Evolution of OAI Software towards 5G NR

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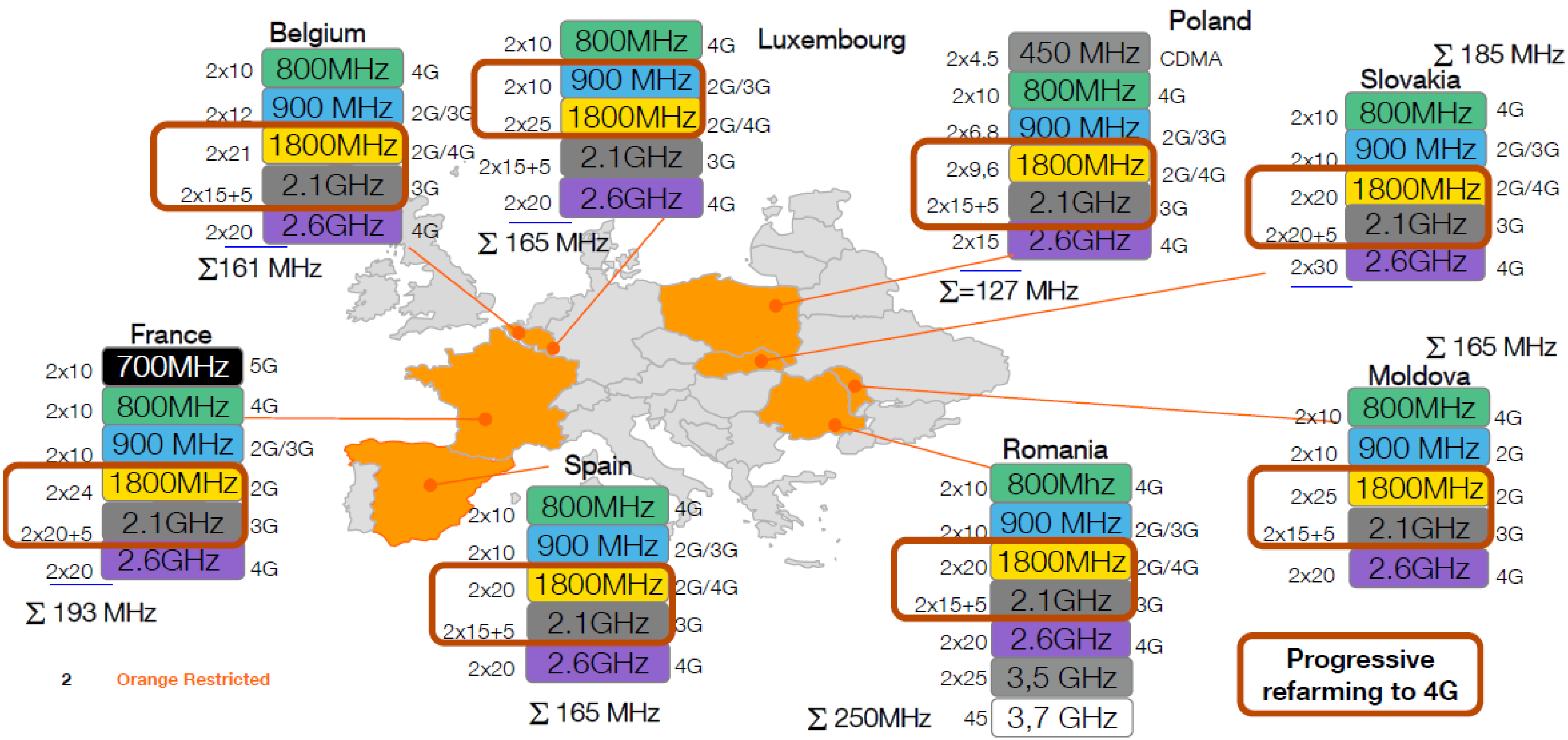
Unleashing the potential of open-source in the 5G arena

Outline

- Overview of 5G NR Network Evolution
- (very quick) Overview of Current 5G NR Air interface specifications
- Evolution of OAI to handle 5G NR and CN

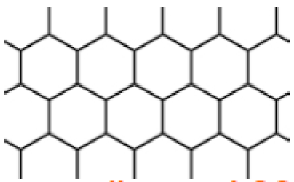
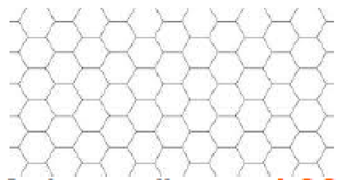
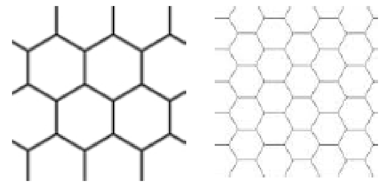
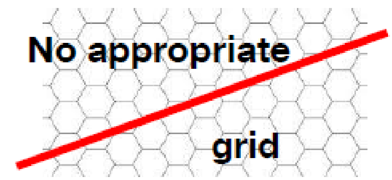
EUROPE Spectrum

In Europe, the main generic transformation ongoing is progressive refarming. ~x2 LTE spectrum possible until 2020.



EUROPE Spectrum

Existing physical sites can be reused for 5G except for spectrum above 10 GHz

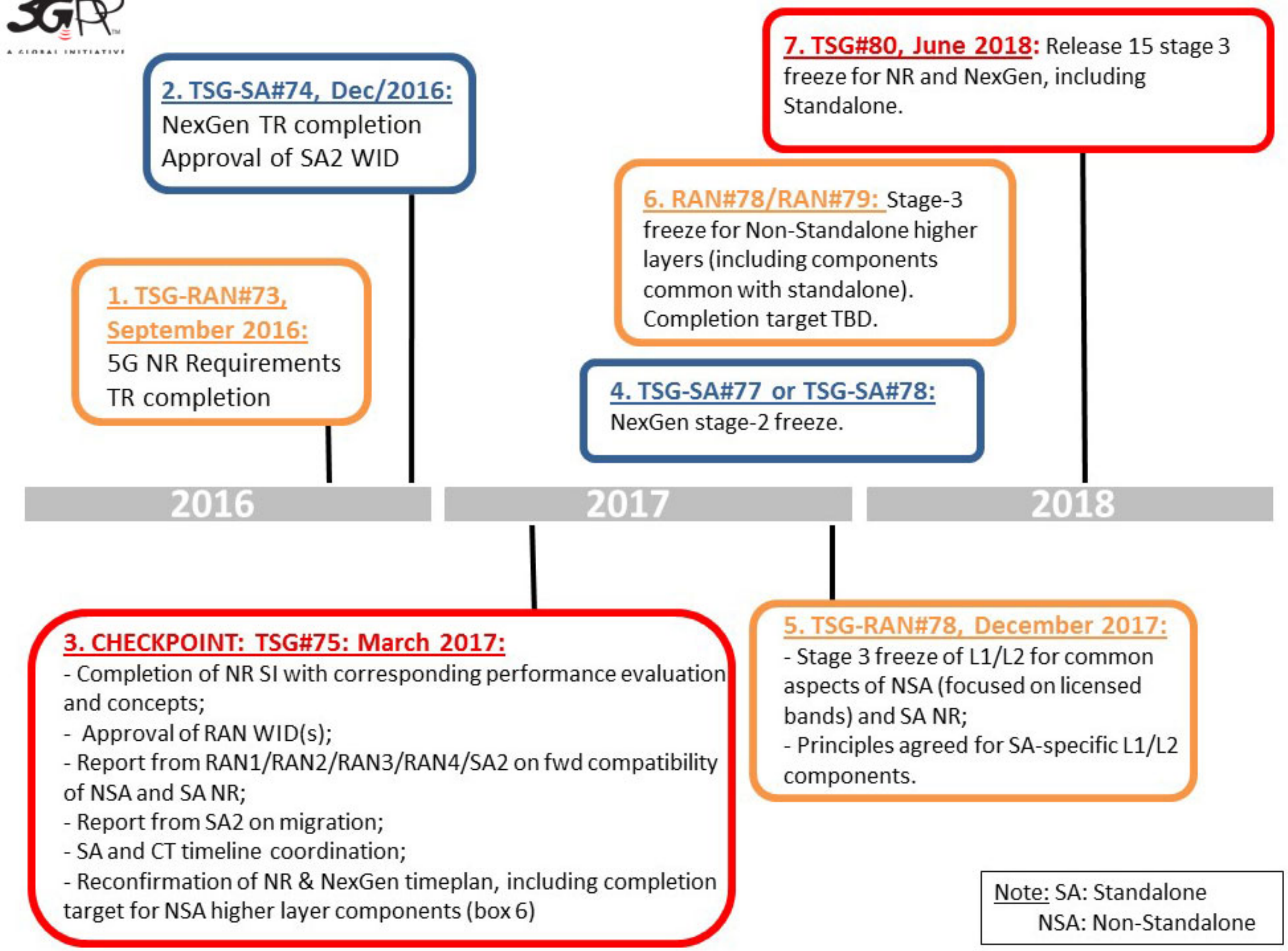
<1 GHz	1 to 4 GHz	6-10 GHz	>10 GHz
macro coverage grid territory and deep indoor coverage	macro capacity grid additional capacity for cities	can reuse macro coverage and capacity grids with limitation	Flexible network partitioning & functionality.
			
Large cells, non-LOS* deep indoor coverage Mobile and fixed wireless low capacity	Medium cells, non-LOS* light indoor coverage Mobile and fixed wireless medium capacity	large & medium, near-LOS window coverage Fixed wireless large capacity	only LOS* outdoor coverage Fixed wireless very large capacity
900 MHz – 2G/3G 800 MHz – 4G 700 MHz – 5G	1800 MHz – 2G/4G 2100 MHz – 3G 2600 MHz – 4G 3500 MHz – 5G with massive MIMO	5G with massive MIMO frequency band(s) not secured	5G with massive MIMO frequency band(s) not secured

6 Orange Restricted

*LOS = Line of sight

A LOOK AT CURRENT 5G STANDARDIZATION

Current Rel 15 timeline



Key RAN specifications (L2)

3GPP TS 23.501: "System Architecture for the 5G System; Stage 2".

3GPP TS 38.401: "NG-RAN; Architecture description".

3GPP TS 33.501: "Security Architecture and Procedures for 5G System".

3GPP TS 37.340: "NR; Multi-connectivity; Overall description; Stage-2".

3GPP TS 38.321: "NR; Medium Access Control (MAC) protocol specification".

3GPP TS 38.322: "NR; Radio Link Control (RLC) protocol specification".

3GPP TS 38.323: "NR; Packet Data Convergence Protocol (PDCP) specification".

3GPP TS 37.324: "NR; Service Data Protocol (SDAP) specification".

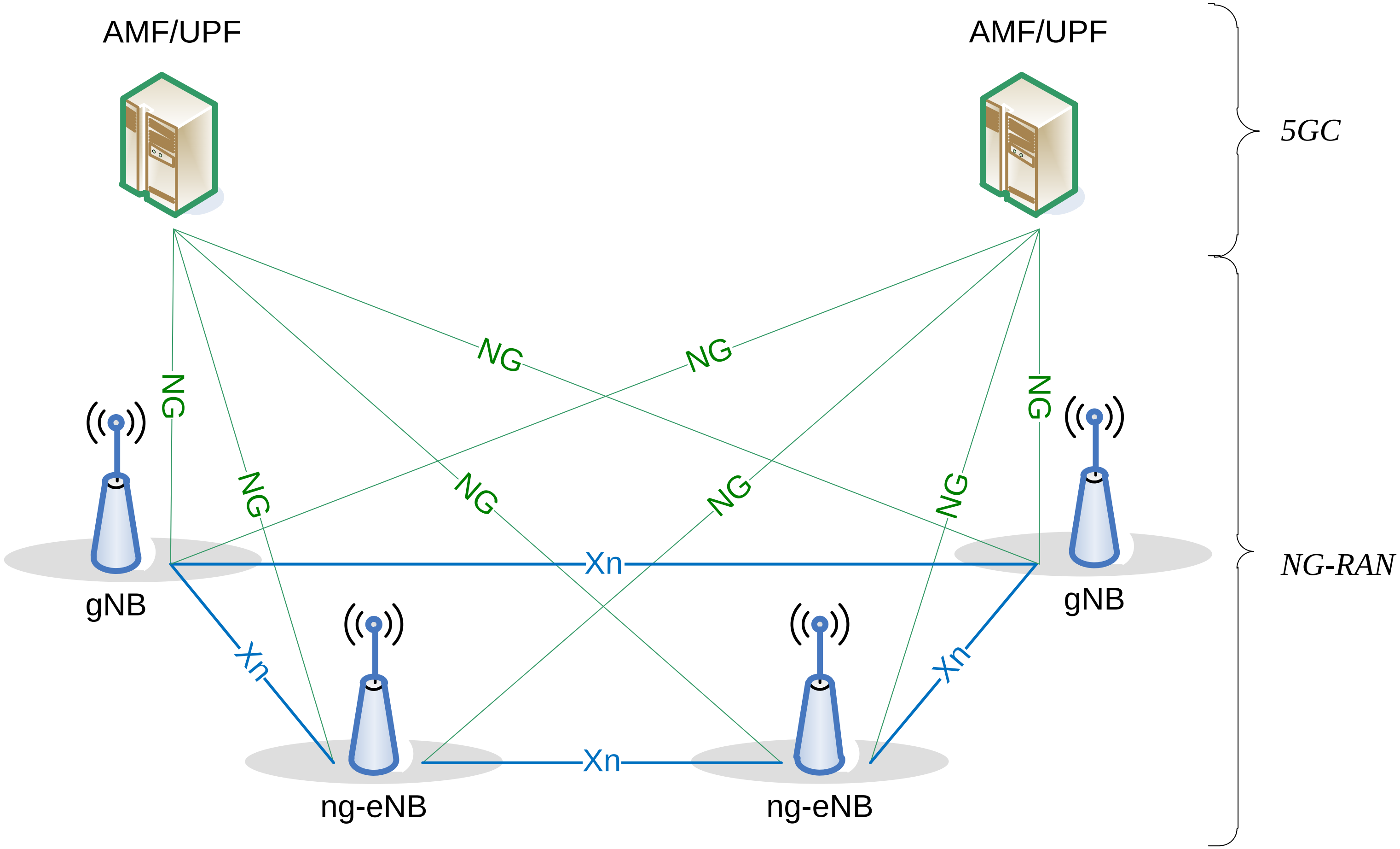
3GPP TS 38.304: "NR; User Equipment (UE) procedures in idle mode".

