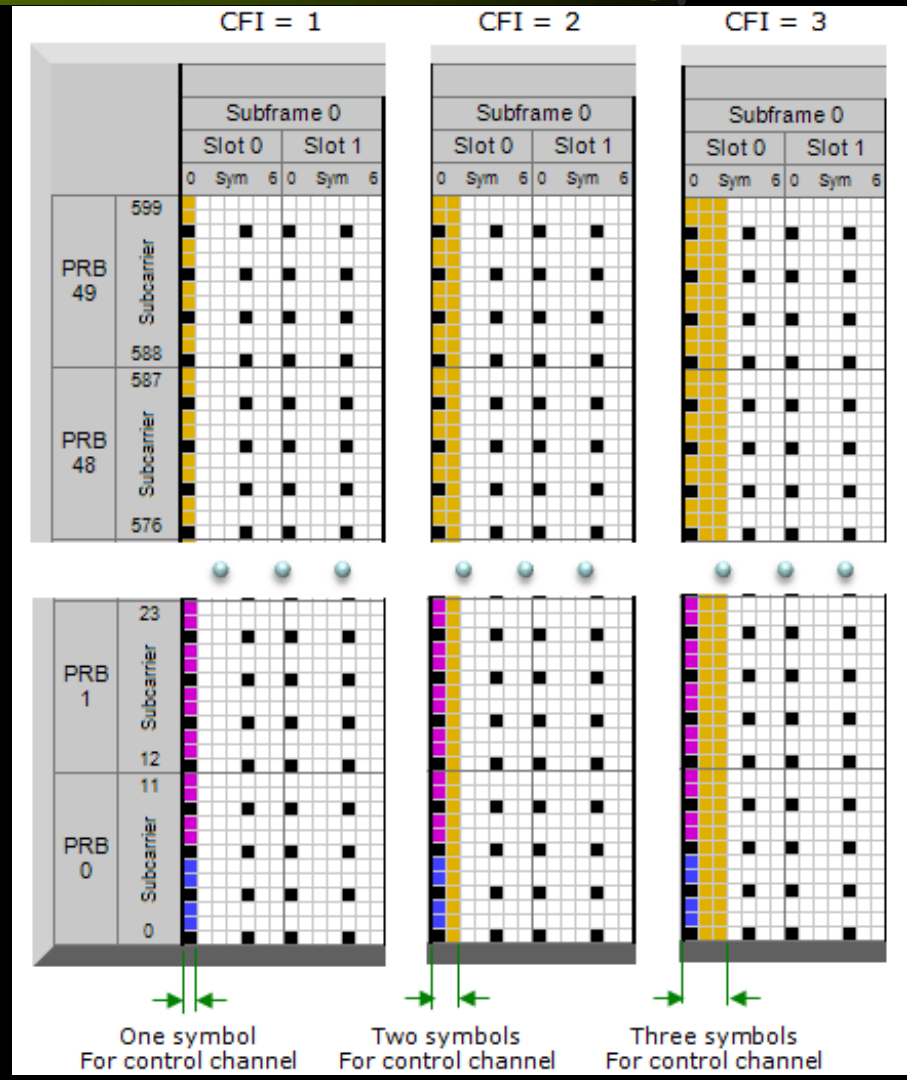
Source: Book-LTE The UMTS Long Term Evolution

PCFICH (Physical Control Format Indicator Channel)

PCFICH (Physical Control Format Indicator Channel)

- Use to send CFI (Control Format Indicator).
- CFI = {1 or 2 or 3}.
- CFI relates with number of symbol(s) to be defined in PDCCH.

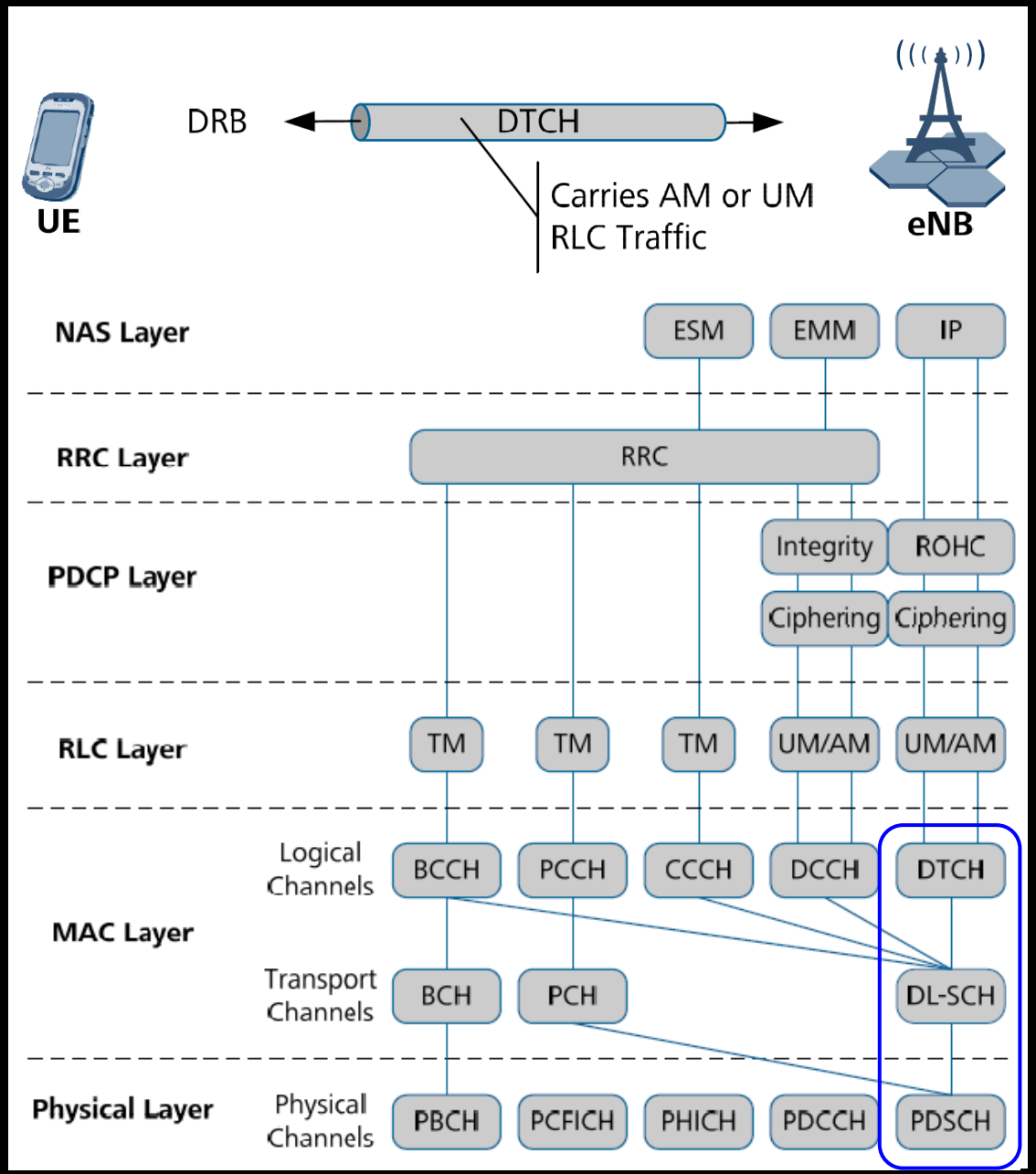




CFI = 2 for 10, 15 and 20 MHz system bandwidth
CFI = 3 for 1.4, 3 and 5 MHz system bandwidths

Source: Book-LTE The UMTS Long Term Evolution

DTCH (Dedicated Traffic Channel)



DTCH: Use to send user traffic between UE and its destination.

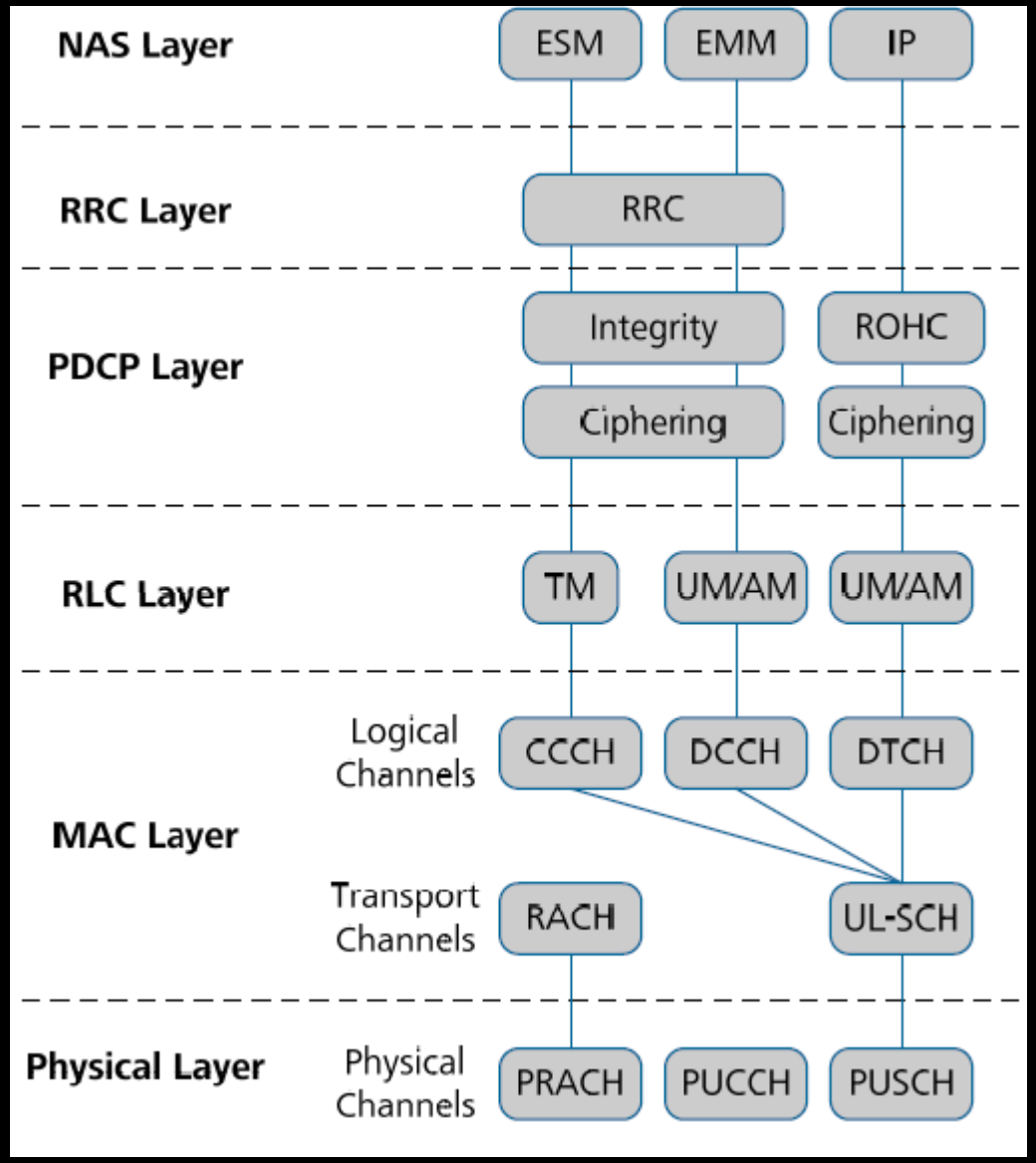
DTCH (Dedicated Traffic Channel)

