Νέες και Παλιές Προκλήσεις στα Δίκτυα Κινητών Επικοινωνιών (M301)

ΤΜΉΜΑ ΠΛΗΡΟΦΟΡΙΚΉΣ ΚΑΙ ΤΗΛΕΠΙΚΟΙΝΩΝΙΏΝ, ΕΚΠΑ

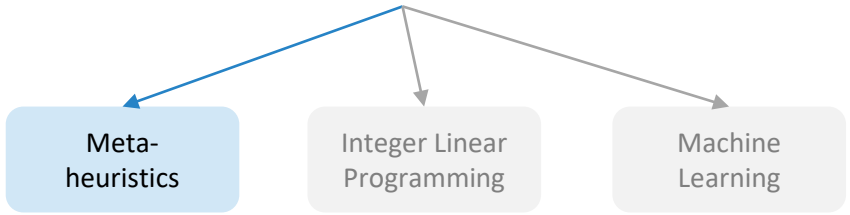
ΔΡ. ΔΗΜΗΤΡΗΣ ΤΣΟΛΚΑΣ & ΚΑΘ. ΛΑΖΑΡΟΣ ΜΕΡΑΚΟΣ

Takeaways (lecture 1)

- 5G mobile system is not only about better performance for the end user.. is also a flexible management platform that creates business opportunities for verticals
- From the standardization point of view 3GPP Rel15/Rel16/Rel17 define the 5G architecture and the related technologies
- There are key advancements from IT sector that are consider in the Telco sector for the realization of 5G features (e.g., ETSI MANO for network slicing)
- The 5G research in EU has recognized the need for 5G (and B5G) experimentation platforms (dedicated spectrum for experimentation, development of 5G testbeds around EU)

Takeaways (lecture 2)

- 5G Architecture – 4 aspects to remember compared to 4G architecture
  - Functions rearrangement | User and control plane decoupling | service-based concept | slicing support
- 5G Core and edge exposure through APIs
- Key functionality in SBA beyond 4G:
  - NEF+AF-> Openess, NSSF-> slicing, NWDAF-> AI
- Slice Concept realization through MANO+NFV Architectures
- Research challenges in Network slicing
  - Minimize Slice set up time by using:



Target topics

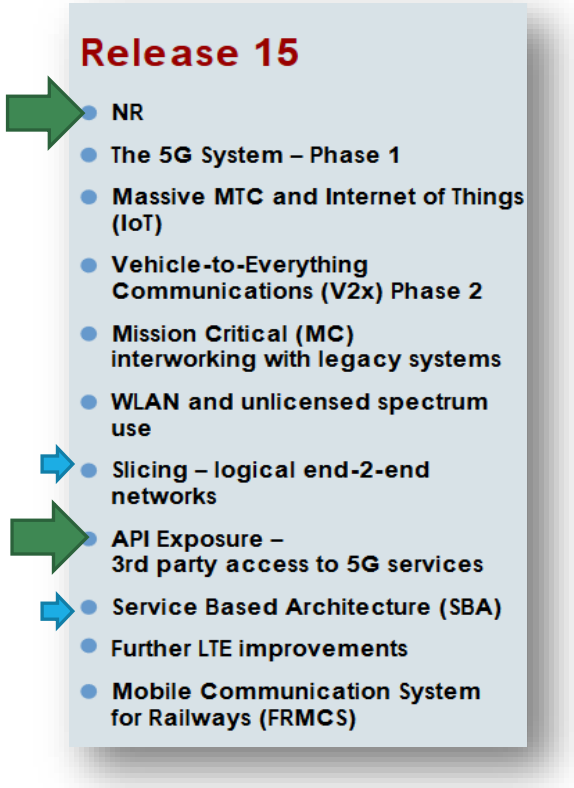
Release 15

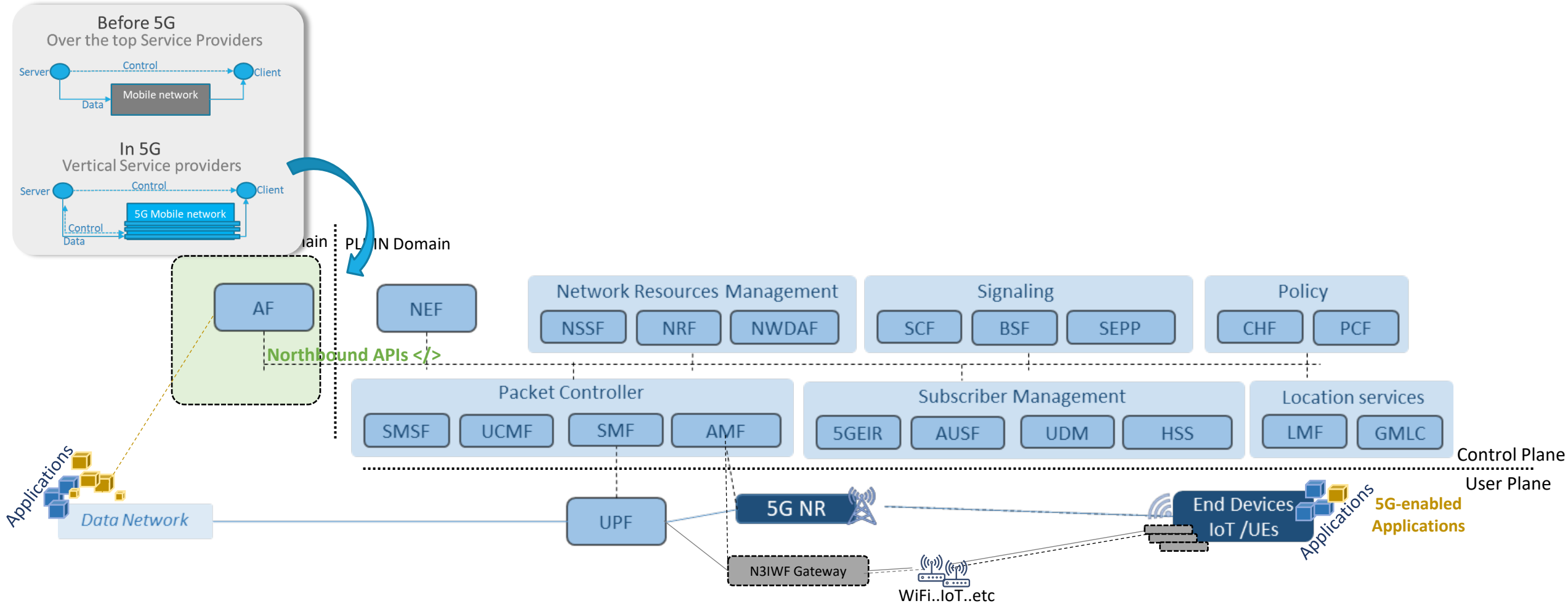
- NR
- The 5G System – Phase 1
- Massive MTC and Internet of Things (IoT)
- Vehicle-to-Everything Communications (V2x) Phase 2
- Mission Critical (MC) interworking with legacy systems
- WLAN and unlicensed spectrum use
- Slicing – logical end-2-end networks
- API Exposure – 3rd party access to 5G services
- Service Based Architecture (SBA)
- Further LTE improvements
- Mobile Communication System for Railways (FRMCS)

Main targets lecture 3

- API exposure: how the third parties can interact with 5G core
- QoS enforcement
  - How do 5G systems separate and treat flows with different QoS?
- 5G New Radio (NR)
  - Deployment options & protocol stack
  - Functional split
  - Performance analysis (in a future lecture)