3GPP TS 38.306: "NR; User Equipment (UE) radio access capabilities".

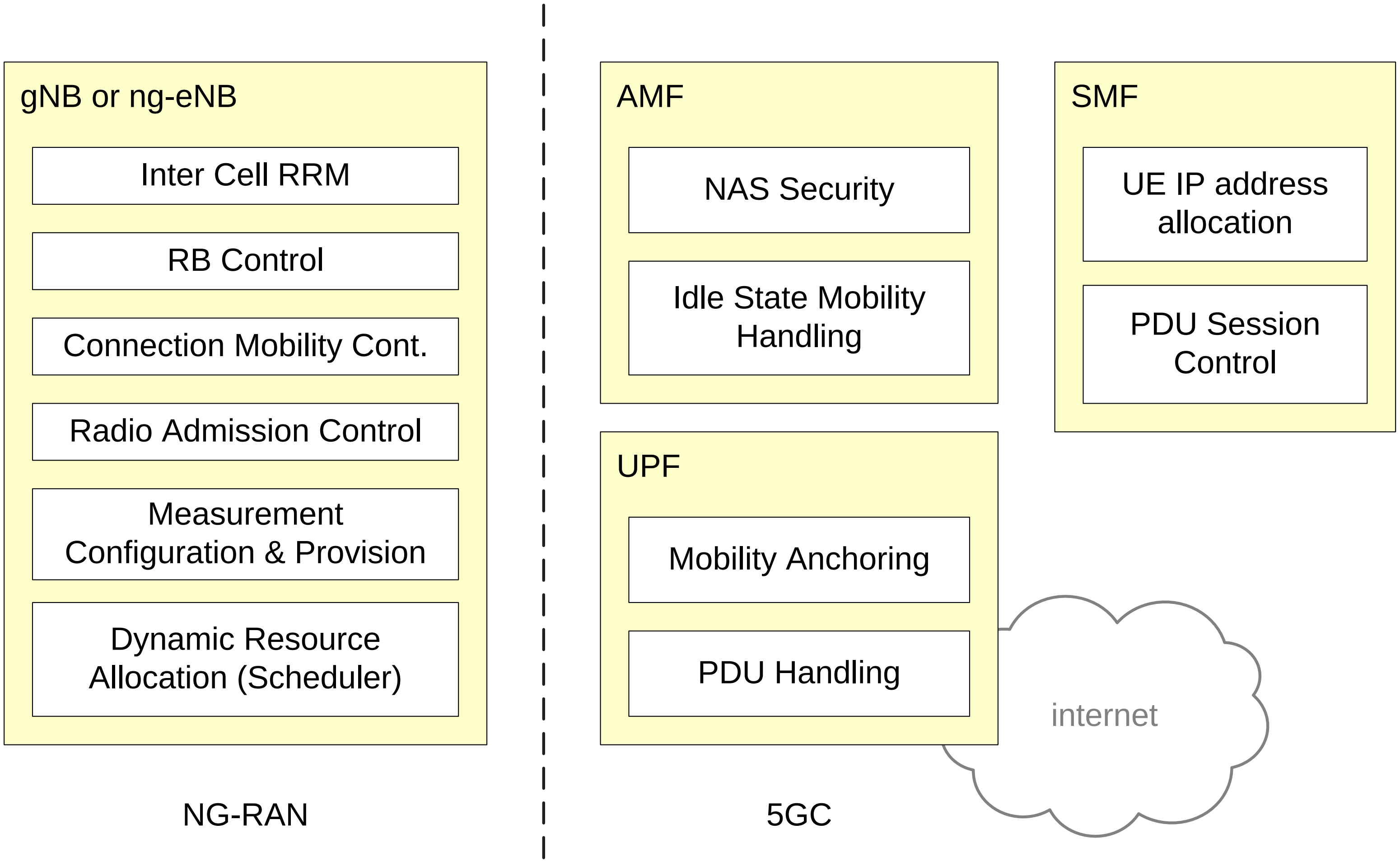
3GPP TS 38.331: "NR; Radio Resource Control (RRC); Protocol specification".

3GPP TS 38.133: "NR; Requirements for support of radio resource management".

Overall Architecture



Functional Split between RAN and 5G Core



Functional Split (gNB, ng-eNB)

- **The gNB and ng-eNB host the following functions:**
  - Functions for Radio Resource Management: Radio Bearer Control, Radio Admission Control, Connection Mobility Control, Dynamic allocation of resources to UEs in both uplink and downlink (scheduling);
  - IP header compression, encryption and integrity protection of data;
  - Selection of an AMF at UE attachment when no routing to an AMF can be determined from the information provided by the UE;
  - Routing of User Plane data towards UPF(s);
  - Routing of Control Plane information towards AMF;
  - Connection setup and release;
  - Scheduling and transmission of paging messages (originated from the AMF);
  - Scheduling and transmission of system broadcast information (originated from the AMF or O&M);Measurement and measurement reporting configuration for mobility and scheduling;
  - Transport level packet marking in the uplink;
  - Session Management;
  - Support of Network Slicing;
  - QoS Flow management and mapping to data radio bearers;
  - Support of UEs in RRC_INACTIVE state;
  - Distribution function for NAS messages;
  - Radio access network sharing;
  - Dual Connectivity;
  - Tight interworking between NR and E-UTRA.

Functional Split (AMF)

- **The AMF hosts the following main functions (see 3GPP TS 23.501):**
  - NAS signalling termination;
  - NAS signalling security;
  - AS Security control;
  - Inter CN node signalling for mobility between 3GPP access networks;
  - Idle mode UE Reachability (including control and execution of paging retransmission);
  - Registration Area management;
  - Support of intra-system and inter-system mobility;
  - Access Authentication;
  - Access Authorization including check of roaming rights;
  - Mobility management control (subscription and policies);
  - Support of Network Slicing;
  - SMF selection.

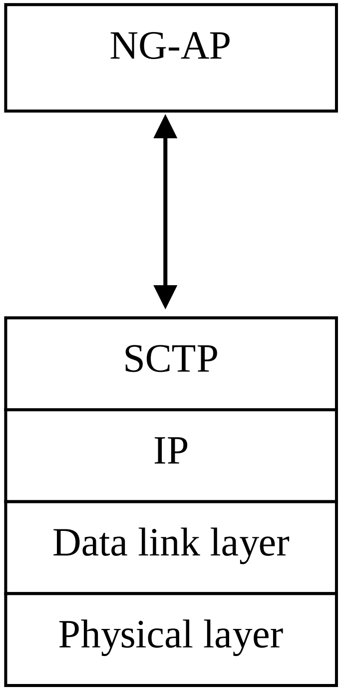
Functional Split (UPF)

- **The UPF hosts the following main functions (see 3GPP TS 23.501):**
  - Anchor point for Intra-/Inter-RAT mobility (when applicable);
  - External PDU session point of interconnect to Data Network;
  - Packet routing & forwarding;
  - Packet inspection and User plane part of Policy rule enforcement;
  - Traffic usage reporting;
  - Uplink classifier to support routing traffic flows to a data network;
  - Branching point to support multi-homed PDU session;
  - QoS handling for user plane, e.g. packet filtering, gating, UL/DL rate enforcement;
  - Uplink Traffic verification (SDF to QoS flow mapping);
  - Downlink packet buffering and downlink data notification triggering.

Functional Split (SPF)

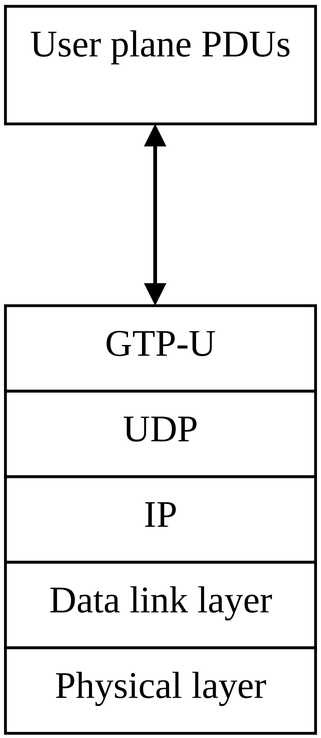
- **The Session Management function (SMF) hosts the following main functions (see 3GPP TS 23.501):**
  - Session Management;
  - UE IP address allocation and management;
  - Selection and control of UP function;
  - Configures traffic steering at UPF to route traffic to proper destination;
  - Control part of policy enforcement and QoS;
  - Downlink Data Notification.

NG-C Interface



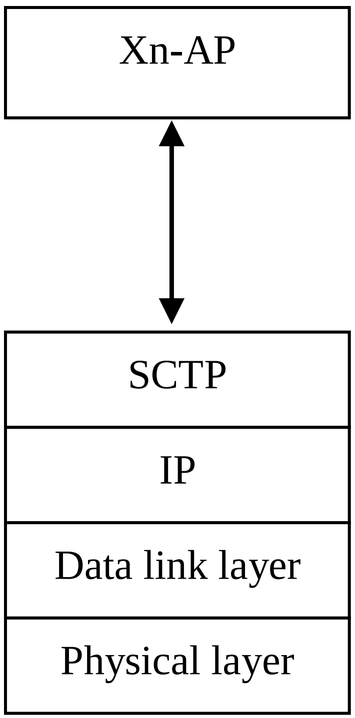
- **NG-C provides the following functions:**
  - NG interface management;
  - UE context management;
  - UE mobility management;
  - Transport of NAS messages;
  - Paging;
  - PDU Session Management;
  - Configuration Transfer;
  - Warning Message Transmission.

NG-U Interface



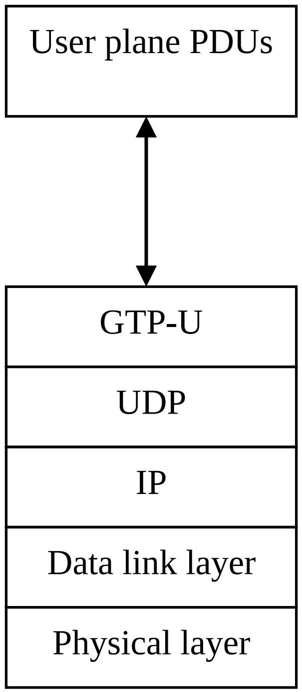
- **NG-U provides non-guaranteed delivery of user plane PDUs between the NG-RAN node and the UPF.**

Xn-C Interface



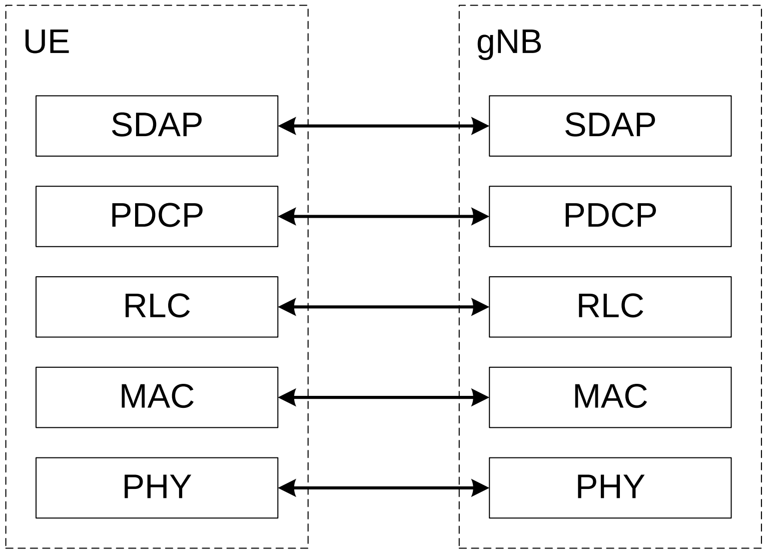
- **The Xn-C interface supports the following functions:**
  - Xn interface management;
  - UE mobility management, including context transfer and RAN paging:
  - Dual connectivity;