↓

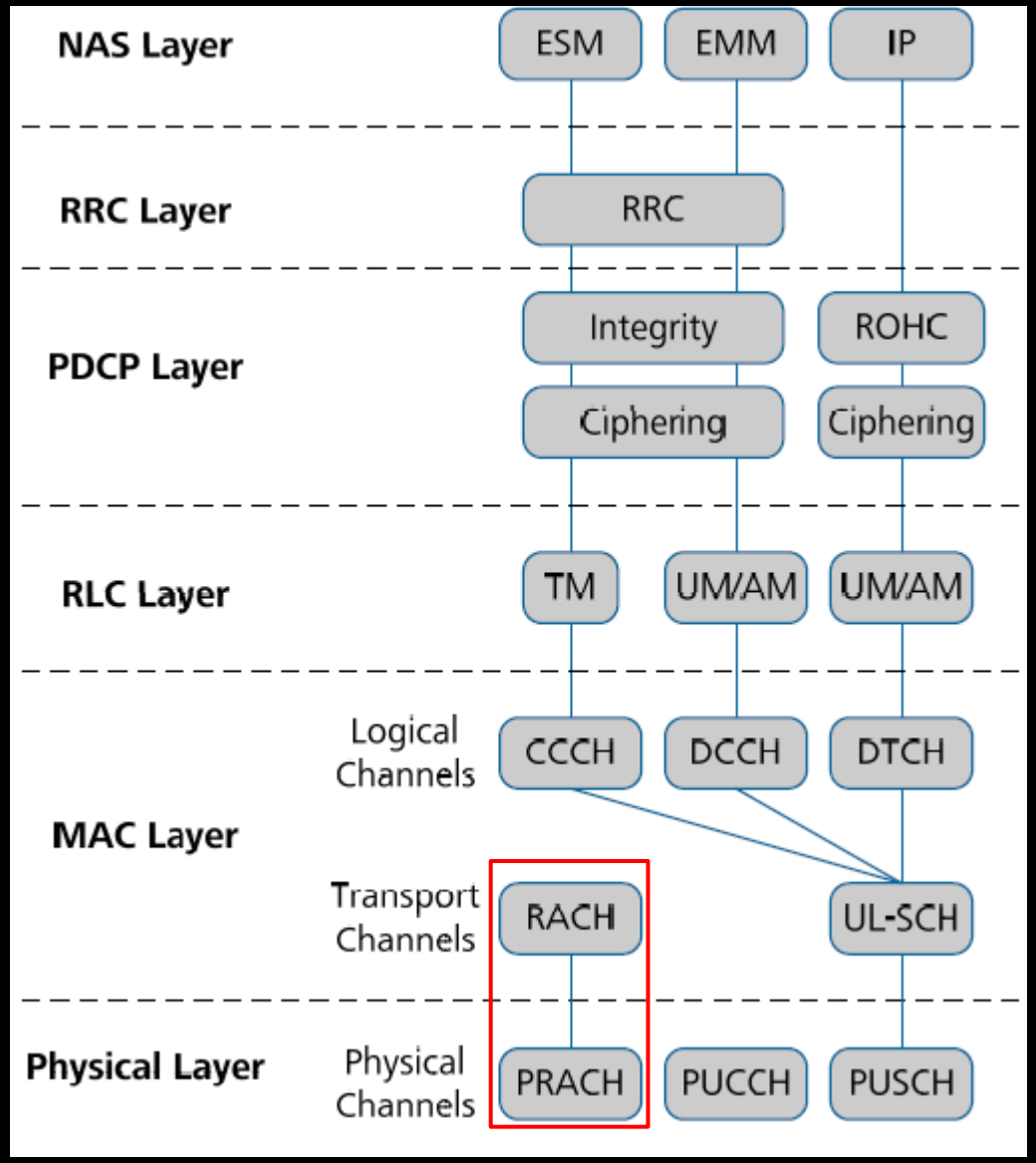
Point-to-Point

Source: Book-LTE The UMTS Long Term Evolution

LTE Uplink Channel Mapping

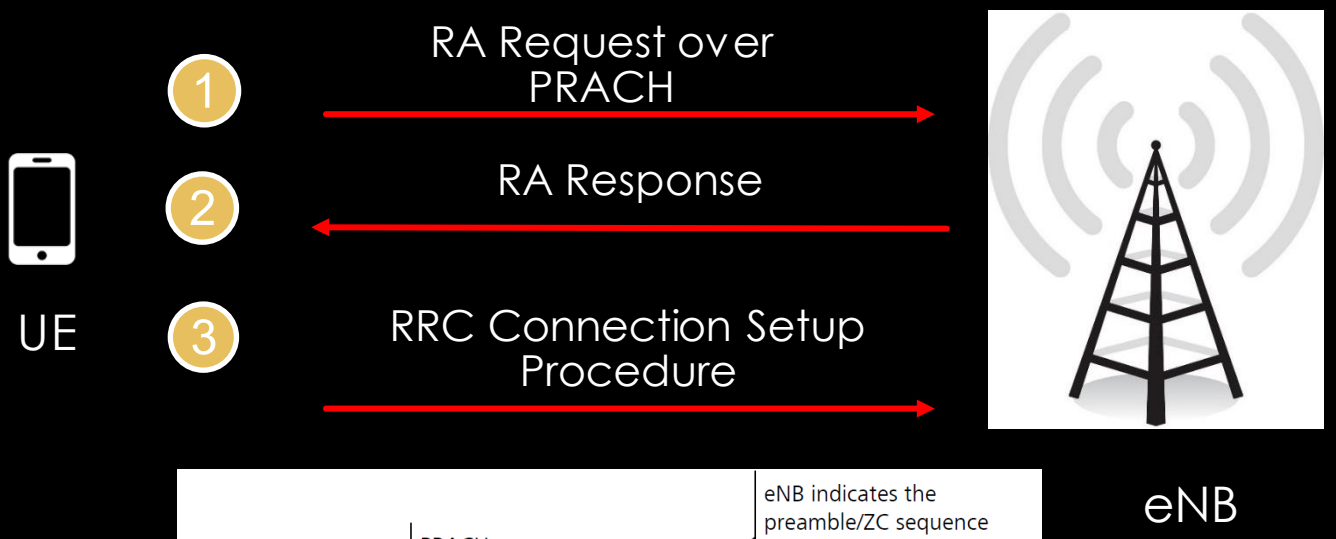


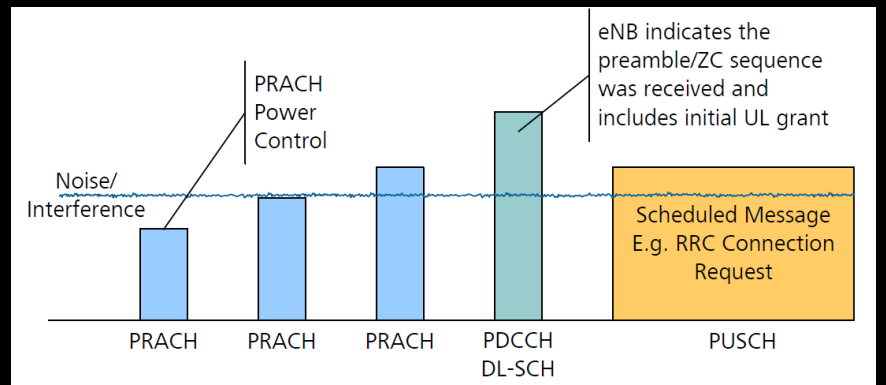
RACH: Random Access Channel



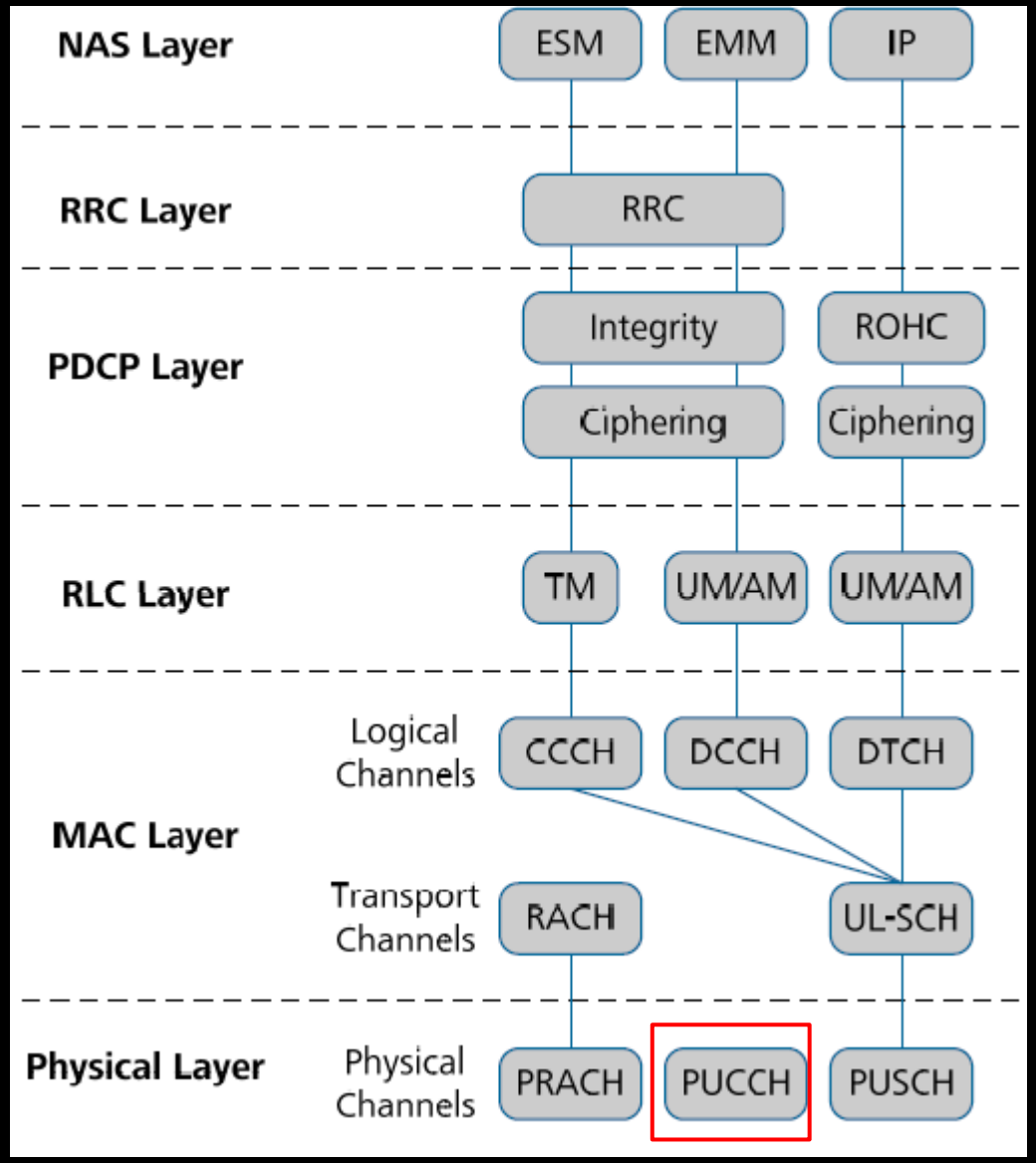
PRACH: Physical Random Access Channel

- Use to send Random Access Request in Radom Access Procedure.
- UE needs to be synchronized with network in uplink.



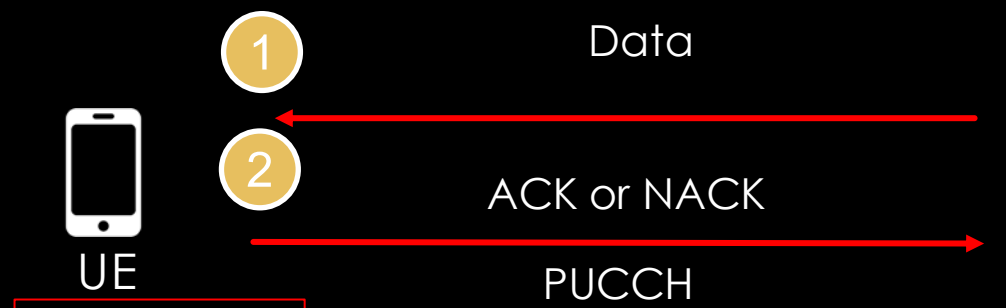


PUCCH: Physical Uplink Control Channel



PUCCH: Physical Uplink Control Channel

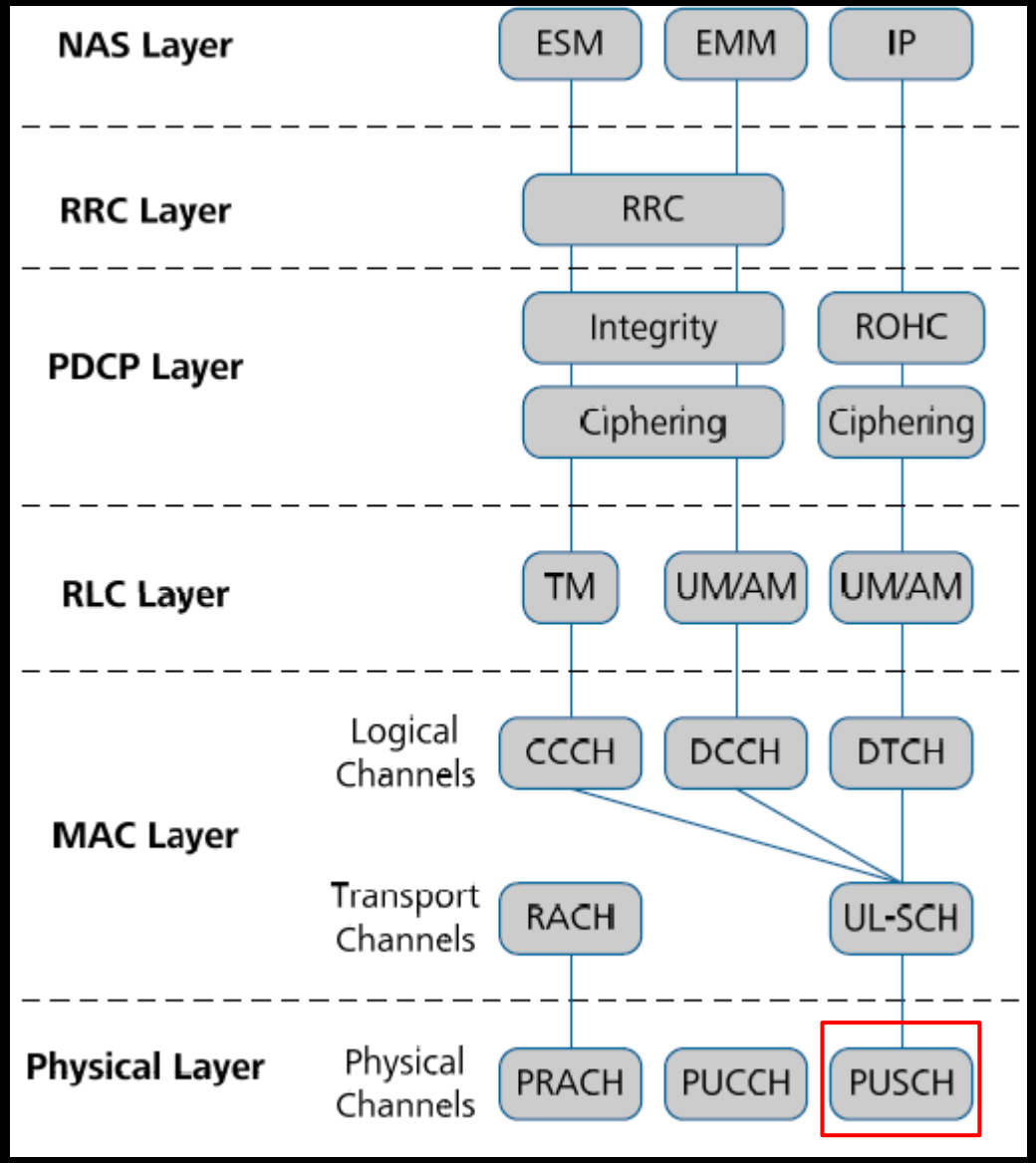
- Use to send HARQ indicator from UE.
- Use to send CQI (Channel Quality Indicator) to eNB which is used to do data scheduling at eNB for UE.
- Use to send Scheduling Request (SR) message from UE which has no UL resources(PUSCH) allocated.