Target topics



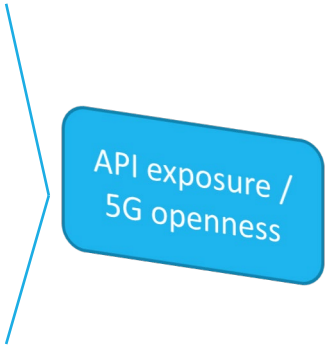


5G Architecture

3GPP 23.501

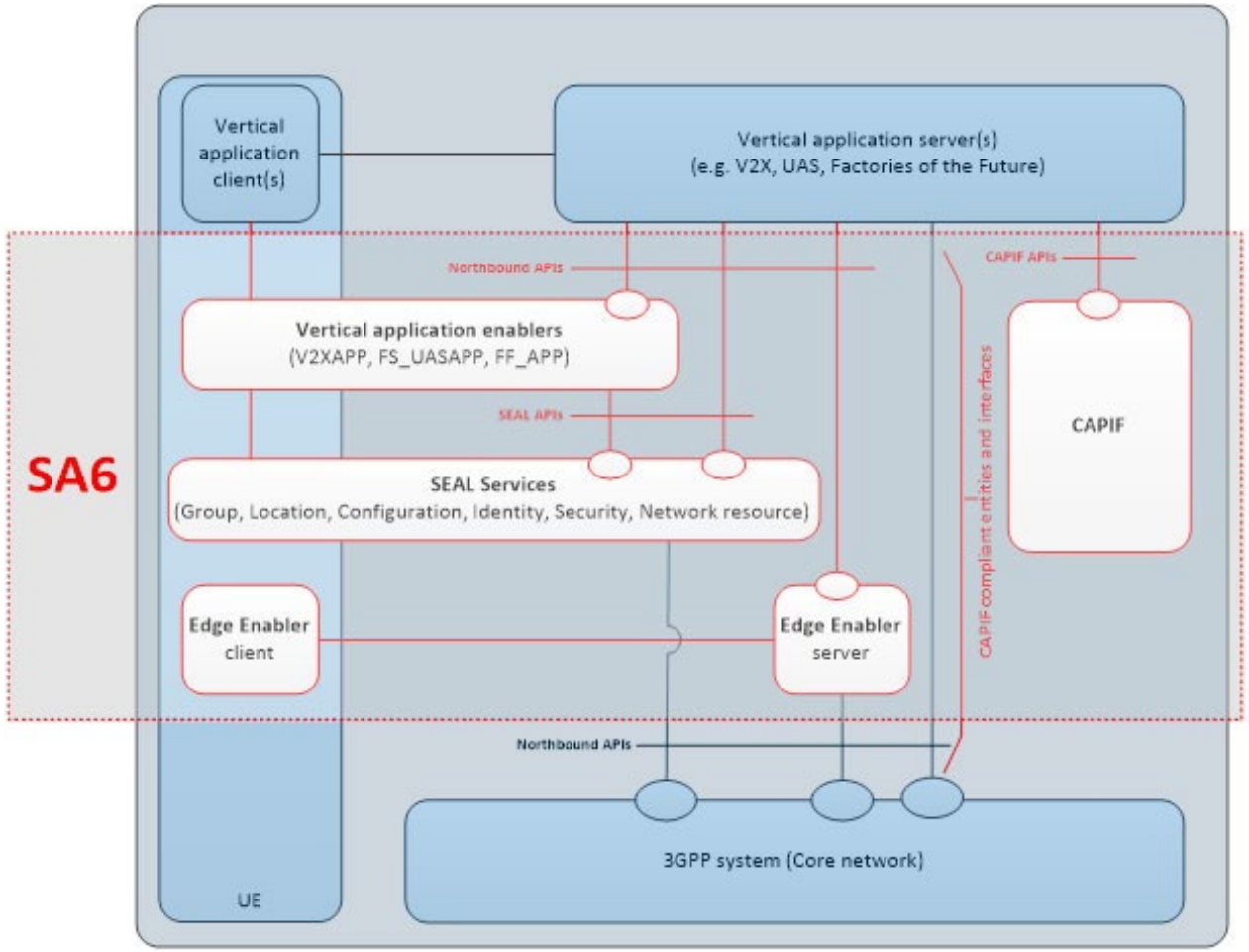
5G Architecture (key entities beyond 4G)

- The **NEF** entity realises a dedicated exposure function, to guarantee that functionality from other entities of the core network is securely exposed to verticals (mobile network externals). It incorporates the interfacing of 5GC with services coming from different vendors. From the verticals' perspective, *NEF enables the creation of new services by consolidating, though APIs, features of the 5G Core*.
- The **AF** is a function that *may or may not reside at the PLMN domain and interacts with the 5GC via the NEF*. Its main functionality includes the provision of Packet-Flow Description - PFD(s) to NEF, and the consumption of RESTful APIs to utilize services and capabilities that are securely exposed by NEF.