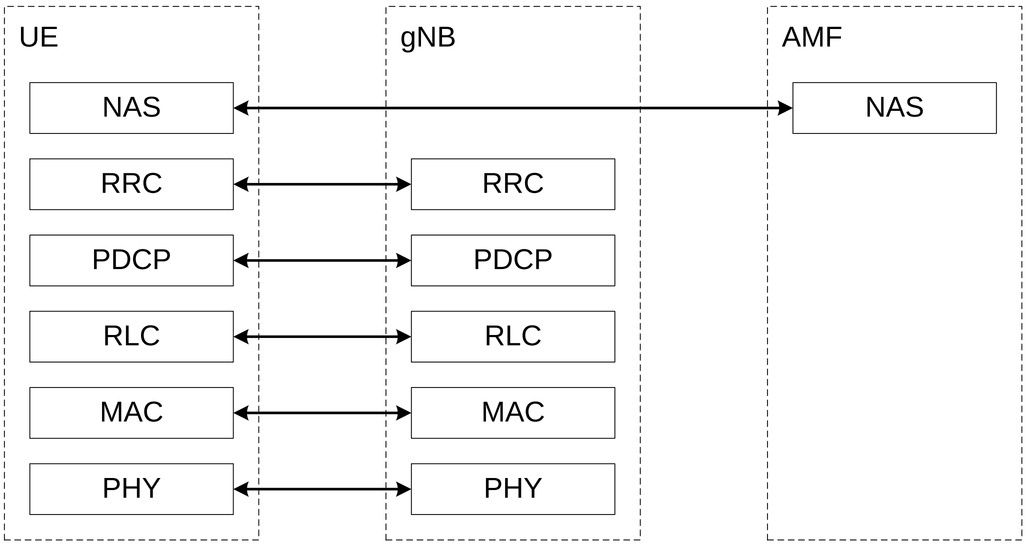
Xn-U Interface

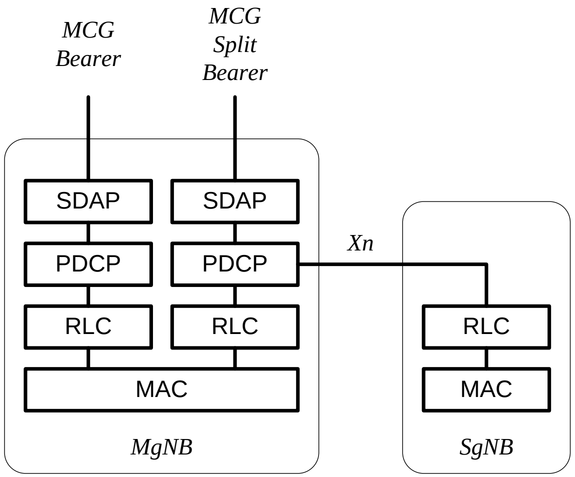


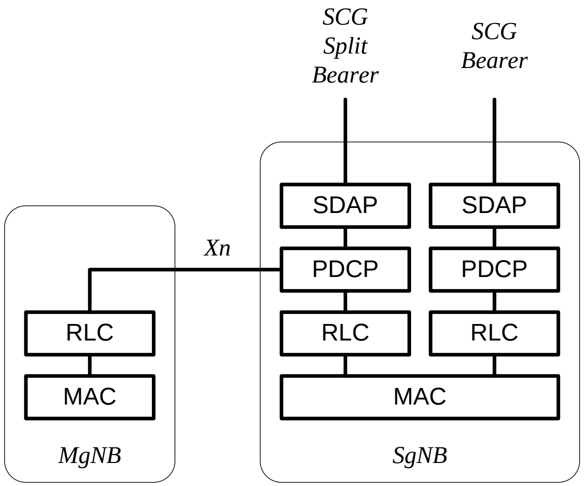
- **Xn-U provides non-guaranteed delivery of user plane PDUs and supports the following functions:**
  - Data forwarding;
  - Flow control.

Radio Protocol

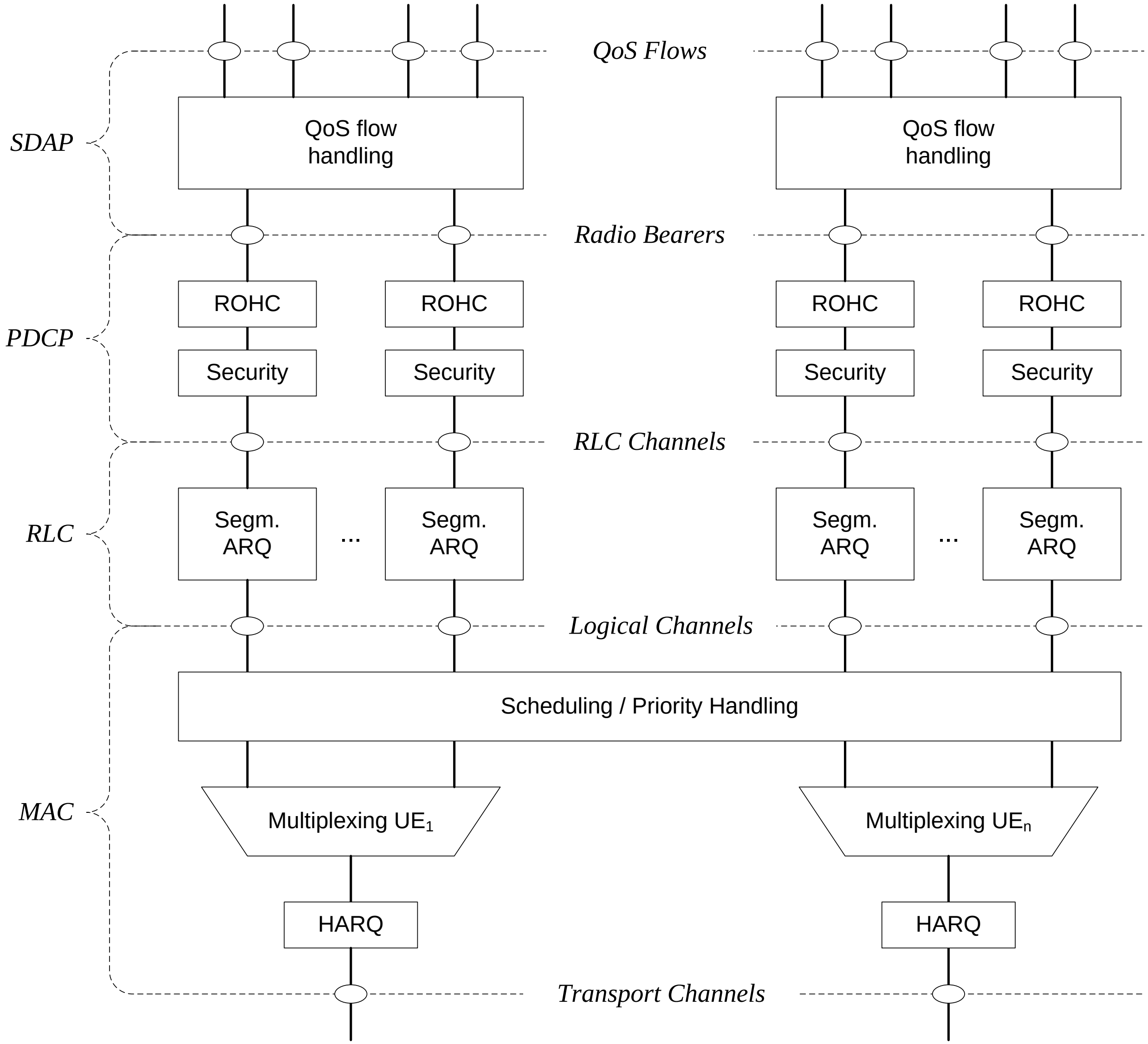




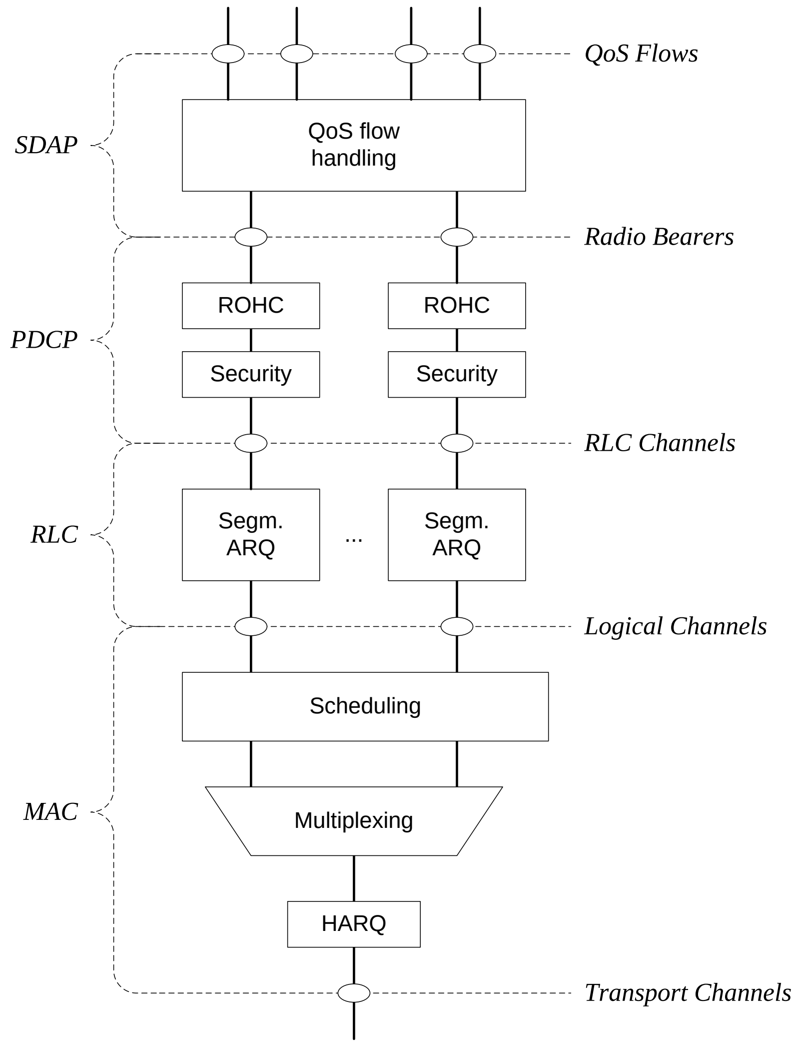




Layer 2 Architecture (Downlink)



Layer 2 (Uplink)



MAC Layer

- **The main services and functions of the MAC sublayer include:**
  - Mapping between logical channels and transport channels;
  - Multiplexing/demultiplexing of MAC SDUs belonging to one or different logical channels into/from transport blocks (TB) delivered to/from the physical layer on transport channels;
  - Scheduling information reporting;
  - Error correction through HARQ (one HARQ entity per carrier in case of CA);
  - Priority handling between UEs by means of dynamic scheduling;
  - Priority handling between logical channels of one UE by means of logical channel prioritisation;
  - Padding.

Logical Channels

- Broadcast Control Channel (BCCH): a downlink channel for broadcasting system control information.
- Paging Control Channel (PCCH): a downlink channel that transfers paging information and system information change notifications.
- Common Control Channel (CCCH): channel for transmitting control information between UEs and network. This channel is used for UEs having no RRC connection with the network.
- Dedicated Control Channel (DCCH): a point-to-point bi-directional channel that transmits dedicated control information between a UE and the network. Used by UEs having an RRC connection.
- Traffic channels are used for the transfer of user plane information only:
- Dedicated Traffic Channel (DTCH): point-to-point channel, dedicated to one UE, for the transfer of user information. A DTCH can exist in both uplink and downlink.

Mapping of Logical to Physical Channels

- **In Downlink, the following connections between logical channels and transport channels exist:**
  - BCCH can be mapped to BCH;
  - BCCH can be mapped to DL-SCH;
  - PCCH can be mapped to PCH;
  - CCCH can be mapped to DL-SCH;
  - DCCH can be mapped to DL-SCH;
  - DTCH can be mapped to DL-SCH.
- **In Uplink, the following connections between logical channels and transport channels exist:**
  - CCCH can be mapped to UL-SCH;
  - DCCH can be mapped to UL- SCH;
  - DTCH can be mapped to UL-SCH.

RLC

- **The RLC sublayer supports three transmission modes:**
  - Transparent Mode (TM);
  - Unacknowledged Mode (UM);
  - Acknowledged Mode (AM).
- **The main services and functions of the RLC sublayer depend on the transmission mode and include:**
  - Transfer of upper layer PDUs;
  - Sequence numbering independent of the one in PDCP (UM and AM);
  - Error Correction through ARQ (AM only);
  - Segmentation (AM and UM) and re-segmentation (AM only) of RLC SDUs;
  - Reassembly of SDU (AM and UM);
  - Duplicate Detection (AM only);
  - RLC SDU discard (AM and UM);
  - RLC re-establishment;
  - Protocol error detection (AM only).

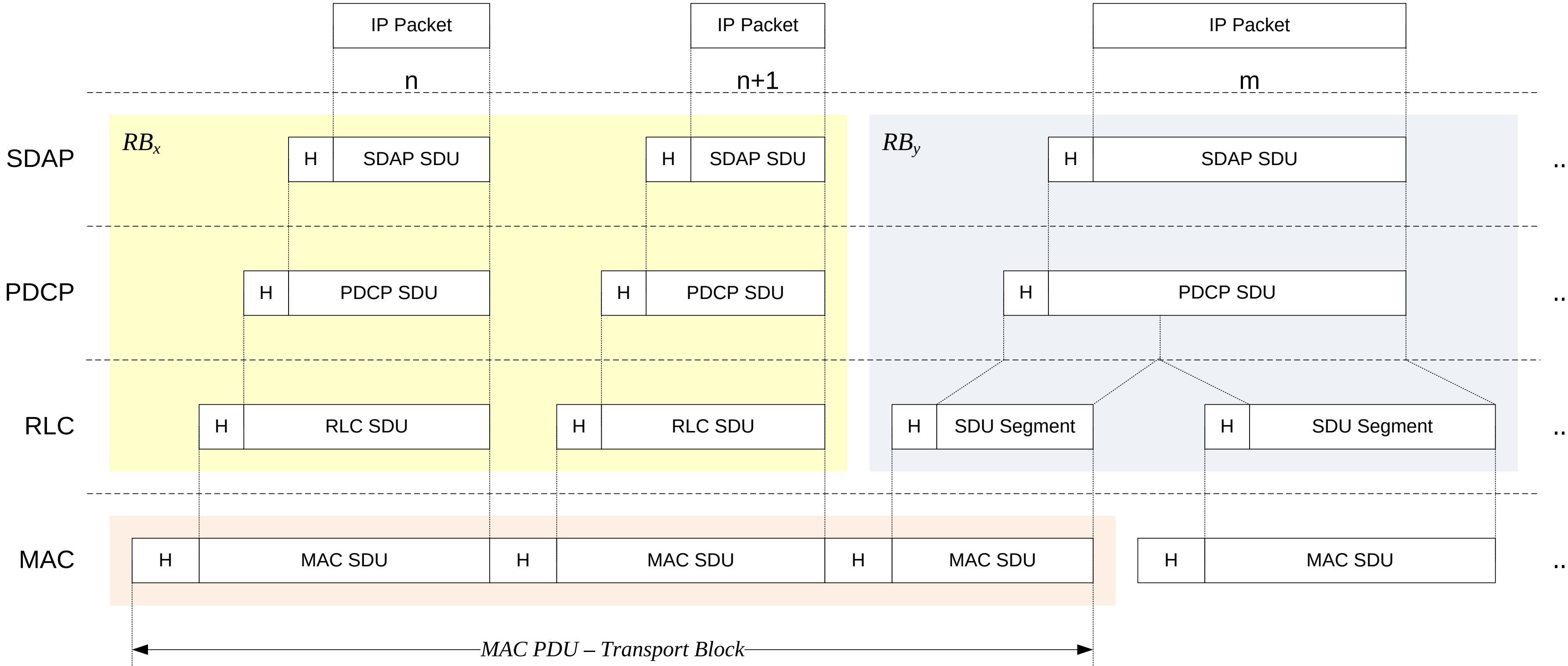
PDCP

- **The main services and functions of the PDCP sublayer for the user plane include:**
  - Sequence Numbering;
  - Header compression and decompression: ROHC only;
  - Transfer of user data;
  - Reordering and duplicate detection;
  - PDCP PDU routing (in case of split bearers);
  - Retransmission of PDCP SDUs;
  - Ciphering, deciphering and integrity protection;
  - PDCP SDU discard;
  - PDCP re-establishment and data recovery for RLC AM;
  - Duplication of PDCP PDUs.
- **The main services and functions of the PDCP sublayer for the control plane include:**
  - Sequence Numbering;
  - Ciphering, deciphering and integrity protection;
  - Transfer of control plane data;
  - Reordering and duplicate detection;
  - Duplication of PDCP PDUs (see subclause 16.1.3).