ACK: OK

NACK: NOT OK

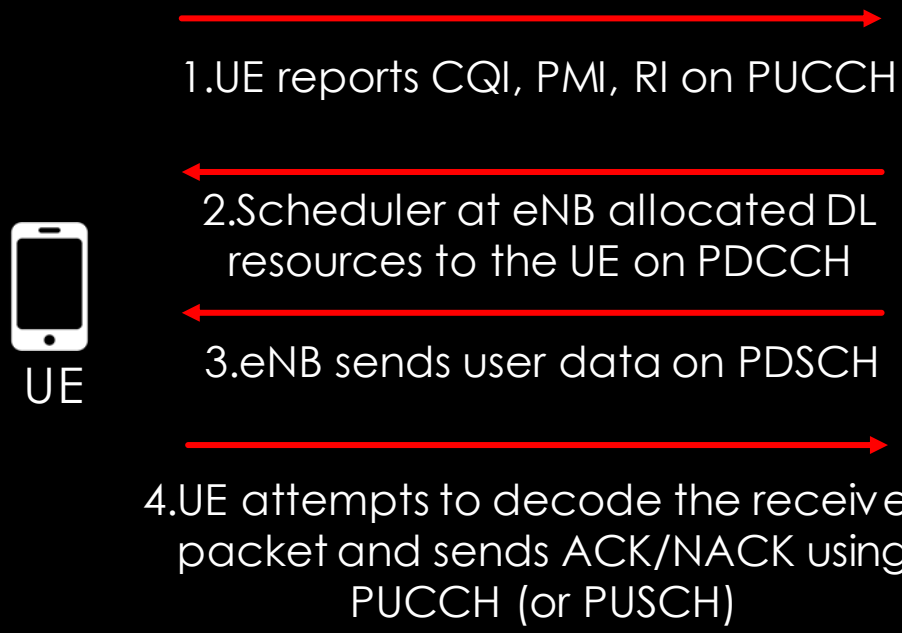
PUSCH: Physical Uplink Shared Channel



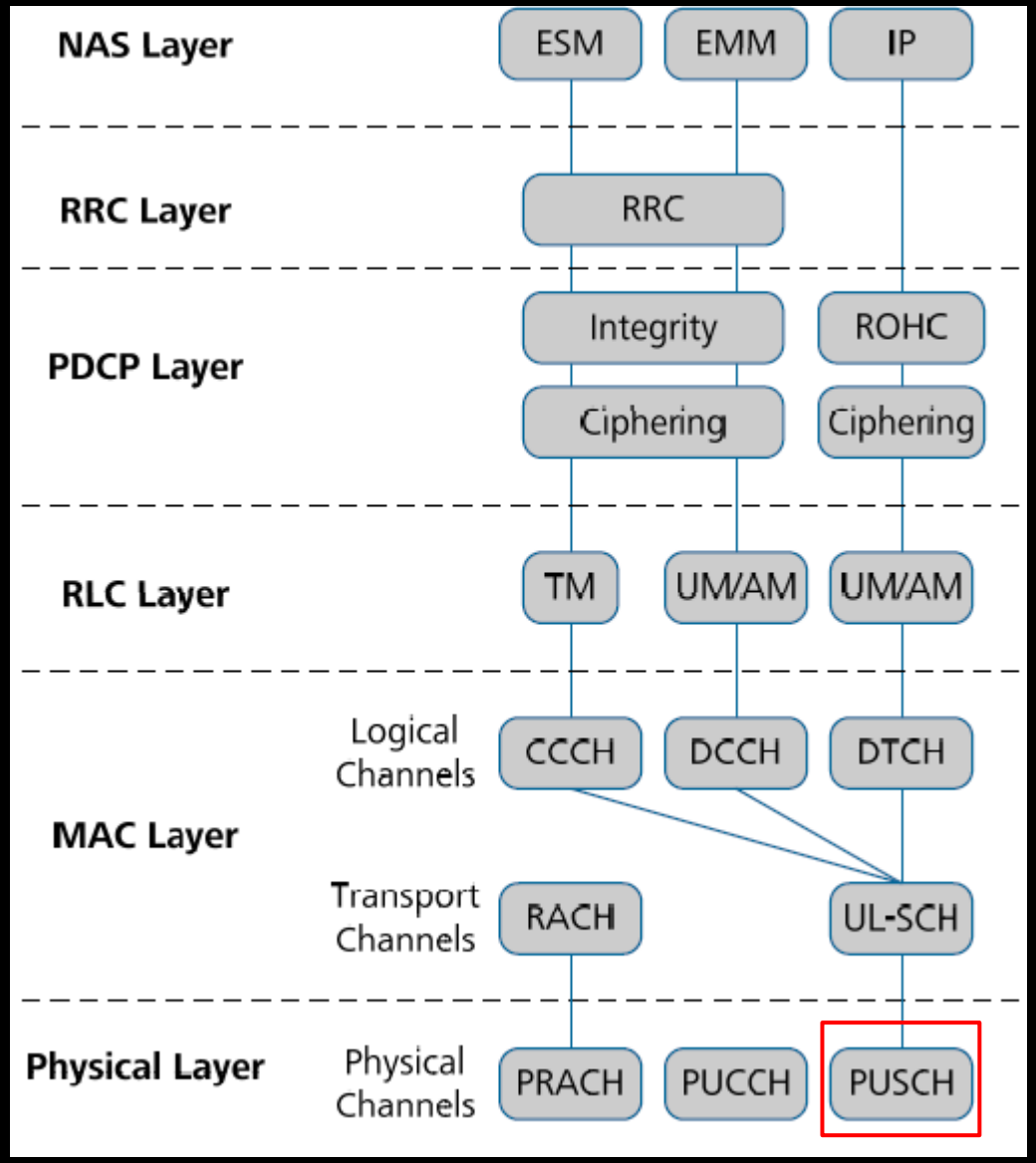
PUSCH: Physical Uplink Shared Channel

- Use to send signaling and user traffic from UE for uplink side.

EX. UE Receives Downlink Data



PUSCH: Physical Uplink Shared Channel



PUSCH: Physical Uplink Shared Channel

- Use to send signaling and user traffic from UE for uplink side.