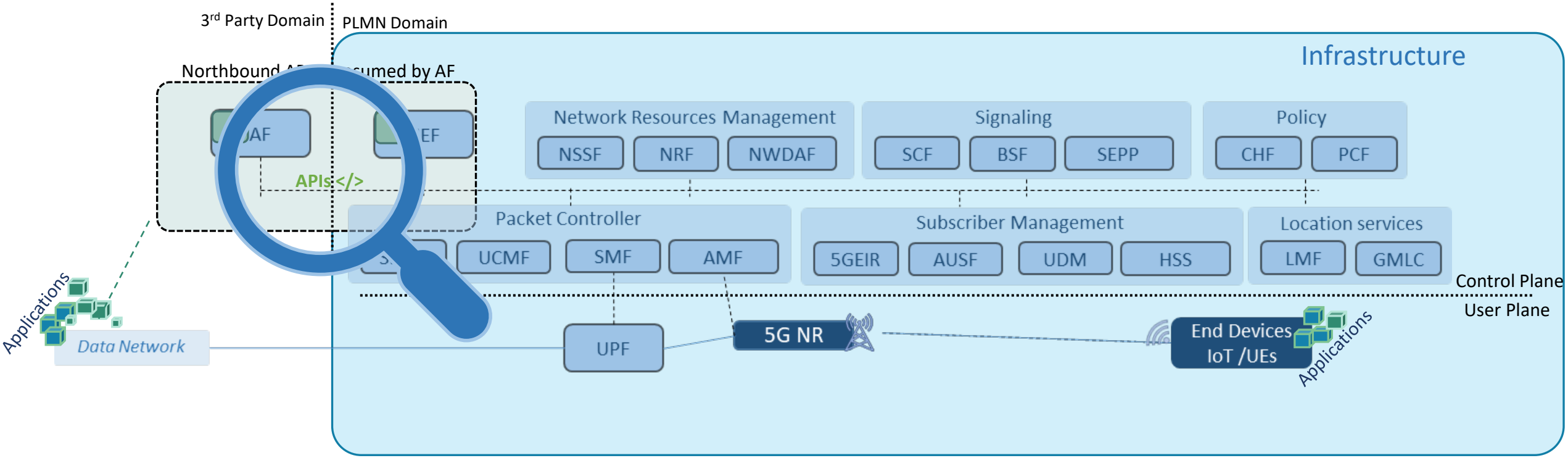


5G Openness

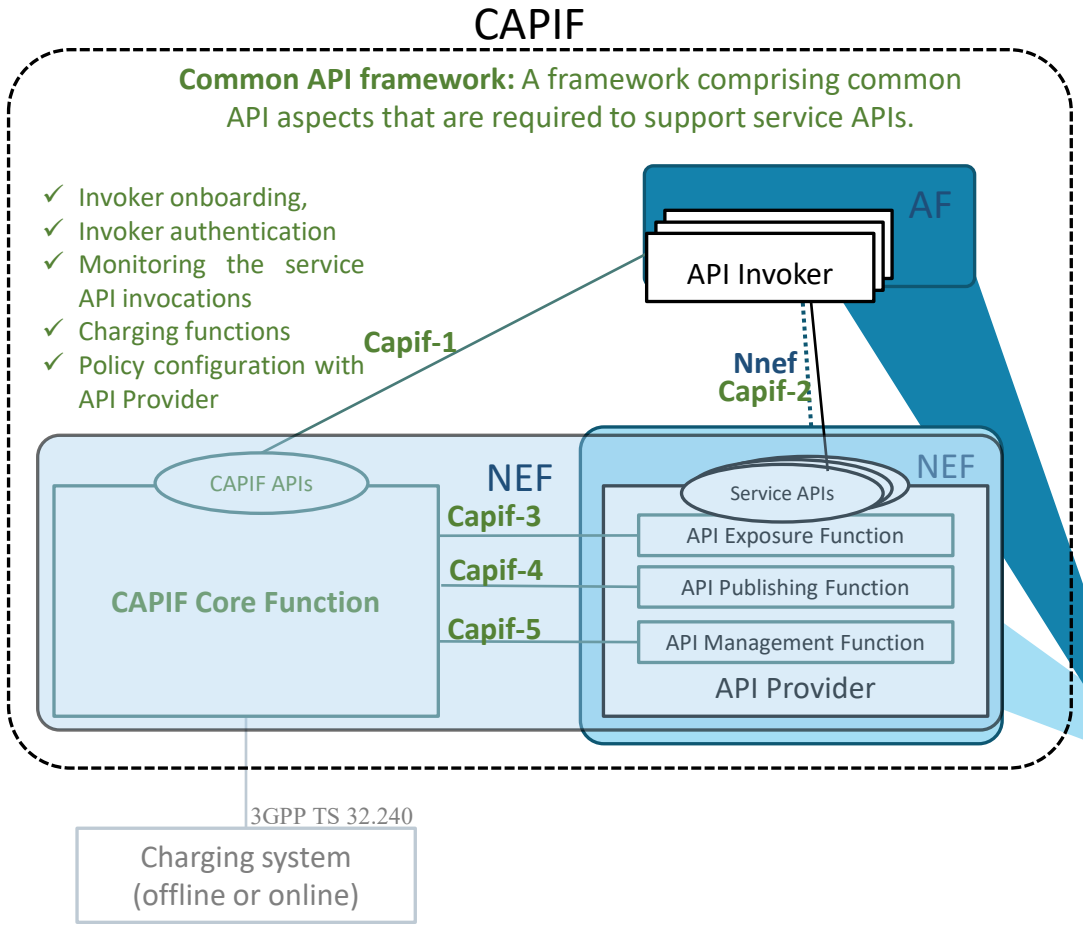
(The interaction with Verticals)



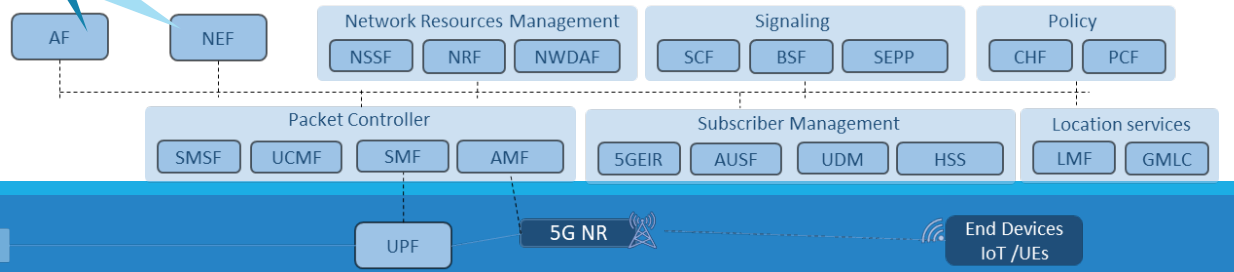
CAPIF: Common API framework



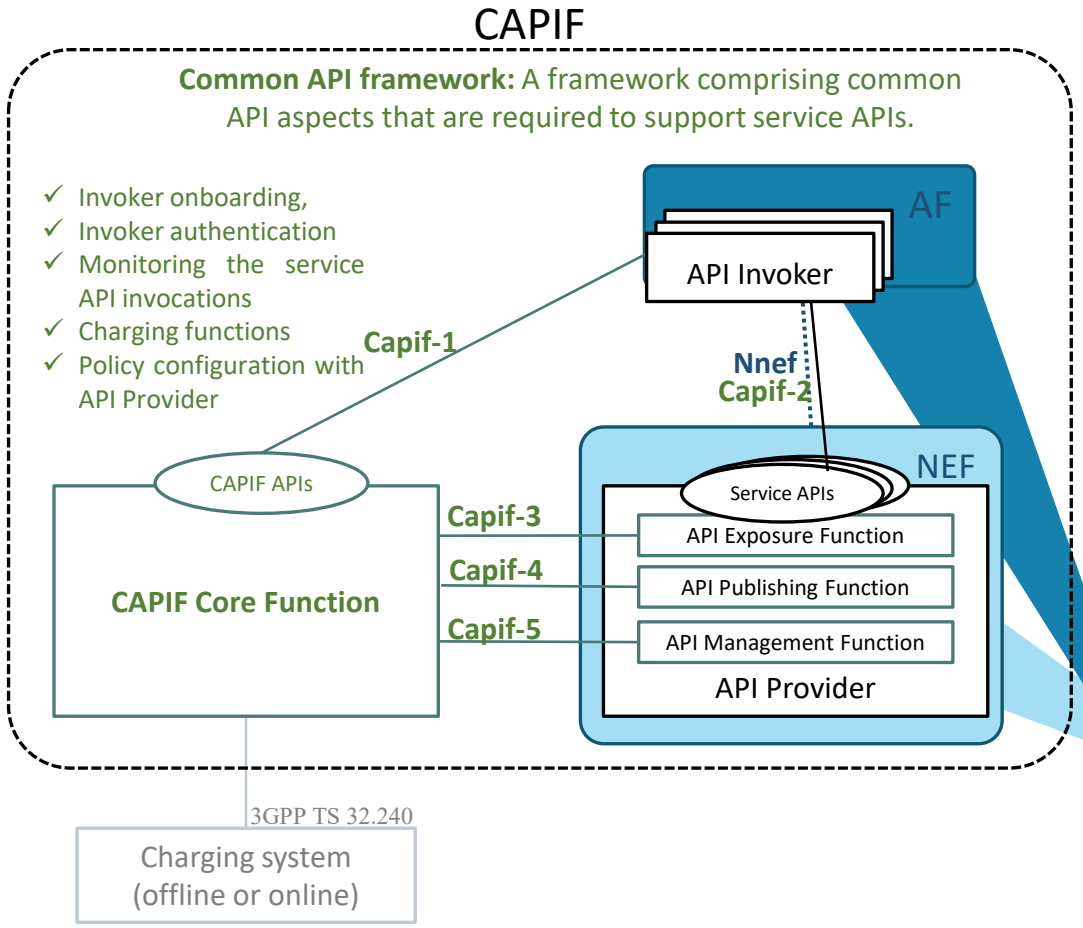
CAPIF: Common API framework (Main components)



Aspects	CAPIF	5GS network exposure
Entity providing the APIs to external or 3rd partyapplications	AEF	NEF
Entity providing framework related services to the applications (discovery, authentication, authorization, etc)	CAPIF core function	NEF (Not specified yet)
Entity representing the external or 3rd party applications	API invoker	AF
Entity providing framework related services to support the APIs operation and management (publish, policy enforcements, charging)	CAPIF core function	NEF (Not specified yet)
Interface/Reference point for exposing network capabilities as APIs	CAPIF-2 and CAPIF-2e (Do not include the service specific aspects)	Nnef
Interface/Reference point for exposing framework services as APIs to the applications	CAPIF-1 and CAPIF-1e	Nnef (Not specified yet)
Interface/Reference point for framework services to support the APIs operation and management	CAPIF-3, CAPIF-4 and CAPIF-5	Internal to NEF

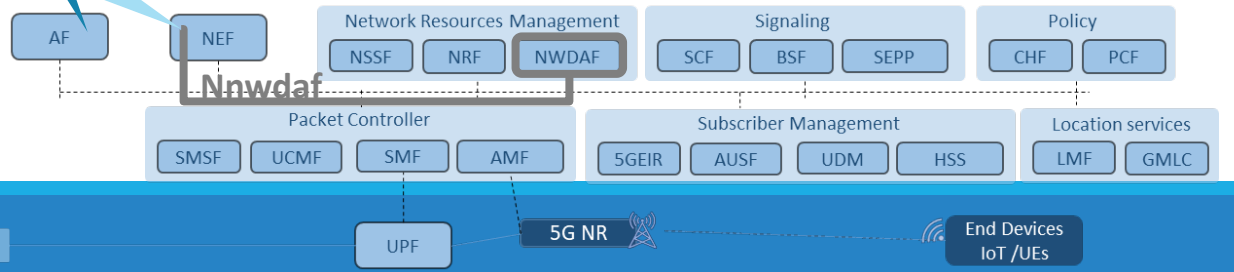


CAPIF: Common API framework (Main components)