SDAP (Service Data Adaptation Protocol)

- **New entity w.r.t. 4G**
- **The main services and functions of SDAP include:**
  - Mapping between a QoS flow and a data radio bearer;
  - Marking QoS flow ID (QFI) in both DL and UL packets.

Example L2 Data Flow



An example of the Layer 2 Data Flow is depicted on Figure 6.6-1, where a transport block is generated by MAC by concatenating two RLC PDUs from RB_x and one RLC PDU from RB_y. The two RLC PDUs from RB_x each corresponds to one IP packet (*n* and *n+1*) while the RLC PDU from RB_y is a segment of an IP packet (*m*).

RRC

- **The main services and functions of the RRC sublayer include:**
  - Broadcast of System Information related to AS and NAS;
  - Paging initiated by 5GC or NG-RAN;
  - Establishment, maintenance and release of an RRC connection between the UE and NG-RAN including:
    - Addition, modification and release of carrier aggregation;
    - Addition, modification and release of Dual Connectivity in NR or between E-UTRA and NR.
  - Security functions including key management;
  - Establishment, configuration, maintenance and release of Signalling Radio Bearers (SRBs) and Data Radio Bearers (DRBs);
  - Mobility functions including:
    - Handover and context transfer;
    - UE cell selection and reselection and control of cell selection and reselection;
    - Inter-RAT mobility.
  - QoS management functions;
  - UE measurement reporting and control of the reporting;
  - Detection of and recovery from radio link failure;
  - NAS message transfer to/from NAS from/to UE.

New RRC States

- **RRC supports the following states which can be characterised as follows:**
  - **RRC_IDLE:**
    - PLMN selection;
    - Broadcast of system information;
    - Cell re-selection mobility;
    - Paging for mobile terminated data is initiated by 5GC;
    - Paging for mobile terminated data area is managed by 5GC;
    - DRX for CN paging configured by NAS.
  - **RRC_INACTIVE:**
    - Broadcast of system information;
    - Cell re-selection mobility;
    - Paging is initiated by NG-RAN (RAN paging);
    - RAN-based notification area (RNA) is managed by NG- RAN;
    - DRX for RAN paging configured by NG-RAN;
    - 5GC - NG-RAN connection (both C/U-planes) is established for UE;
    - The UE AS context is stored in NG-RAN and the UE;
    - NG-RAN knows the RNA which the UE belongs to.
  - **RRC_CONNECTED:**
    - 5GC - NG-RAN connection (both C/U-planes) is established for UE;
    - The UE AS context is stored in NG-RAN and the UE;
    - NG-RAN knows the cell which the UE belongs to;
    - Transfer of unicast data to/from the UE;
    - Network controlled mobility including measurements.

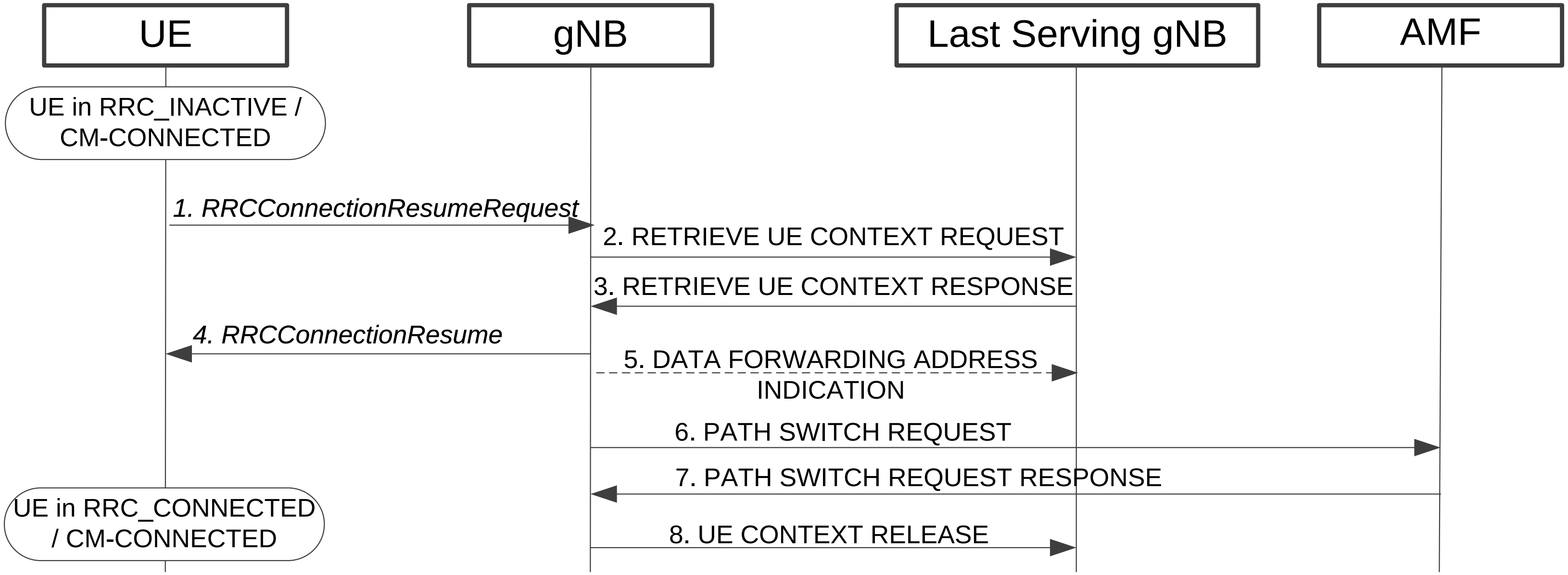
UE Identities

- **For NR connected to 5GC, the following UE identities are used at cell level:**
  - C-RNTI: unique identification, which is used as an identifier of the RRC Connection and for scheduling;
  - Temporary C-RNTI: identification used for the random access procedure;
  - Random value for contention resolution: during some transient states, the UE is temporarily identified with a random value used for contention resolution purposes.
- **In DC, two C-RNTIs are independently allocated to the UE: one for MCG, and one for SCG.**
- **For NR connected to 5GC, the following UE identities are used at NG-RAN level:**
  - I-RNTI: unique identification used to identify the UE context for RRC_INACTIVE.

Network Identities

- **The following identities are used in NG-RAN for identifying a specific network entity:**
  - AMF Identifier: used to identify an AMF.
  - NR Cell Global Identifier (NCGI): used to identify NR cells globally. The NCGI is constructed from the PLMN identity the cell belongs to and the NR Cell Identity (NCI) of the cell.
  - gNB Identifier (gNB ID): used to identify gNBs within a PLMN. The gNB ID is contained within the NCI of its cells.
  - Global gNB ID: used to identify gNBs globally. The Global gNB ID is constructed from the PLMN identity the gNB belongs to and the gNB ID. The MCC and MNC are the same as included in the NCGI.
  - Tracking Area identity (TAI): used to identify tracking areas. The TAI is constructed from the PLMN identity the tracking area belongs to and the TAC (Tracking Area Code) of the Tracking Area.
  - Single Network Slice Selection Assistance information (S-NSSAI): identifies a network slice.

UE triggered transition from RRC_INACTIVE to RRC_CONNECTED

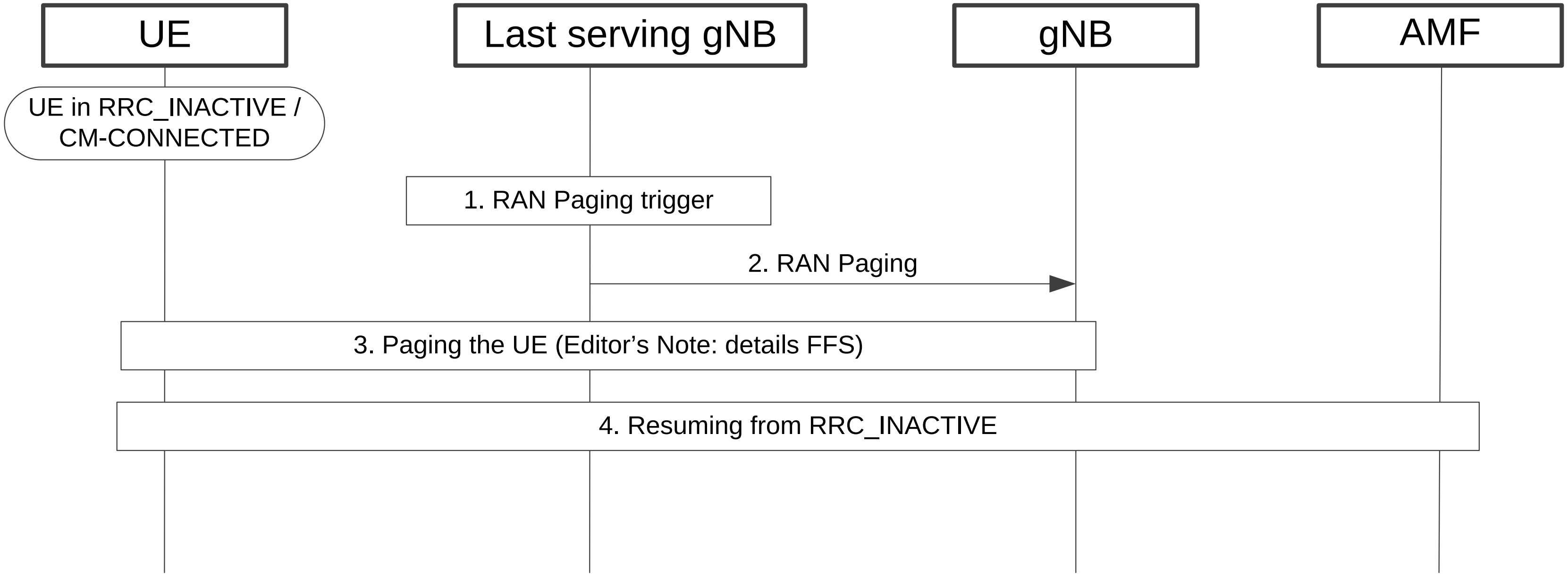


1. The UE resumes from RRC_INACTIVE, providing the I-RNTI, allocated by the last serving gNB.
2. The gNB, if able to resolve the gNB identity contained in the I-RNTI, requests the last serving gNB to provide UE Context data.
3. The last serving gNB provides UE context data.
4. The gNB completes the resumption of the RRC connection.
5. If loss of DL user data buffered in the last serving gNB shall be prevented, the gNB provides forwarding addresses.

6./7. The gNB performs path switch.

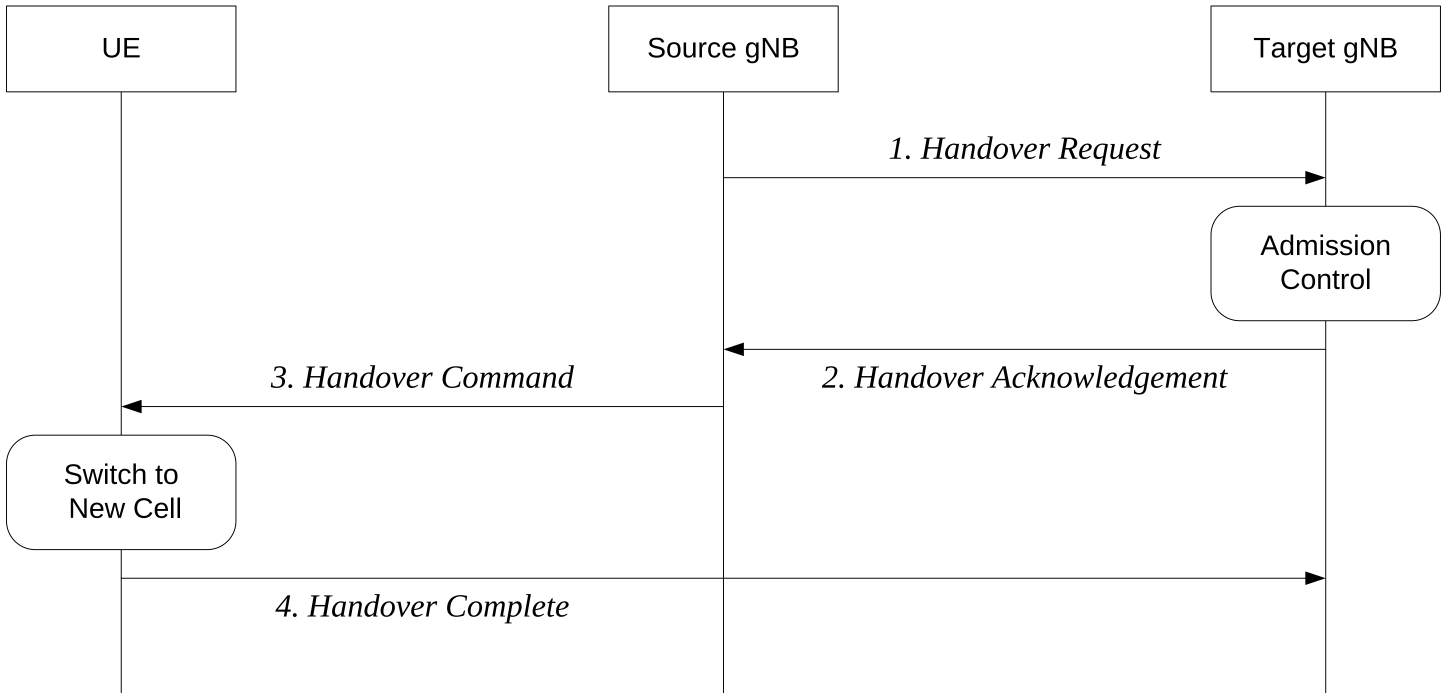
8. The gNB triggers the release of the UE resources at the last serving gNB.