EX. UE Sends Uplink Data

1.If UE does not have UL-SCH resources, UE sends SR on PUCCH

2.Scheduler at eNB allocates resources to UE through "uplink grant" on PDCCH

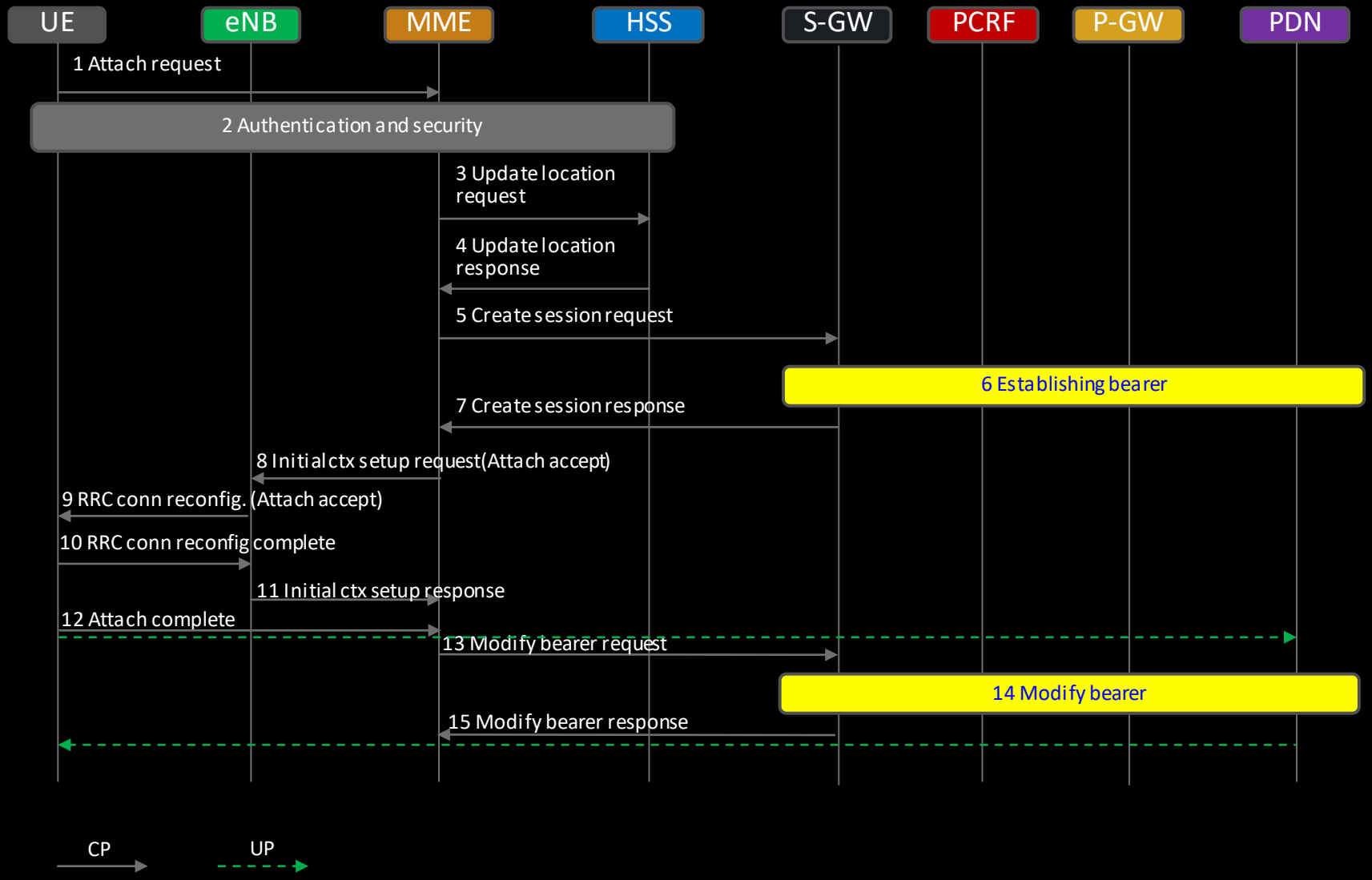
3.UE sends user data on PUSCH

4.If eNB decodes the uplink data successfully, it sends ACK on PHICH

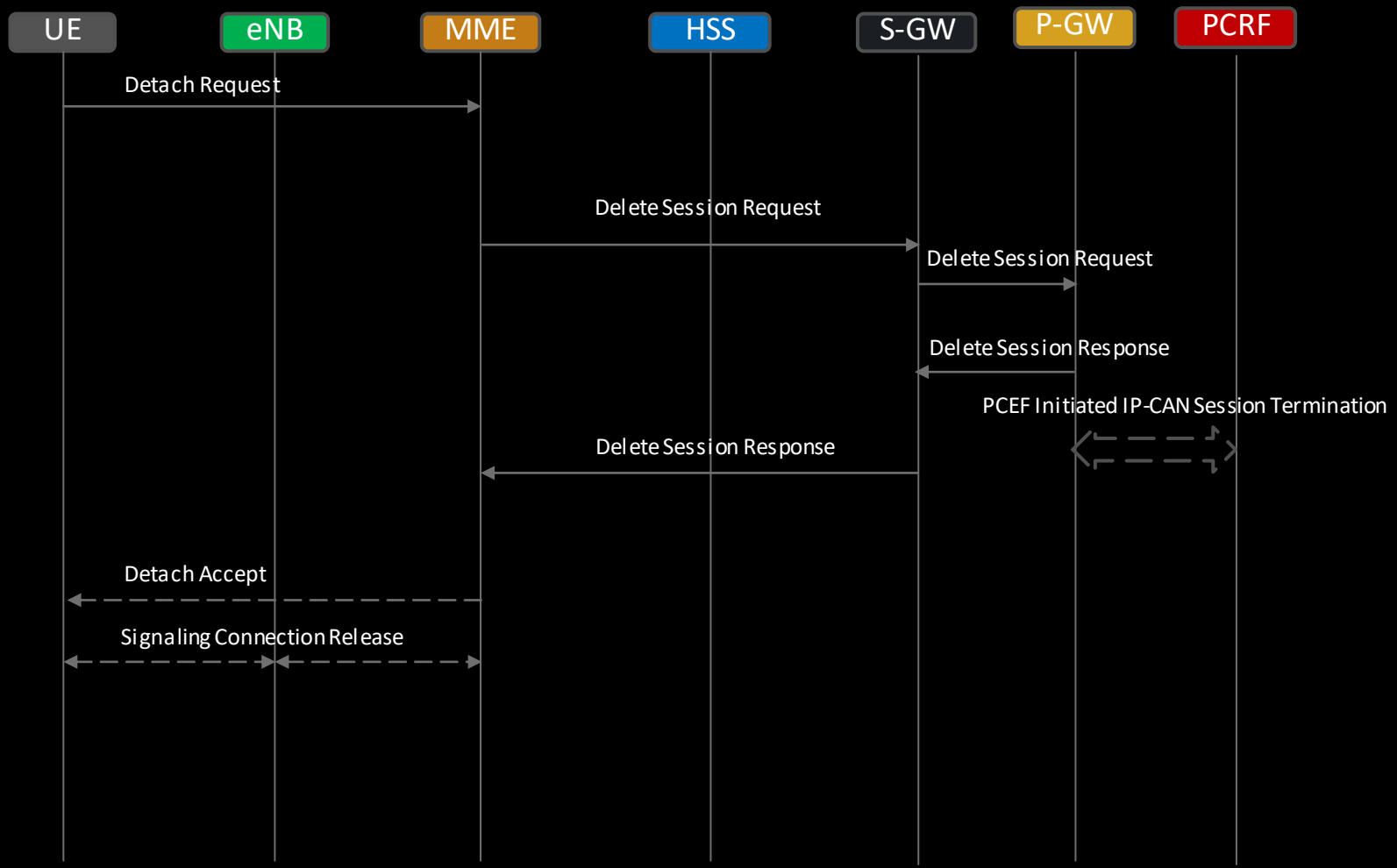
Signaling Flow for basic 4G procedures

10/02/2022

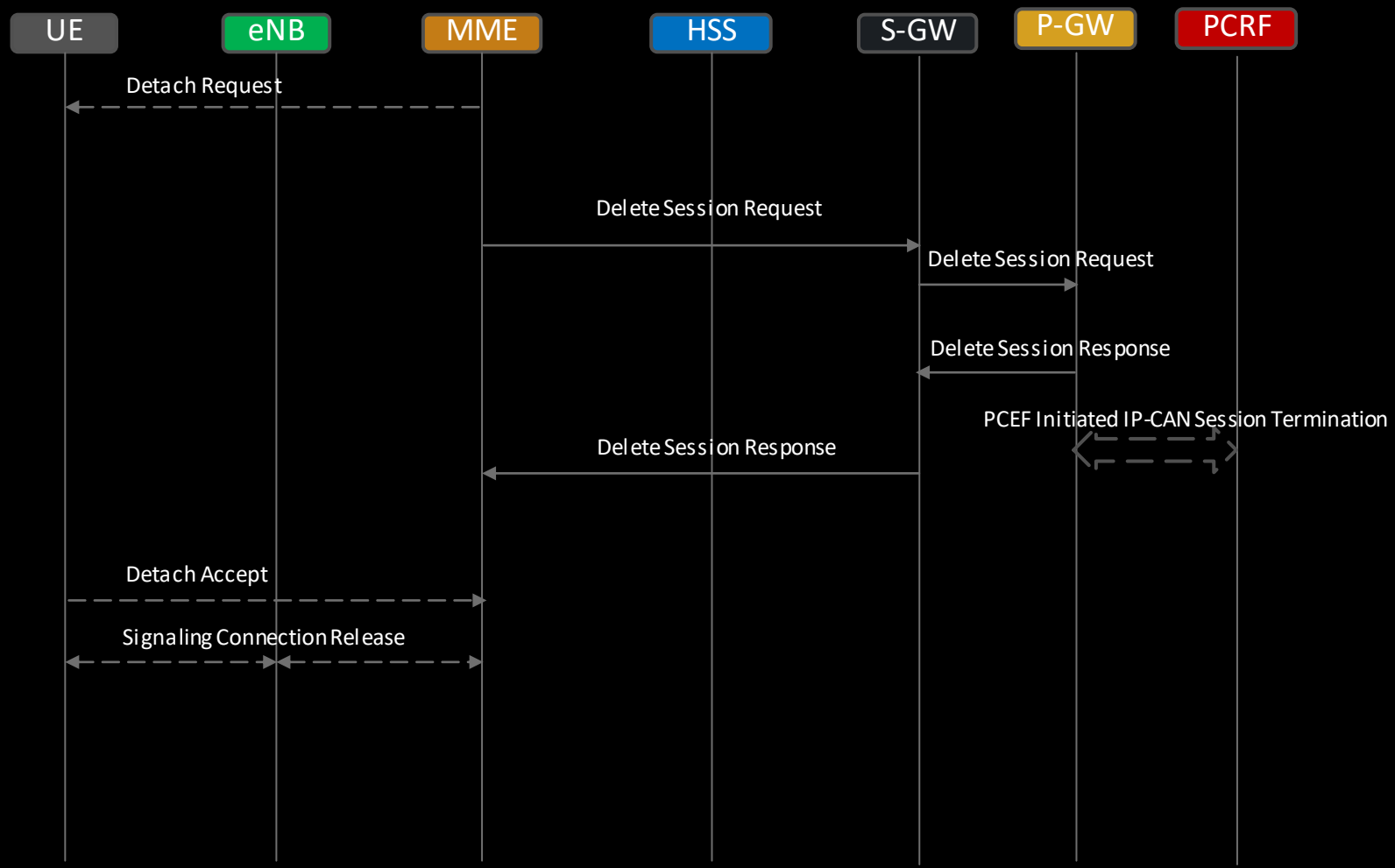
LTE Attach Procedure



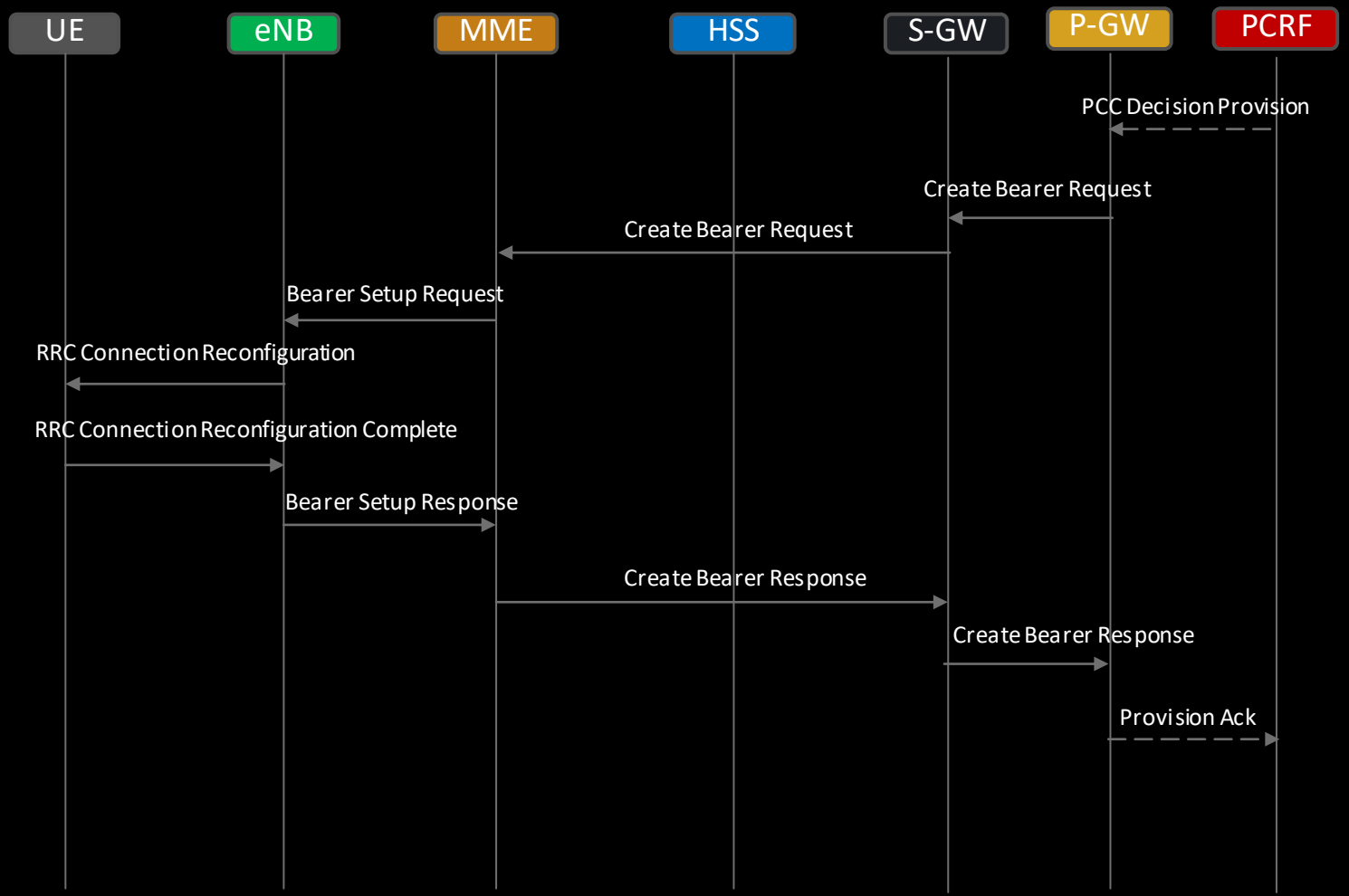
UE-Initiated Detachment Procedure



MME-Initiated Detachment Procedure



Dedicated Bearer Establishment Procedure

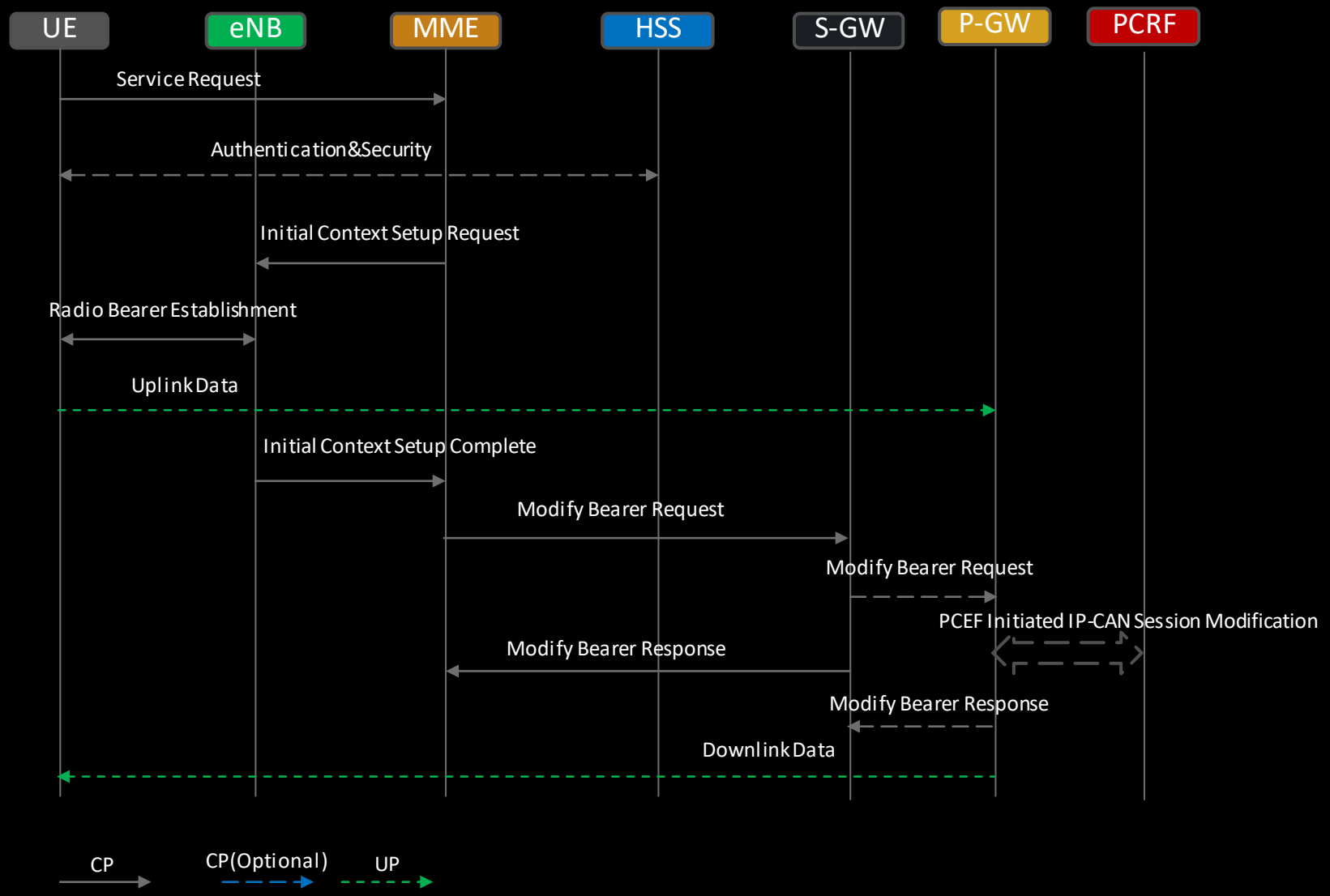


Tracking Area Update Procedure (Intra-MME)

