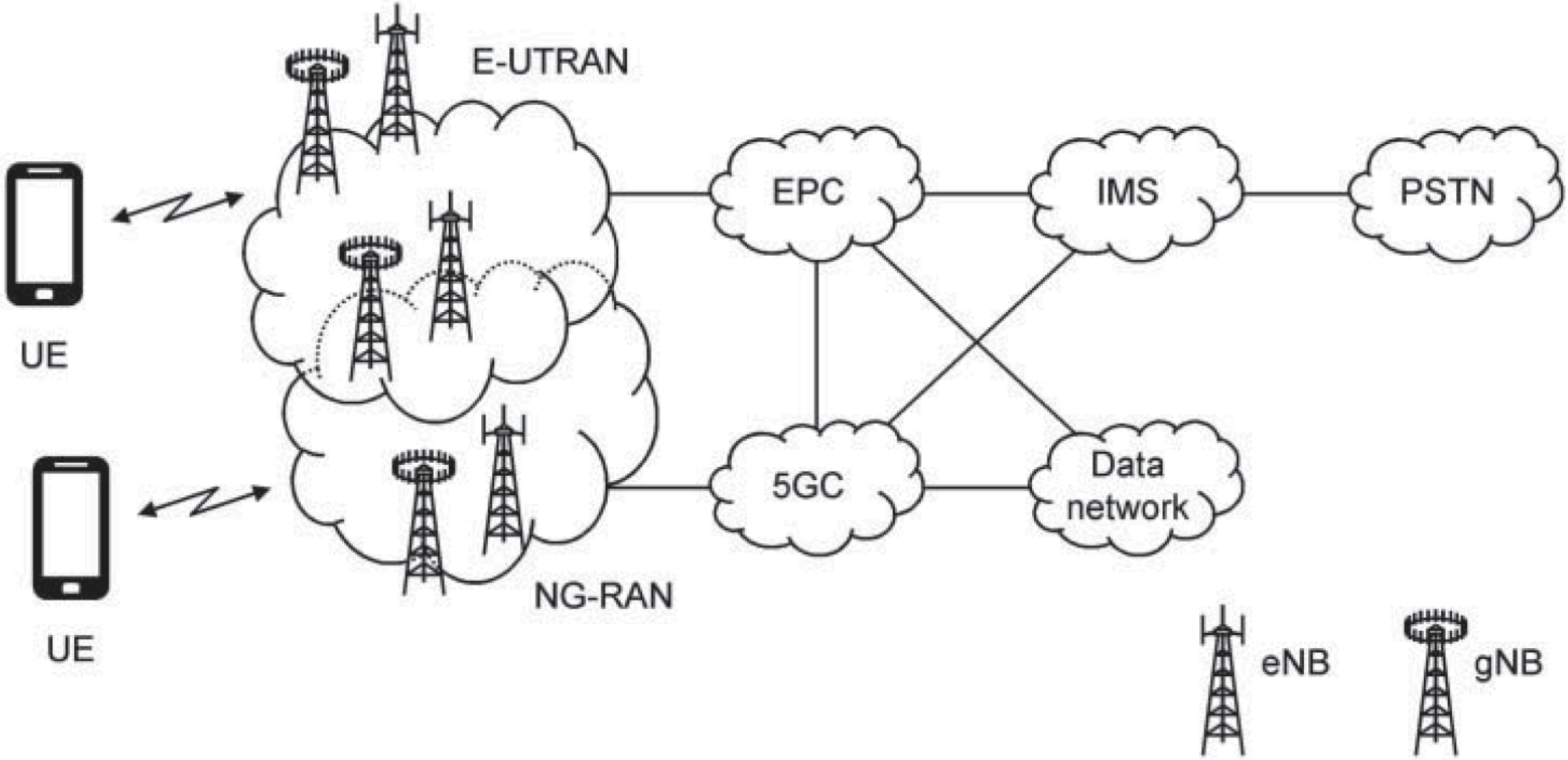
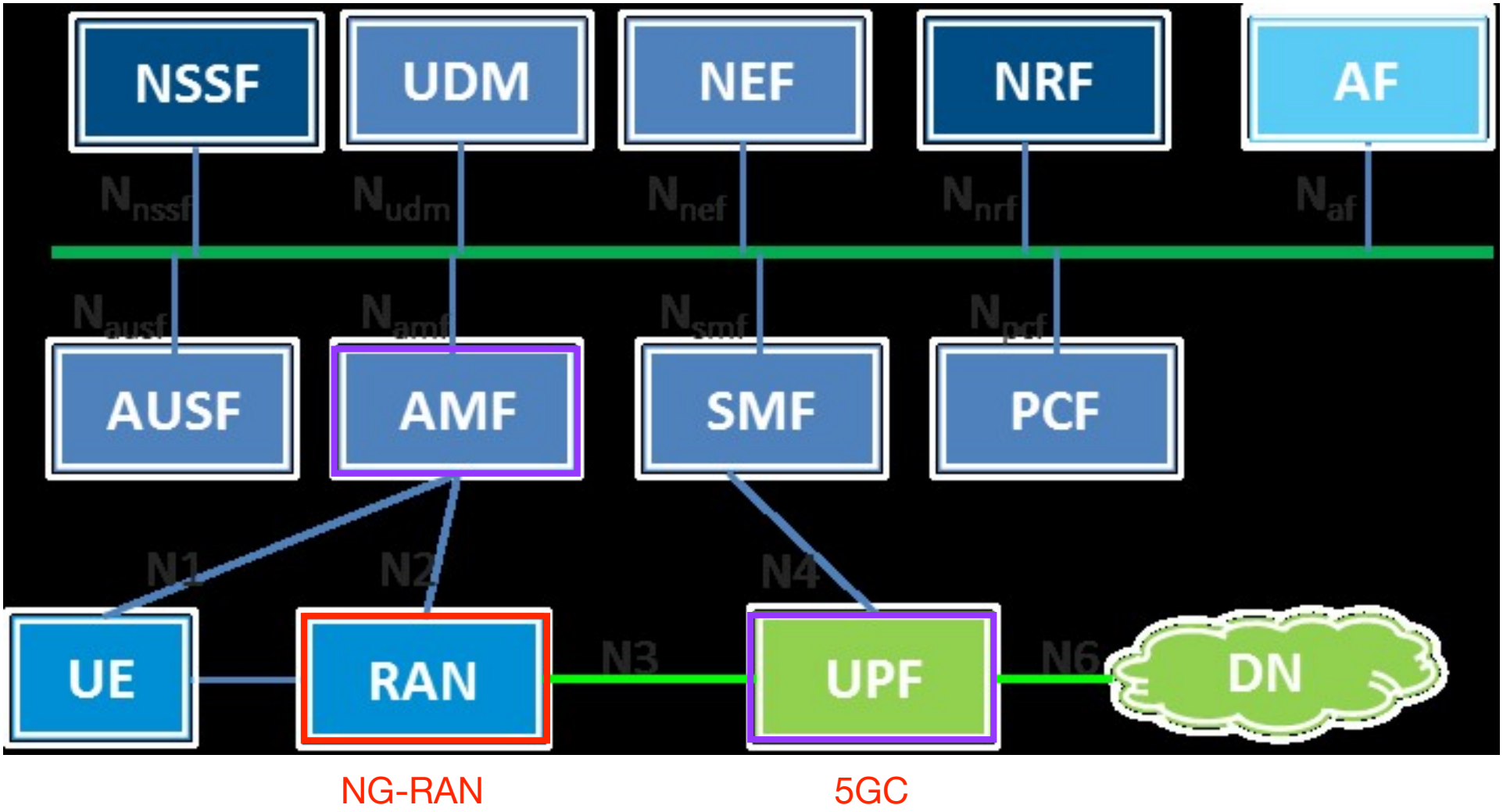
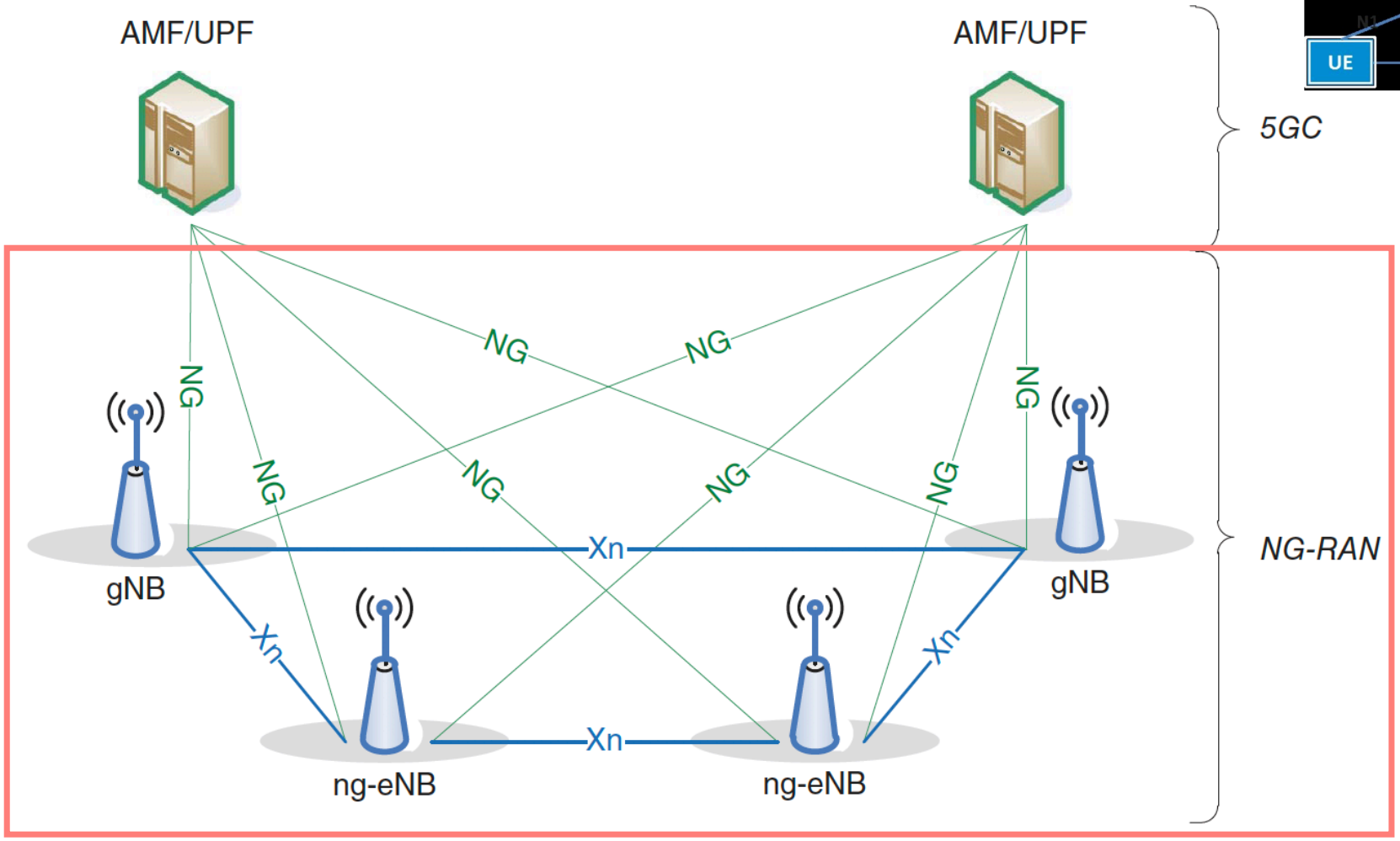
NG Protocol Stack

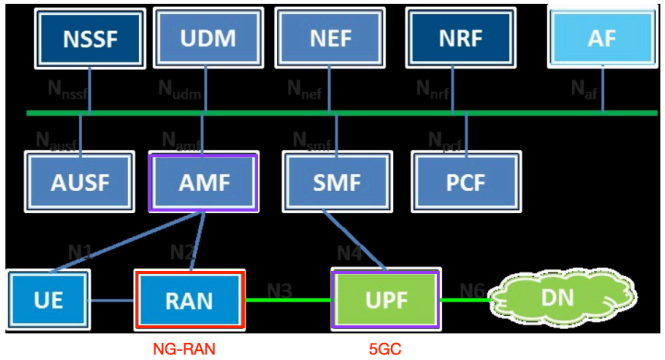
1. **Introduction**
2. NG-RAN Architecture
3. NR User Plane
4. Supporting QoS with 5GC
5. NR Control Plane

1. Introduction

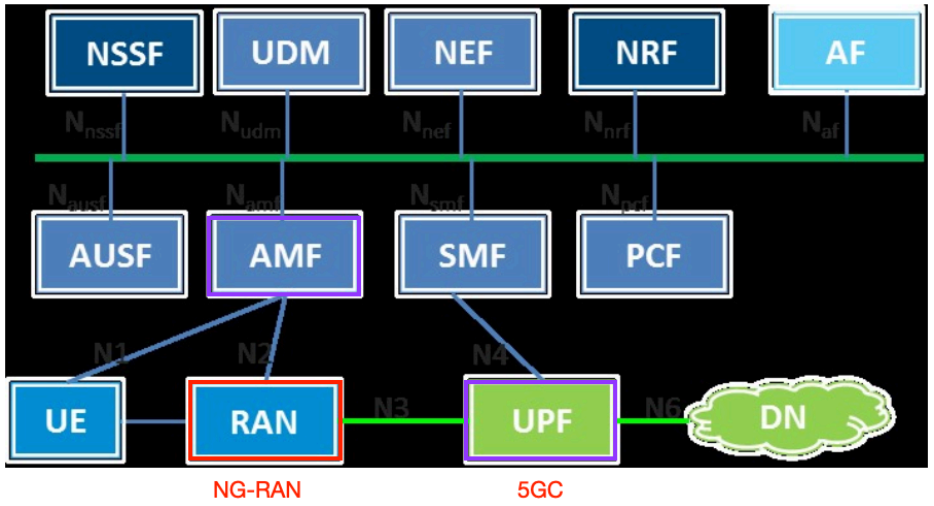



NSSF
UDM
NEF
NRF
AF
N_nssf
N_udm
N_nef
N_nrf
N_af
N_ausf
N_amf
N_smf
N_pcf
AUSF
AMF
SMF
PCF
N1
N2
N4
UE
RAN
N3
UPF
N6
DN
NG-RAN
5GC

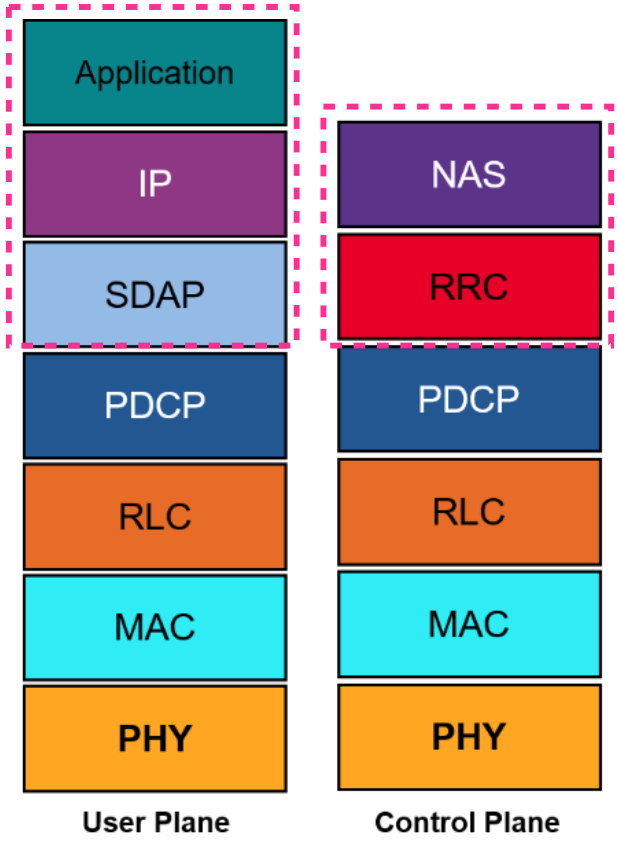

AMF/UPF
AMF/UPF
5GC
NG
NG
NG
NG
NG
NG
NG
Xn
Xn
Xn
gNB
gNB
ng-eNB
ng-eNB
NG-RAN

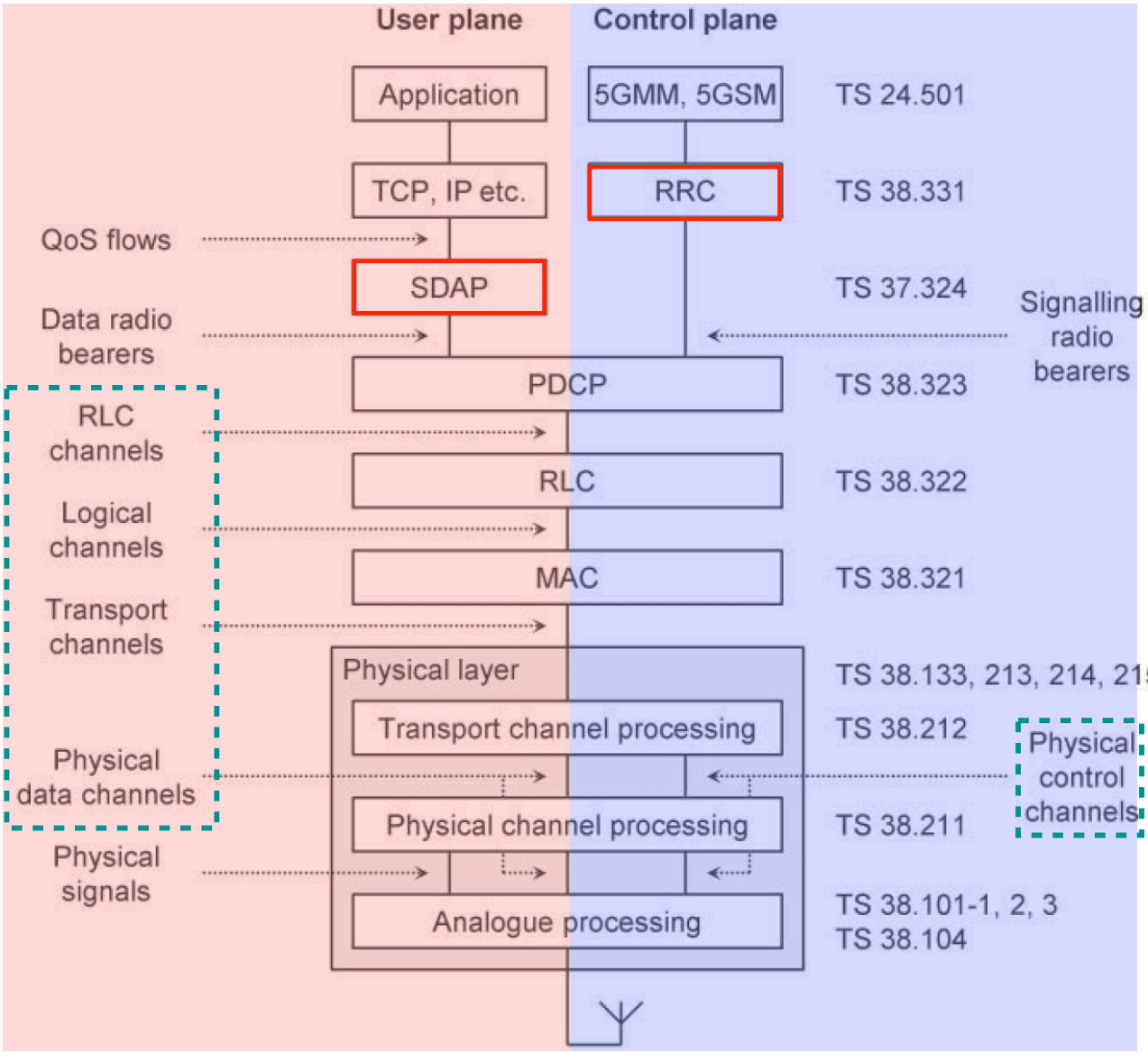

NSSF
UDM
NEF
NRF
AF
AUSF
AMF
SMF
PCF
UE
RAN
UPF
DN
N1
N2
N3
N4
N6
NG-RAN
5GC

- NG-RAN
  - Provide connectivity over radio interface between network and UE with user-plane functions
  - Provide required QoS for data over radio interface

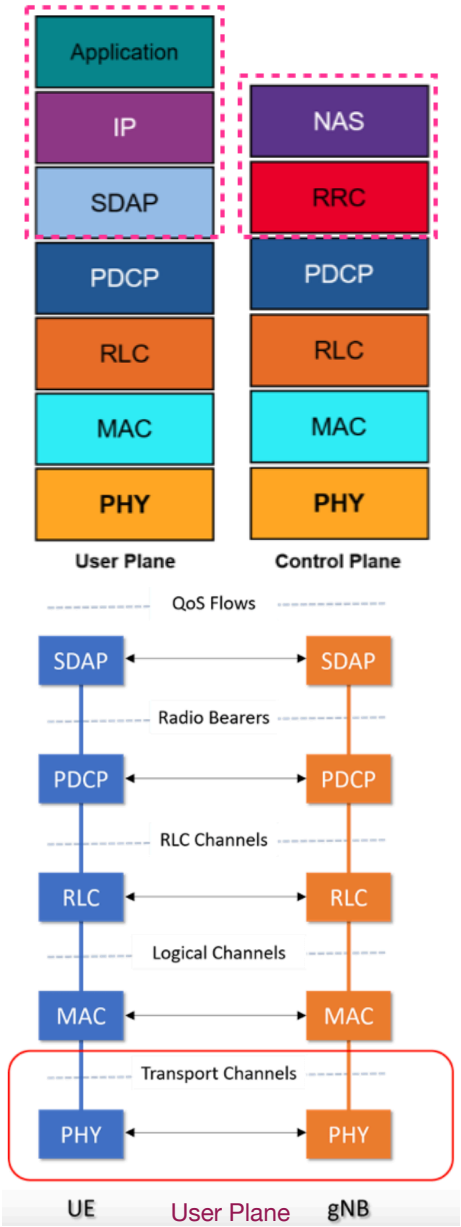


- Focus on air interface protocol stack
  - (1) NR protocol stack consists of
    - **User-plane part**
      - Handles transfer of data across radio interface with required QoS
    - **Control-plane part**
      - Handles configuration of radio interface connection

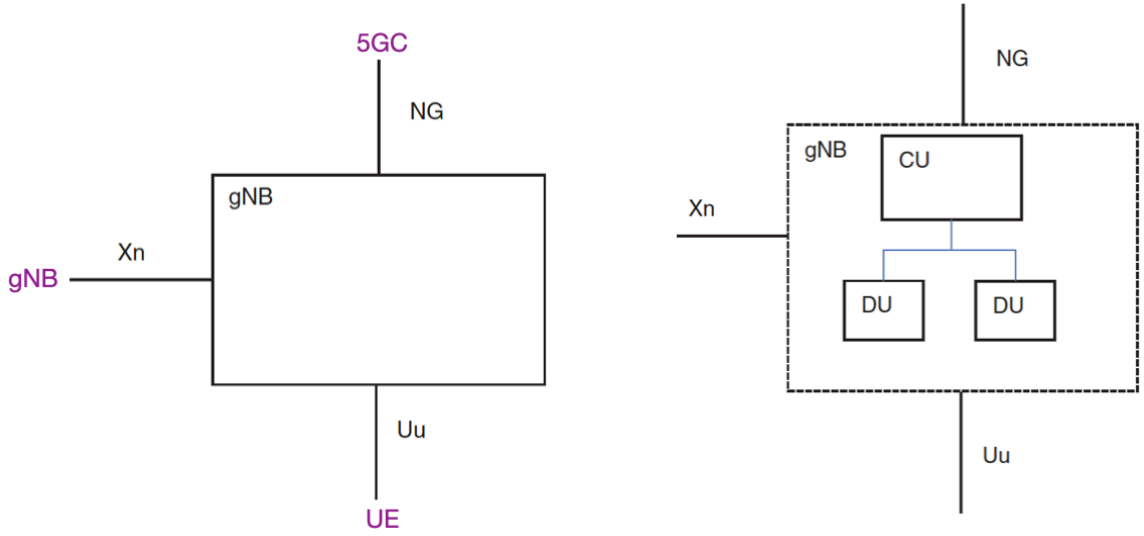


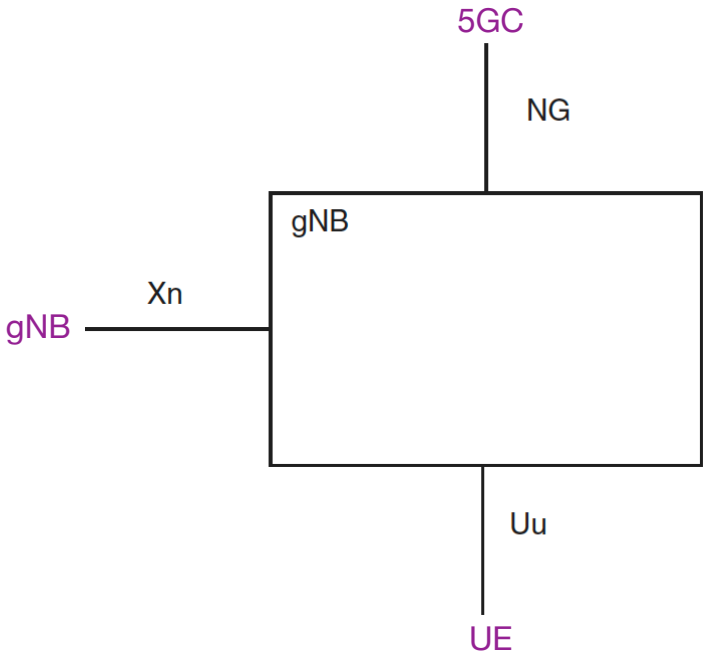


Air interface protocol stack for architectural

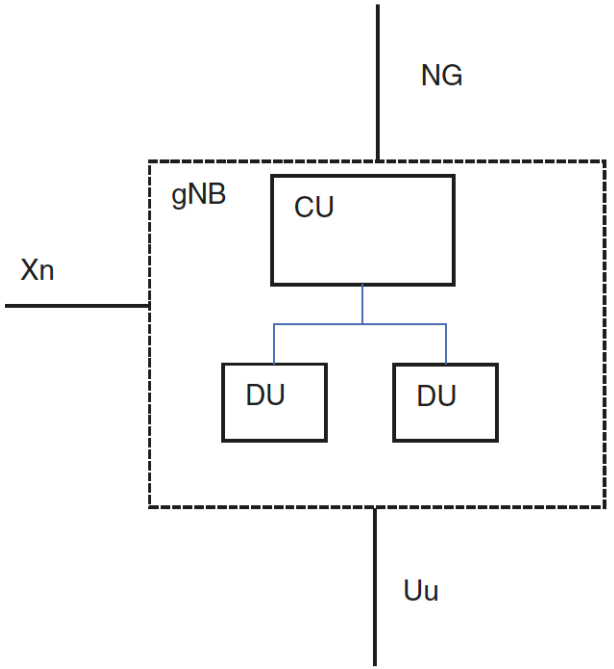


- (2) NG-RAN architecture
  - **Non-split** NG-RAN architecture
    - gNB hosts all of the protocol stack functionality
  - **Split** NG-RAN architecture (gNB-CU/DU)
    - Different protocol stack layers are hosted in different logical network nodes (CU/DU)

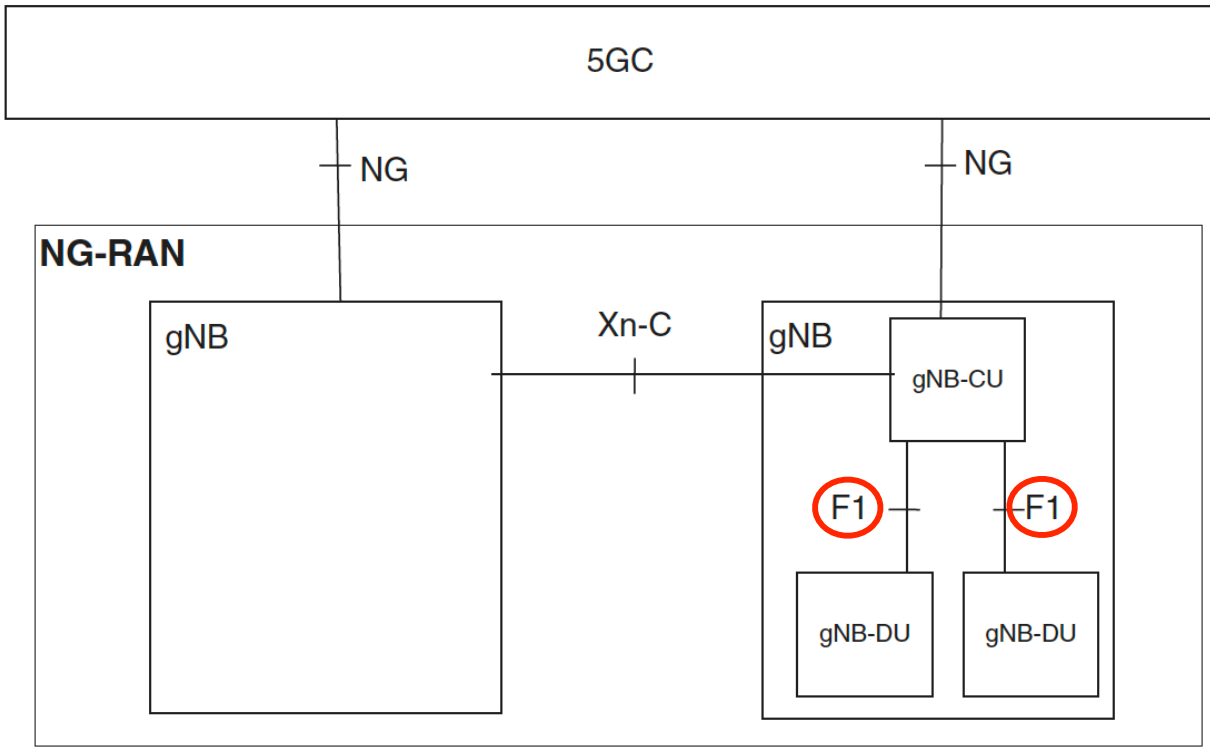




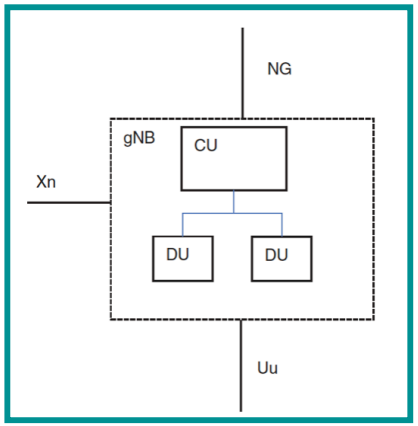
Monolithic gNB architecture

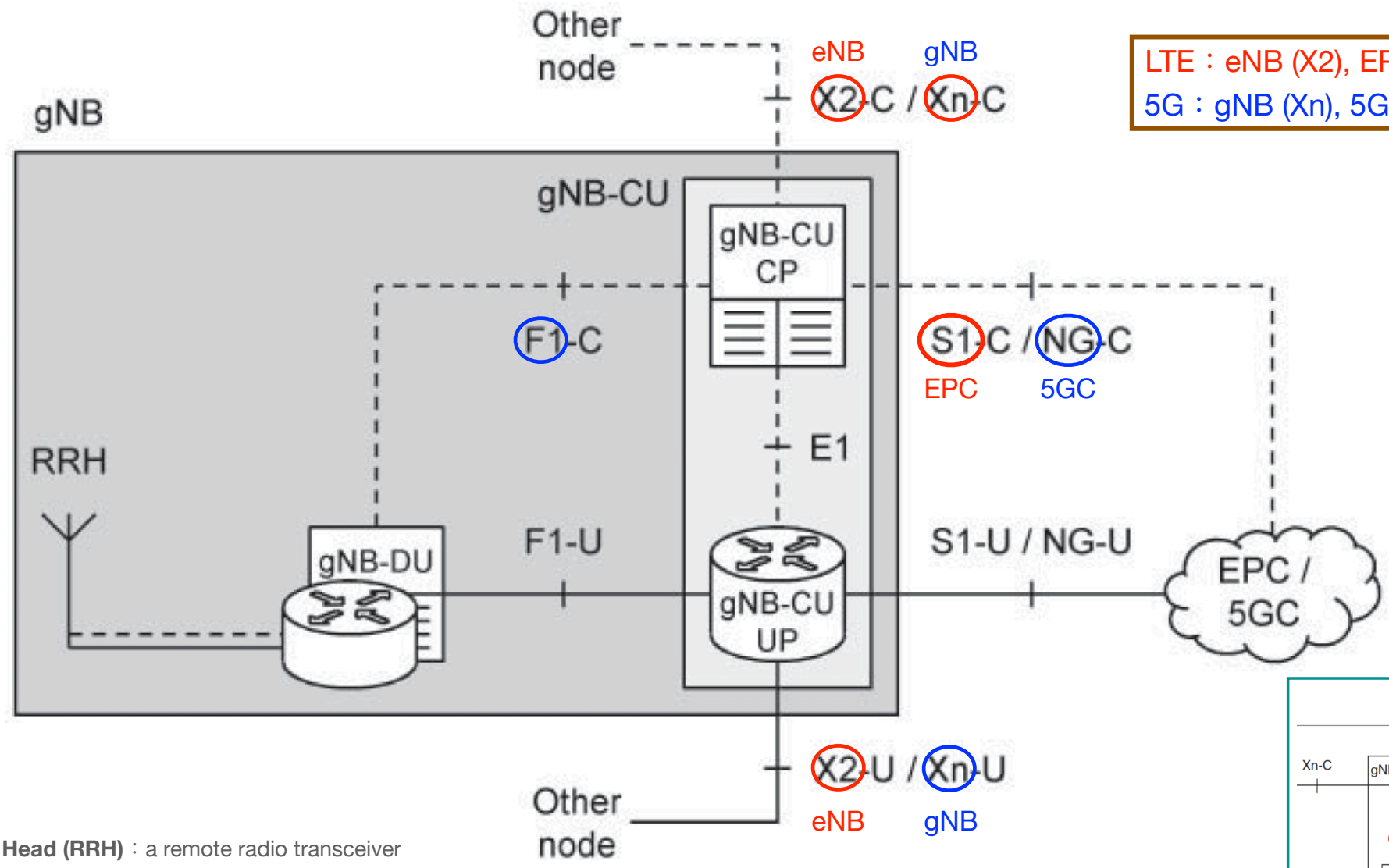


gNB architecture with Centralized Unit (**CU**)
and multiple Distributed Units (**DU**)

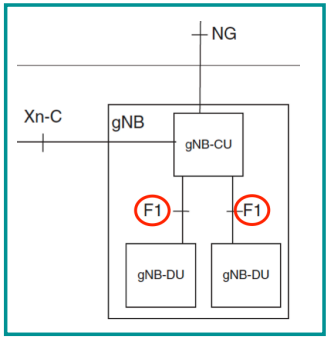


Overall NG-RAN architecture





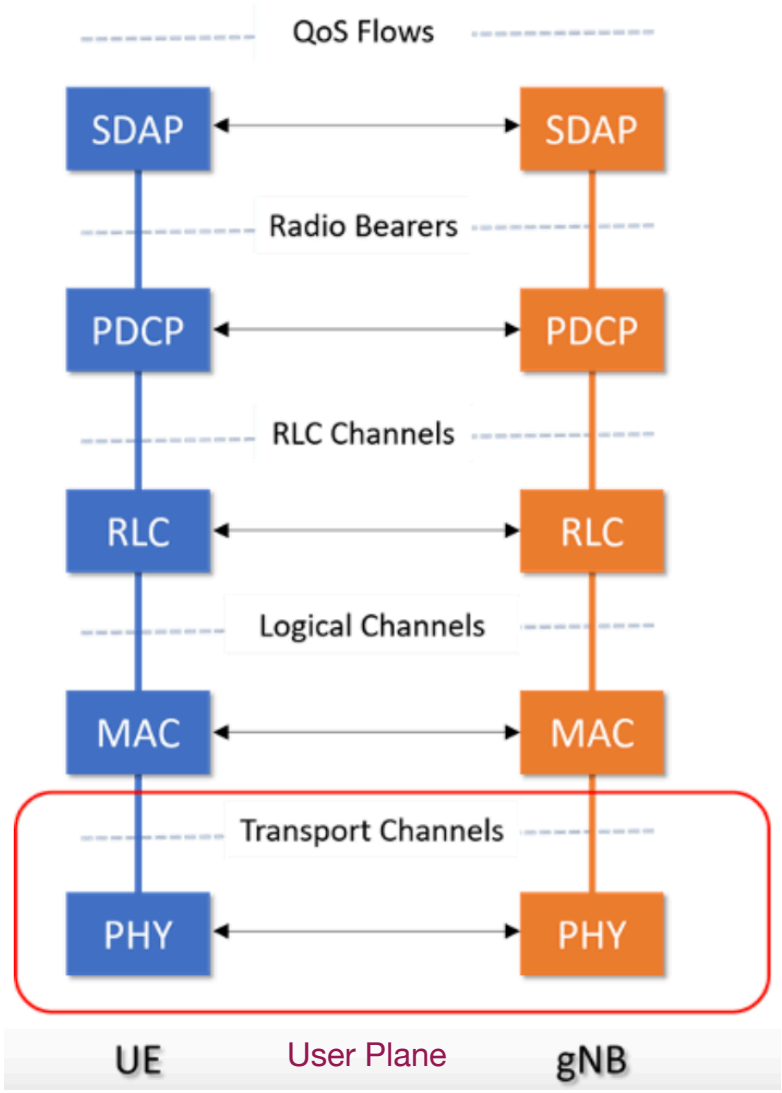
LTE：eNB (X2), EPC (S1)
5G：gNB (Xn), 5GC (NG)

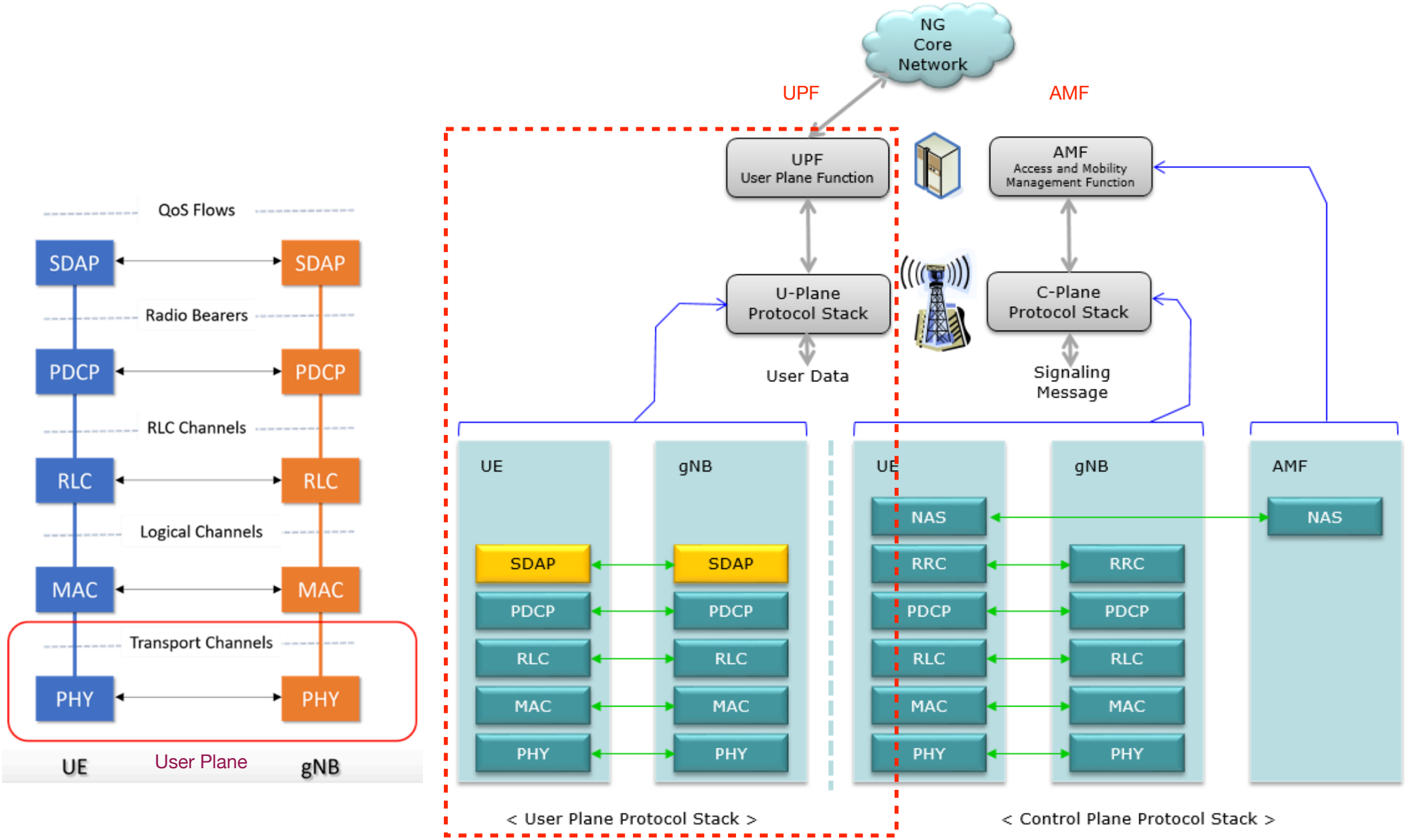


Remote Radio Head (RRH)：a remote radio transceiver that connects to an operator radio control panel via electrical or wireless interface

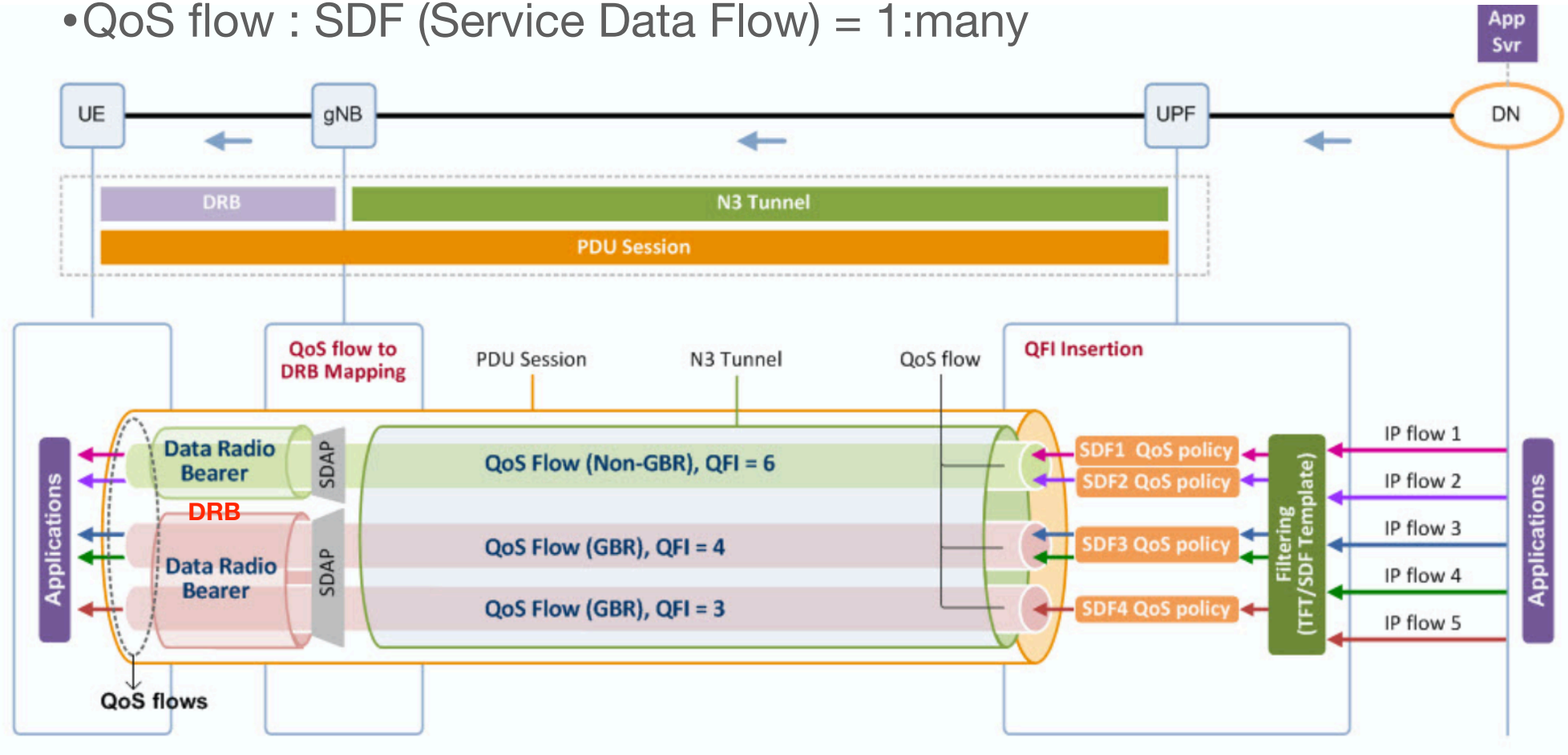
Internal architecture of the gNB

- (3) User-plane protocol stack consists of
  - **SDAP** (Service Data Adaptation Protocol) layer
  - **PDCP** (Packet Data Convergence Protocol) layer
  - **RLC** (Radio Link Control) layer
  - **MAC** (Medium Access Control) layer

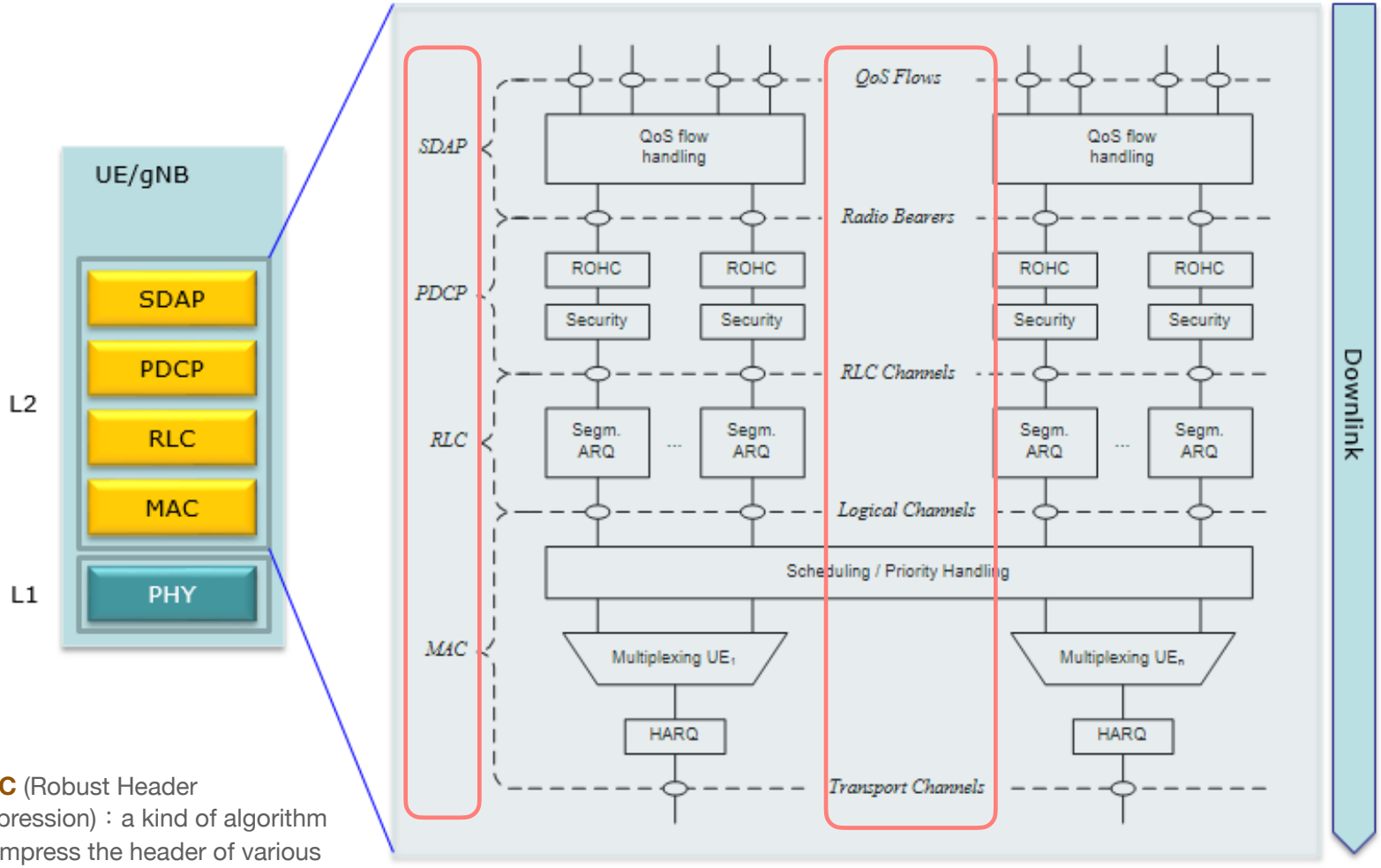


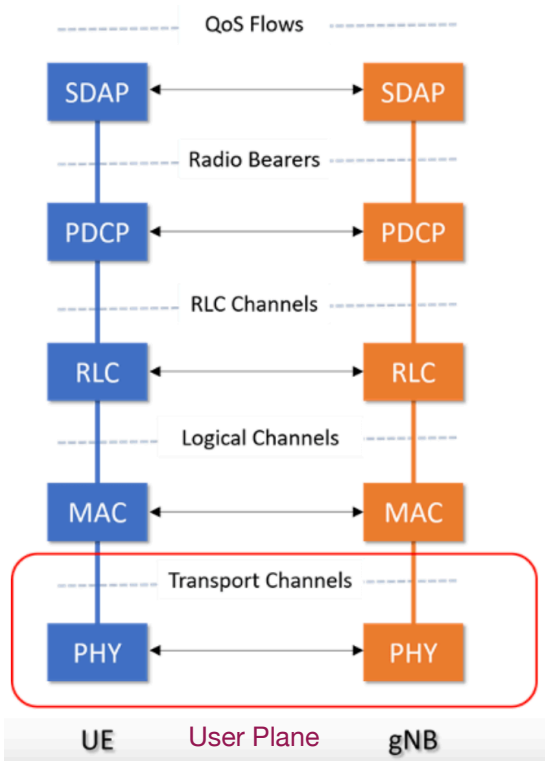

NG
Core
Network
UPF
AMF
UPF
User Plane Function
AMF
Access and Mobility
Management Function
U-Plane
Protocol Stack
C-Plane
Protocol Stack
User Data
Signaling
Message
QoS Flows
SDAP
SDAP
Radio Bearers
PDCP
PDCP
RLC Channels
RLC
RLC
Logical Channels
MAC
MAC
Transport Channels
PHY
PHY
UE
User Plane
gNB
UE
gNB
SDAP
SDAP
PDCP
PDCP
RLC
RLC
MAC
MAC
PHY
PHY
< User Plane Protocol Stack >
UE
gNB
AMF
NAS
NAS
RRC
RRC
PDCP
PDCP
RLC
RLC
MAC
MAC
PHY
PHY
< Control Plane Protocol Stack >

- PDU session : QoS flow = 1:many
- QoS flow : QFI = 1:1
- QoS flow : SDF (Service Data Flow) = 1:many



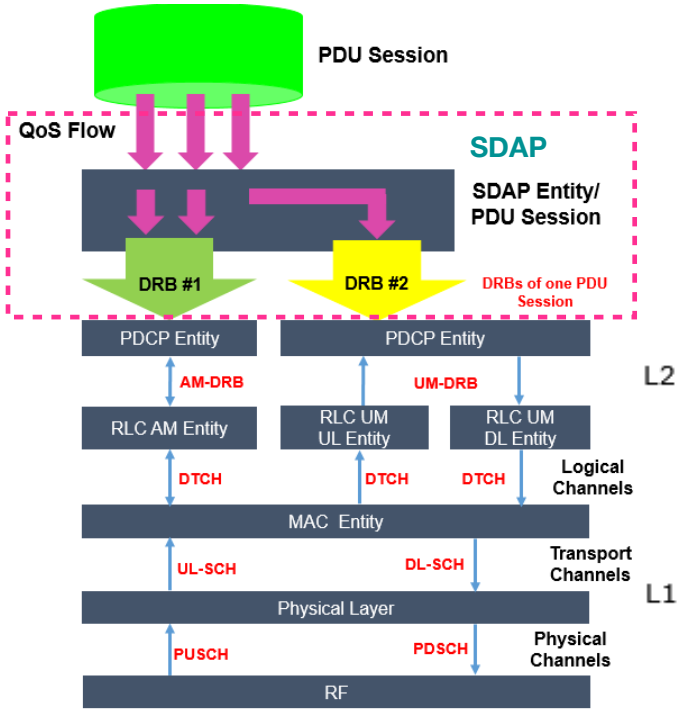
SDAP：Service Data Adaptation Protocol

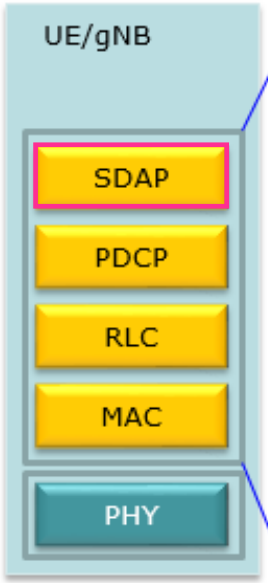


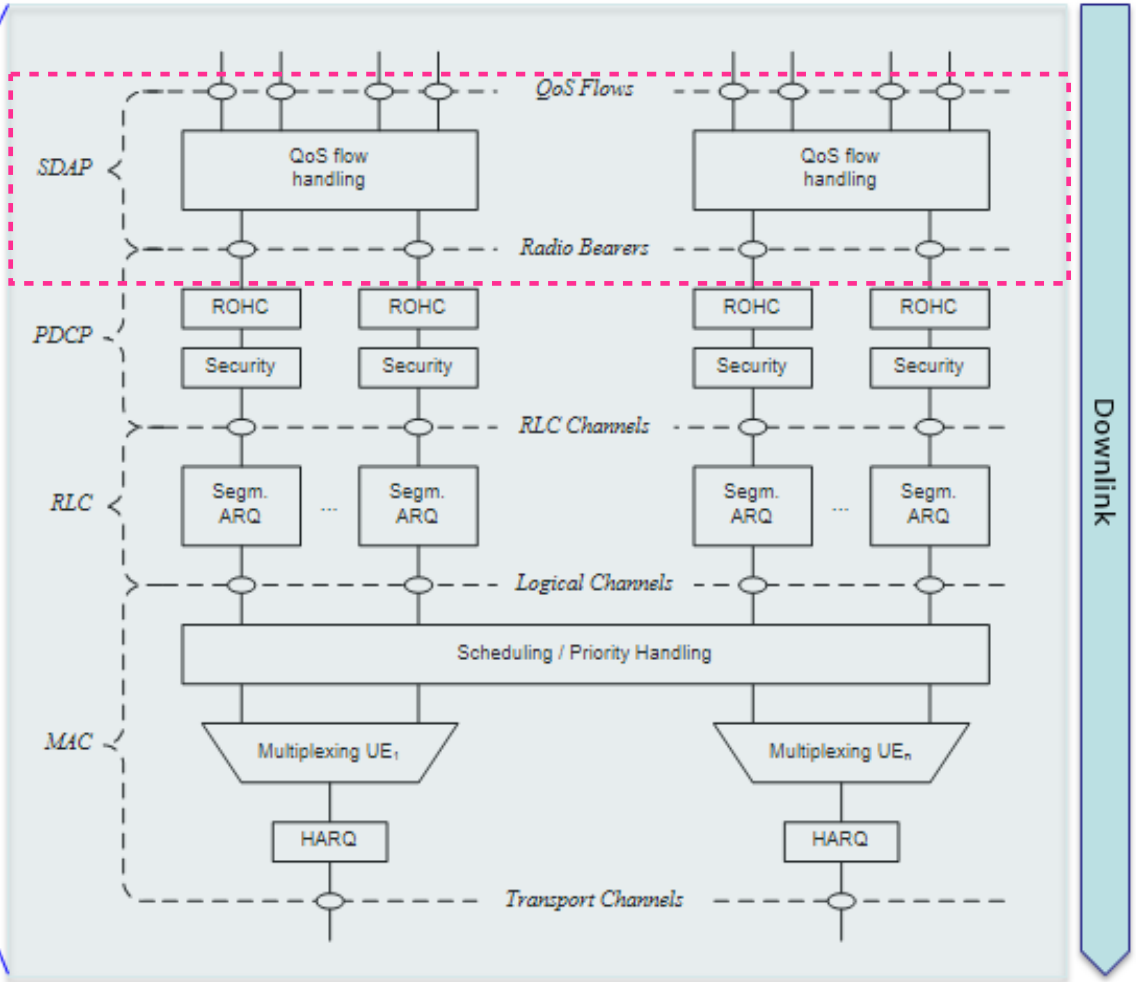


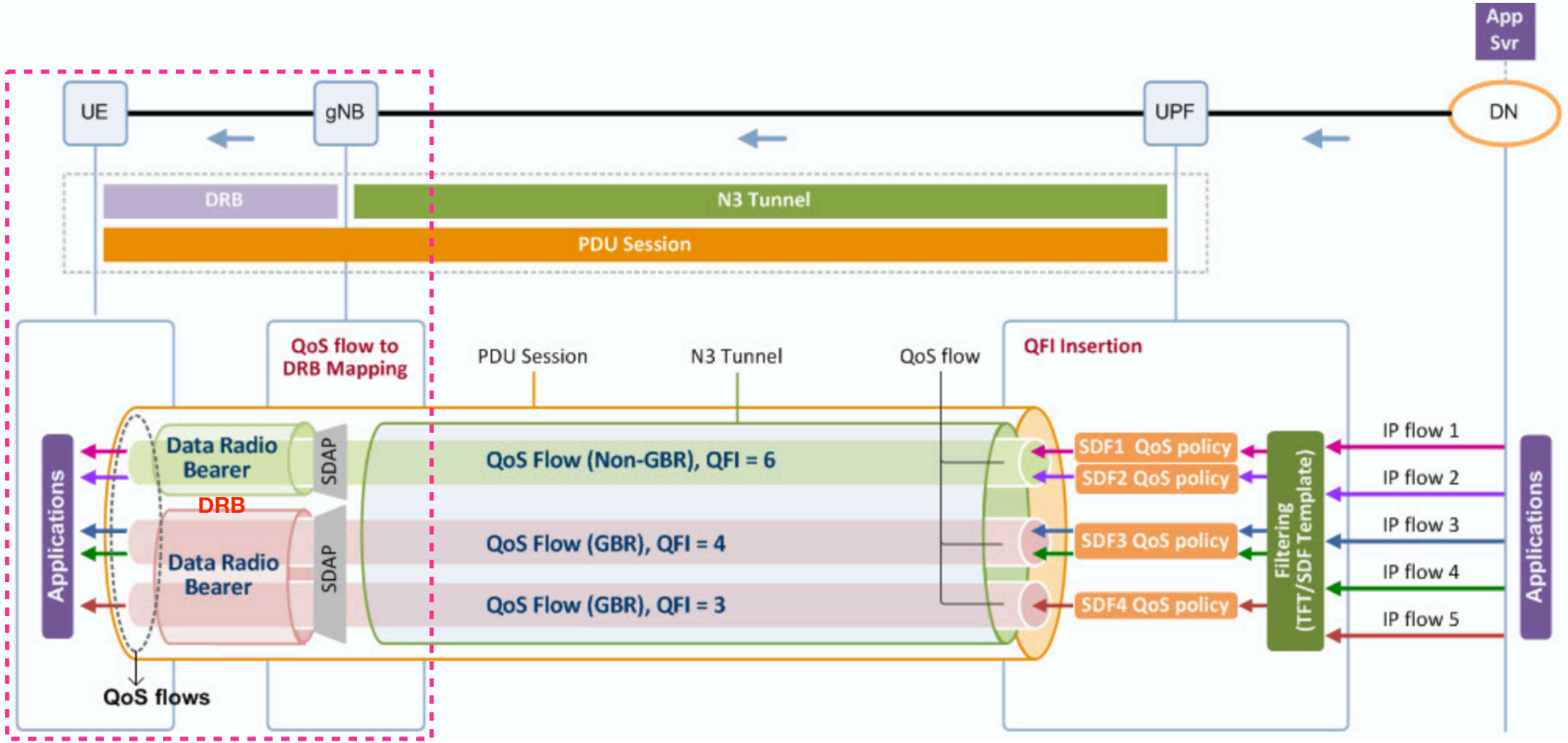
ROHC (Robust Header Compression)：a kind of algorithm to compress the header of various IP packets.

- **SDAP layer**: maps a packet to a DRB based on QFI (QoS Flow ID)



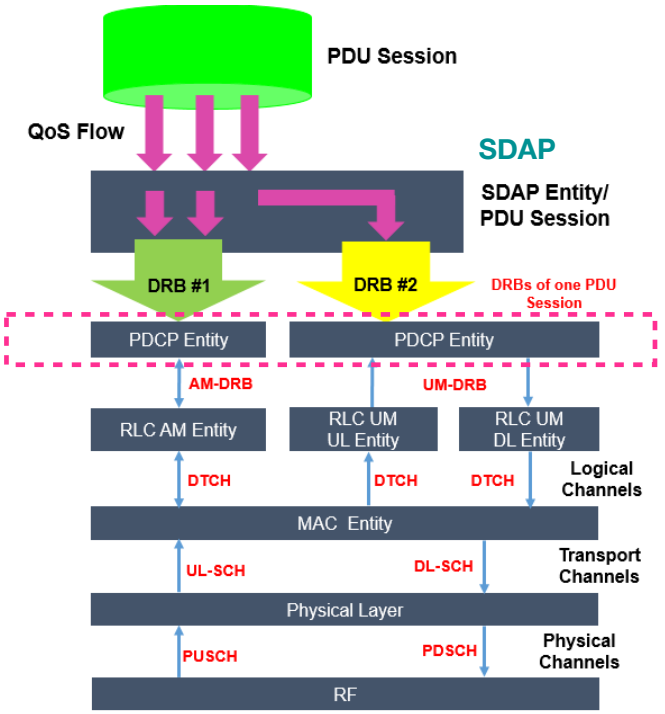


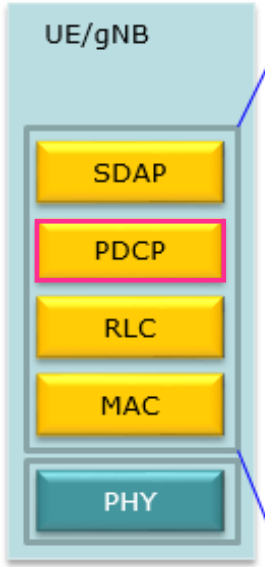


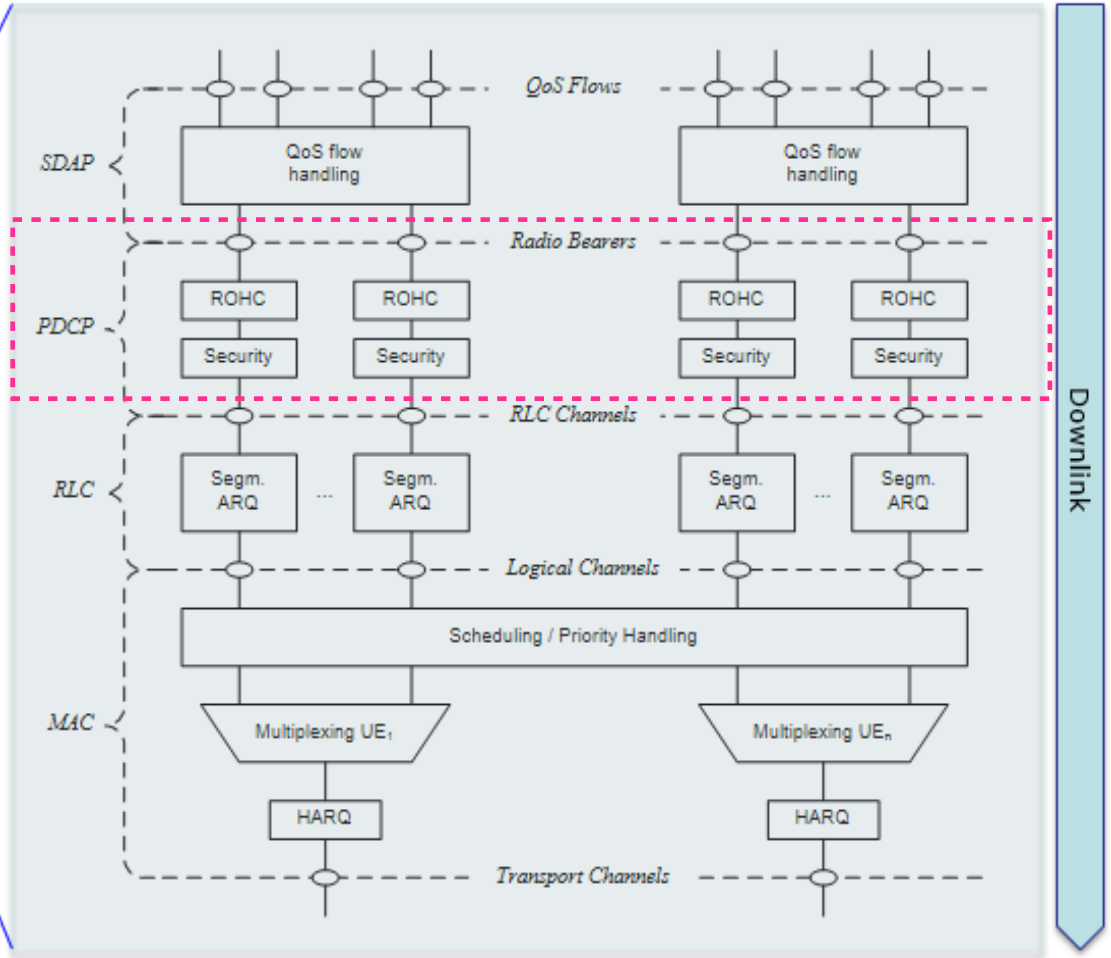


SDF：Service Data Flow

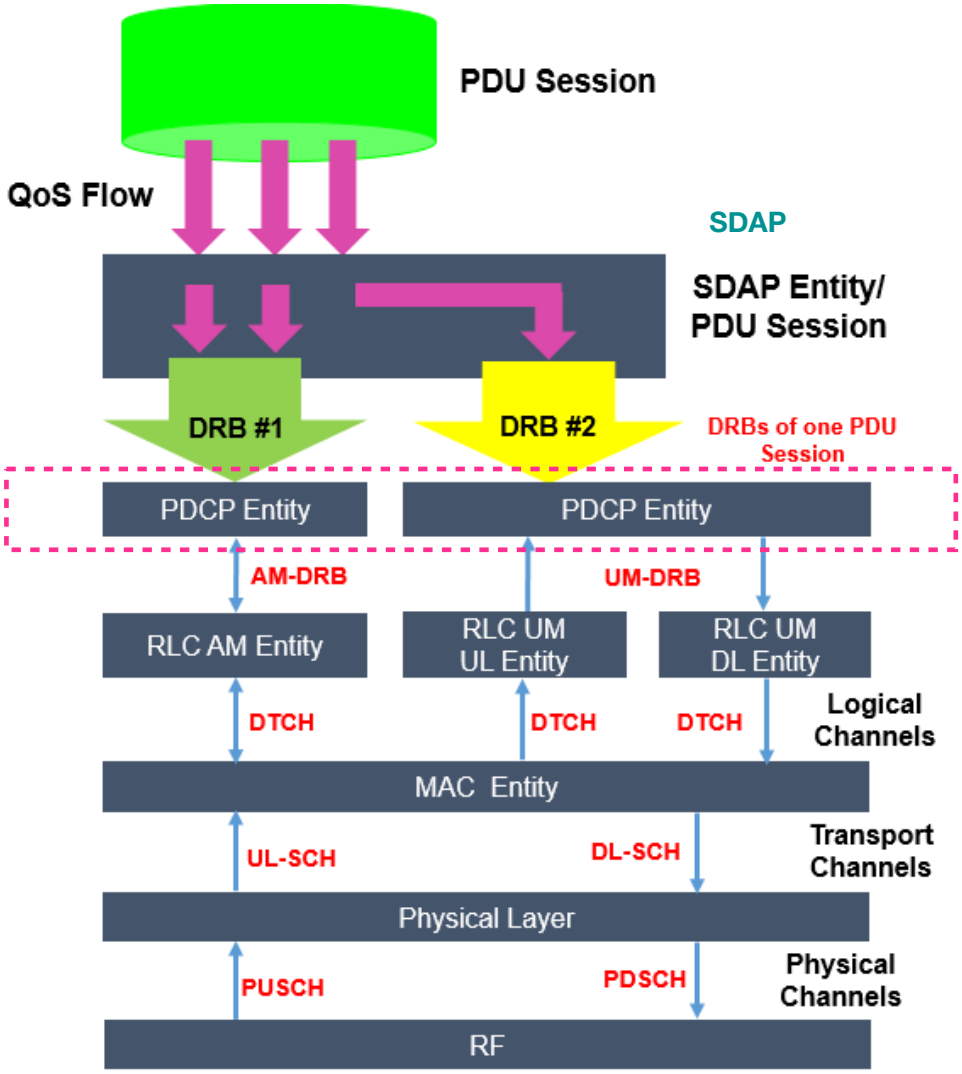
- **PDCP layer**: provides encryption, integrity protection, reordering and IP header compression functionalities

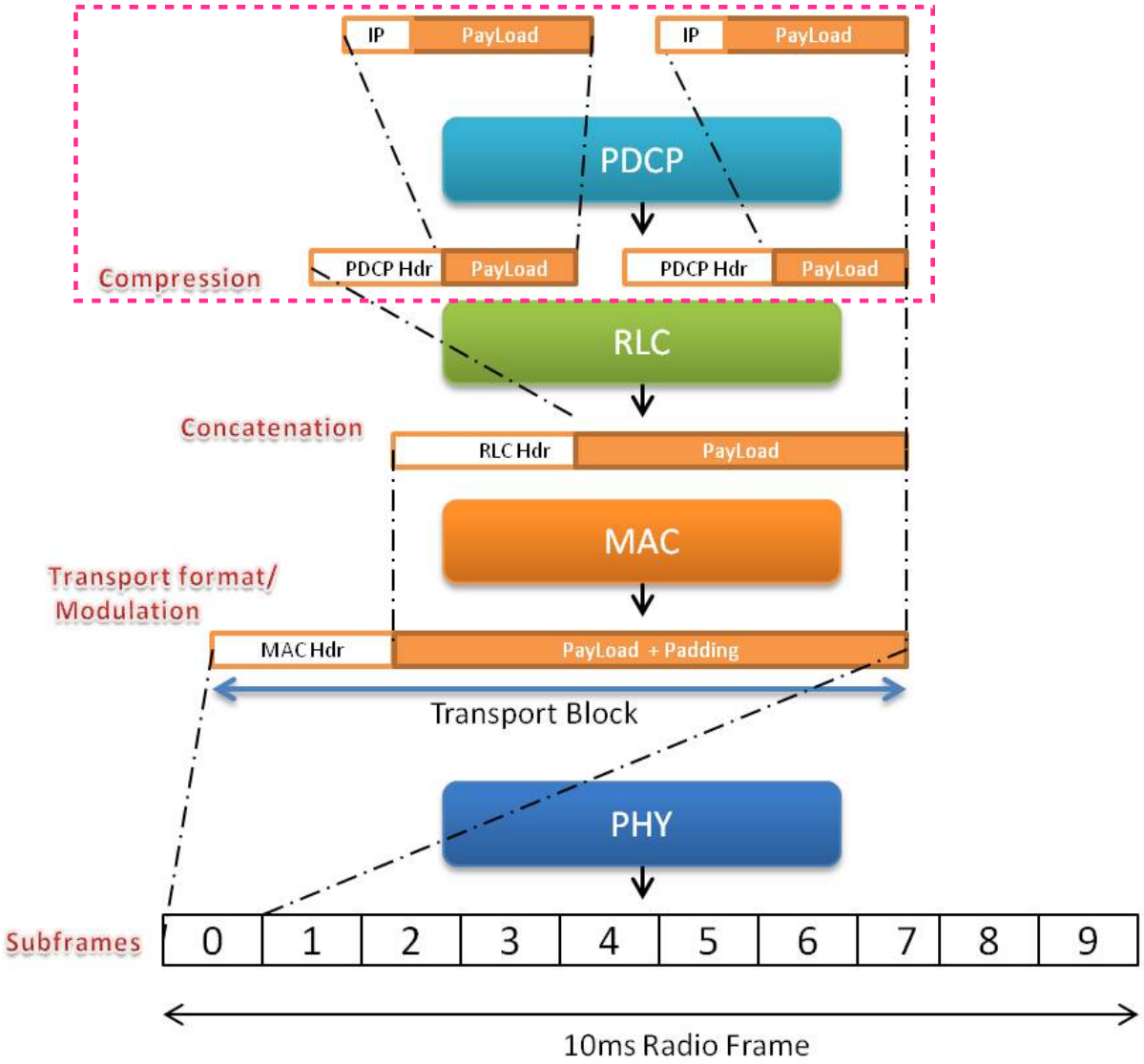




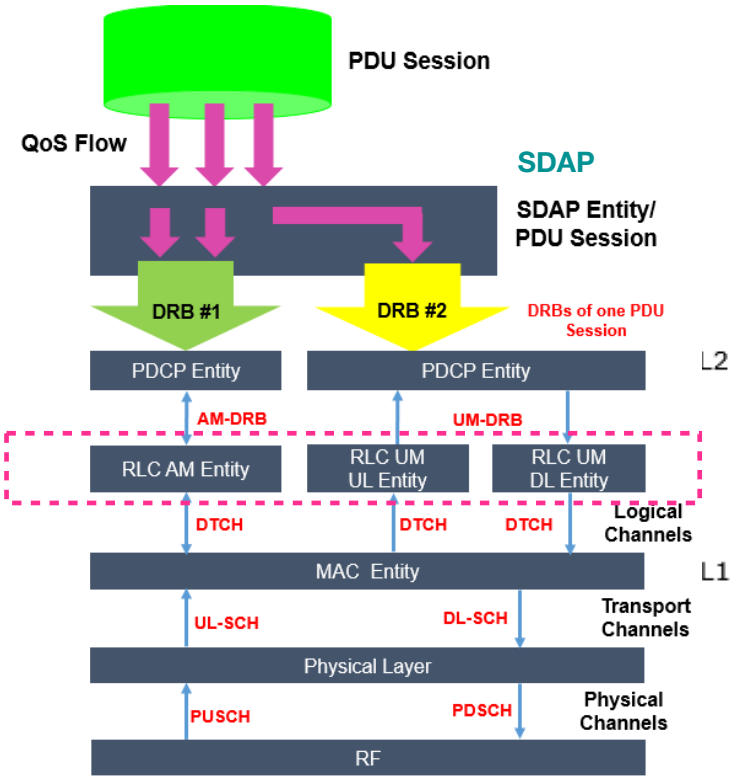


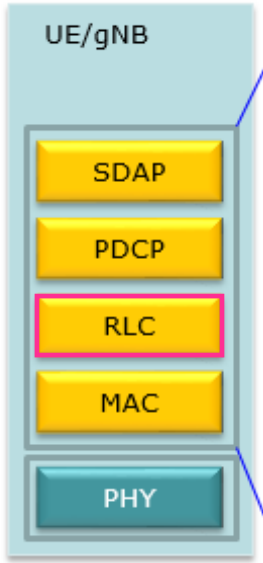
ROHC (Robust Header Compression)：a kind of algorithm to compress the header of various IP packets