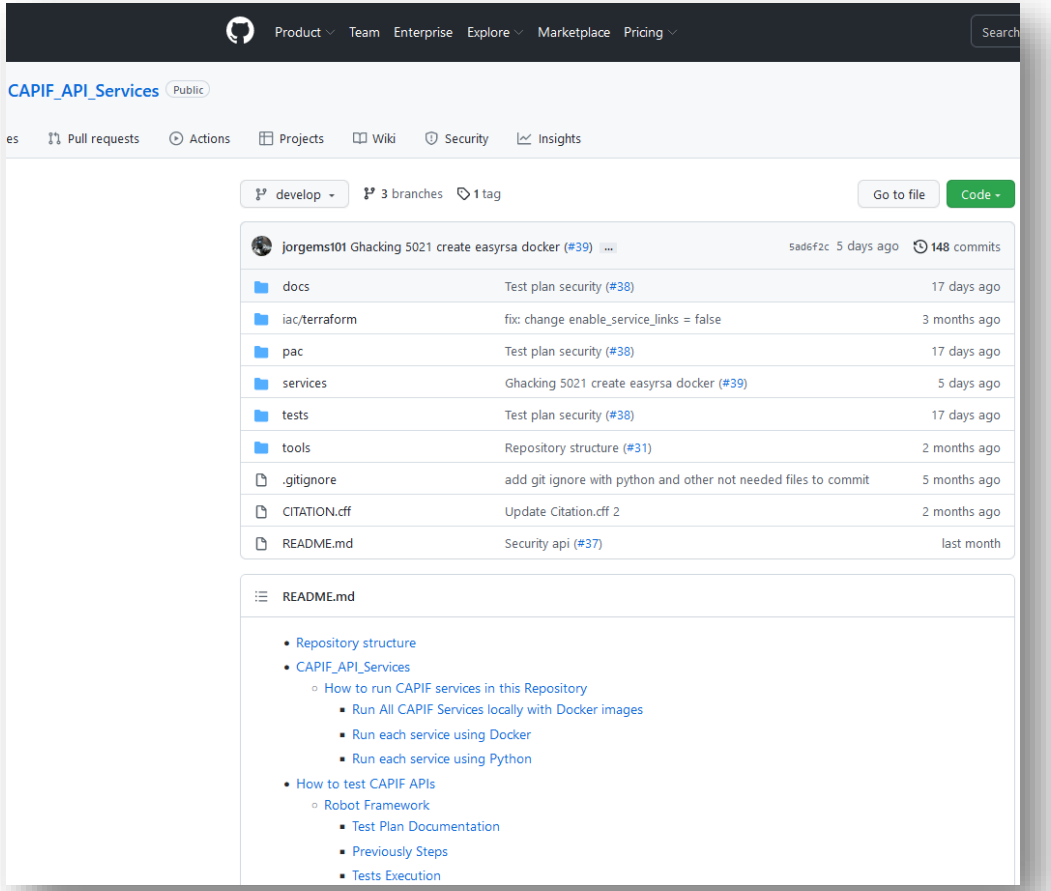


Service APIs exposed (example)

Feature number	Feature Name	Description
1	ServiceExperience	This feature indicates support for the event related to service experience.
2	UeMobility	This feature indicates the support of analytics based on UE mobility information.
3	UeCommunication	This feature indicates the support of analytics based on UE communication information.
4	QoSSustainability	This feature indicates support for the event related to QoS sustainability.
5	AbnormalBehaviour	This feature indicates support for the event related to abnormal behaviour information.
6	UserDataCongestion	This feature indicates support for the event related to user data congestion.
7	NfLoad	This feature indicates the support of the analytics related to the load of NF instances.
8	NetworkPerformance	This feature indicates the support of analytics based on network performance.
9	NsiLoad	This feature indicates the support of the event related to the load level of Network Slice and the optionally associated Network Slice Instance.