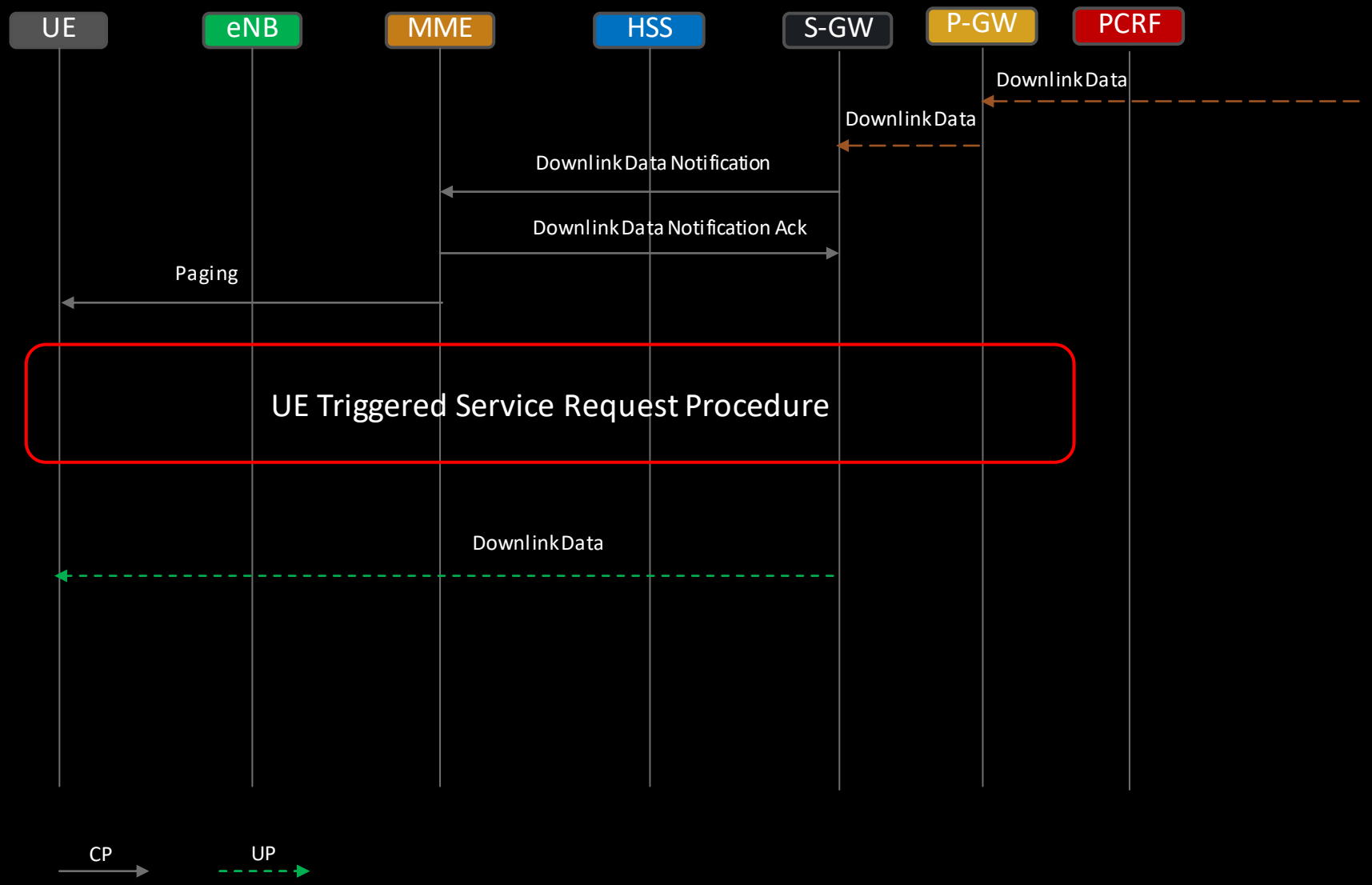
Tracking Area Update Trigger Conditions

1. Periodic TAU
2. TAI List changes
3. Inter RAT changes

UE Triggered Service Request Procedure



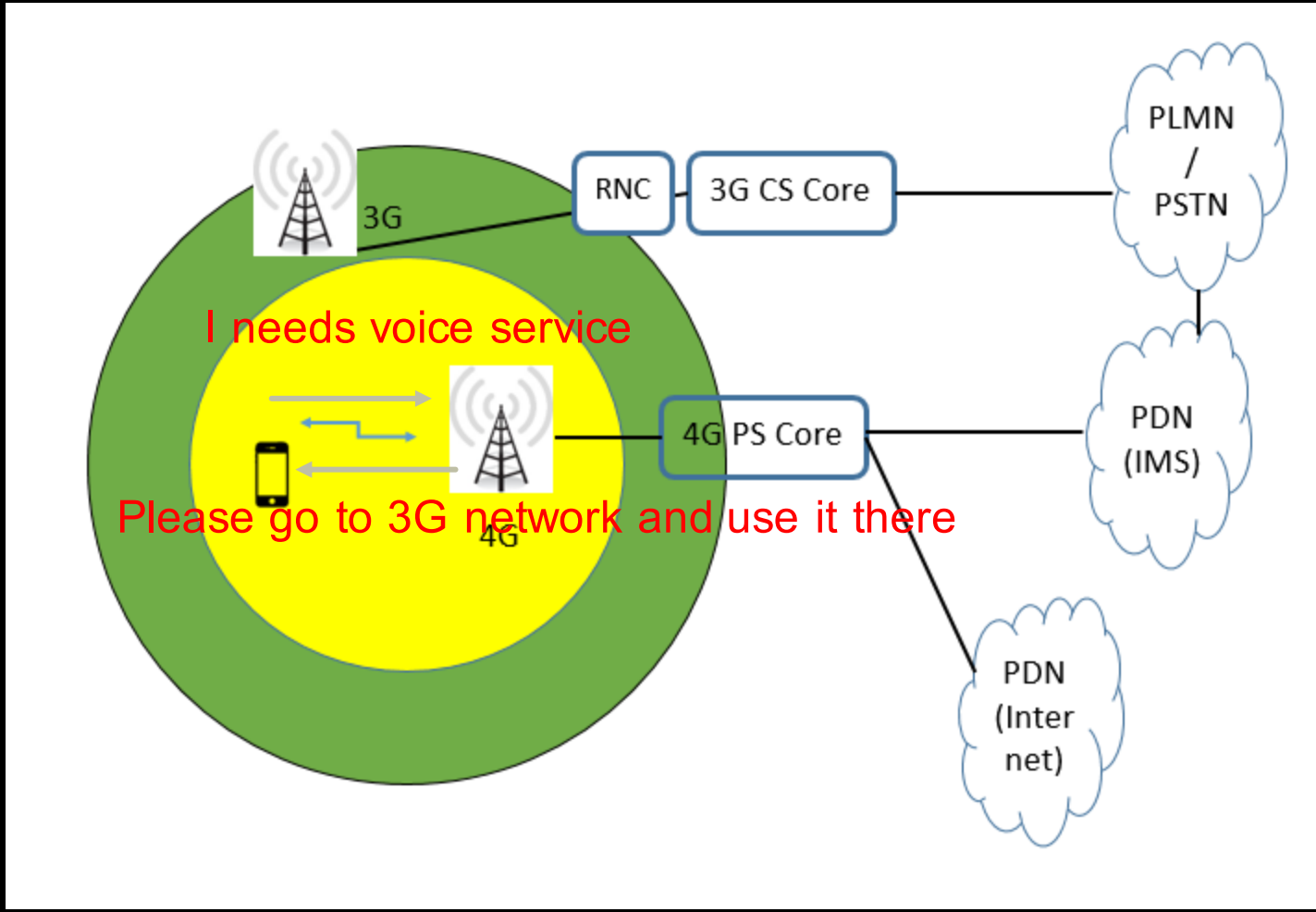
Network-Triggered Service Request Procedure