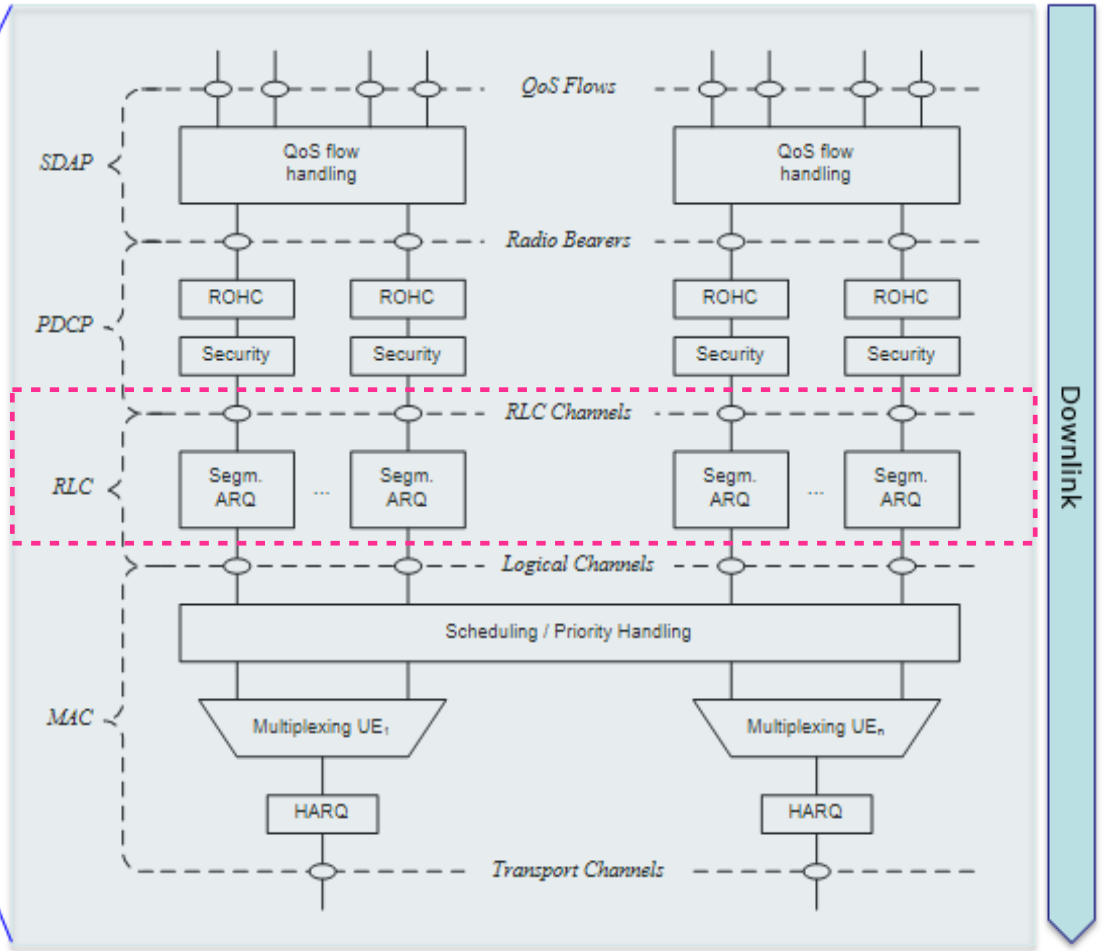

PDU Session
QoS Flow
SDAP
SDAP Entity/
PDU Session
DRB #1
DRB #2
DRBs of one PDU
Session
PDCP Entity
PDCP Entity
AM-DRB
UM-DRB
RLC AM Entity
RLC UM
UL Entity
RLC UM
DL Entity
DTCH
DTCH
DTCH
Logical
Channels
MAC Entity
UL-SCH
DL-SCH
Transport
Channels
Physical Layer
PUSCH
PDSCH
Physical
Channels
RF

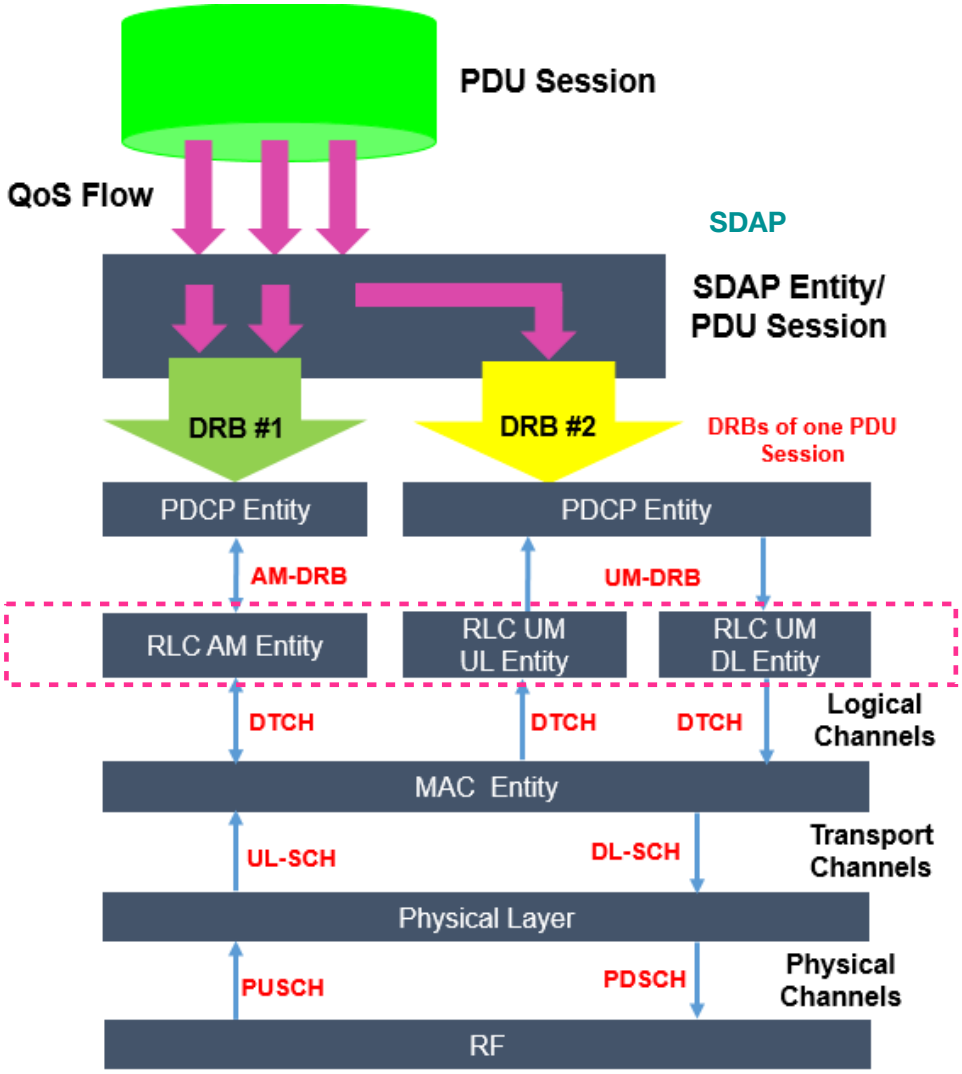

IP
PayLoad
IP
PayLoad
PDCP
Compression
PDCP Hdr
PayLoad
PDCP Hdr
PayLoad
RLC
Concatenation
RLC Hdr
PayLoad
MAC
Transport format/
Modulation
MAC Hdr
PayLoad + Padding
Transport Block
PHY
Subframes
0
1
2
3
4
5
6
7
8
9
10ms Radio Frame

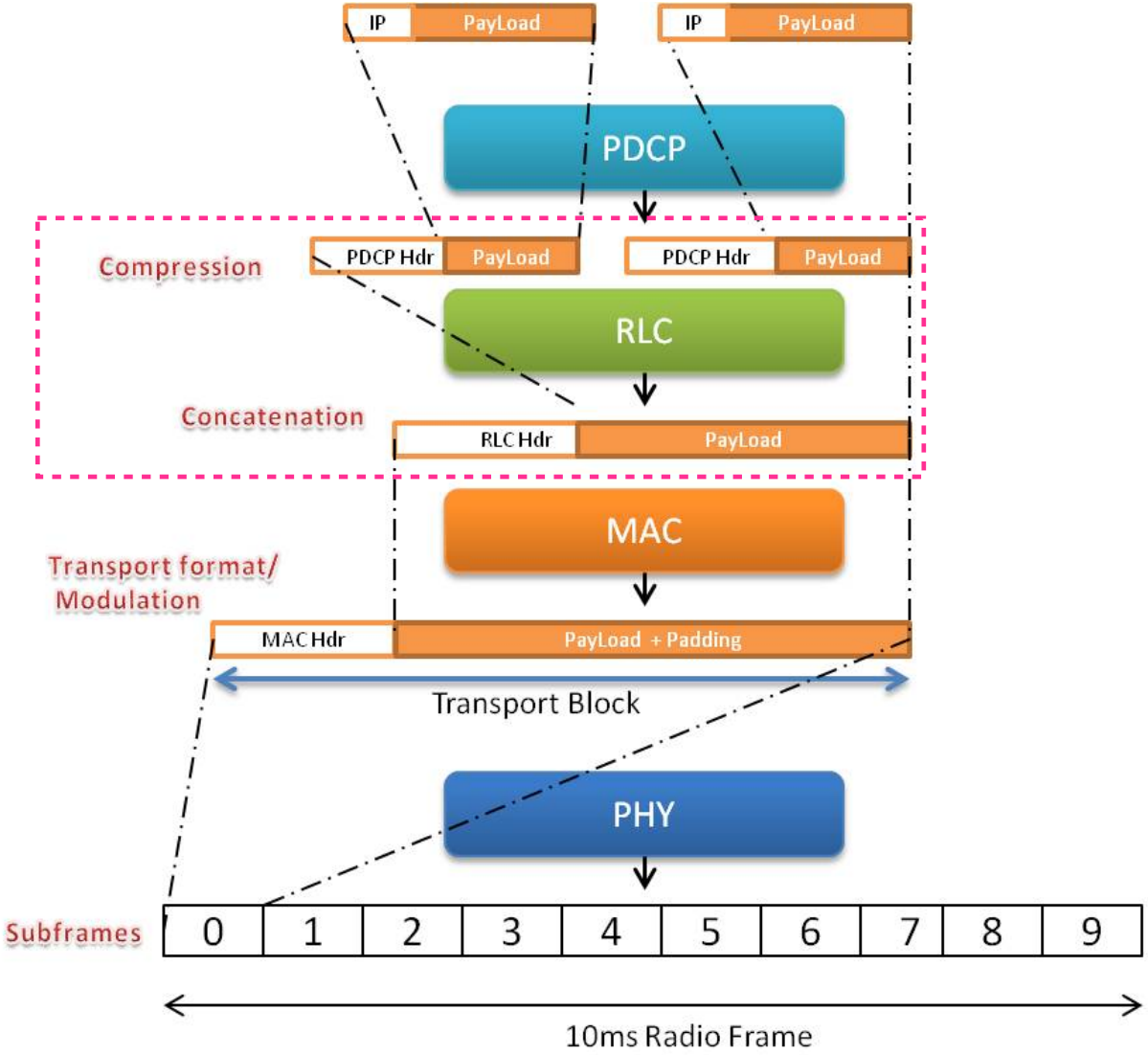
- **RLC layer**: provides segmentation and reliability with Automatic Repeat Request (ARQ) functionality








PDU Session
QoS Flow
SDAP
SDAP Entity/
PDU Session
DRB #1
DRB #2
DRBs of one PDU
Session
PDCP Entity
PDCP Entity
AM-DRB
UM-DRB
RLC AM Entity
RLC UM
UL Entity
RLC UM
DL Entity
DTCH
DTCH
DTCH
Logical
Channels
MAC Entity
UL-SCH
DL-SCH
Transport
Channels
Physical Layer
PUSCH
PDSCH
Physical
Channels
RF


IP
PayLoad
IP
PayLoad
PDCP
Compression
PDCP Hdr
PayLoad
PDCP Hdr
PayLoad
RLC
Concatenation
RLC Hdr
PayLoad
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Modulation
MAC Hdr
PayLoad + Padding
Transport Block
PHY
Subframes
0
1
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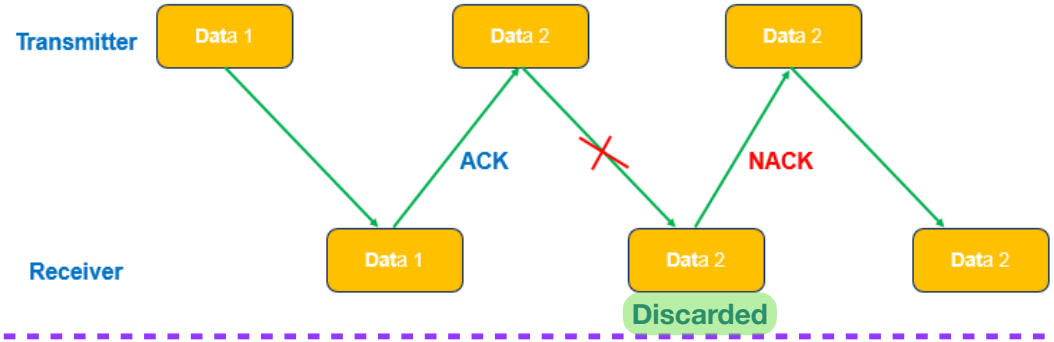
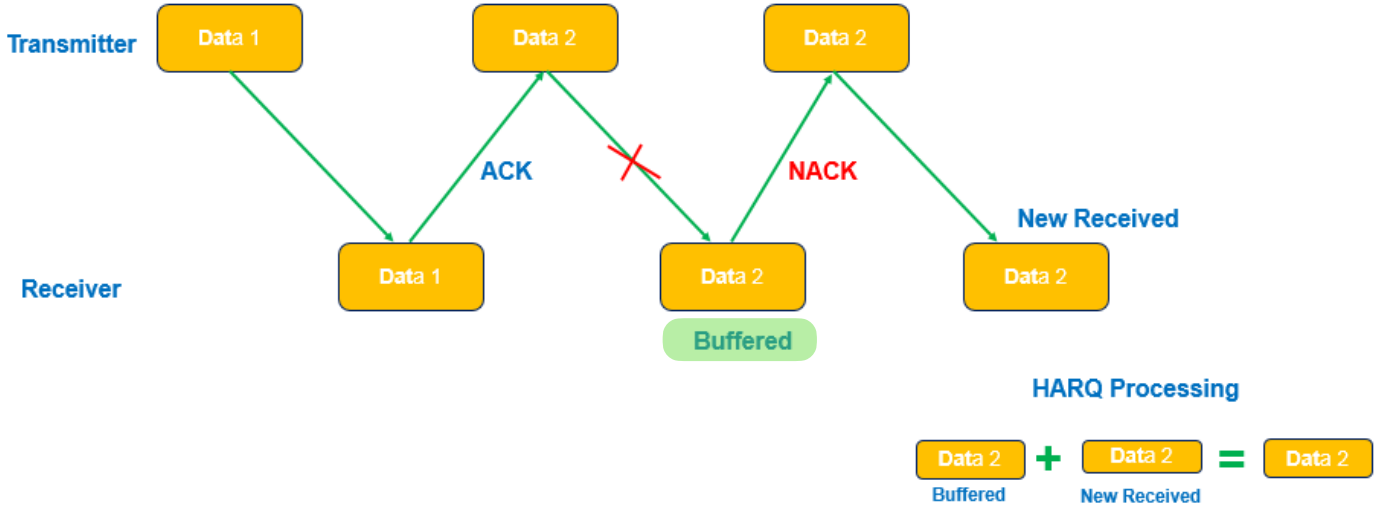
3
4
5
6
7
8
9
10ms Radio Frame

- **HARQ** (Hybrid Automatic Repeat Request)
  = ARQ + FEC (Forward Error Correction)/Soft Combining
  - **ARQ** (Automatic Repeat Request)
    - If sender doesn't receive Acknowledgement (ACK) before timeout, the receiver discards the bad packet and sender shall re-transmit the packet
  - **Soft Combining**
    - An error correction technique in which the bad packets are not discarded but stored in a buffer
    - Basic idea: two or more packets received with insufficient information can be combined together in such a way that total signal can be decoded

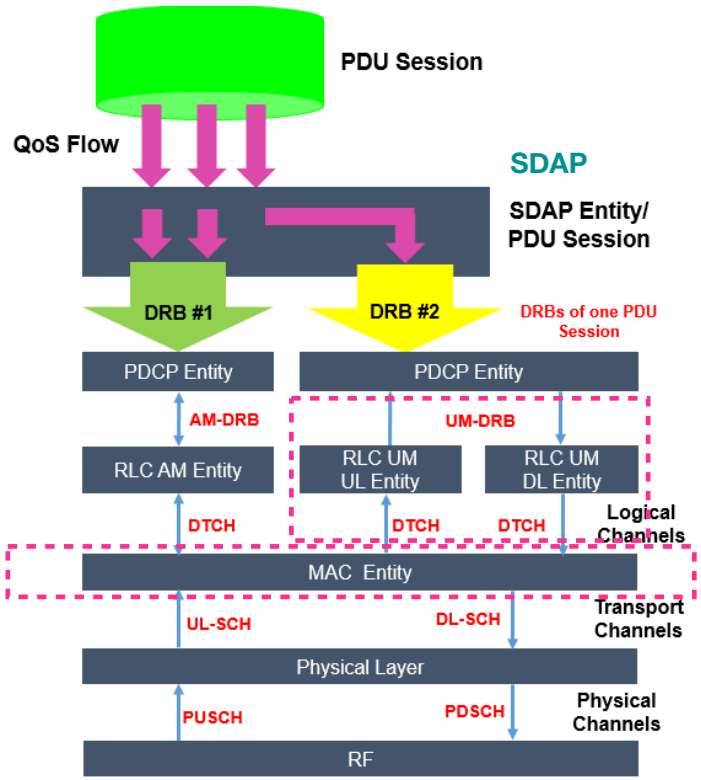
Automatic Repeat Request (ARQ)

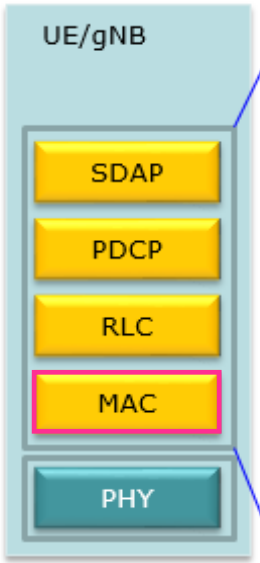


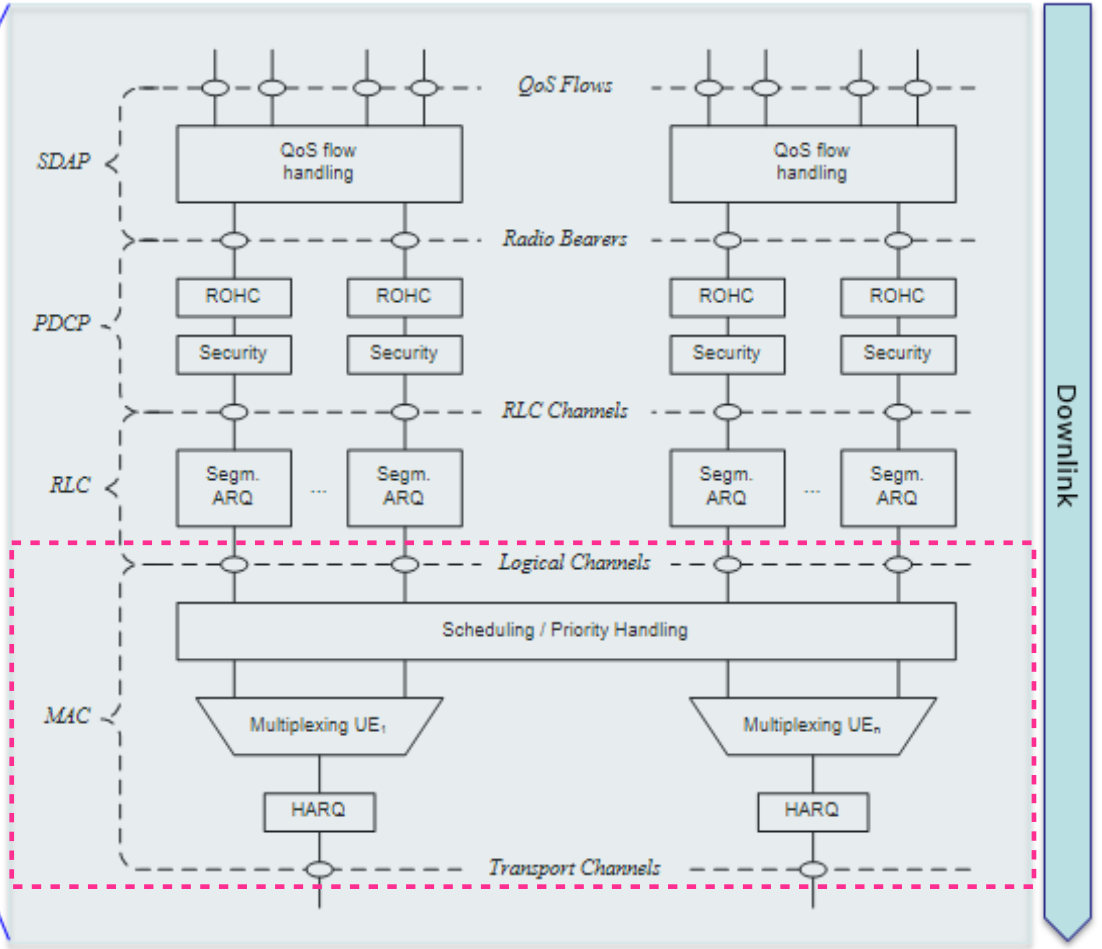
Hybrid Automatic Repeat Request (HARQ)

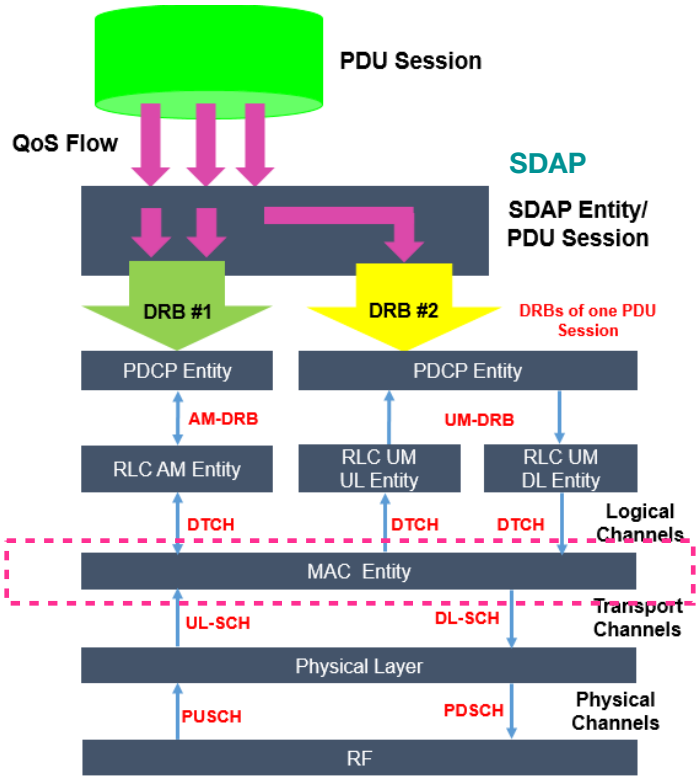


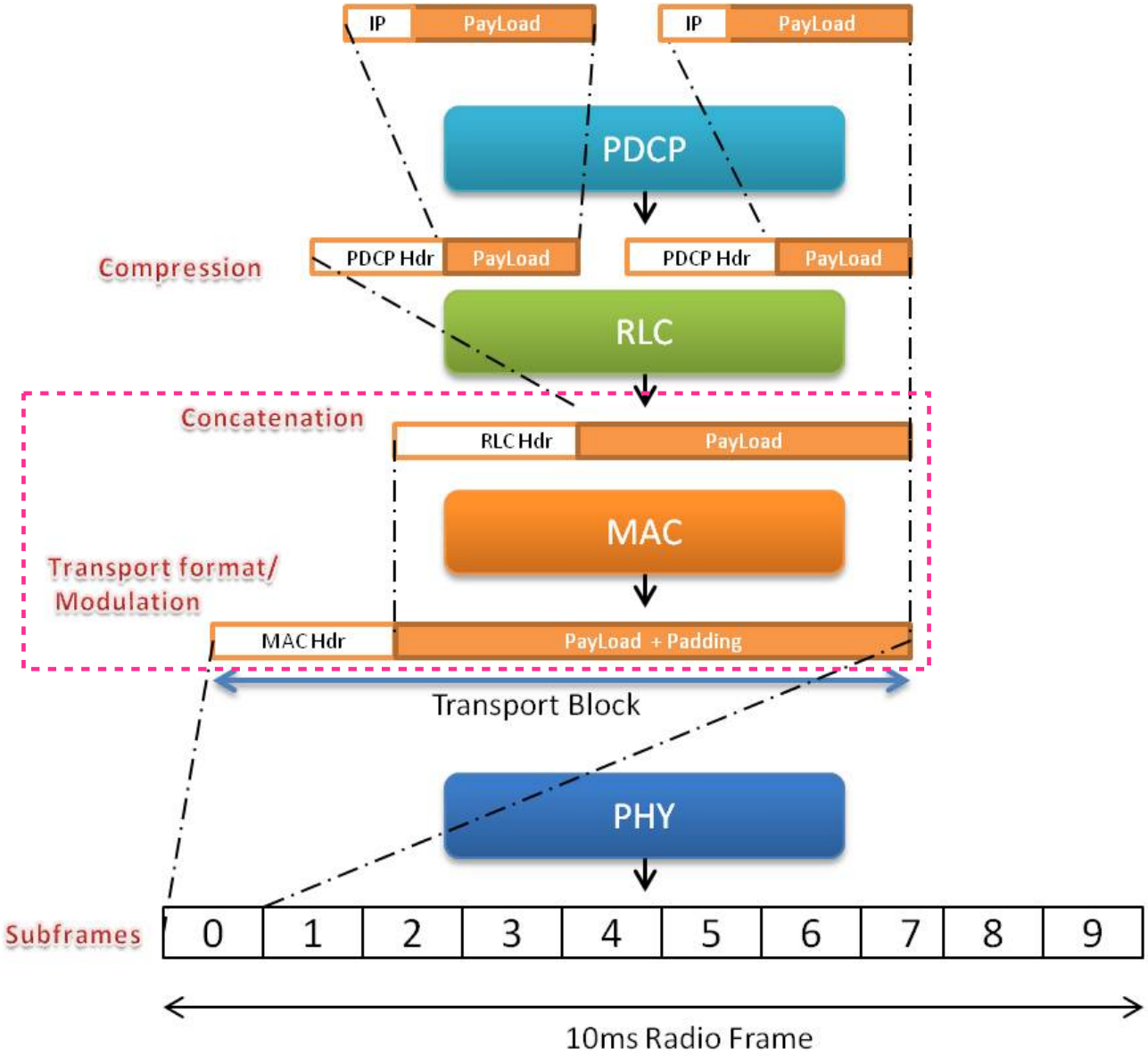
- **MAC layer**: multiplex data from different logical channels into a transport block and scheduling



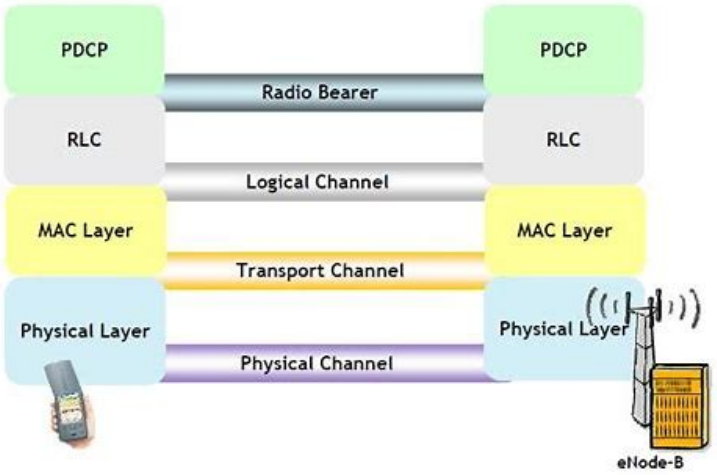


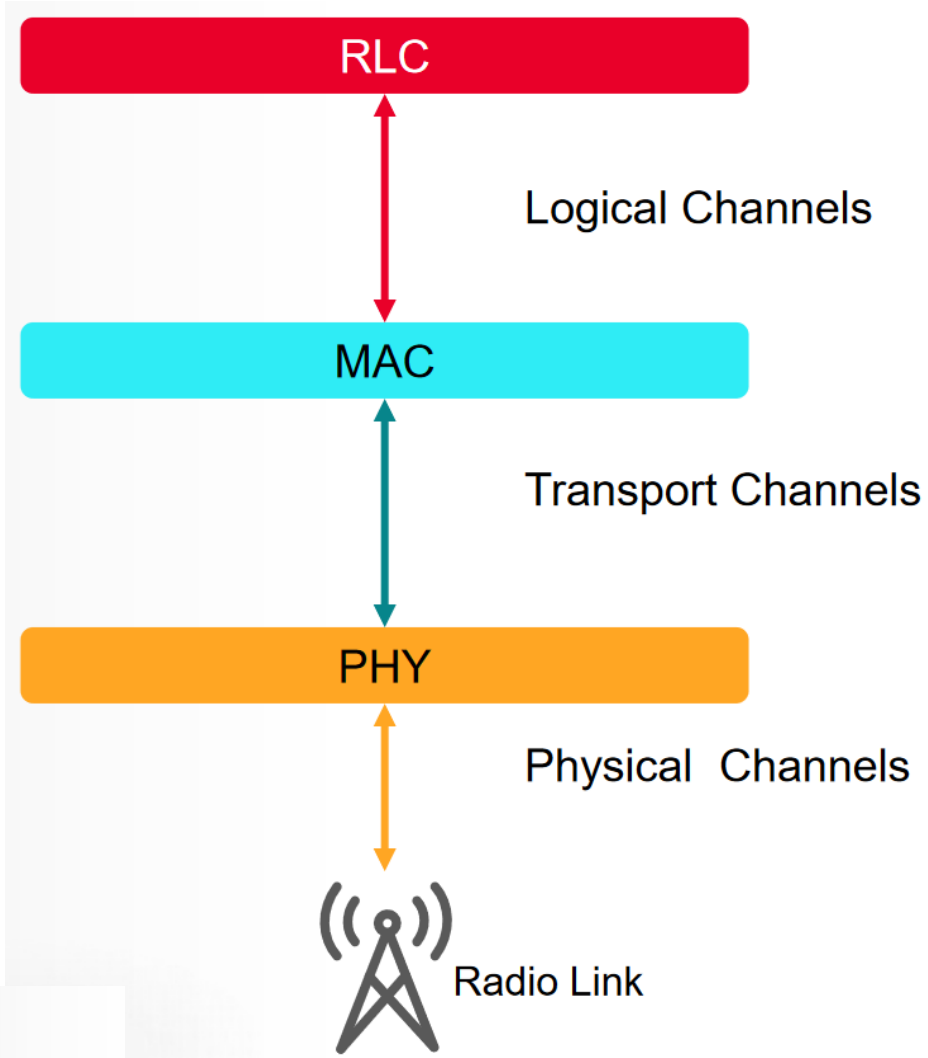



PDU Session
QoS Flow
SDAP
SDAP Entity/
PDU Session
DRB #1
DRB #2
DRBs of one PDU Session
PDCP Entity
PDCP Entity
AM-DRB
UM-DRB
RLC AM Entity
RLC UM UL Entity
RLC UM DL Entity
DTCH
DTCH
DTCH
Logical Channels
MAC Entity
UL-SCH
DL-SCH
Transport Channels
Physical Layer
PUSCH
PDSCH
Physical Channels
RF


IP
PayLoad
IP
PayLoad
PDCP
Compression
PDCP Hdr
PayLoad
PDCP Hdr
PayLoad
RLC
Concatenation
RLC Hdr
PayLoad
MAC
Transport format/
Modulation
MAC Hdr
PayLoad + Padding
Transport Block
PHY
Subframes
0
1
2
3
4
5
6
7
8
9
10ms Radio Frame

- 5G Data Channels
  - **Logical channel** (What?) can be one of two groups
    - Control channels: used for transfer of data from control plane
    - Traffic channels: used for transfer of user plane data
  - **Transport channel** (How?)
    - Multiplex logical data to be transported by physical layer and its channels over radio interface
  - **Physical channel**
    - Closest to actual transmission of the data over radio access network / 5G RF signal
    - Used to carry data over radio interface

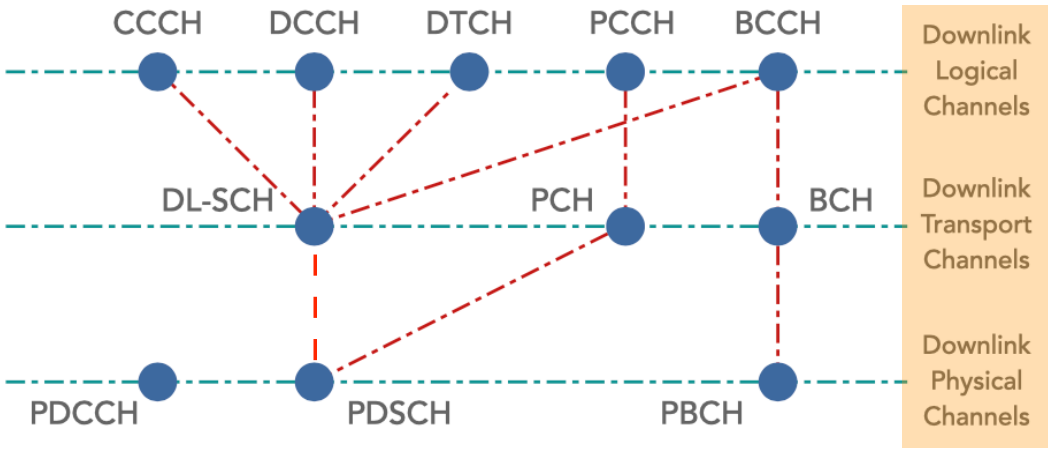




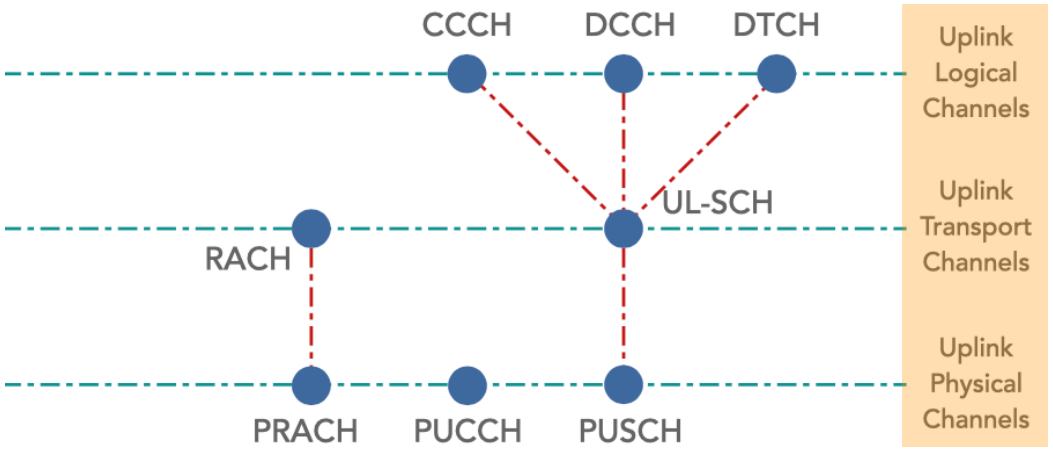
Define **the type of data to be transferred:** traffic (user data), paging messages, dedicated control information…

Define **how the information will be carried to the physical layer** and the characteristics of the data: error protection, channel coding and CRC, data packet size…

Characterized by their timing and access protocols (ex: random access channels), **data rates** (ex: traffic channels)…

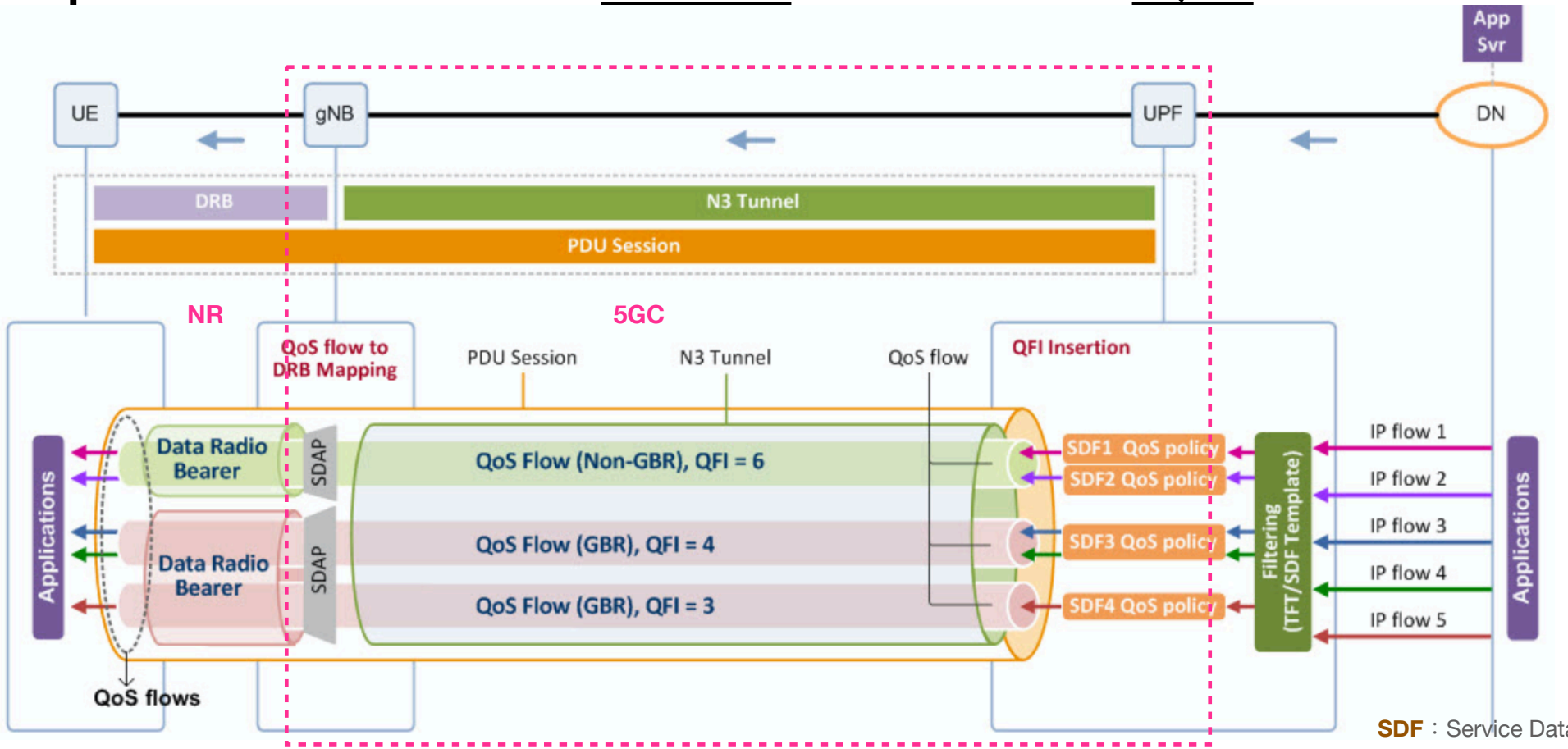


5G NR downlink logical, transport & physical channel mapping



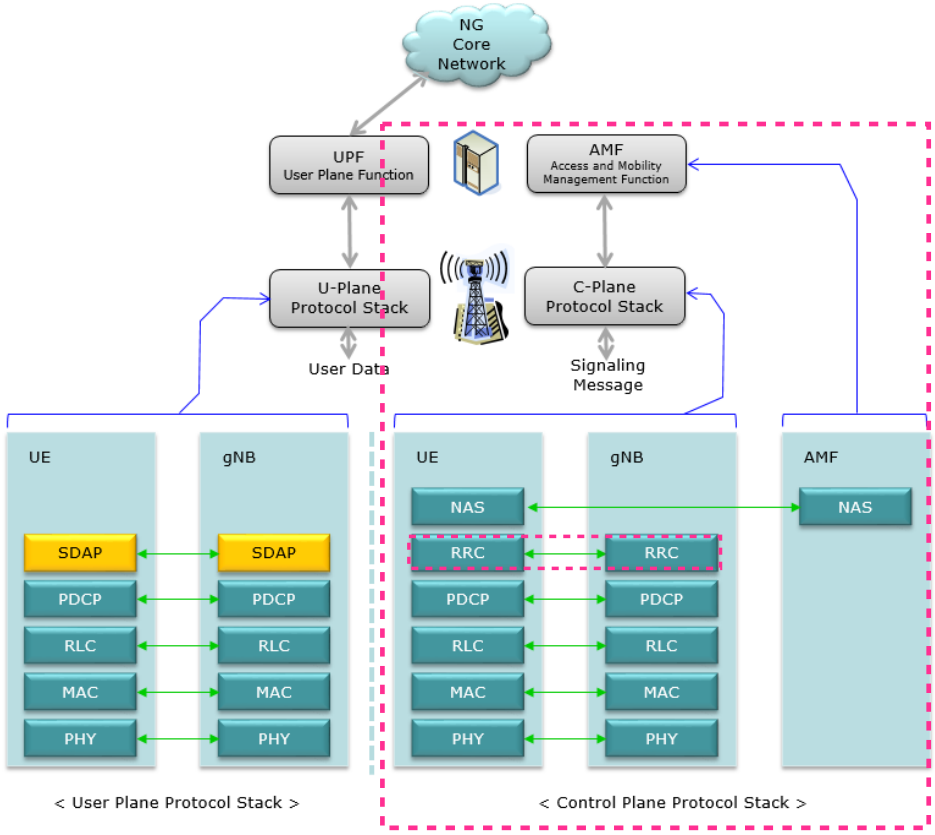
5G NR uplink logical, transport & physical channel mapping

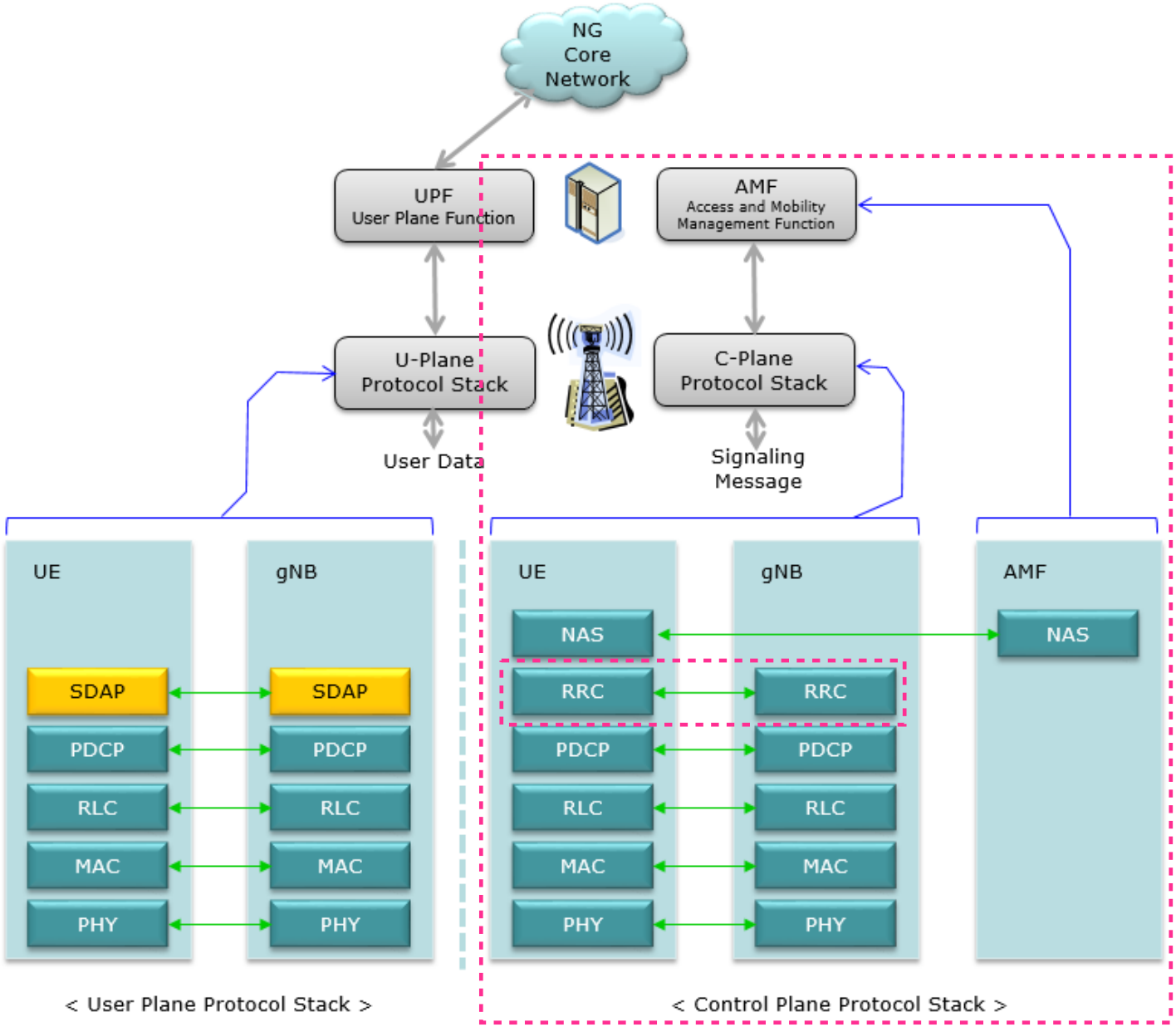
- (4) 5GC no longer uses the notion of bearers, the concept of radio bearers is kept in NR, which maps 5GC flows to DRBs based on QFI



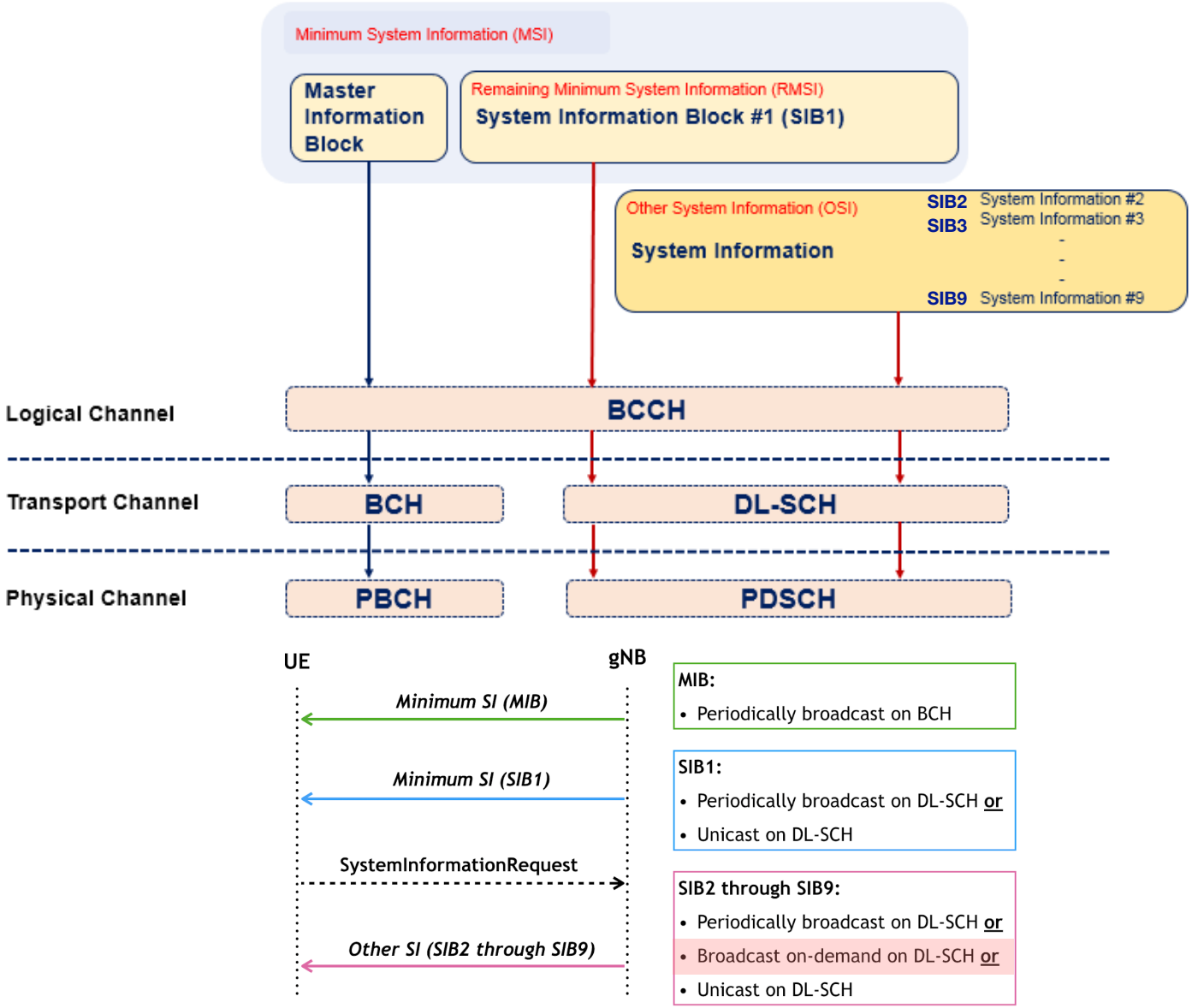
SDF：Service Data Flow

- (5) RRC (Radio Resource Control) is the control-plane protocol of NR
  - **Similar to LTE**
    - The protocol has a number of "transparent containers" used to convey, e.g. UE configuration messages to be delivered to UE by an intermediate network node
  - **Different with LTE**
    - Related to beam-based measurements and on-demand System Information Broadcast



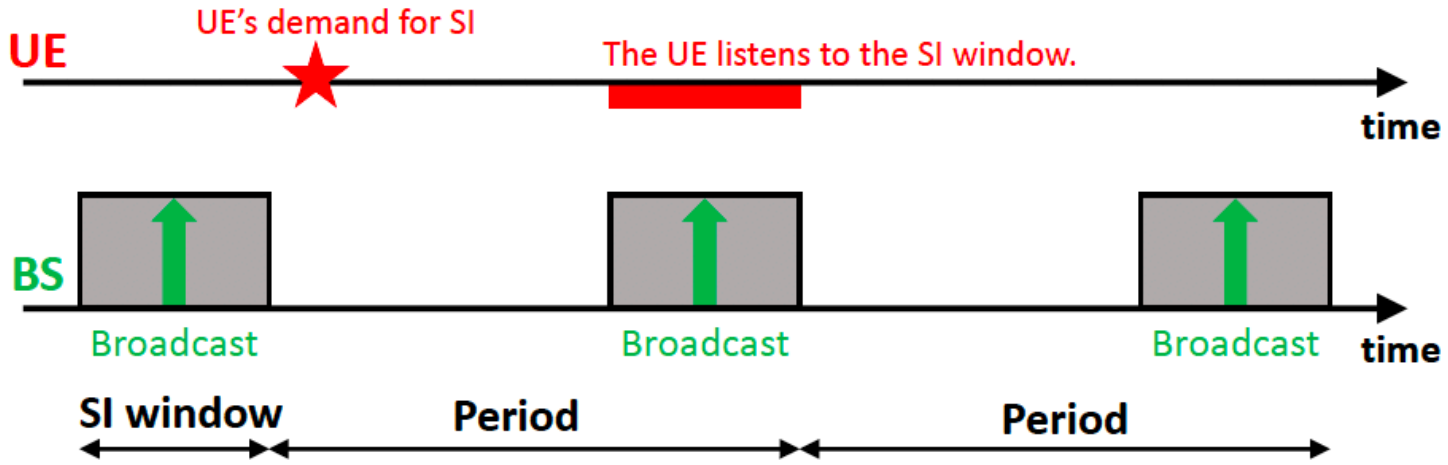

NG
Core
Network
UPF
User Plane Function
AMF
Access and Mobility
Management Function
U-Plane
Protocol Stack
C-Plane
Protocol Stack
User Data
Signaling
Message
UE
gNB
UE
gNB
AMF
NAS
NAS
SDAP
SDAP
RRC
RRC
PDCP
PDCP
PDCP
PDCP
RLC
RLC
RLC
RLC
MAC
MAC
MAC
MAC
PHY
PHY
PHY
PHY
< User Plane Protocol Stack >
< Control Plane Protocol Stack >

5G NR system



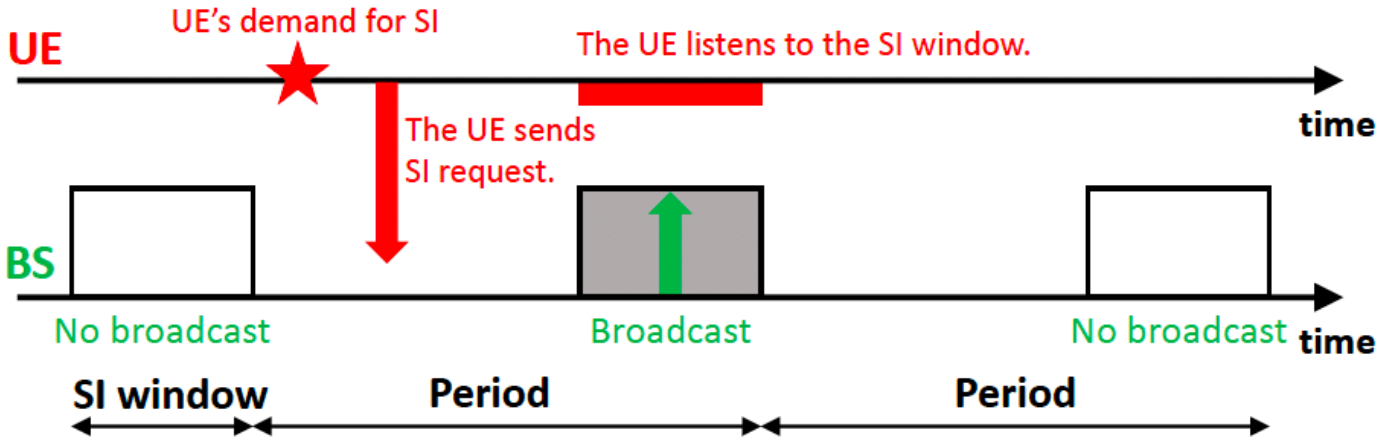
Mapping of 5G NR system information and different channels

Periodically



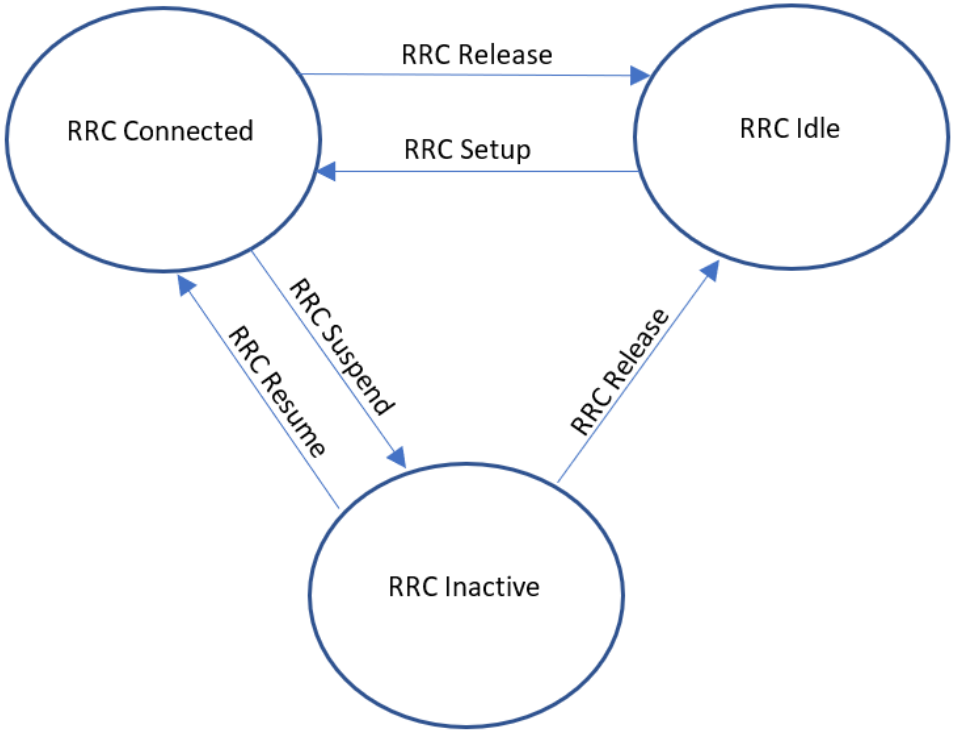
Periodically broadcasting for SI delivery in LTE

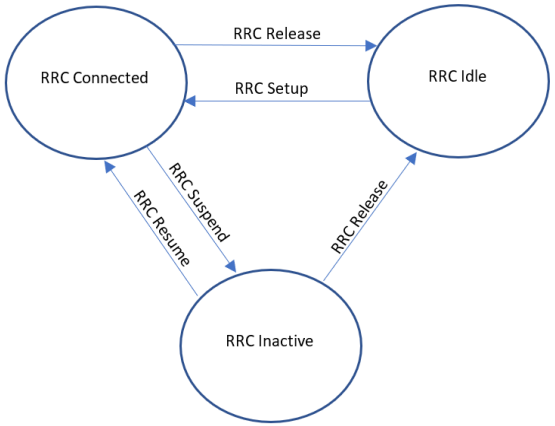
On-demand

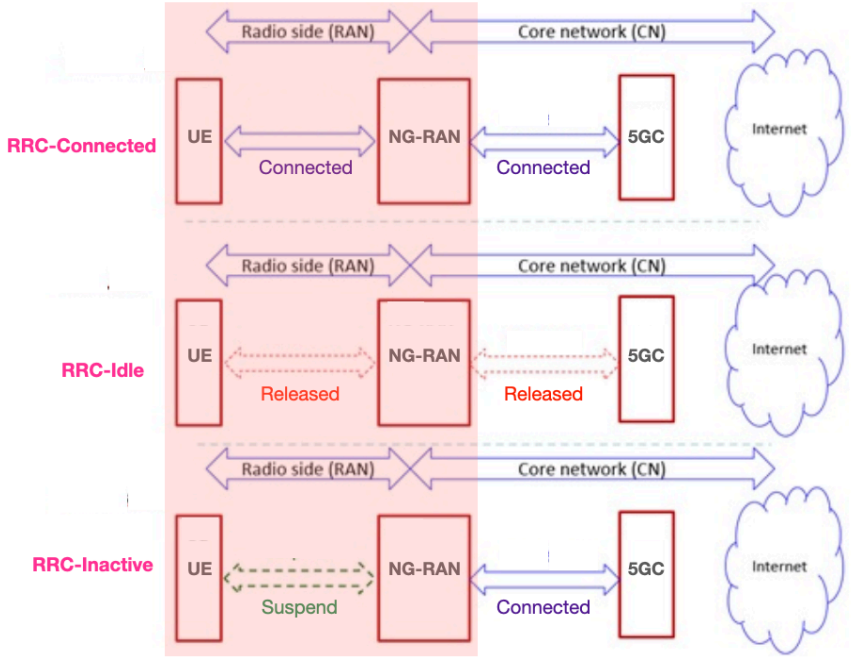


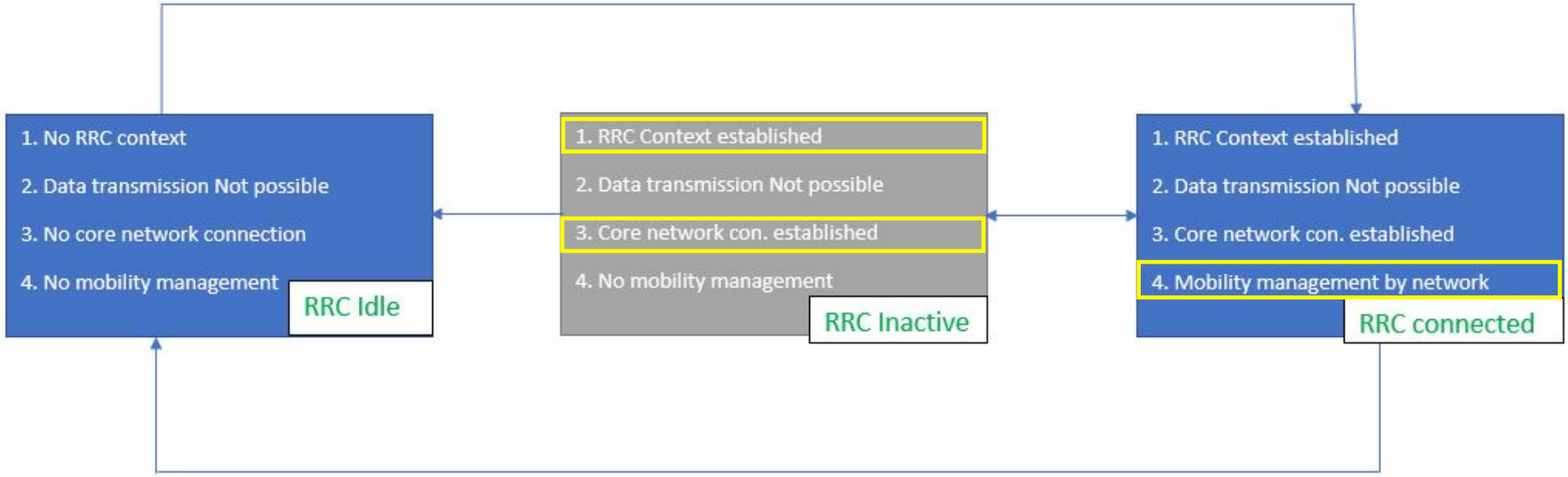
On-demand broadcasting for the delivery of other SI in 5G NR

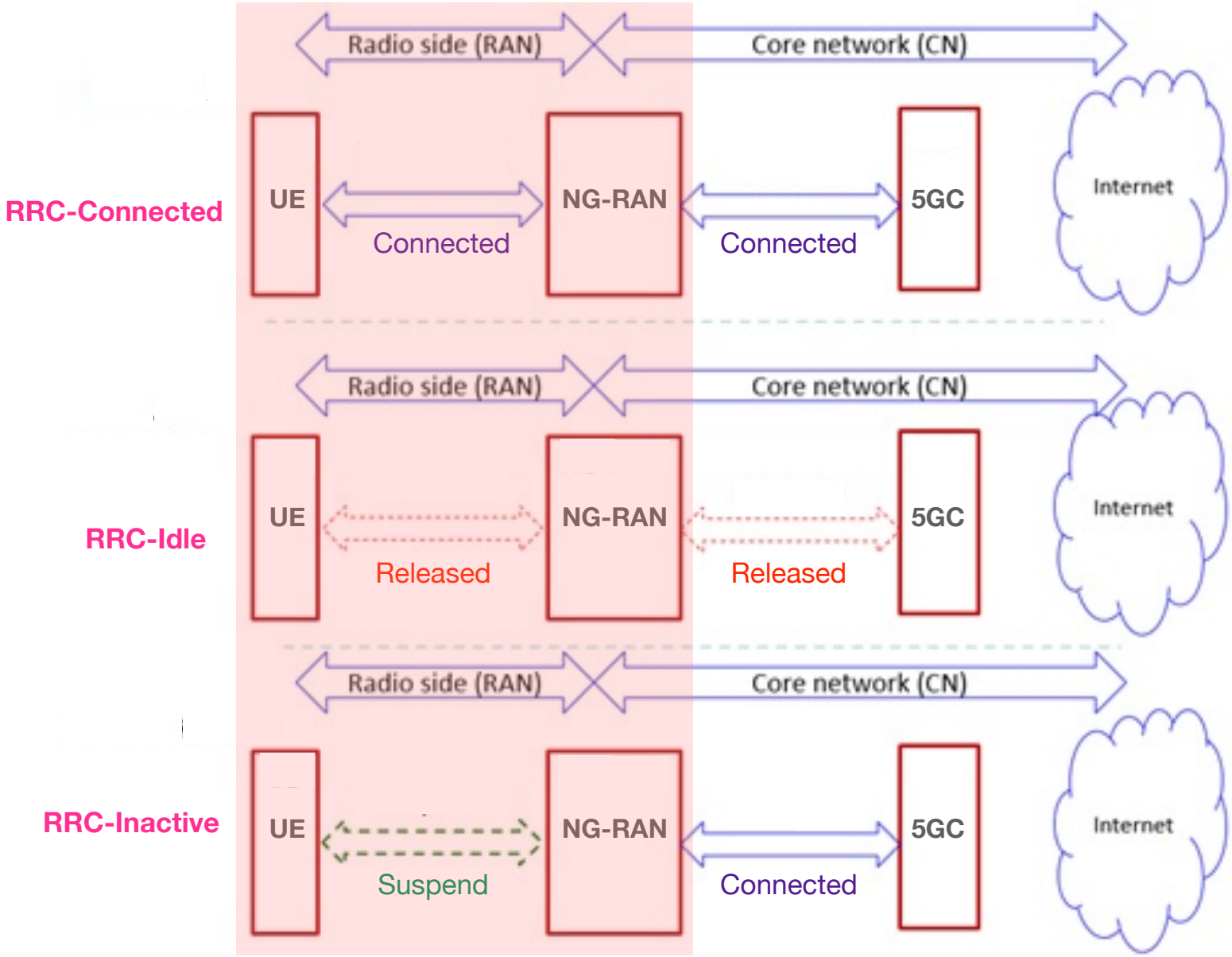
- (6) NR RRC supports three different UE states
  - IDLE
  - CONNECTED
  - INACTIVE
    - Similar to IDLE in terms of UE actions
    - Main difference: NG-RAN maintains the UE context and the connection to 5GC




RRC Connected
RRC Idle
RRC Inactive
RRC Release
RRC Setup
RRC Suspend
RRC Resume
RRC Release


RRC-Connected
Radio side (RAN)
Core network (CN)
UE
Connected
NG-RAN
Connected
5GC
Internet
RRC-Idle
Radio side (RAN)
Core network (CN)
UE
Released
NG-RAN
Released
5GC
Internet
RRC-Inactive
Radio side (RAN)
Core network (CN)
UE
Suspend
NG-RAN
Connected
5GC
Internet

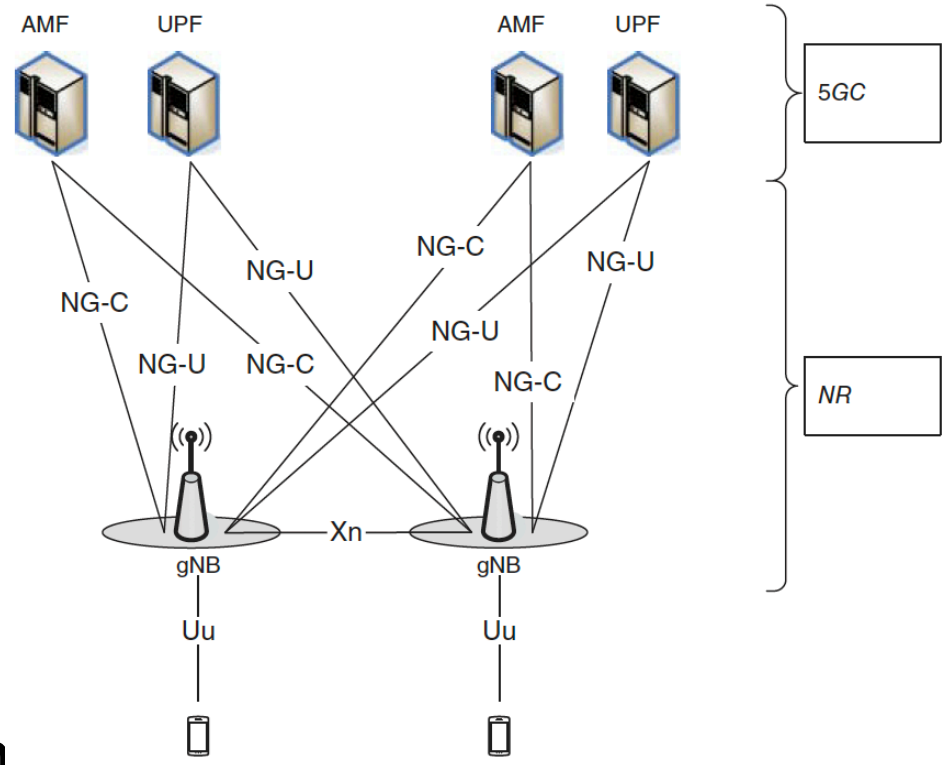

1. No RRC context
2. Data transmission Not possible
3. No core network connection
4. No mobility management
RRC Idle
1. RRC Context established
2. Data transmission Not possible
3. Core network con. established
4. No mobility management
RRC Inactive
1. RRC Context established
2. Data transmission Not possible
3. Core network con. established
4. Mobility management by network
RRC connected


RRC-Connected
Radio side (RAN)
Core network (CN)
UE
Connected
NG-RAN
Connected
5GC
Internet
RRC-Idle
Radio side (RAN)
Core network (CN)
UE
Released
NG-RAN
Released
5GC
Internet
RRC-Inactive
Radio side (RAN)
Core network (CN)
UE
Suspend
NG-RAN
Connected
5GC
Internet

1. Introduction
2. **NG-RAN Architecture**
3. NR User Plane
4. Supporting QoS with 5GC
5. NR Control Plane

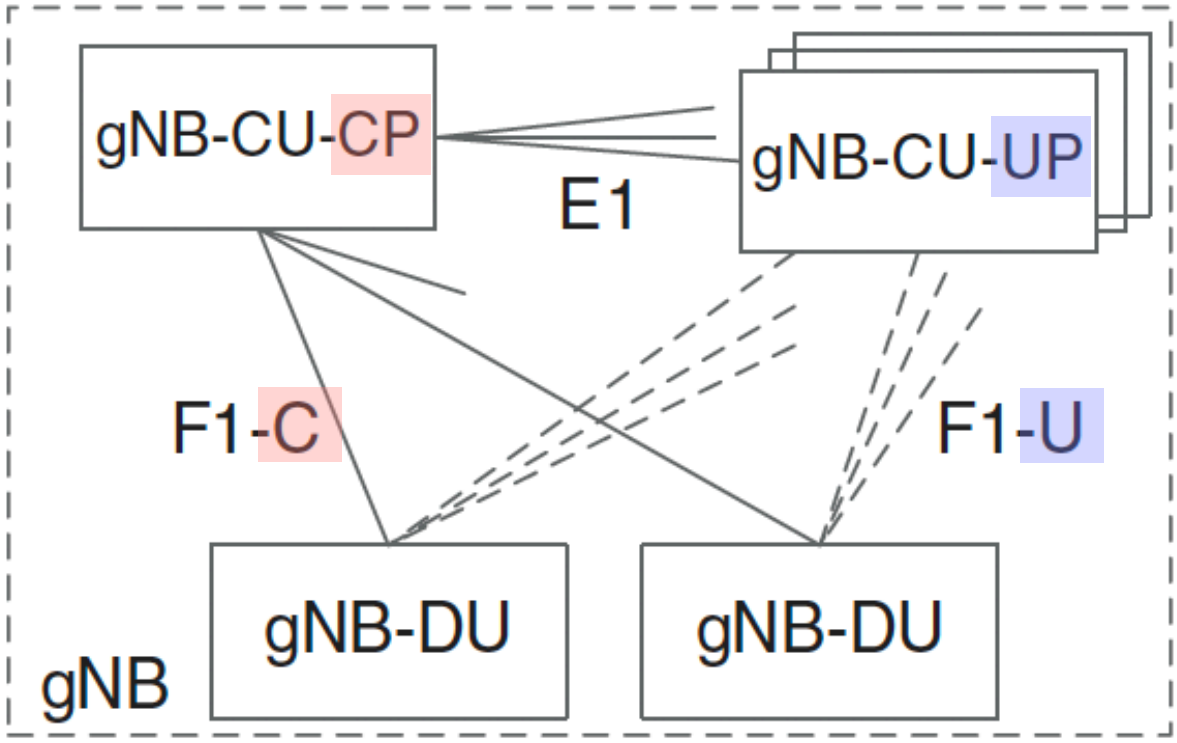
2. NG-RAN Architecture

- The RAN functions in NR reside in the logical node, gNB
- gNBs are connected by means of NG interfaces to 5GC, more specifically
  - To AMF by means of NG-C interface
  - To UPF by means of NG-U interface
- gNBs are interconnected with each other by means of Xn interface

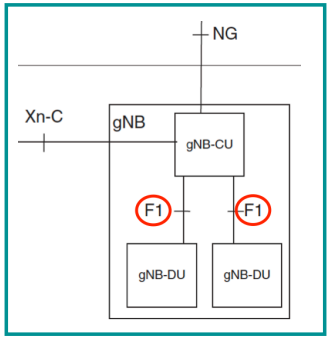


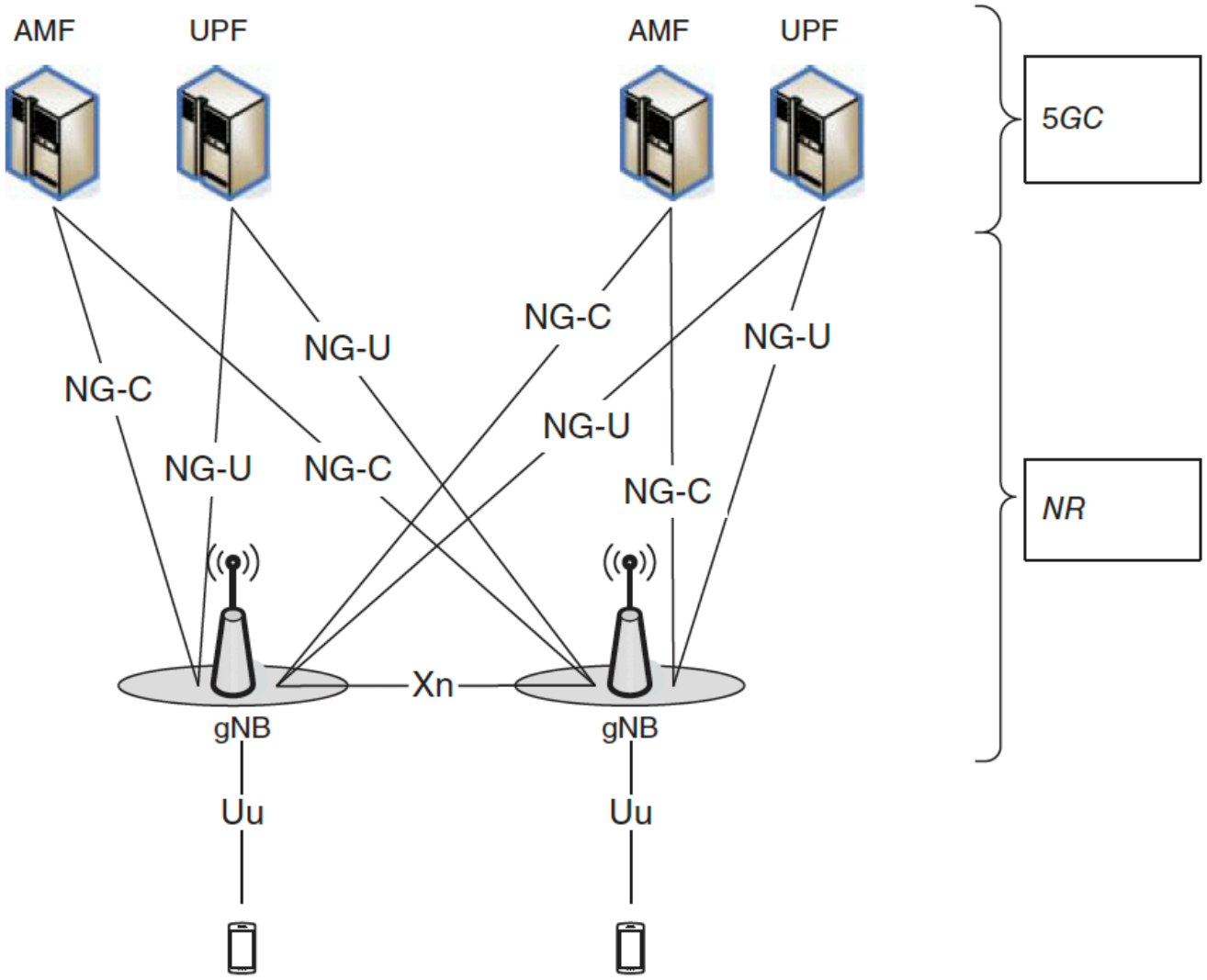
NG-RAN architecture

- A gNB can be further split into different logical nodes (gNB-CU/DU)