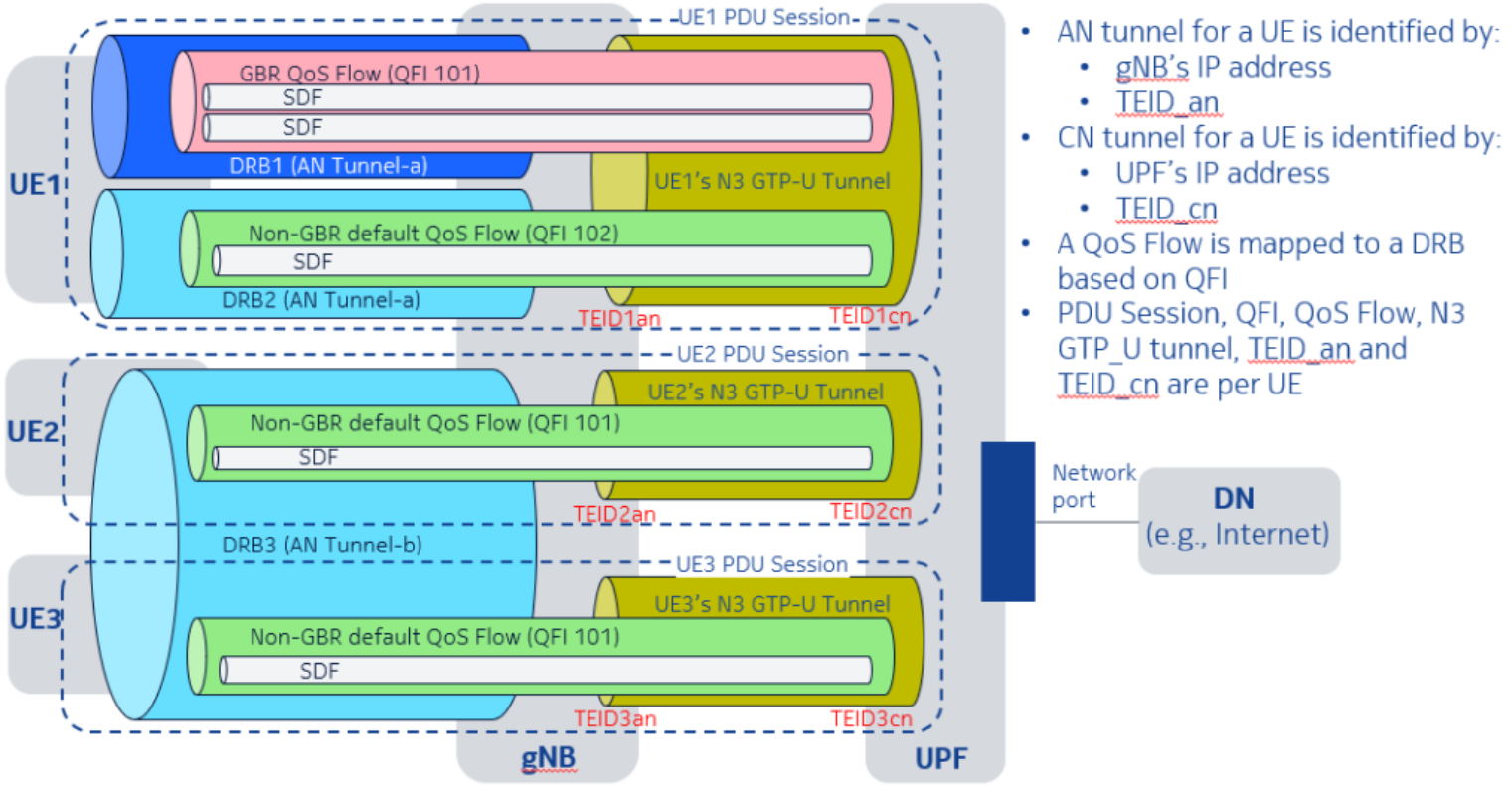


CAPIF Implementation



5G QoS Flows

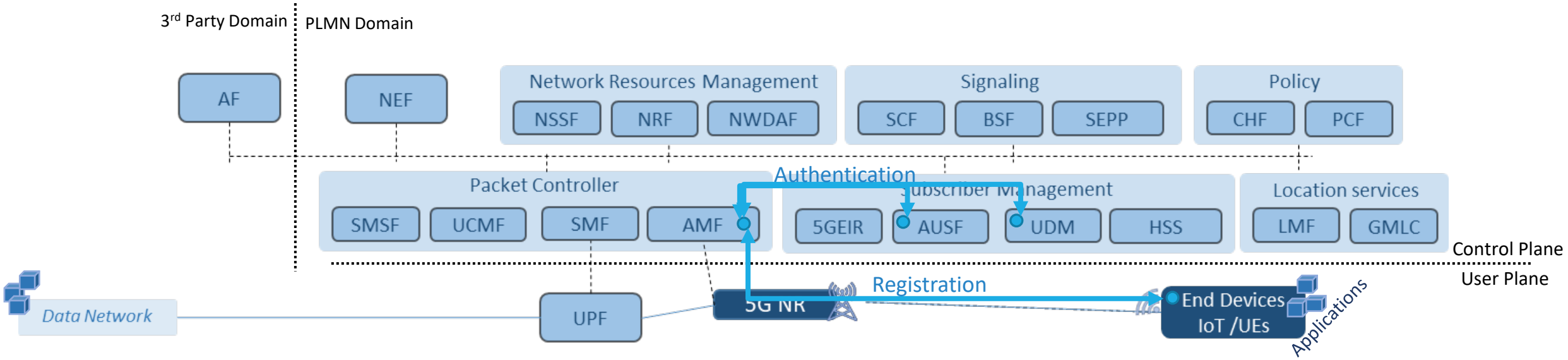
Traffic detection and QoS enforcement



- AN tunnel for a UE is identified by:
  - gNB's IP address
  - TEID_an
- CN tunnel for a UE is identified by:
  - UPF's IP address
  - TEID_cn
- A QoS Flow is mapped to a DRB based on QFI
- PDU Session, QFI, QoS Flow, N3 GTP_U tunnel, TEID_an and TEID_cn are per UE

Packet Data Unit (PDU) sessions in 5G

Set up process and QoS enforcement

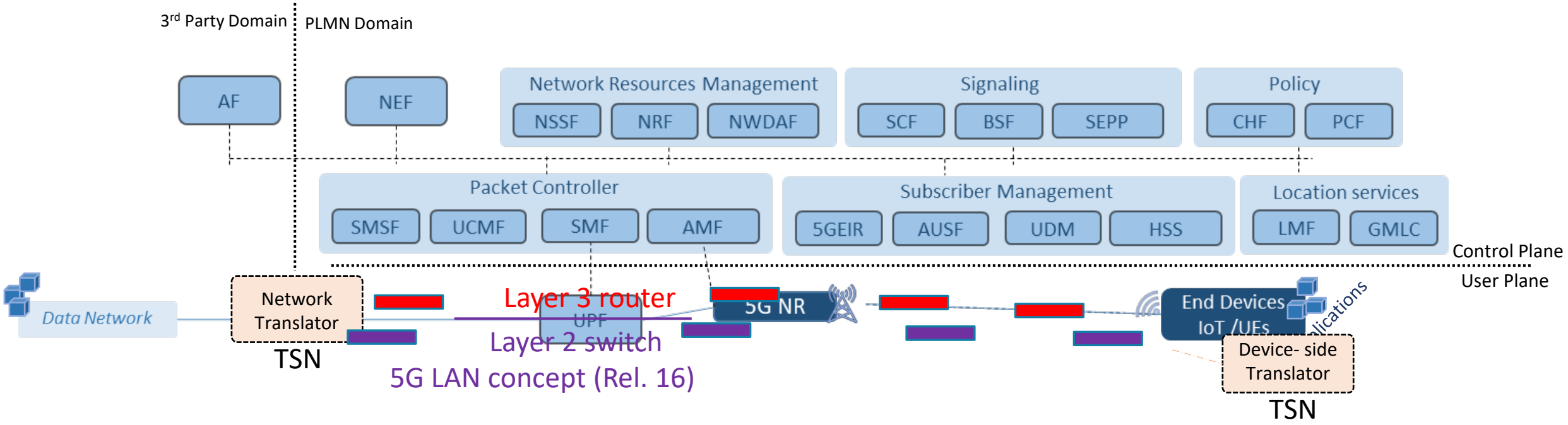


Only registered UEs can set up a PDU session

The UE performs the Registration Procedure with 5GS for AMF to authenticate the UE's SIM card with help from UDM and AUSF to make sure that the UE has a valid subscription in the 5GS

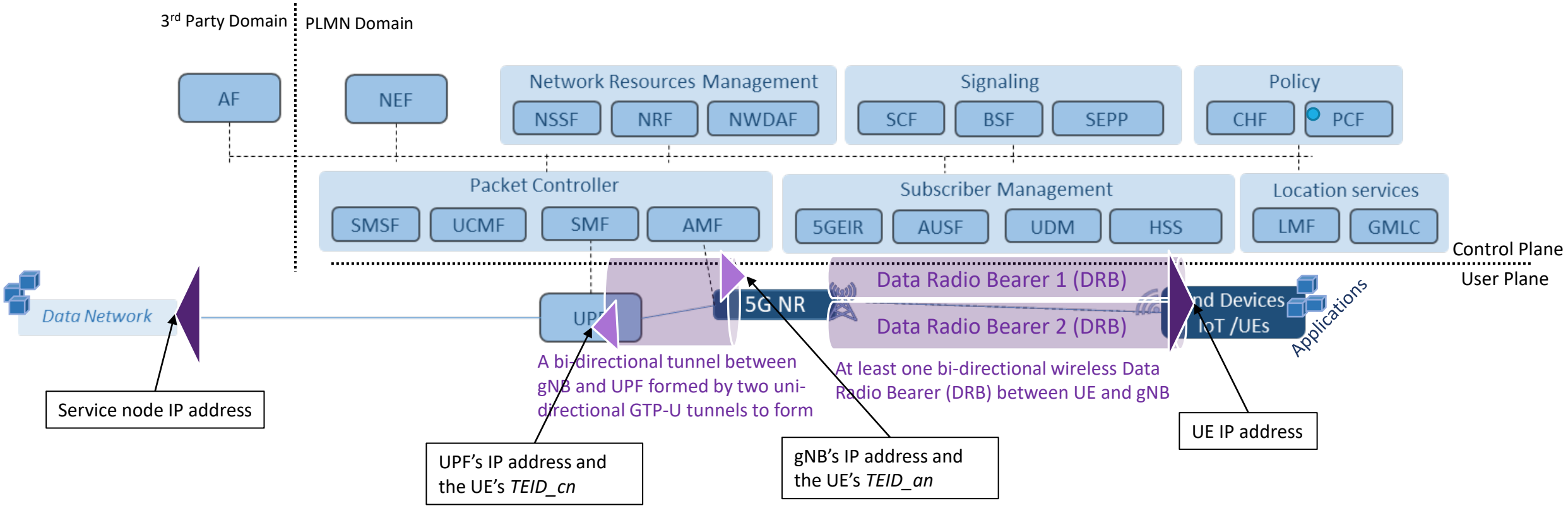
Packet Data Unit (PDU) sessions in 5G

Packet Data Unit (PDU) sessions (IP sessions only?)