Network triggered transition from RRC_INACTIVE to RRC_CONNECTED



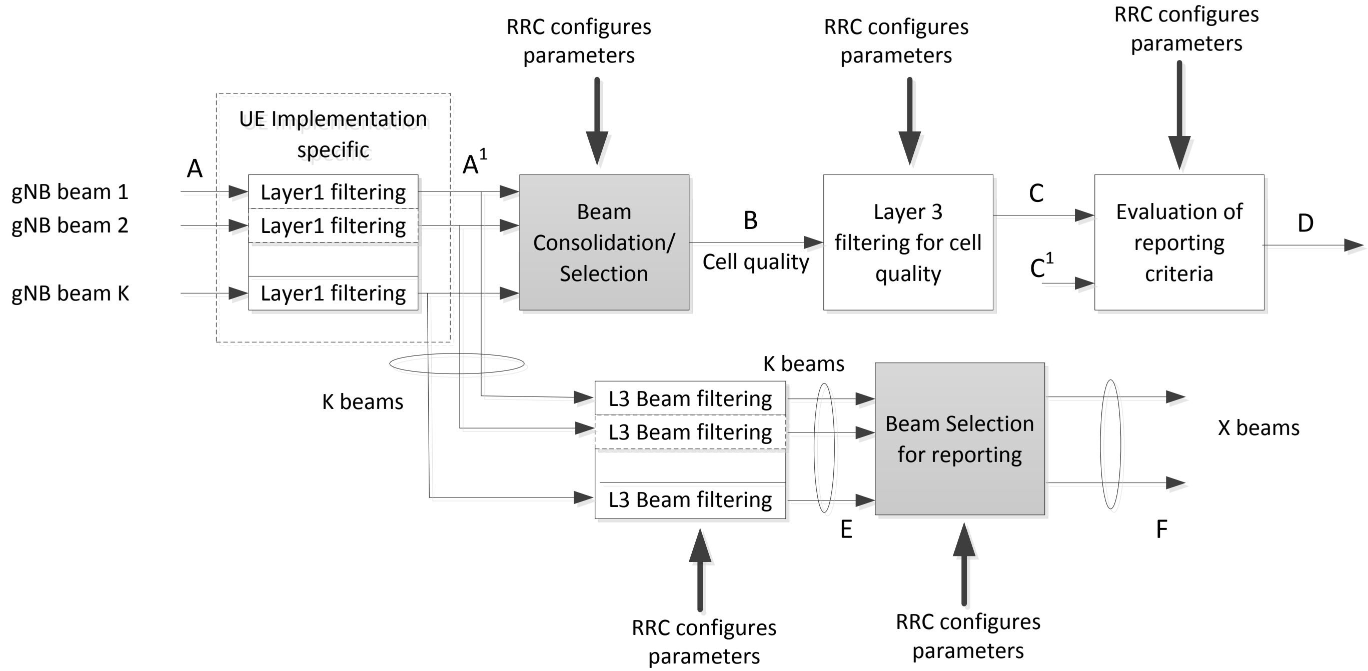
1. A RAN paging trigger event occurs (incoming DL user plane, DL signalling from 5GC, etc.)
2. RAN paging is triggered; either only in the cells controlled by the last serving gNB or also by means of Xn RAN Paging, in other gNBs, being member of the RAN Paging area the UE is registered with.
3. The UE is paged with an NG-RAN allocated UE identity.
Details are FFS.
4. If the UE has been successfully reached, it attempts to resume from RRC_INACTIVE, as described in other sections.

Mobility in RRC Connected



1. The source gNB initiates handover and issues a Handover Request over the Xn interface.
2. The target gNB performs admission control and provides the RRC configuration as part of the Handover Acknowledgement.
3. The source gNB provides the RRC configuration to the UE in the Handover Command. The Handover Command message includes at least cell ID and all information required to access the target cell so that the UE can access the target cell without reading system information. For some cases, the information required for contention based and contention free random access can be included in the Handover Command message. The access information to the target cell may include beam specific information, if any.
4. The UE moves the RRC connection to the target gNB and replies the Handover Complete.

Measurements



In RRC_CONNECTED, the UE measures multiple beams (at least one) of a cell and the measurements results (power values) are averaged to derive the cell quality. In doing so, the UE is configured to consider a subset of the detected beams: the N best beams above an absolute threshold. Filtering takes place at two different levels: at the physical layer to derive beam quality and then at RRC level to derive cell quality from multiple beams. Cell quality from beam measurements is derived in the same way for the serving cell(s) and for the non-serving cell(s). Measurement reports may contain the measurement results of the X best beams if the UE is configured to do so by the gNB.

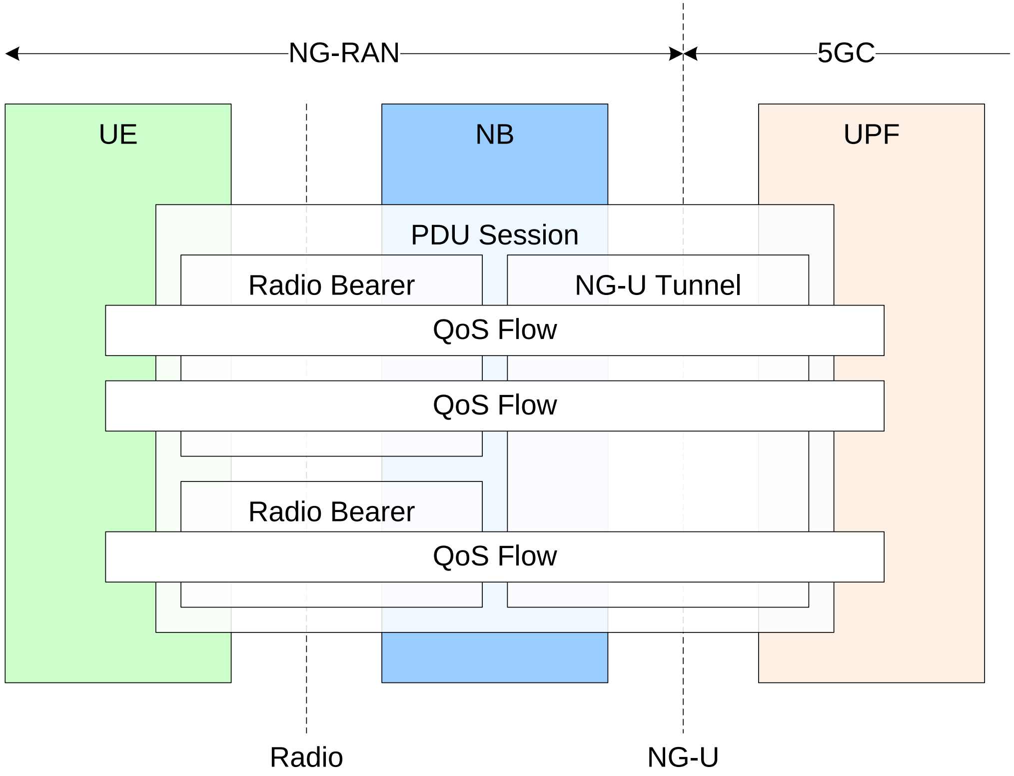
Paging

- **The UE in RRC_IDLE and RRC_INACTIVE states may use DRX in order to reduce power consumption. While in RRC_IDLE the UE monitors 5GC-initiated paging, in RRC_INACTIVE the UE is reachable via RAN-initiated paging and 5GC-initiated paging. RAN and 5GC paging occasions overlap and same paging mechanism is used. The UE monitors one paging occasion per DRX cycle for the reception of paging as follows:**
- **Paging DRX cycle length is configurable:**
  - A default DRX cycle for CN paging is configurable via system information;
  - A UE specific DRX cycle for CN paging is configurable via UE dedicated signalling;
  - NG-RAN can configure a UE with a DRX cycle for RAN paging. This configuration can be UE specific.
- **The number of paging occasions in a DRX cycle is configurable via system information:**
  - A network may distribute UEs to the paging occasions based on UE id when multiple paging occasions are configured in the DRX cycle.
- **Paging occasion can consist of multiple time slots (e.g. subframe or OFDM symbol). The number of time slots in a paging occasion is configurable via system information:**
  - A network may transmit a paging using a different set of DL Tx beam(s) or repetitions in each time slot.

QoS

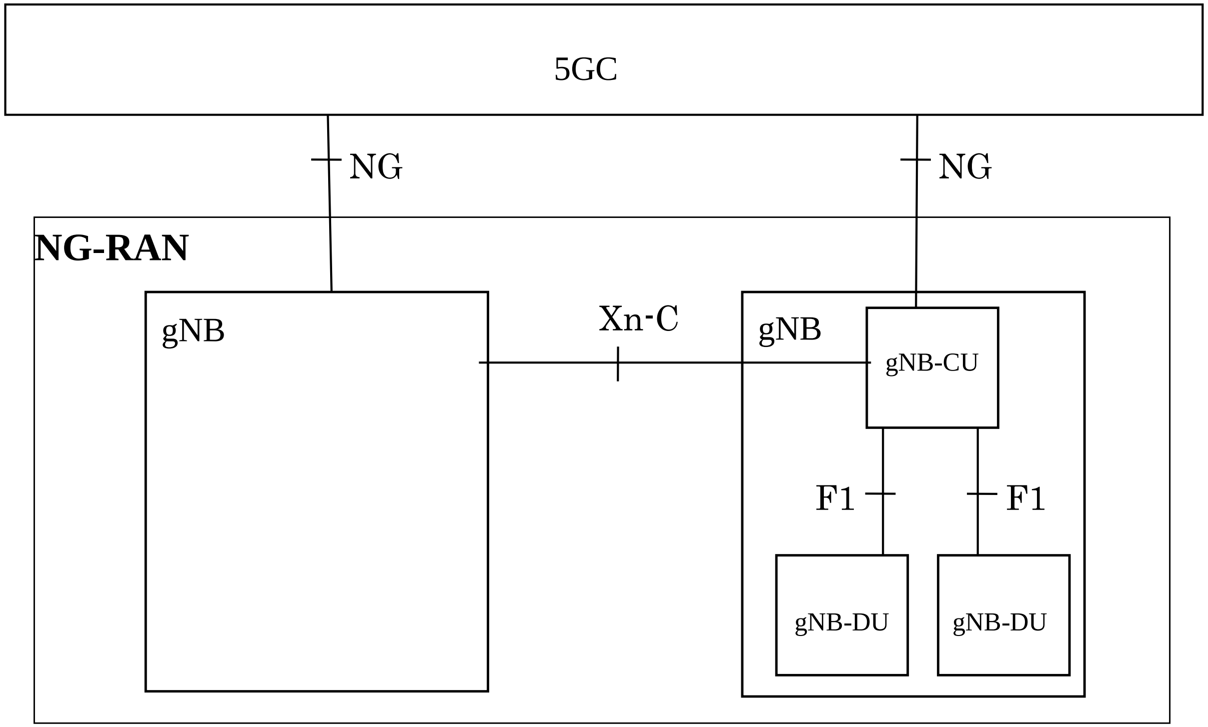
- **The QoS architecture in NG-RAN, both for NR connected to 5GC and for E-UTRA connected to 5GC, is depicted in the Figure 12-1 and described in the following:**
  - For each UE, 5GC establishes one or more PDU Sessions.
  - For each UE, the NG-RAN establishes one or more Data Radio Bearers (DRB) per PDU Session. The NG-RAN maps packets belonging to different PDU sessions to different DRBs. Hence, the NG-RAN establishes at least one default DRB for each PDU Session.
  - NAS level packet filters in the UE and in the 5GC associate UL and DL packets with QoS Flows.
  - AS-level mapping rules in the UE and in the NG-RAN associate UL and DL QoS Flows with DRBs.