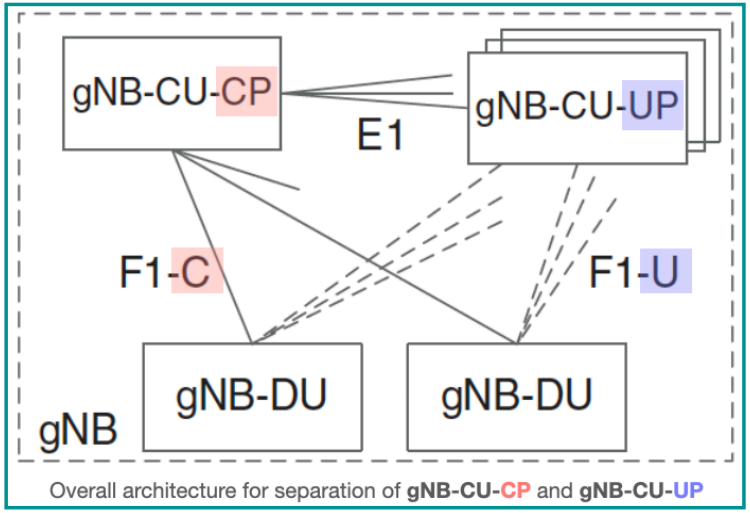


Overall architecture for separation of **gNB-CU-CP** and **gNB-CU-UP**





NG-RAN architecture



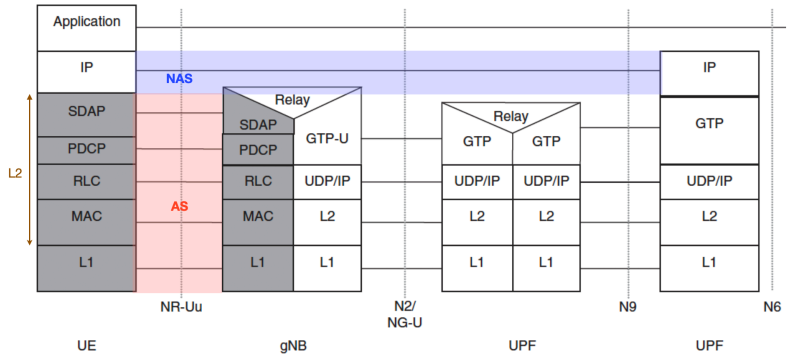
Overall architecture for separation of **gNB-CU-CP** and **gNB-CU-UP**

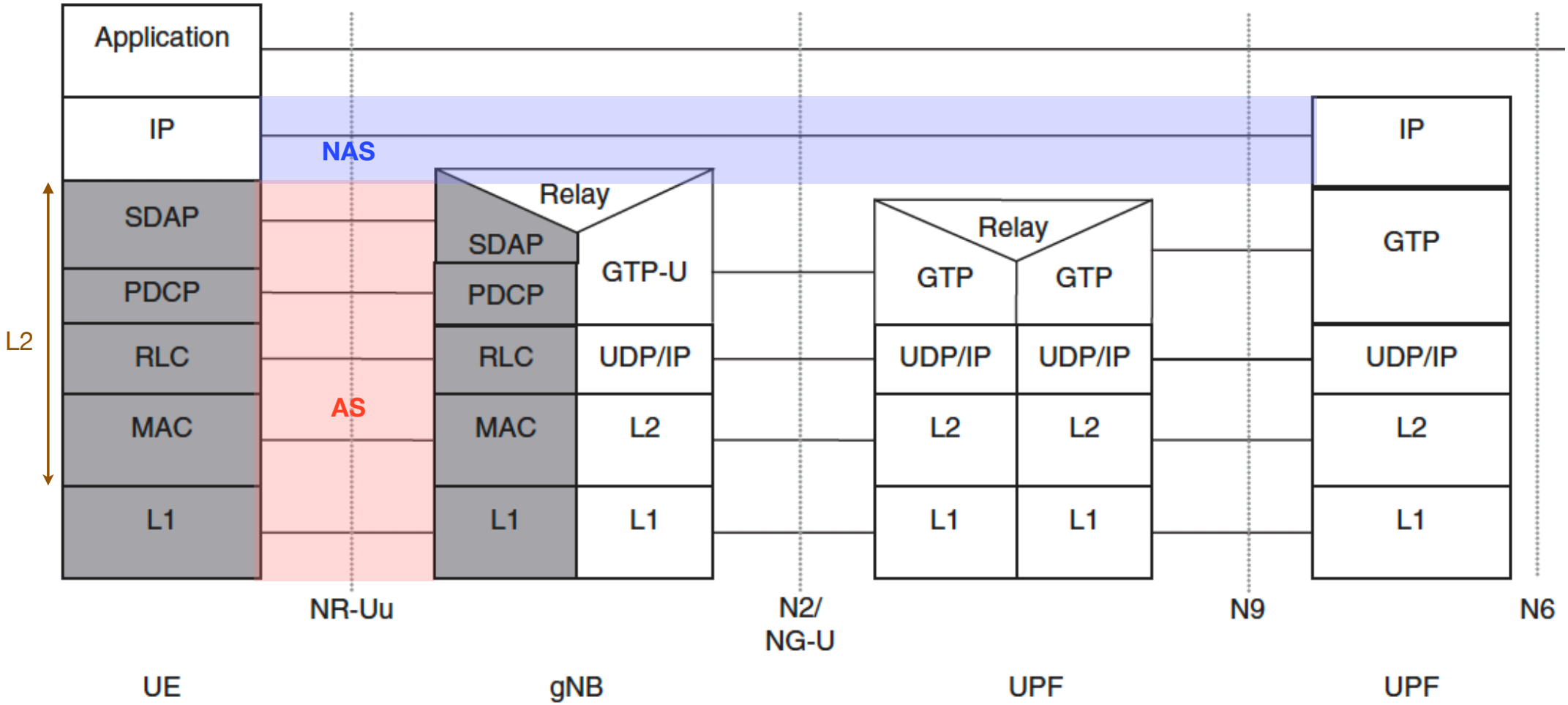
1. Introduction
2. NG-RAN Architecture
3. **NR User Plane**
4. Supporting QoS with 5GC
5. NR Control Plane

3. NR User Plane

- Primary role of user plane
  - Transfer data across radio interface efficiently and with required QoS
- The protocols across different interfaces for transfer of a user IP packet between UPF and UE
  - **AS**：the radio protocols are shown in gray
  - **NAS**：the higher layer protocols, indicate QoS handling required for a packet

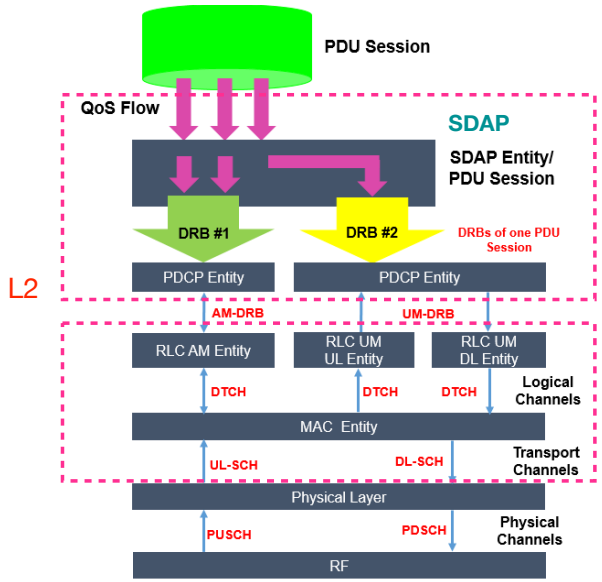
AS：Access Stratum
NAS：Non-Access Stratum

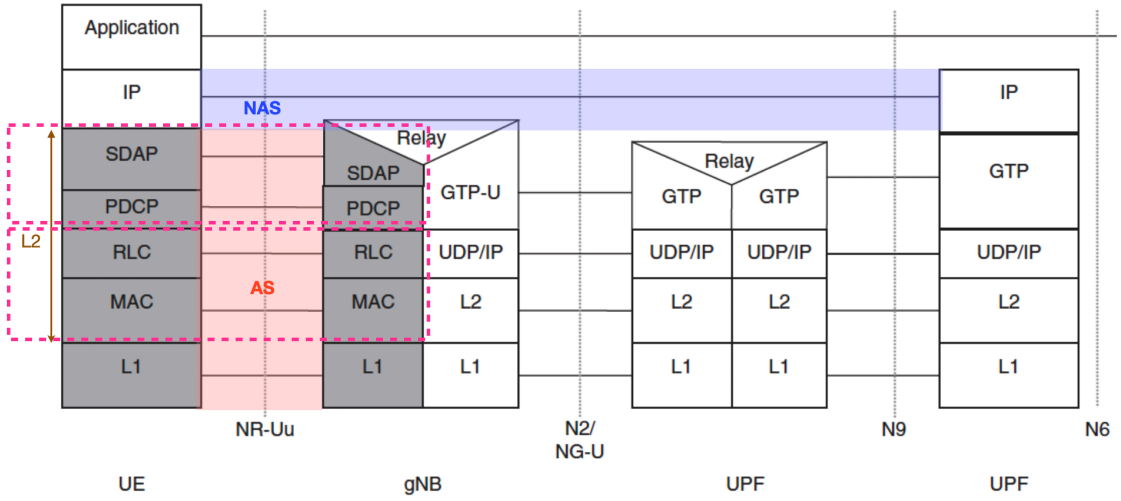




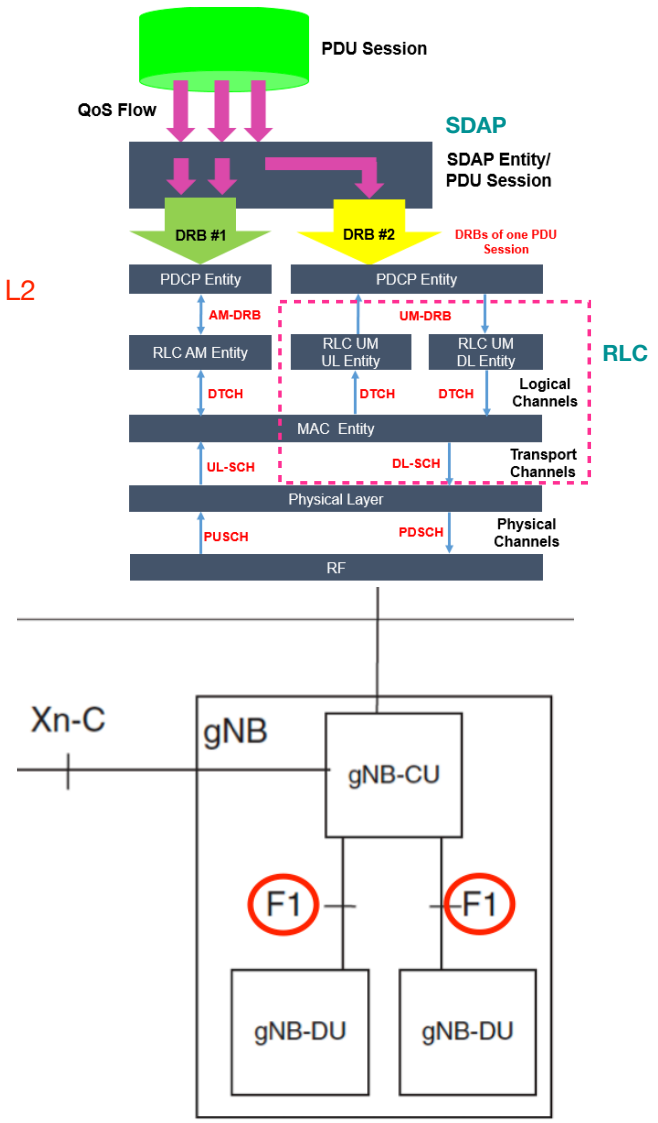
User-plane protocol stack

- Each RB has four L2 protocol layers
  - **Upper layers**
    - SDAP (used only for DRBs)
    - PDCP
  - **Lower layers**
    - RLC
    - MAC (called RLC bearer, which corresponds roughly to a logical channel)

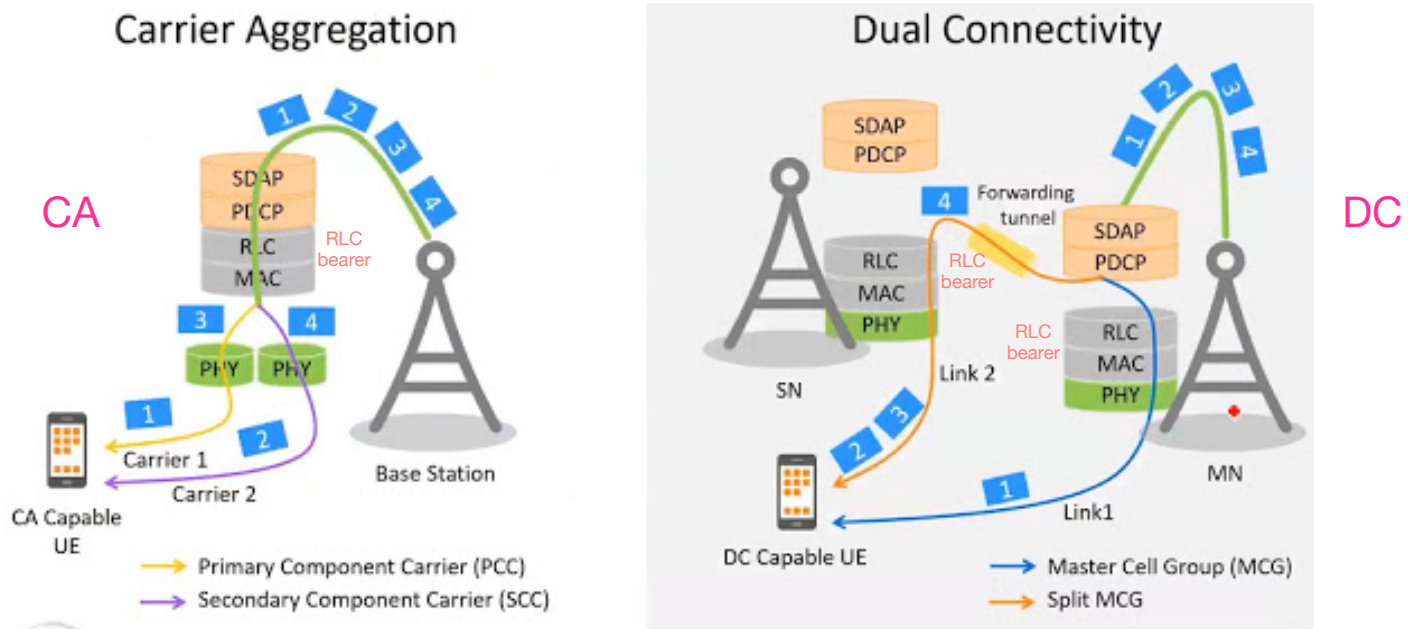




- Such a split between upper and lower layers of DRB
  - Allow easier logical separation of RLC bearer (MAC) into a different logical node from upper protocol layers
  - Applied for CU–DU architecture and dual connectivity architectures

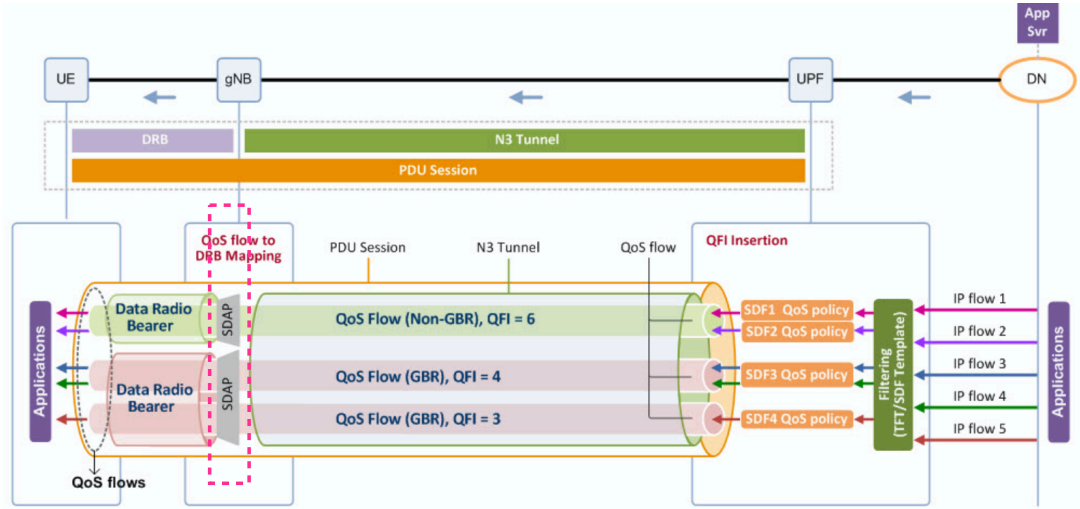


- Each RB can be configured with more than one of the RLC bearers that may
  - Reside in the same cell group for Carrier Aggregation (CA) or
  - A different cell group in case of dual connectivity (DC)

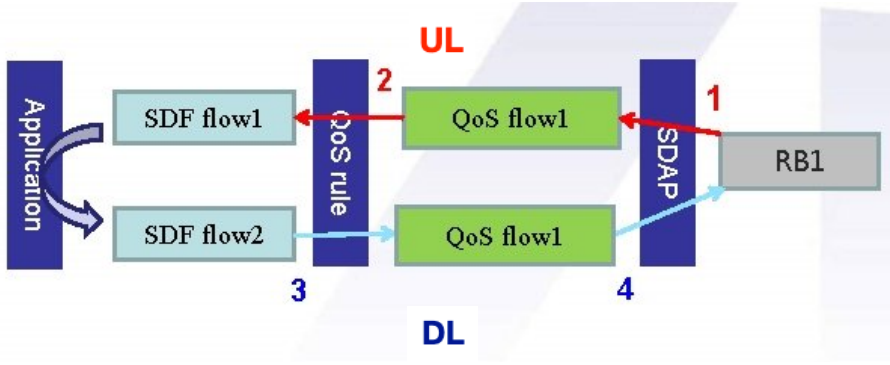


Carrier Aggregation (**CA**) and Dual Connectivity (**DC**)

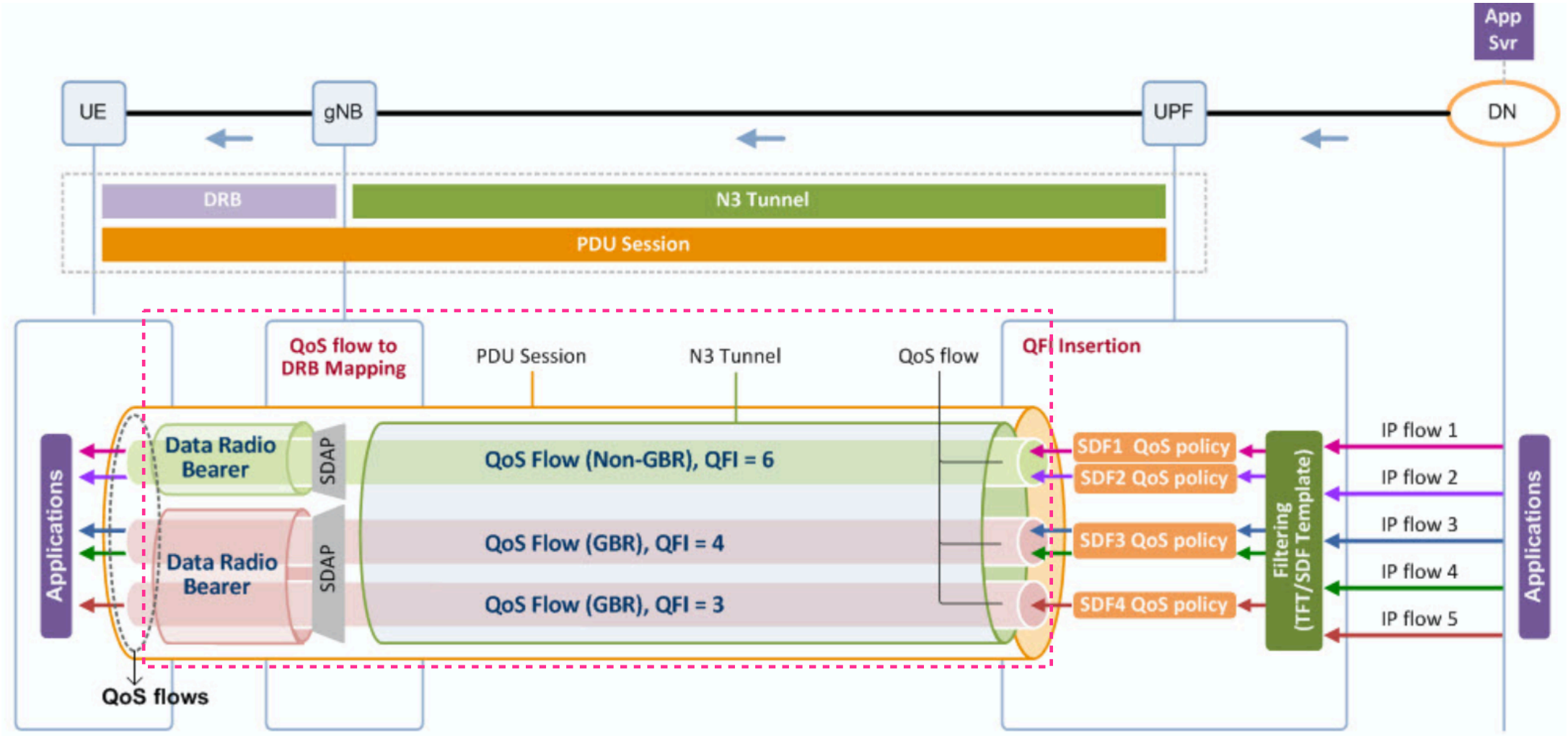
- **SDAP layer**
  - Common across all the RBs of a PDU session
  - Split data into different RBs of PDU session in accordance with QoS information
  - Primary functionality
    - Map a packet to a DRB based on its QFI
  - The mapping table is configured using
    - RRC signaling (called explicit), or
    - A SDAP header (called AS reflective)

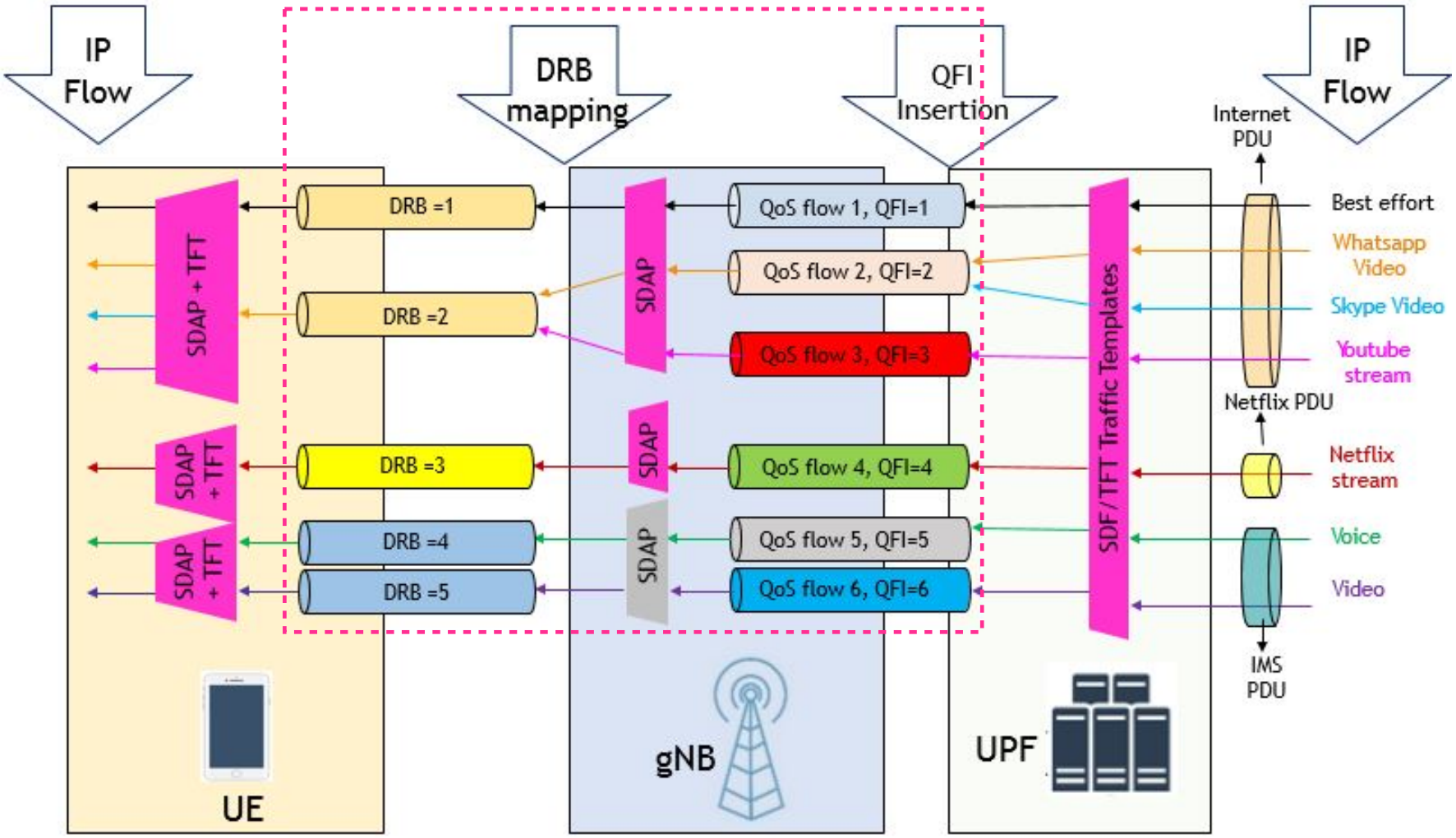


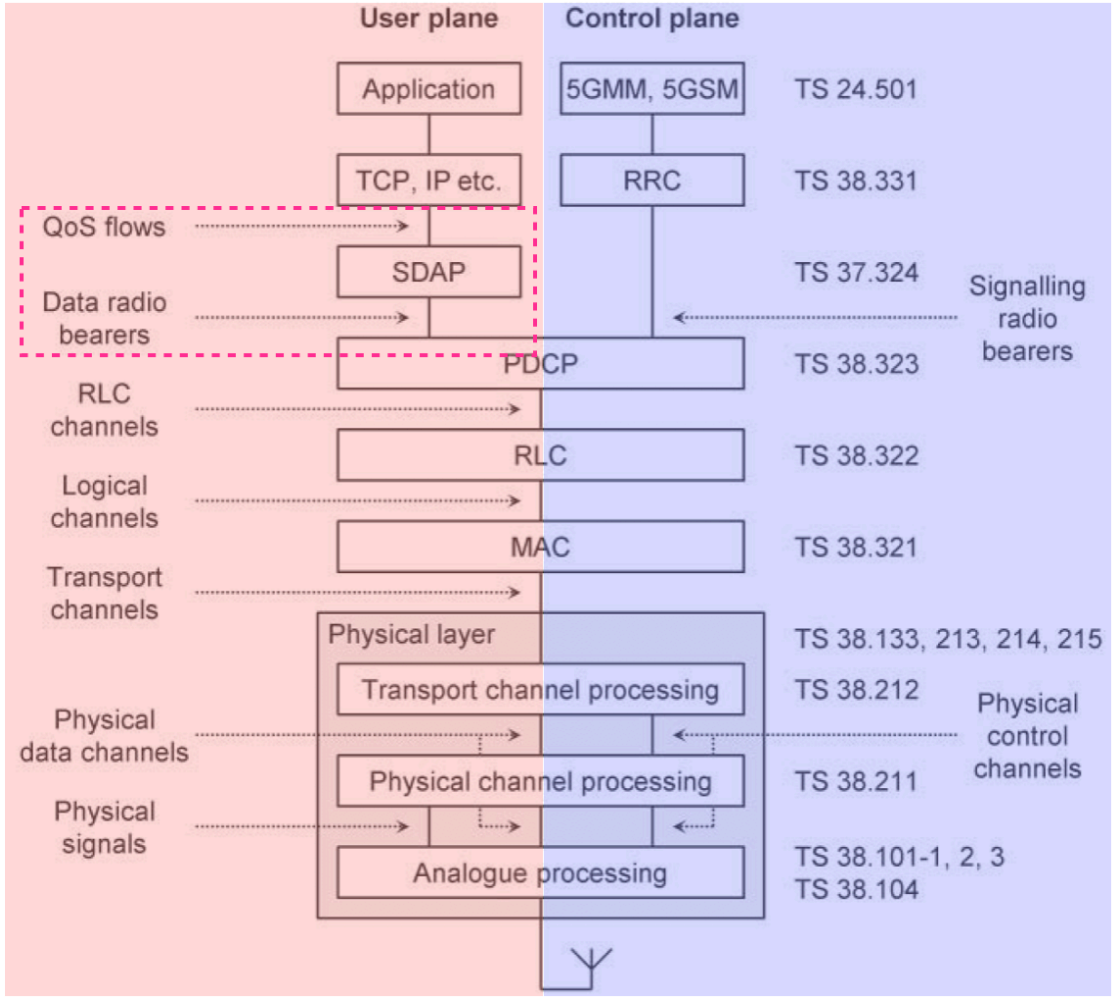
RRC signaling: used to control and manage the use of radio resources

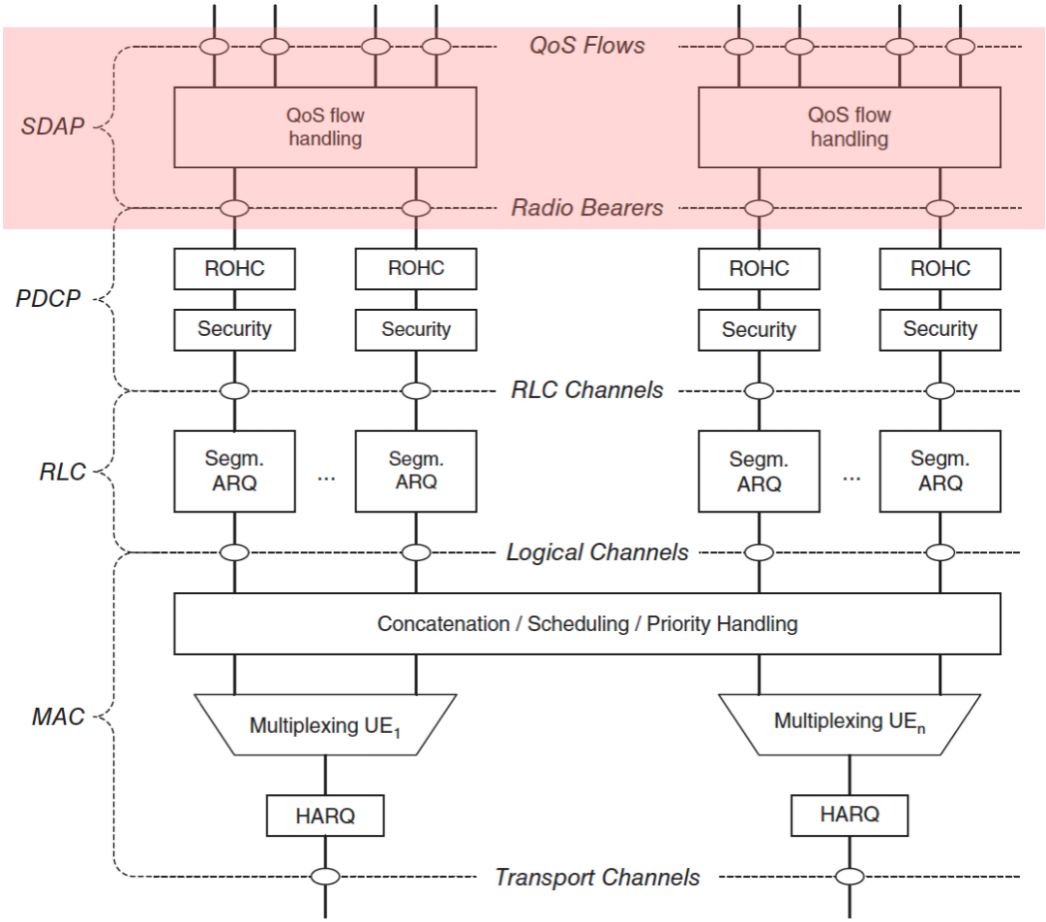


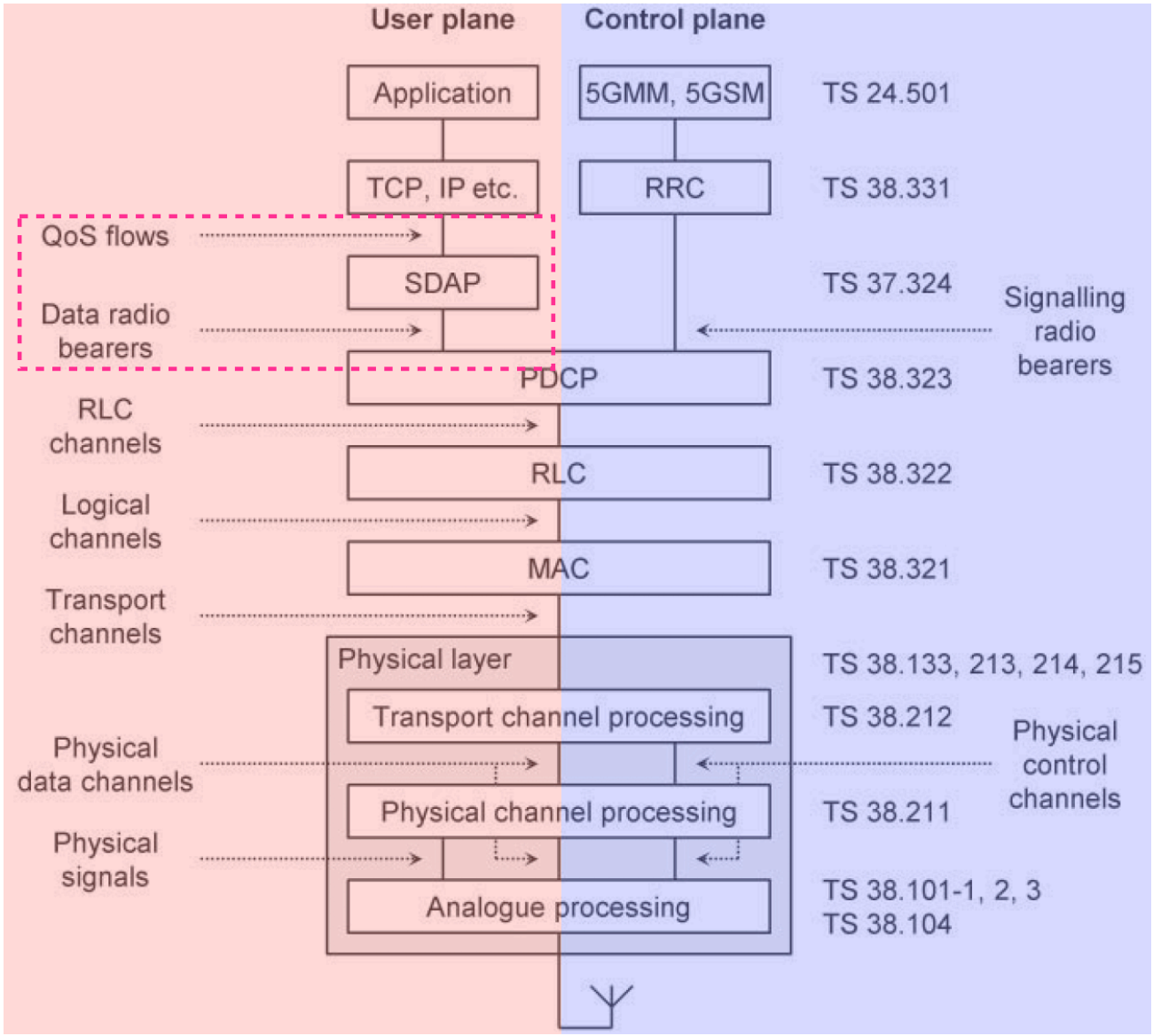
AS reflective QoS


App Svr
UE
gNB
UPF
DN
DRB
N3 Tunnel
PDU Session
QoS flow to DRB Mapping
PDU Session
N3 Tunnel
QoS flow
QFI Insertion
Applications
Data Radio Bearer
SDAP
Data Radio Bearer
SDAP
QoS Flow (Non-GBR), QFI = 6
QoS Flow (GBR), QFI = 4
QoS Flow (GBR), QFI = 3
QoS flows
SDF1 QoS policy
SDF2 QoS policy
SDF3 QoS policy
SDF4 QoS policy
Filtering (TFT/SDF Template)
IP flow 1
IP flow 2
IP flow 3
IP flow 4
IP flow 5
Applications

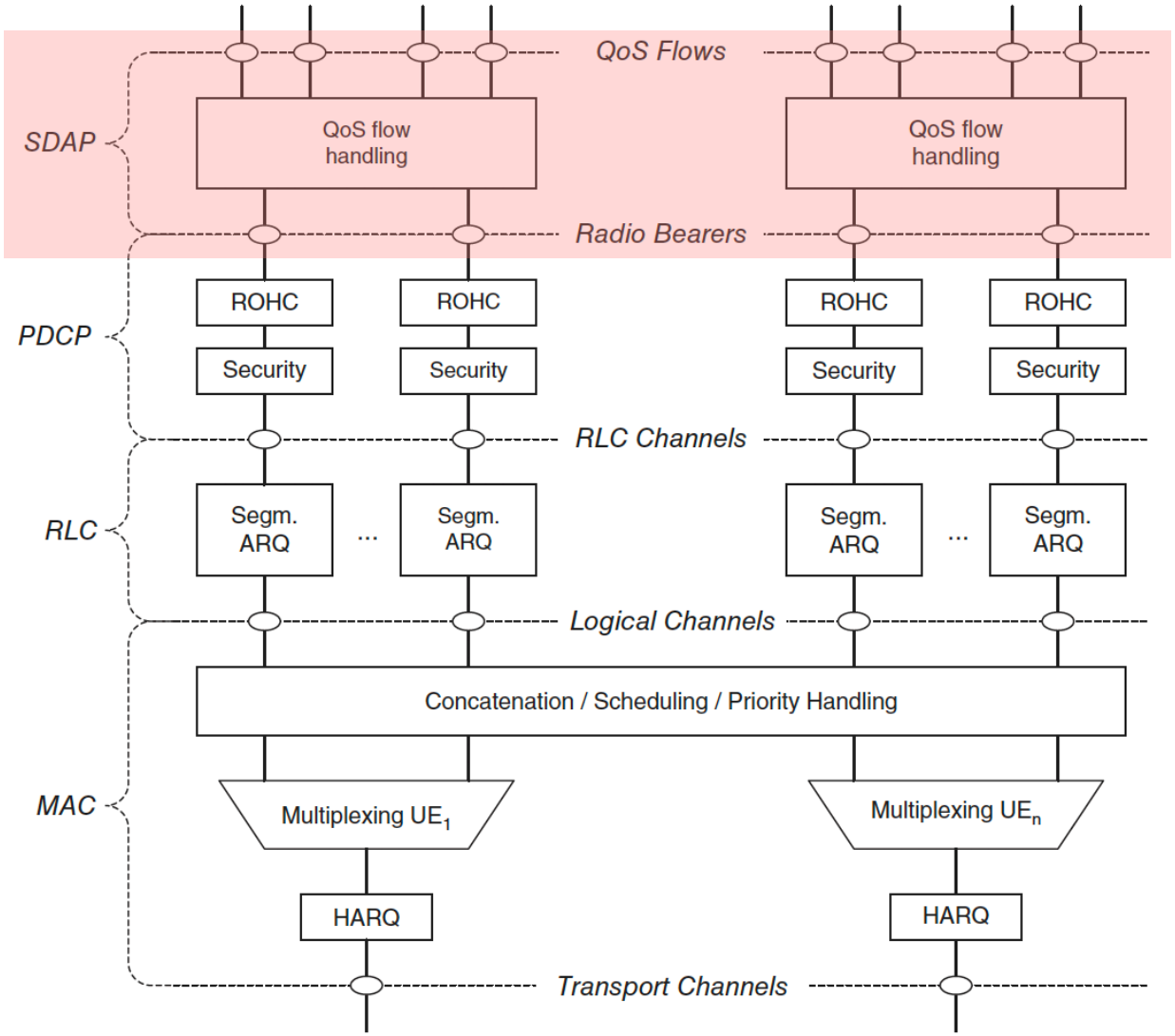

IP Flow
DRB mapping
QFI Insertion
IP Flow
Internet PDU
SDAP + TFT
SDAP + TFT
SDAP + TFT
DRB =1
DRB =2
DRB =3
DRB =4
DRB =5
SDAP
SDAP
SDAP
QoS flow 1, QFI=1
QoS flow 2, QFI=2
QoS flow 3, QFI=3
QoS flow 4, QFI=4
QoS flow 5, QFI=5
QoS flow 6, QFI=6
SDF / TFT Traffic Templates
Best effort
Whatsapp Video
Skype Video
Youtube stream
Netflix PDU
Netflix stream
Voice
Video
IMS PDU
UE
gNB
UPF


User plane
Control plane
Application
5GMM, 5GSM
TS 24.501
TCP, IP etc.
RRC
TS 38.331
QoS flows
SDAP
TS 37.324
Signalling radio bearers
Data radio bearers
PDCP
TS 38.323
RLC channels
RLC
TS 38.322
Logical channels
MAC
TS 38.321
Transport channels
Physical layer
TS 38.133, 213, 214, 215
Transport channel processing
TS 38.212
Physical control channels
Physical data channels
Physical channel processing
TS 38.211
Physical signals
Analogue processing
TS 38.101-1, 2, 3
TS 38.104


QoS Flows
SDAP
QoS flow handling
QoS flow handling
Radio Bearers
PDCP
ROHC
ROHC
ROHC
ROHC
Security
Security
Security
Security
RLC Channels
RLC
Segm. ARQ
...
Segm. ARQ
Segm. ARQ
...
Segm. ARQ
Logical Channels
Concatenation / Scheduling / Priority Handling
MAC
Multiplexing UE1
Multiplexing UEn
HARQ
HARQ
Transport Channels

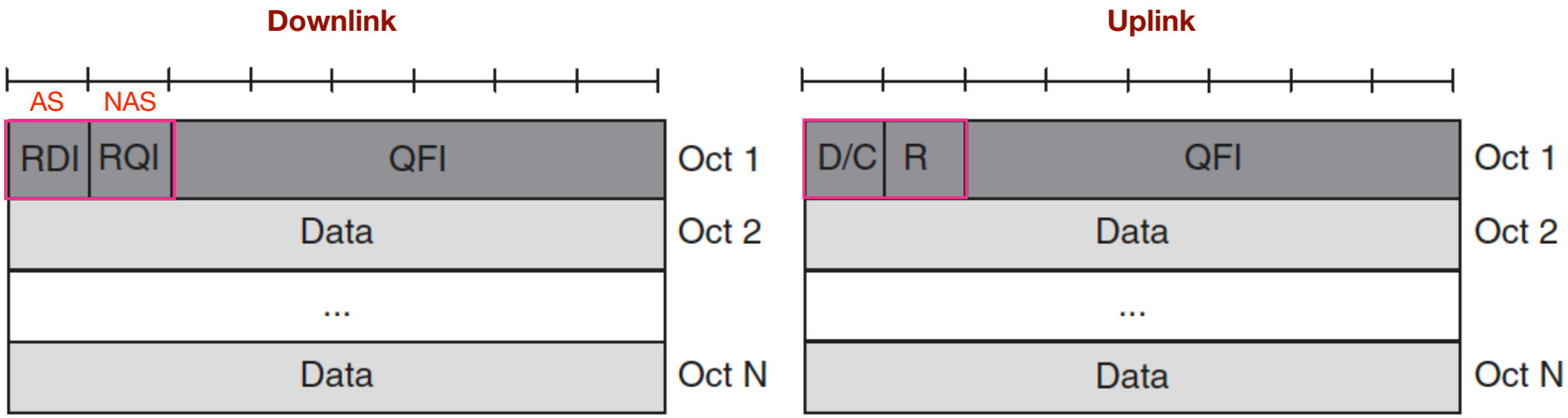


Air interface protocol stack for architectural



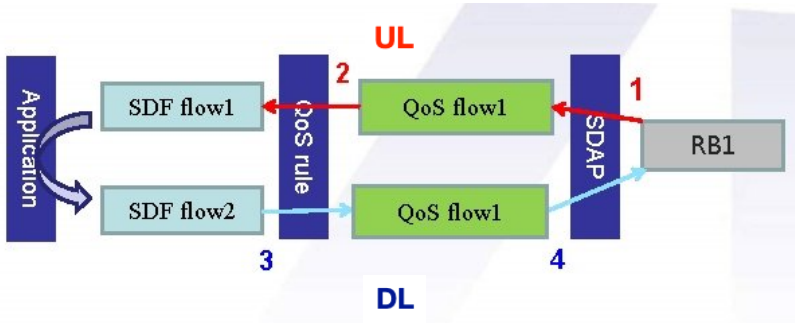
Downlink **Layer 2** Structure Protocol

- SDAP layer
  - Has an optional configurable header
  - Carry different information in uplink and downlink

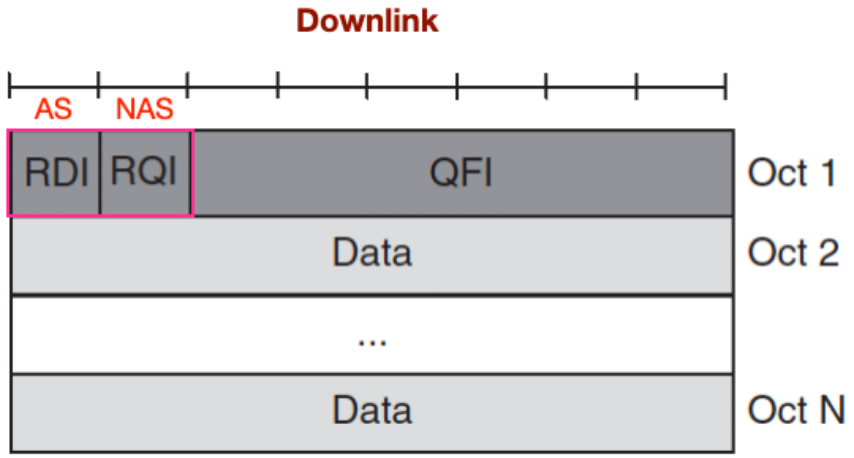


Downlink (left) and **uplink** (right) SDAP Data PDU format with SDAP header

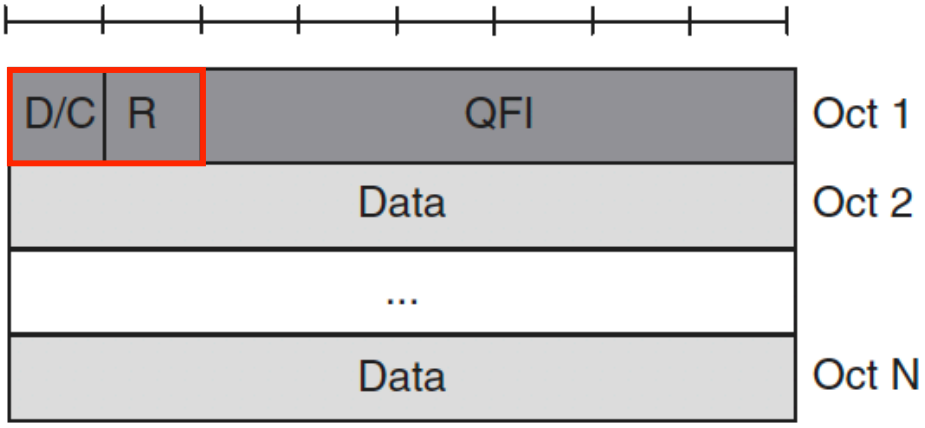
- In the downlink, SDAP header includes
  - **Reflective QoS flow to DRB mapping Indication (RDI) bit**
    - The AS reflective mapping bit
    - On receipt of a packet with this bit set, UE updates mapping table to map uplink packets of that QFI to the DRB the packet was received in
  - **Reflective QoS Indication (RQI) bit**
    - The NAS reflective mapping bit
    - Provided to the upper layers of UE along with QFI of the data packet



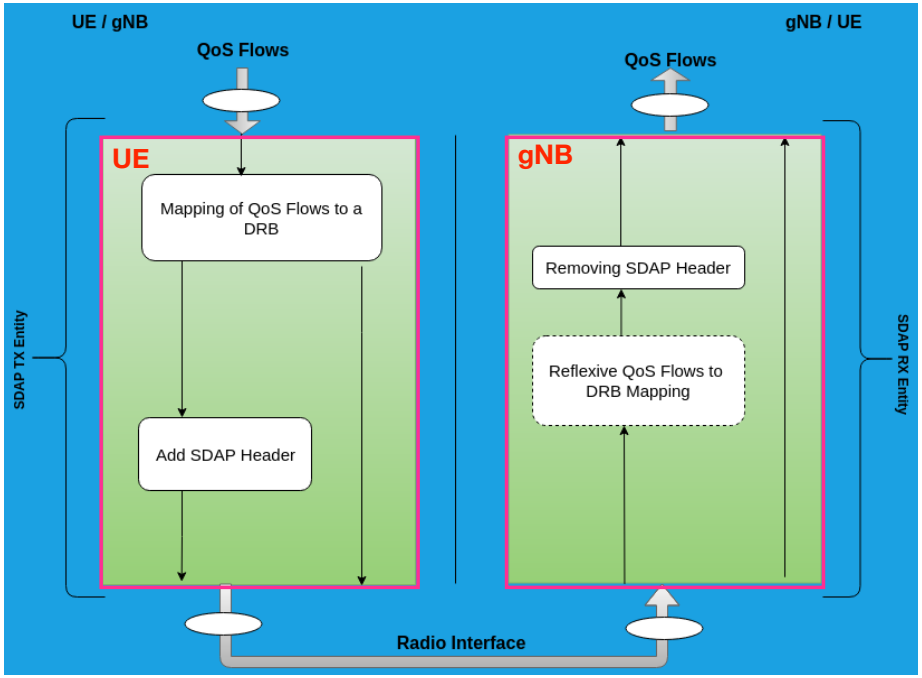
AS reflective QoS

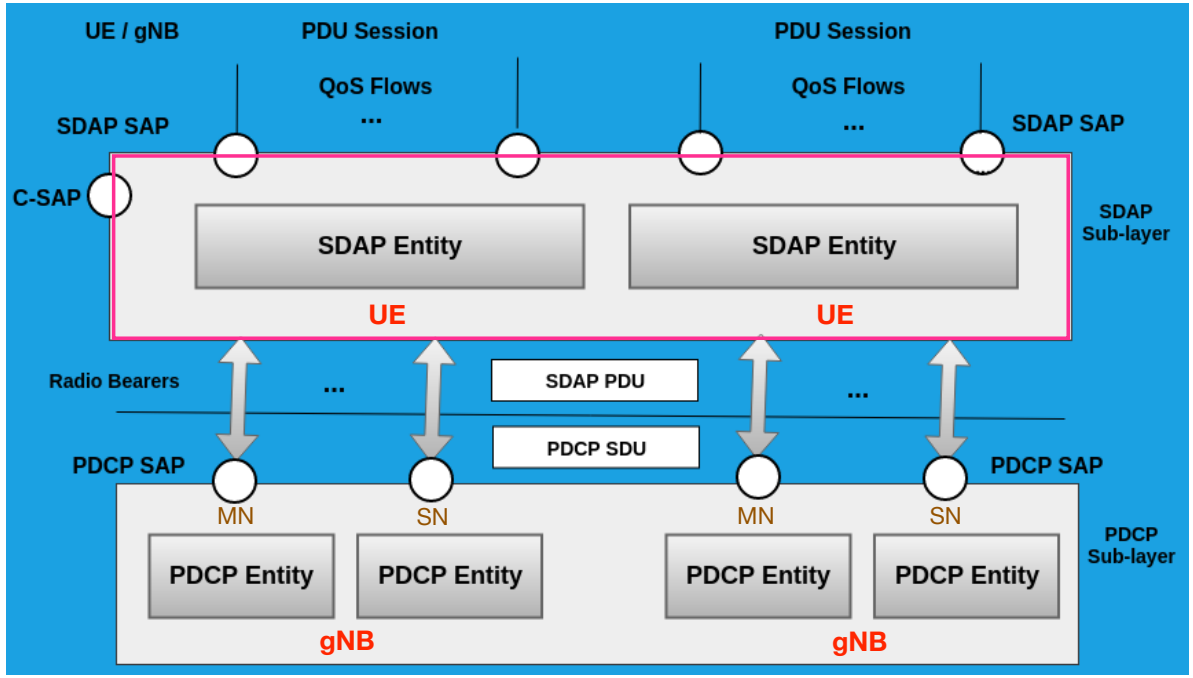


- In the uplink, SDAP header
  - Carry only QFI
  - Used by network for handling packet over CN network nodes and interfaces
  - **D/C bit**: indicates whether the SDAP PDU is an SDAP Data PDU or an SDAP Control PDU
  - **R (Reserved) bit**: the specification reserved bits shall be set to 0

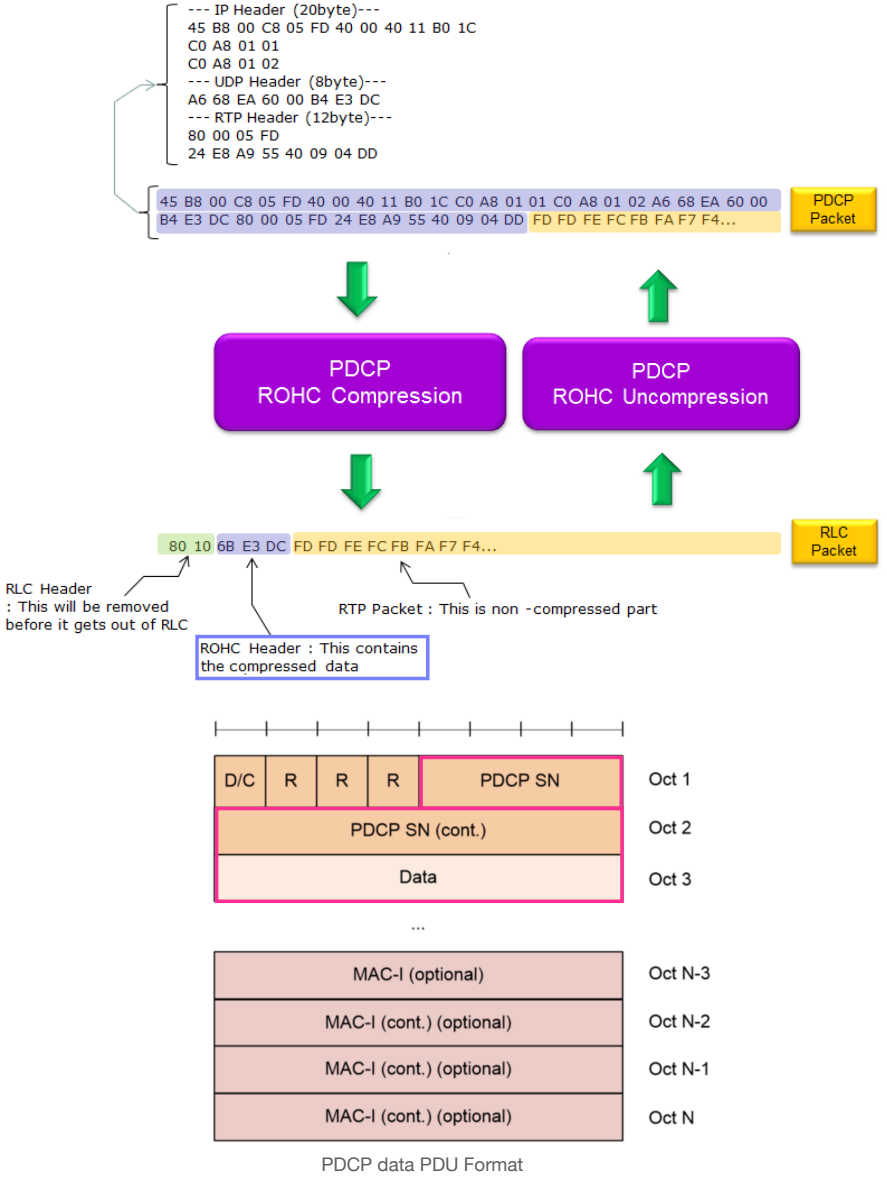


- Number of SDAP entities per PDU session
  - UE side：<u>one</u> SDAP entity
  - Network side: may be up to <u>two</u> SDAP entities
    - One in MN
    - The other in SN in case of <u>dual connectivity</u>

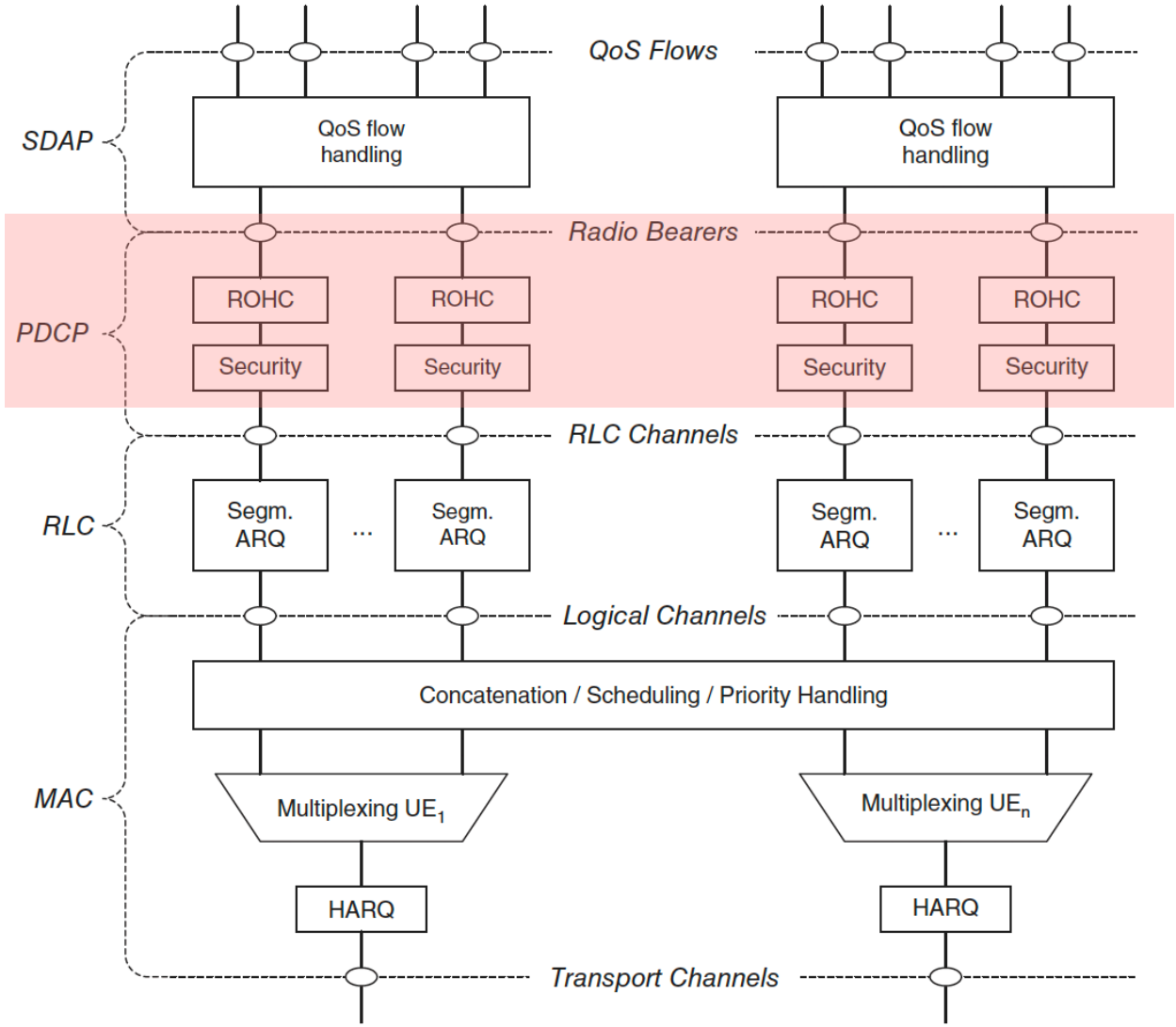




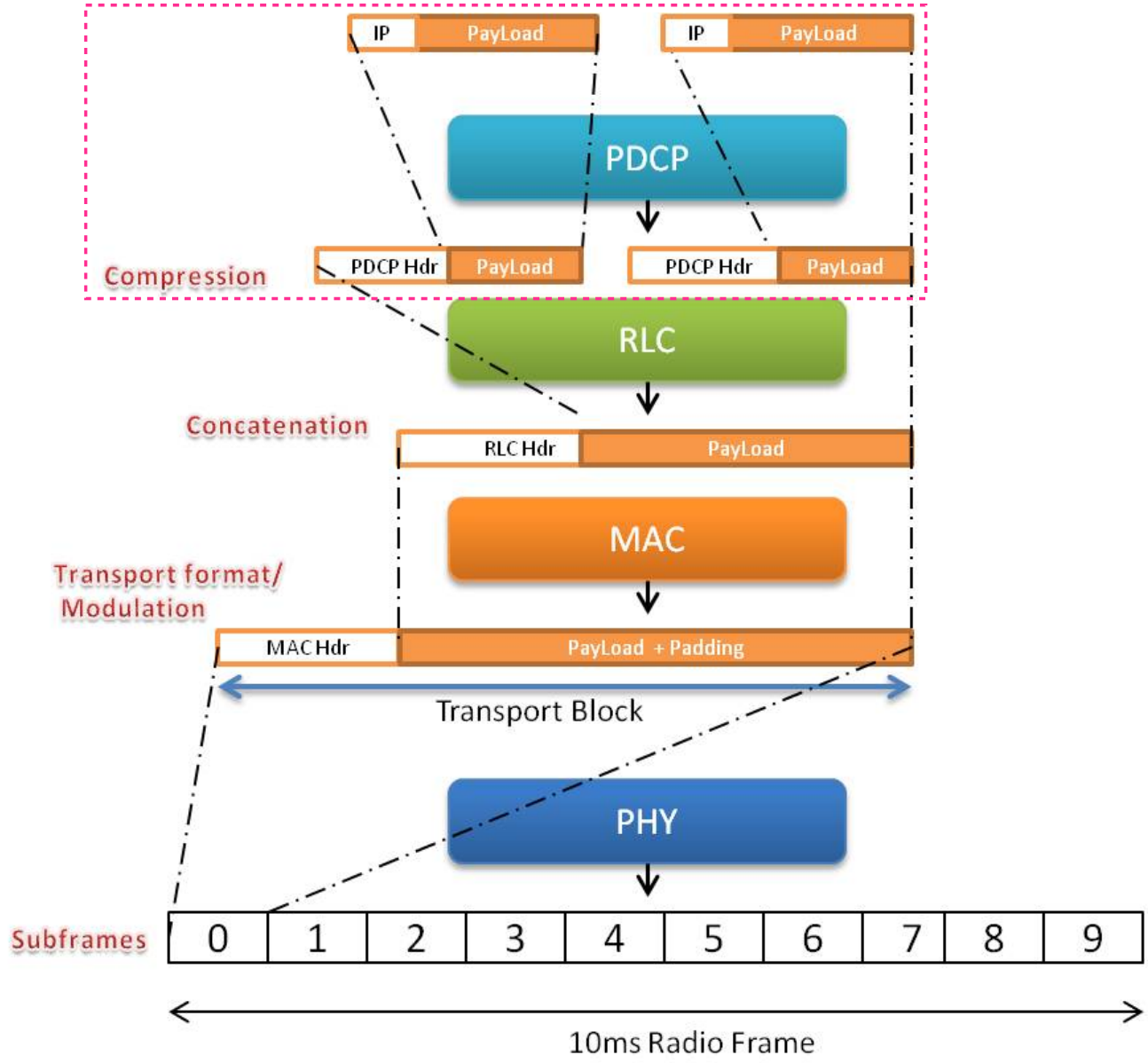
- **PDCP layer**
  - Provide security functions of encryption and integrity protection for data packets
  - Offer Robust Header Compression (RoHC) header compression for IP traffic
  - PDCP data PDU consists of
    - A header containing Sequence Number (SN)
    - Data payload
    - An optional integrity protection checksum



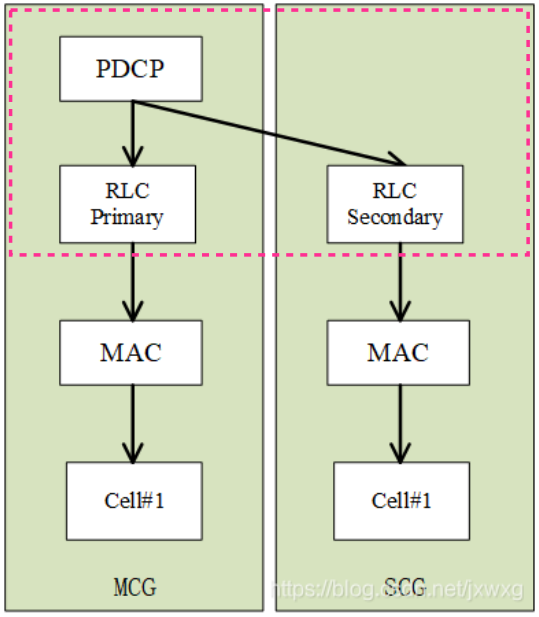
PDCP data PDU Format



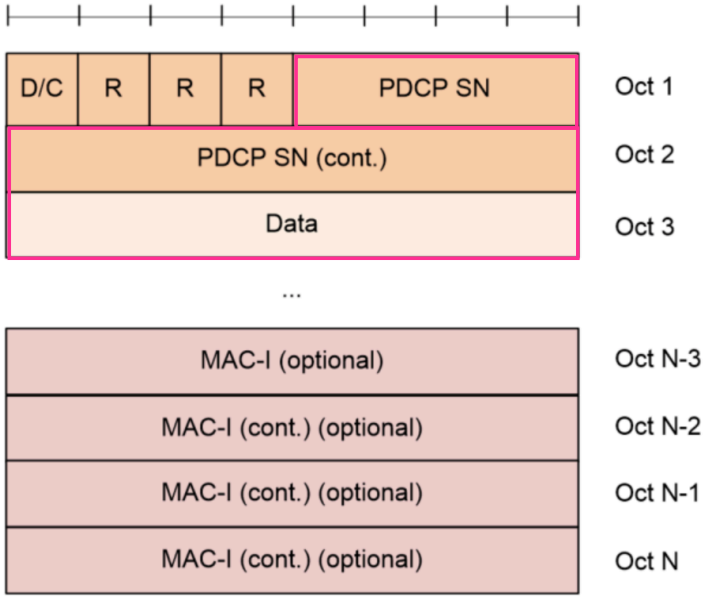
Downlink **Layer 2** Structure Protocol


IP
PayLoad
IP
PayLoad
PDCP
Compression
PDCP Hdr
PayLoad
PDCP Hdr
PayLoad
RLC
Concatenation
RLC Hdr
PayLoad
MAC
Transport format/
Modulation
MAC Hdr
PayLoad + Padding
Transport Block
PHY
Subframes
0
1
2
3
4
5
6
7
8
9
10ms Radio Frame

- PDCP is responsible for retransmission of packets based on PDCP status reports to
  - Ensure lossless delivery of packets where RLC cannot ensure lossless delivery due to
    - RLC bearers are released
    - UE moved to another network node (such as during handover, with dual connectivity, or CA)
- PDCP can be used to duplicate packets across multiple RLC bearers to
  - Improve reliability with lower latency compared with RLC-based retransmission

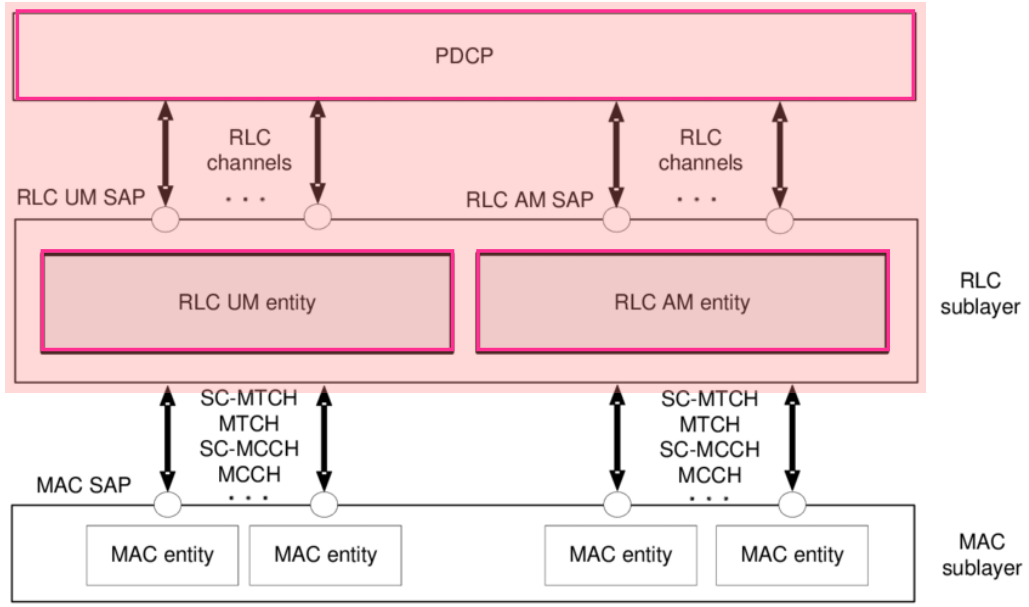


- PDCP is responsible for reordering and duplicate detection continuously rather than just during a handover
  - Duplicate detection and reordering based on PDCP SN is built into PDCP protocol itself at the receiving end and operates continuously

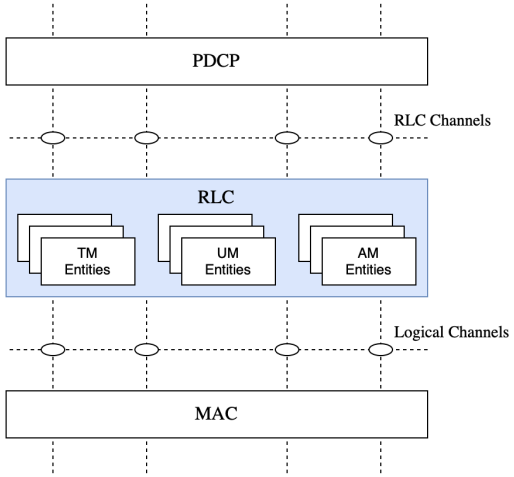


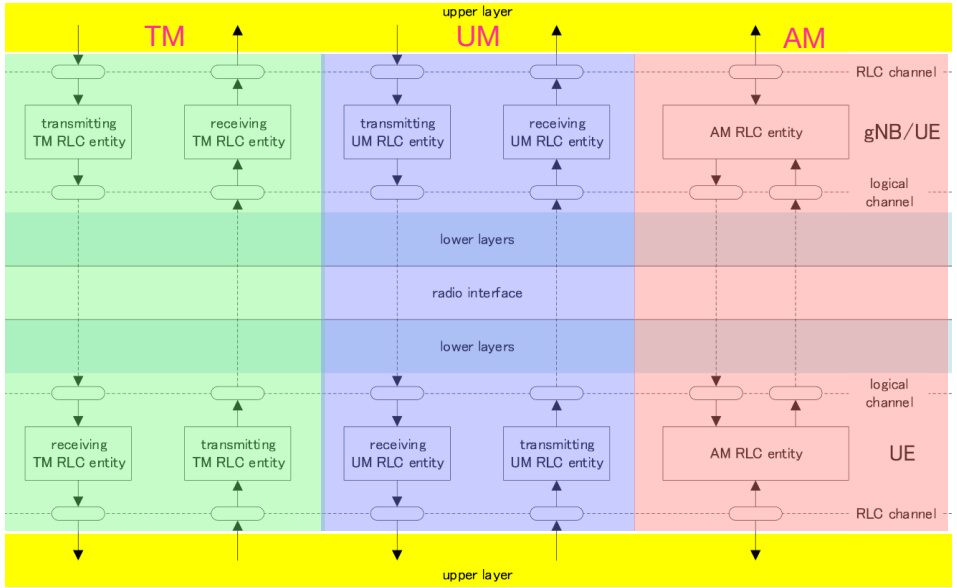
PDCP data PDU Format

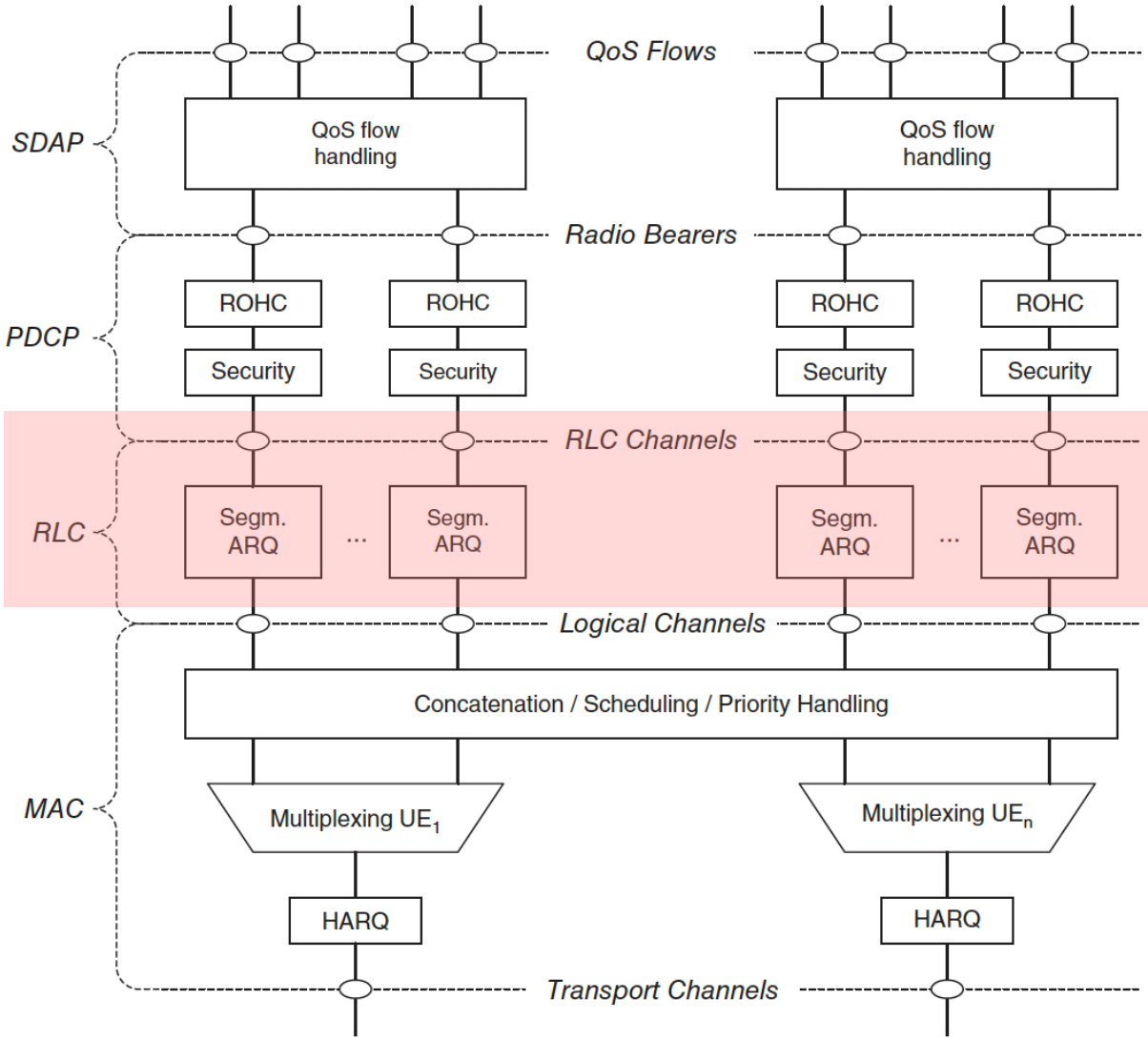
- Each DRB has exactly one PDCP entity and one or more RLC bearers
  - The interface between PDCP and RLC is well specified to allow PDCP and RLC to be in different nodes such as in the case of dual connectivity or split CU–DU architecture