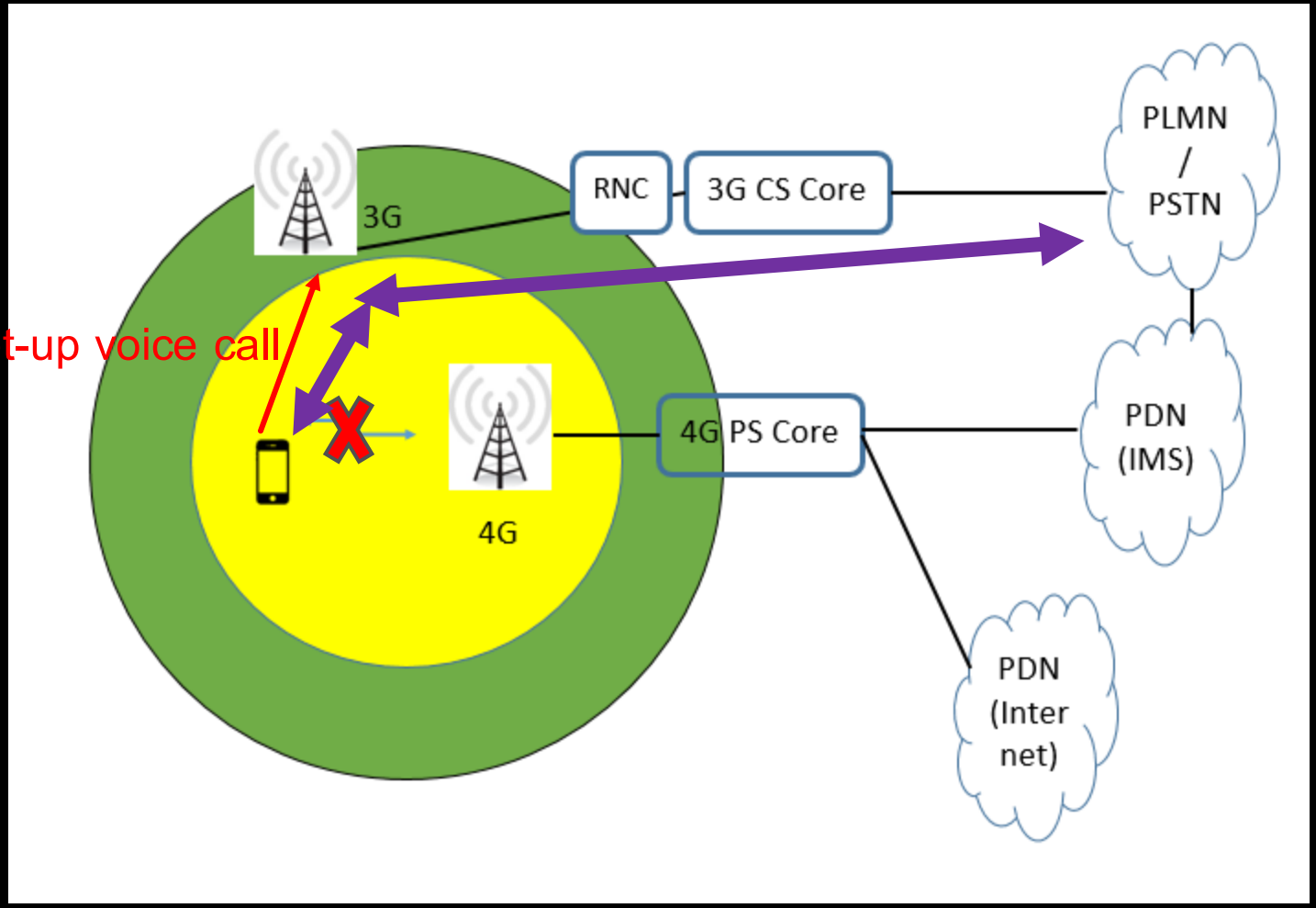
CSFB vs VoLTE

10/02/2022

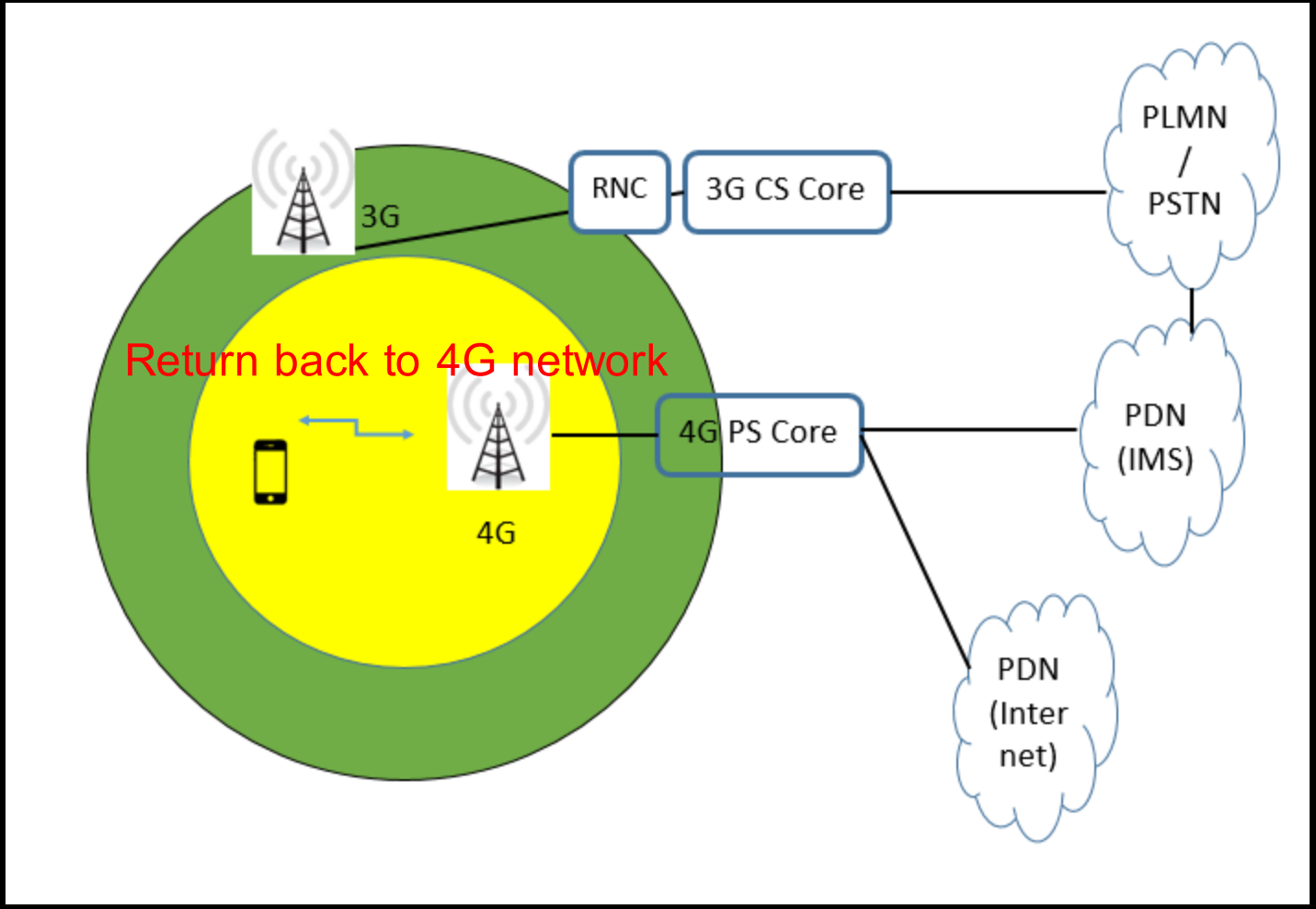
CSFB


3G
RNC
3G CS Core
PLMN
/
PSTN
I needs voice service
4G PS Core
PDN
(IMS)
Please go to 3G network and use it there
4G
PDN
(Inter
net)

CSFB

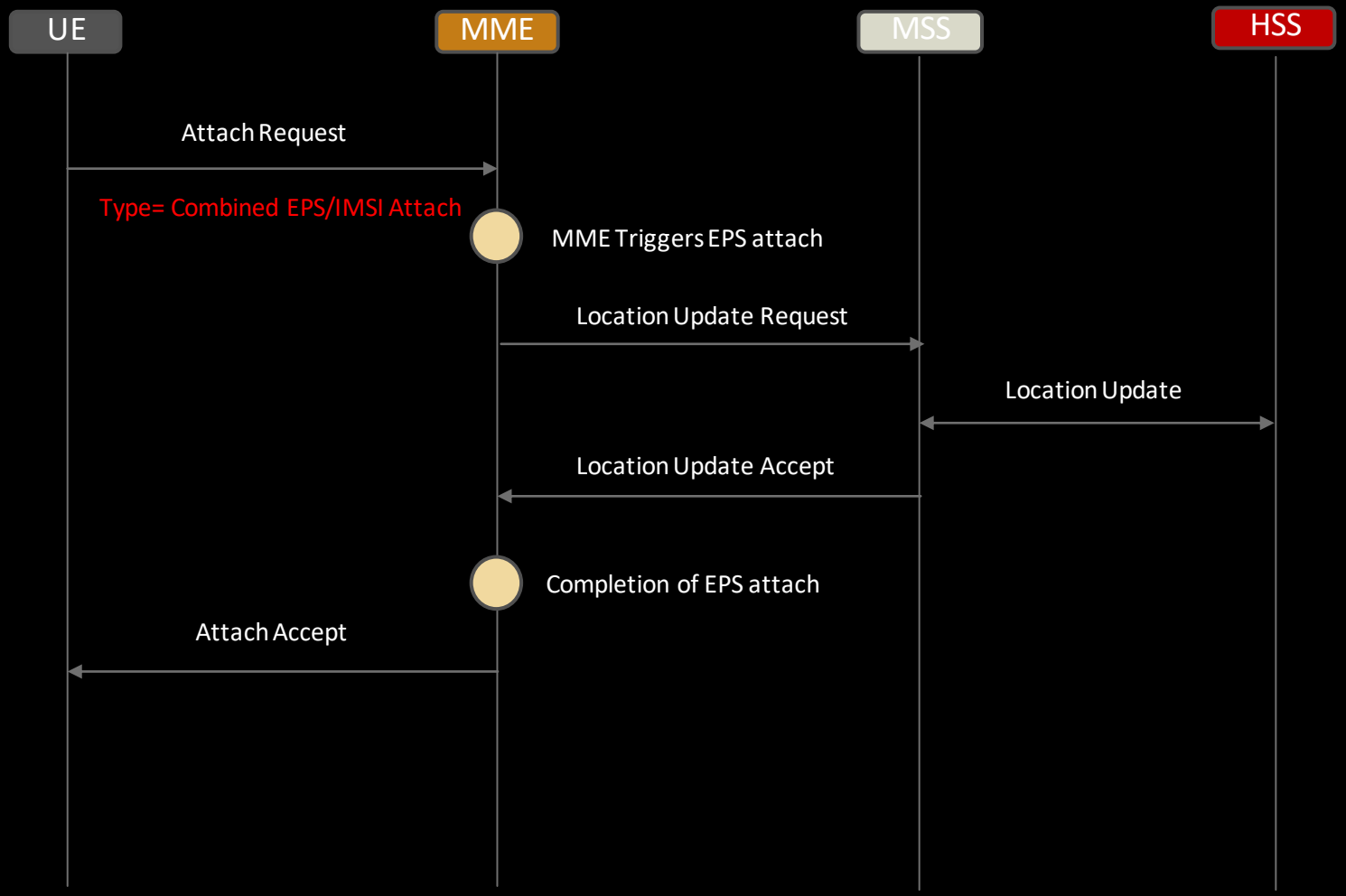

Set-up voice call
3G
RNC
3G CS Core
PLMN
/
PSTN
4G
4G PS Core
PDN
(IMS)
PDN
(Inter
net)

CSFB


3G
RNC
3G CS Core
PLMN
/
PSTN
Return back to 4G network
4G
4G PS Core
PDN
(IMS)
PDN
(Inter
net)