QoS

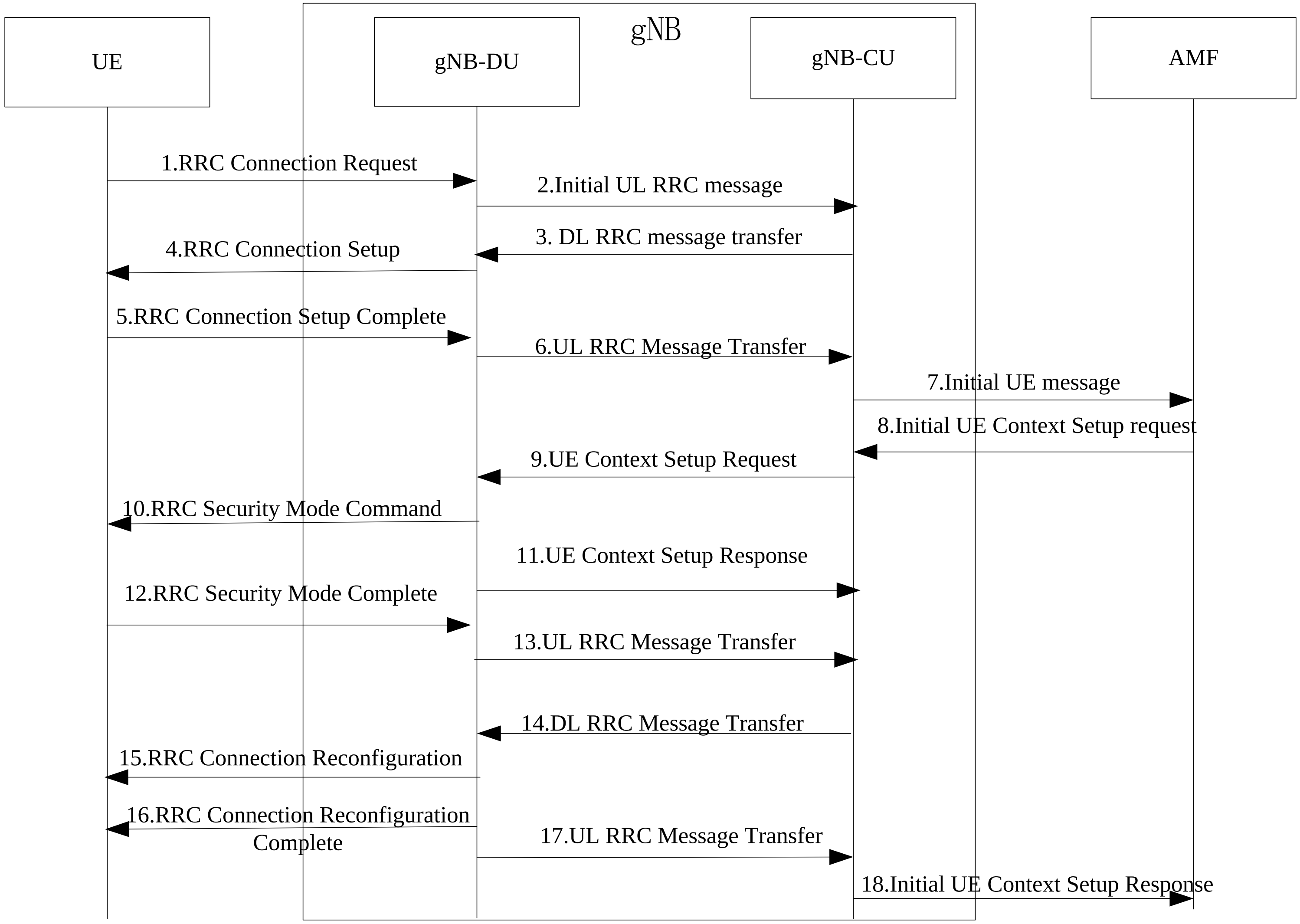


NG-RAN
5GC
UE
NB
UPF
PDU Session
Radio Bearer
NG-U Tunnel
QoS Flow
QoS Flow
Radio Bearer
QoS Flow
Radio
NG-U

NG-RAN Functional Split



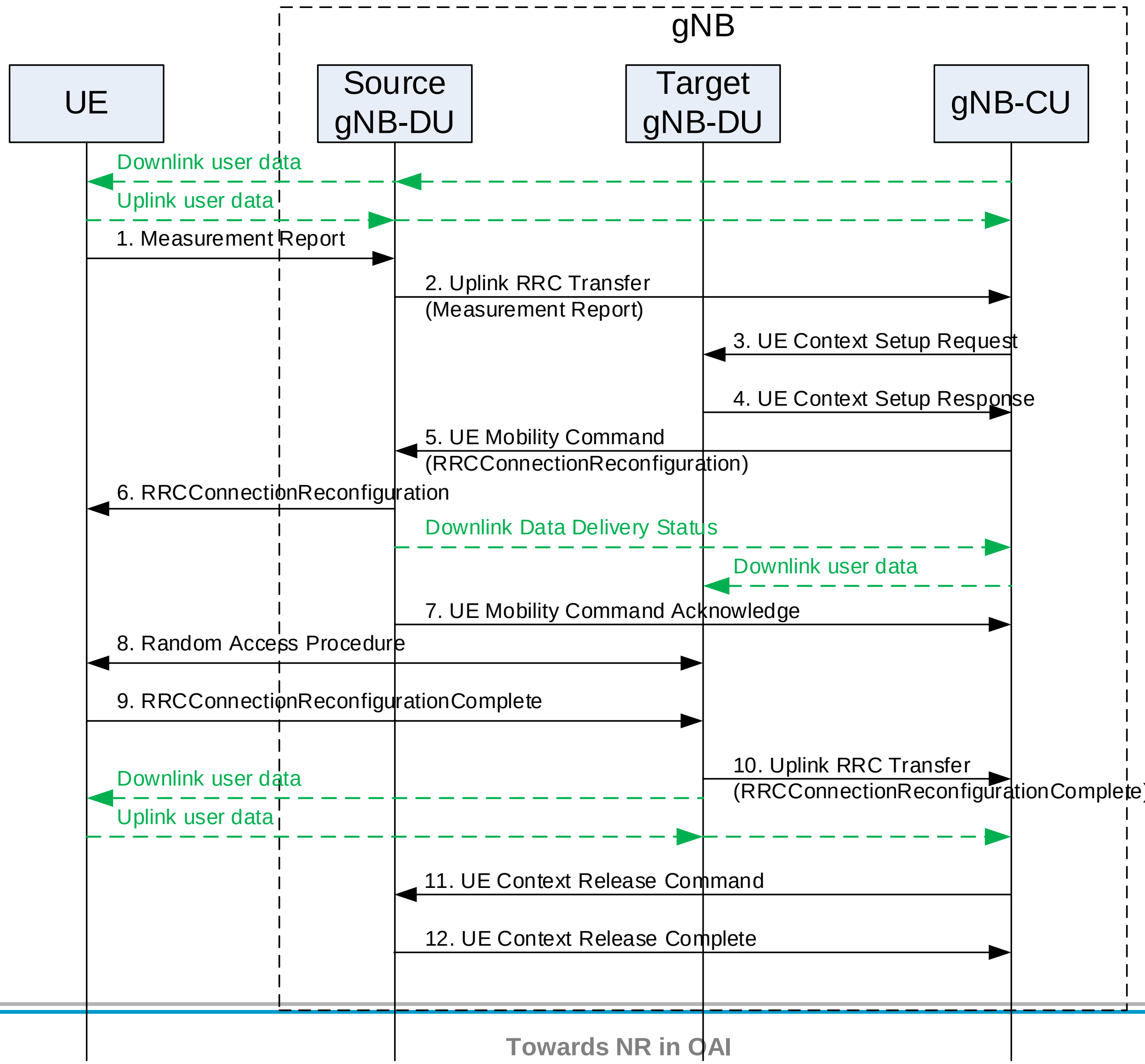
UE Initial Access



UE Initial Access

- Step1: UE sends RRC Connection Request message to the gNB-CU.
- Step 2:The gNB-DU includes the RRC message in a non-UE associated F1-AP INITIAL UL RRC MESSAGE TRANSFER message and transfer to the gNB-CU. The INITAIL UL RRC MESSAGE TRANSFER message should include C-RNTI.
- Step3: The gNB-CU allocates UE F1AP ID for the UE and generates RRC CONNECTION SETUP message towards UE.The RRC message is encapsulated in F1-AP DL RRC MESSAGE TRANSFER message.
- Step4: The gNB-DU sends RRC CONNECTION SETUP message to UE.
- Step5: UE sends RRC CONNECTION SETUP COMPLETE message to the gNB-CU.
- Step6: The gNB-DU encapsulates the RRC message in F1-AP UL RRC MESSAGE TRANSFER message and send to gNB-CU.
- Step7: The gNB-CU sends the INITIAL UE MESSAGE to the AMF.
- Step8: The AMF sends INITIAL UE CONTEXT SETUP REQUEST message to the gNB-CU.
- Step9:The gNB-CU sends UE CONTEXT SETUP REQUESTmessage to establish overall initial UE context in the gNB-DU.In this message,it may also encapsulate RRC SECURITY MODE COMMAND message.
- Step10: The gNB-DU sends RRC SECURITY MODE COMMAND message to UE.
- Step11:The gNB-DU sends UE CONTEXT SETUP RESPONSE message to gNB-CU.
- Step 12:UE responds with RRC SECURITY MODE COMPLETE message
- Step 13:The gNB-DU encapsulates the RRC message in F1-AP UL RRC MESSAGE TRANSFER message and sends to gNB-CU.
- Step14:The gNB-CU generates RRC CONNECTION RECONFIGURATION message and encapsulates it in F1-AP DL RRC MESSAGE TRANSFER message
- Step 15: The gNB-DU sends RRC CONNECTION RECONFIGURATION message to UE.
- Step 16: UE sends RRC CONNECTION RECONFIGURATION COMPLETE message to the gNB-DU.
- Step 17:The gNB-DU encapsulates the RRC message in F1-AP UL RRC MESSAGE TRANSFER message and send to gNB-CU.
- Step18: The gNB-CU sends Initial UE Context Setup Response message to the AMF.

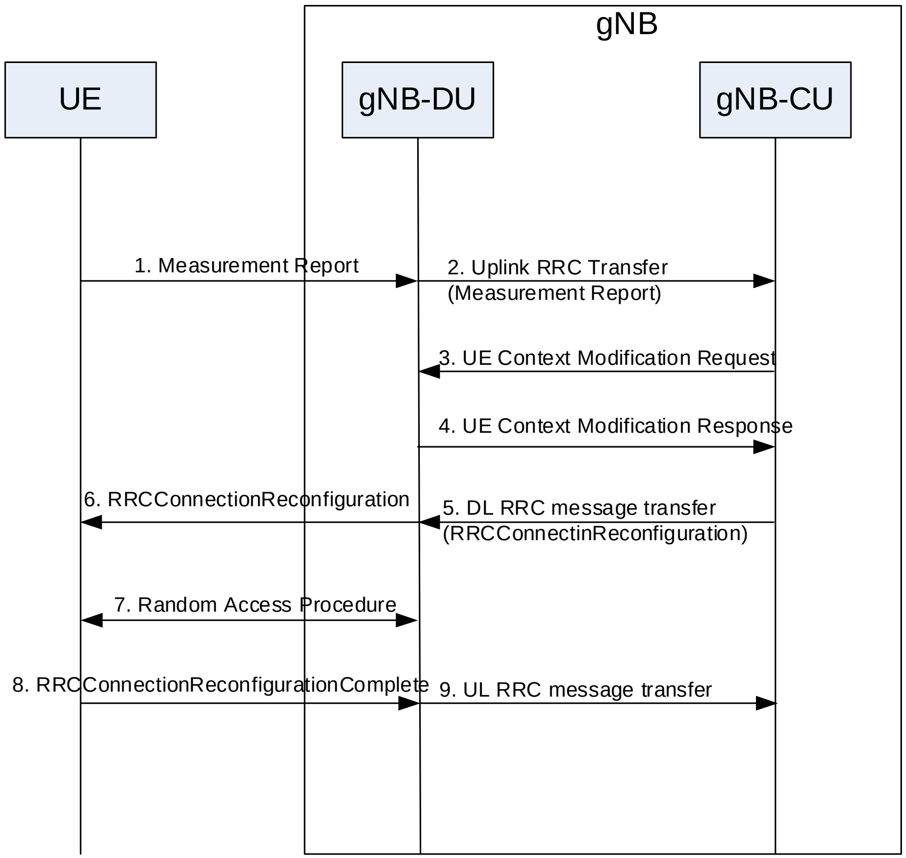
Inter-gNB-DU Mobility for intra-NR



Inter-gNB-DU Mobility for intra-NR

1. The UE sends a *Measurement Report* message to the source gNB-DU.
2. The source gNB-DU sends an Uplink RRC Transfer message to the gNB-CU to convey the received *Measurement Report*.
3. The gNB-CU sends an UE Context Setup Request message to the target gNB-DU to create an UE context and setup one or more bearers, which contains *Target Cell ID (FFS)*.
4. The target gNB-DU responds the gNB-CU with an UE Context Setup Response message, which contains *MobilityControlInfo (FFS)*.
5. The gNB-CU sends a UE Mobility Command message, which includes a generated *RRCConnectionReconfiguration* message and indicates to stop the data transmission for the UE, to the source gNB-DU. The source gNB-DU also sends a Downlink Data Delivery Status frame to inform the gNB-CU about the unsuccessfully transmitted downlink data to the UE. Downlink packets, which may include PDCP PDUs not successfully transmitted in the source gNB-DU, are sent from the gNB-CU to the target gNB-DU.
6. The source gNB-DU forwards the received *RRCConnectionReconfiguration* to the UE.
7. The source gNB-DU responds the gNB-CU with UE Mobility Command Acknowledge message.
8. Random Access procedure is performed at the target gNB-DU.
9. The UE responds the target gNB-DU with an *RRCConnectionReconfigurationComplete* message.
10. The target gNB-DU sends an Uplink RRC Transfer message to convey the received *RRCConnectionReconfigurationComplete* to the gNB-CU. Downlink packets are sent to the UE. Also, uplink packets are sent from the UE, which are forwarded to the gNB-CU through the target gNB-DU.
11. The gNB-CU sends an UE Context Release Command message to the source gNB-DU.
12. The source gNB-DU releases the UE context and responds the gNB-CU with an UE Context Release Complete message.