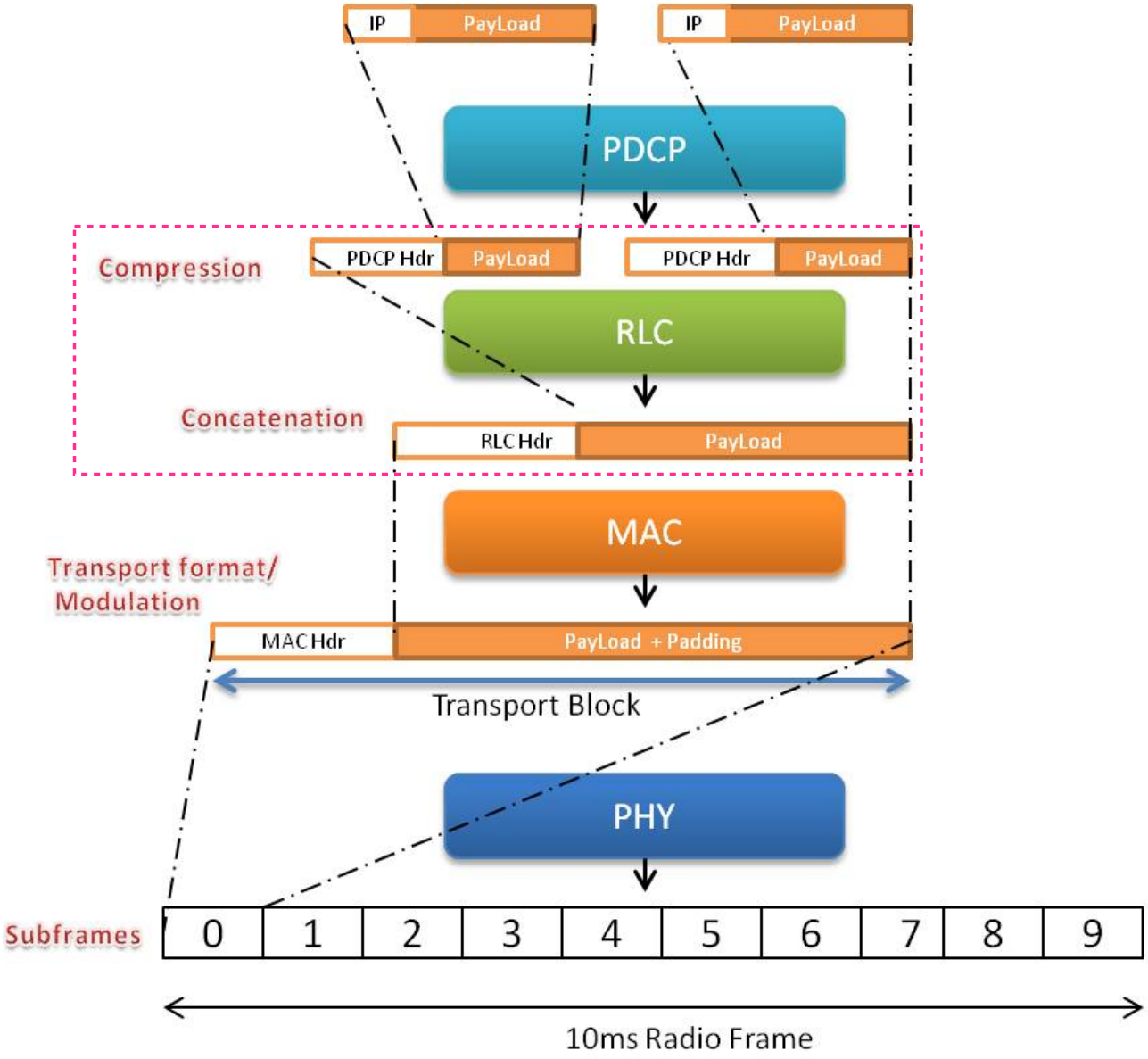
- **RLC layer**
  - Provide required reliability for data transmission
  - Support three transmission modes
    - **Transparent Mode (TM)**
      - Used for data that are broadcast
    - **Unacknowledged Mode (UM)**
      - Used for services that can tolerate data loss such as voice
    - **Acknowledged Mode (AM)** with retransmission mechanism (ARQ)
      - For services such as TCP/IP and RRC signaling (SRBs) that require reliable delivery of data

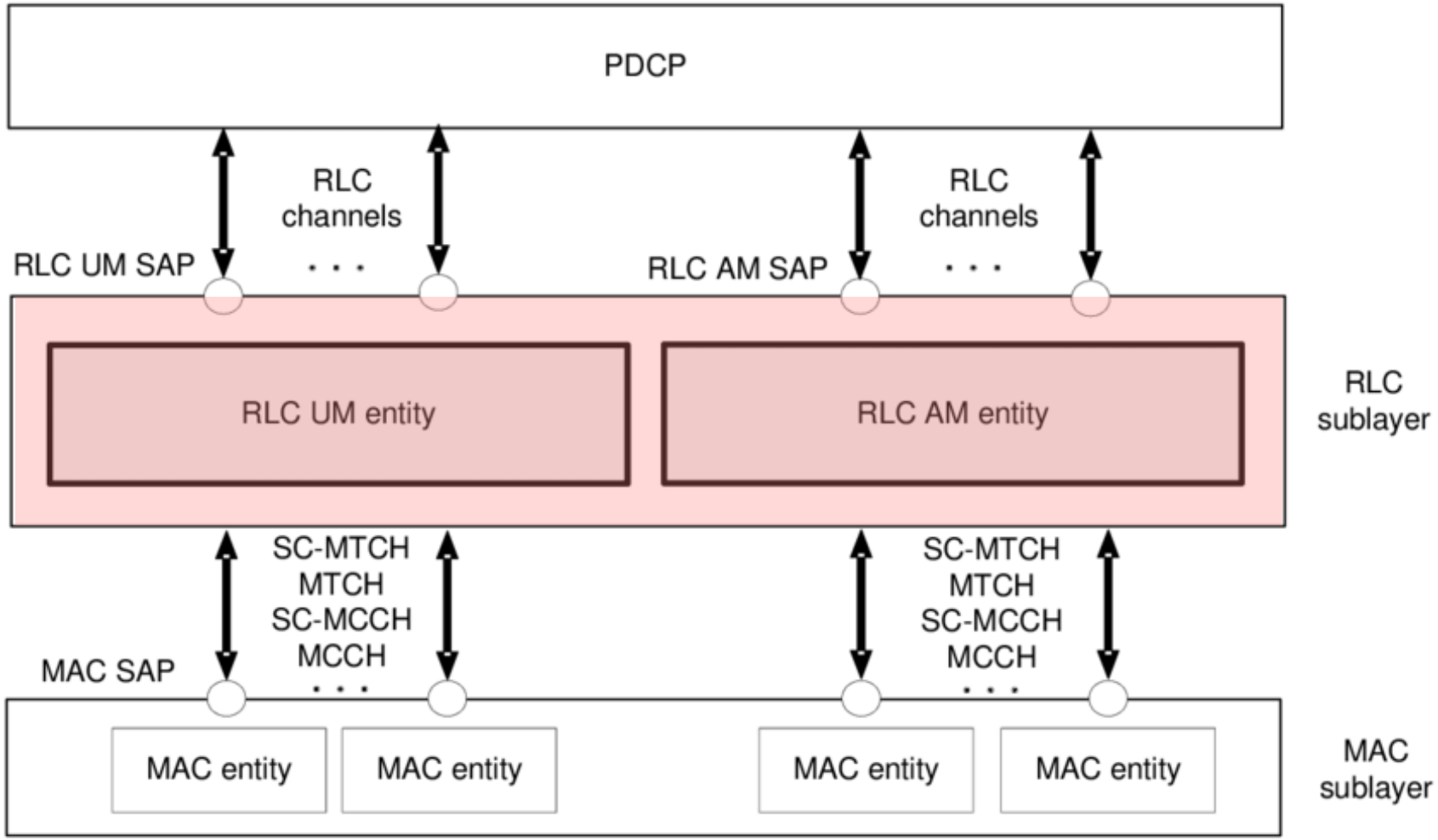






Downlink **Layer 2** Structure Protocol


IP
PayLoad
IP
PayLoad
PDCP
Compression
PDCP Hdr
PayLoad
PDCP Hdr
PayLoad
RLC
Concatenation
RLC Hdr
PayLoad
MAC
Transport format/
Modulation
MAC Hdr
PayLoad + Padding
Transport Block
PHY
Subframes
0
1
2
3
4
5
6
7
8
9
10ms Radio Frame


PDCP
RLC channels
RLC UM SAP
RLC channels
RLC AM SAP
RLC UM entity
RLC AM entity
RLC sublayer
SC-MTCH
MTCH
SC-MCCH
MCCH
MAC SAP
SC-MTCH
MTCH
SC-MCCH
MCCH
MAC entity
MAC entity
MAC entity
MAC entity
MAC sublayer

RLC channels

↓

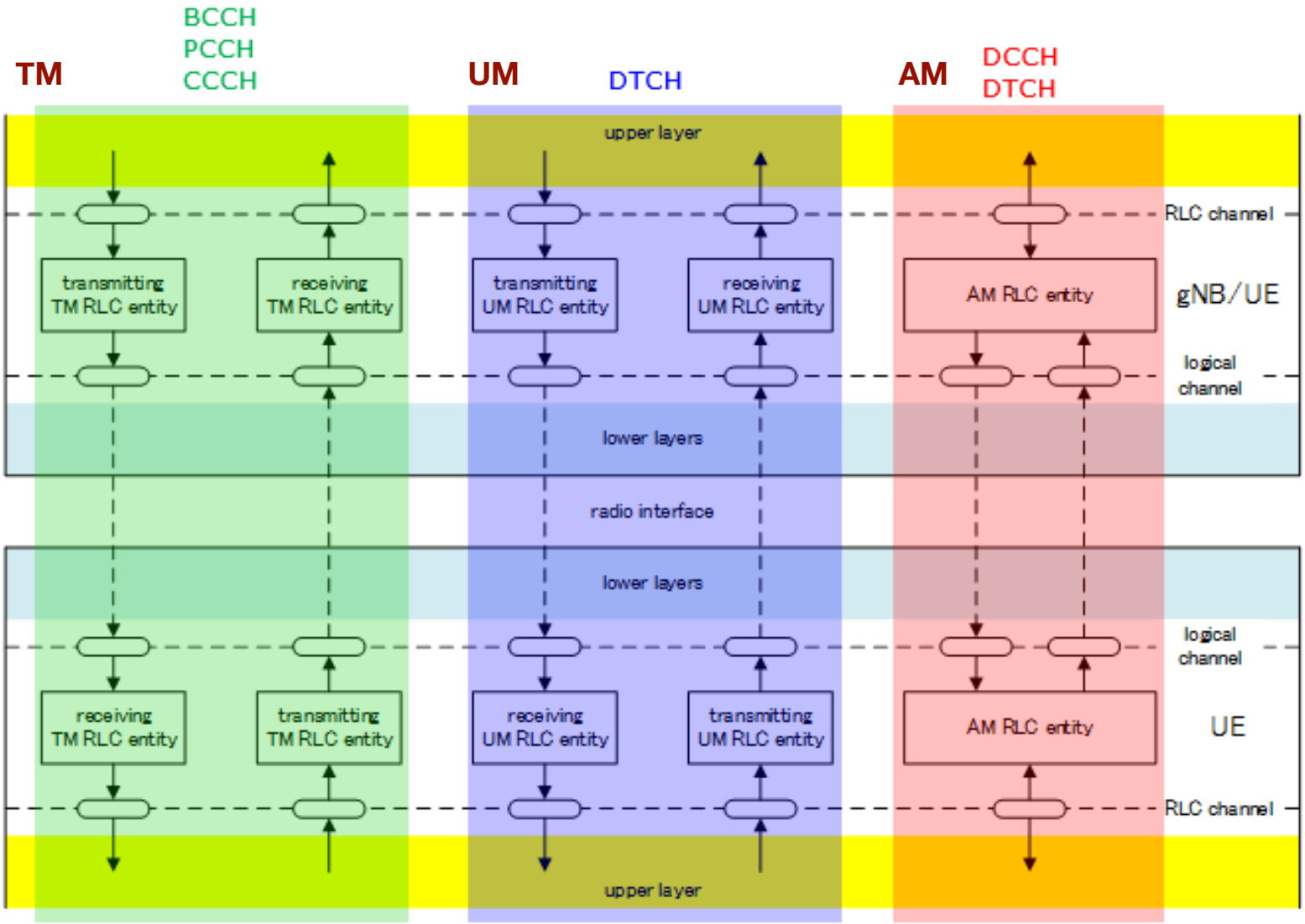
Logical channels

↓

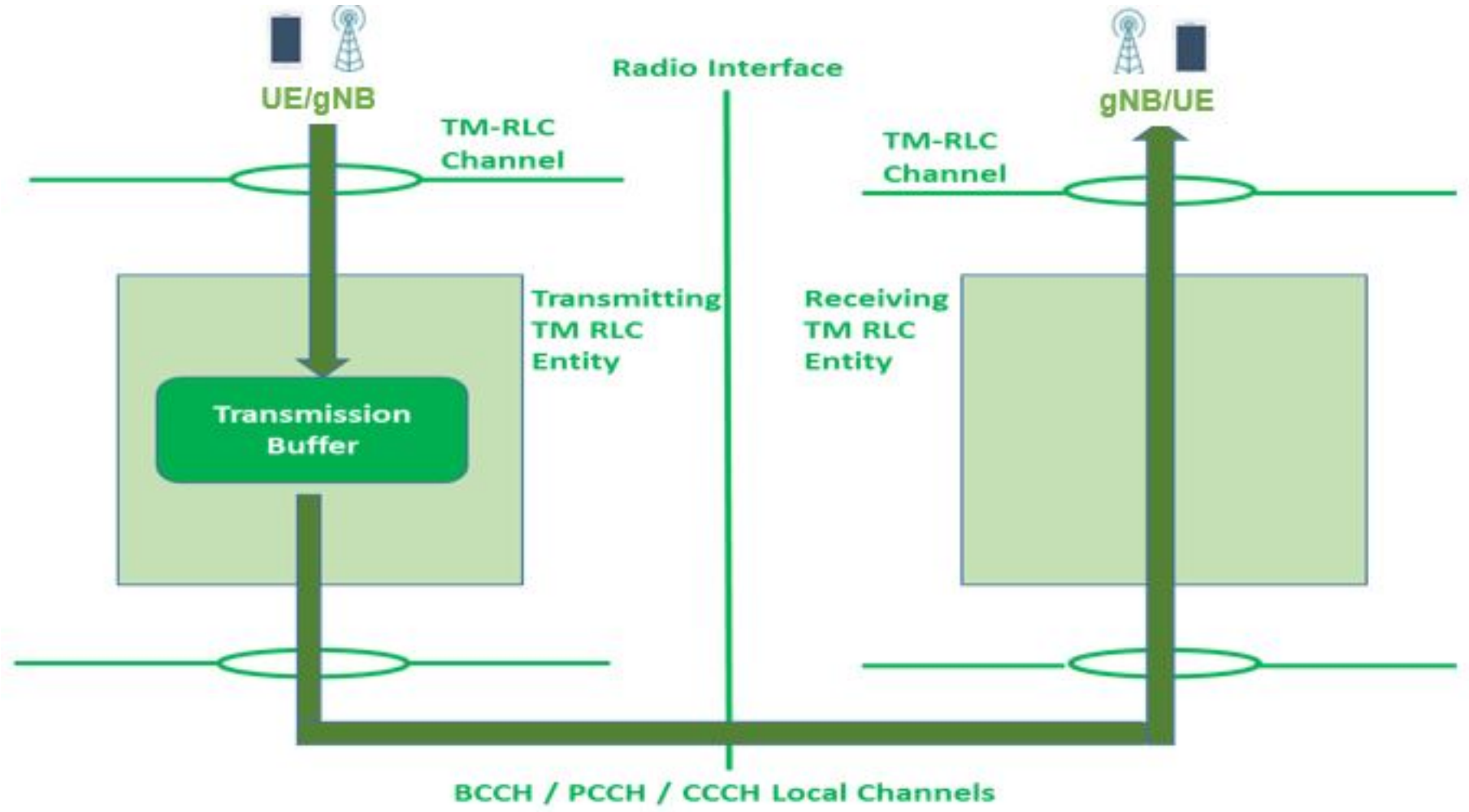
Transport channels

↓

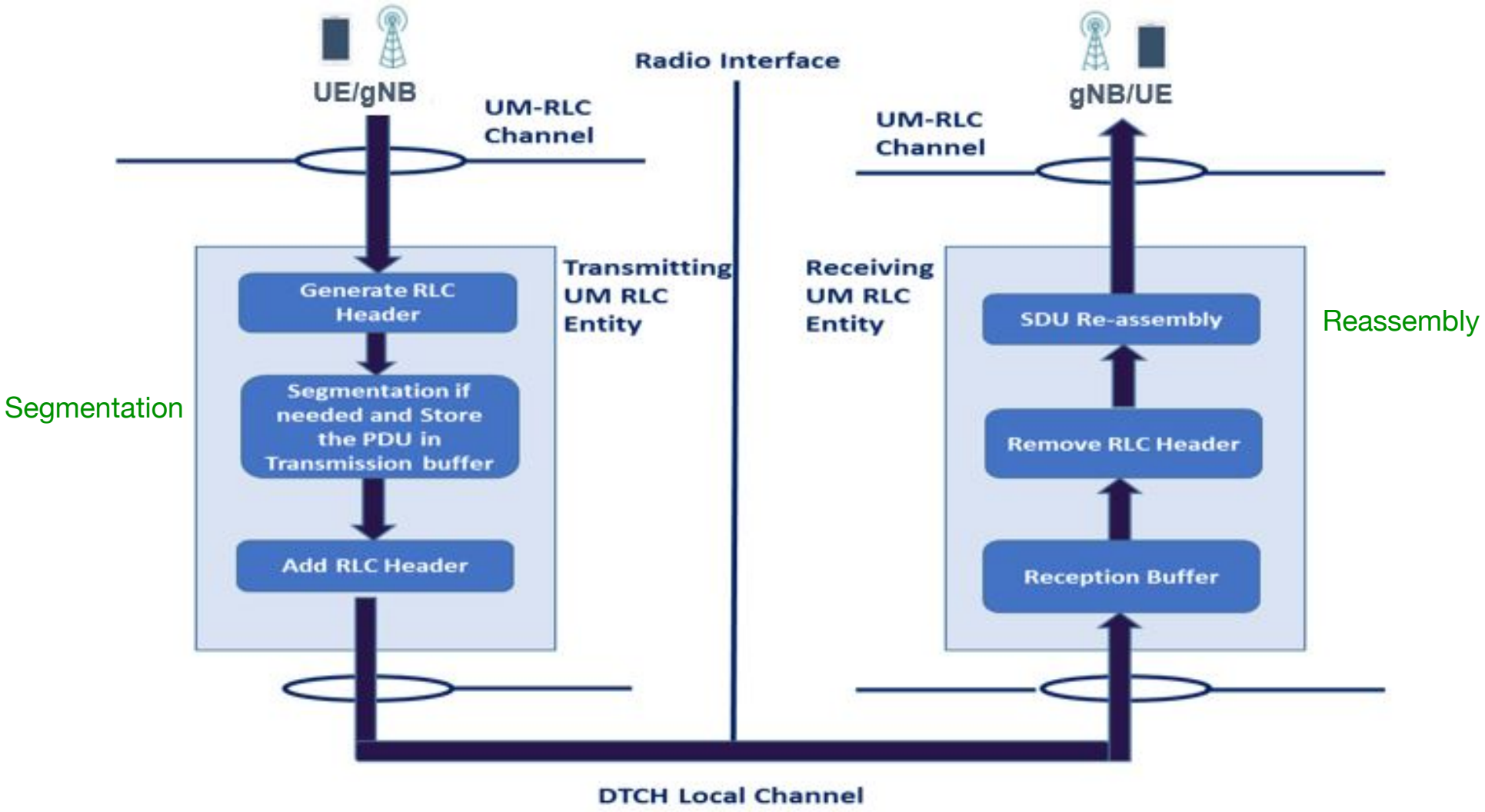
Physical channels



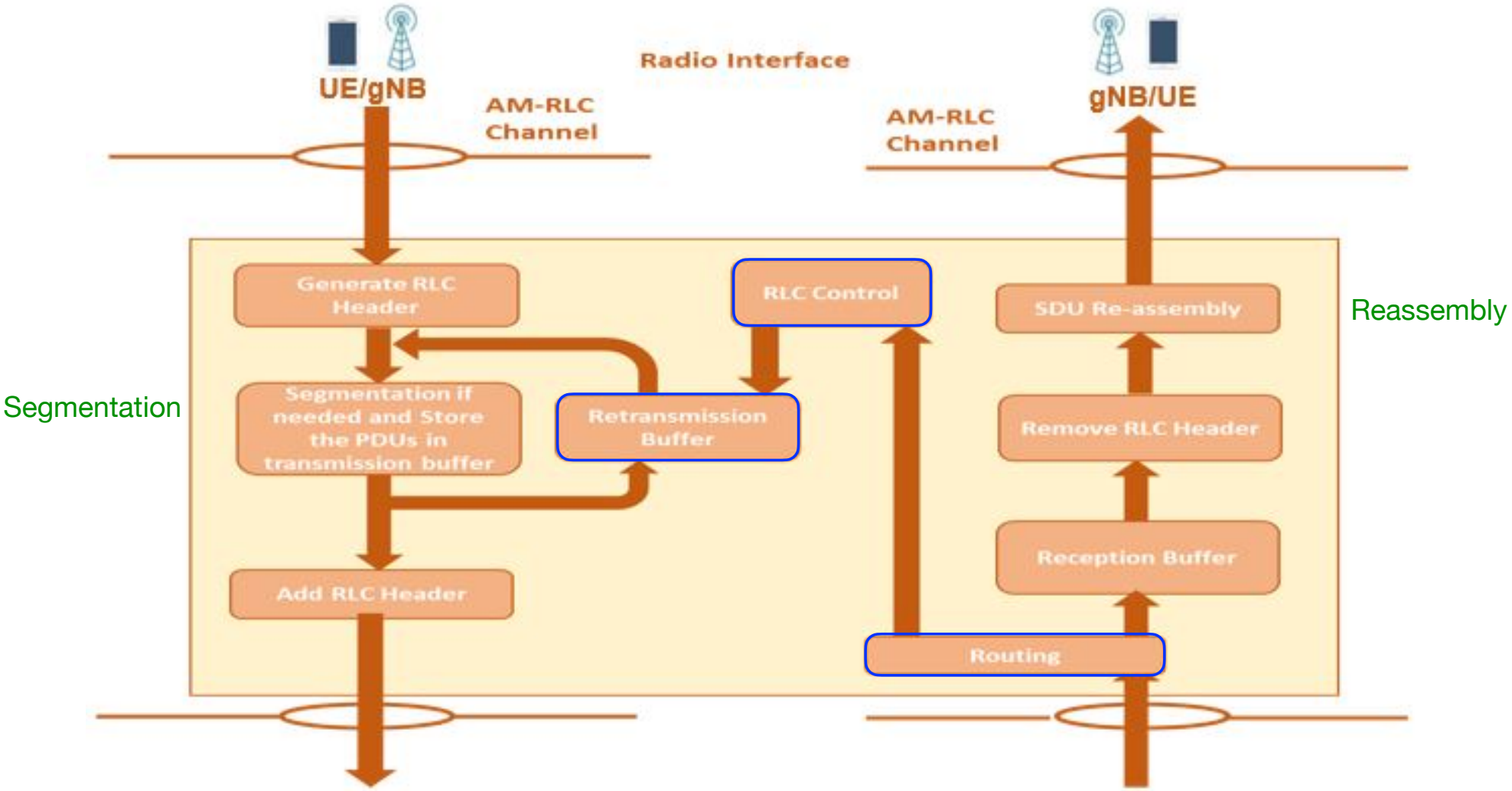
RLC Entity in TM-Mode (Transparent Mode) (broadcast)



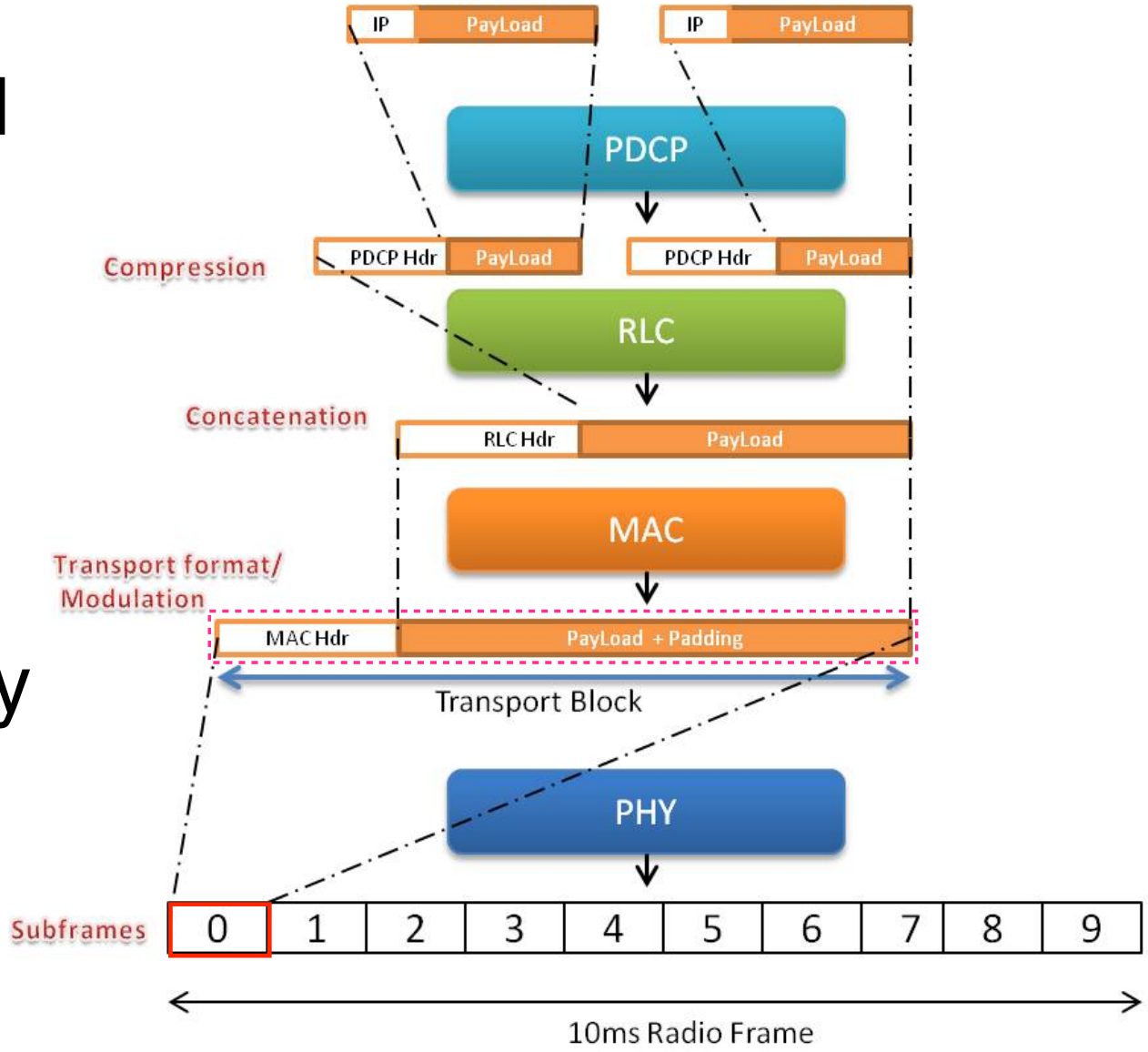
RLC Entity in UM-Mode (Un-Acknowledged Mode) (tolerate data loss)



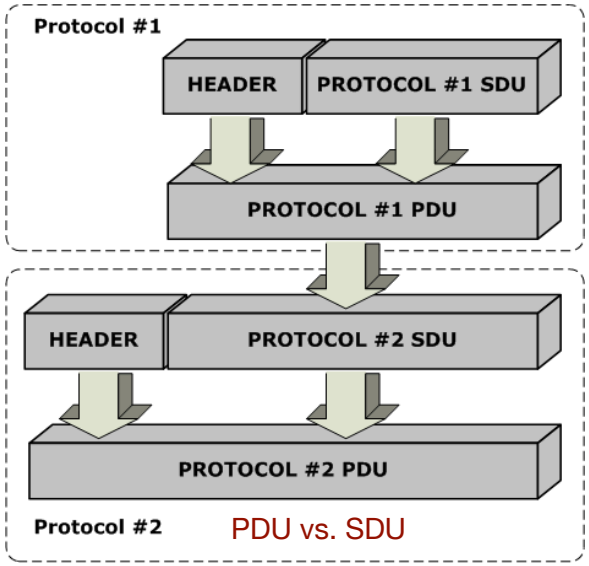
RLC Entity in AM-Mode (Acknowledged Mode) (retransmission)



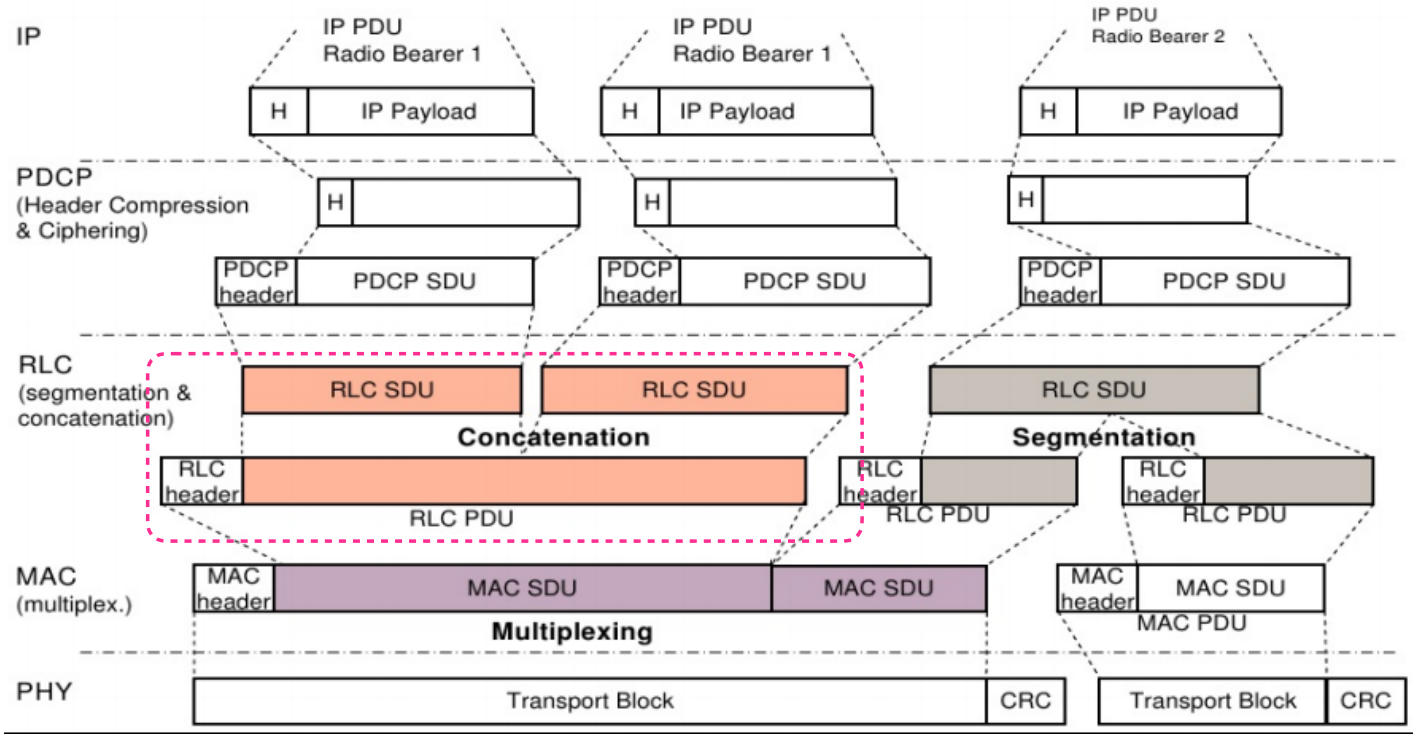
- Both RLC UM and AM modes also support segmentation and reassembly of data
  - Transmitter: fit into transport block size
  - Receiver: reassembly



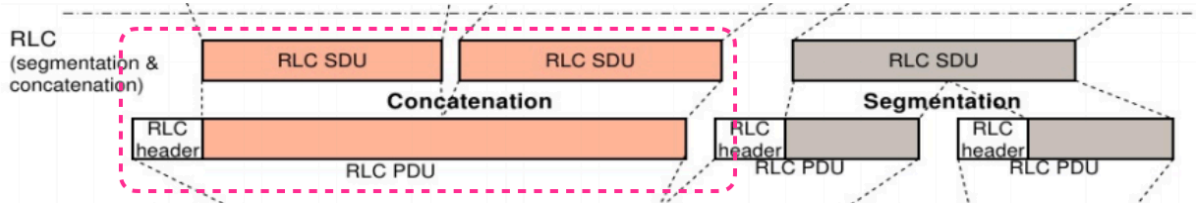
- RLC status PDUs provide
  - Positive and/or negative acknowledgments of RLC SDUs for ARQ functionality
- RLC AM also provides duplicate detection

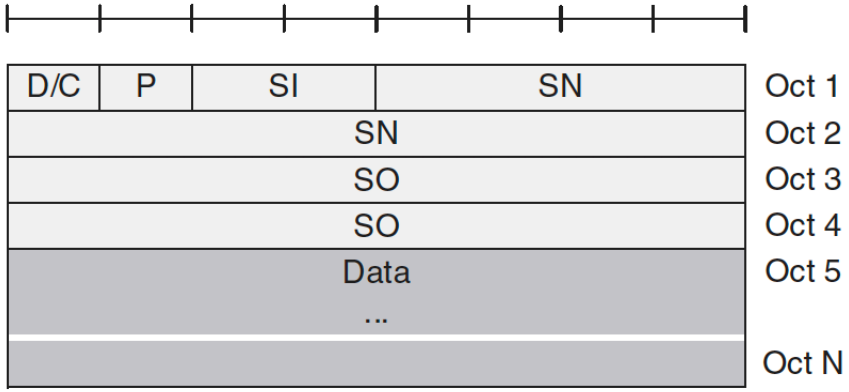


PDU vs. SDU



- The follows is one of RLC PDU structures
  - **D/C** (Data/Control)：whether the PDU is a Data or Control PDU
  - **P** (Polling bit)：trigger status reporting from the peer AM RLC entity
  - **SI** (Segmentation Information)：whether data are segmented and whether it is the first, last, or an intermediate segment
  - **SN** (Sequence Number): RLC sequence number
  - **SO** (Segment Offset)：the position of RLC SDU segment in bytes within original RLC SDU

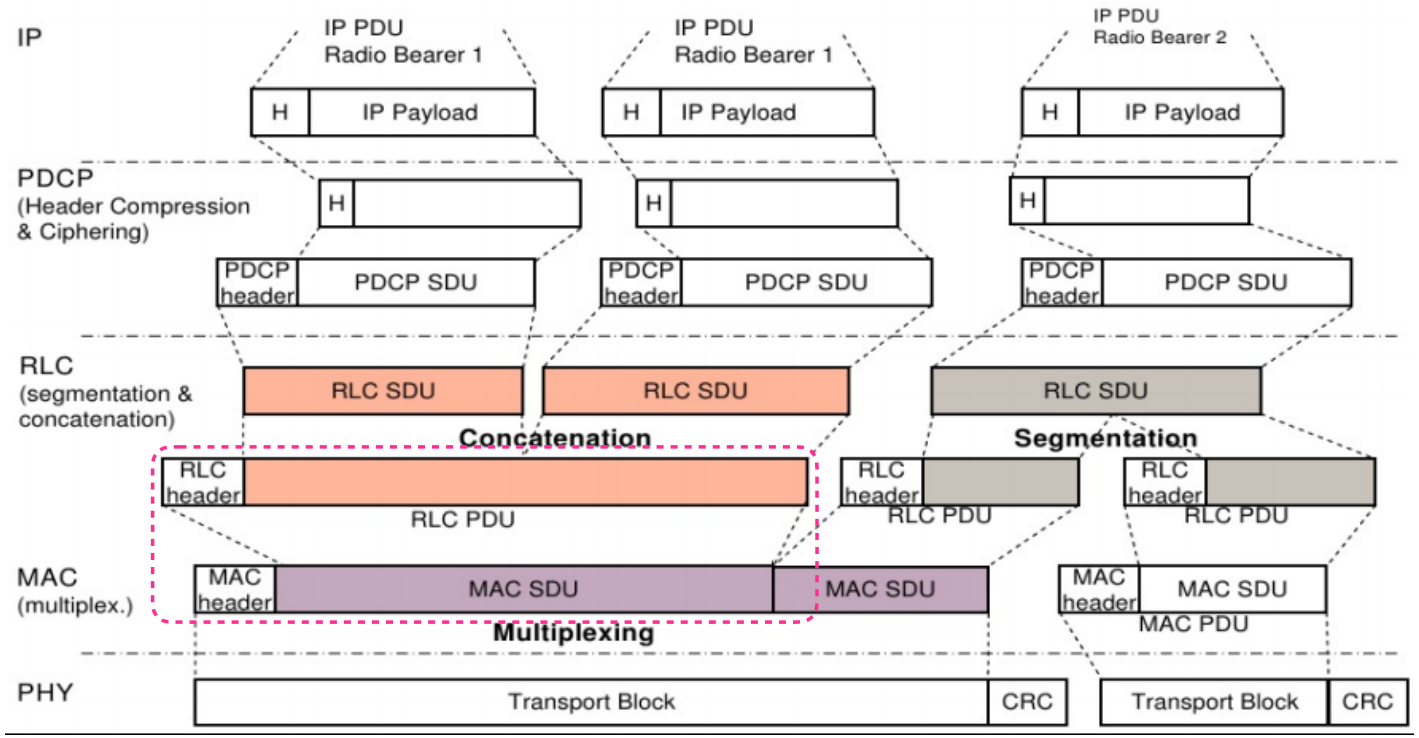


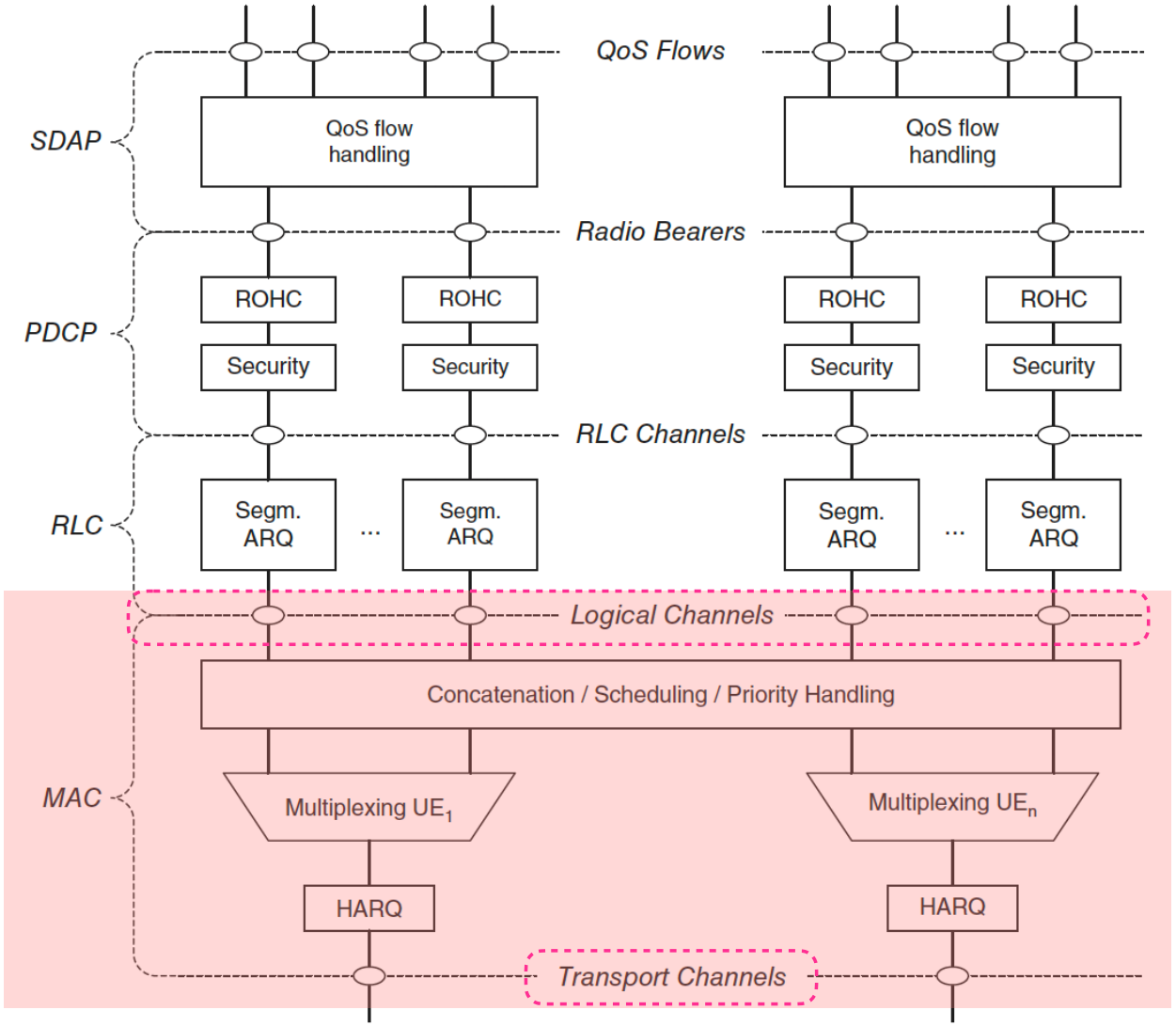


RLC AMD PDU with 12 bit Sequence Number (SN) with Segment Offset (SO)

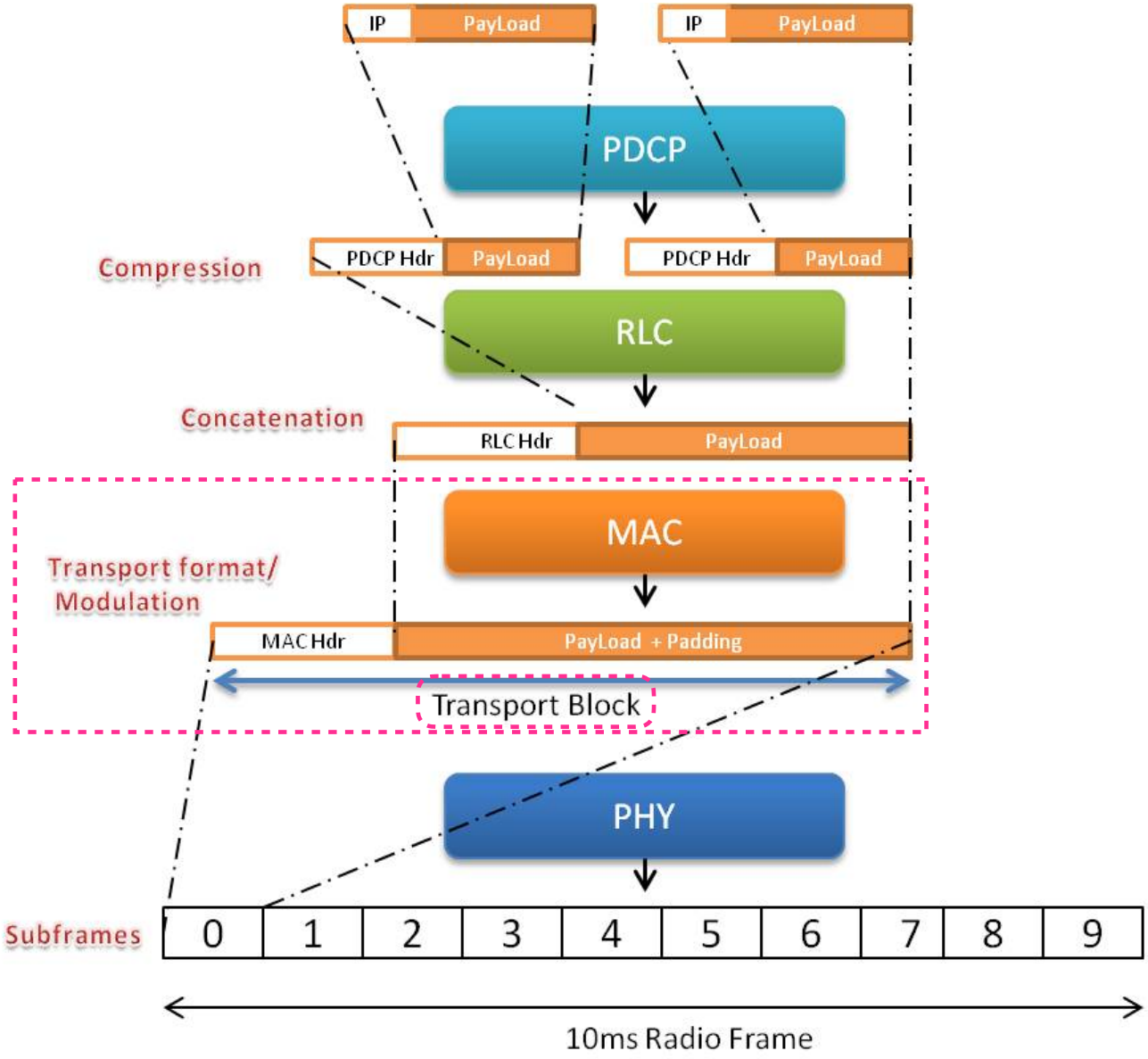
AMD PDU：used to transfer upper layer PDUs by an AM RLC entity

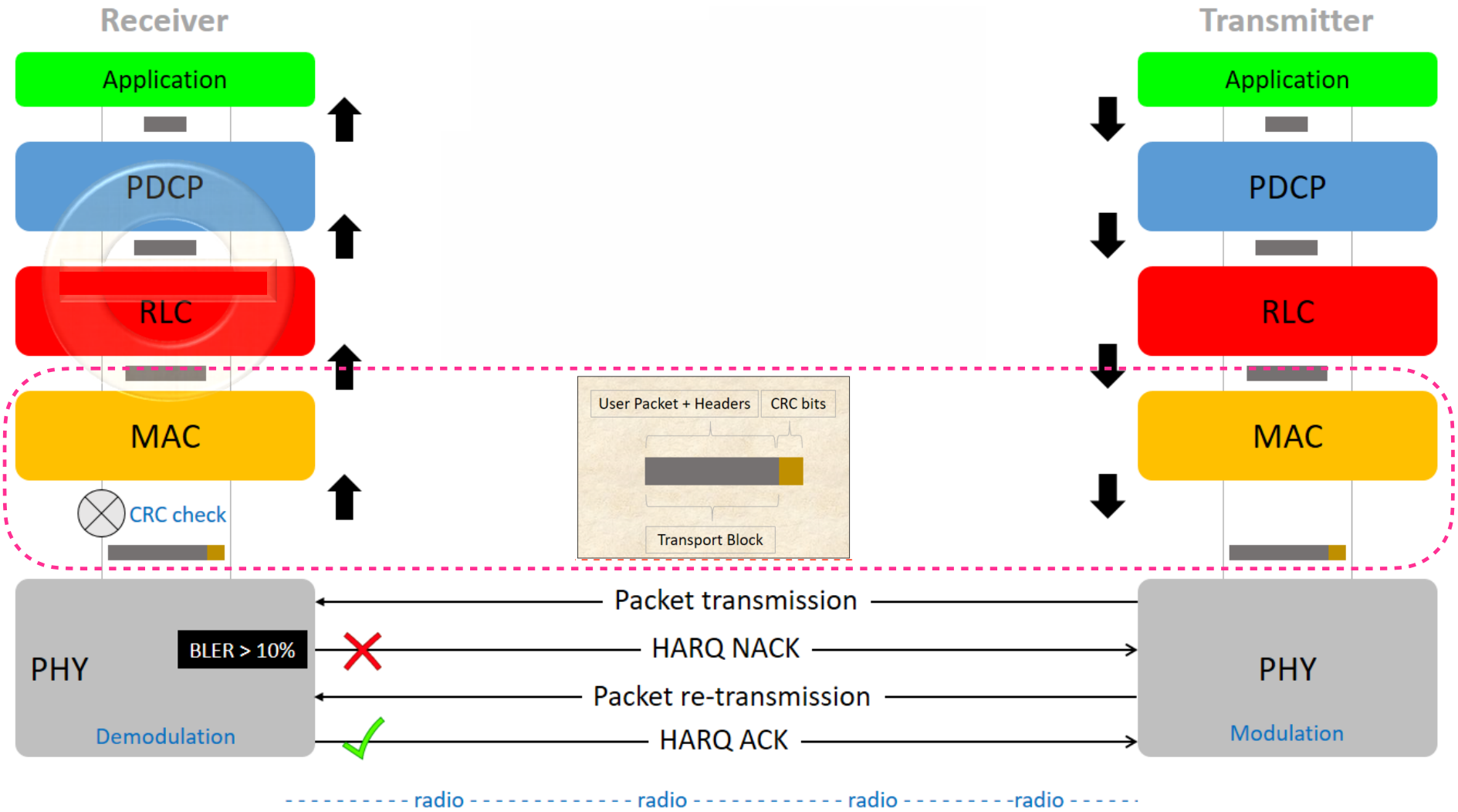
- **MAC layer**
  - Multiplex data (RLC PDUs) from different logical channels into a transport block for transmission over radio interface





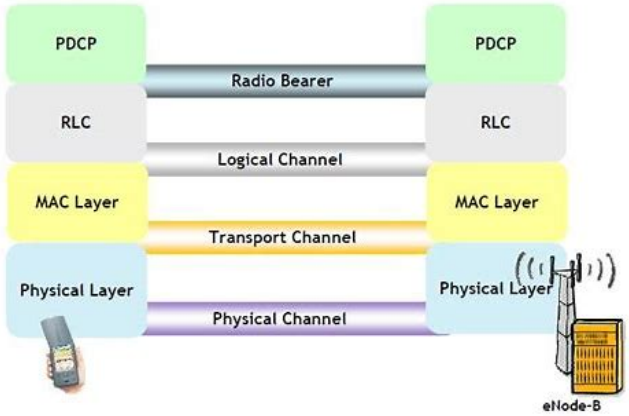
Downlink **Layer 2** Structure Protocol


IP
PayLoad
IP
PayLoad
PDCP
Compression
PDCP Hdr
PayLoad
PDCP Hdr
PayLoad
RLC
Concatenation
RLC Hdr
PayLoad
MAC
Transport format/
Modulation
MAC Hdr
PayLoad + Padding
Transport Block
PHY
Subframes
0
1
2
3
4
5
6
7
8
9
10ms Radio Frame


Receiver
Transmitter
Application
PDCP
RLC
MAC
CRC check
PHY
BLER > 10%
Demodulation
User Packet + Headers
CRC bits
Transport Block
Packet transmission
HARQ NACK
Packet re-transmission
HARQ ACK
Application
PDCP
RLC
MAC
PHY
Modulation
radio
radio
radio
radio

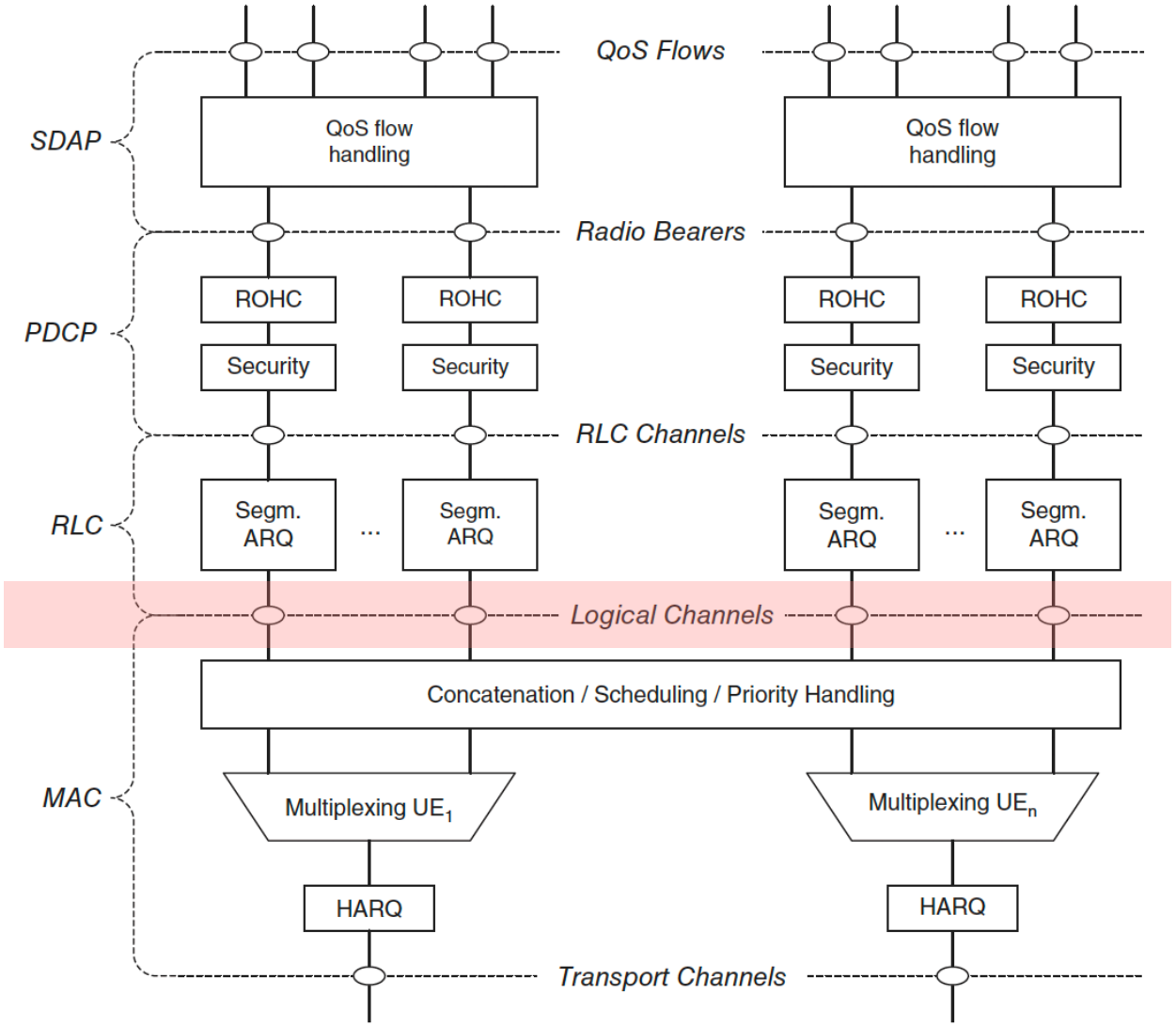
Logical / Transport / Physical channels

- 5G Data Channels
  - **Logical channel** (What?) can be one of two groups
    - Control channels: used for transfer of data from control plane
    - Traffic channels: used for transfer of user plane data
  - **Transport channel** (How?)
    - Multiplex logical data to be transported by physical layer and its channels over radio interface
  - **Physical channel**
    - Closest to actual transmission of the data over radio access network / 5G RF signal
    - Used to carry data over radio interface



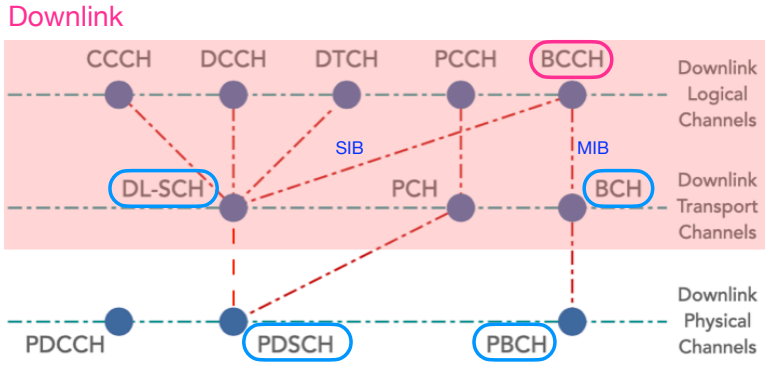
Logical channels

Channel	Name	Information carried	Direction
BCCH	Broadcast control channel	System information	DL
PCCH	Paging control channel	Paging messages	DL
CCCH	Common control channel	Signalling messages on SRB 0	UL, DL
DCCH	Dedicated control channel	Signalling messages on SRB 1–3	UL, DL
DTCH	Dedicated traffic channel	User plane traffic	UL, DL

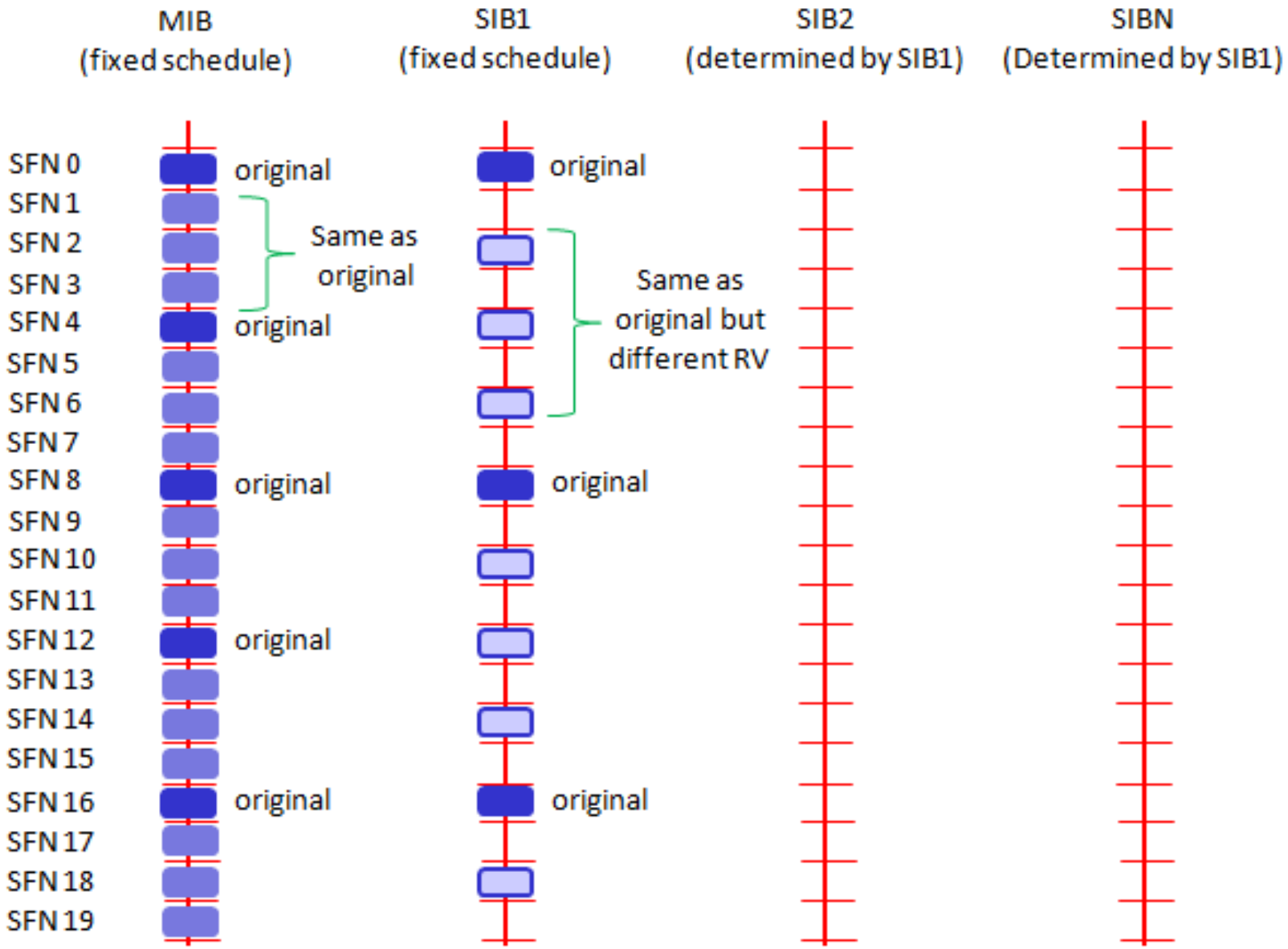


Downlink **Layer 2** Structure Protocol

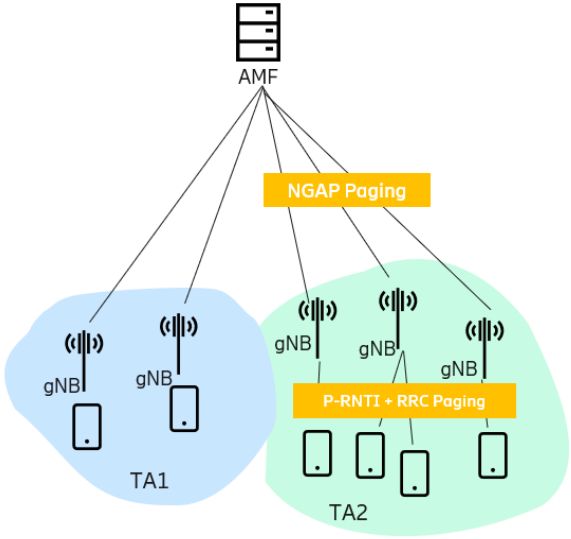
- **Broadcast Control Channel (BCCH)**
  - Used within downlink, and used for sending broadcast style information to the UEs within that cell
  - The system information transmitted is divided into different blocks
    - Master Information Block (MIB)
      - There is one MIB and mapped onto BCH transport channel and then to PBCH physical channel
    - System Information Block (SIB)
      - There are 9 system information blocks (SIB 1 to SIB 9)
      - These are mapped onto DL-SCH transport channel and then onto PDSCH physical channel

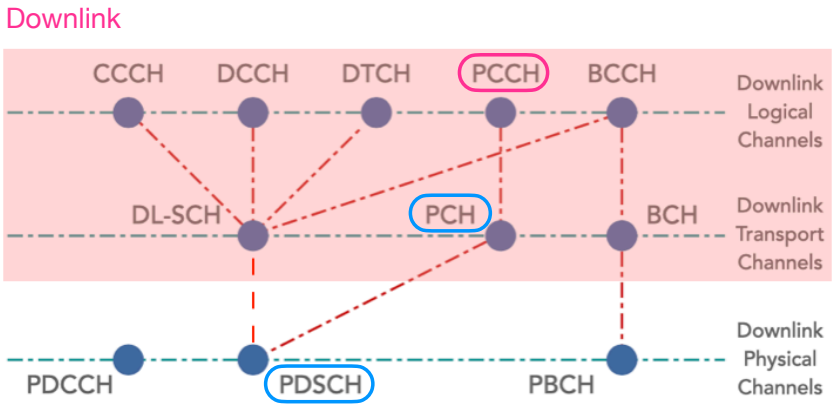


LTE MIB/SIBs scheduling

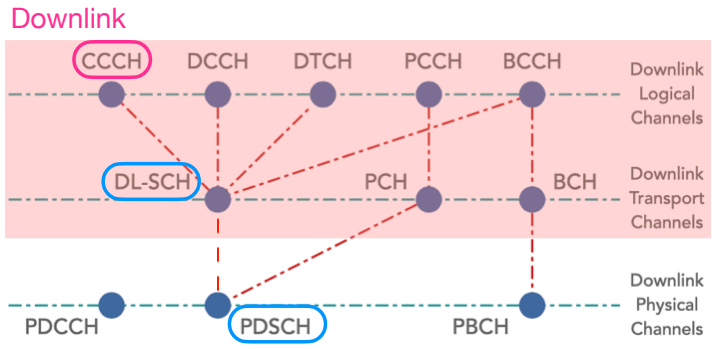


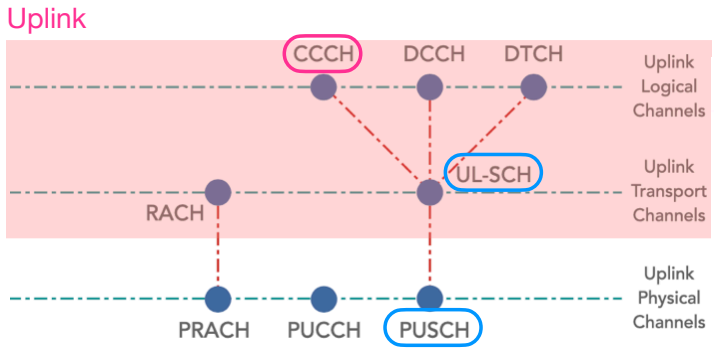
- **Paging Control Channel (PCCH)**
  - A downlink channel
  - Used to page the UEs whose location at cell level is not known to network
  - Paging message needs to be transmitted in multiple cells
  - PCCH is mapped to PCH transport channel and then to PDSCH physical channel

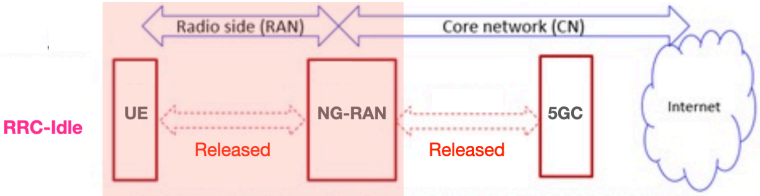




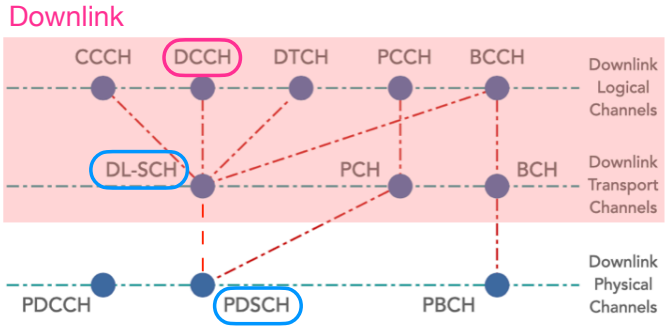
- **Common Control Channel (CCCH)**
  - Used on both downlink and uplink for transmitting control information to and from UEs
  - CCCH is used for initial access, i.e. those mobiles that do not have a radio resource control (RRC) connection

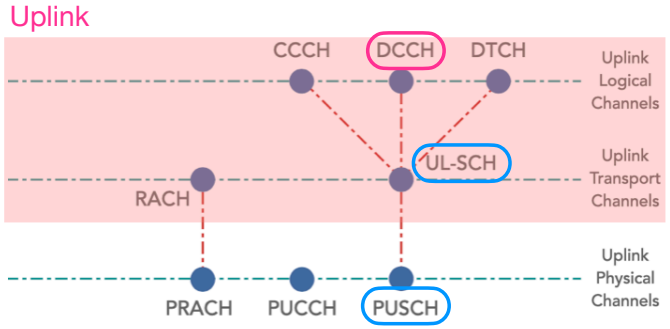


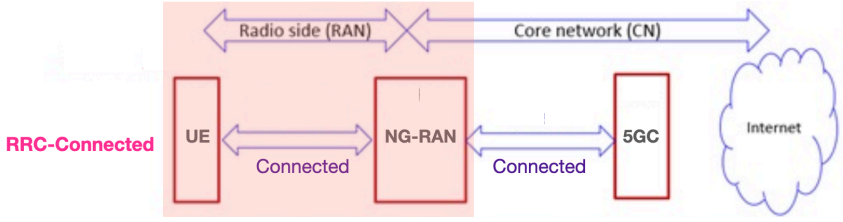




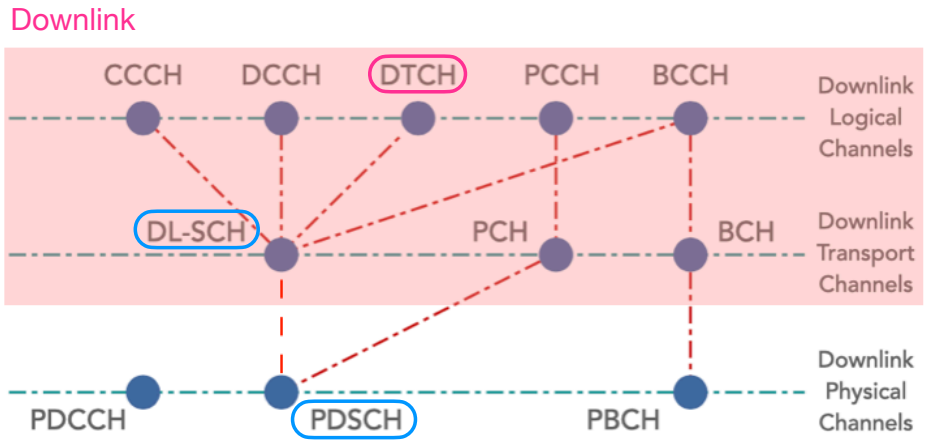
- **Dedicated Control Channel (DCCH)**
  - Used within uplink and downlink to carry dedicated control information between UE and network
  - Used by UE and network after a radio resource control (RRC) connection has been established

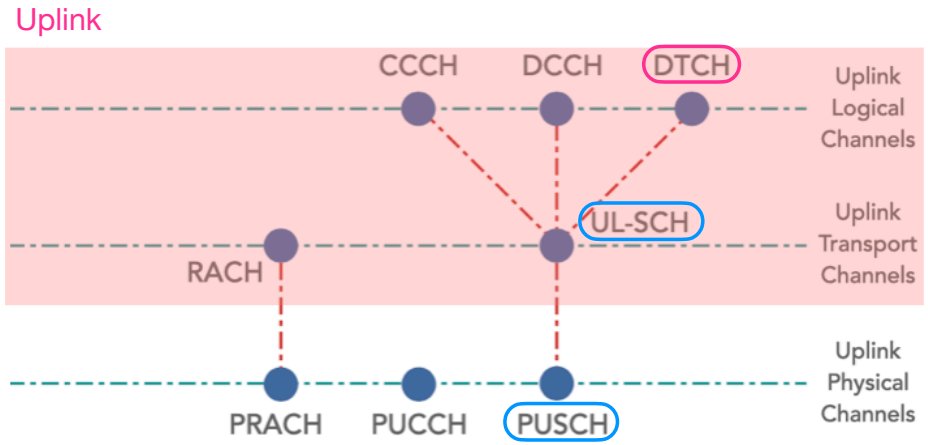






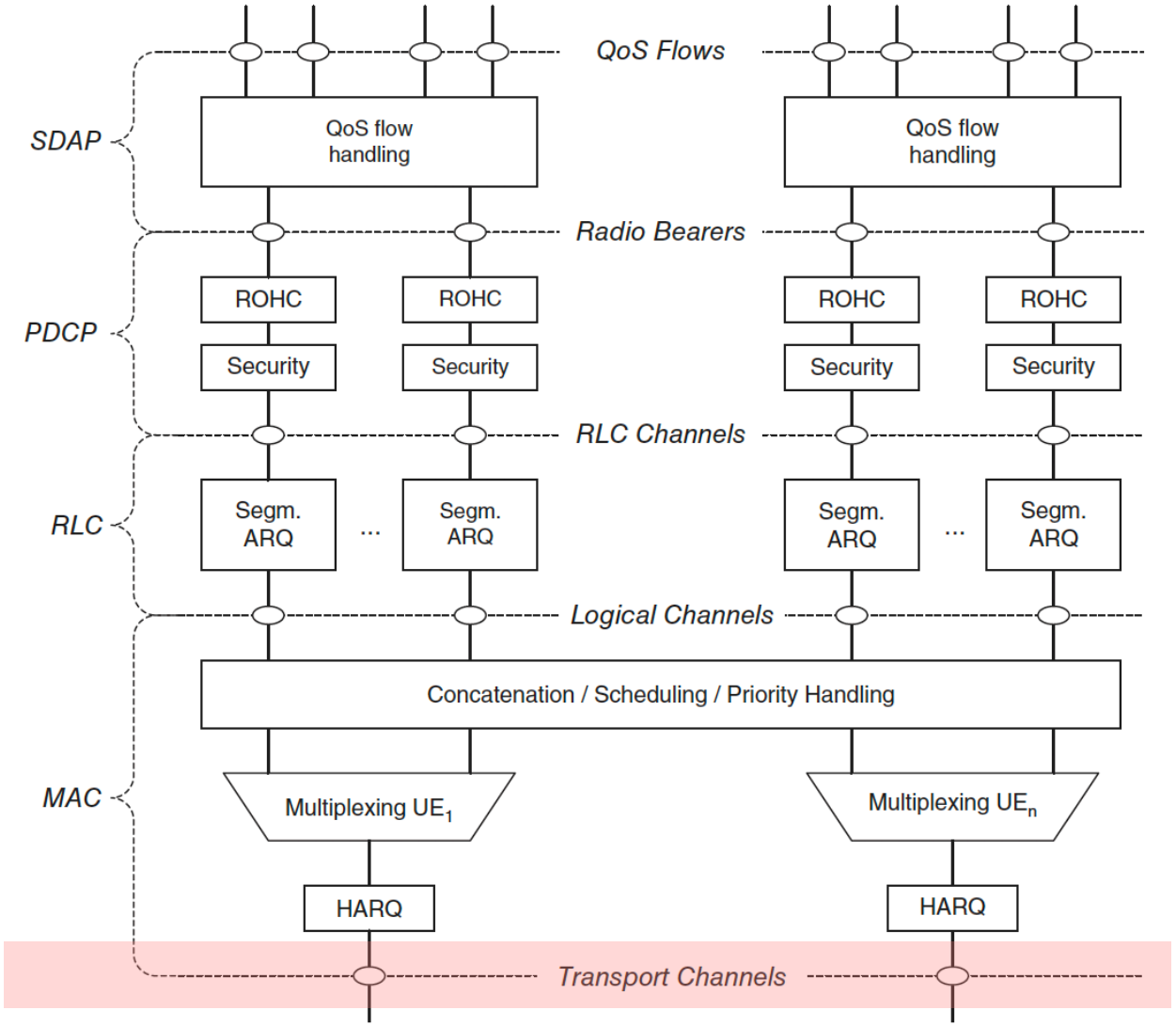
- **Dedicated Traffic Channel (DTCH)**
  - Present in both uplink and downlink
  - Dedicated to one UE and is used for carrying user information to and from a specific UE and network





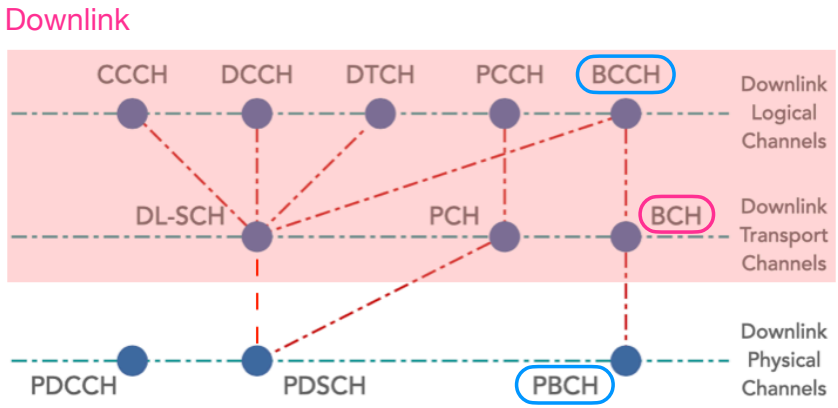
Transport channels

Channel	Name	Information carried	Direction
BCH	Broadcast channel	Master information block	DL
PCH	Paging channel	Paging messages	DL
DL-SCH	Downlink shared channel	Downlink traffic and signalling	DL
RACH	Random access channel	Random access requests	UL
UL-SCH	Uplink shared channel	Uplink traffic and signalling	UL

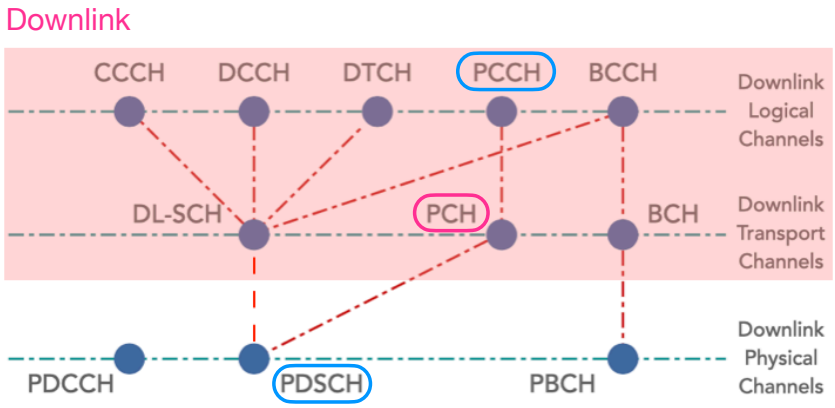


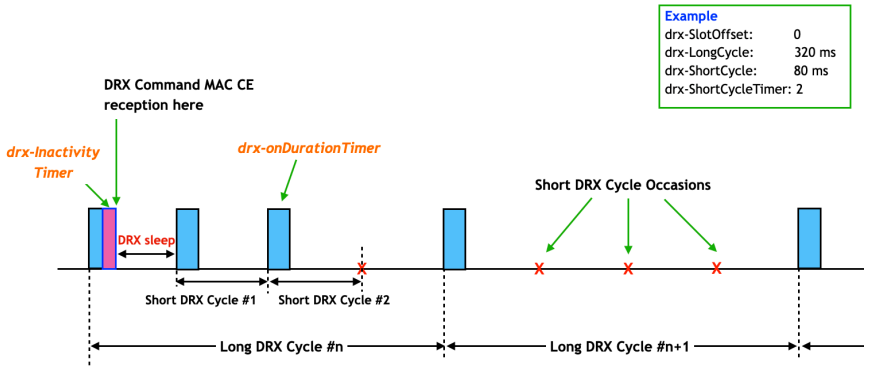
Downlink **Layer 2** Structure Protocol

- **Broadcast Channel (BCH)**
  - Used in downlink only for transmitting BCCH system information and specifically Master Information Block (MIB) information