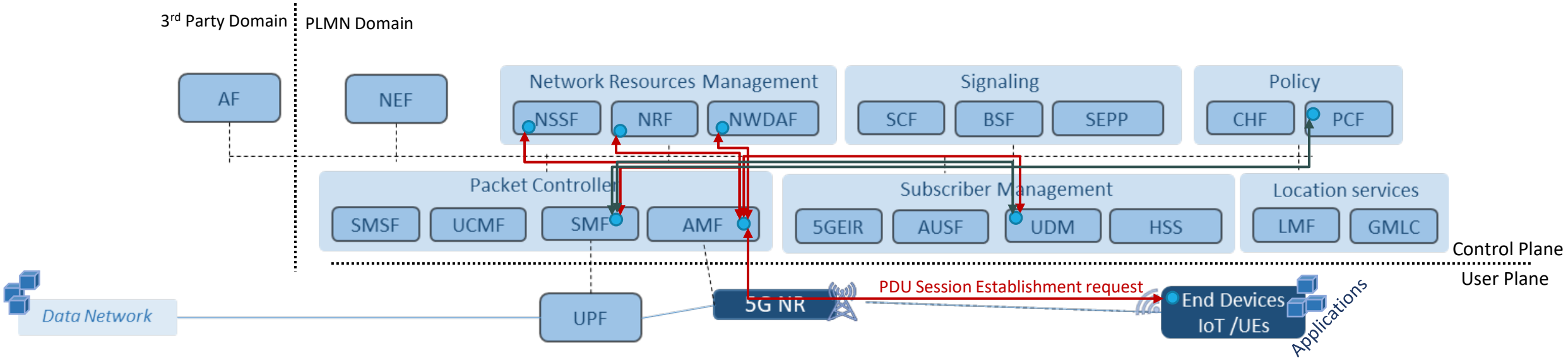
Packet Data Unit (PDU) sessions in 5G

For a UE the PDU session is supported by ONE CN tunnel and ONE OR MORE AN tunnels (DRB)



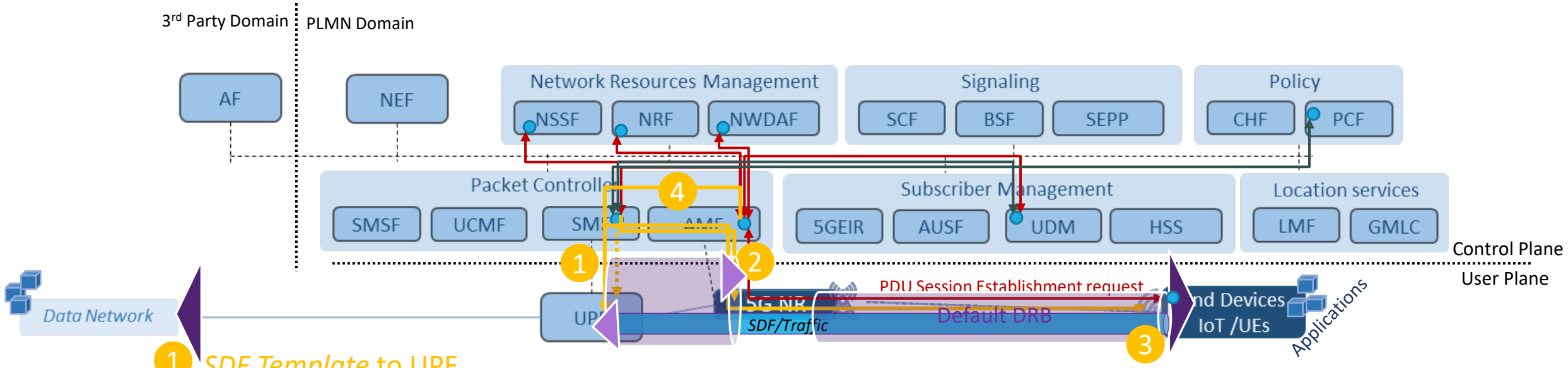
Packet Data Unit (PDU) sessions in 5G

Set up process



Packet Data Unit (PDU) sessions in 5G

Set up process

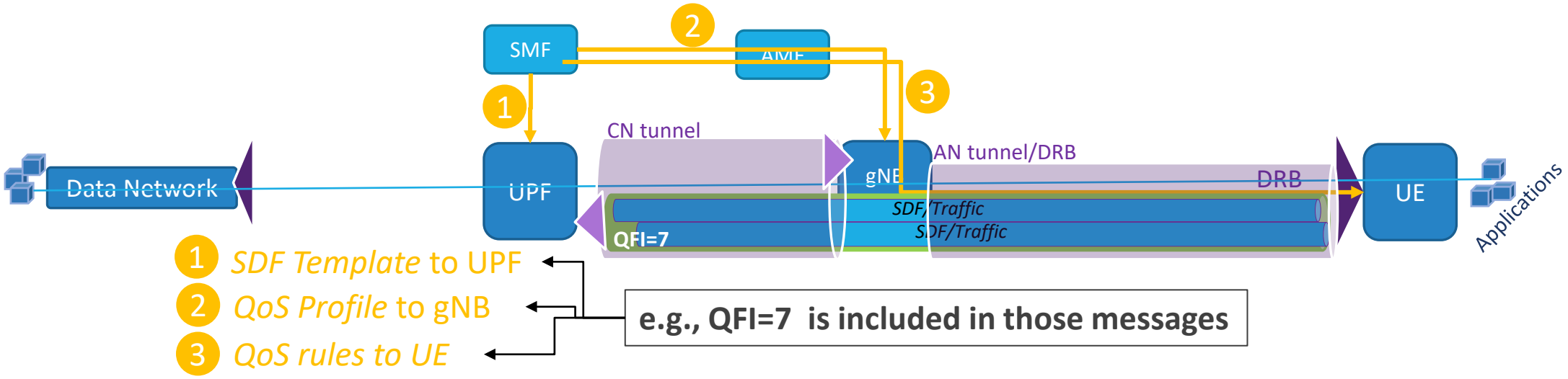


1. *SDF Template* to UPF
2. *QoS Profile* to gNB (UPF's IP address and the UE's *TEID_cn*)
3. *QoS rules to UE* (UE IP address)
4. *SM update to UPF* (gNB's IP address and the UE's *TEID_an*)

Packet Data Unit (PDU) sessions in 5G

QoS enforcement – Quality Flow concept / use of Quality Flow Identifiers (QFI)

- **Each Service Data Flow (SDF) / traffic flow is characterized by a QFI**
- **The same value for the QFI is send to UPF / gNB/ UE**



Packet Data Unit (PDU) sessions in 5G

QoS enforcement – Quality Flow concept / use of Quality Flow Identifiers (QFI)

1 *SDF Template* to UPF

PDR (Packet Detection Rule)

- Include PDI (*Packet Detection Information*) to **classify** DL traffic using 5-tuple to map the DL traffic (i.e., SDF) to a QoS Flow (i.e., **SDF Binding**) within the PDU Session. The UL PDI is used to **verify** the UL SDF to QoS Flow mapping before the UPF **forward** the UE's traffic to the DN
- *Pointers to FARs, QERs, URRs and BARs*
- *Precedence* to determine when the PDR and its associated FARs, QERs, URRs and BARs will be used
  - **FAR (Forwarding Rule)**
    - Service chaining's packet processing operations such as forward, duplicate, send to Control Plane etc
    - QoS marking (e.g., DSCP) to the DN
  - **QER (QoS Enforcement Rule)**
    - Enforce traffic such as GBR and non-GBR bandwidth and latency. For example, if DL Session-AMBR is set to 30Mbps, the UPF will drop DL non-GBR SDF traffic above 30Mbps
  - **URR (Usage Report Rule)**
    - Usage reporting from UPF to SMF. SMF can forward the info to PCF for any UE over-usage policies
  - **BAR (Buffer Action Rule)**
    - Support buffering DL traffic for an idle UE before the UE is woke up by the SMF and ready to receive DL traffic

Packet Data Unit (PDU) sessions in 5G

QoS enforcement – Quality Flow concept / use of Quality Flow Identifiers (QFI)

2 *QoS Profile* to gNB

- 5QI (**5G quality indicator**) describes the QoS characteristic (e.g., best-effort non-GBR) of the default QoS Flow in the UE's PDU Session
- The UL and DL UE-AMBRs (Aggregated Maximum Bit Rate). In other words, if for UL is 20Mbps and for DL 30Mbps the gNB will drop any non-GBR AMBR traffic for the UE that is above 20Mbps for UL and 30Mbps for DL