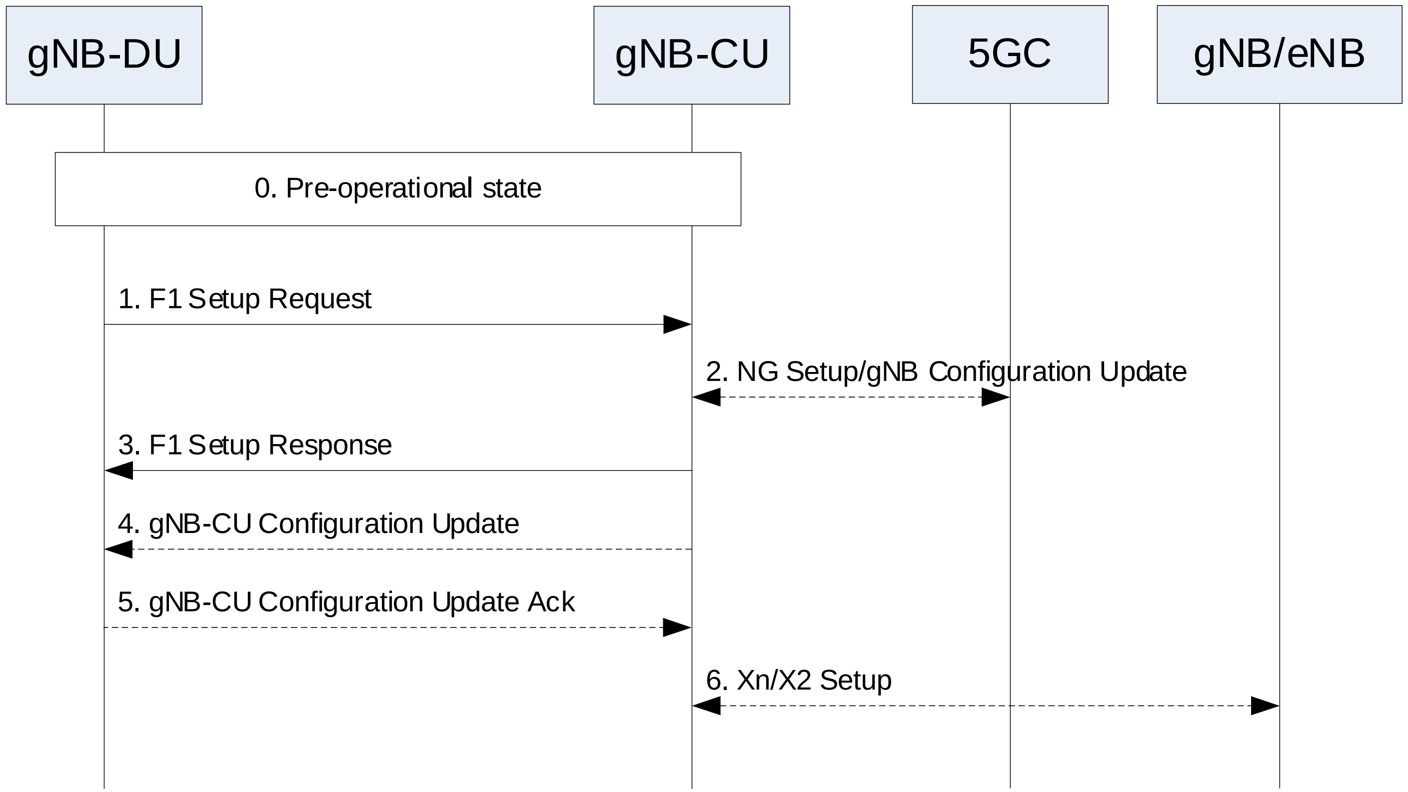
Intra-gNB-DU inter-cell mobility



Intra-gNB-DU inter-cell mobility

1. Data transmission is ongoing.
2. The gNB-CU makes a handover decision.
3. The gNB-CU sends the UE Context Modification Request message to the gNB-DU, which contains Target Cell ID for handover (FFS).
4. The gNB-DU responds the gNB-CU with an UE Context Modification Response after resource preparation in target cell is finished, which contains MobilityControlInfo (FFS).
5. The gNB-CU sends a DL RRC message transfer which includes RRCConnectionReconfiguration to the gNB-DU.
6. The gNB-DU forwards the received RRCConnectionReconfiguration to the UE.
7. Random Access procedure is performed at the target cell of gNB-DU.
8. The UE responds the gNB-DU with an RRCConnectionReconfigurationComplete message.
9. The gNB-DU sends an Uplink RRC Transfer message to convey the received RRCConnectionReconfigurationComplete to the gNB-CU.

F1 Startup



gNB-DU
gNB-CU
5GC
gNB/eNB
0. Pre-operational state
1. F1 Setup Request
2. NG Setup/gNB Configuration Update
3. F1 Setup Response
4. gNB-CU Configuration Update
5. gNB-CU Configuration Update Ack
6. Xn/X2 Setup

F1 Startup

- The gNB-DU and its cells are configured by OAM in the F1 pre-operational state. The gNB-DU has TNL connectivity toward the gNB-CU.
- The gNB-DU sends an F1 Setup Request message to the gNB-CU including a list of cells that are configured and ready to be activated.
- In NG-RAN, the gNB-CU ensures the connectivity toward the core network. For this reason, the gNB-CU may initiate NG Setup or gNB Configuration Update procedure towards 5GC.
- The gNB-CU sends an F1 Setup Response message to the gNB-DU that optionally includes a list of cells to be activated. If the gNB-DU succeeds to activate the cell(s), then the cells become operational. If the gNB-DU fails to activate some cell(s), the gNB-DU may initiate gNB-DU Configuration Update procedure towards the gNB-CU.
- The gNB-CU may send a gNB-CU Configuration Update message to the gNB-DU that optionally includes a list of cells to activated, e.g., in case that these cells were not activated using the F1 Setup Response message.
- The gNB-DU replies with a gNB-DU Configuration Update Acknowledge message that optionally includes a list of cells that failed to be activated.
- The gNB-CU may initiate Xn Setup or X2 Setup procedure towards the neighbor gNB or eNB, respectively.

F1AP – UE Context Setup

- The purpose of the UE Context Setup procedure is to establish the UE Context including among others SRB, and DRB data. The procedure uses UE-associated signalling.

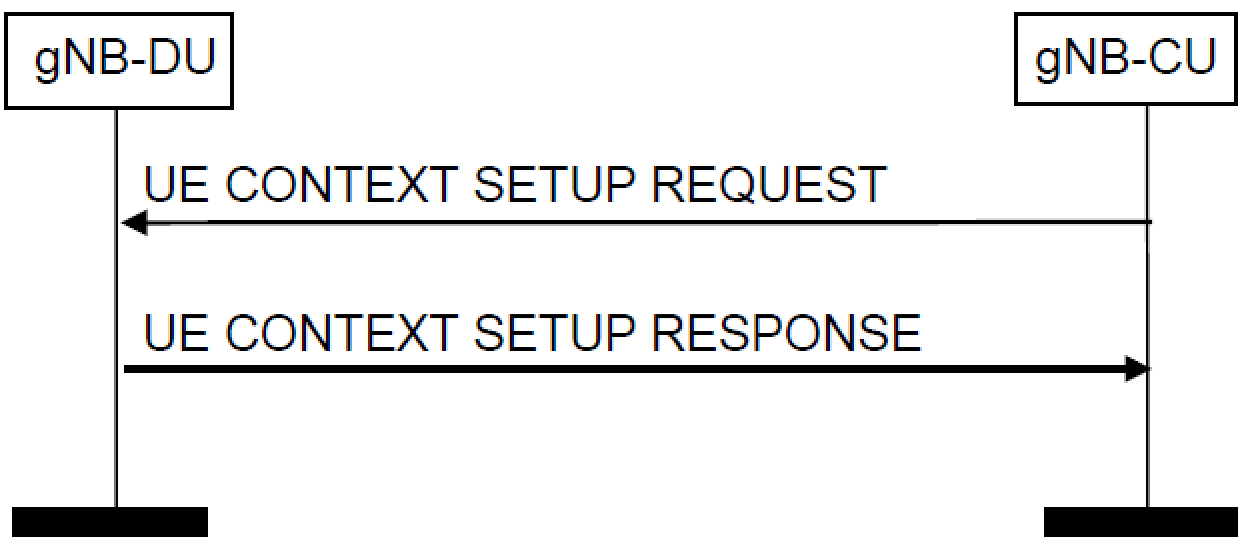


Figure 8.3.1.2-1: UE Context Setup Request procedure: Successful Operation

F1AP- UE CONTEXT Modificiation

- The purpose of the UE Context Modification procedure is to modify the established UE Context, e.g., establishing, modifying and releasing radio resources for user data transport. This procedure is also used to command the gNB-DU to stop data transmission for the UE. The procedure uses UE-associated signalling.

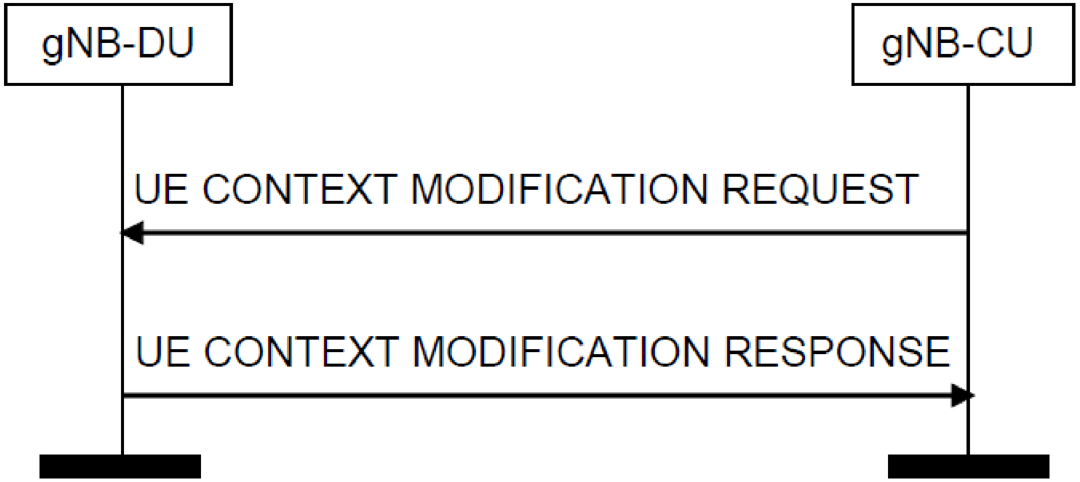


Figure 8.3.4.2-1: UE Context Modification procedure. Successful operation

RRC Message Transfer

- The purpose of the DL RRC Message Transfer procedure is to transfer an RRC message as a DL PDCP-PDU to the gNB-DU.
- The purpose of the UL RRC Message Transfer procedure is to transfer an RRC message as an UL PDCP-PDU to the gNB-CU.

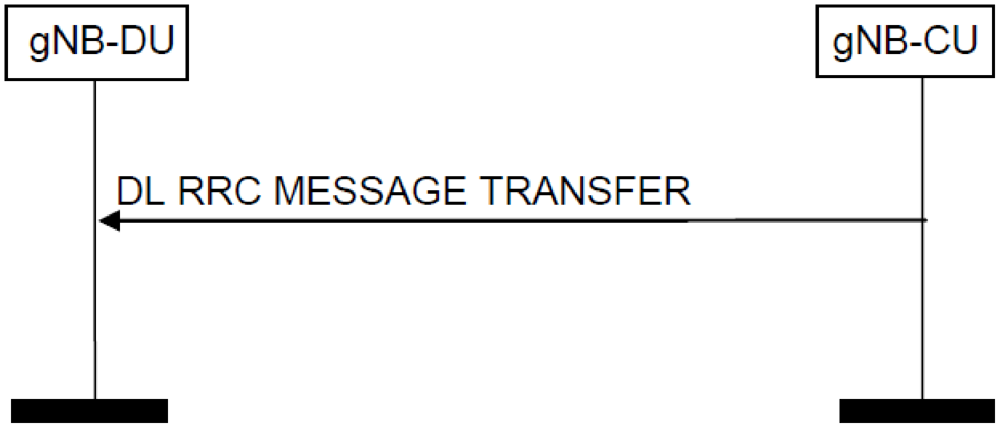


Figure 8.4.2.2-1: DL RRC Message Transfer procedure

OAI TOWARDS 5G NR

Physical Layer Evolution

- **OAI is currently implementing 5G NR waveforms for numerologies up to 80 MHz bandwidth and 250 µs TTI**
  – Executable on high-end USRP devices (X3x0, N3x0) with recent Analog Devices RF chipsets
  – gNB and UE
- **Parallelization strategies for**
  – Multi-core IA
  – GPU (channel coding/decoding)
  – FPGA Acceleration (channel coding/decoding)

5G Vs 4G (main differences)

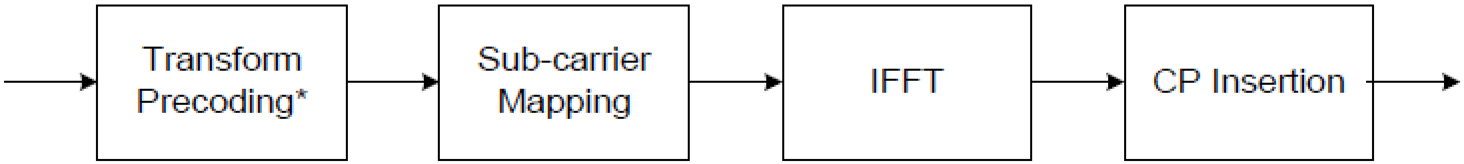
- **Support of scalable waveforms**
  - Scalable numerology should allow at least from 15kHz to 120kHz subcarrier spacing
    - Up to 275 PRBs of 12 sub-carriers (up to 396 MHz bandwidth)
  - Slot : 14 OFDM symbols
  - Subframe : 1ms / Frame : 10ms

SCS [KHz]	15	30	60	120	240	480
BW [MHz]	20	40	80	160	320	640
OFDM Symb duration [us]	71.3	35.7	17.8	8.9	4.5	2.2

80MHz BW with SCS of 60KHz is equivalent to 20MHz Bd with 15KHz SCS

TTI = 250us ➔ 5G Timing Constraint = 500us (Vs 2ms for 4G)

5G vs 4G (main differences)



**Optionally present in UL, not present in DL*

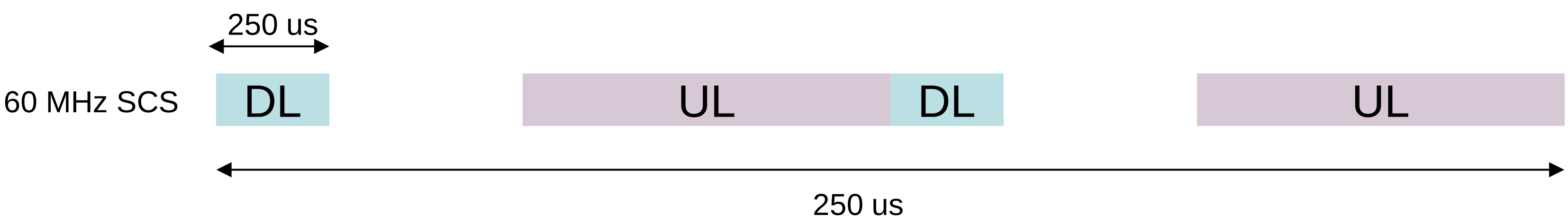
Figure 5.1-1: Transmitter block diagram for CP-OFDM with optional DFT-spreading

Table 5.1-1: Supported transmission numerologies.