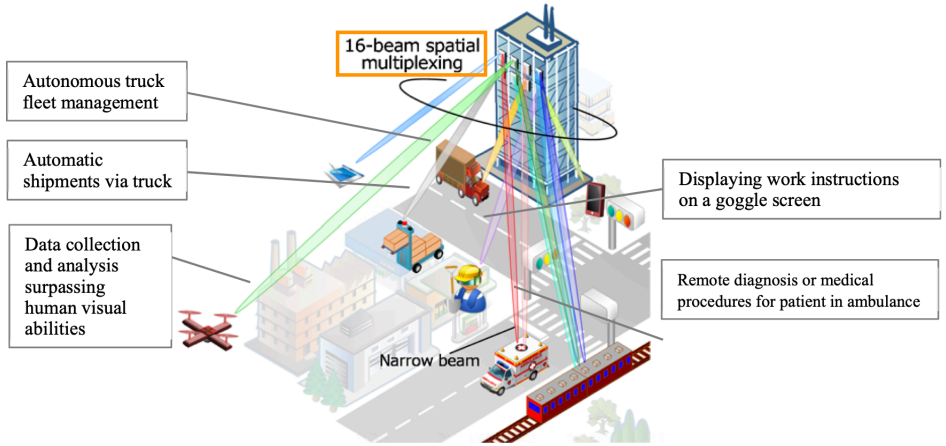


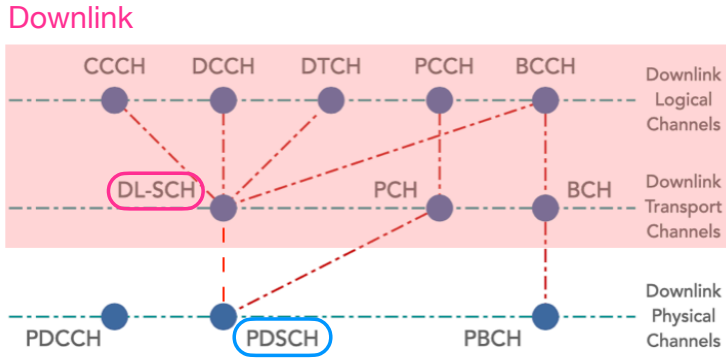
- **Paging Channel (PCH)**
  - Used for carrying paging information from PCCH logical channel
  - PCH supports discontinuous reception (DRX) to enable UE to save battery power by waking up at a specific time to receive PCH
  - PCH must be broadcast over the entire cell as a single message, or where beam forming is used



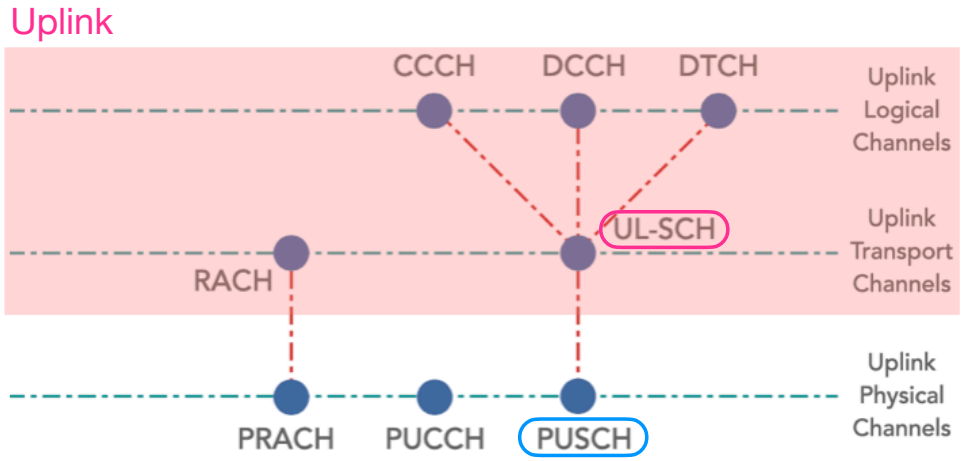


- **Downlink Shared Channel (DL-SCH)**
  - A downlink only channel
  - The main transport channel used for transmitting downlink data
  - Supports all the key 5G NR features
    - Dynamic rate adaptation
    - HARQ
    - Channel aware scheduling
    - Spatial multiplexing
  - Also used for transmitting some parts of the BCCH system information, specifically SIB

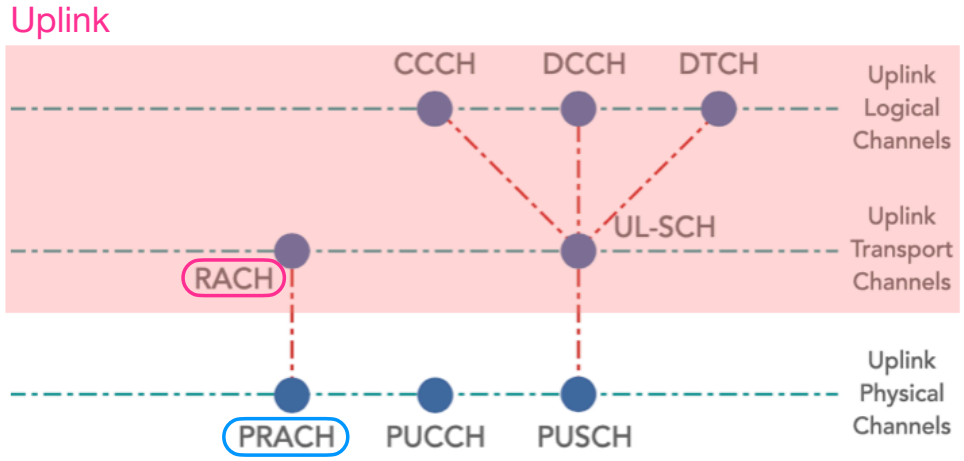


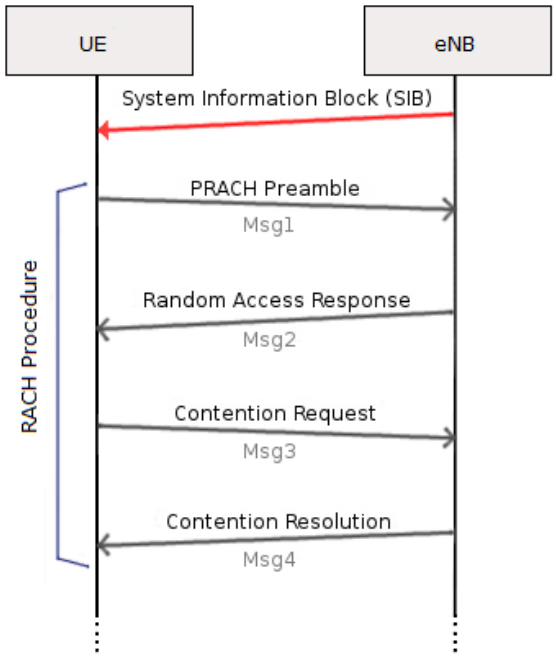


- **Uplink Shared Channel (UL-SCH)**
  - The uplink counterpart to the DL-SCH, i.e., the uplink transport channel used for transmission of uplink data



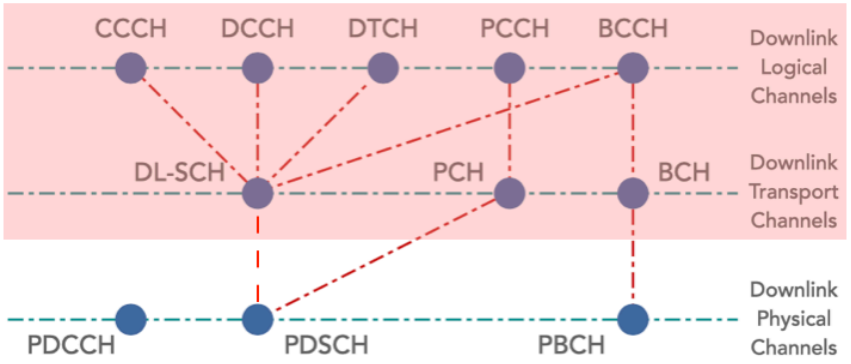
- **Random-Access Channel (RACH)**
  - Carry the random access preamble which is used to overcome the message collisions that can occur when UEs access the system simultaneously





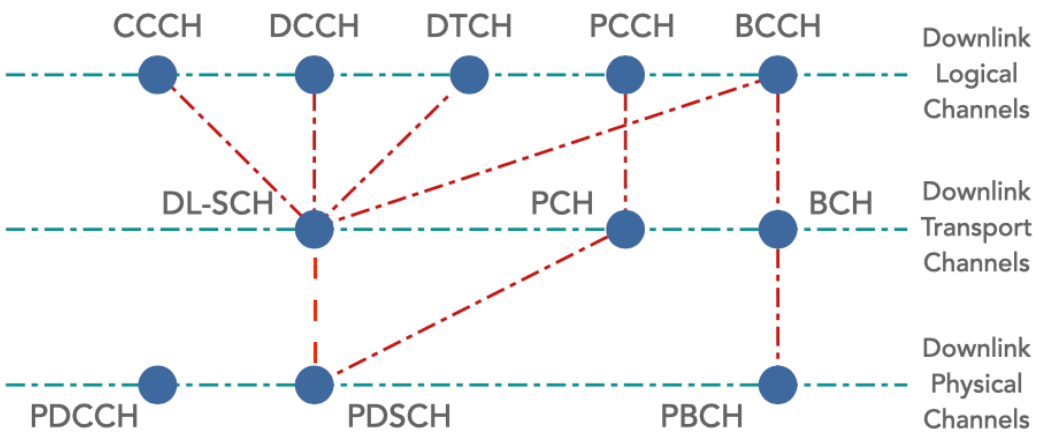
- The mapping between logical channels and transport channels in the downlink

Transport channel Logical channel	BCH (broadcast channel)	PCH (paging channel)	DL-SCH (downlink Shared channel)
BCCH (Broadcast Control Channel)	X		X
PCCH (Paging Control Channel)		X	
CCCH (Common Control Channel)			X
DCCH (Dedicated Control Channel)			X
DTCH (Dedicated Traffic Channel)			X



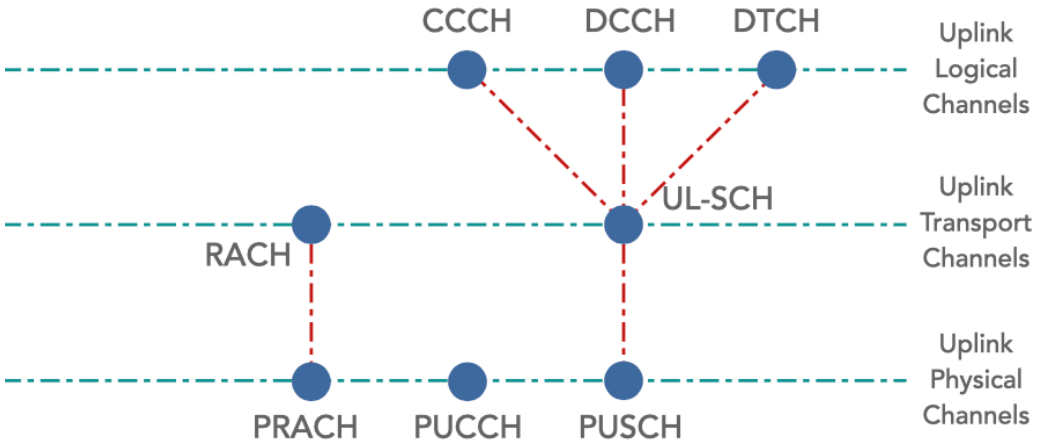
Downlink channel mapping

Downlink



5G NR downlink logical, transport & physical channel mapping

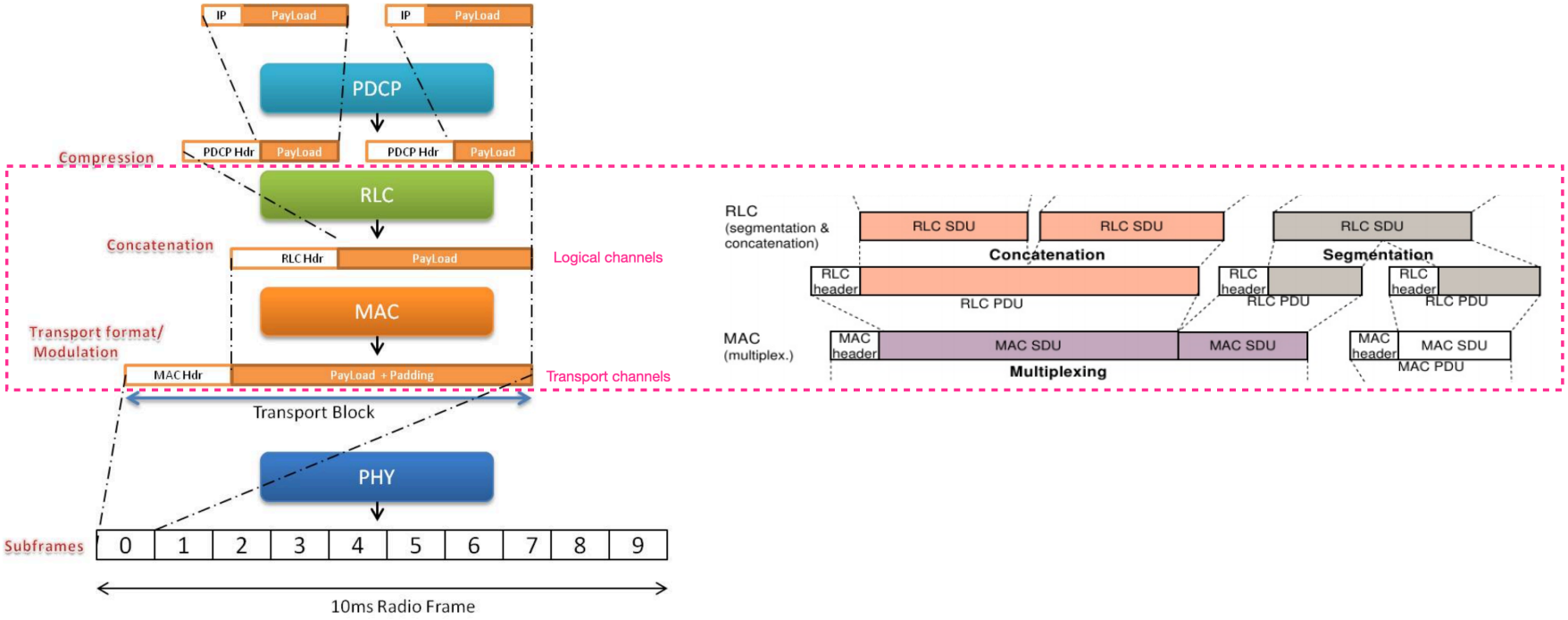
Uplink



5G NR uplink logical, transport & physical channel mapping

MAC layer (cont.)

- Mapping function
  - Multiplex RLC PDUs from different logical channels
  - Concatenate different RLC PDUs from the same logical channel
  - Each logical channel is assigned a scheduling priority and Prioritized Bit Rate (PBR)
  - On receipt of an uplink grant
    - UE MAC fills each MAC PDU with data from highest priority logical channel up to PBR
    - Then, Cycles through lower priority logical channels in sequence

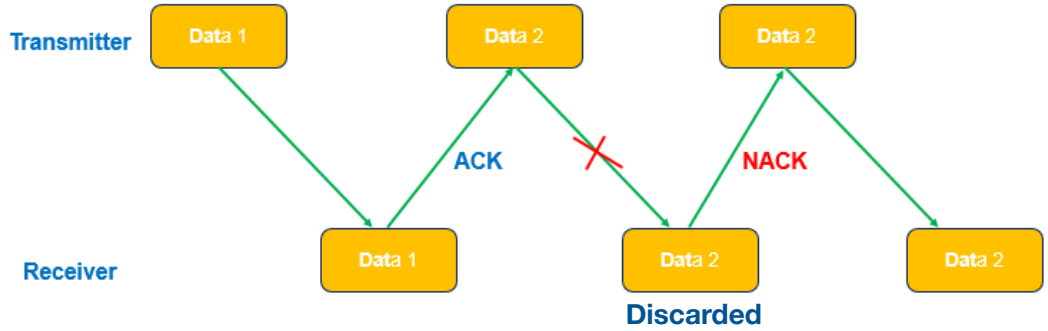


- NR MAC includes a new functionality to restrict data from certain logical channels to be sent only on certain numerologies/cells
- MAC is also responsible for handling Hybrid ARQ (HARQ) processing and retransmissions

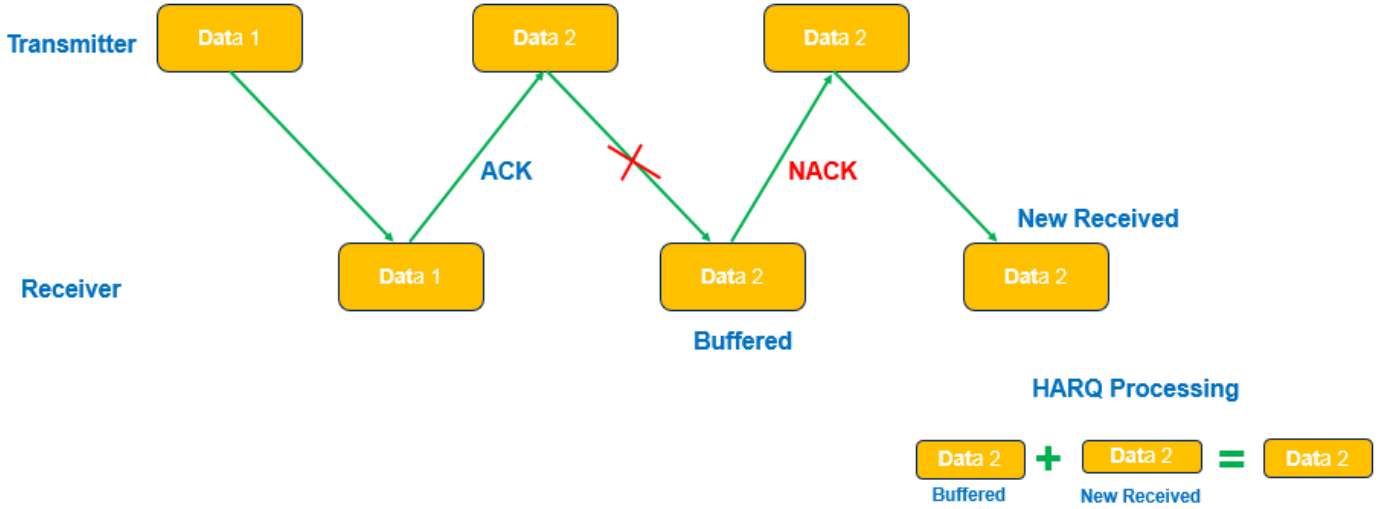
μ	Subcarrier spacing, $\Delta f = 2^{\mu} \times 15$kHz	1 PRB = 12 subcarriers	Cyclic Prefix	Support for Data	Support for PSS, SSS and PBCH
0	15 kHz	180 kHz	Normal	Yes	Yes
1	30 kHz	360 kHz	Normal	Yes	Yes
2	60 kHz	720 kHz	Normal, Extnd	Yes	No
3	120 kHz	1440 kHz	Normal	Yes	Yes
4	240 kHz	2880 kHz	Normal	No	Yes
5	480 kHz	5760 kHz	Normal		

- **HARQ** (Hybrid Automatic Repeat Request)
  = ARQ + FEC (Forward Error Correction)/Soft Combining
  - **ARQ** (Automatic Repeat Request)
    - If sender doesn't receive Acknowledgement (ACK) before timeout, the receiver discards the bad packet and sender shall re-transmit the packet
  - **Soft Combining**
    - An error correction technique in which the bad packets are not discarded but stored in a buffer
    - Basic idea: two or more packets received with insufficient information can be combined together in such a way that total signal can be decoded

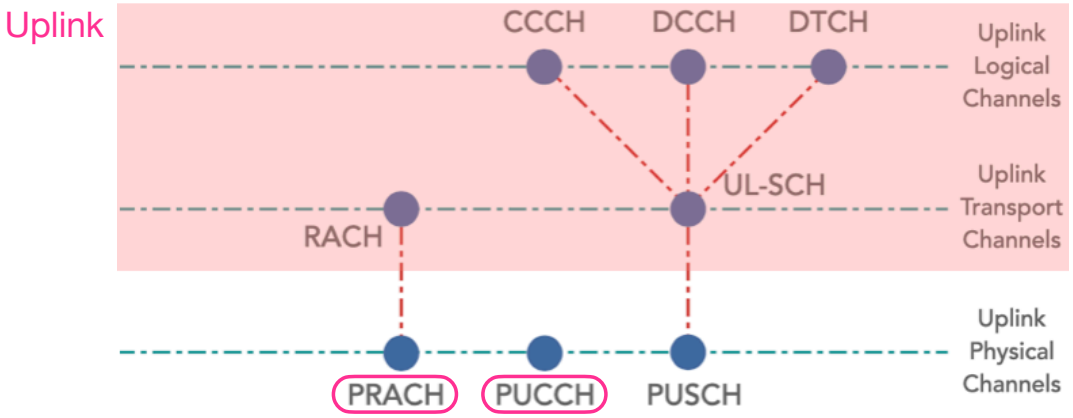
Automatic Repeat Request (ARQ)



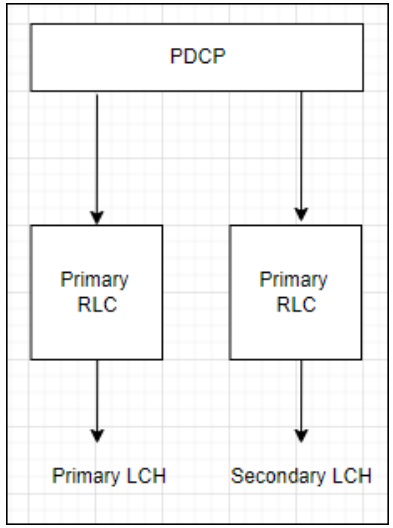
Hybrid Automatic Repeat Request (HARQ)



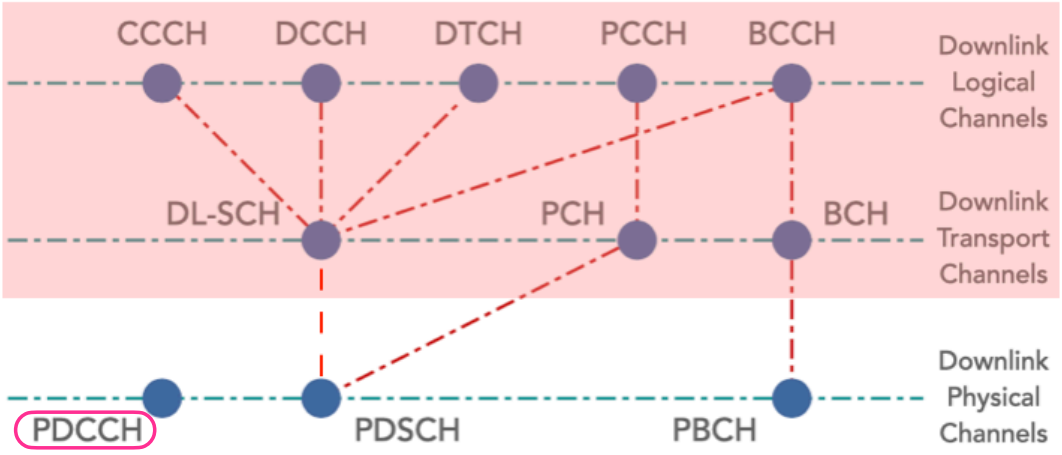
- MAC protocol supports several control elements that are used for signaling and configuration of user plane
  - **Scheduling Request (SR)**
    - Used for requesting UL-SCH (Uplink Shared Channel) resources for new transmission
    - SR can be transmitted on Physical Uplink Control Channel (PUCCH) resources if available or using Random Access (RACH) procedure

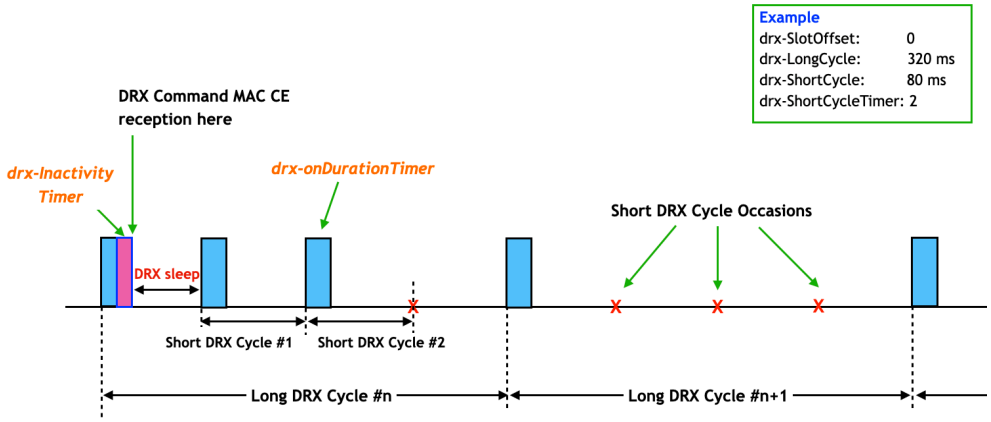


- **Buffer Status reports**
  - Generated by MAC to inform network about pending uplink data in the buffer
- **PDCP duplication**
  - Can be enabled/disabled using a MAC control element
  - If PDCP duplication is not enabled
    - PDCP packet will be transmitted to an RLC entity and RLC entity will send to MAC layer
  - If PDCP duplication is enabled
    - PDCP packet will be transmitted to 2 RLC entities, i.e Primary RLC entity and Secondary RLC entity



- MAC includes several power saving functionalities
  - When Discontinuous reception (DRX) is configured
    - Controls UE's PDCCH (Physical Downlink Control Channel) monitoring activity
    - Saves UE power consumption
  - When DC is configured
    - Secondary Cells (SCells) can be activated or deactivated using MAC control elements to save power



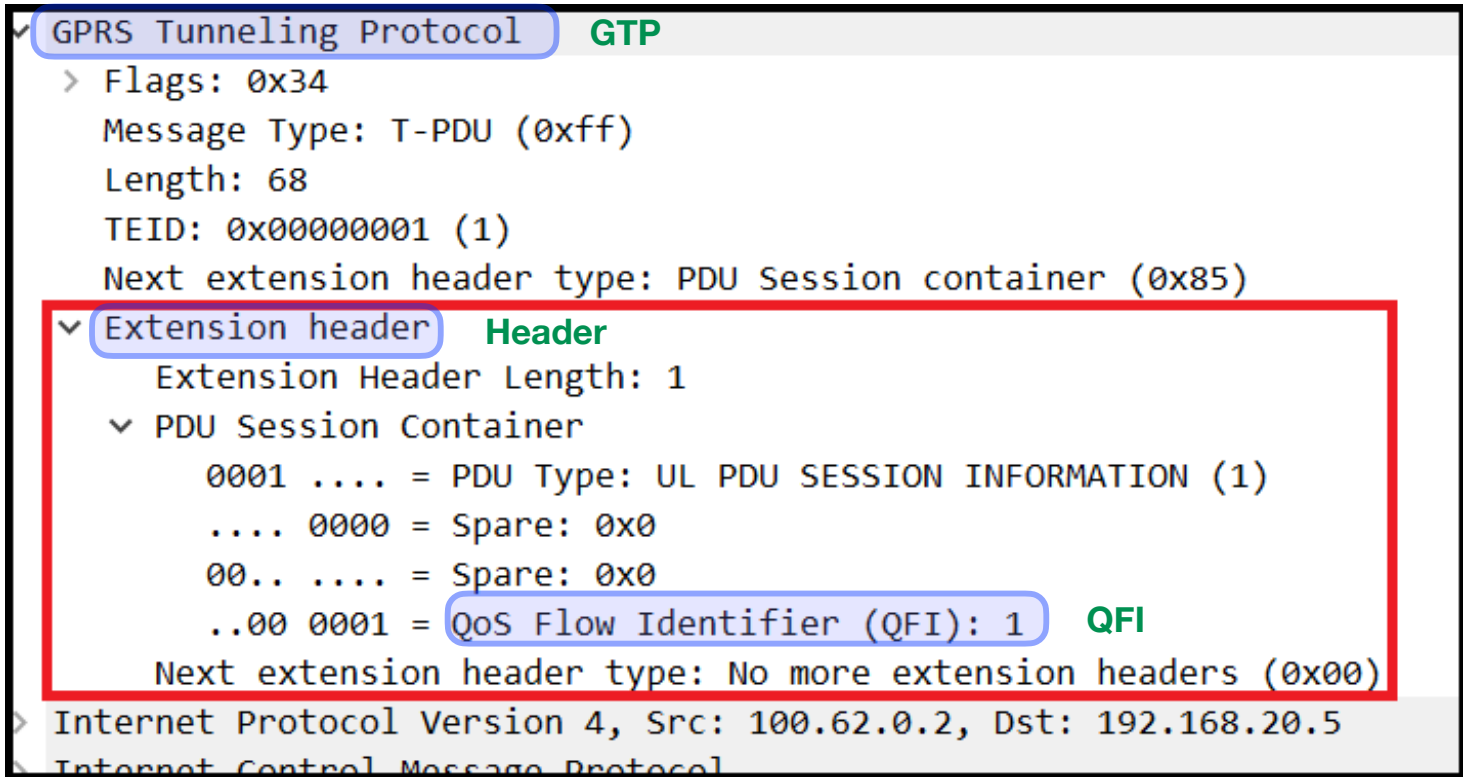


1. Introduction
2. NG-RAN Architecture
3. NR User Plane
4. **Supporting QoS with 5GC**
5. NR Control Plane

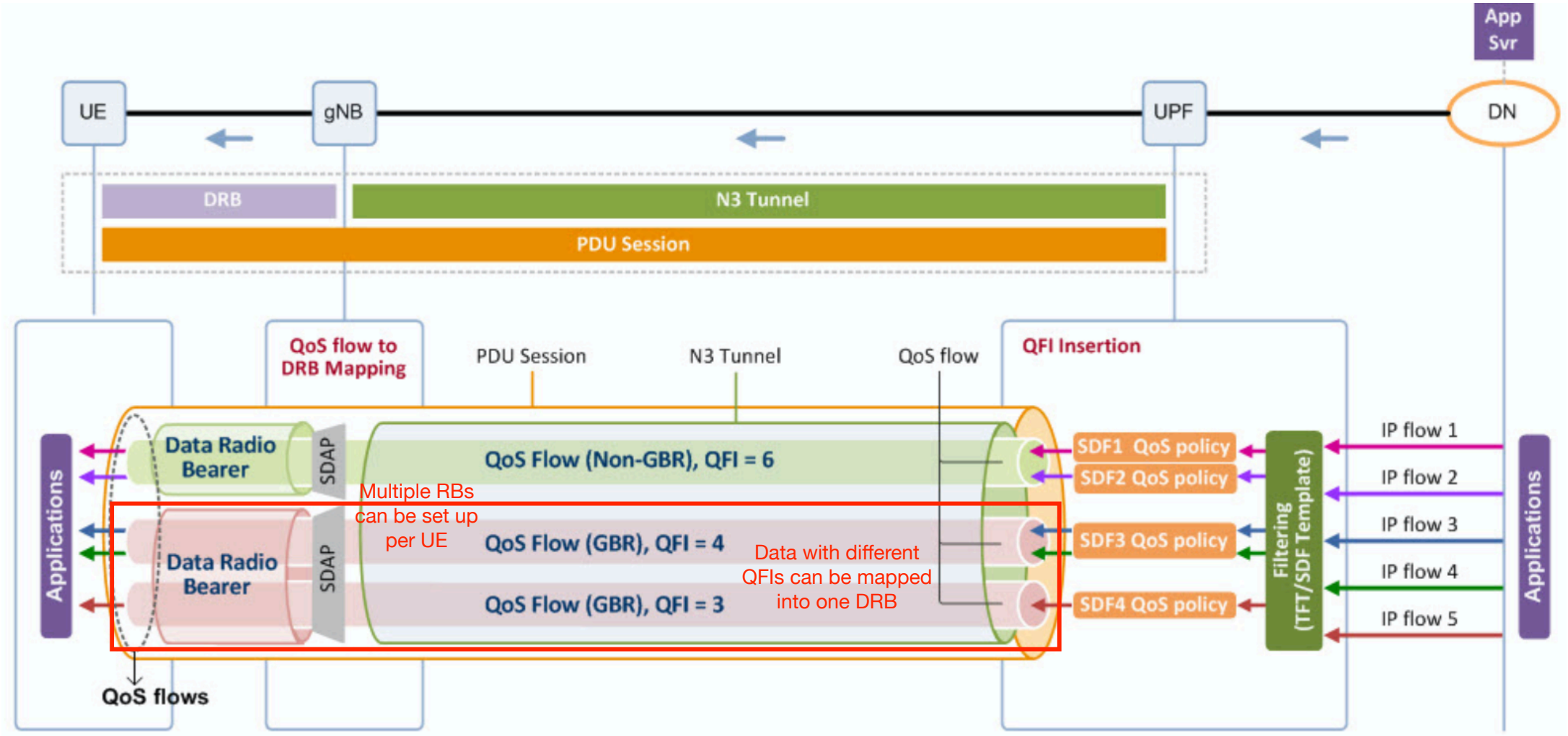
4. Supporting QoS with 5GC

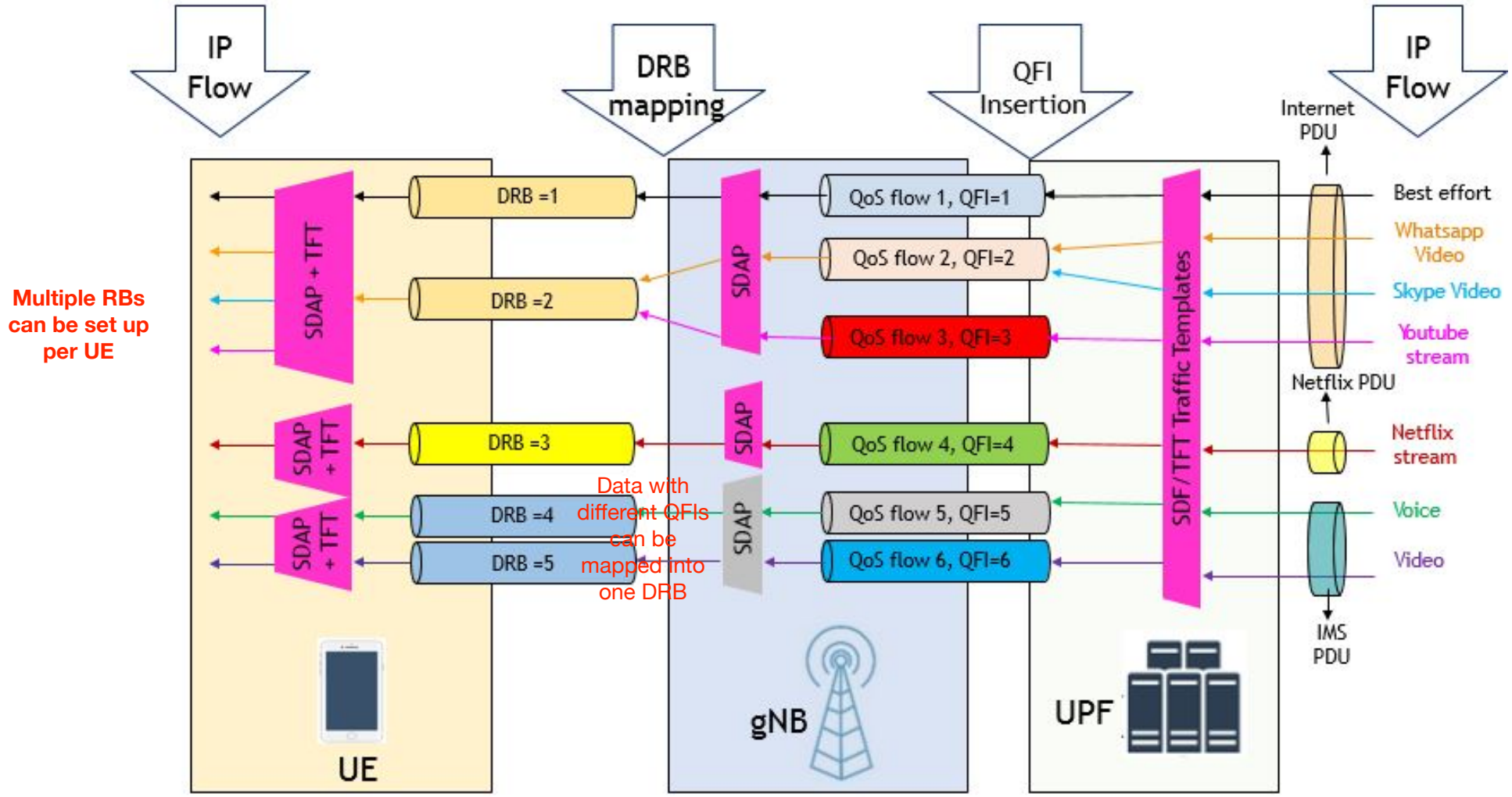
- **Downlink**
  - Each downlink data packet is marked by 5GC with a QFI indicating the QoS requirement for the packet
- **Uplink**
  - Such marking of an IP packet to QFI is performed by NAS layer, based on its configuration

- QFI
  - Carried in GTP header and provided to gNB with each packet



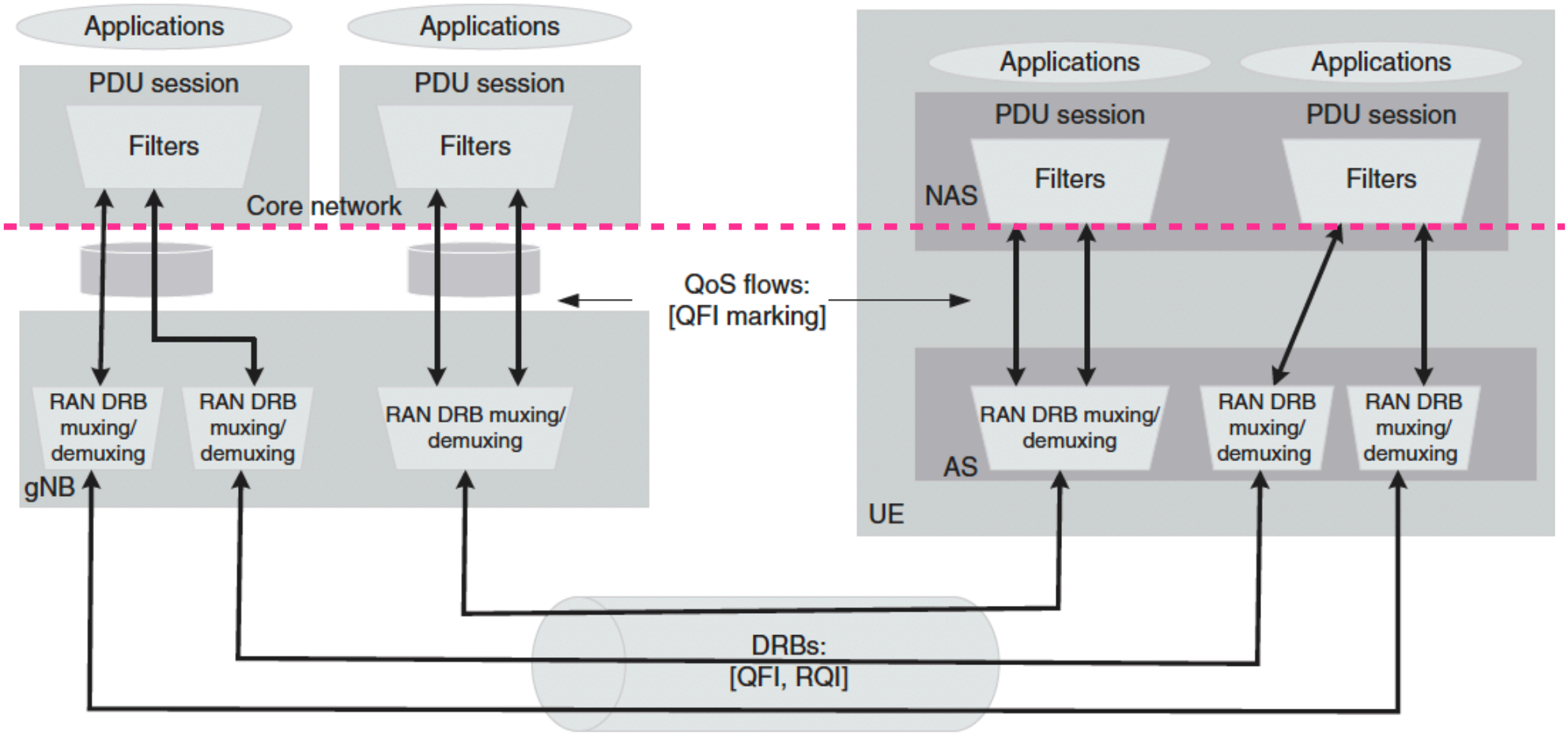
- Radio Bearers
  - Used for transferring data over radio interface
    - RRC messages are carried by SRBs
    - User data is transferred over DRB
  - Each radio bearer provides a certain QoS for the data exchanged over it
  - Multiple RBs can be set up per UE as needed to provide different QoS requirements for different services


App Svr
UE
gNB
UPF
DN
DRB
N3 Tunnel
PDU Session
QoS flow to DRB Mapping
PDU Session
N3 Tunnel
QoS flow
QFI Insertion
Applications
Data Radio Bearer
SDAP
Data Radio Bearer
SDAP
QoS Flow (Non-GBR), QFI = 6
QoS Flow (GBR), QFI = 4
QoS Flow (GBR), QFI = 3
Multiple RBs can be set up per UE
Data with different QFIs can be mapped into one DRB
SDF1 QoS policy
SDF2 QoS policy
SDF3 QoS policy
SDF4 QoS policy
Filtering (TFT/SDF Template)
IP flow 1
IP flow 2
IP flow 3
IP flow 4
IP flow 5
Applications
QoS flows


IP Flow
DRB mapping
QFI Insertion
IP Flow
Internet PDU
Multiple RBs can be set up per UE
SDAP + TFT
SDAP + TFT
SDAP + TFT
DRB =1
DRB =2
DRB =3
DRB =4
DRB =5
SDAP
SDAP
SDAP
QoS flow 1, QFI=1
QoS flow 2, QFI=2
QoS flow 3, QFI=3
QoS flow 4, QFI=4
QoS flow 5, QFI=5
QoS flow 6, QFI=6
SDF / TFT Traffic Templates
Best effort
Whatsapp Video
Skype Video
Youtube stream
Netflix PDU
Netflix stream
Voice
Video
IMS PDU
Data with different QFIs can be mapped into one DRB
UE
gNB
UPF

- RAN is responsible for
  - Setting up DRBs supporting different QoS
  - Data to be sent on the DRB that meets its QoS requirement
- RAN node has the flexibility to decide when and how many DRBs are to be set up for UE, e.g.
  - Data with different QFIs can be mapped into one DRB, provided that the QoS of the DRB meets the QoS requirements of all the QFIs mapped to it

•The mapping of QoS flows to DRBs



QoS flow mapping in the CN, RAN, and UE.

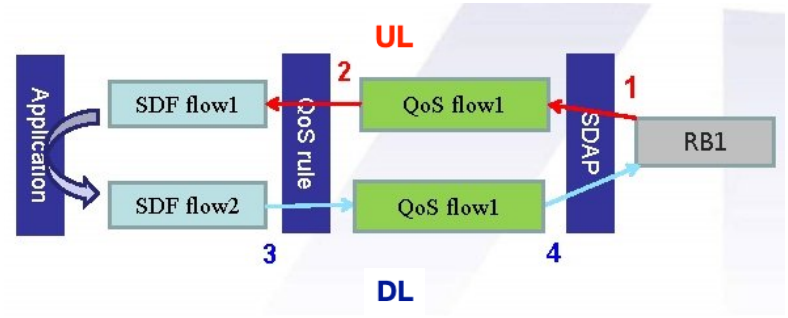
RQI：Reflective QoS Indicator

- **Downlink**
  - This mapping can be decided by gNB without any preconfiguration to UE by simply sending data for QFI on a DRB

- **Uplink**
  - The mapping information from QFI to DRB has to be provided to UE by gNB
    - Using RRC Reconfiguration message (called explicit signaling) or
    - Using a SDAP header (called AS reflective mapping)

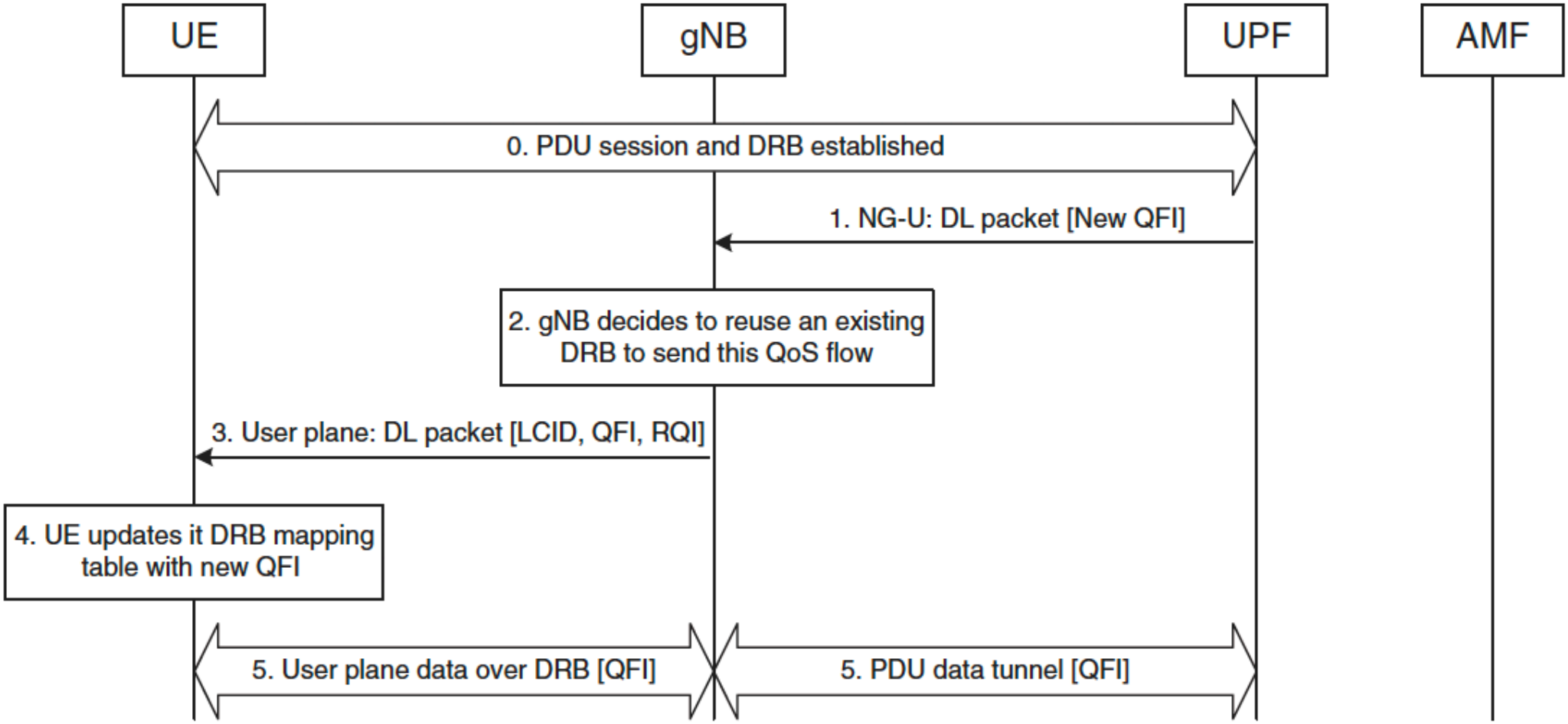
- With AS reflective mapping
  - The mapping table for a QFI can be updated to use the DRB on which the UE received a downlink packet for QFI with a RQI (Reflective QoS Indicator) bit set in SDAP header
  - This allows RAN to change the uplink mapping dynamically using user-plane signaling without using RRC

AS reflective QoS

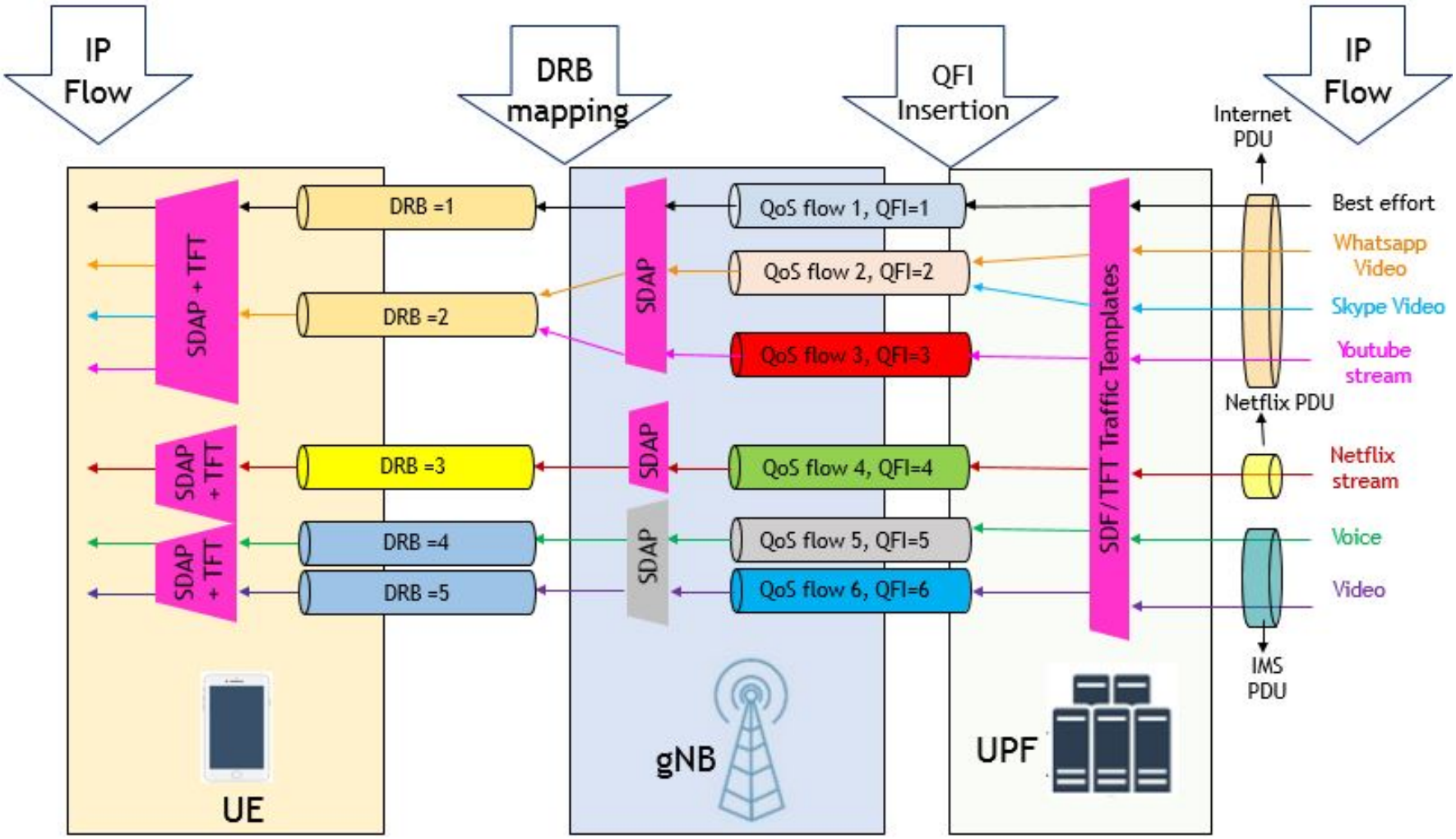


To minimize the control signaling between network and UE

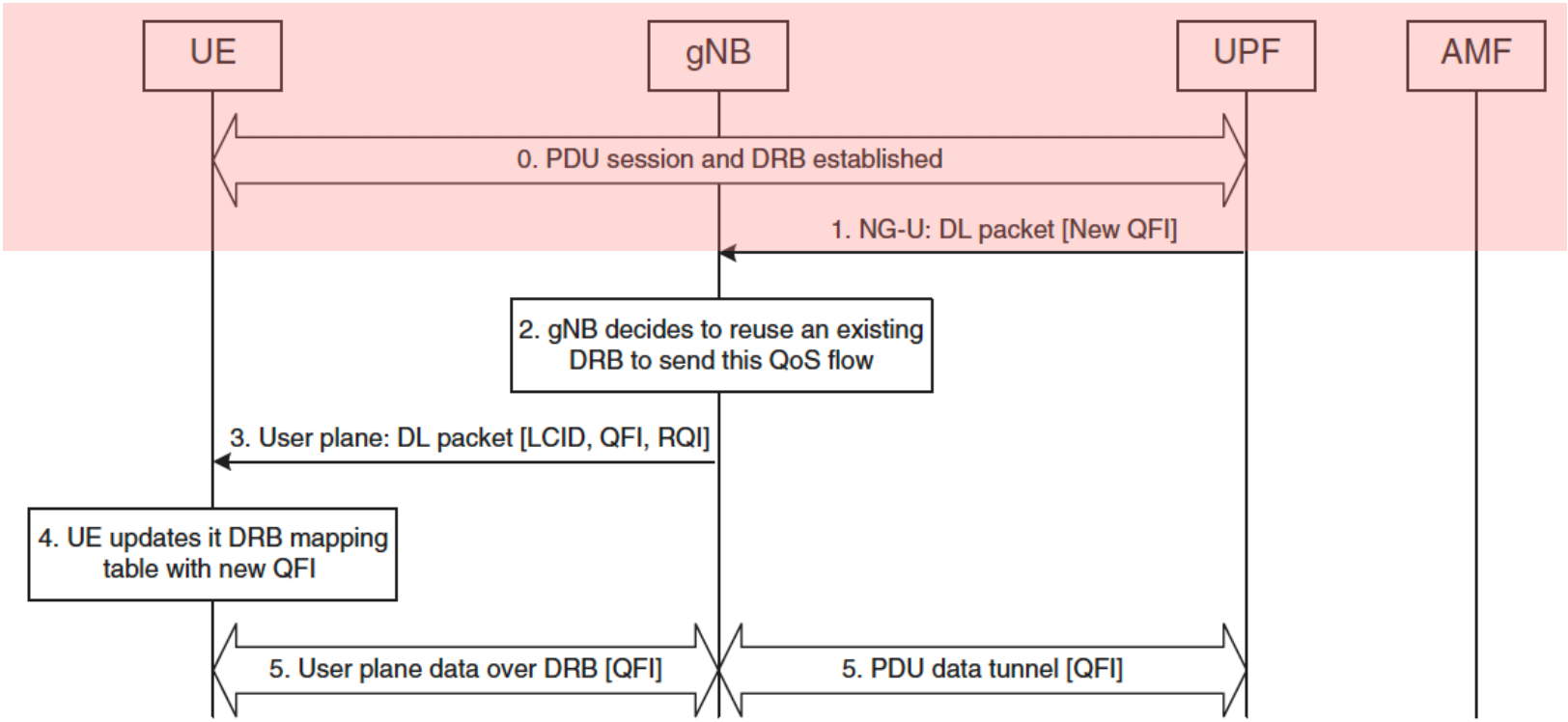
- The signaling for allocation of the QoS flow to a DRB



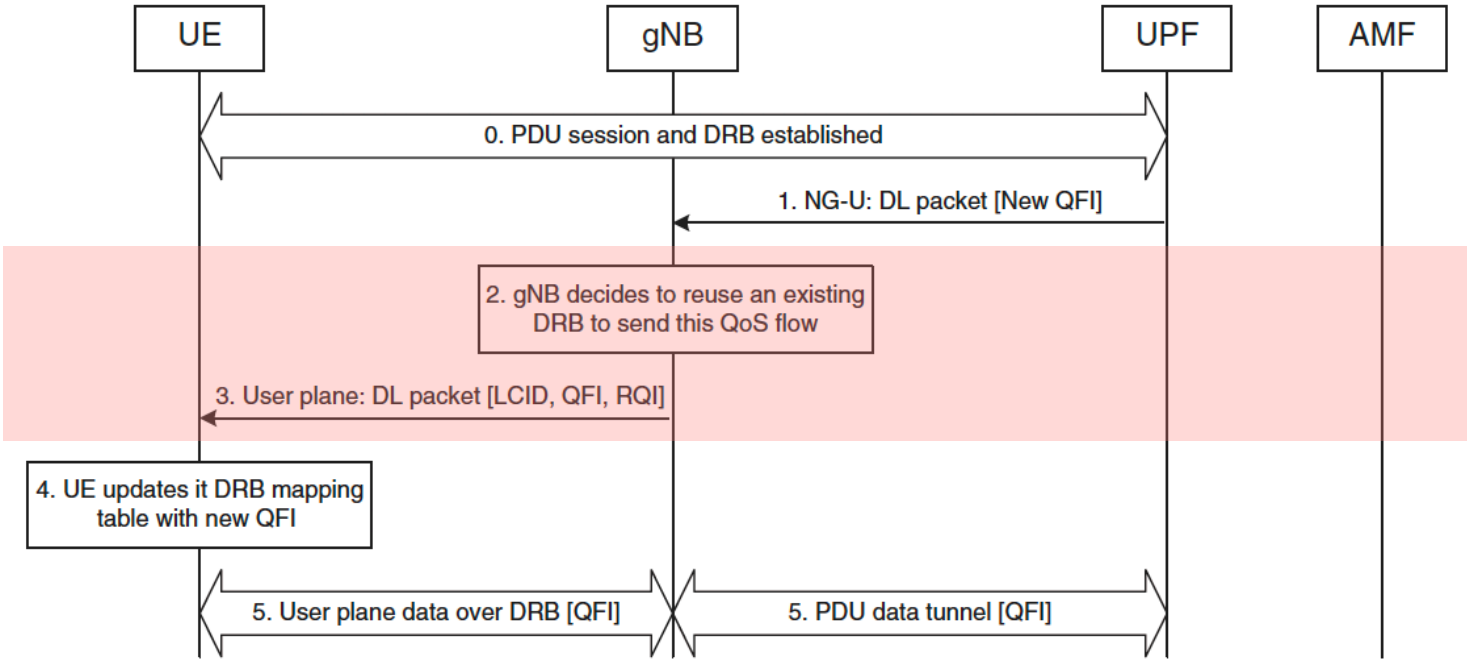
An example **signaling** for a UE configuration of the DRB mapping for a new QoS flow using AS reflective mapping.


IP Flow
DRB mapping
QFI Insertion
IP Flow
Internet PDU
Best effort
Whatsapp Video
Skype Video
Youtube stream
Netflix PDU
Netflix stream
Voice
Video
IMS PDU
SDAP + TFT
SDAP + TFT
SDAP + TFT
DRB =1
DRB =2
DRB =3
DRB =4
DRB =5
SDAP
SDAP
SDAP
QoS flow 1, QFI=1
QoS flow 2, QFI=2
QoS flow 3, QFI=3
QoS flow 4, QFI=4
QoS flow 5, QFI=5
QoS flow 6, QFI=6
SDF / TFT Traffic Templates
UE
gNB
UPF

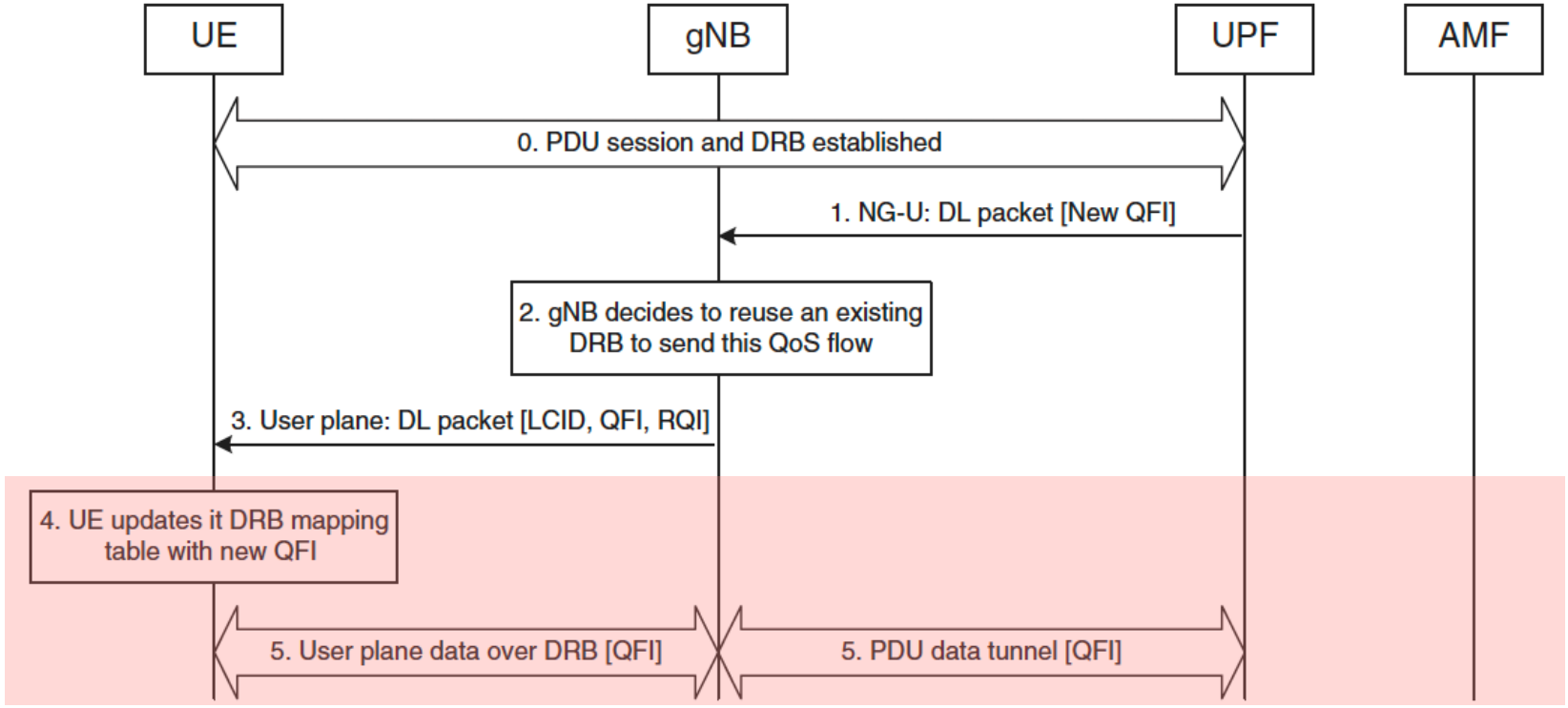
- 0. UE is registered with network, PDU sessions and DRBs are established to send data between UE and network
- 1. gNB receives a new data packet with a new QFI marking



- 2. gNB decides to send this QoS flow on an existing DRB that meets the QoS requirement and to use AS reflective mapping
- 3. gNG sends the data packet on the chosen DRB with the QFI and RQI bit set in SDAP header



- 4. UE, upon receipt of the packet with RQI bit set, updates the mapping table to send UL data with this QFI on this DRB
- 5. Data for this QoS flow are exchanged over DRB



1. Introduction
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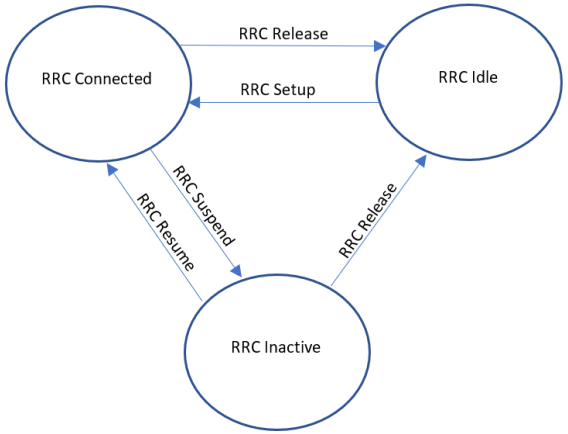
5. **NR Control Plane**

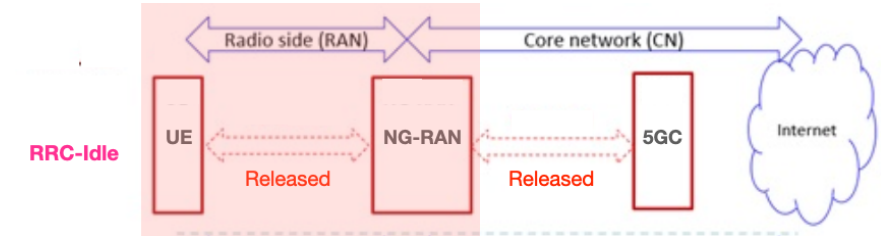
5. NR Control Plane

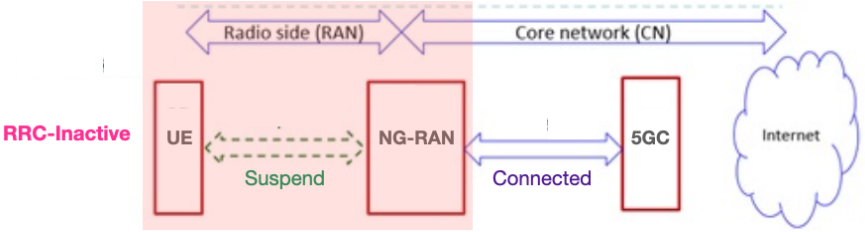
- RRC
  - A control-plane protocol used to configure and manage radio interface connection
  - Provide a set of procedures
    - Connection establishment
    - Security configuration
    - Mobility
    - Physical layer
    - User-plane configurations

5.1 RRC States

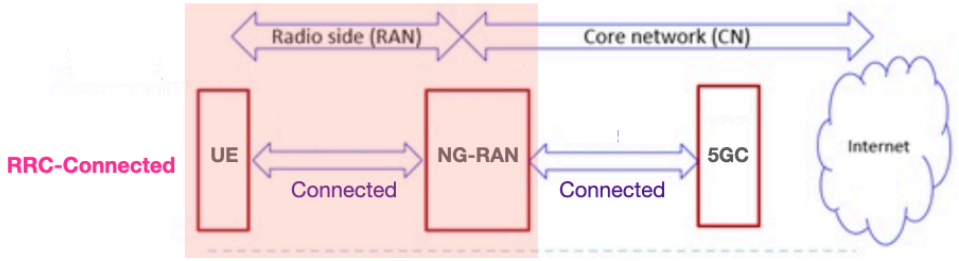
- RRC supports three different UE states
  - IDLE
  - INACTIVE
  - CONNECTED
- **IDLE**
  - Similar to LTE
  - Not in active communication
- **INACTIVE**
  - Not in active communication

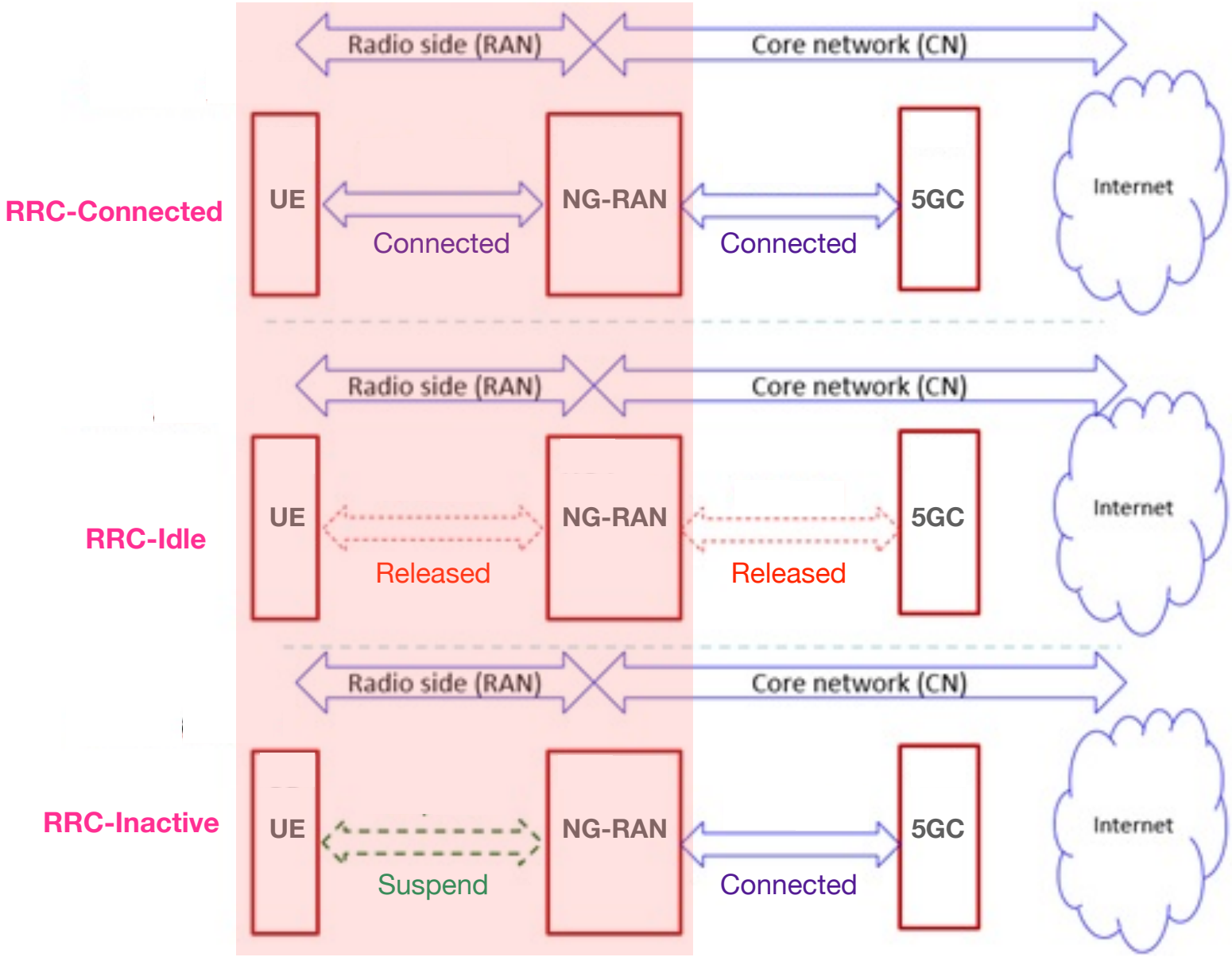






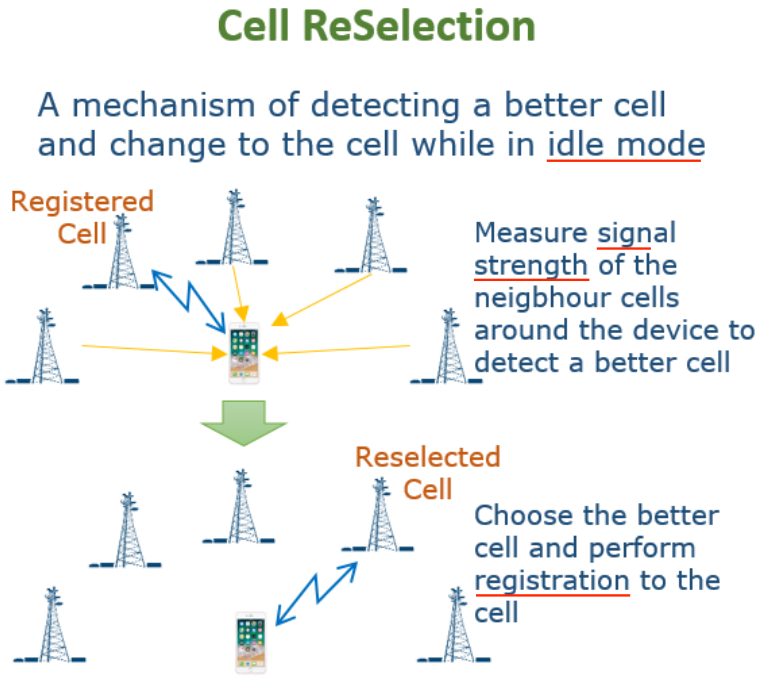
- **CONNECTED**
  - Similar to LTE
  - A UE in active communication exchanging data with network
  - Physical channels and user-plane protocols are configured and set up
  - UE mobility is controlled by network using RRC messages



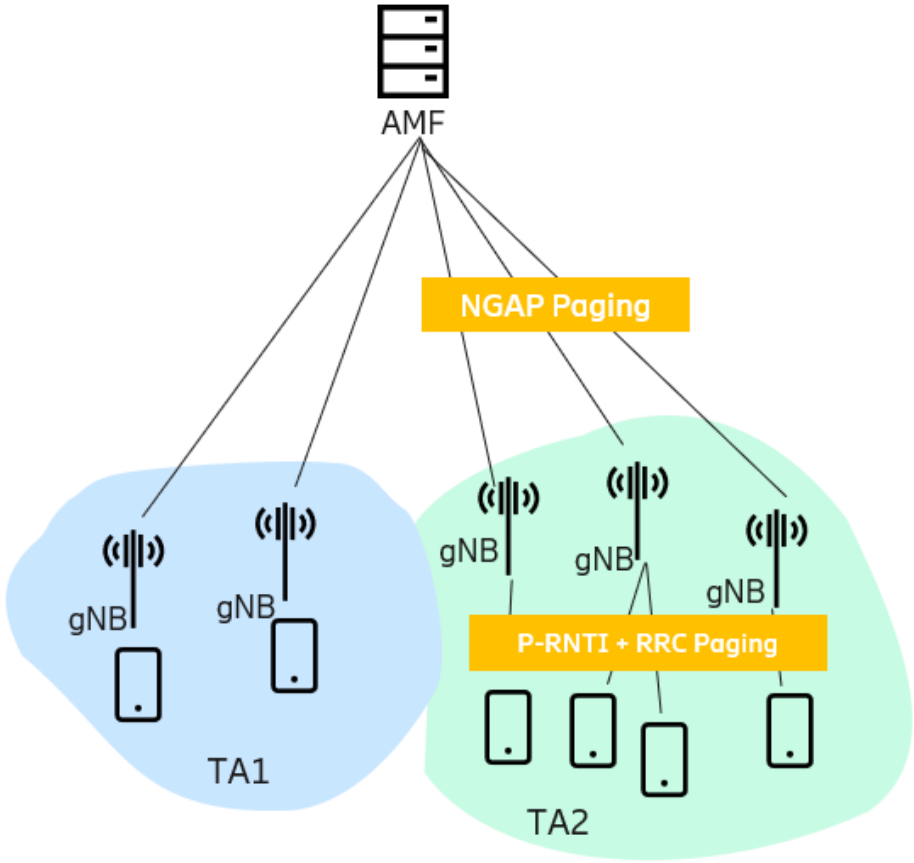

RRC-Connected
Radio side (RAN)
Core network (CN)
UE
Connected
NG-RAN
Connected
5GC
Internet
RRC-Idle
Radio side (RAN)
Core network (CN)
UE
Released
NG-RAN
Released
5GC
Internet
RRC-Inactive
Radio side (RAN)
Core network (CN)
UE
Suspend
NG-RAN
Connected
5GC
Internet

- A UE context is created in RAN, which includes the information about
  - Connection to CN
  - User plane
  - Physical layer configurations
- UE context is cleared when UE leaves RRC CONNECTED and goes back to RRC IDLE

- When a UE is in IDLE or INACTIVE state, a UE
  - Perform cell reselection to camp on the best cell
  - Stay up to date with System Information Broadcast (SIB) information
  - Monitor Paging for downlink data and Public warning messages