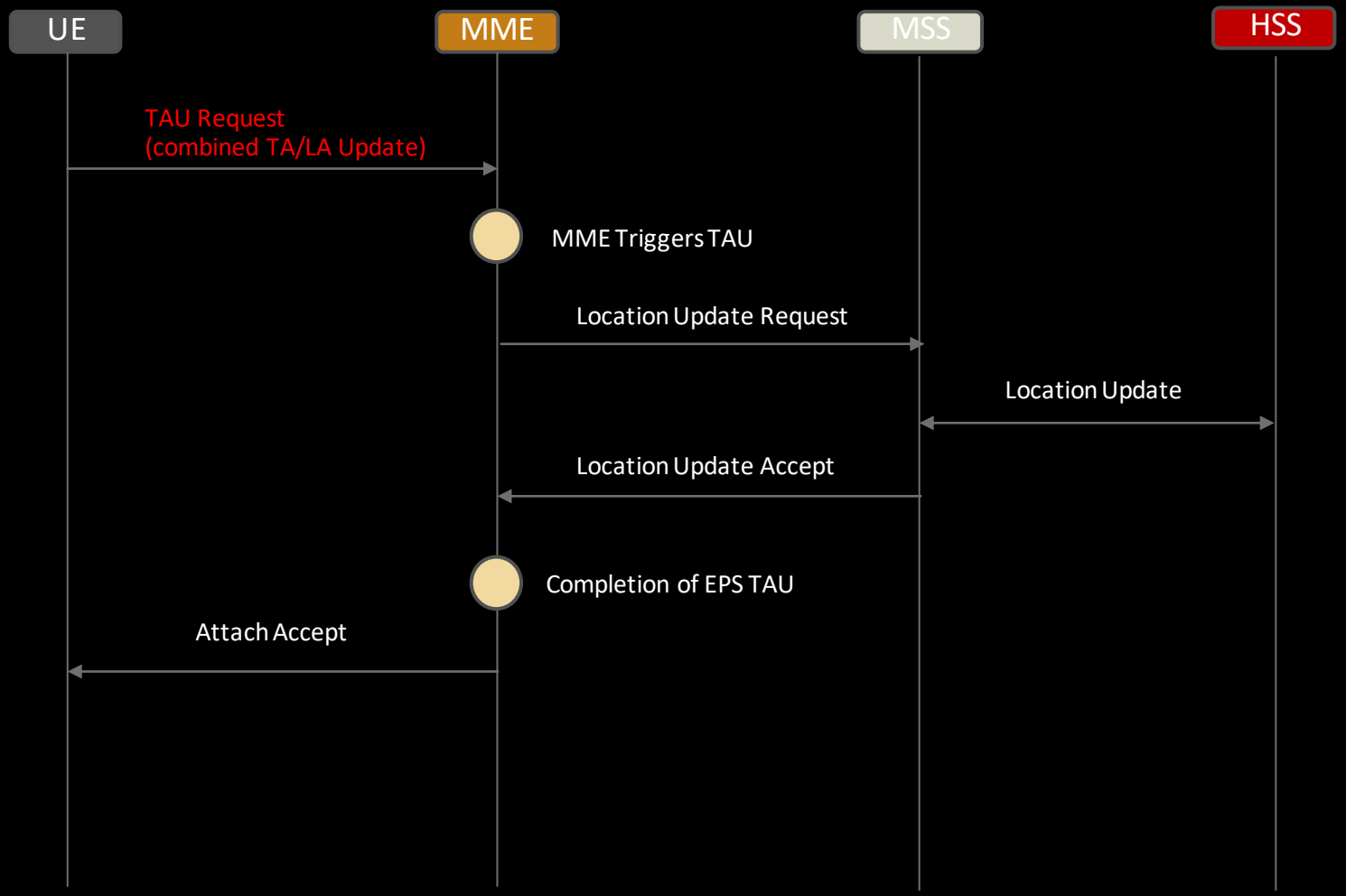
Circuit-Switched Fallback

Attachment Procedure



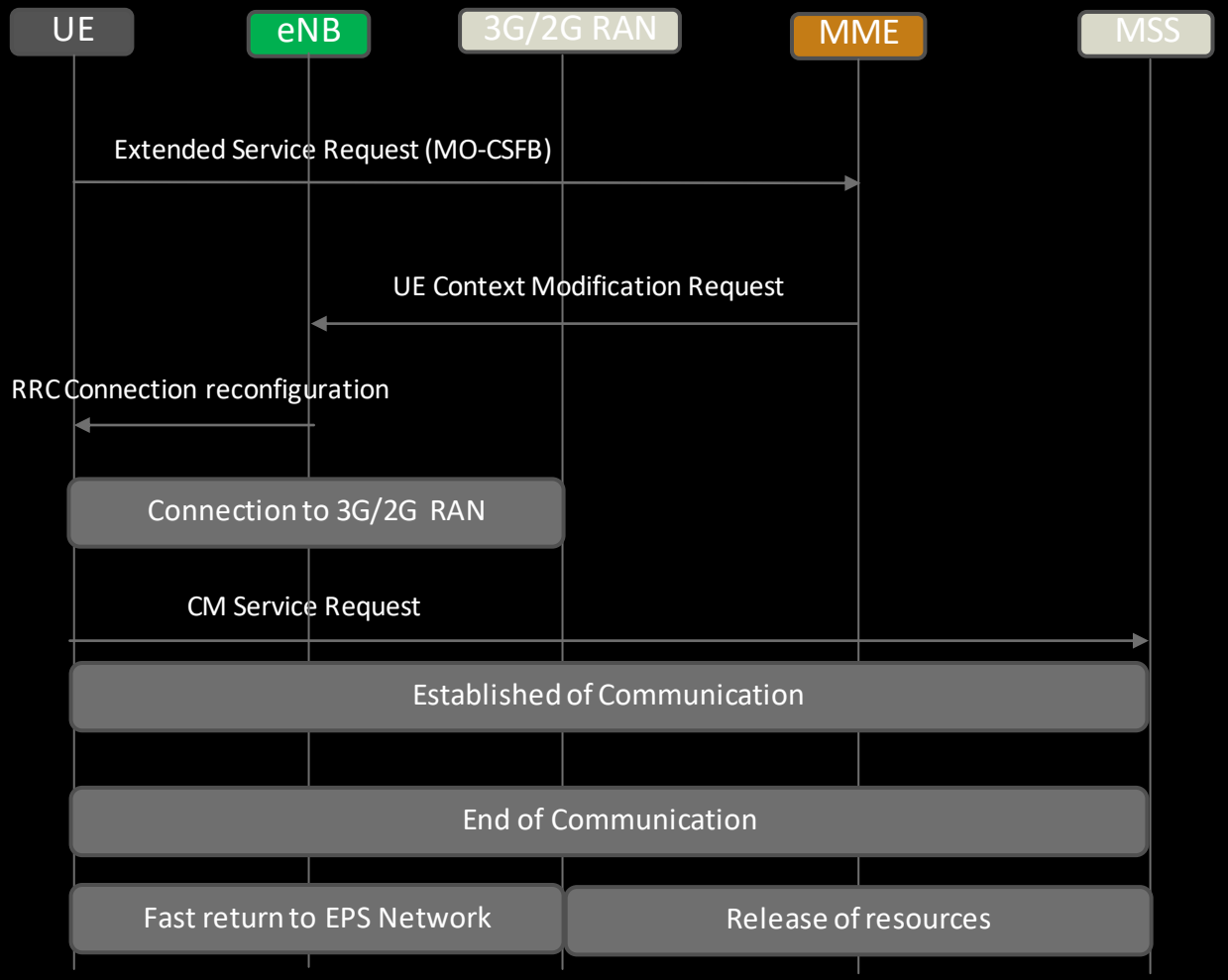
Circuit-Switched Fallback

Combined TA/LA Update Procedure



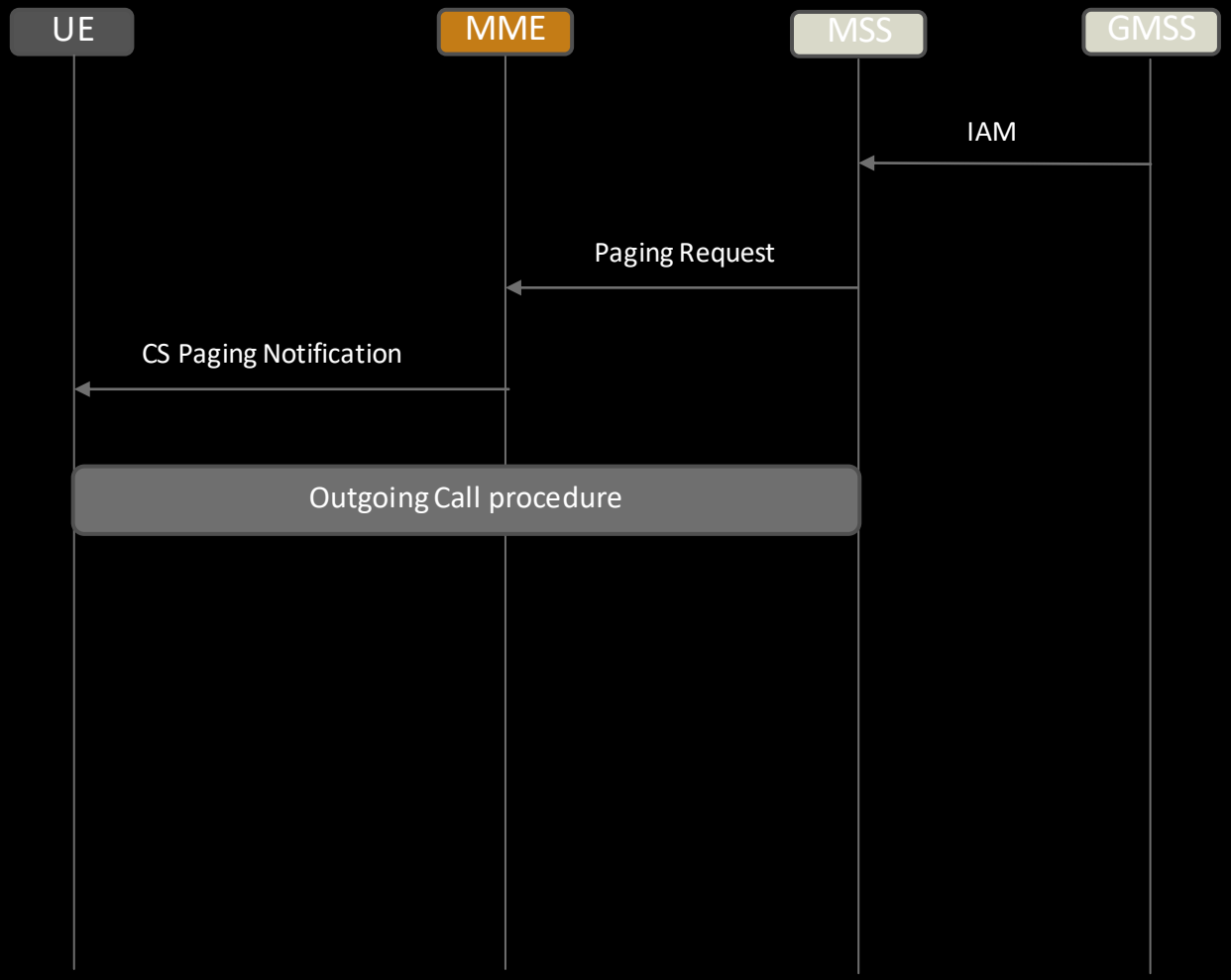
Circuit-Switched Fallback

Outgoing Call Procedure



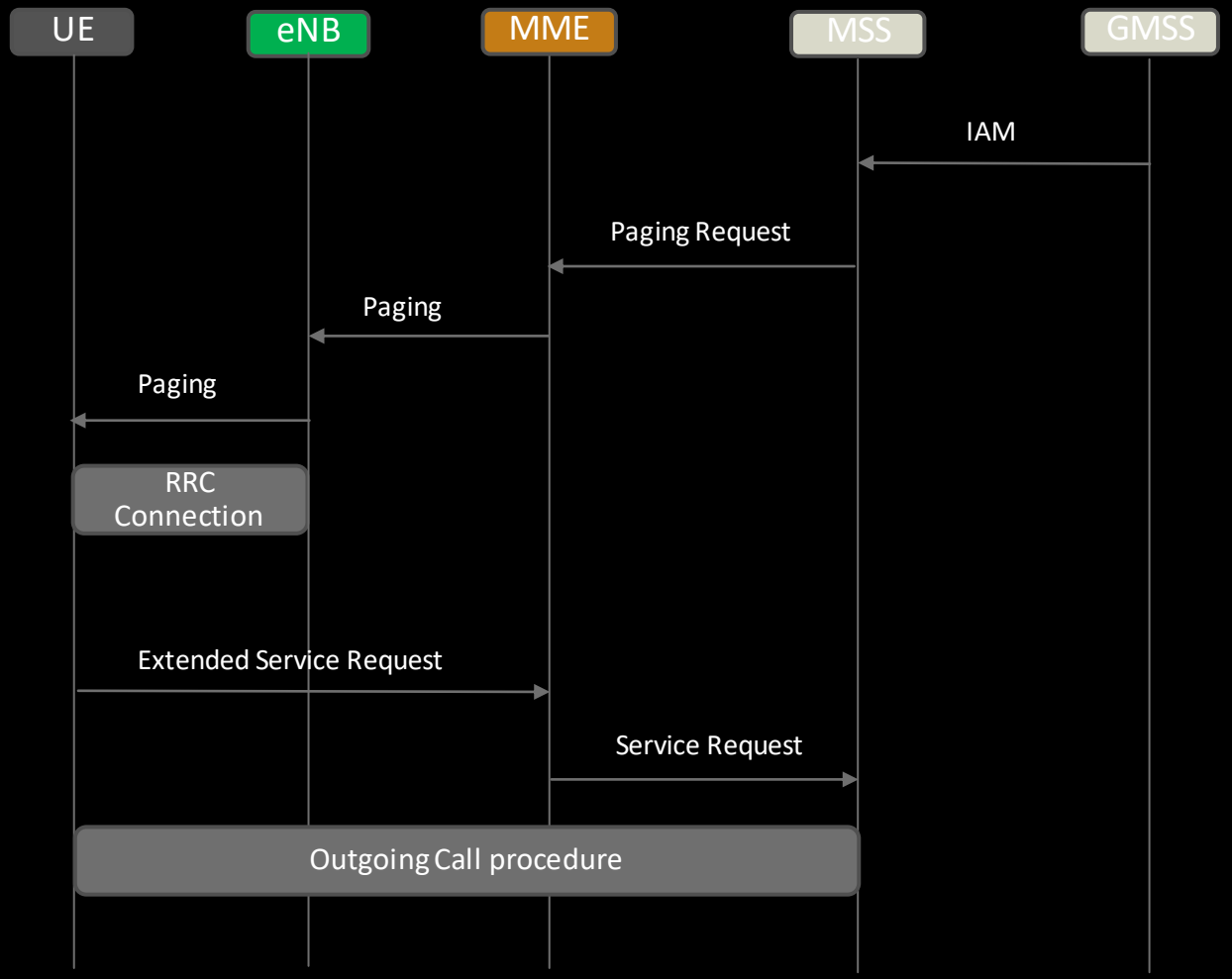
Circuit-Switched Fallback

Incoming Call Procedure - mobile is connected

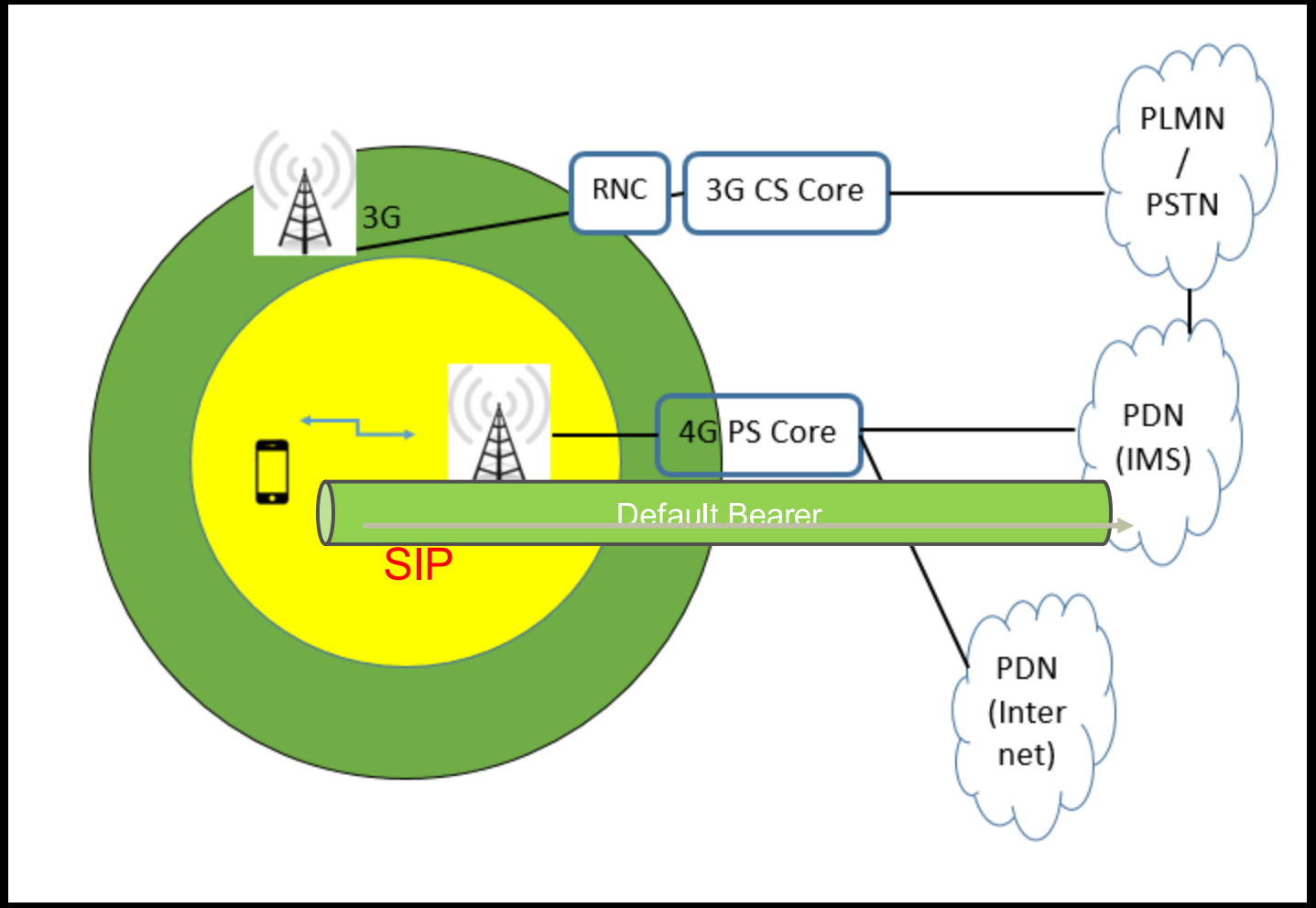


Circuit-Switched Fallback