100 PRBs	μ	$\Delta f = 2^{\mu} \cdot 15\,[\text{kHz}]$	**Cyclic prefix**	**Supported for data**	**Supported for synch**
20 MHz	0	15	Normal	Yes	Yes
40 MHz	1	30	Normal	Yes	Yes
80 MHz	2	60	Normal, Extended	Yes	No
160 MHz	3	120	Normal	Yes	Yes
	4	240	Normal	No	Yes

5G vs 4G (main differences)

- **Many variable slot formats**
  - Short-packet Low-latency transmission



47	D	D	D	D	D	X	X	D	D	D	D	D	X	X
48	D	D	X	X	X	X	X	D	D	X	X	X	X	X
49	D	X	X	X	X	X	X	D	X	X	X	X	X	X
50	X	U	U	U	U	U	U	X	U	U	U	U	U	U
51	X	X	U	U	U	U	U	X	X	U	U	U	U	U
52	X	X	X	U	U	U	U	X	X	X	U	U	U	U
53	X	X	X	X	U	U	U	X	X	X	X	U	U	U
54	D	D	D	D	D	X	U	D	D	D	D	D	X	U
55	D	D	X	U	U	U	U	D	D	X	U	U	U	U
56	D	X	U	U	U	U	U	D	X	U	U	U	U	U
57	D	D	D	D	X	X	U	D	D	D	D	X	X	U
58	D	D	X	X	U	U	U	D	D	X	X	U	U	U
59	D	X	X	U	U	U	U	D	X	X	U	U	U	U
60	D	X	X	X	X	X	U	D	X	X	X	X	X	U

5G vs 4G (main differences)

5.2.1 Downlink transmission scheme

A closed loop DMRS based spatial multiplexing is supported for PDSCH. Up to 8 and 12 orthogonal DL DMRS ports are supported type 1 and type 2 DMRS respectively. Up to 8 orthogonal DL DMRS ports per UE are supported for SU-MIMO and up to 4 orthogonal DL DMRS ports per UE are supported for MU-MIMO. The number of SU-MIMO code words is one for 1-4 layer transmissions and two for 5-8 layer transmissions.

The DMRS and corresponding PDSCH are transmitted using the same precoding matrix and the UE does not need to know the precoding matrix to demodulate the transmission. The transmitter may use different precoder matrix for different parts of the transmission bandwidth, resulting in frequency selective precoding. The UE may also assume that the same precoding matrix is used across a set of PRBs denoted Precoding Resource Block Group (PRG).

5.2.2 Physical-layer processing for physical downlink shared channel

The downlink physical-layer processing of transport channels consists of the following steps:

- Transport block CRC attachment (TBS above 3824 has 24 bit CRC, otherwise 16 bit CRC)
- Code block segmentation and code block CRC attachment (24 bit CRC)
- Channel coding: LDPC coding (base graph #1 or base graph #2);
- Physical-layer hybrid-ARQ processing and rate matching;
- Bit-interleaving;
- Modulation: QPSK, 16QAM, 64QAM and 256QAM;
- Layer mapping and pre-coding;
- Mapping to assigned resources and antenna ports.

The UE may assume that at least one symbol with demodulation reference signal is present on each layer in which PDSCH is transmitted to a UE. The number of DMRS symbols and resource element mapping is configured by higher layers.

Phase Tracking RS may be transmitted on additional symbols to aid receiver phase tracking.

5G vs 4G (main differences)

5.2.3 Physical downlink control channels

The UE-specific Physical Downlink Control Channel (PDCCH) is used to schedule DL transmissions on PDSCH and UL transmissions on PUSCH. The Downlink Control Information (DCI) on PDCCH includes:

- Downlink assignments containing at least modulation and coding format, resource allocation, and hybrid-ARQ information related to DL-SCH;
- Uplink scheduling grants containing at least modulation and coding format, resource allocation, and hybrid-ARQ information related to UL-SCH;

Control channels are formed by aggregation of control channel elements, each control channel element consisting of set of resource element groups. Different code rates for the control channels are realized by aggregating different numbers of control channel elements.

Polar coding is used for PDCCH.

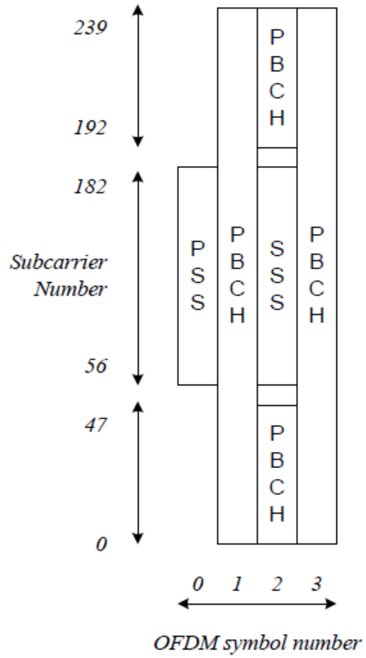
Each resource element group carrying PDCCH carries its own DMRS.

QPSK modulation is used for PDCCH.

5G vs 4G (main differences)

5.2.4 Synchronization signal and PBCH

The synchronization signal and PBCH block consists of primary and secondary synchronization signals (PSS, SSS), each occupying 1 symbol and 127 subcarriers, and PBCH spanning across 3 OFDM symbols and 240 subcarriers, but on one symbol leaving an unused part in the middle for SSS as show in figure 5.2.4-1. The periodicity of the SS/PBCH block can be configured by the network and the time locations where SS/PBCH block can be sent are determined by sub-carrier spacing.



Polar coding is used for PBCH.

The UE may assume a band-specific sub-carrier spacing for the SS/PBCH block unless a network has configured the UE to assume a different sub-carrier spacing.

PBCH symbols carry its own frequency-multiplexed DMRS.

5G vs 4G (main differences)

5.3.2 Physical-layer processing for physical uplink shared channel

The uplink physical-layer processing of transport channels consists of the following steps:

- Transport Block CRC attachment (TBS above 3824 has 24 bit CRC, otherwise 16 bit CRC);
- Code block segmentation and Code Block CRC attachment (24 bit CRC);
- Channel coding: LDPC coding (base graph #1 or base graph #2);
- Bit-interleaving;
- Modulation: Pi/2 BPSK (with transform precoding only), QPSK, 16QAM, 64QAM and 256QAM;
- Layer mapping, transform precoding (enabled/disabled by configuration), and pre-coding;
- Mapping to assigned resources and antenna ports.

The UE transmits at least one symbol with demodulation reference signal on each layer in which PUSCH is transmitted. The number of DMRS symbols and resource element mapping is configured by higher layers.

Phase Tracking RS may be transmitted on additional symbols to aid receiver phase tracking.

5G vs 4G (main differences)

5.3.3 Physical uplink control channel

Physical uplink control channel (PUCCH) carries the Uplink Control Information (UCI) from the UE to the gNB. Five formats of PUCCH exist, depending on the duration of PUCCH and the UCI payload size.

- Short PUCCH of 1 or 2 symbols with small UCI payloads of up to two bits with UE multiplexing in the same PRB;
- Short PUCCH of 1 or 2 symbols with large UCI payloads of more than two bits with no multiplexing in the same PRB;
- Long PUCCH of 4-14 symbols with small UCI payloads of up to two bits with multiplexing in the same PRB;
- Long PUCCH of 4-14 symbols with moderate UCI payloads with some multiplexing capacity in the same PRB;
- Long PUCCH of 4-14 symbols with large UCI payloads with no multiplexing capacity in the same PRB.

The short PUCCH format of up to two UCI bits is based on sequence selection, while the short PUCCH format of more than two UCI bits frequency multiplexes UCI and DMRS. The long PUCCH formats time-multiplex the UCI and DMRS. Frequency hopping is supported for long PUCCH formats and for short PUCCH formats of duration 2 symbols. Long PUCCH formats can be repeated over multiple slots.

UCI multiplexing in PUSCH is supported when UCI and PUSCH transmissions coincide in the same slot:

- UCI carrying HARQ-ACK feedback with 1 or 2 bits is multiplexed by punctured PUSCH;
- In all other cases UCI is multiplexed by rate matching PUSCH.

5G vs 4G (main differences)

UCI consists of the following information:

- CSI;
- ACK/NAK;
- Scheduling request.

QPSK modulation is used for long PUCCH with 2 or more bits of information, and short PUCCH with more than 2 bits of information. BPSK modulation is used for long PUCCH with 1 information bit.

Transform precoding is applied to long PUCCH.

Channel coding used for uplink control information is described in table 5.3.3-1.

Table 5.3.3-1: Channel coding for uplink control information

Uplink Control Information size including CRC, if present	Channel code
1	Repetition code
2	Simplex code
3-11	Reed Muller code
>11	Polar code

PRACH

5.3.4 Random access

Random access preamble sequences, of two different lengths are supported. Long sequence length 839 is applied with subcarrier spacings of 1.25 and 5 kHz and short sequence length 139 is applied with sub-carrier spacings 15, 30, 60 and 120 kHz. Long sequences support unrestricted sets and restricted sets of Type A and Type B, while short sequences support unrestricted sets only.

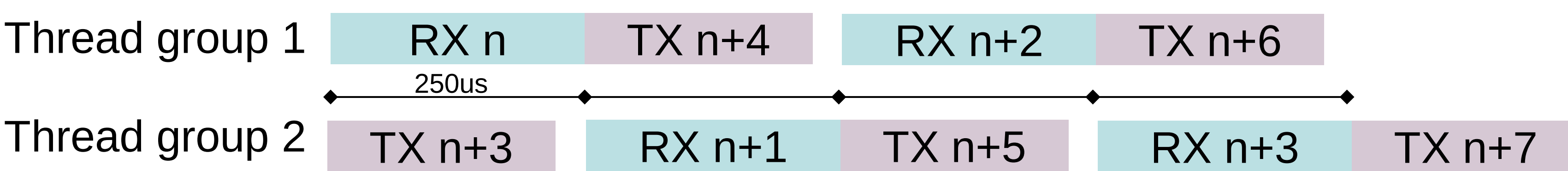
Multiple RACH preamble formats are defined with one or more RACH OFDM symbols, and different cyclic prefix and guard time. The PRACH preamble configuration to use is provided to the UE in the system information.

The UE calculates the PRACH transmit power for the retransmission of the preamble based on the most recent estimate pathloss and power ramping counter. If the UE conducts beam switching, the counter of power ramping remains unchanged.

The system information informs the UE of the association between the SS blocks and the RACH resources. The threshold of the SS block for RACH resource association is based on the RSRP and network configurable.

Impact on Threading Architecture

- **Essentially the same as current OAI**
- **BUT: many parallel threads are needed to ensure latency requirement**
  - 3-4 parallel channel encoding/decoding threads
  - 2-3 parallel FFT/IFFT threads

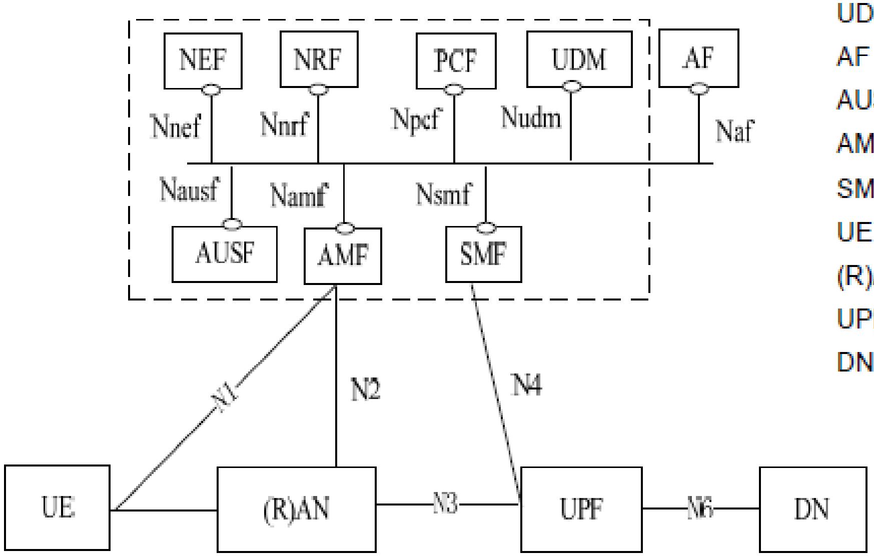


Key new elements to be developed

- **Efficient LDPC encode/decode**
  - Full SIMD software when possible
  - HW accelerator on GPU/FPGA
- **Efficient Polar code/decode (both gNB and UE)**
- **Higher-order MIMO receivers**
- **Not much but very hard**

5G Core

- **Activity driven in OAI community primarily by Beijing University of Posts and Telecommunications**
  - Built based on existing openairCN 4G core
- **Service-oriented architecture**



NEF	Network Exposure Function
NRF	Network Repository Function
PCF	Policy Control Function
UDM	Unified Data Management
AF	Application Function
AUSF	Authentication Server Function
AMF	Access &Mobility Management Function
SMF	Session Management Function
UE	User Equipment
(R)AN	(Radio) Access Network
UPF	User Plane Function
DN	Data Network

QUESTIONS