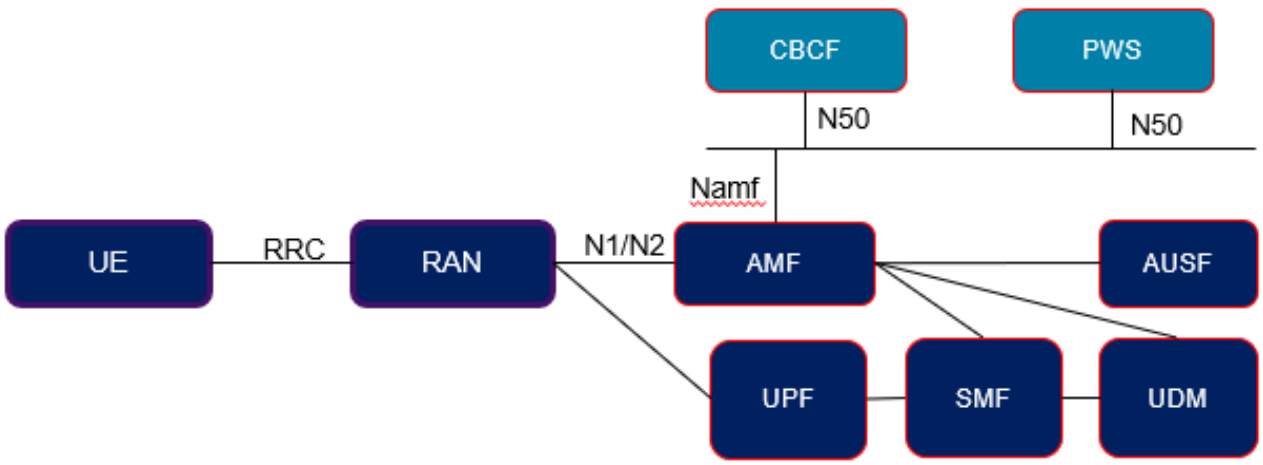


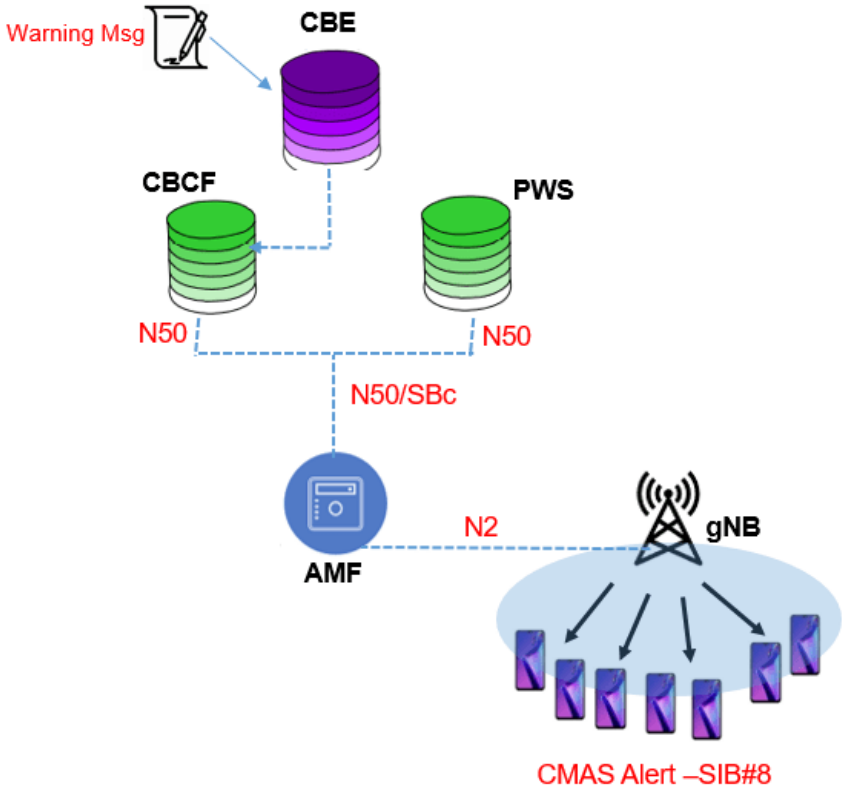
Paging



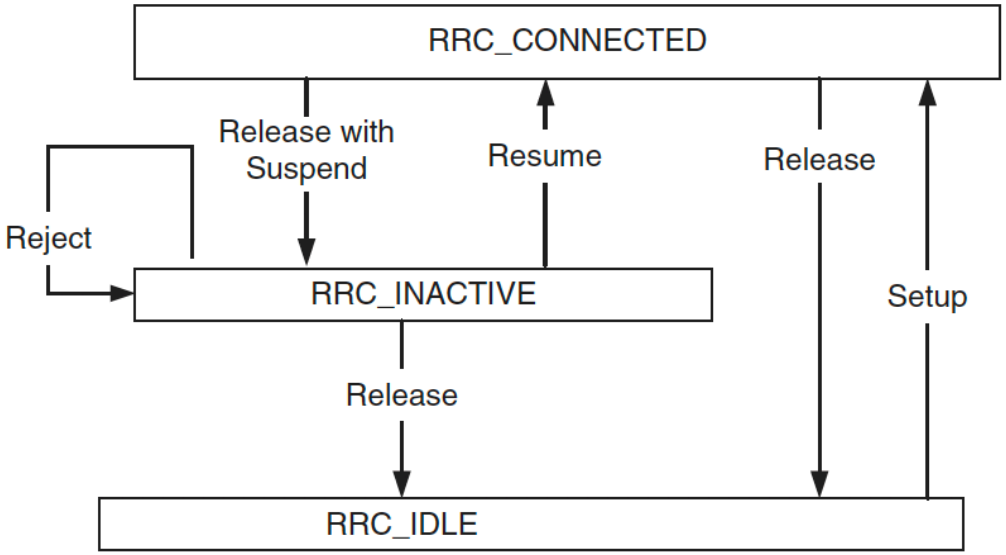
TA : Tracking Area

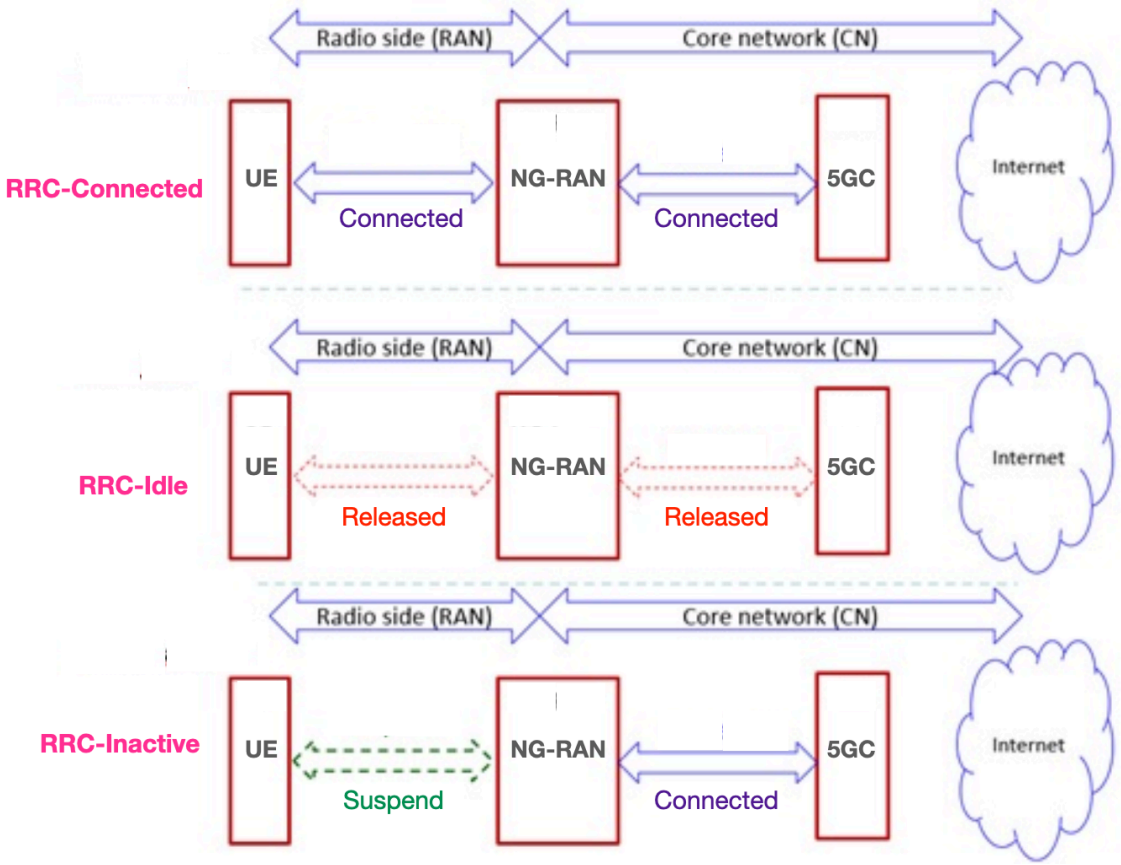
Public Warning System





CBE：Cell Broadcast Entity
CBCF：Cell Broadcast Centre Function
PWS：Public Warning System





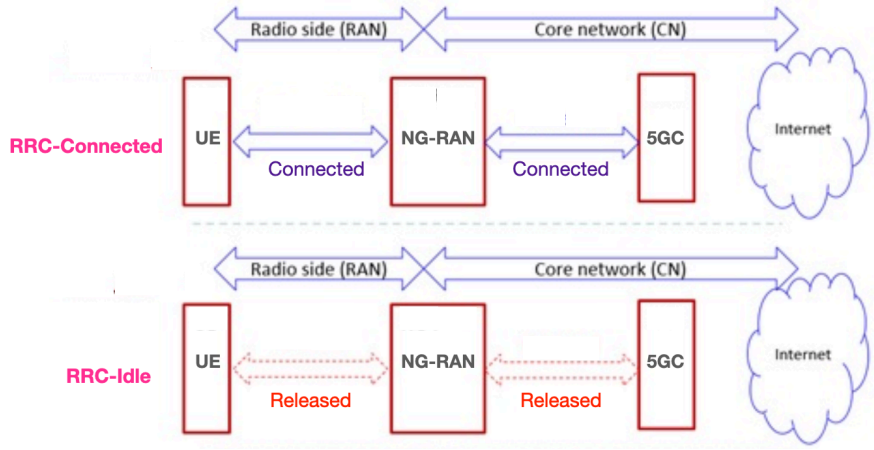
RRC states and state transitions

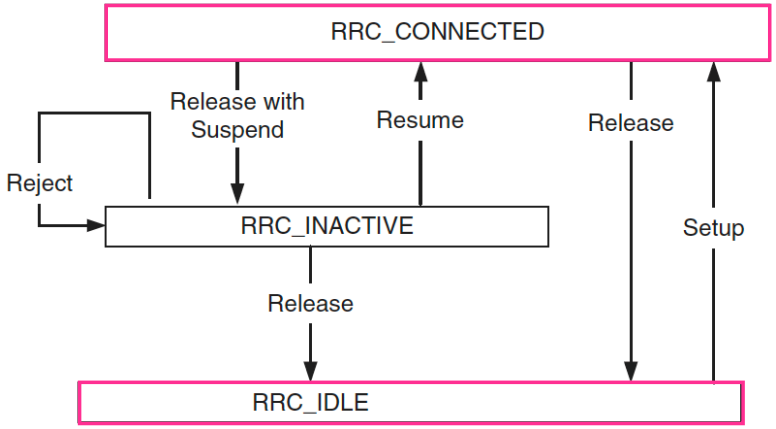
5.2 RRC Procedures and Functions

- RRC connection establishment
- Security
- Mobility
- Radio link failure recovery
- UE AS capability retrieval
- RRC INACTIVE state
- Broadcast information
- Slicing

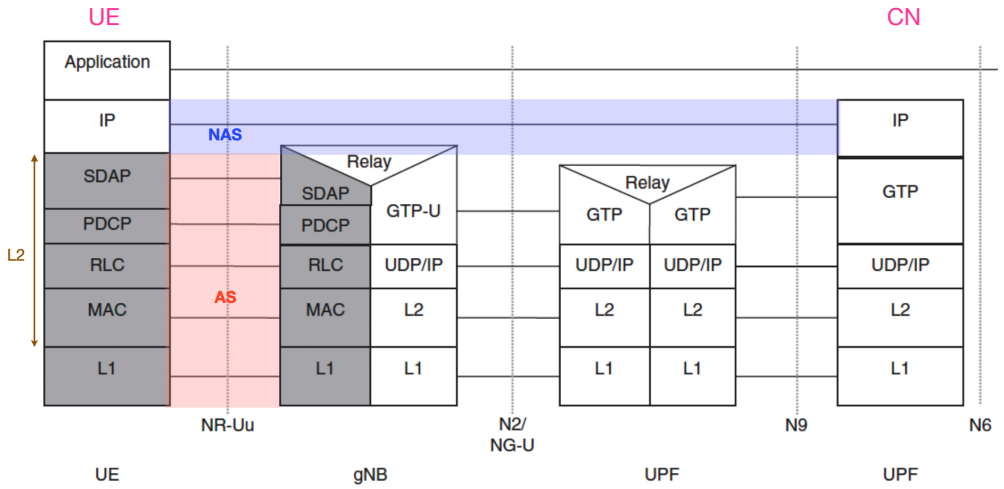
5.2.1 RRC Connection Establishment

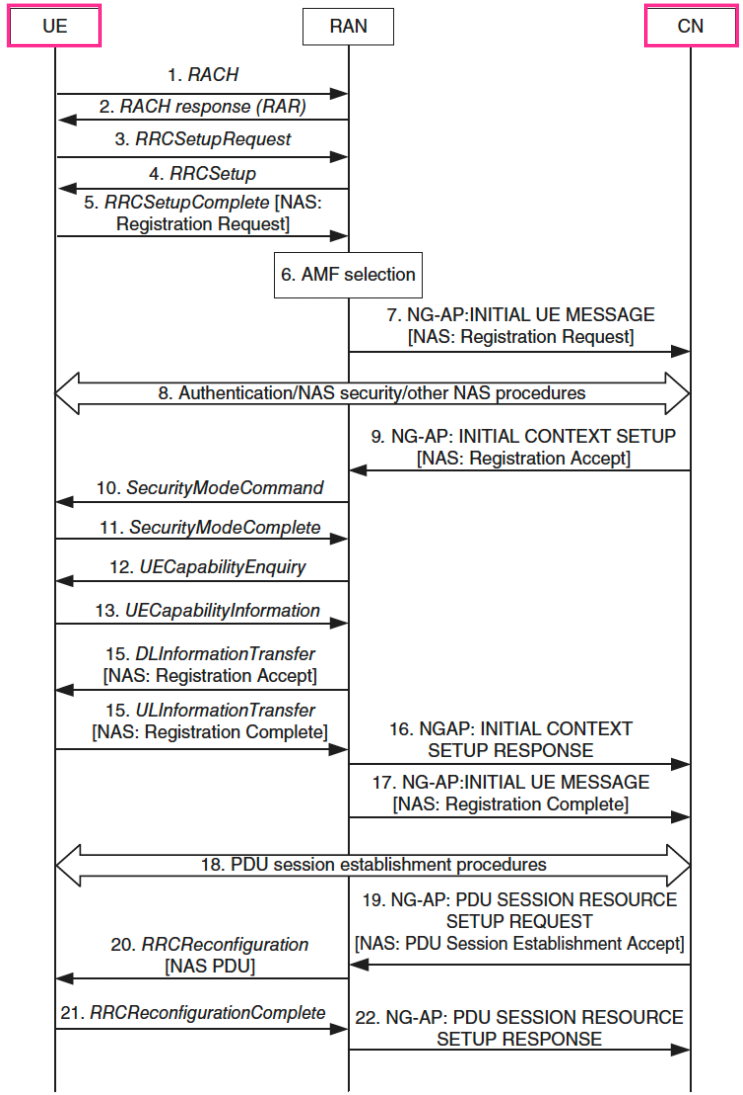
- RRC connection establishment procedure
  - Used to move UE from RRC state IDLE to CONNECTED to communicate with network
- From core network perspective, this procedure may also involve registration with 5GC to obtain 5G services





•Example: NAS message flow for registration

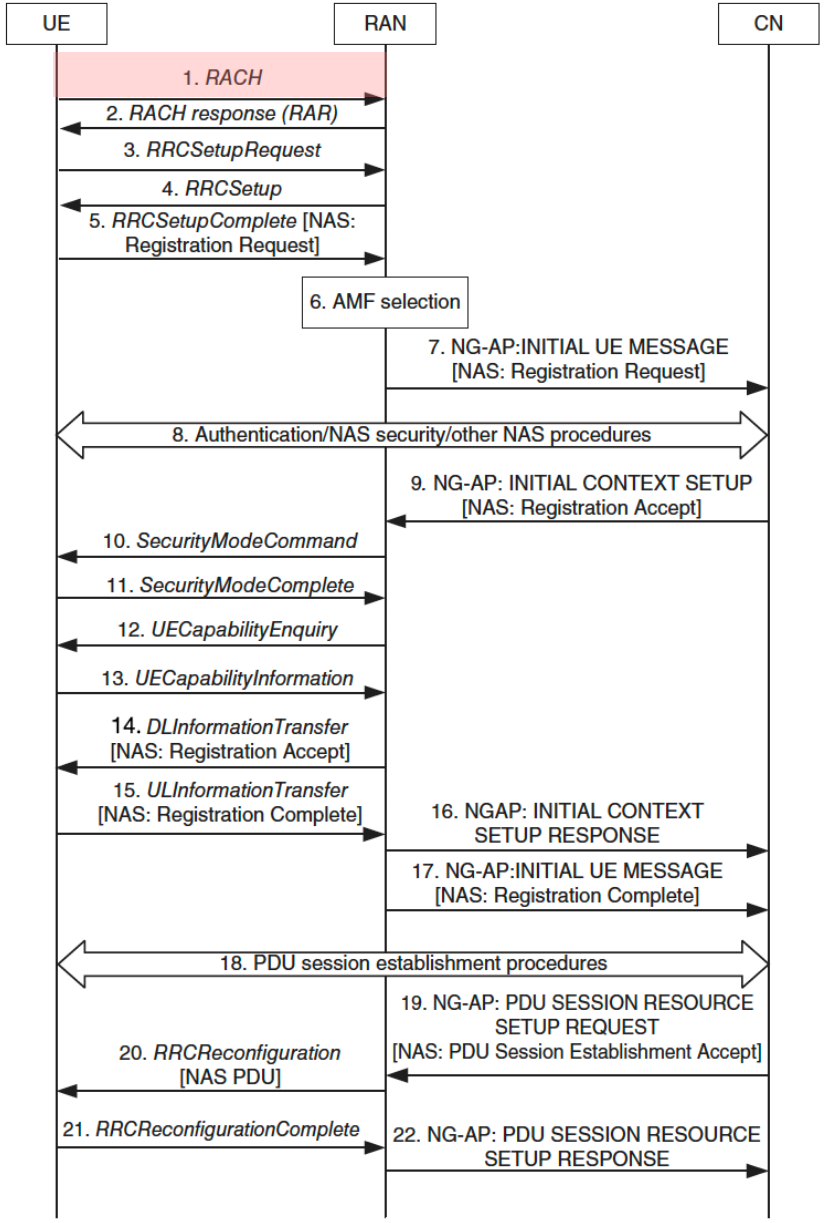




An example message flow for **initial NAS registration**

1. A UE in IDLE that intends to perform a NAS registration procedure to attach to network

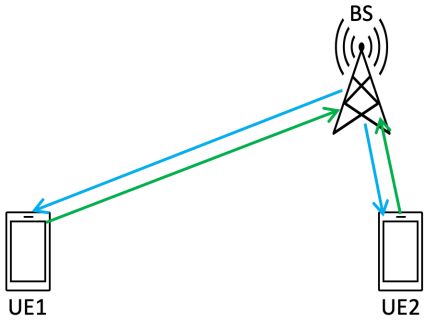
- Initiate a RACH procedure with a RACH preamble



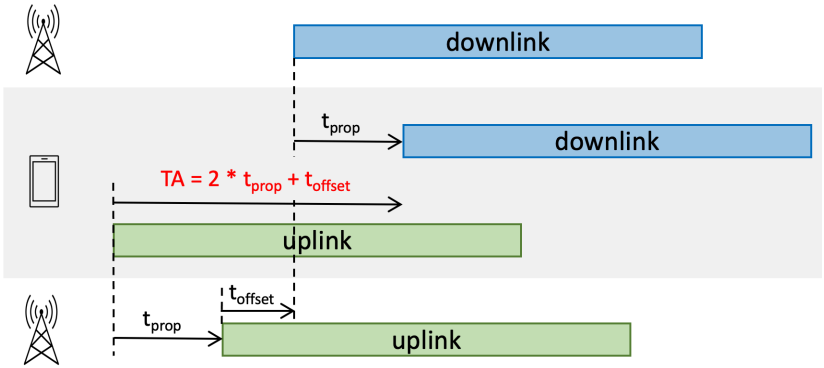
RACH：Random Access Channel

2. gNB responds with a RAR (Random Access Response) message

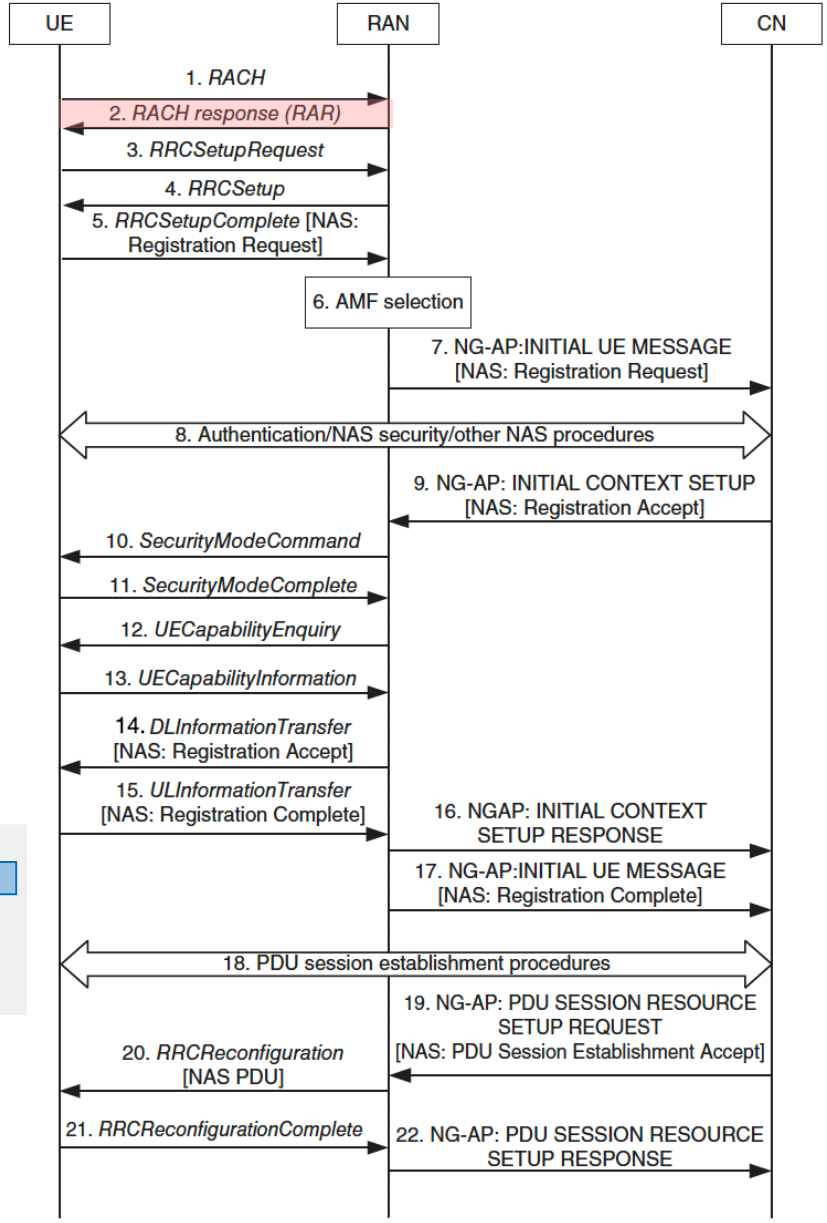
- Providing the timing advance and resources to use for subsequent uplink message

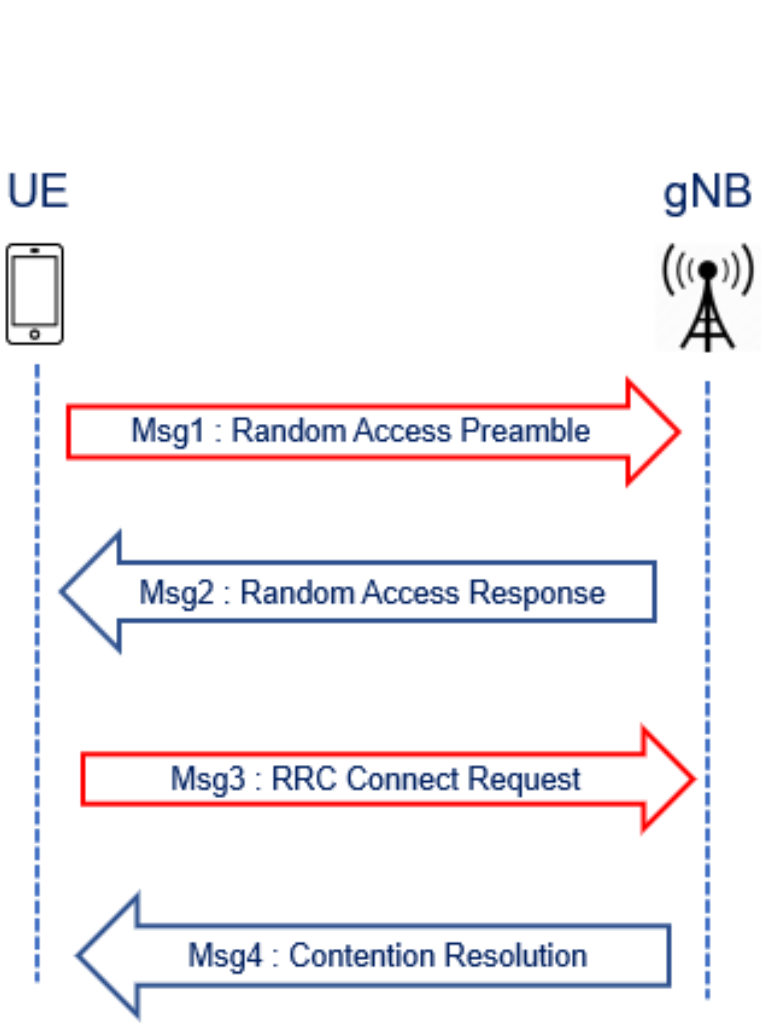


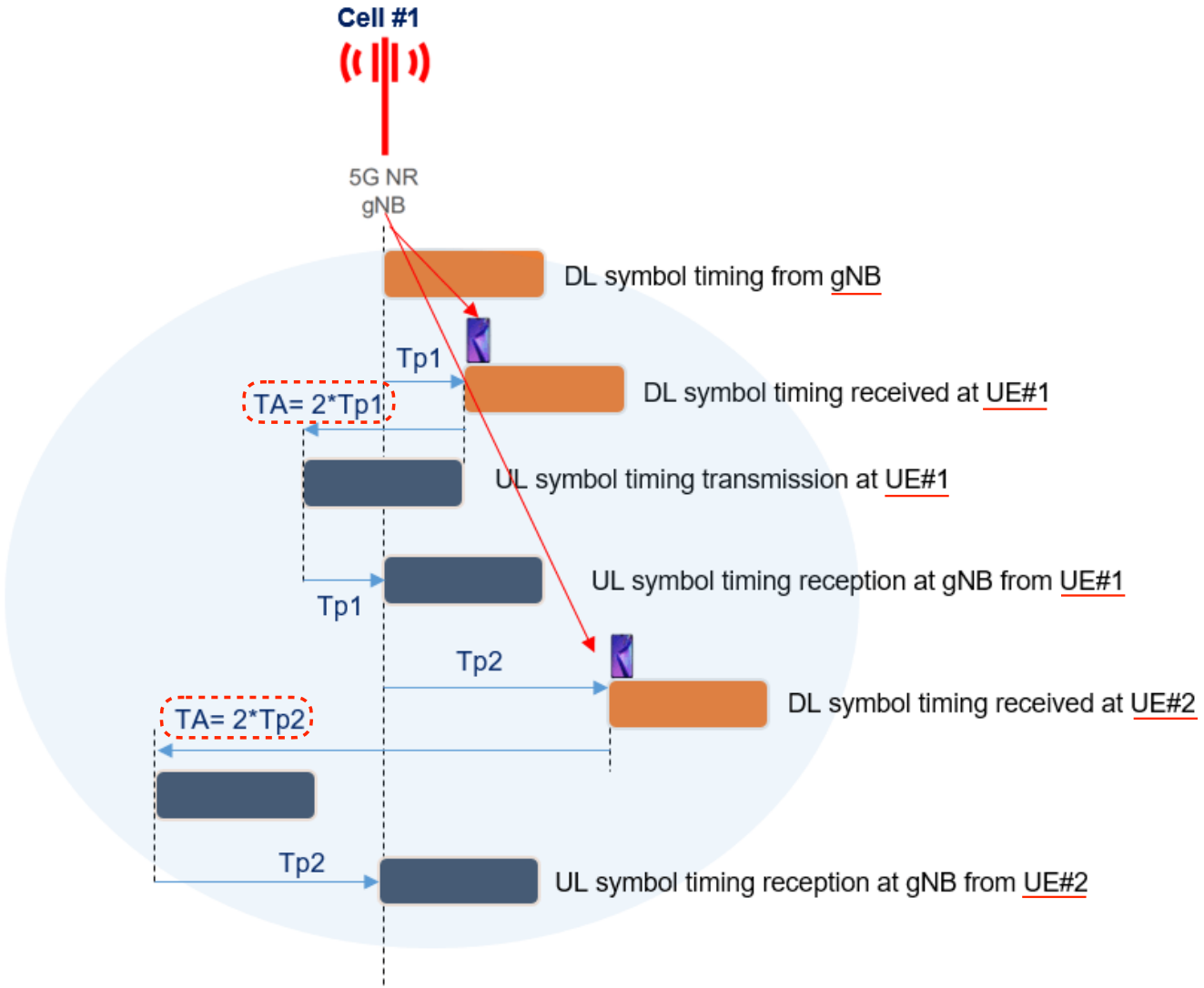
1) TA for different UEs



2) Uplink/downlink timing from BS/UE perspective



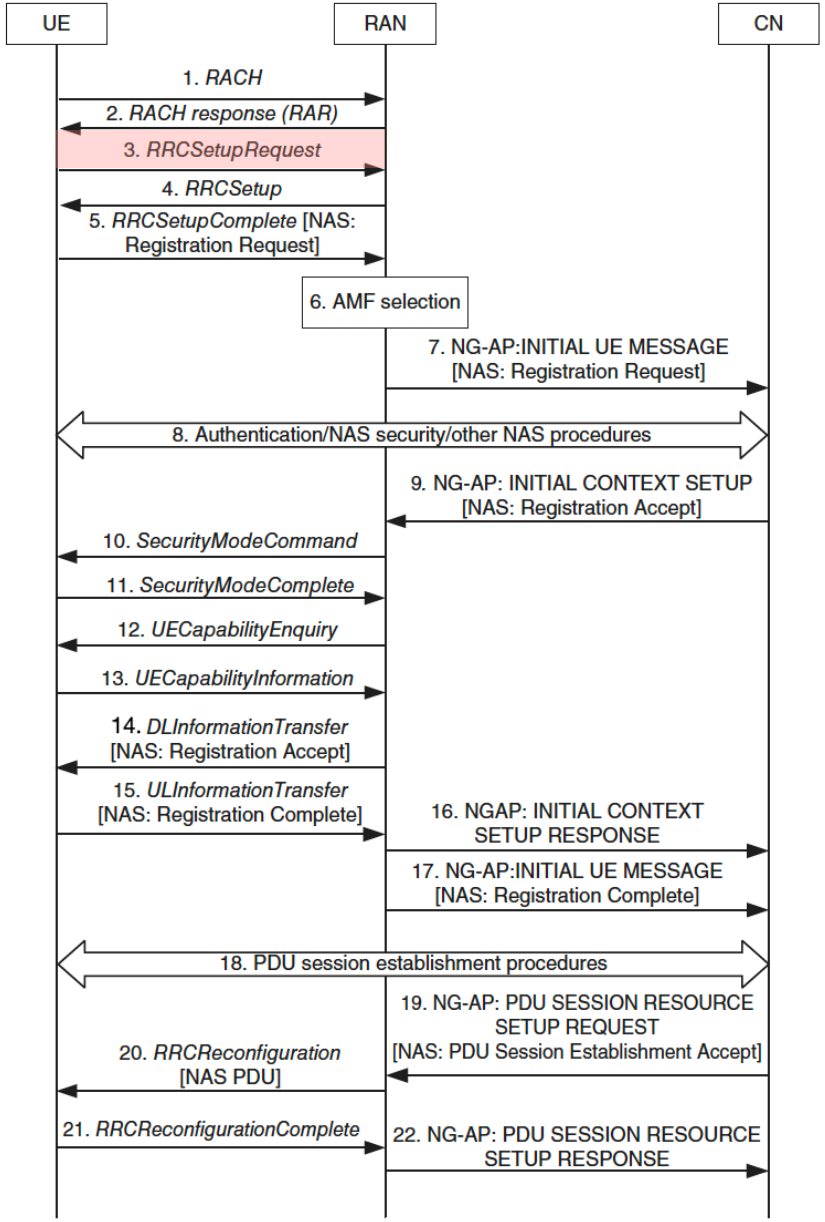

UE
gNB
Msg1 : Random Access Preamble
Msg2 : Random Access Response
Msg3 : RRC Connect Request
Msg4 : Contention Resolution


Cell #1
5G NR
gNB
DL symbol timing from gNB
Tp1
TA= 2*Tp1
DL symbol timing received at UE#1
UL symbol timing transmission at UE#1
Tp1
UL symbol timing reception at gNB from UE#1
Tp2
TA= 2*Tp2
DL symbol timing received at UE#2
Tp2
UL symbol timing reception at gNB from UE#2

3. UE then sends RRCSetupRequest message as a CCCH message, also referred to as RACH message 3 (Msg3)

- It contains NAS UE identifier if available, or a random number if not

RACH：Random Access Channel
CCCH：Common Control Channel

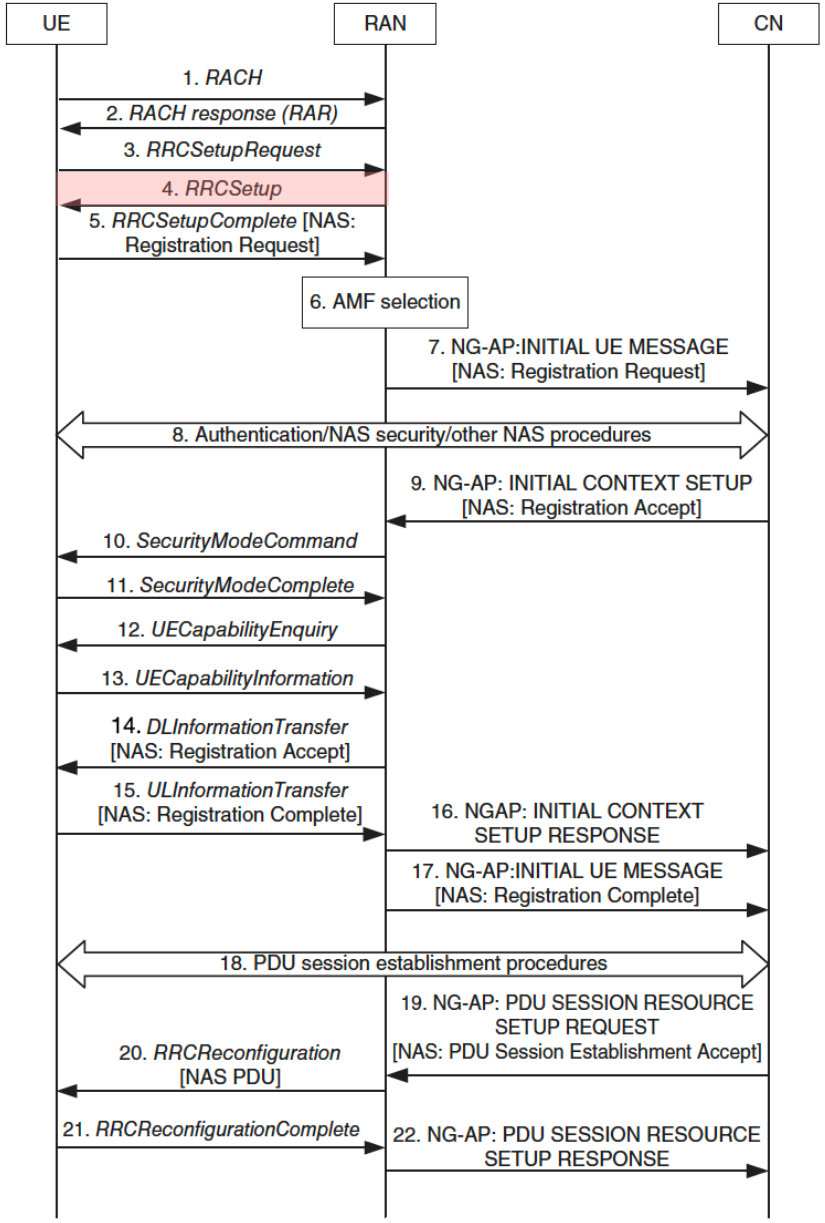


SRB	Direction	Message	RLC mode
SRBO CCCH	Downlink	RRCSetup	Transparent Mode RLC
		RRCReject	
	uplink	Uplink RRCSetupRequest	
		RRCResumeRequest	
		RRCResumeRequestl (uses CCCH I)	
		RRCReestablishmentRoquesl	
		RRCSystemlofoRequest	
SRB1-DCCH	Downlink	RRCReconfiguration	Acknowledged Mode RLC
		RRCResume	
		RRCReestablishment	
		RRCRclcase	
		SecurityModeCommand	
		DLInformationTransferi(ifSRB2 has not been setup)	
		UECapabilityEoquiry	
		CounterCheck	
		MobilityFromNRCommand	
	Uplink	R RCSetupComplete	
		RRCResumeComplete	
		RRCReestablishmentComplete	
		RRCReconfigurationCompletc	
		SecurityModeComplete	
		SccurityModcFailurc	
		ULInformationTnmsfer {if SRB2 has not been setup)	
		MeasuremcntReport	
		UECapabilityInformatio:n	
		LocalionMeasuremcntIndication	
		U EAssistanceln formation	
		CounterCheck Response	
SRB-2 DCCH	Downlink	DLInformationTnmsfer	
	Uplink	U Lin formation Transfer	
SRB-3 DCCH	Downlink	RRCRcconfiguration (also on SRB I)	
	uplink	RRCReconfigumtionComplete (also on SRB 1)	
		McasuremcntRcport (also on SRB I)	

Mapping between RRC messages and SRB

4. The UE ID contained in RACH message 3 is then echoed back to the UE in UE Contention Resolution Identity MAC CE for contention resolution in RACH message 4 (Msg4)

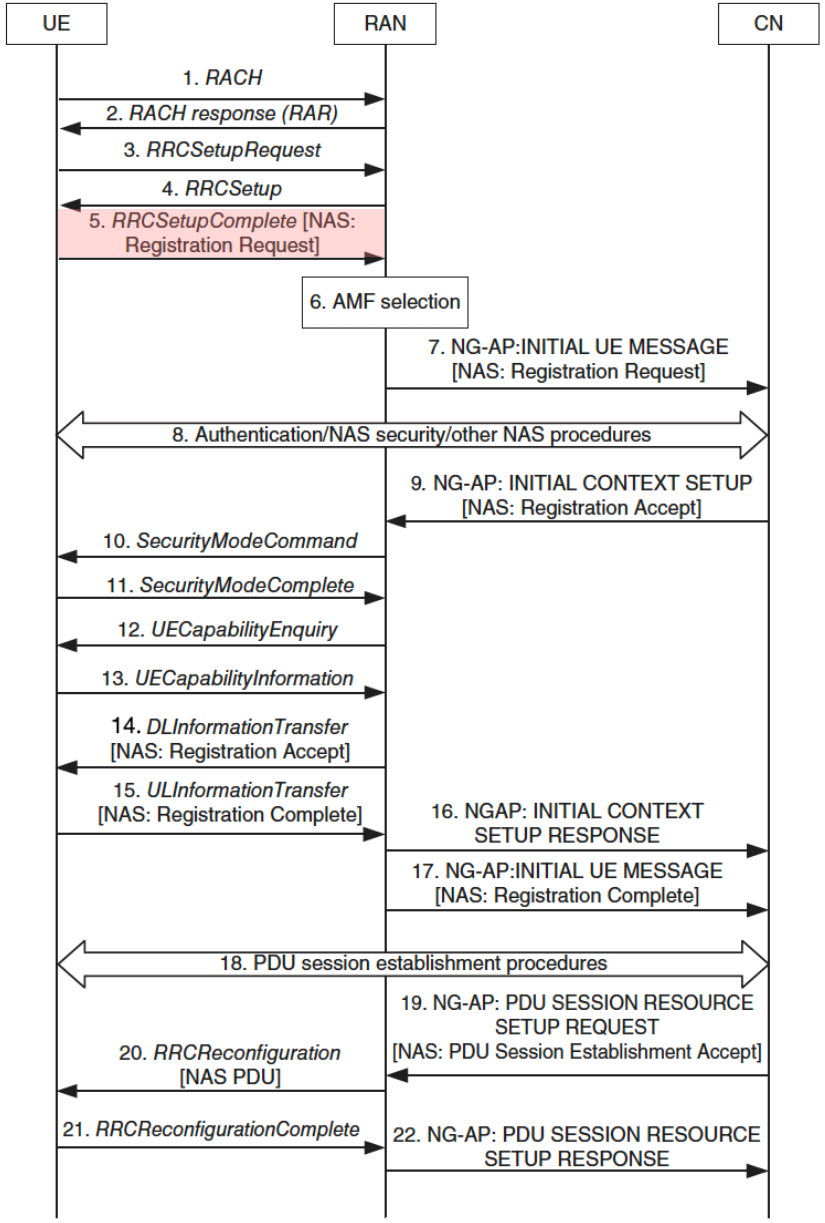
- RRC Setup message, also a CCCH message, could be included in RACH message 4 or sent separately to UE
- It contains initial configuration to set up DCCH logical channel and SRB1
- Subsequent RRC messages are sent over DCCH on SRB1



SRB	Direction	Message	RLC mode
SRBO CCCH	Downlink	RRCSetup	Transparent Mode RLC
		RRCReject	
	uplink	Uplink RRCSetupRequest	
		RRCResumeRequest	
		RRCResumeRequestl (uses CCCH I)	
		RRCReestablishmentRoquesl	
		RRCSystemlofoRequest	
SRB1-DCCH	Downlink	RRCReconfiguration	Acknowledged Mode RLC
		RRCResume	
		RRCReestablishment	
		RRCRclcase	
		SecurityModeCommand	
		DLInformationTransferi(ifSRB2 has not been setup)	
		UECapabilityEoquiry	
		CounterCheck	
		MobilityFromNRCommand	
	Uplink	R RCSetupComplete	
		RRCResumeComplete	
		RRCReestablishmentComplete	
		RRCReconfigurationCompletc	
		SecurityModeComplete	
		SccurityModcFailurc	
		ULInformationTnmsfer {if SRB2 has not been setup)	
		MeasuremcntReport	
		UECapabilityInformatio:n	
		LocalionMeasuremcntIndication	
		U EAssistanceln formation	
		CounterCheck Response	
SRB-2 DCCH	Downlink	DLInformationTnmsfer	
	Uplink	U Lin formation Transfer	
SRB-3 DCCH	Downlink	RRCRcconfiguration (also on SRB I)	
	uplink	RRCReconfigumtionComplete (also on SRB 1)	
		McasuremcntRcport (also on SRB I)	

Mapping between RRC messages and SRB

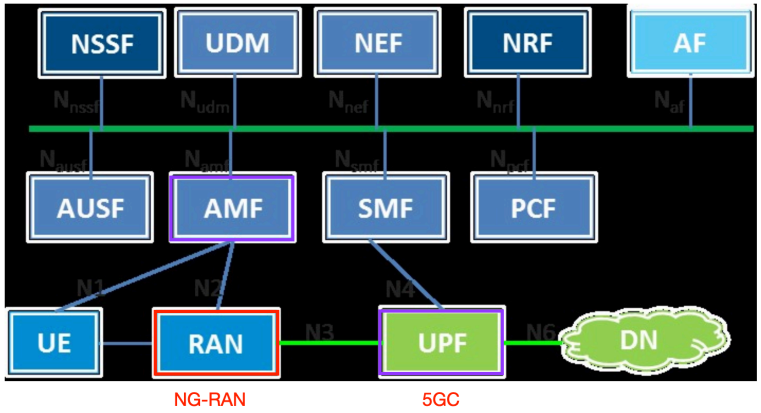
- 5. After the set up of SRB1, UE can send NAS messages to core network that are encapsulated in RRC messages and subsequently sent to core network by gNB
  - NAS registration request is encapsulated in RRC Setup Complete message
  - Additional NAS messages can be exchanged from UE to core network encapsulated in RRC ULInformationTransfer message over SRB1 and SRB2 after SRB2 is established

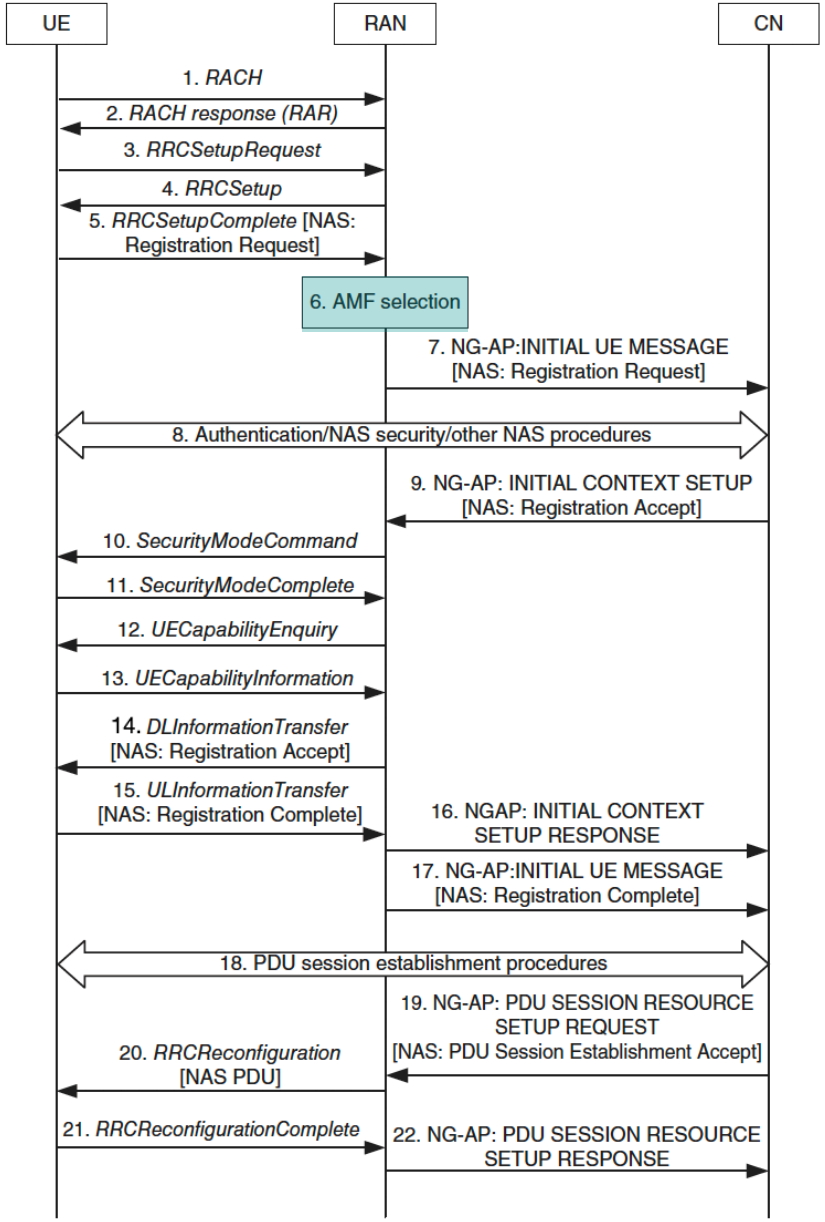


SRB	Direction	Message	RLC mode
SRBO CCCH	Downlink	RRCSetup	Transparent Mode RLC
		RRCReject	
	uplink	Uplink RRCSetupRequest	
		RRCResumeRequest	
		RRCResumeRequestl (uses CCCH I)	
		RRCReestablishmentRoquesl	
		RRCSystemlofoRequest	
SRB1-DCCH	Downlink	RRCReconfiguration	Acknowledged Mode RLC
		RRCResume	
		RRCReestablishment	
		RRCRclcase	
		SecurityModeCommand	
		DLInformationTransferi(ifSRB2 has not been setup)	
		UECapabilityEoquiry	
		CounterCheck	
		MobilityFromNRCommand	
	Uplink	R RCSetupComplete	
		RRCResumeComplete	
		RRCReestablishmentComplete	
		RRCReconfigurationCompletc	
		SecurityModeComplete	
		SccurityModcFailurc	
		ULInformationTnmsfer {if SRB2 has not been setup)	
		MeasuremcntReport	
		UECapabilityInformatio:n	
		LocalionMeasuremcntIndication	
		U EAssistanceln formation	
		CounterCheck Response	
SRB-2 DCCH	Downlink	DLInformationTnmsfer	
	Uplink	U Lin formation Transfer	
SRB-3 DCCH	Downlink	RRCRcconfiguration (also on SRB I)	
	uplink	RRCReconfigumtionComplete (also on SRB 1)	
		McasuremcntRcport (also on SRB I)	

Mapping between RRC messages and SRB

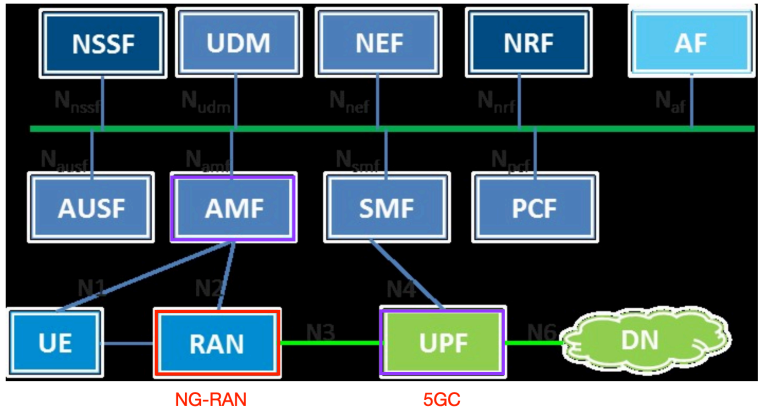
- 6. gNB selects the AMF based on UE ID and other NAS selection information such as
  - NSSAI
  - The registered AMF included in RRC Setup Complete message

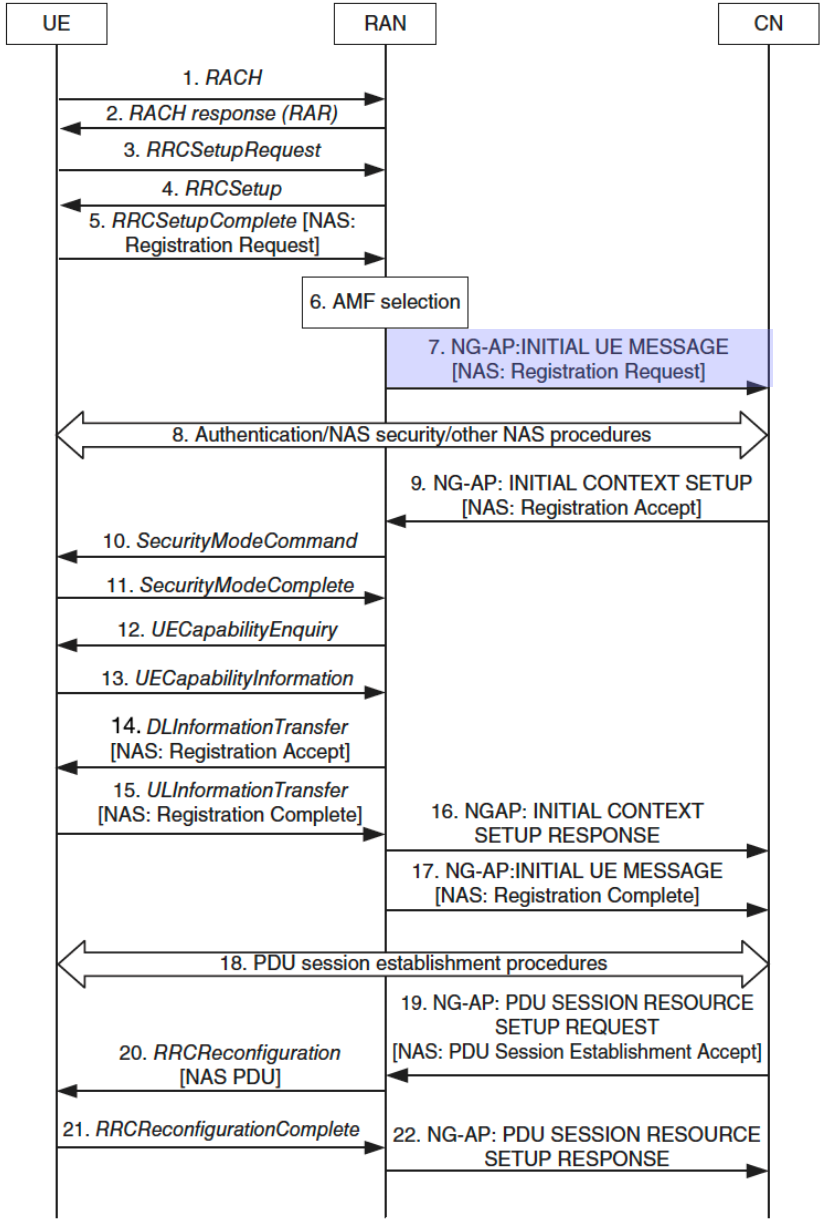




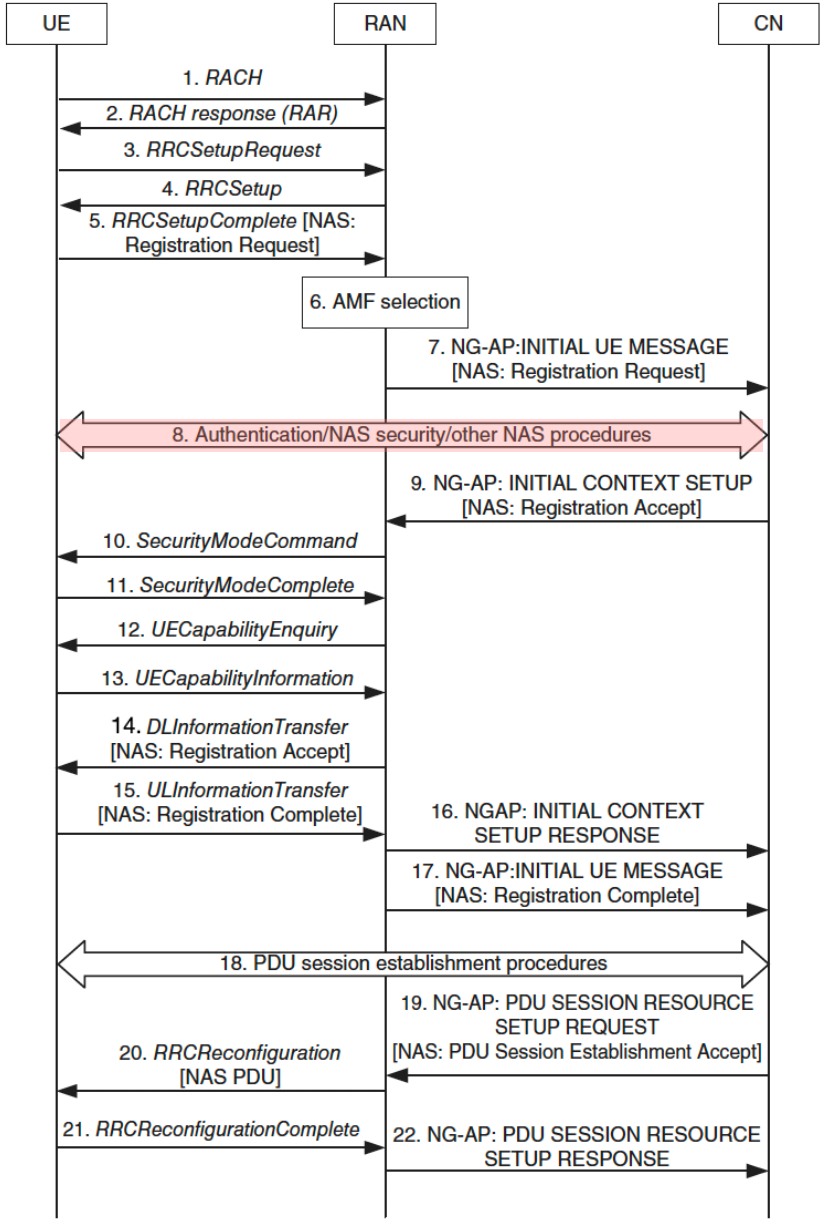
NSSAI：Network Slice Selection Assistance Information

- 7. gNB forwards NAS registration request to the AMF in NG-AP INITIAL UE MESSAGE





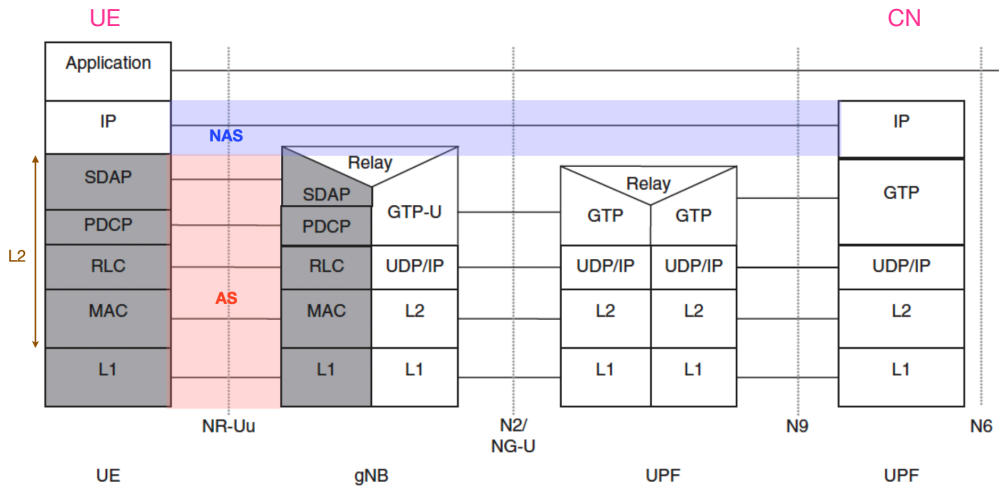
- 8. AMF may initiate additional procedures with UE NAS that are encapsulated and transferred using RRC DLInformationTransfer and ULInformationTransfer messages

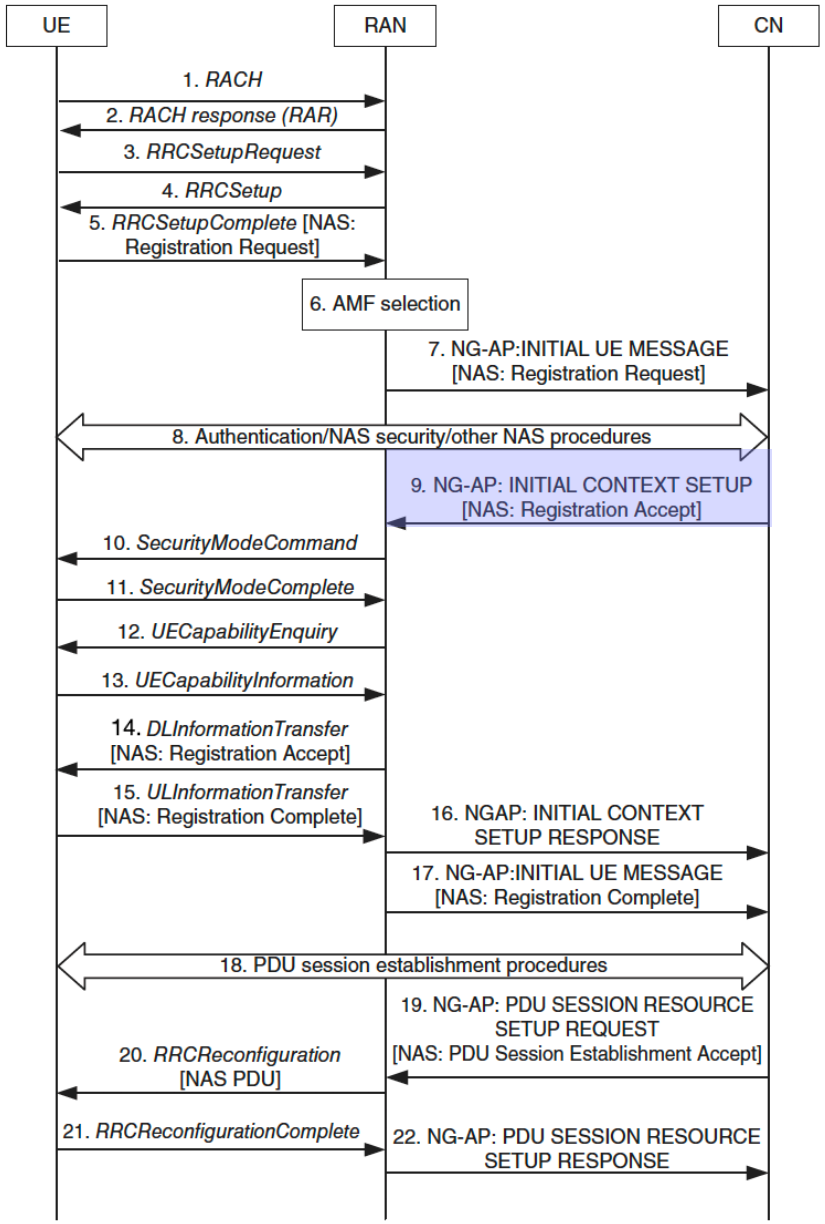


SRB	Direction	Message	RLC mode
SRBO CCCH	Downlink	RRCSetup	Transparent Mode RLC
		RRCReject	
	uplink	Uplink RRCSetupRequest	
		RRCResumeRequest	
		RRCResumeRequestl (uses CCCH I)	
		RRCReestablishmentRoquesl	
		RRCSystemlofoRequest	
SRB1-DCCH		RRCReconfiguration	Acknowledged Mode RLC
		RRCResume	
		RRCReestablishment	
		RRCRclcase	
	Downlink	SecurityModeCommand	
		DLInformationTransferi(ifSRB2 has not been setup)	
		UECapabilityEoquiry	
		CounterCheck	
		MobilityFromNRCommand	
		R RCSetupComplete	
		RRCResumeComplete	
		RRCReestablishmentComplete	
		RRCReconfigurationCompletc	
		SecurityModeComplete	
		SccurityModcFailurc	
	Uplink	ULInformationTnmsfer {if SRB2 has not been setup)	
		MeasuremcntReport	
		UECapabilityInformatio:n	
		LocalionMeasuremcntIndication	
		U EAssistanceln formation	
		CounterCheck Response	
SRB-2 DCCH	Downlink	DLInformationTnmsfer	
	Uplink	U Lin formation Transfer	
SRB-3 DCCH	Downlink	RRCRcconfiguration (also on SRB I)	
	uplink	RRCReconfigumtionComplete (also on SRB 1)	
		McasuremcntRcport (also on SRB I)	

Mapping between RRC messages and SRB

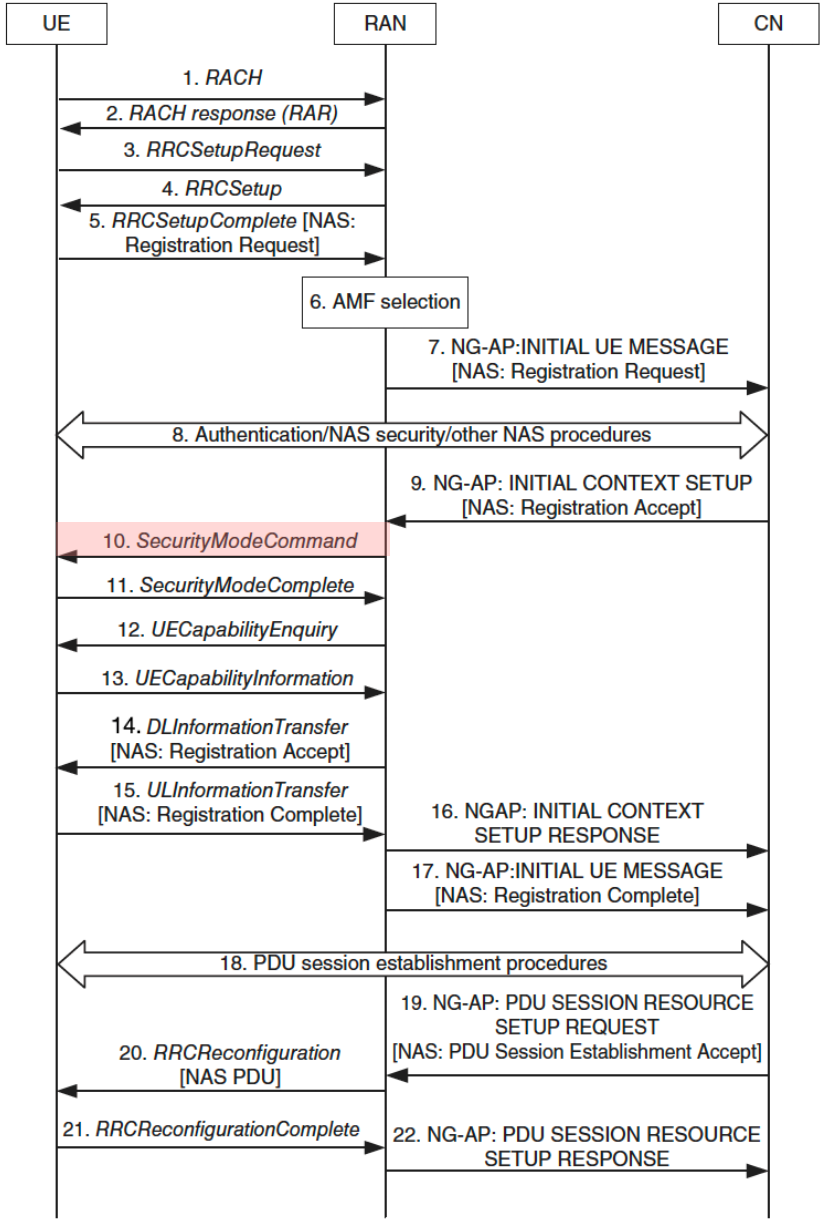
- 9. CN provides NG-AP INITIAL CONTEXT SETUP REQUEST message to gNB, which
  - Contains information to establish AS security and optionally PDU session information to set up DRBs





- UE context
  - Refers to the state and information associated with a UE in a cellular network
  - Includes various parameters
    - UE's identity, current location, session information, and QoS requirements
- Used by the network to
  - Establish and maintain communication with the UE
  - Manage its mobility within the network
  - Ensure that the required QoS is provided
- An essential component in the operation of mobile networks and is used in various procedures
  - Handover, paging, and session management

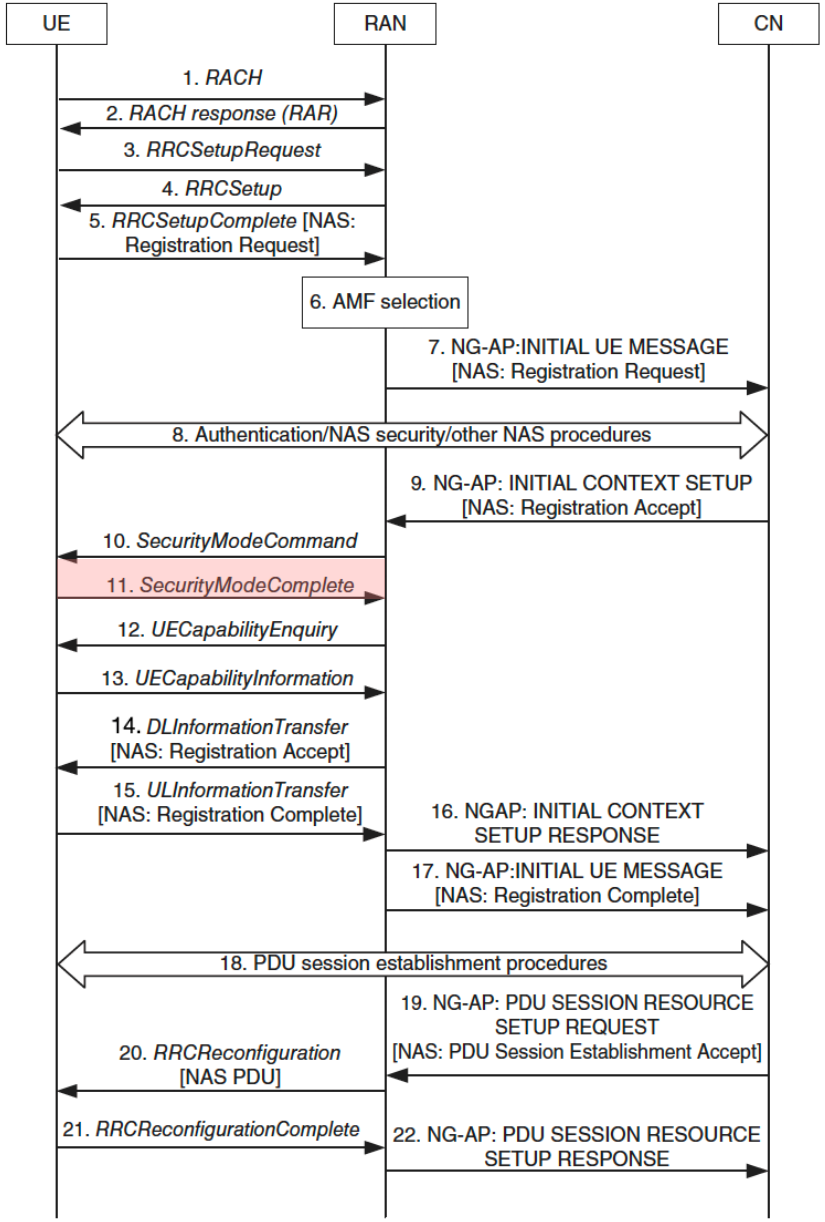
- 10. RRC SecurityModeCommand configures the security algorithms and establishes AS security



SRB	Direction	Message	RLC mode
SRBO CCCH	Downlink	RRCSetup	Transparent Mode RLC
		RRCReject	
	uplink	Uplink RRCSetupRequest	
		RRCResumeRequest	
		RRCResumeRequestl (uses CCCH I)	
		RRCReestablishmentRoquesl	
		RRCSystemlofoRequest	
SRB1-DCCH		RRCReconfiguration	Acknowledged Mode RLC
		RRCResume	
		RRCReestablishment	
		RRCRclcase	
	Downlink	SecurityModeCommand	
		DLInformationTransferi(ifSRB2 has not been setup)	
		UECapabilityEoquiry	
		CounterCheck	
		MobilityFromNRCommand	
	Uplink	R RCSetupComplete	
		RRCResumeComplete	
		RRCReestablishmentComplete	
		RRCReconfigurationCompletc	
		SecurityModeComplete	
		SccurityModcFailurc	
		ULInformationTnmsfer {if SRB2 has not been setup)	
		MeasuremcntReport	
		UECapabilityInformatio:n	
		LocalionMeasuremcntIndication	
		U EAssistanceln formation	
		CounterCheck Response	
SRB-2 DCCH	Downlink	DLInformationTnmsfer	
	Uplink	U Lin formation Transfer	
SRB-3 DCCH	Downlink	RRCRcconfiguration (also on SRB I)	
	uplink	RRCReconfigumtionComplete (also on SRB 1)	
		McasuremcntRcport (also on SRB I)	

Mapping between RRC messages and SRB

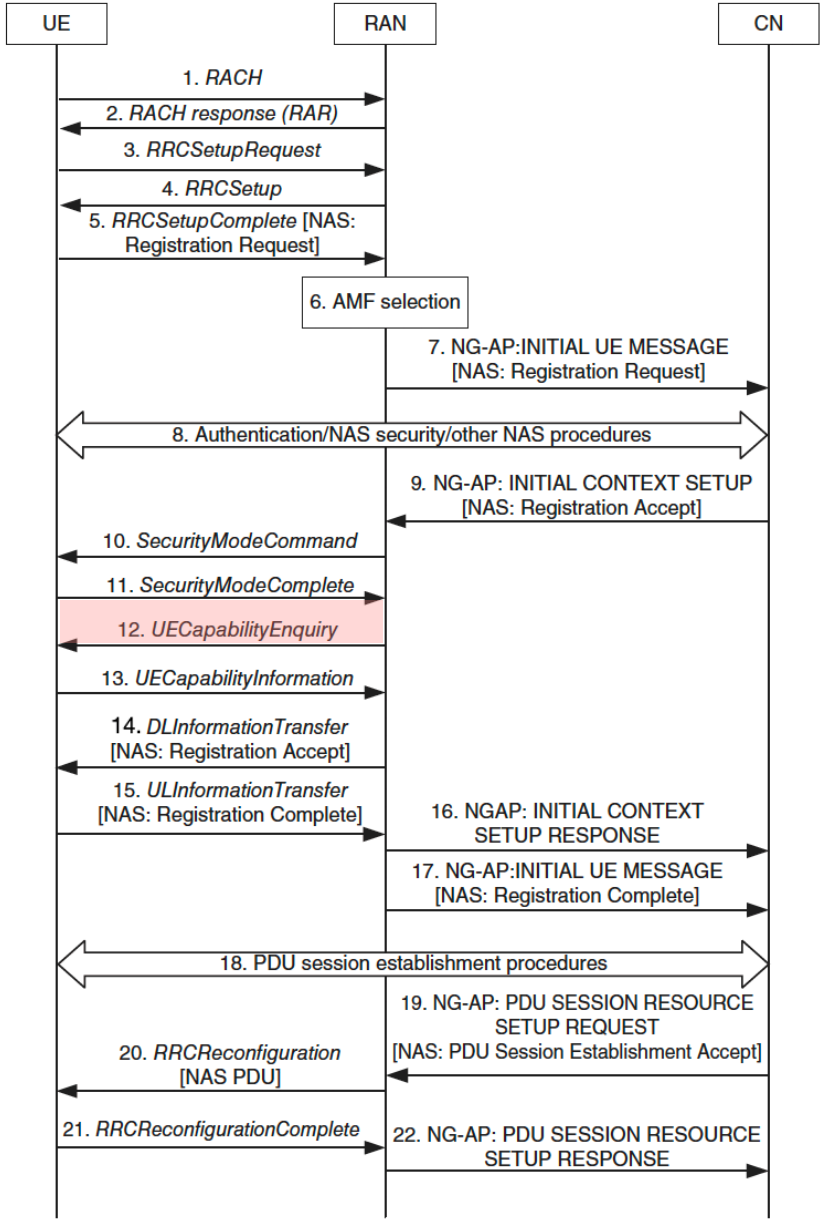
- 11. UE acknowledges successful completion of the security configuration with RRC SecurityModeComplete



SRB	Direction	Message	RLC mode
SRBO CCCH	Downlink	RRCSetup	Transparent Mode RLC
		RRCReject	
	uplink	Uplink RRCSetupRequest	
		RRCResumeRequest	
		RRCResumeRequestl (uses CCCH I)	
		RRCReestablishmentRoquesl	
		RRCSystemlofoRequest	
SRB1-DCCH	Downlink	RRCReconfiguration	Acknowledged Mode RLC
		RRCResume	
		RRCReestablishment	
		RRCRclcase	
		SecurityModeCommand	
		DLInformationTransferi(ifSRB2 has not been setup)	
		UECapabilityEoquiry	
		CounterCheck	
		MobilityFromNRCommand	
	Uplink	R RCSetupComplete	
		RRCResumeComplete	
		RRCReestablishmentComplete	
		RRCReconfigurationCompletc	
		SecurityModeComplete	
		SccurityModcFailurc	
		ULInformationTnmsfer {if SRB2 has not been setup)	
		MeasuremcntReport	
		UECapabilityInformatio:n	
		LocalionMeasuremcntIndication	
		U EAssistanceIn formation	
		CounterCheck Response	
SRB-2 DCCH	Downlink	DLInformationTnmsfer	
	Uplink	U Lin formation Transfer	
SRB-3 DCCH	Downlink	RRCRcconfiguration (also on SRB I)	
	uplink	RRCReconfigumtionComplete (also on SRB 1)	
		McasuremcntRcport (also on SRB I)	