Packet Data Unit (PDU) sessions in 5G

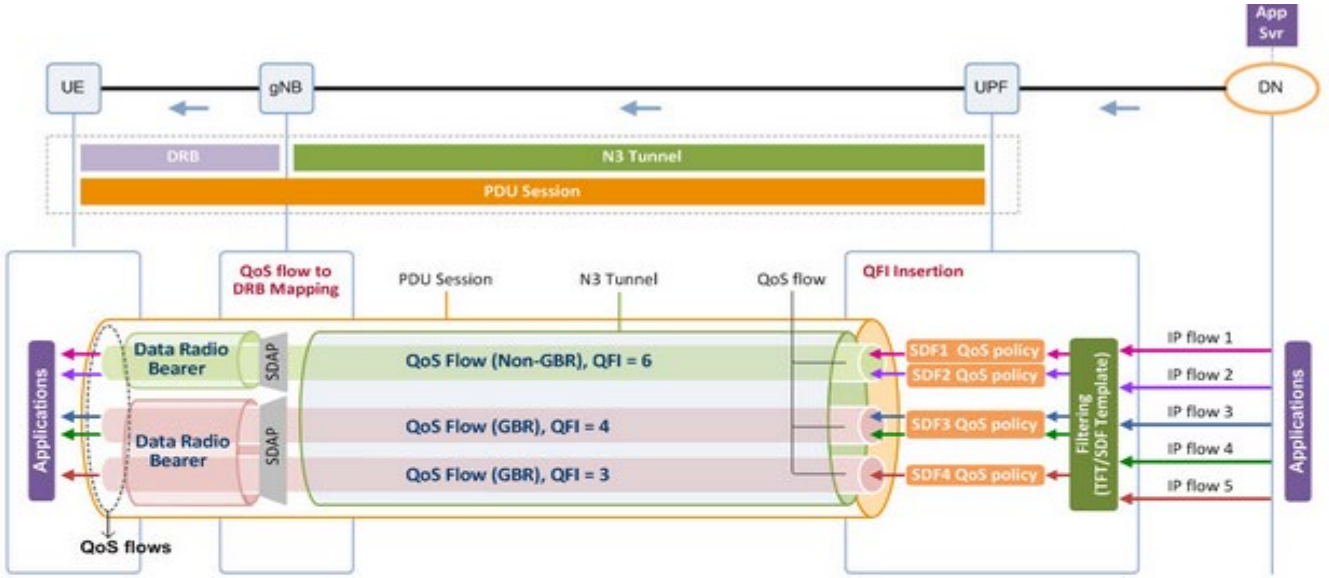
QoS enforcement – Quality Flow concept / use of Quality Flow Identifiers (QFI)

3 *QoS rules to UE*

- The SMF advises the UE (over the N1 HTTP/2 interface) to setup **Packet Filters** to classify UL traffic to the DN.
- The UL and DL UE-AMBRs (Aggregated Maximum Bit Rate). In other words, if for UL is 20Mbps and for DL 30Mbps the gNB will drop any non-GBR AMBR traffic for the UE that is above 20Mbps for UL and 30Mbps for DL
- UL/DL Session AMBRs
- The value of the reserved SST/NSSAI
  - 001 — eMBB (enhanced Mobile Broadband)
  - 002 — URLLC (ultra-reliable low latency communication
  - 003 — MIoT (Massive IoT)
  - 004 — V2X (Vehicle to Vehicle communication)

Network Slice Selection Assistance Information (NSSAI)
Used in support of Network Slicing, the S-NSSAI is used to uniquely identify a Network Slice. The NSSAI contains two components: the SST (Slice/Service Type) and an optional SD (Slice Differentiator)

5G QoS enforcement



5QI	: 5G QoS Identifier
ARP	: Allocation and Retention Priority
GFBR	: Guaranteed Flow Bit Rate
MFBR	: Maximum Flow Bit Rate
PDB	: Packet Delay Budget
PER	: Packet Error Rate
QFI	: QoS Flow Identifier
RQA	: Reflective QoS Attribute

QoS Flow type		QoS Flow parameters
GBR flow	Non-GBR flow	5QI
		ARP
		RQA
		GFBR
		MFBR
		Notification Control
		Maximum Packet Loss Rate

5QI

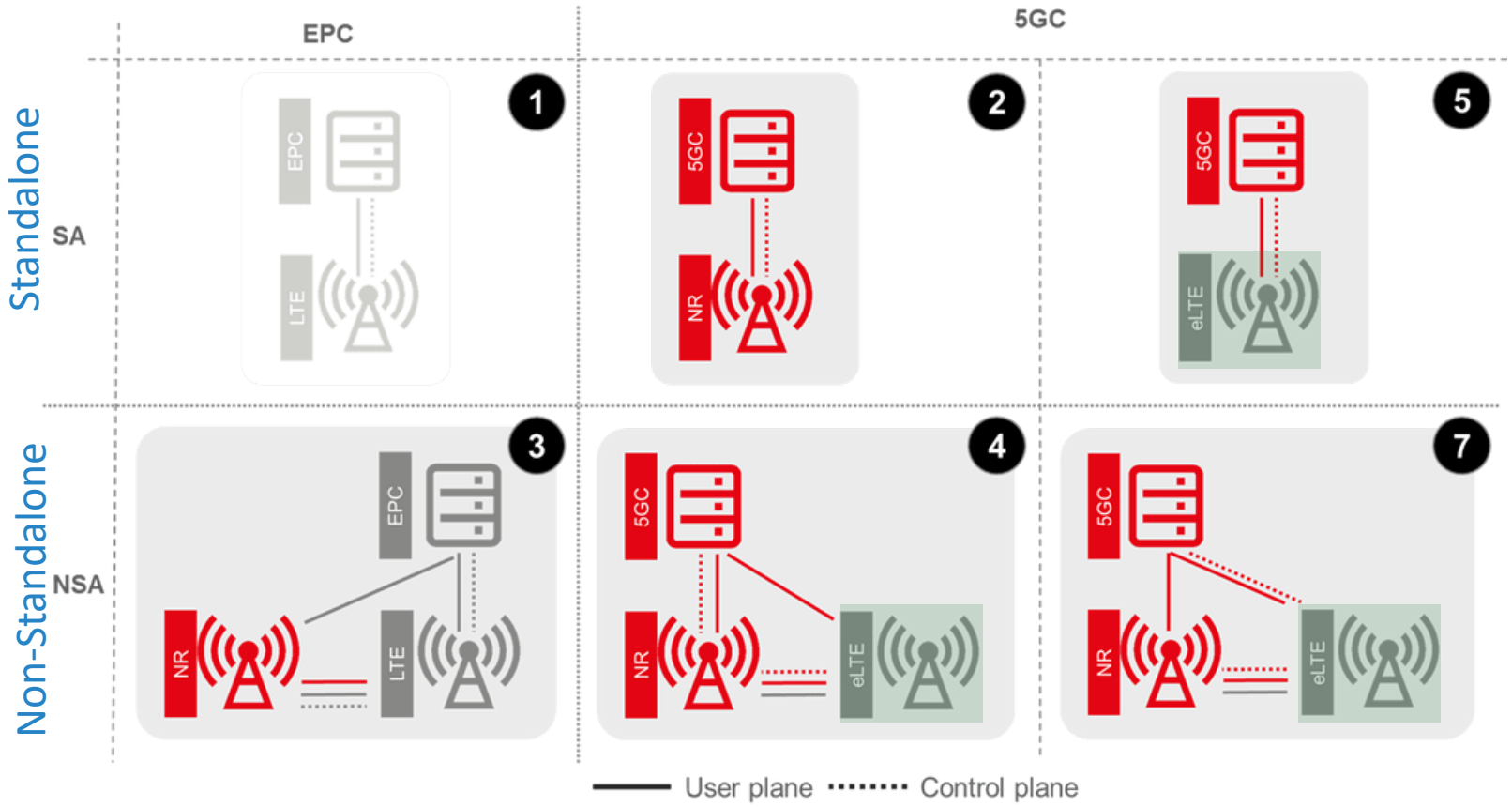
- Resource Type*
- Default Priority Level
- PDB
- PER
- Default Maximum Data Burst Volume
- Default Averaging Window