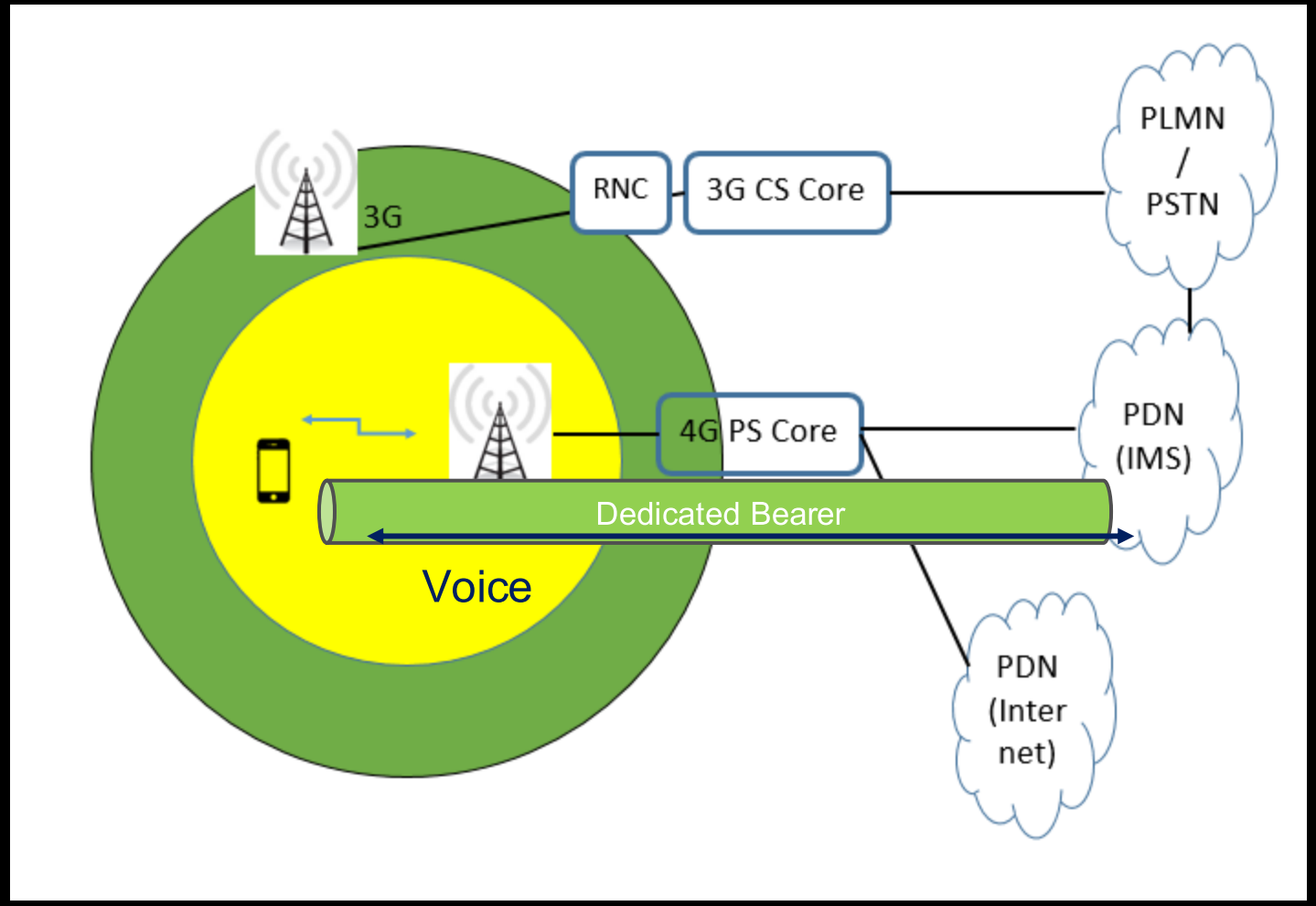
Incoming Call Procedure - mobile is in idle mode



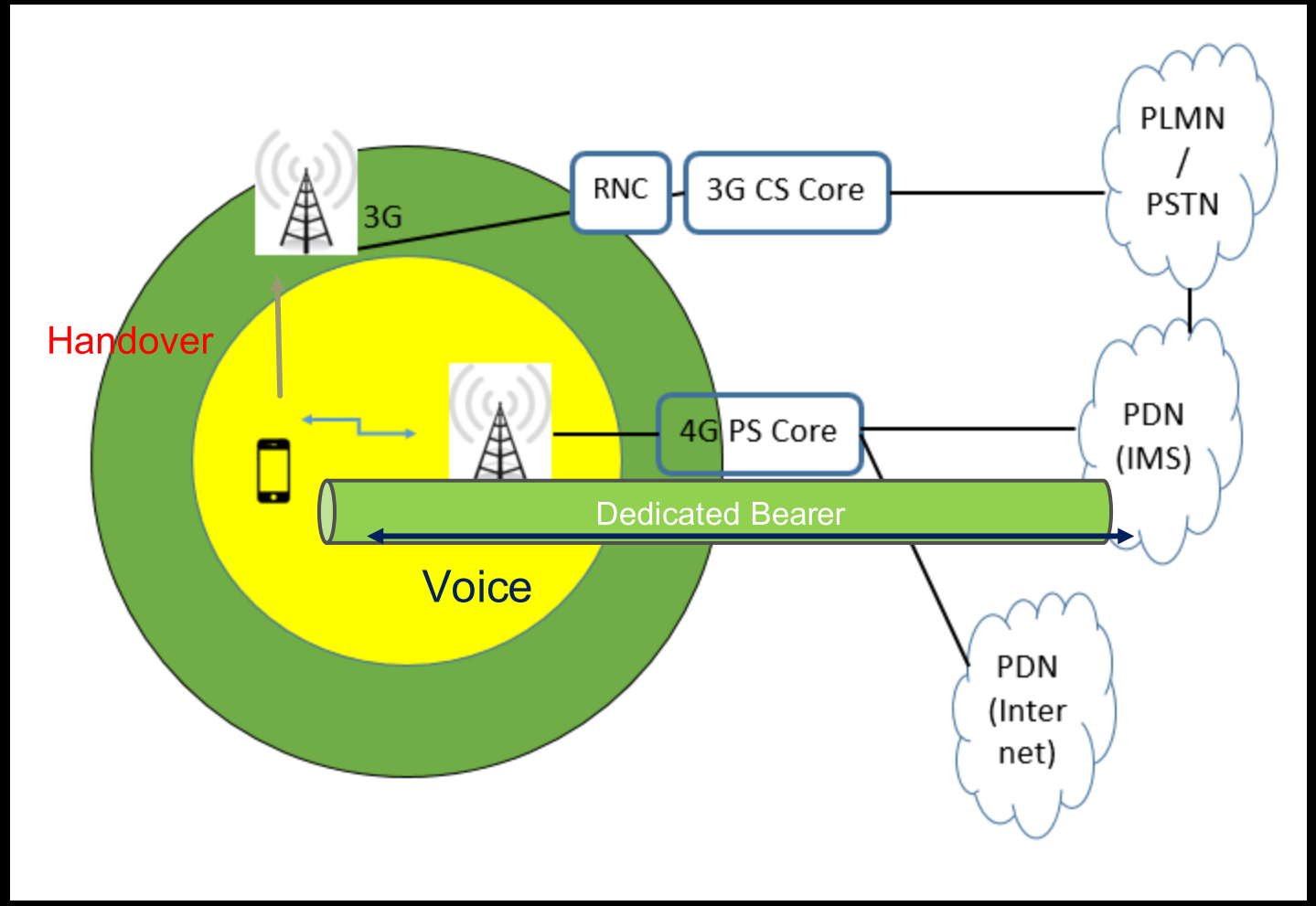
VoLTE


3G
RNC
3G CS Core
PLMN
/
PSTN
4G PS Core
PDN
(IMS)
Default Bearer
SIP
PDN
(Inter
net)

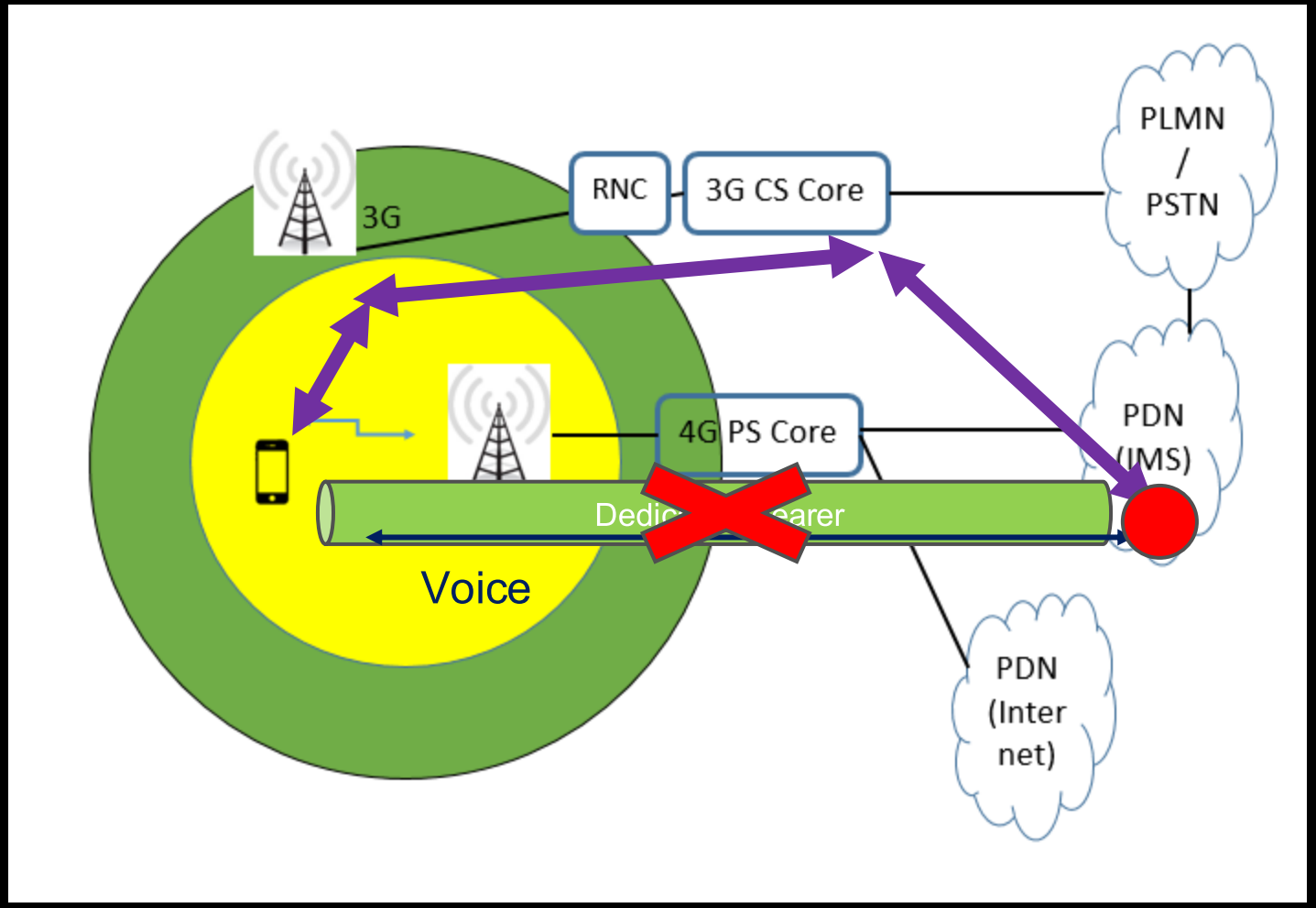
VoLTE & eSRVCC (enhanced Single Radio Voice Call Continuity)



VoLTE & eSRVCC (enhanced Single Radio Voice Call Continuity)



VoLTE & eSRVCC (enhanced Single Radio Voice Call Continuity)



Q&A