Mapping between RRC messages and SRB

- 12. RRC UECapabilityEnquiry is used to retrieve UE AS capability
- UE capability in NR is subdivided into NR Standalone and capability related to dual connectivity in MR-DC capability containers
- gNB may request one or more of these capabilities

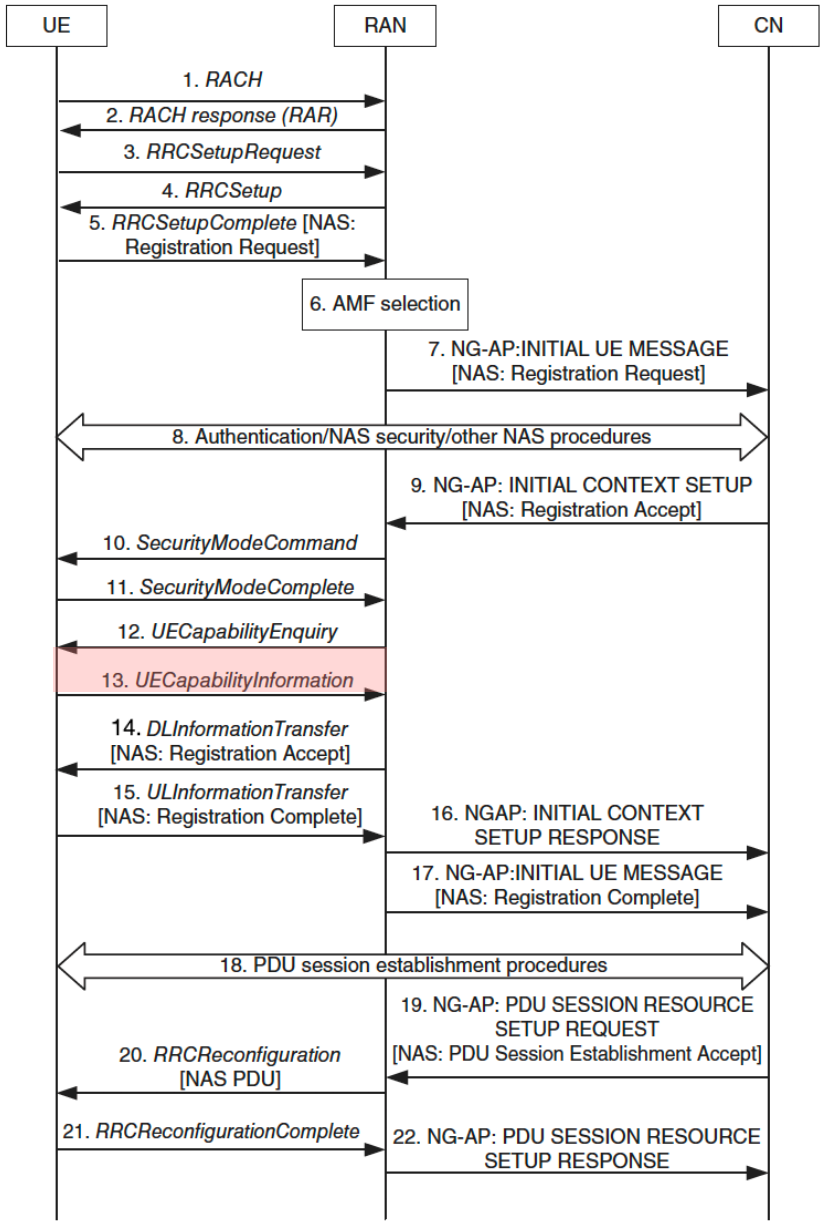


MR-DC：Multi-RAT Dual Connectivity

SRB	Direction	Message	RLC mode
SRBO CCCH	Downlink	RRCSetup	Transparent Mode RLC
		RRCReject	
	uplink	Uplink RRCSetupRequest	
		RRCResumeRequest	
		RRCResumeRequestl (uses CCCH I)	
		RRCReestablishmentRoquesl	
		RRCSystemlofoRequest	
SRB1-DCCH		RRCReconfiguration	Acknowledged Mode RLC
		RRCResume	
		RRCReestablishment	
		RRCRclcase	
	Downlink	SecurityModeCommand	
		DLInformationTransferi(ifSRB2 has not been setup)	
		UECapabilityEoquiry	
		CounterCheck	
		MobilityFromNRCommand	
	Uplink	R RCSetupComplete	
		RRCResumeComplete	
		RRCReestablishmentComplete	
		RRCReconfigurationCompletc	
		SecurityModeComplete	
		SccurityModcFailurc	
		ULInformationTnmsfer {if SRB2 has not been setup)	
		MeasuremcntReport	
		UECapabilityInformatio:n	
		LocalionMeasuremcntIndication	
		U EAssistanceln formation	
		CounterCheck Response	
SRB-2 DCCH	Downlink	DLInformationTnmsfer	
	Uplink	U Lin formation Transfer	
SRB-3 DCCH	Downlink	RRCRcconfiguration (also on SRB I)	
	uplink	RRCReconfigumtionComplete (also on SRB 1)	
		McasuremcntRcport (also on SRB I)	

Mapping between RRC messages and SRB

- 13. UE responds with requested capabilities in RRC UECapabilityInformation



SRB	Direction	Message	RLC mode
SRBO CCCH	Downlink	RRCSetup	Transparent Mode RLC
		RRCReject	
	uplink	Uplink RRCSetupRequest	
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		RRCSystemlofoRequest	
SRB1-DCCH	Downlink	RRCReconfiguration	Acknowledged Mode RLC
		RRCResume	
		RRCReestablishment	
		RRCRclcase	
		SecurityModeCommand	
		DLInformationTransferi(ifSRB2 has not been setup)	
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		CounterCheck	
		MobilityFromNRCommand	
	Uplink	R RCSetupComplete	
		RRCResumeComplete	
		RRCReestablishmentComplete	
		RRCReconfigurationCompletc	
		SecurityModeComplete	
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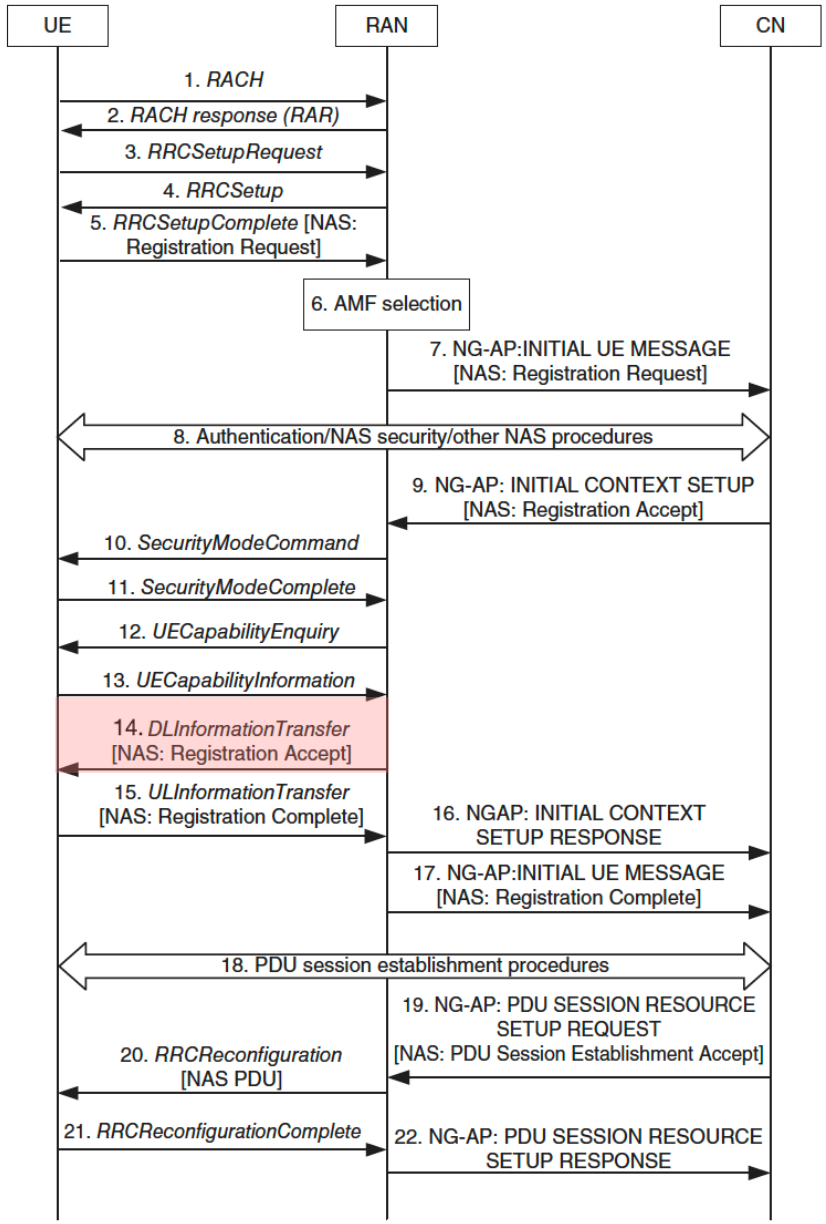
		UECapabilityInformatio:n	
		LocalionMeasuremcntIndication	
		U EAssistanceIn formation	
		CounterCheck Response	
SRB-2 DCCH	Downlink	DLInformationTnmsfer	
	Uplink	U Lin formation Transfer	
SRB-3 DCCH	Downlink	RRCRcconfiguration (also on SRB I)	
	uplink	RRCReconfigumtionComplete (also on SRB 1)	
		McasuremcntRcport (also on SRB I)	

Mapping between RRC messages and SRB

- 14. RRC DLInformationTransfer encapsulates NAS Registration Accept message to be sent to UE



SRB	Direction	Message	RLC mode
SRBO CCCH	Downlink	RRCSetup	Transparent Mode RLC
		RRCReject	
	uplink	Uplink RRCSetupRequest	
		RRCResumeRequest	
		RRCResumeRequestl (uses CCCH I)	
		RRCReestablishmentRoquesl	
		RRCSystemlofoRequest	
SRB1-DCCH		RRCReconfiguration	Acknowledged Mode RLC
		RRCResume	
		RRCReestablishment	
		RRCRclcase	
	Downlink	SecurityModeCommand	
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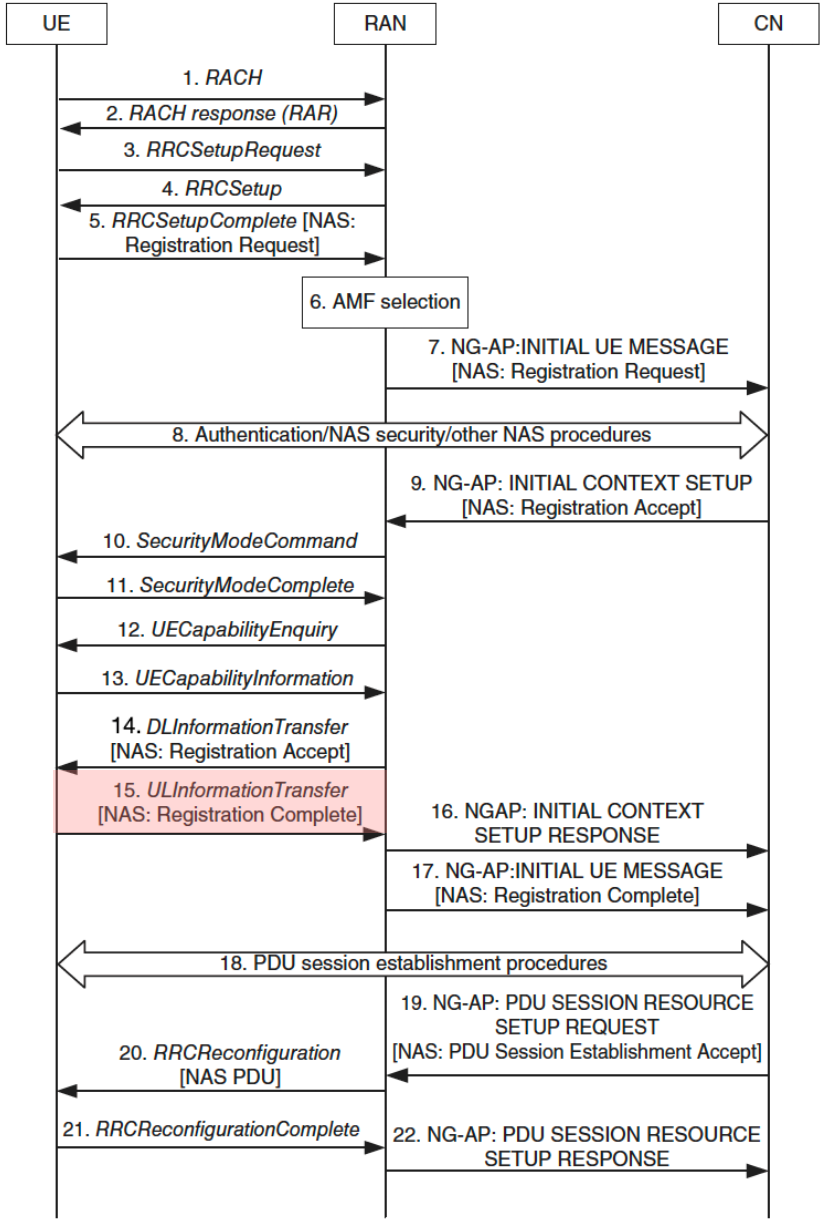
		UECapabilityEoquiry	
		CounterCheck	
		MobilityFromNRCommand	
	Uplink	R RCSetupComplete	
		RRCResumeComplete	
		RRCReestablishmentComplete	
		RRCReconfigurationCompletc	
		SecurityModeComplete	
		SccurityModcFailurc	
		ULInformationTnmsfer {if SRB2 has not been setup)	
		MeasuremcntReport	
		UECapabilityInformatio:n	
		LocalionMeasuremcntIndication	
		U EAssistanceIn formation	
		CounterCheck Response	
SRB-2 DCCH	Downlink	DLInformationTnmsfer	
	Uplink	U Lin formation Transfer	
SRB-3 DCCH	Downlink	RRCRcconfiguration (also on SRB I)	
	uplink	RRCReconfigumtionComplete (also on SRB 1)	
		McasuremcntRcport (also on SRB I)	

Mapping between RRC messages and SRB

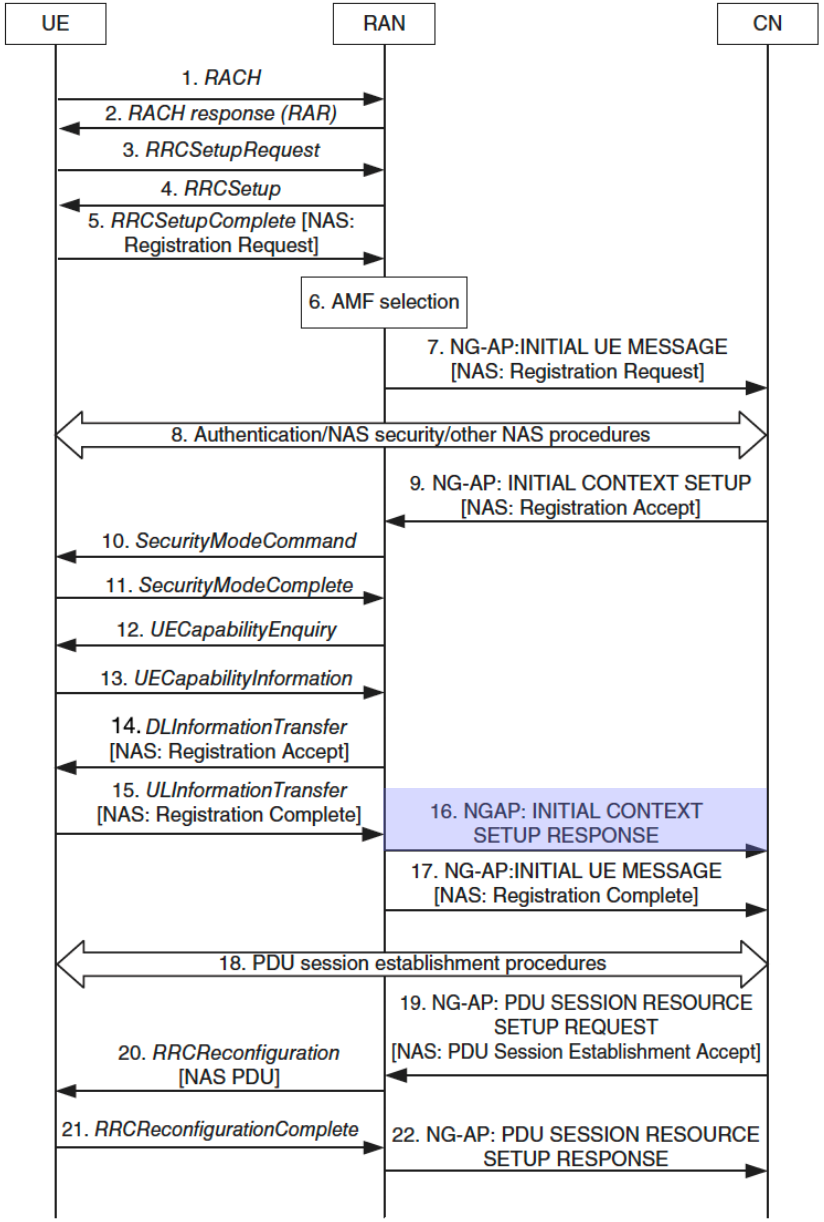
- 15. RRC ULInformationTransfer encapsulates NAS Registration Complete message to be sent to network



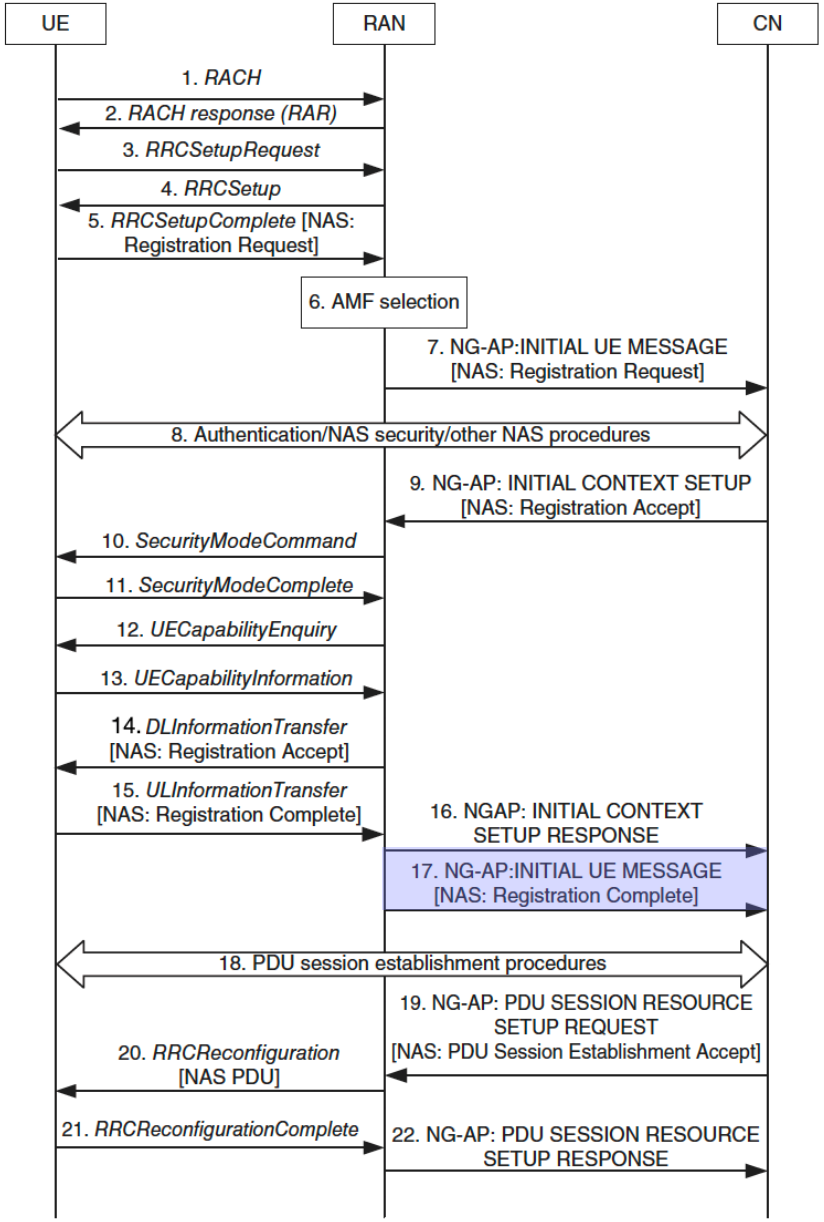
SRB	Direction	Message	RLC mode
SRBO CCCH	Downlink	RRCSetup	Transparent Mode RLC
		RRCReject	
	uplink	Uplink RRCSetupRequest	
		RRCResumeRequest	
		RRCResumeRequestl (uses CCCH I)	
		RRCReestablishmentRoquesl	
		RRCSystemlofoRequest	
SRB1-DCCH	Downlink	RRCReconfiguration	Acknowledged Mode RLC
		RRCResume	
		RRCReestablishment	
		RRCRclcase	
		SecurityModeCommand	
		DLInformationTransferi(ifSRB2 has not been setup)	
		UECapabilityEoquiry	
		CounterCheck	
		MobilityFromNRCommand	
	Uplink	R RCSetupComplete	
		RRCResumeComplete	
		RRCReestablishmentComplete	
		RRCReconfigurationCompletc	
		SecurityModeComplete	
		SccurityModcFailurc	
		ULInformationTnmsfer {if SRB2 has not been setup)	
		MeasuremcntReport	
		UECapabilityInformatio:n	
		LocalionMeasuremcntIndication	
		U EAssistanceln formation	
		CounterCheck Response	
SRB-2 DCCH	Downlink	DLInformationTnmsfer	
	Uplink	U Lin formation Transfer	
SRB-3 DCCH	Downlink	RRCRcconfiguration (also on SRB I)	
	uplink	RRCReconfigumtionComplete (also on SRB 1)	
		McasuremcntRcport (also on SRB I)	

Mapping between RRC messages and SRB

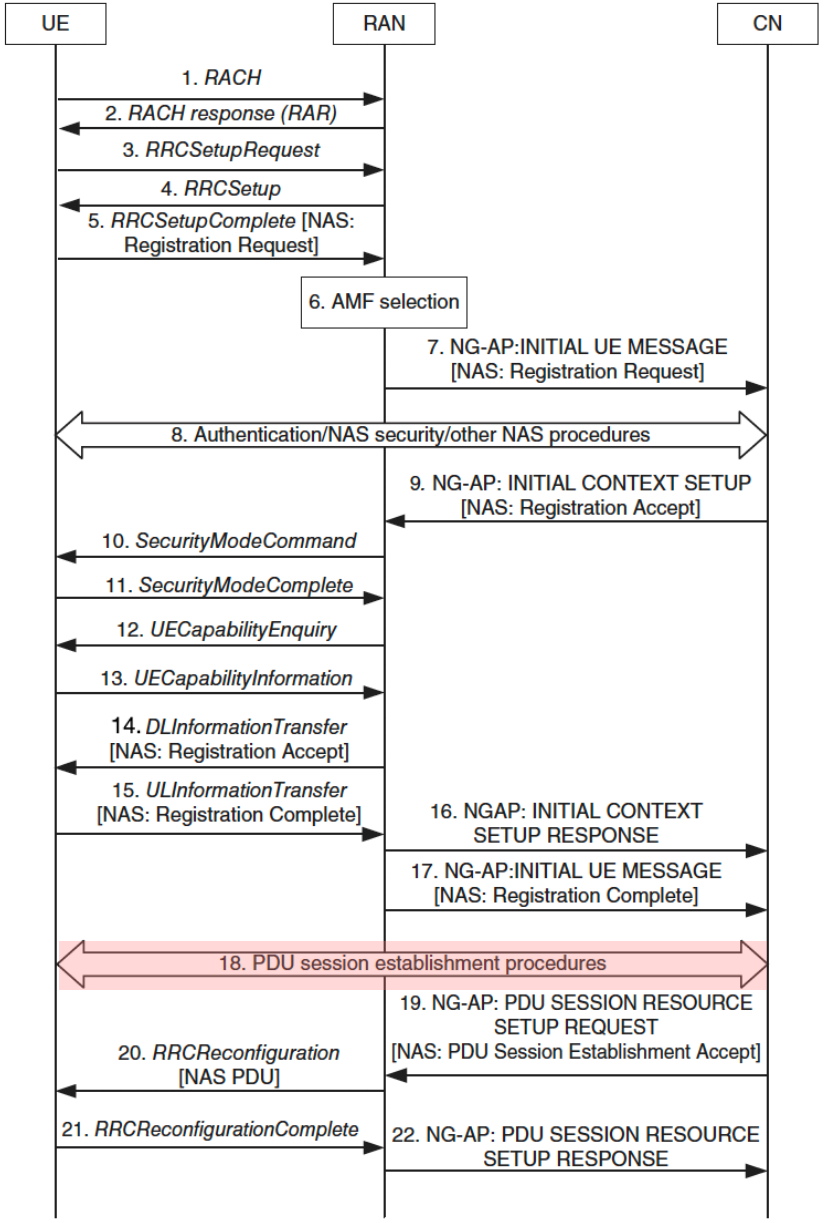
- 16. gNB sends NG-AP INITIAL CONTEXT SETUP RESPONSE message to AMF indicating successful completion of UE context set up procedure



- 17. gNB forwards NAS Registration Complete message received from UE to AMF



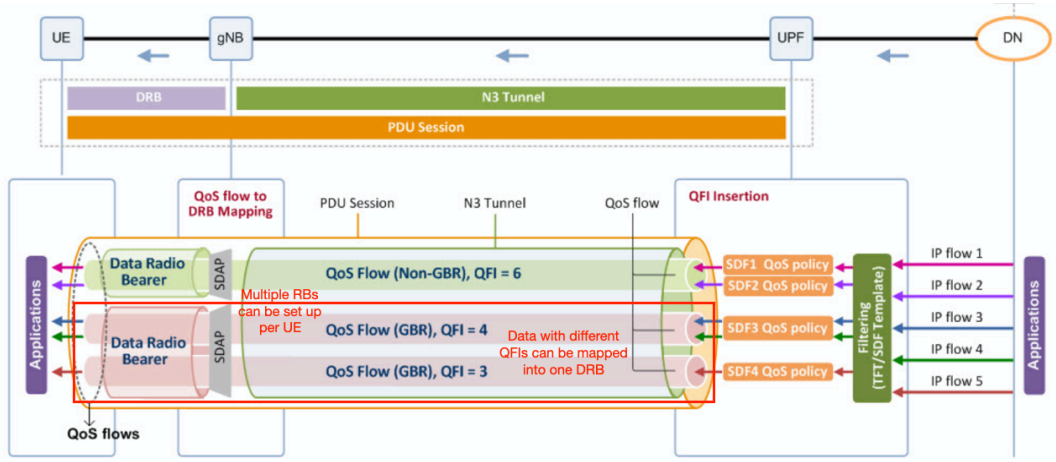
- 18. UE initiates PDU Session Establishment procedure with CN
  - These are carried transparently over RAN using RRC uplink and downlink InformationTransfer messages

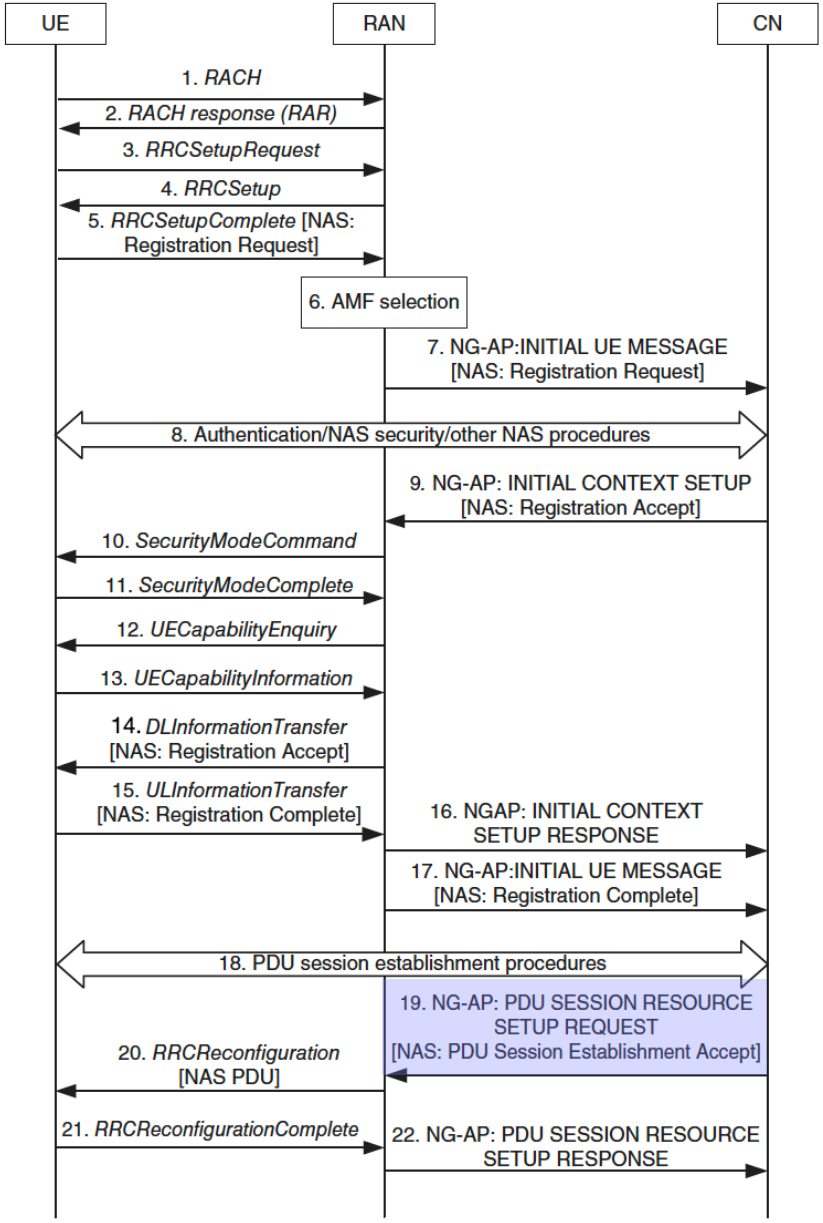


SRB	Direction	Message	RLC mode
SRBO CCCH	Downlink	RRCSetup	Transparent Mode RLC
		RRCReject	
	uplink	Uplink RRCSetupRequest	
		RRCResumeRequest	
		RRCResumeRequestl (uses CCCH I)	
		RRCReestablishmentRoquesl	
		RRCSystemlofoRequest	
SRB1-DCCH		RRCReconfiguration	Acknowledged Mode RLC
		RRCResume	
		RRCReestablishment	
		RRCRclcase	
	Downlink	SecurityModeCommand	
		DLInformationTransferi(ifSRB2 has not been setup)	
		UECapabilityEoquiry	
		CounterCheck	
		MobilityFromNRCommand	
		R RCSetupComplete	
		RRCResumeComplete	
		RRCReestablishmentComplete	
		RRCReconfigurationCompletc	
		SecurityModeComplete	
		SccurityModcFailurc	
	Uplink	ULInformationTnmsfer {if SRB2 has not been setup)	
		MeasuremcntReport	
		UECapabilityInformatio:n	
		LocalionMeasuremcntIndication	
		U EAssistanceln formation	
		CounterCheck Response	
SRB-2 DCCH	Downlink	DLInformationTnmsfer	
	Uplink	U Lin formation Transfer	
SRB-3 DCCH	Downlink	RRCRcconfiguration (also on SRB I)	
	uplink	RRCReconfigumtionComplete (also on SRB 1)	
		McasuremcntRcport (also on SRB I)	

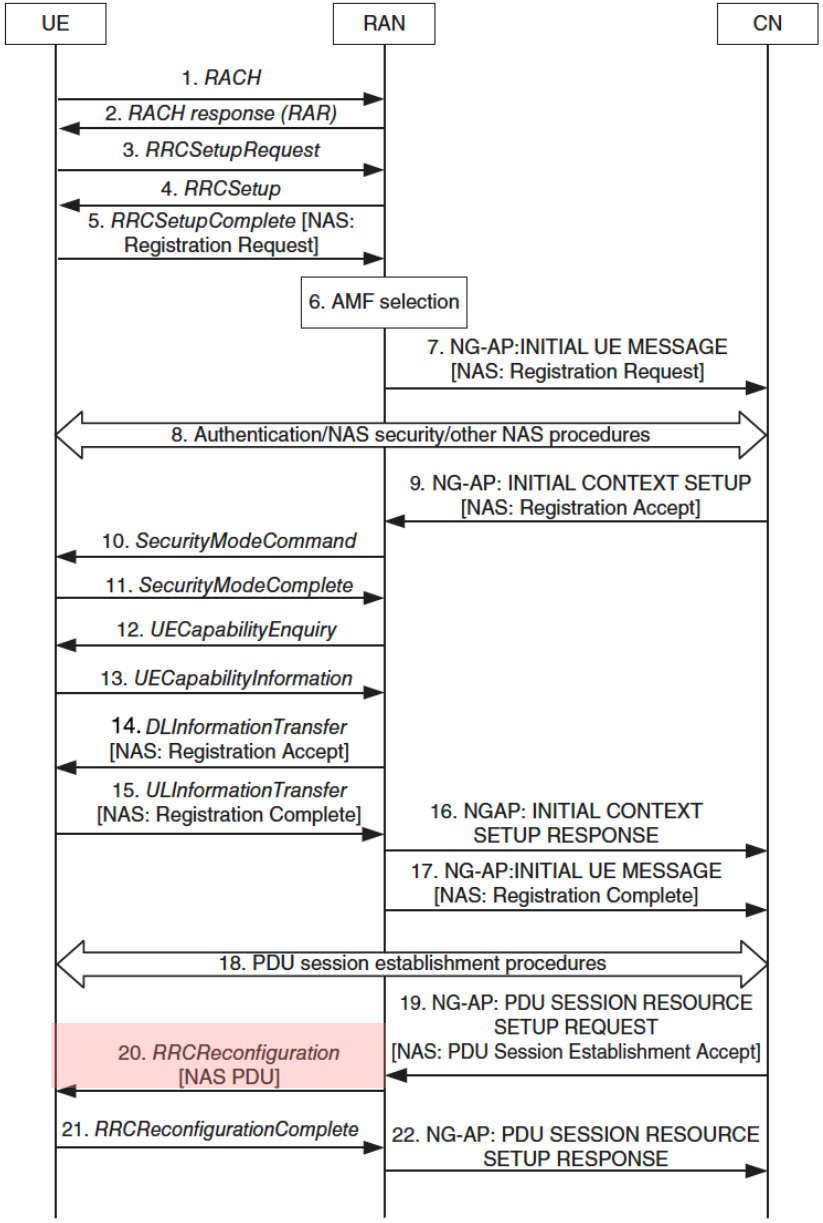
Mapping between RRC messages and SRB

- 19. Core network initiates bearer set up procedures for PDU session using NG-AP PDU SESSION RESOURCE SETUP REQUEST message
  - It encapsulates the NAS PDU to be sent to UE





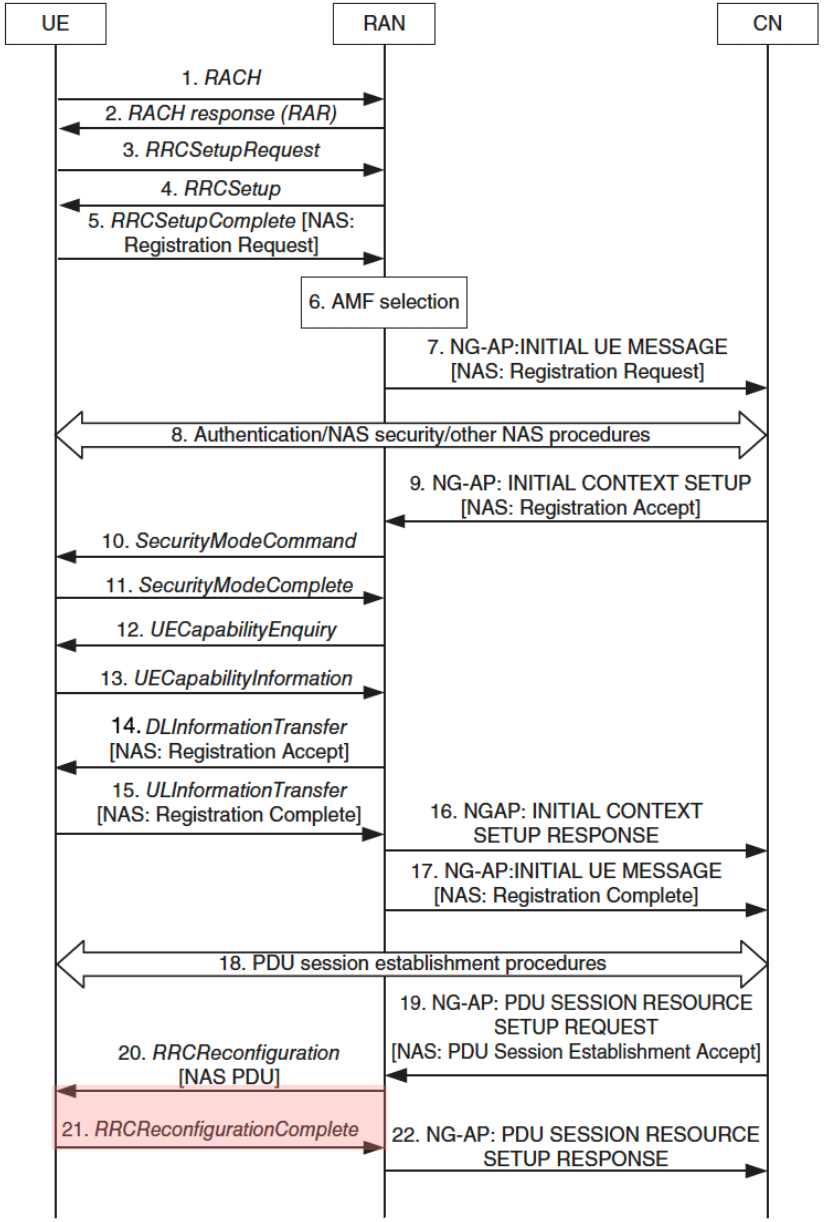
- 20. gNB configures DRB(s) for PDU session using an RRC Reconfiguration message, which also encapsulates NAS PDU to be sent to UE
- It can also provide other radio configuration such as physical layer, measurements, etc.



SRB	Direction	Message	RLC mode
SRBO CCCH	Downlink	RRCSetup	Transparent Mode RLC
		RRCReject	
	uplink	Uplink RRCSetupRequest	
		RRCResumeRequest	
		RRCResumeRequestl (uses CCCH I)	
		RRCReestablishmentRoquesl	
		RRCSystemlofoRequest	
SRB1-DCCH		RRCReconfiguration	Acknowledged Mode RLC
		RRCResume	
		RRCReestablishment	
		RRCRclcase	
	Downlink	SecurityModeCommand	
		DLInformationTransferi(ifSRB2 has not been setup)	
		UECapabilityEoquiry	
		CounterCheck	
		MobilityFromNRCommand	
	Uplink	R RCSetupComplete	
		RRCResumeComplete	
		RRCReestablishmentComplete	
		RRCReconfigurationCompletc	
		SecurityModeComplete	
		SccurityModcFailurc	
		ULInformationTnmsfer {if SRB2 has not been setup)	
		MeasuremcntReport	
		UECapabilityInformatio:n	
		LocalionMeasuremcntIndication	
		U EAssistanceIn formation	
		CounterCheck Response	
SRB-2 DCCH	Downlink	DLInformationTnmsfer	
	Uplink	U Lin formation Transfer	
SRB-3 DCCH	Downlink	RRCRcconfiguration (also on SRB I)	
	uplink	RRCReconfigumtionComplete (also on SRB 1)	
		McasuremcntRcport (also on SRB I)	

Mapping between RRC messages and SRB

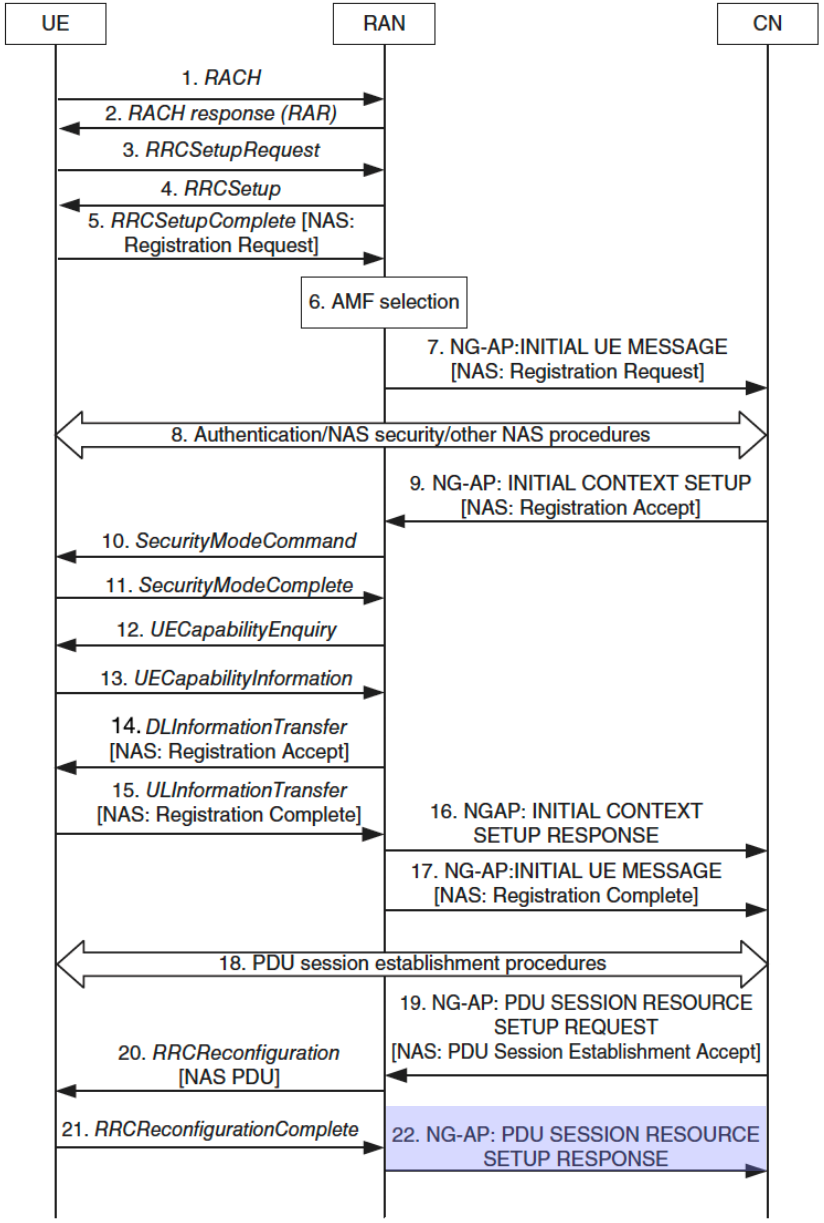
- 21. UE replies with an RRC Reconfiguration Complete message upon successful completion of configuration



SRB	Direction	Message	RLC mode
SRBO CCCH	Downlink	RRCSetup	Transparent Mode RLC
		RRCReject	
	uplink	Uplink RRCSetupRequest	
		RRCResumeRequest	
		RRCResumeRequestl (uses CCCH I)	
		RRCReestablishmentRoquesl	
		RRCSystemlofoRequest	
SRB1-DCCH	Downlink	RRCReconfiguration	Acknowledged Mode RLC
		RRCResume	
		RRCReestablishment	
		RRCRclcase	
		SecurityModeCommand	
		DLInformationTransferi(ifSRB2 has not been setup)	
		UECapabilityEoquiry	
		CounterCheck	
		MobilityFromNRCommand	
	Uplink	R RCSetupComplete	
		RRCResumeComplete	
		RRCReestablishmentComplete	
		RRCReconfigurationCompletc	
		SecurityModeComplete	
		SccurityModcFailurc	
		ULInformationTnmsfer {if SRB2 has not been setup)	
		MeasuremcntReport	
		UECapabilityInformatio:n	
		LocalionMeasuremcntIndication	
		U EAssistanceIn formation	
		CounterCheck Response	
SRB-2 DCCH	Downlink	DLInformationTnmsfer	
	Uplink	U Lin formation Transfer	
SRB-3 DCCH	Downlink	RRCRcconfiguration (also on SRB I)	
	uplink	RRCReconfigumtionComplete (also on SRB 1)	
		McasuremcntRcport (also on SRB I)	

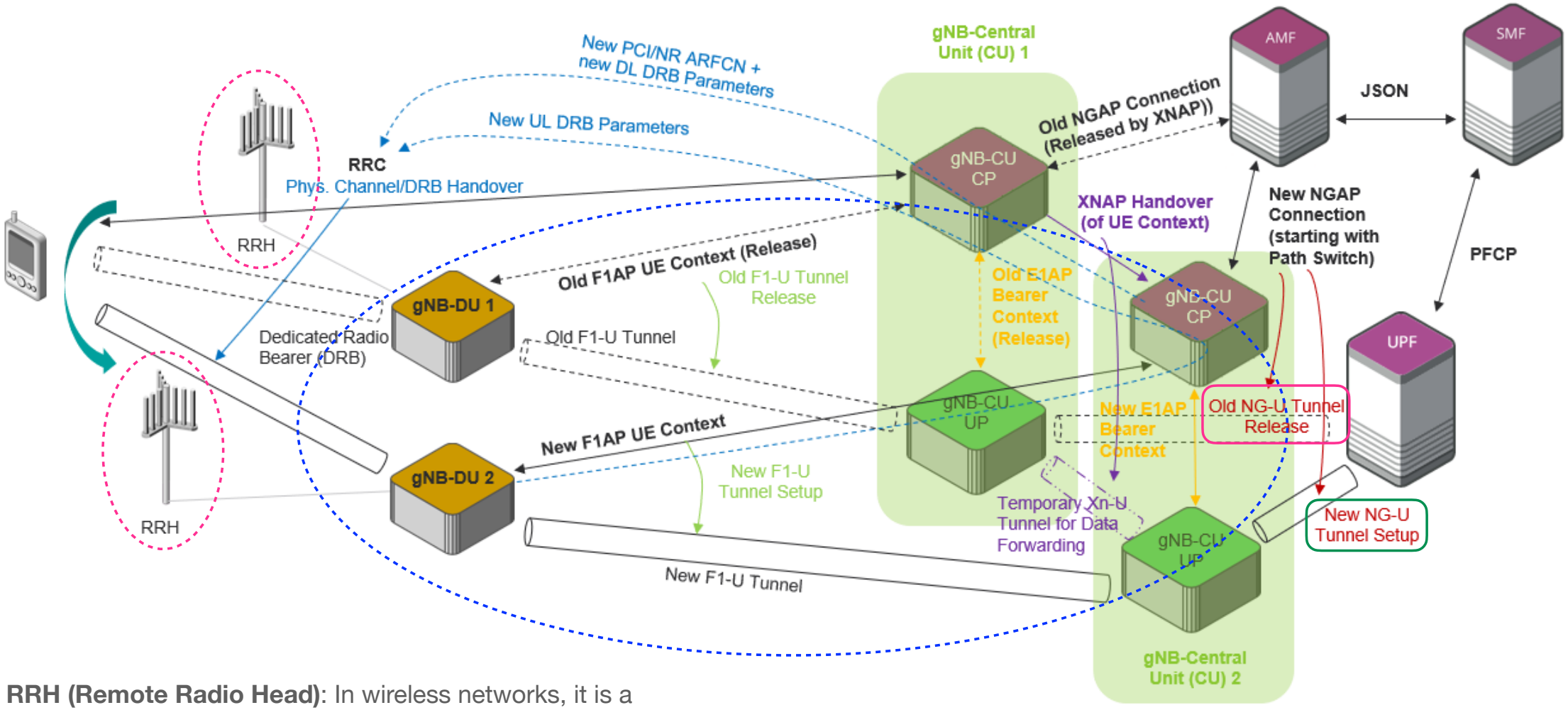
Mapping between RRC messages and SRB

- 22. gNB indicates successful completion using NG-AP PDU SESSION RESOURCE SETUP RESPONSE message



5.2.2 Security

- Security procedures for NR
  - All RBs are encrypted
  - SRBs: also integrity protected
  - DRBs: both encryption and integrity protection are configurable per DRB
- Not all handovers involve a change of security key because
  - Inter-DU handover within a gNB-CU does not change the security location and hence such a handover does not require a key change

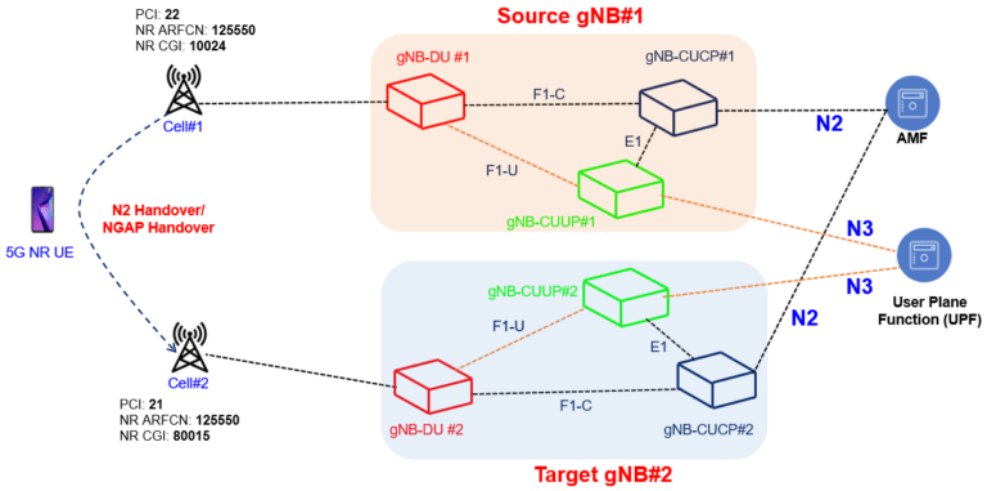


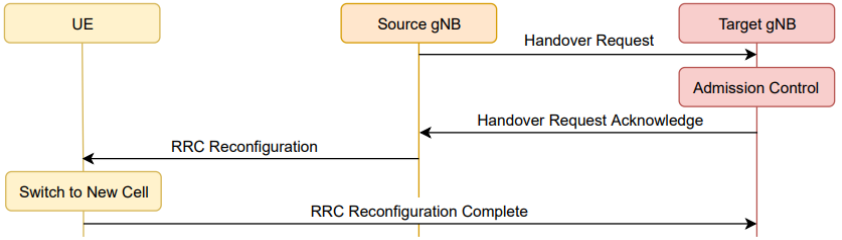
RRH (Remote Radio Head): In wireless networks, it is a remote radio transceiver that connects to an operator radio control panel via electrical or wireless interface

5.2.3 Mobility

- Measurement configuration provided by a gNB to a UE indicates
  - Which objects (frequencies) to measure
  - What quantities should be measured
  - The trigger events for measurement reporting
- When a measurement report is triggered
  - UE sends report with measured results to gNB

- If source gNB decides to hand over UE
  - It indicates so to target gNB via Xn handover preparation procedure
- Target gNB then reserves resources and provides target cell configuration to source gNB, to be delivered to UE over source cell using RRC Reconfiguration message including reconfigwithSync



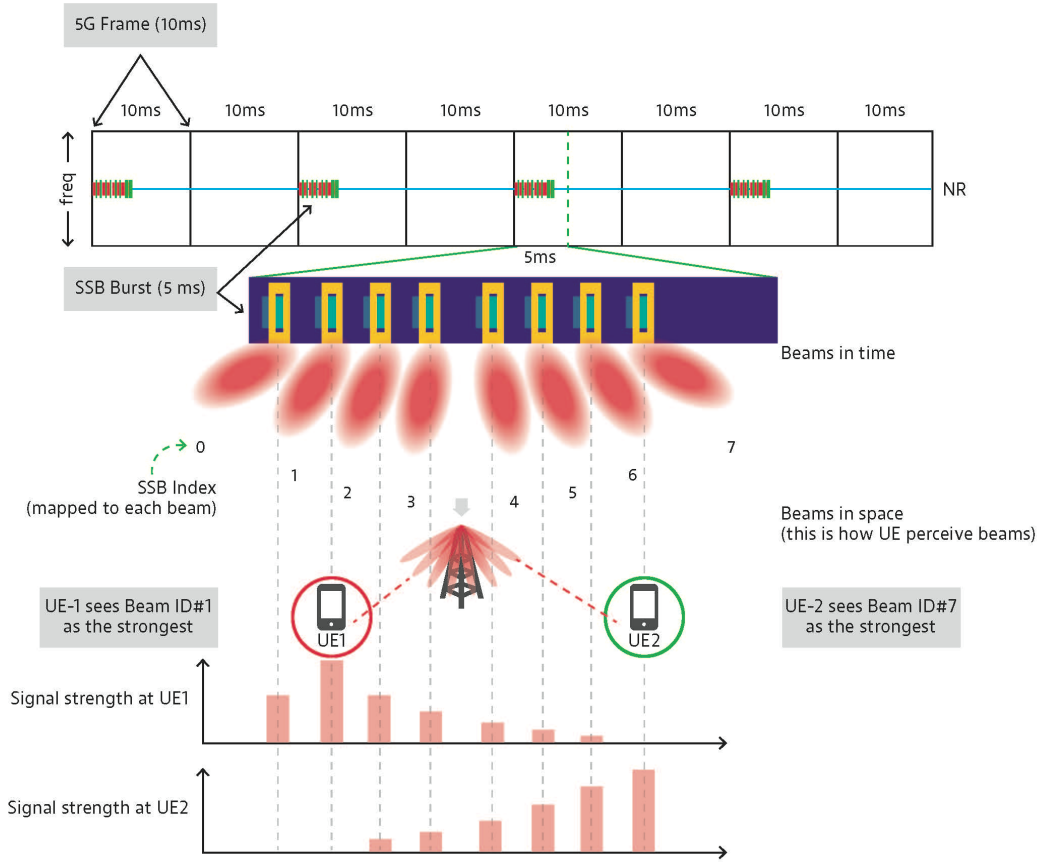


SRB	Direction	Message	RLC mode
SRBO CCCH	Downlink	RRCSetup	Transparent Mode RLC
		RRCReject	
	uplink	Uplink RRCSetupRequest	
		RRCResumeRequest	
		RRCResumeRequestl (uses CCCH I)	
		RRCReestablishmentRoquesl	
		RRCSystemlofoRequest	
SRB1-DCCH		RRCReconfiguration	Acknowledged Mode RLC
		RRCResume	
		RRCReestablishment	
		RRCRclcase	
	Downlink	SecurityModeCommand	
		DLInformationTransferi(ifSRB2 has not been setup)	
		UECapabilityEoquiry	
		CounterCheck	
		MobilityFromNRCommand	
	Uplink	R RCSetupComplete	
		RRCResumeComplete	
		RRCReestablishmentComplete	
		RRCReconfigurationCompletc	
		SecurityModeComplete	
		SccurityModcFailurc	
		ULInformationTnmsfer {if SRB2 has not been setup)	
		MeasuremcntReport	
		UECapabilityInformatio:n	
		LocalionMeasuremcntIndication	
		U EAssistanceln formation	
		CounterCheck Response	
SRB-2 DCCH	Downlink	DLInformationTnmsfer	
	Uplink	U Lin formation Transfer	
SRB-3 DCCH	Downlink	RRCRcconfiguration (also on SRB I)	
	uplink	RRCReconfigumtionComplete (also on SRB 1)	
		McasuremcntRcport (also on SRB I)	

Mapping between RRC messages and SRB

- NR allows reference signal to be
  - SSB (Synchronization Signal Block) for IDLE state
  - SSB and/or CSI-RS (Channel State Information Reference Signal) for CONNECTED state

- UE measures multiple beams of a cell and derives cell quality from multiple beams
- Measurement reports contain
  - Beam results
    - Beam identifier
    - Measurement result
  - Cell quantities



5.2.4 Radio Link Failure Recovery

- Radio Link Failure (RLF) (reestablishment procedure)
  - RRC Reestablishment message does not contain any configuration information other than security parameters (between UE and network)
  - A subsequent RRC Reconfiguration message is then sent with security to provide all configuration information

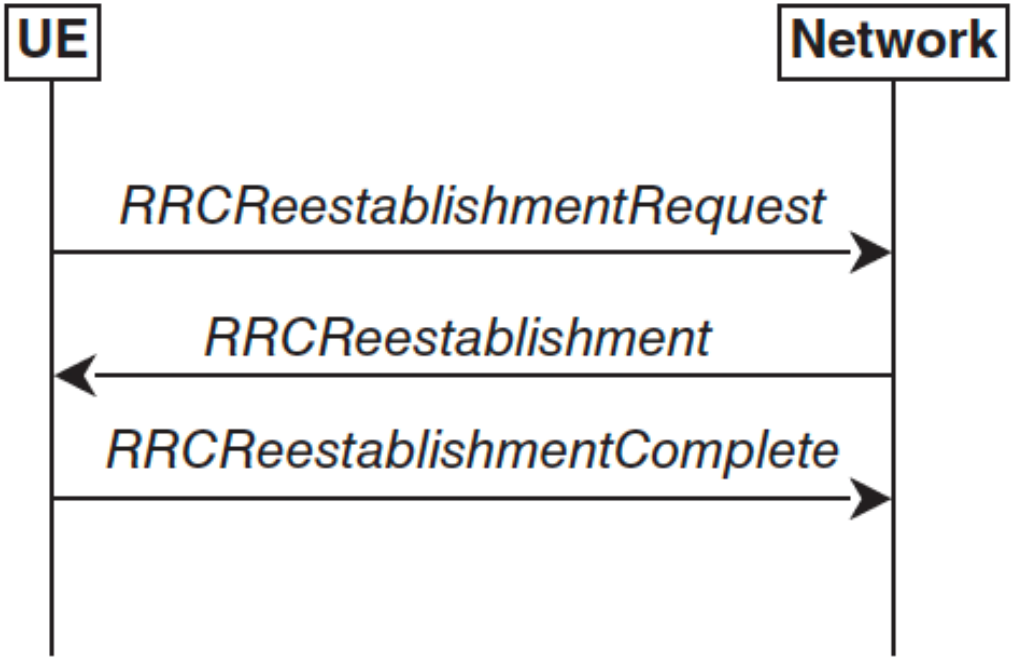
SRB	Direction	Message	RLC mode
SRBO CCCH	Downlink	RRCSetup	Transparent Mode RLC
		RRCReject	
	uplink	Uplink RRCSetupRequest	
		RRCResumeRequest	
		RRCResumeRequestl (uses CCCH I)	
		RRCReestablishmentRoquesl	
		RRCSystemlofoRequest	
SRB1-DCCH		RRCReconfiguration	Acknowledged Mode RLC
		RRCResume	
		RRCReestablishment	
		RRCRclcase	
	Downlink	SecurityModeCommand	
		DLInformationTransferi(ifSRB2 has not been setup)	
		UECapabilityEoquiry	
		CounterCheck	
		MobilityFromNRCommand	
	Uplink	R RCSetupComplete	
		RRCResumeComplete	
		RRCReestablishmentComplete	
		RRCReconfigurationCompletc	
		SecurityModeComplete	
		SccurityModcFailurc	
		ULInformationTnmsfer {if SRB2 has not been setup)	
		MeasuremcntReport	
		UECapabilityInformatio:n	
		LocalionMeasuremcntIndication	
		U EAssistanceln formation	
		CounterCheck Response	
SRB-2 DCCH	Downlink	DLInformationTnmsfer	
	Uplink	U Lin formation Transfer	
SRB-3 DCCH	Downlink	RRCRcconfiguration (also on SRB I)	
	uplink	RRCReconfigumtionComplete (also on SRB 1)	
		McasuremcntRcport (also on SRB I)	

Mapping between RRC messages and SRB

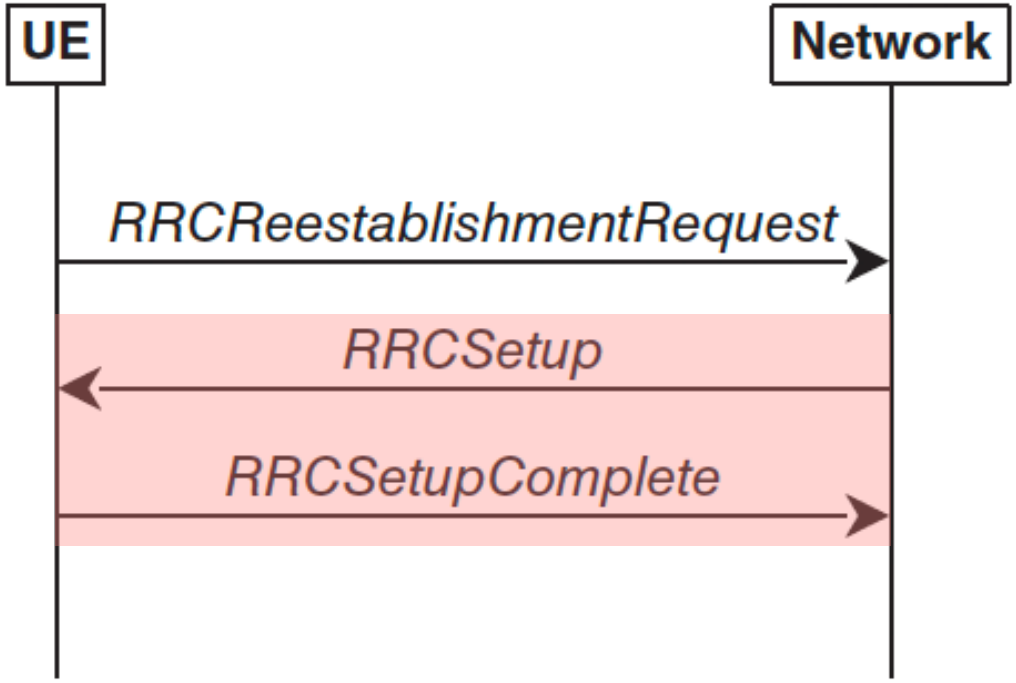
- If the target cannot continue with reestablishment, e.g., if it does not have UE context, then
  - It can use a fallback procedure and convert the reestablishment to a new RRC set up procedure without the UE having to initiate a RACH attempt again

SRB	Direction	Message	RLC mode
SRBO CCCH	Downlink	RRCSetup	Transparent Mode RLC
		RRCReject	
	uplink	Uplink RRCSetupRequest	
		RRCResumeRequest	
		RRCResumeRequestl (uses CCCH I)	
		RRCReestablishmentRoquesl	
		RRCSystemlofoRequest	
SRB1-DCCH	Downlink	RRCReconfiguration	Acknowledged Mode RLC
		RRCResume	
		RRCReestablishment	
		RRCRclcase	
		SecurityModeCommand	
		DLInformationTransferi(ifSRB2 has not been setup)	
		UECapabilityEoquiry	
		CounterCheck	
		MobilityFromNRCommand	
	Uplink	R RCSetupComplete	
		RRCResumeComplete	
		RRCReestablishmentComplete	
		RRCReconfigurationCompletc	
		SecurityModeComplete	
		SccurityModcFailurc	
		ULInformationTnmsfer {if SRB2 has not been setup)	
		MeasuremcntReport	
		UECapabilityInformatio:n	
		LocalionMeasuremcntIndication	
		U EAssistanceln formation	
		CounterCheck Response	
SRB-2 DCCH	Downlink	DLInformationTnmsfer	
	Uplink	U Lin formation Transfer	
SRB-3 DCCH	Downlink	RRCRcconfiguration (also on SRB I)	
	uplink	RRCReconfigumtionComplete (also on SRB 1)	
		McasuremcntRcport (also on SRB I)	

Mapping between RRC messages and SRB



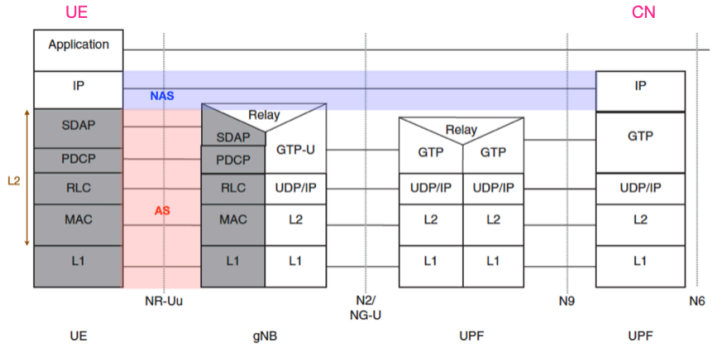
Successful RRC connection **reestablishment**

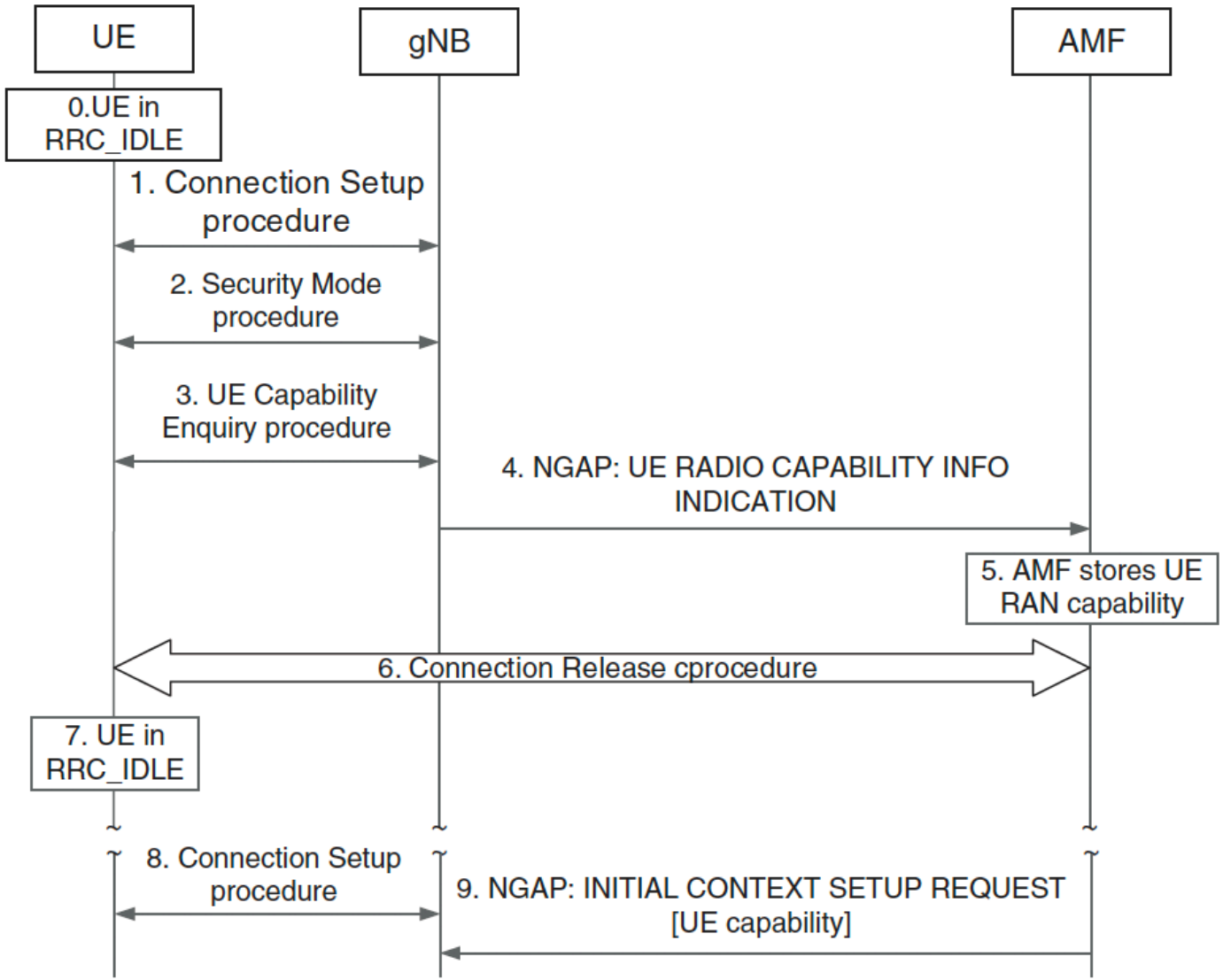


RRC connection reestablishment with **fallback**

5.2.5 UE AS Capability Retrieval

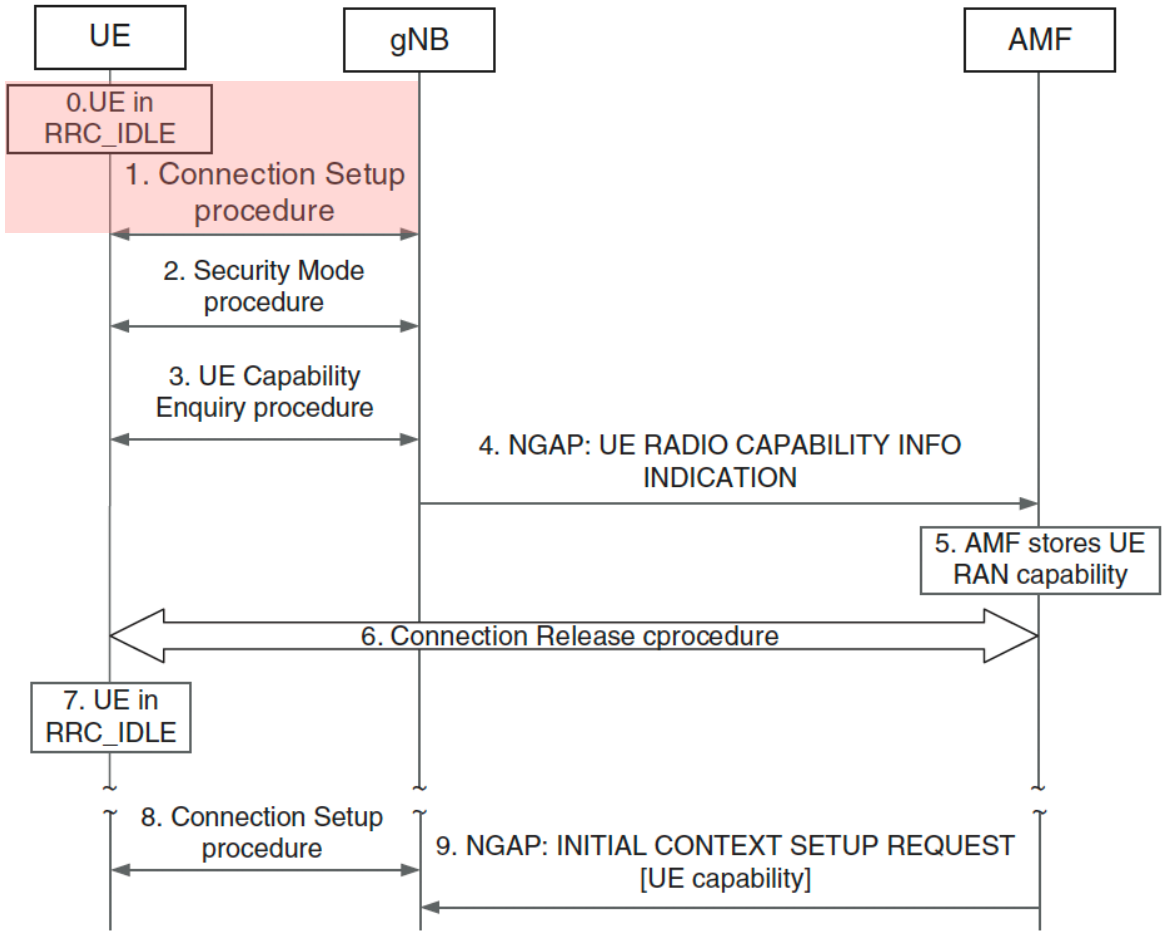
- UE capability enquiry procedure is used to retrieve and store UE AS capability in core network as part of UE connection establishment procedure
  - This procedure is normally only run once per UE registration
  - For subsequent connection establishments
    - The core network provides the stored UE capability to gNB
  - During handover and dual connectivity establishment, the source node provides UE capability to the target node during preparation phase
- The stored UE capability can be released and updated with a new NAS registration procedure





UE **AS capability** enquiry, network storage, and retrieval

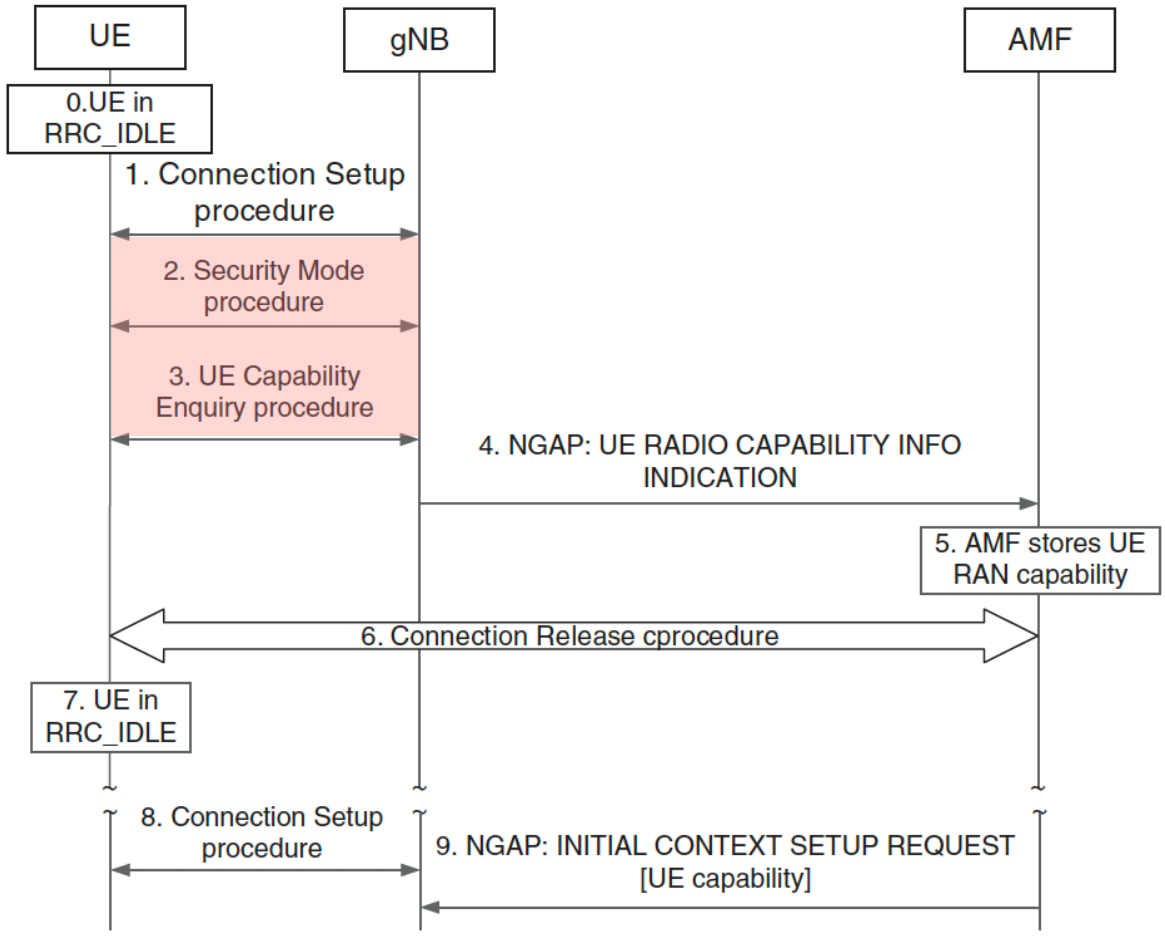
- 0. A UE is in RRC IDLE state
- 1. UE goes into CONNECTED state using Connection Establishment procedure, e.g., at NAS registration



SRB	Direction	Message	RLC mode
SRBO CCCH	Downlink	RRCSetup	Transparent Mode RLC
		RRCReject	
	uplink	Uplink RRCSetupRequest	
		RRCResumeRequest	
		RRCResumeRequestl (uses CCCH I)	
		RRCReestablishmentRoquesl	
		RRCSystemlofoRequest	
SRB1-DCCH	Downlink	RRCReconfiguration	Acknowledged Mode RLC
		RRCResume	
		RRCReestablishment	
		RRCRclcase	
		SecurityModeCommand	
		DLInformationTransferi(ifSRB2 has not been setup)	
		UECapabilityEoquiry	
		CounterCheck	
		MobilityFromNRCommand	
	Uplink	R RCSetupComplete	
		RRCResumeComplete	
		RRCReestablishmentComplete	
		RRCReconfigurationCompletc	
		SecurityModeComplete	
		SccurityModcFailurc	
		ULInformationTnmsfer {if SRB2 has not been setup)	
		MeasuremcntReport	
		UECapabilityInformatio:n	
		LocalionMeasuremcntIndication	
		U EAssistanceln formation	
		CounterCheck Response	
SRB-2 DCCH	Downlink	DLInformationTnmsfer	
	Uplink	U Lin formation Transfer	
SRB-3 DCCH	Downlink	RRCRcconfiguration (also on SRB I)	
	uplink	RRCReconfigumtionComplete (also on SRB 1)	
		McasuremcntRcport (also on SRB I)	

Mapping between RRC messages and SRB

2. AS security is configured
3. gNB retrieves the UE RAN capability from UE using UE Capability Enquiry procedure



SRB	Direction	Message	RLC mode
SRBO CCCH	Downlink	RRCSetup	Transparent Mode RLC
		RRCReject	
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		RRCSystemlofoRequest	
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		RRCResume	
		RRCReestablishment	
		RRCRclcase	
		SecurityModeCommand	
		DLInformationTransferi(ifSRB2 has not been setup)	
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		CounterCheck	
		MobilityFromNRCommand	
	Uplink	R RCSetupComplete	
		RRCResumeComplete	
		RRCReestablishmentComplete	
		RRCReconfigurationCompletc	
		SecurityModeComplete	
		SccurityModcFailurc	
		ULInformationTnmsfer {if SRB2 has not been setup)	
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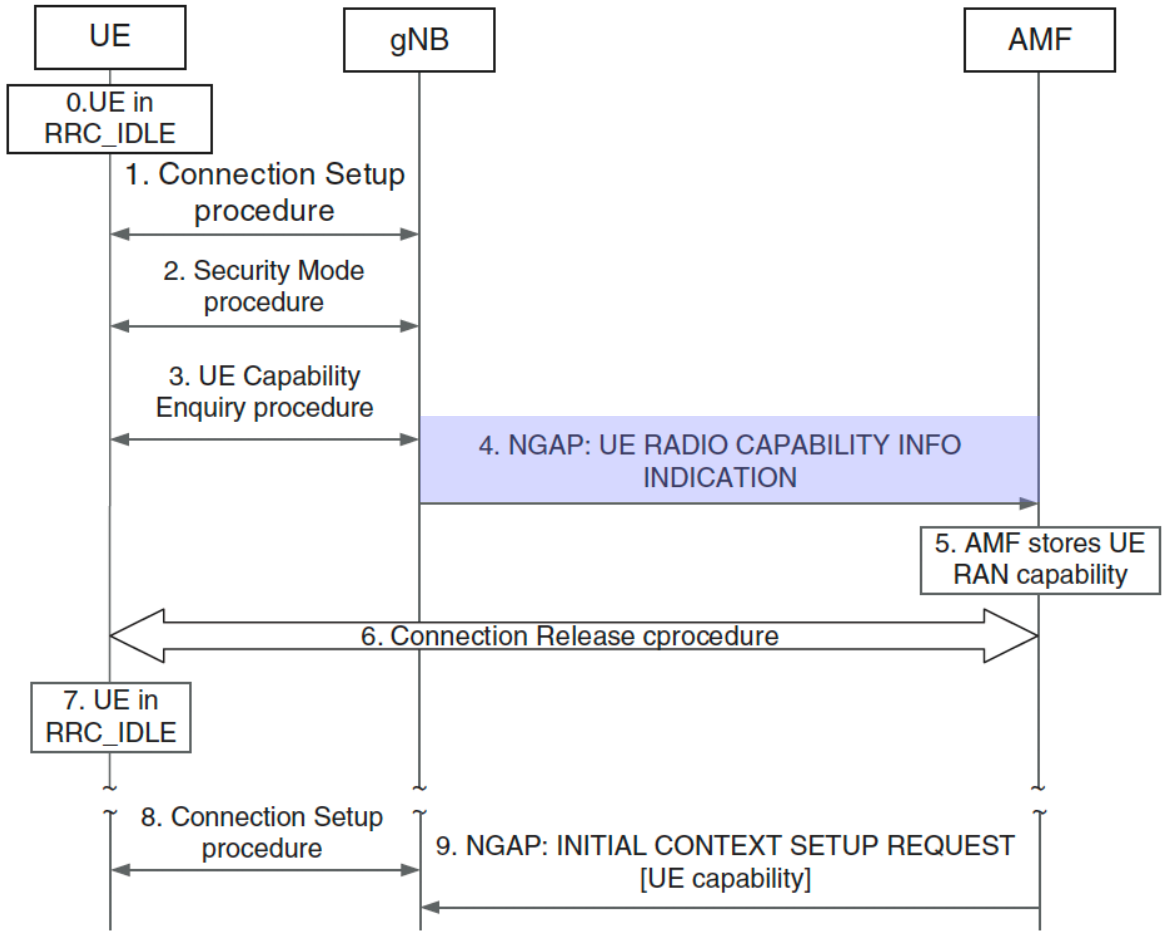
		LocalionMeasuremcntIndication	
		U EAssistanceln formation	
		CounterCheck Response	
SRB-2 DCCH	Downlink	DLInformationTnmsfer	
	Uplink	U Lin formation Transfer	
SRB-3 DCCH	Downlink	RRCRcconfiguration (also on SRB I)	
	uplink	RRCReconfigumtionComplete (also on SRB 1)	
		McasuremcntRcport (also on SRB I)	

Mapping between RRC messages and SRB

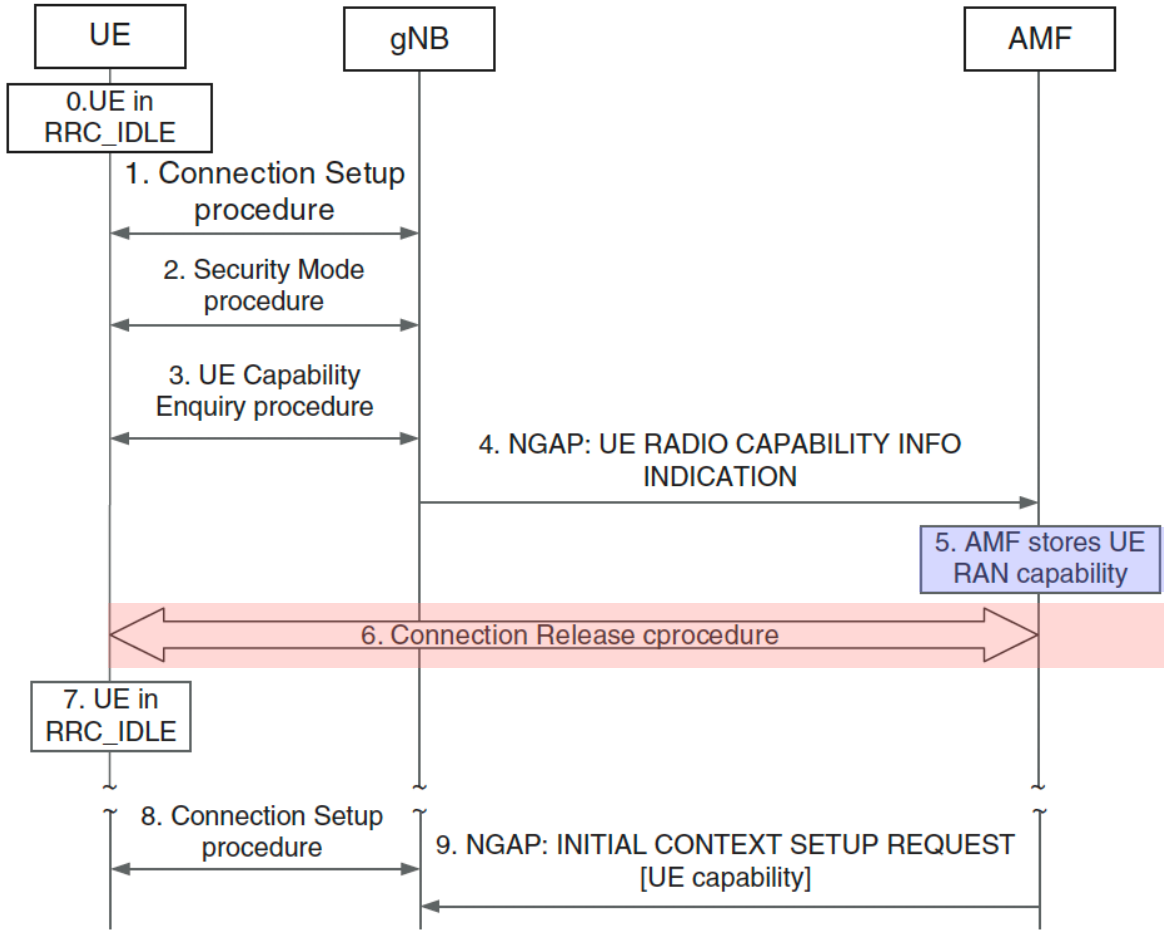
4. gNB forwards the retrieved UE RAN capability to the AMF using NG-AP UE RADIO CAPABILITY INFO INDICATION message



5. AMF stores the UE RAN capability as part of UE context stored in AMF as a transparent container

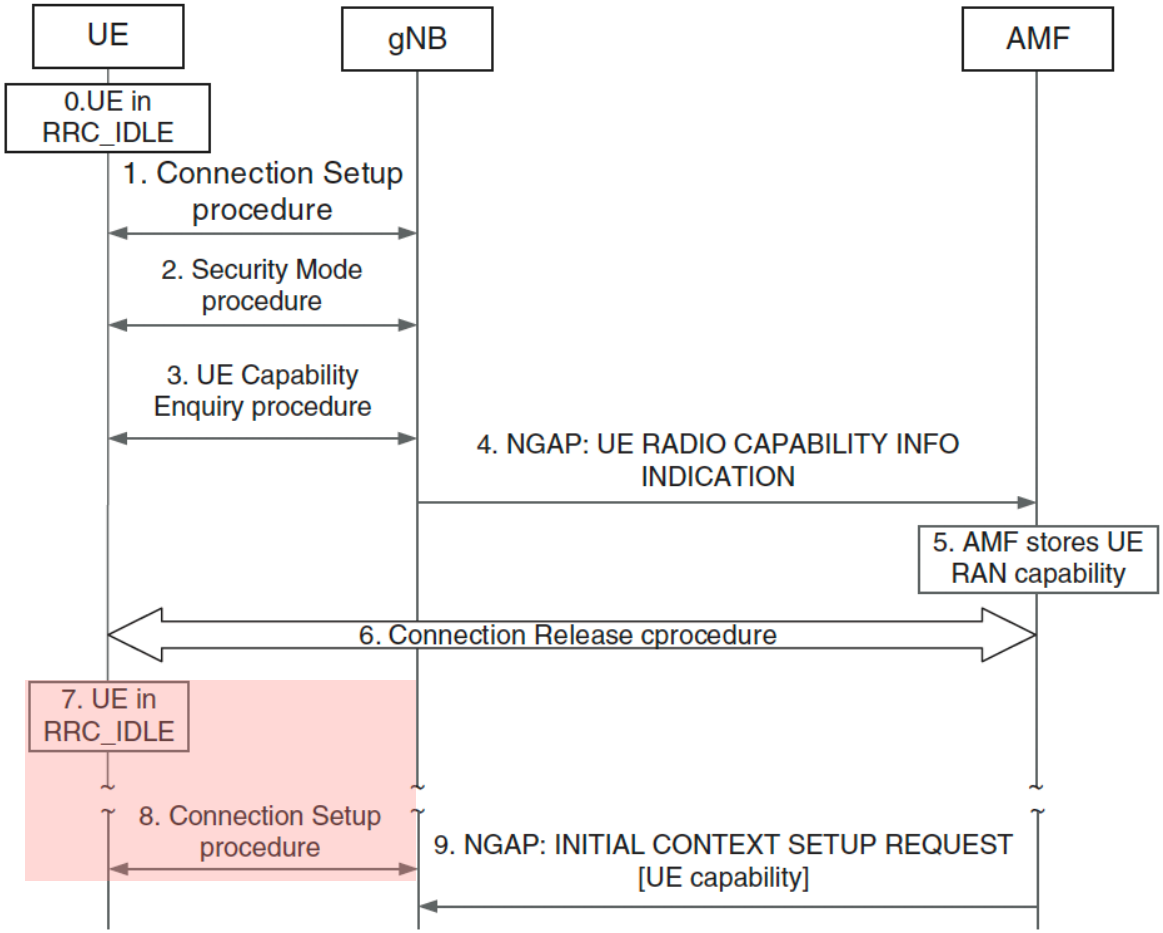
6. The UE RRC connection is subsequently released

- The UE context in the gNB is released



7. UE goes to RRC IDLE state

8. UE starts a new RRC Connection Establishment procedure

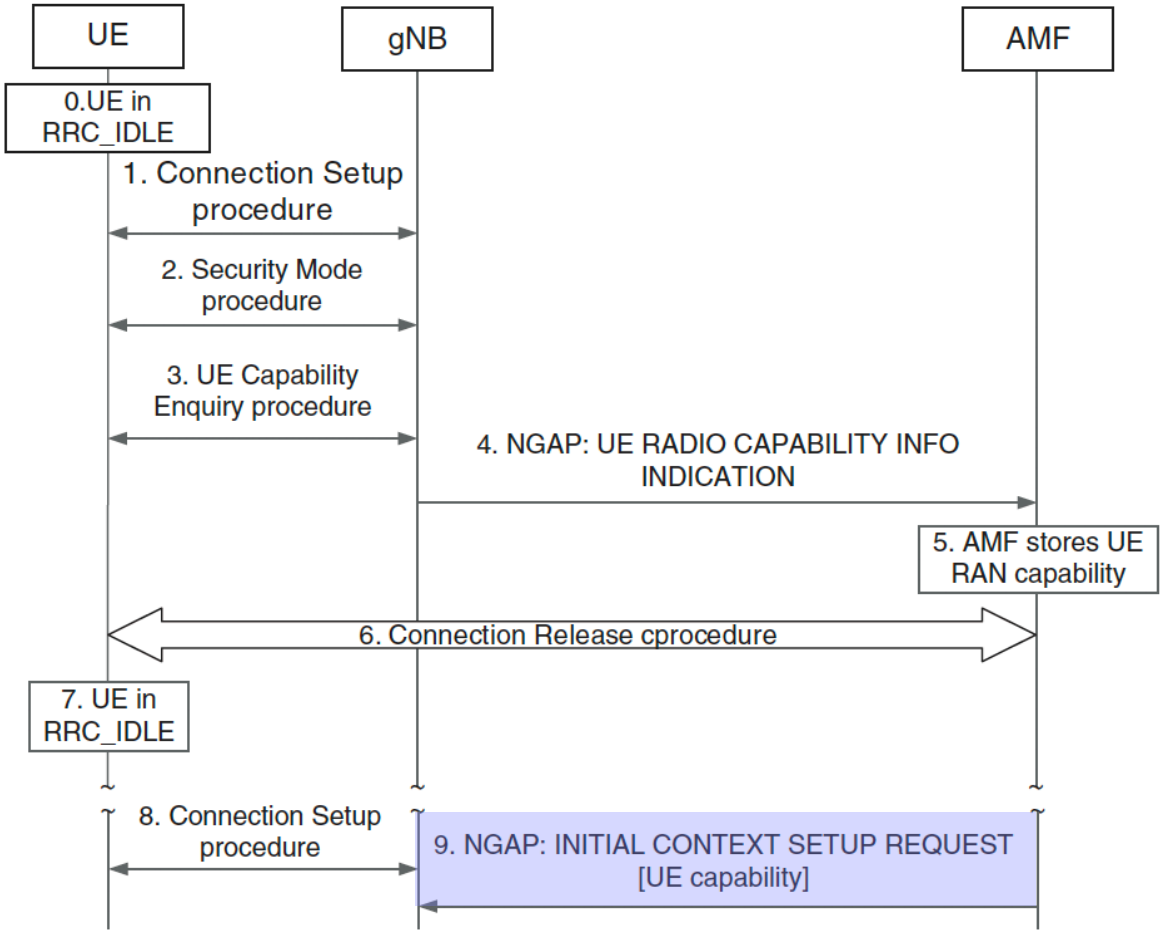


SRB	Direction	Message	RLC mode
SRBO CCCH	Downlink	RRCSetup	Transparent Mode RLC
		RRCReject	
	uplink	Uplink RRCSetupRequest	
		RRCResumeRequest	
		RRCResumeRequestl (uses CCCH I)	
		RRCReestablishmentRoquesl	
		RRCSystemlofoRequest	
SRB1-DCCH	Downlink	RRCReconfiguration	Acknowledged Mode RLC
		RRCResume	
		RRCReestablishment	
		RRCRclcase	
		SecurityModeCommand	
		DLInformationTransferi(ifSRB2 has not been setup)	
		UECapabilityEoquiry	
		CounterCheck	
		MobilityFromNRCommand	
	Uplink	R RCSetupComplete	
		RRCResumeComplete	
		RRCReestablishmentComplete	
		RRCReconfigurationCompletc	
		SecurityModeComplete	
		SccurityModcFailurc	
		ULInformationTnmsfer {if SRB2 has not been setup)	
		MeasuremcntReport	
		UECapabilityInformatio:n	
		LocalionMeasuremcntIndication	
		U EAssistanceln formation	
		CounterCheck Response	
SRB-2 DCCH	Downlink	DLInformationTnmsfer	
	Uplink	U Lin formation Transfer	
SRB-3 DCCH	Downlink	RRCRcconfiguration (also on SRB I)	
	uplink	RRCReconfigumtionComplete (also on SRB 1)	
		McasuremcntRcport (also on SRB I)	

Mapping between RRC messages and SRB

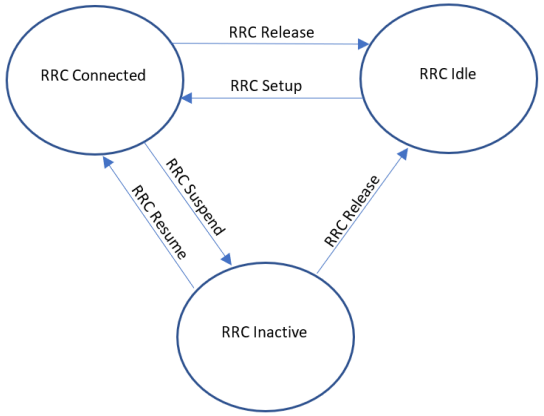
9. AMF includes the stored UE RAN capability in NG-AP INITIAL CONTEXT SETUP REQUEST message sent to gNB

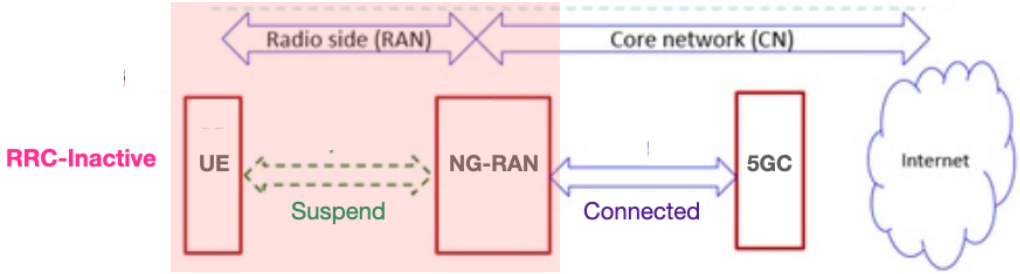
- gNB can use this for RRC connection without having to retrieve it from UE again



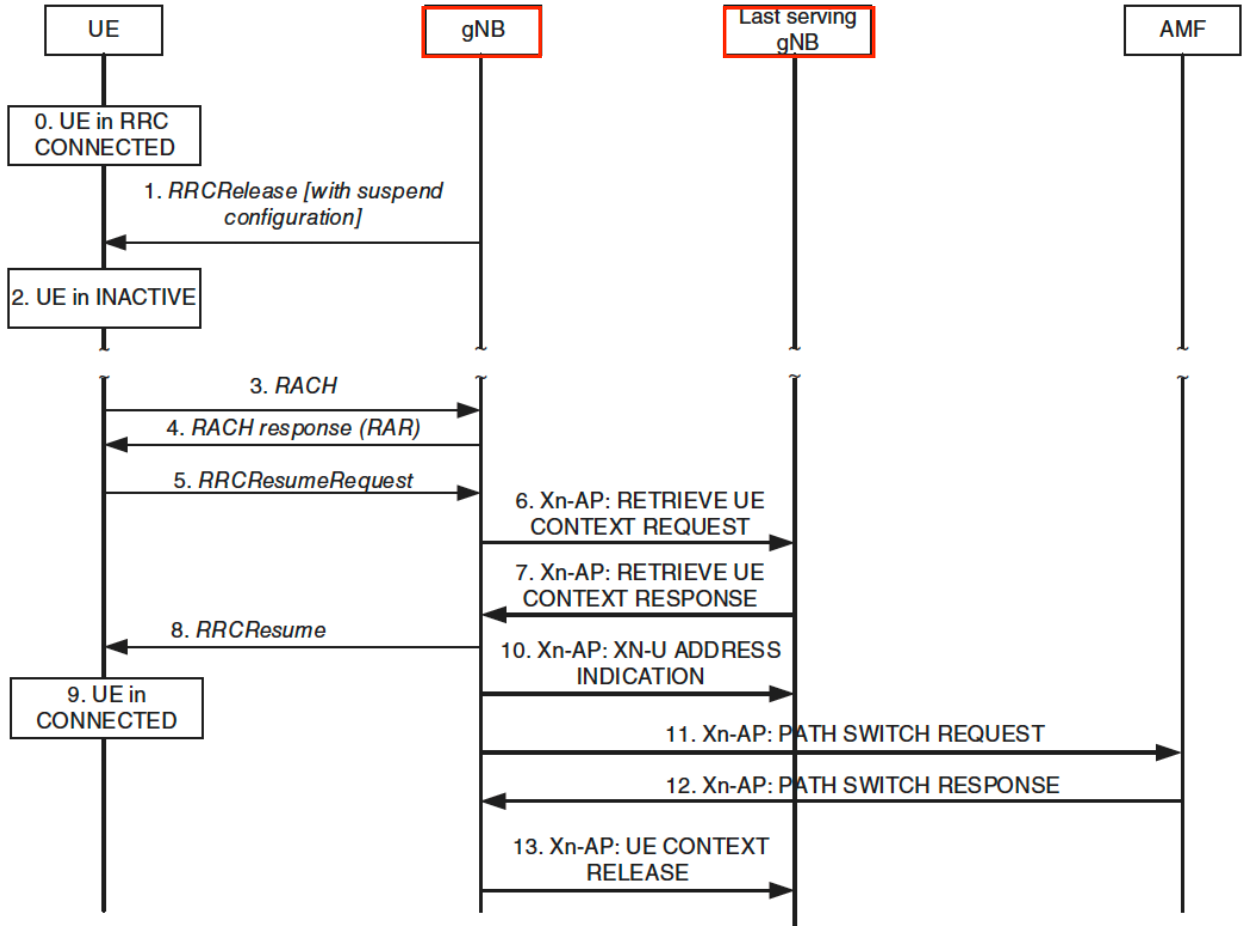
5.2.6 RRC INACTIVE State

- When a UE is in INACTIVE state
  - The network and UE store the previously used configurations
  - The network provides to UE a context RAN ID called I-RNTI (Inactive-Radio Network Temporary Identifier)





- The message flow for a UE moving to CONNECTED from INACTIVE that also involves a change of gNB

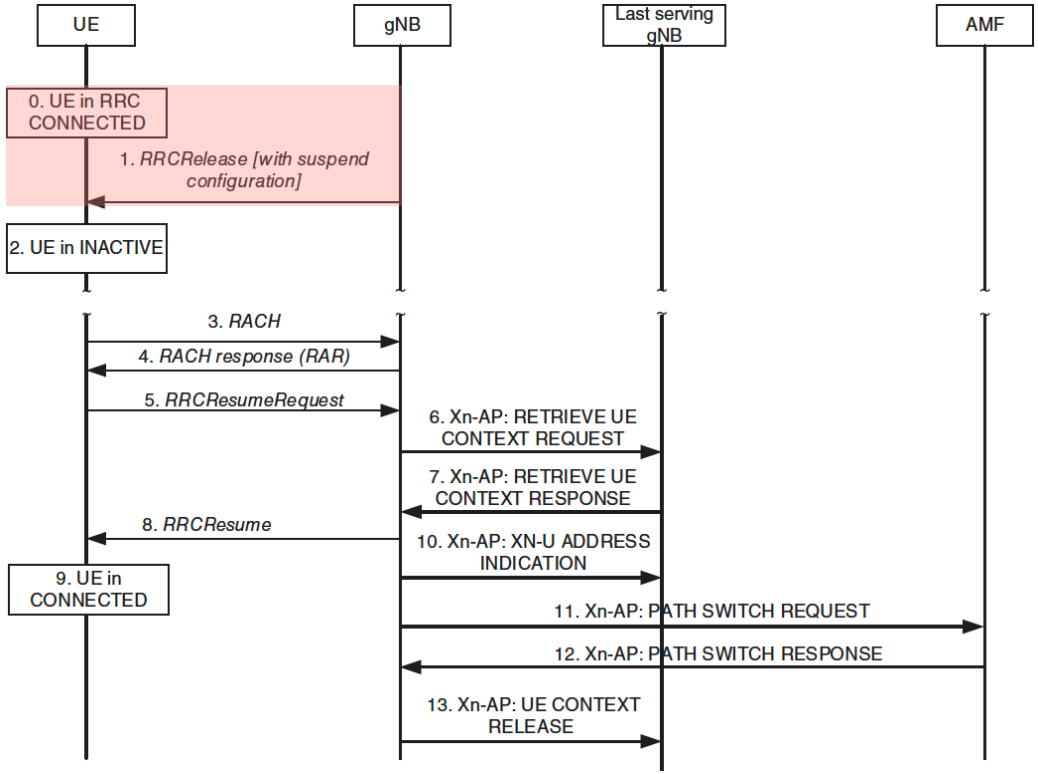


Example **message flow** for **state transition** from INACTIVE to CONNECTED

0. A UE is in CONNECTED state

1. Network releases the connection and moves UE to INACTIVE state by providing an RRC Release message with suspend configuration

- Suspend configuration includes a UE RAN ID called I-RNTI
- It also includes security configuration to use when resuming the connection

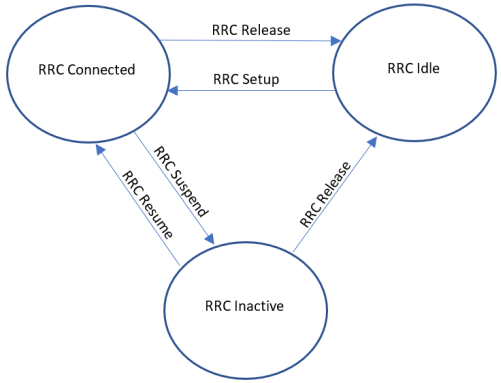


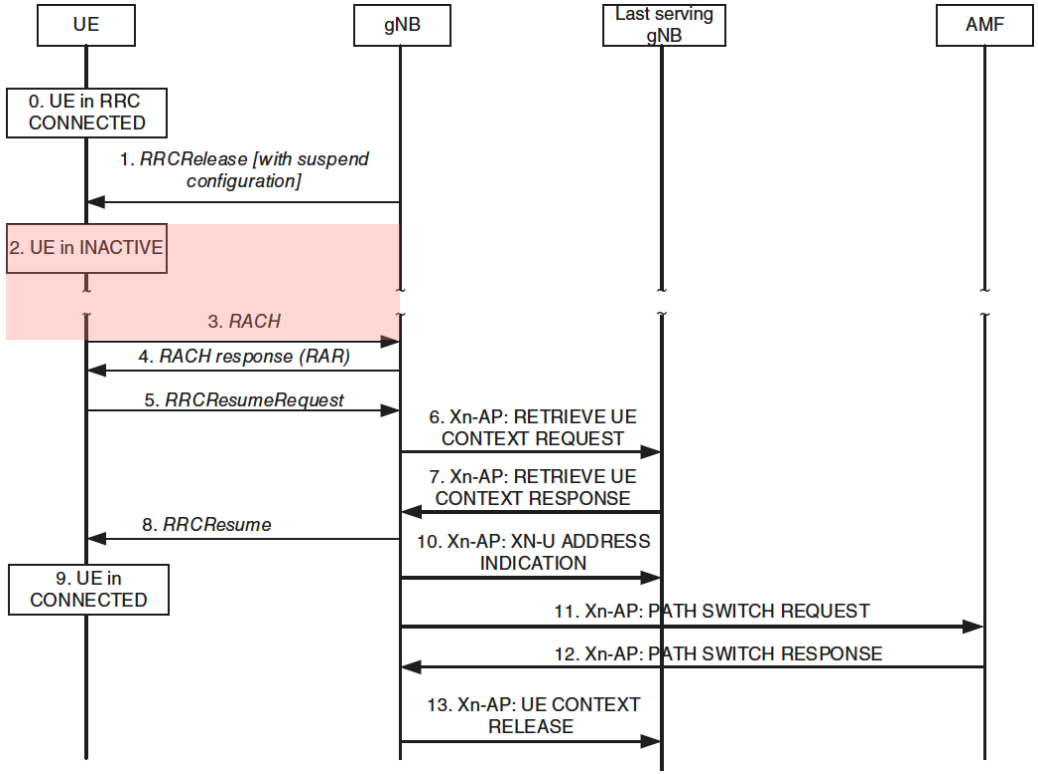
SRB	Direction	Message	RLC mode
SRBO CCCH	Downlink	RRCSetup	Transparent Mode RLC
		RRCReject	
	uplink	Uplink RRCSetupRequest	
		RRCResumeRequest	
		RRCResumeRequestl (uses CCCH I)	
		RRCReestablishmentRoquesl	
		RRCSystemlofoRequest	
SRB1-DCCH		RRCReconfiguration	Acknowledged Mode RLC
		RRCResume	
		RRCReestablishment	
		RRCRclcase	
	Downlink	SecurityModeCommand	
		DLInformationTransferi(ifSRB2 has not been setup)	
		UECapabilityEoquiry	
		CounterCheck	
		MobilityFromNRCommand	
	Uplink	R RCSetupComplete	
		RRCResumeComplete	
		RRCReestablishmentComplete	
		RRCReconfigurationCompletc	
		SecurityModeComplete	
		SccurityModcFailurc	
		ULInformationTnmsfer {if SRB2 has not been setup)	
		MeasuremcntReport	
		UECapabilityInformatio:n	
		LocalionMeasuremcntIndication	
		U EAssistanceIn formation	
		CounterCheck Response	
SRB-2 DCCH	Downlink	DLInformationTnmsfer	
	Uplink	U Lin formation Transfer	
SRB-3 DCCH	Downlink	RRCRcconfiguration (also on SRB I)	
	uplink	RRCReconfigumtionComplete (also on SRB 1)	
		McasuremcntRcport (also on SRB I)	

Mapping between RRC messages and SRB

2. UE moves to INACTIVE state
3. When UE wants to move to RRC CONNECTED, either to initiate communication with network or in response to RAN or CN paging message, UE initiates connection using RACH procedure

- This is the same as when UE is moving to CONNECTED from IDLE

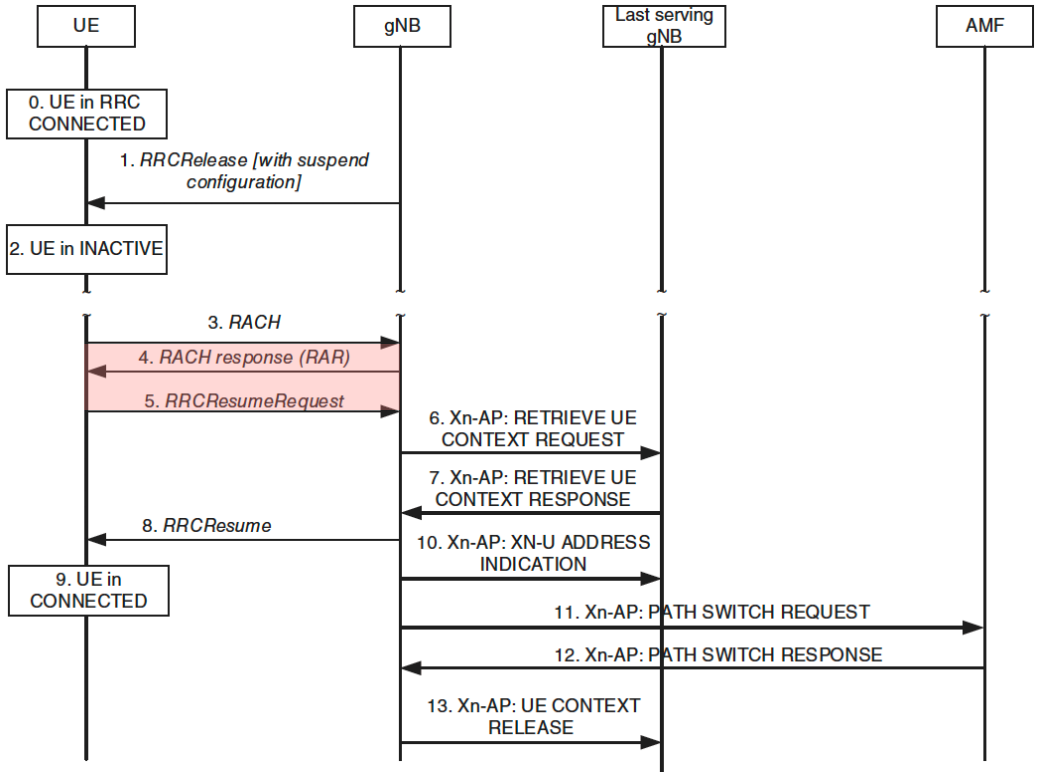




4. Network responds with a RACH response, the same as for an IDLE to CONNECTED connection establishment procedure

5. UE requests the transition to CONNECTED using an RRC Resume Request message in RACH message 3 that contains

- I-RNTI
- Authentication information ResumeMAC-I
- Cause value



SRB	Direction	Message	RLC mode
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		RRCReject	
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		RRCResume	
		RRCReestablishment	
		RRCRclcase	
		SecurityModeCommand	
		DLInformationTransferi(ifSRB2 has not been setup)	
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		MobilityFromNRCommand	
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		RRCResumeComplete	
		RRCReestablishmentComplete	
		RRCReconfigurationCompletc	
		SecurityModeComplete	
		SccurityModcFailurc	
		ULInformationTnmsfer {if SRB2 has not been setup)	
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SRB-2 DCCH	Downlink	DLInformationTnmsfer	
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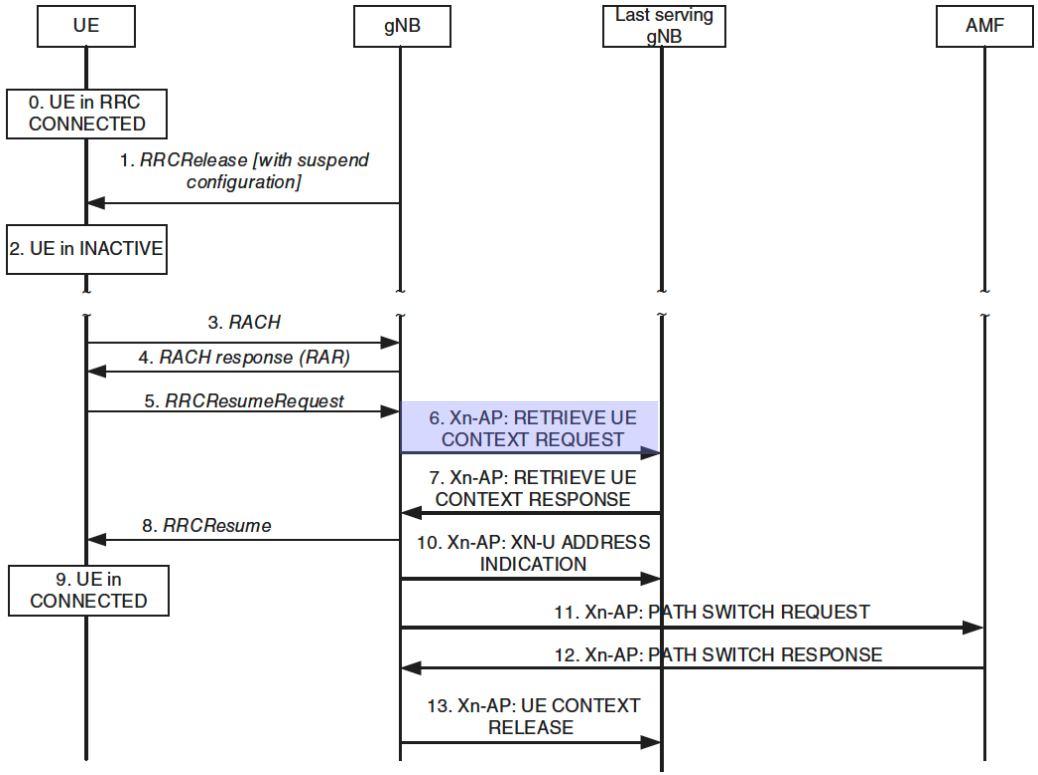
SRB-3 DCCH	Downlink	RRCRcconfiguration (also on SRB I)	
	uplink	RRCReconfigumtionComplete (also on SRB 1)	
		McasuremcntRcport (also on SRB I)	

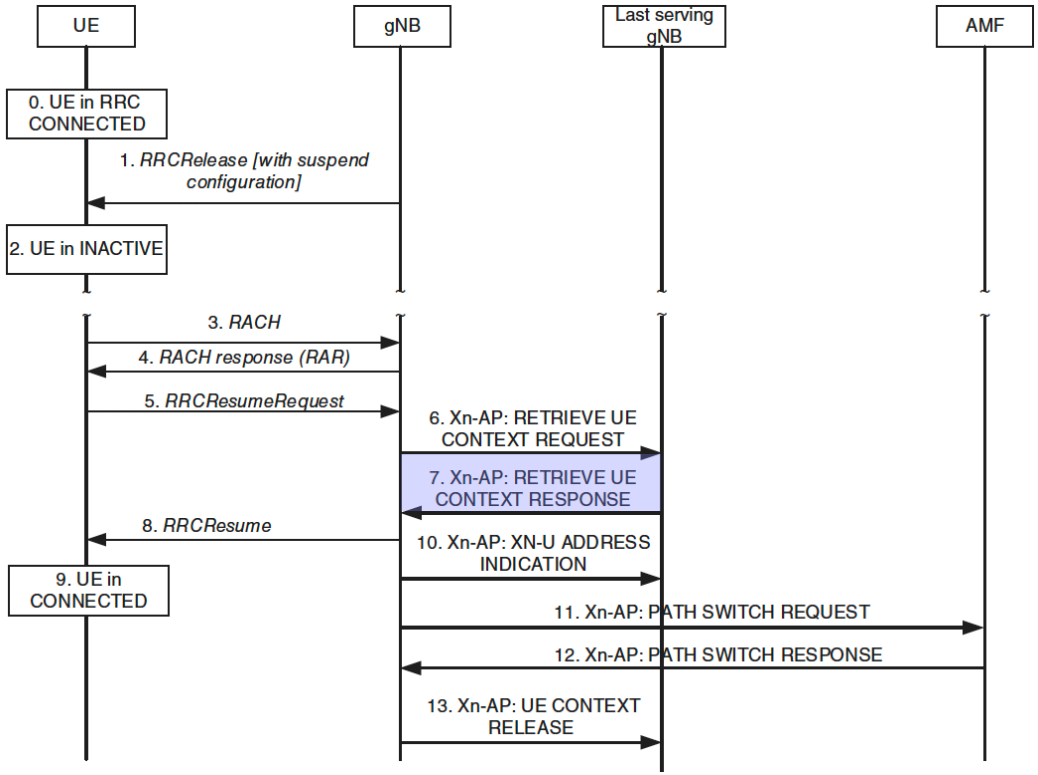
Mapping between RRC messages and SRB

6. If the resume request is received in a new gNB, the UE context has to be relocated from the previous gNB (i.e. the last serving gNB) to the current gNB

- The new gNB requests UE context using NG-AP RETRIEVE UE CONTEXT REQUEST message

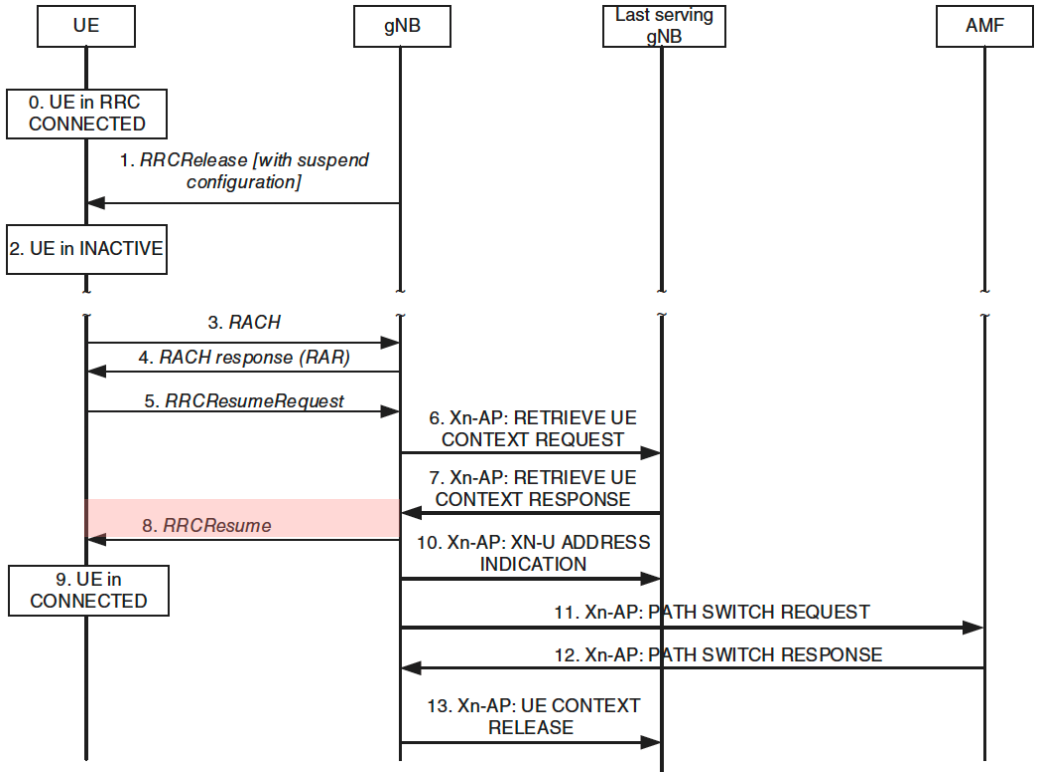


7. After successful authentication of the UE based on ResumeMAC-I, the previous gNB provides UE context using NG-AP RETRIEVE UE CONTEXT RESPONSE message



8. gNB indicates successful resumption to the UE using RRC Resume message

- It is sent with security over DCCH as security context in the UE was already provided when the UE went to INACTIVE
- Hence Resume message can provide additional UE configuration



SRB	Direction	Message	RLC mode
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		RRCResumeRequestl (uses CCCH I)	
		RRCReestablishmentRoquesl	
		RRCSystemlofoRequest	
SRB1-DCCH		RRCReconfiguration	Acknowledged Mode RLC
		RRCResume	
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	Downlink	SecurityModeCommand	
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		MobilityFromNRCommand	
	Uplink	R RCSetupComplete	
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		RRCReestablishmentComplete	
		RRCReconfigurationCompletc	
		SecurityModeComplete	
		SccurityModcFailurc	
		ULInformationTnmsfer {if SRB2 has not been setup)	
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SRB-2 DCCH	Downlink	DLInformationTnmsfer	
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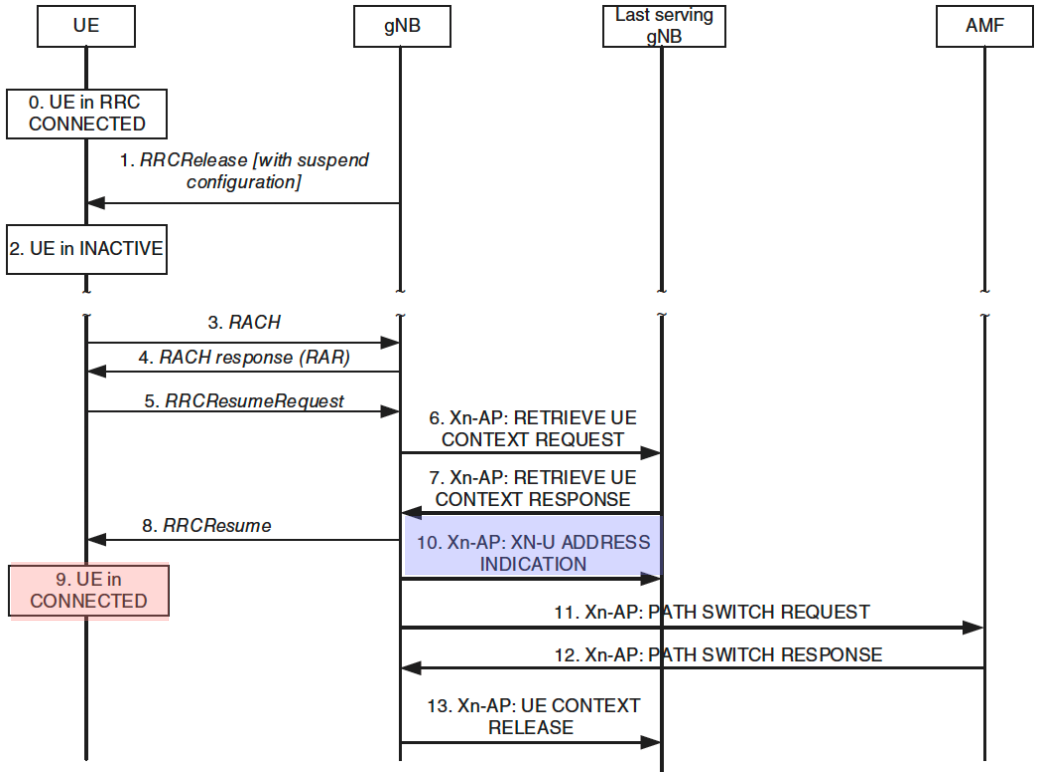
	uplink	RRCReconfigumtionComplete (also on SRB 1)	
		McasuremcntRcport (also on SRB I)	

Mapping between RRC messages and SRB

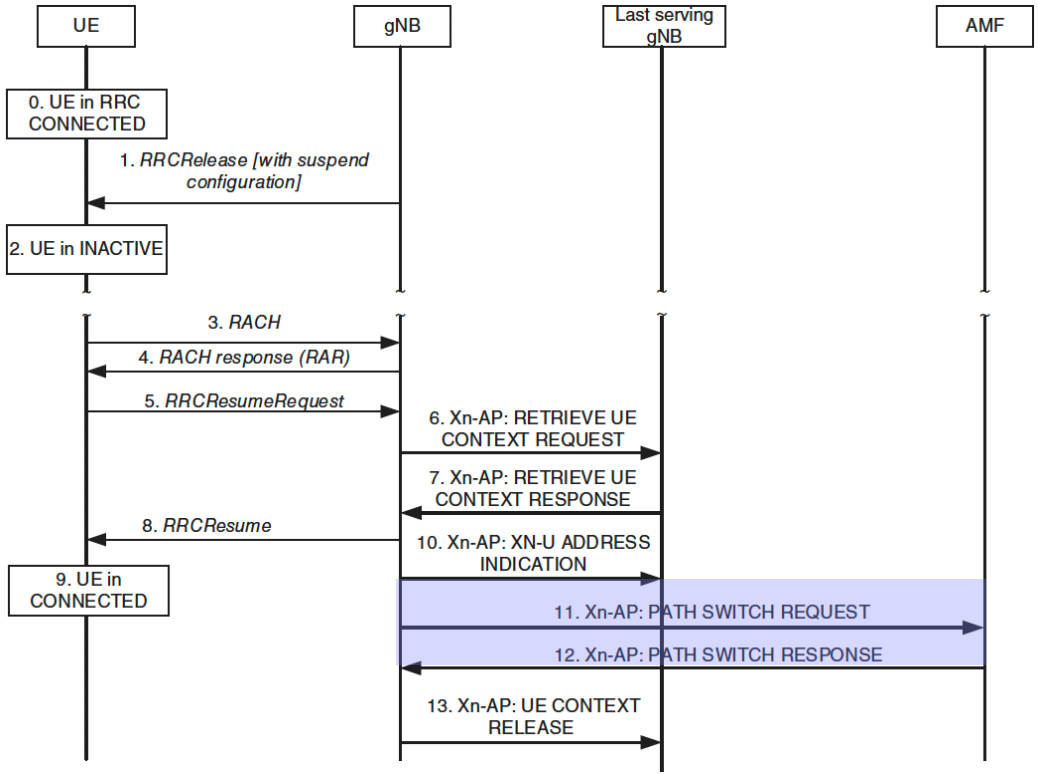
9. Upon successfully processing RRC Resume message, UE enters RRC CONNECTED

10. Xn-AP XN-U ADDRESS INDICATION message is used to provide the previous gNB with the address of the new gNB to forward data to

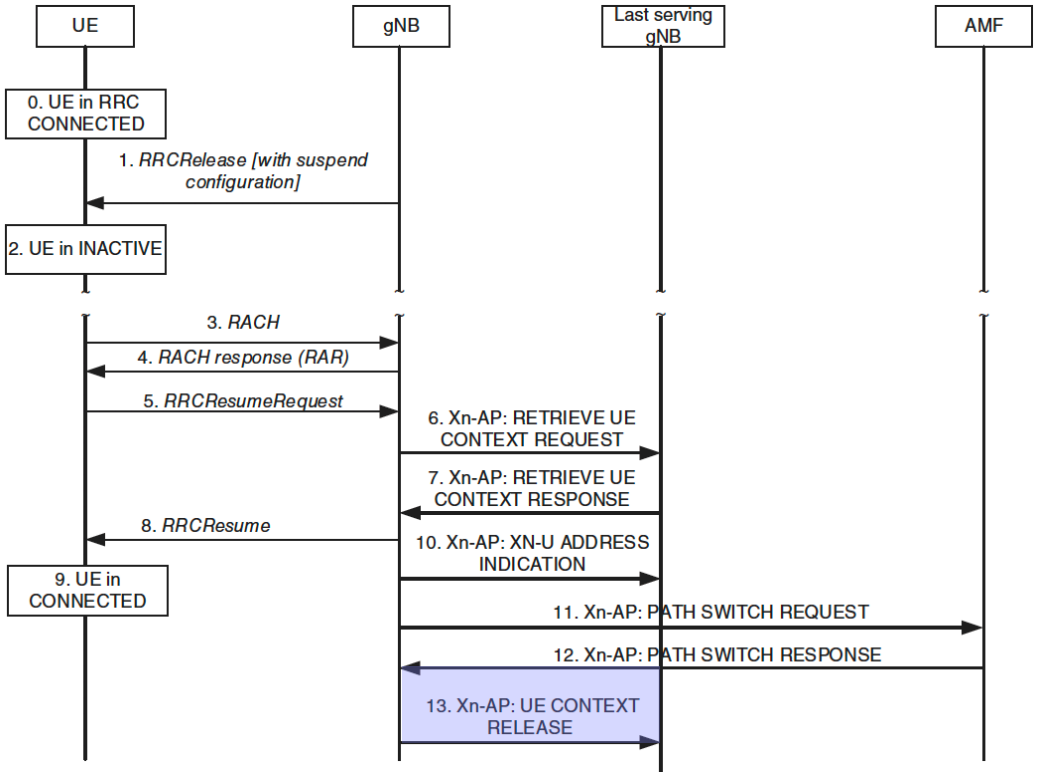


11. AMF is updated with the new gNB address with NG-AP PATH SWITCH REQUEST message

12. AMF responds with NG-AP PATH SWITCH RESPONSE message



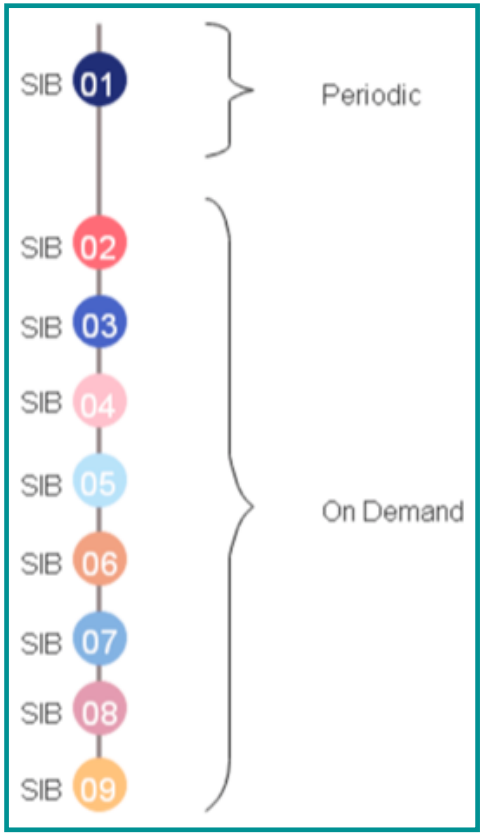
13. Upon successful completion of resumption, UE context in the previous gNB is released using Xn-AP UE CONTEXT RELEASE message



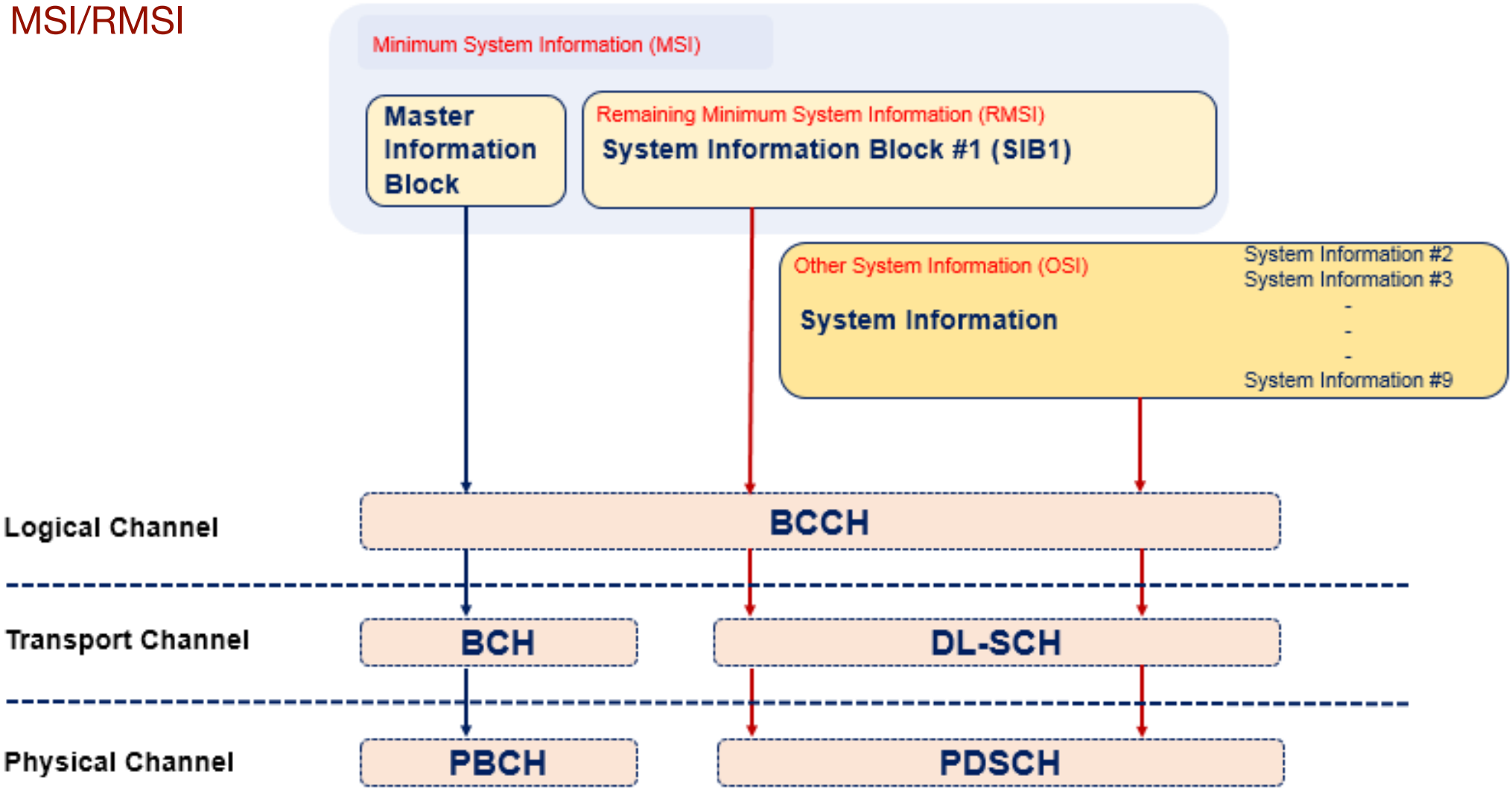
5.2.7 Broadcast Information

- System Information Broadcast (SIB) is primarily used to provide configuration information required for IDLE UEs to make an initial access to network
- Main components of broadcast information
  - **Master Information Block (MIB)**
    - Also called Minimum System Information (MSI)
    - Provide information about the cell and how to acquire SIB1

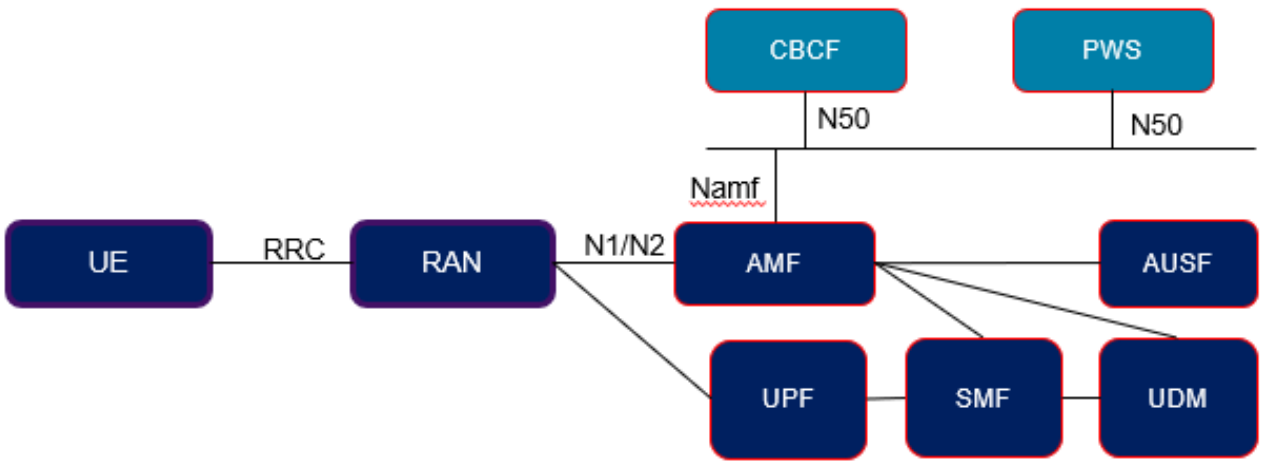
- **SIB1**
  - Also called Remaining Minimum System Information (RMSI)
  - Contain information necessary for UE to
    - Decide whether it can camp on
    - Initiate access in the cell
  - Also contains information about how to acquire the rest of SIBs
- **Other SIBs** (from SIB2 to SIB9)
  - Contain function-specific information for cell reselection functions, Public Warning, etc.

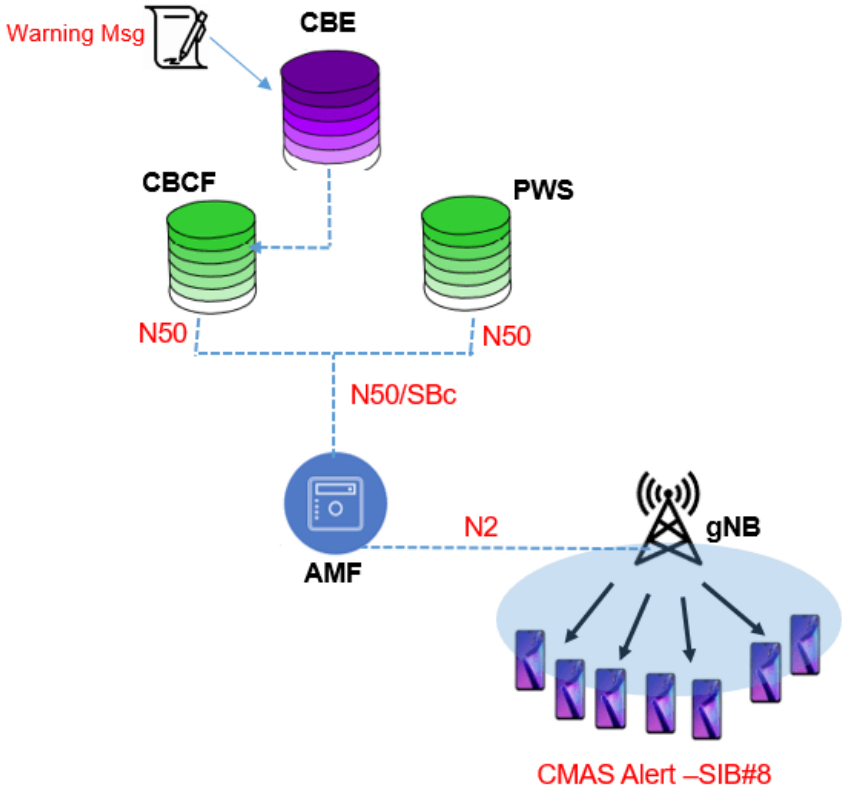


MSI/RMSI


Minimum System Information (MSI)
Master Information Block
Remaining Minimum System Information (RMSI)
System Information Block #1 (SIB1)
Other System Information (OSI)
System Information
System Information #2
System Information #3
-
-
-
System Information #9
Logical Channel
BCCH
Transport Channel
BCH
DL-SCH
Physical Channel
PBCH
PDSCH

Public Warning System





CBE：Cell Broadcast Entity
CBCF：Cell Broadcast Centre Function
PWS：Public Warning System

5G MIB	Description
SystemFrameNumber (SFN)	Data Type/Size: BIT STRING (SIZE (8))
brsTransmissionPeriod	• Data Type/Size: ENUMERATED {mx5, ms5, ms10, ms20} • Defines the transmission period of Beam Reference Symbol. Value in number of milliseconds. • Value mx5 corresponds 5ms repetition when half subframe is used for xPBCH and BRS transmission. • ms5, ms10, ms20 corresponds 5ms 10ms, and 20 ms periodicity when complete subframes are used for BRS transmission.
ePBCHTransmissionPeriod	• Data Type/Size: ENUMERATED {ms0, ms40, ms80, ms160} • Defines the transmission periodicity of ePBCH. ePBCH as defined in V5G.211 Table 6.5.A.4-1. • The ms0 defines that ePBCH is not transmitted and ms40 defines transmission period of 40ms and so on.
Spare	BIT STRING (SIZE (2))

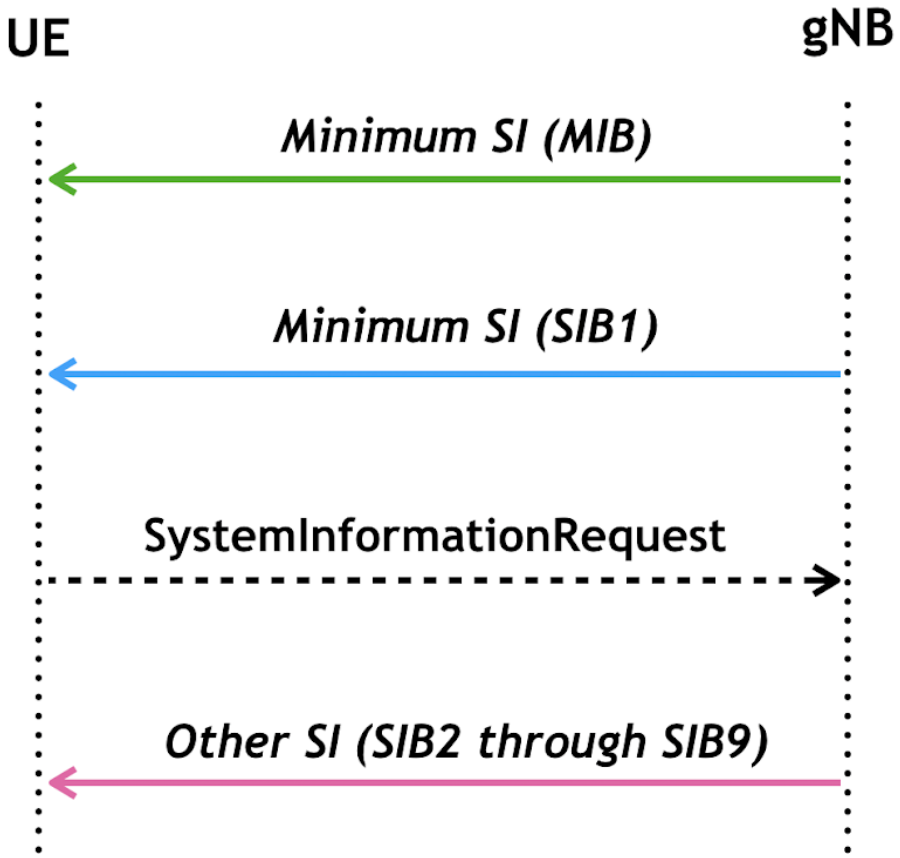
5G SIB	Description
plmn-Identity	• The IE PLMN-Identity identifies a Public Land Mobile Network. • Further information regarding how to set the IE are specified in TS 23.003 • It contains MCC, MNC etc.
cellIdentity	• The IE CellIdentity is used to unambiguously identify a cell within a PLMN. • Data type/size: BIT STRING (SIZE (28))
cellBarred	Data type/size: ENUMERATED {barred, notBarred}
cellReservedForOperatorUse	Data type/size: ENUMERATED {reserved, notReserved}
defaultConfigID	Data type/size: INTEGER(0..15)
prach-uRoot	Data type/size: INTEGER (1..70)

SIB	5G SIB Contents	4G SIB Contents
SIB1	Carries PLMN ID, Tracking Area ID, Cell ID, RAN Areas Code (For RAN based Paging), Cell Reserved Flag, Carries Common and sharred channel information, SSB Scheduling Information, Slot Configuration for TDD and etc	Carries PLMN ID, Tracking Area ID, Cell ID, Cell Barring Status, etc
SIB2	Carries cell reselection information, mainly related to the serving cell	Carries common and shared channel informations
SIB3	Information about the serving frequency and intra-frequency neighboring cells relevant for cell re-selection (including cell re-selection parameters common for a frequency as well as cell specific re- selection parameters)	Carries cell reselection information, mainly related to the serving cell
SIB4	Information about other NR frequencies and inter-frequency neighboring cells relevant for cell re-selection (including cell re-selection parameters common for a frequency as well as cell specific re- selection parameters)	Carries information about the serving neighboring frequencies and intra frequencies neighoring cell relevant for cell re-selection, covering both E UTRA and other RATs
SIB5	Information about E-UTRA frequencies and E-UTRA neighboring cells relevant for cell re- selection (including cell re-selection parameters common for a frequency as well as cell specific re-selection parameters)	Carries information about other E UTRA frequencies and inter frequence neighboring cell required for cell reselection
SIB6	ETWS (Earthquake & Tsunami Warning System) primary notification.	Carries information about other UTRA frequencies and UTRA neighboring cell required for cell reselection
SIB7	ETWS (Earthquake & Tsunami Warning System) secondary notification, Supports additional segments of ETWS information.	Carries information about other GERAN frequencies and GERAN neighboring cell required for cell reselection
SIB8	CMAS (Commercial Mobile Alert System) warning notification	Carries information about other GCDMA200 frequencies and GCDMA200 neighboring cell required for cell reselection
SIB9	Information related to GPS time and Coordinated Universal Time (UTC)	Carries Identifier os the home eNB
SIB 10	Not Avaiable in 5G	ETWS (Earthquake & Tsunami Warning System) primary notification
SIB 11	Not Avaiable in 5G	ETWS (Earthquake & Tsunami Warning System)Secondary notification

- System Information update procedure
  - An indication about System Information change is provided to UE, which triggers the System Information acquisition procedure
  - System Information change indication and presence of Public Warning System message is provided directly in PDCCH itself, called Short Message

- In NR, network may decide not to continuously broadcast other SIBs (i.e. SIB2 to SIB9)
  - This concept is called On Demand System Information
  - When an IDLE UE requires those SIBs that are not broadcast, it can make a request to network using an RRC System Info Request message for the SIB that it is interested in to trigger broadcast of the SIB in the cell

On Demand System Information



MIB:

- Periodically broadcast on BCH

SIB1:

- Periodically broadcast on DL-SCH **or**
- Unicast on DL-SCH

SIB2 through SIB9:

- Periodically broadcast on DL-SCH **or**
- Broadcast on-demand on DL-SCH **or**
- Unicast on DL-SCH

SRB	Direction	Message	RLC mode
SRBO CCCH	Downlink	RRCSetup	Transparent Mode RLC
		RRCReject	
	uplink	Uplink RRCSetupRequest	
		RRCResumeRequest	
		RRCResumeRequestl (uses CCCH I)	
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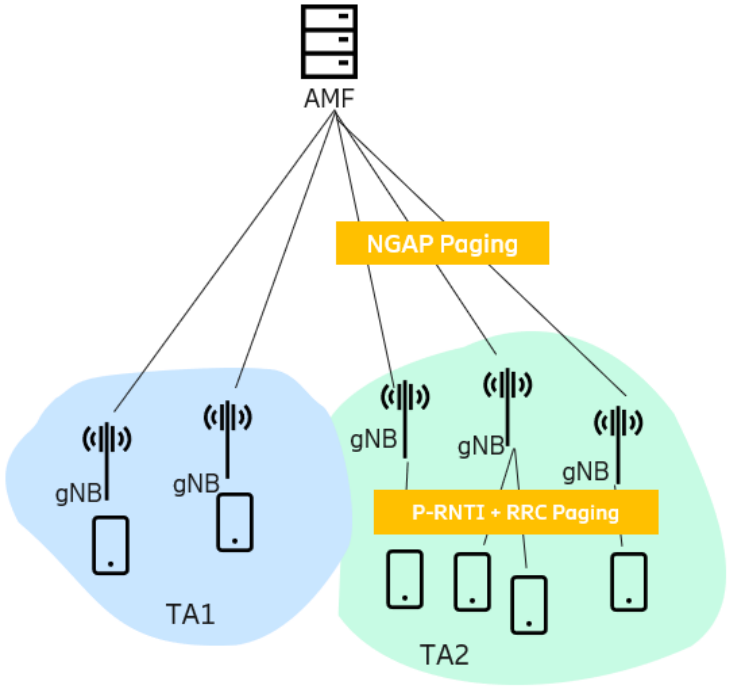
		McasuremcntRcport (also on SRB I)	

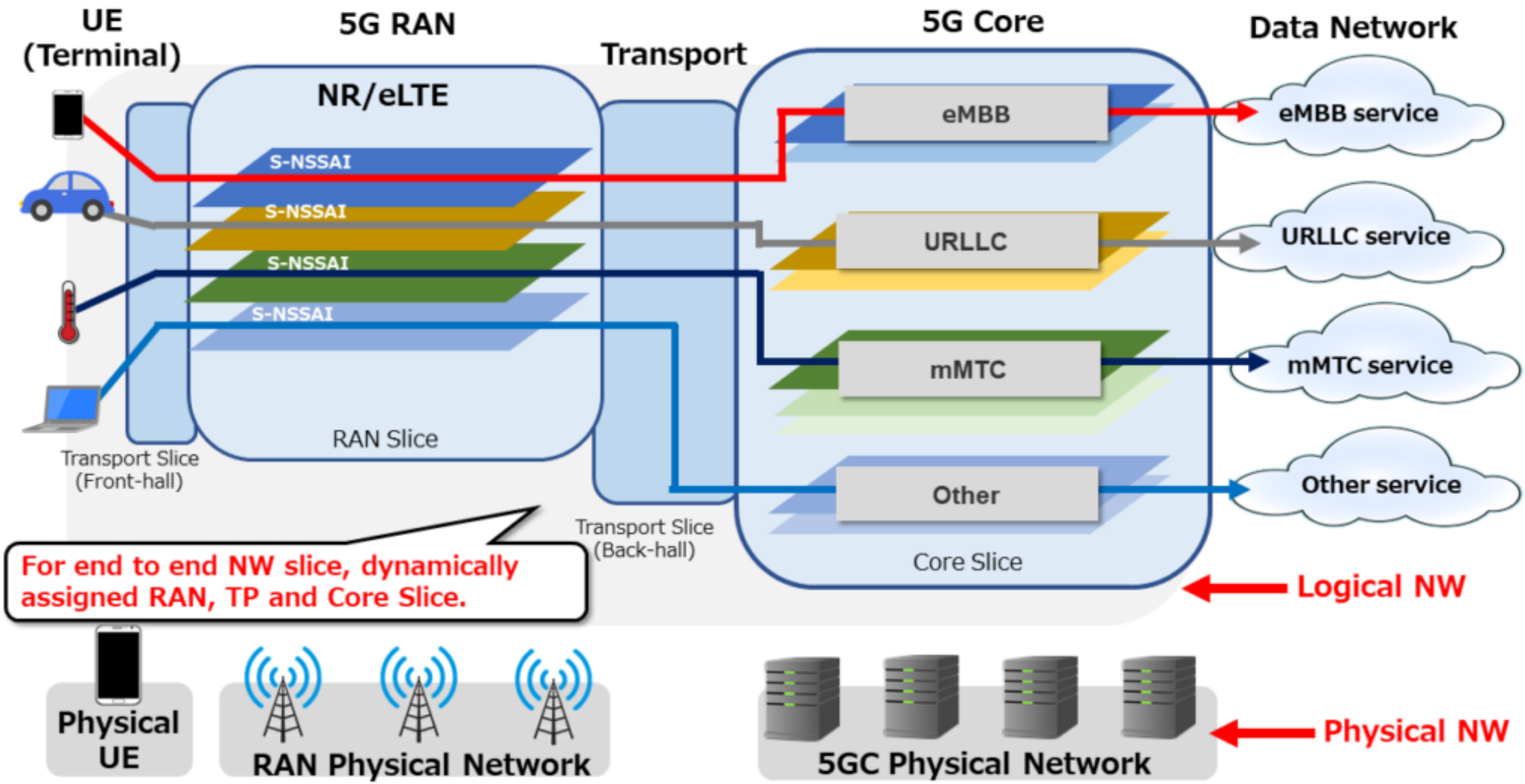
Mapping between RRC messages and SRB

- Another information that is broadcast by network is UE Paging
  - Inform an IDLE or INACTIVE UE that there is pending downlink data to UE
  - Request UE to initiate an RRC connection
- Paging message
  - Sent on a specific paging occasion that the UE monitors
  - Includes the UE identity
- Paging could be triggered
  - By core network for UEs in IDLE or
  - By RAN for UEs in INACTIVE



5.2.8 Slicing

- Slicing is a new functionality supported in 5GS to allow partitioning of RAN and core network resources across different slices
- A slice could be used to provide a particular service or belong to an administrative domain


UE
(Terminal)
5G RAN
NR/eLTE
Transport
5G Core
Data Network
S-NSSAI
S-NSSAI
S-NSSAI
S-NSSAI
RAN Slice
Transport Slice
(Front-hall)
Transport Slice
(Back-hall)
eMBB
URLLC
mMTC
Other
Core Slice
eMBB service
URLLC service
mMTC service
Other service
For end to end NW slice, dynamically assigned RAN, TP and Core Slice.
Logical NW
Physical UE
RAN Physical Network
5GC Physical Network
Physical NW

- During a connection establishment
  - A UE indicates the slice it wants to connect to, which the network uses to select the appropriate core network node that supports the requested slice
- Most of the slicing functionality is internal to gNB implementation
  - gNB scheduler should ensure that data for a slice uses only its allocated partition and that the slice does not exceed its allocated resources

Summary

- In NR, a new protocol layer SDAP was introduced to support 5G QoS concept
- Compared with LTE, PDCP, RLC, and MAC protocol layers of NR were enhanced to support lower latency and higher throughput more efficiently
- NR MAC also supports beam failure recovery procedure
- NR RRC supports a new state, INACTIVE, to provide for quick and efficient transition to CONNECTED state