* GBR, non-GBR or delay critical GBR

5QI Value	Resource Type	Default Priority Level	Packet Delay Budget	Packet Error Rate	Default Maximum Data Burst Volume (NOTE 2)	Default Averaging Window	Example Services
1	GBR	20	100 ms (NOTE 11, NOTE 13)	10^{-2}	N/A	2000 ms	Conversational Voice
2	(NOTE 1)	40	150 ms (NOTE 11, NOTE 13)	10^{-3}	N/A	2000 ms	Conversational Video (Live Streaming)
3 (NOTE 14)		30	50 ms (NOTE 11, NOTE 13)	10^{-3}	N/A	2000 ms	Real Time Gaming, V2X messages Electricity distribution – medium voltage, Process automation - monitoring
4		50	300 ms (NOTE 11, NOTE 13)	10^{-6}	N/A	2000 ms	Non-Conversational Video (Buffered Streaming)
65 (NOTE 9, NOTE 12)		7	75 ms (NOTE 7, NOTE 8)	10^{-2}	N/A	2000 ms	Mission Critical user plane Push To Talk voice (e.g., MCPTT)
66 (NOTE 12)		20	100 ms (NOTE 10, NOTE 13)	10^{-2}	N/A	2000 ms	Non-Mission-Critical user plane Push To Talk voice
67 (NOTE 12)		15	100 ms (NOTE 10, NOTE 13)	10^{-3}	N/A	2000 ms	Mission Critical Video user plane
75 (NOTE 14)							
71		56	150 ms (NOTE 11, NOTE 13, NOTE 15)	10^{-6}	N/A	2000 ms	"Live" Uplink Streaming (e.g. TS 26.238 [76])
72		56	300 ms (NOTE 11, NOTE 13, NOTE 15)	10^{-4}	N/A	2000 ms	"Live" Uplink Streaming (e.g. TS 26.238 [76])
73		56	300 ms (NOTE 11, NOTE 13, NOTE 15)	10^{-8}	N/A	2000 ms	"Live" Uplink Streaming (e.g. TS 26.238 [76])
74		56	500 ms (NOTE 11, NOTE 15)	10^{-8}	N/A	2000 ms	"Live" Uplink Streaming (e.g. TS 26.238 [76])
76		56	500 ms (NOTE 11, NOTE 13, NOTE 15)	10^{-4}	N/A	2000 ms	"Live" Uplink Streaming (e.g. TS 26.238 [76])
5	Non-GBR	10	100 ms NOTE 10, NOTE 13)	10^{-6}	N/A	N/A	IMS Signalling
6	(NOTE 1)	60	300 ms (NOTE 10, NOTE 13)	10^{-6}	N/A	N/A	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
7		70	100 ms (NOTE 10, NOTE 13)	10^{-3}	N/A	N/A	Voice, Video (Live Streaming) Interactive Gaming
8		80	300 ms (NOTE 13)	10^{-6}	N/A	N/A	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive
9		90					video, etc.)
69 (NOTE 9, NOTE 12)		5	60 ms (NOTE 7, NOTE 8)	10^{-6}	N/A	N/A	Mission Critical delay sensitive signalling (e.g., MC-PTT signalling)
70 (NOTE 12)		55	200 ms (NOTE 7, NOTE 10)	10^{-6}	N/A	N/A	Mission Critical Data (e.g. example services are the same as 5QI 6/8/9)
79		65	50 ms (NOTE 10, NOTE 13)	10^{-2}	N/A	N/A	V2X messages
80		68	10 ms (NOTE 5, NOTE 10)	10^{-6}	N/A	N/A	Low Latency eMBB applications Augmented Reality
82	Delay Critical GBR	19	10 ms (NOTE 4)	10^{-4}	255 bytes	2000 ms	Discrete Automation (see TS 22.261 [2])
83		22	10 ms (NOTE 4)	10^{-4}	1354 bytes (NOTE 3)	2000 ms	Discrete Automation (see TS 22.261 [2])
84		24	30 ms (NOTE 6)	10^{-5}	1354 bytes (NOTE 3)	2000 ms	Intelligent transport systems (see TS 22.261 [2])
85		21	5 ms (NOTE 5)	10^{-5}	255 bytes	2000 ms	Electricity Distribution-high voltage (see TS 22.261 [2])

5G-New Radio

Deployment options & protocol stack



5G Standardization: 3GPP Rel.15/16

EXAMPLE: the 5G NR

Release 15

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- Mission Critical (MC) interworking with legacy systems
- WLAN and unlicensed spectrum use
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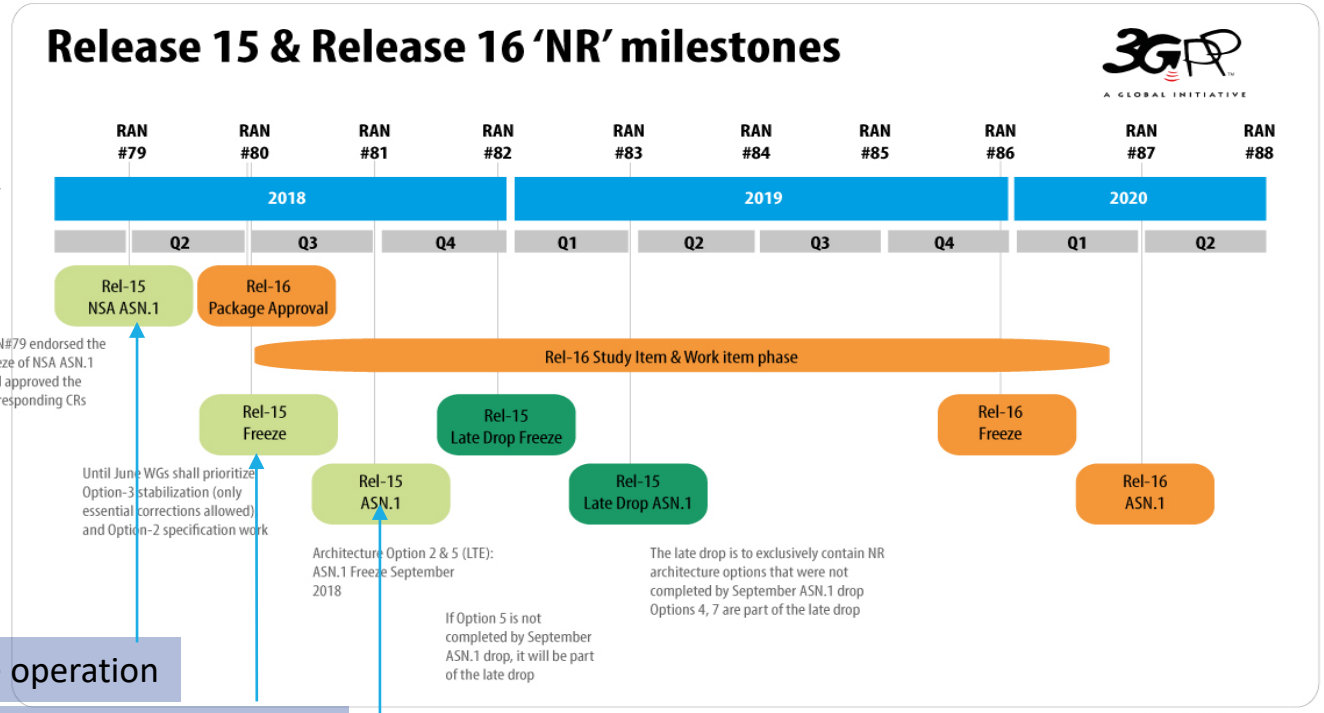


NR non-standalone operation

NR standalone operation

Specs 23.501 & 23.502

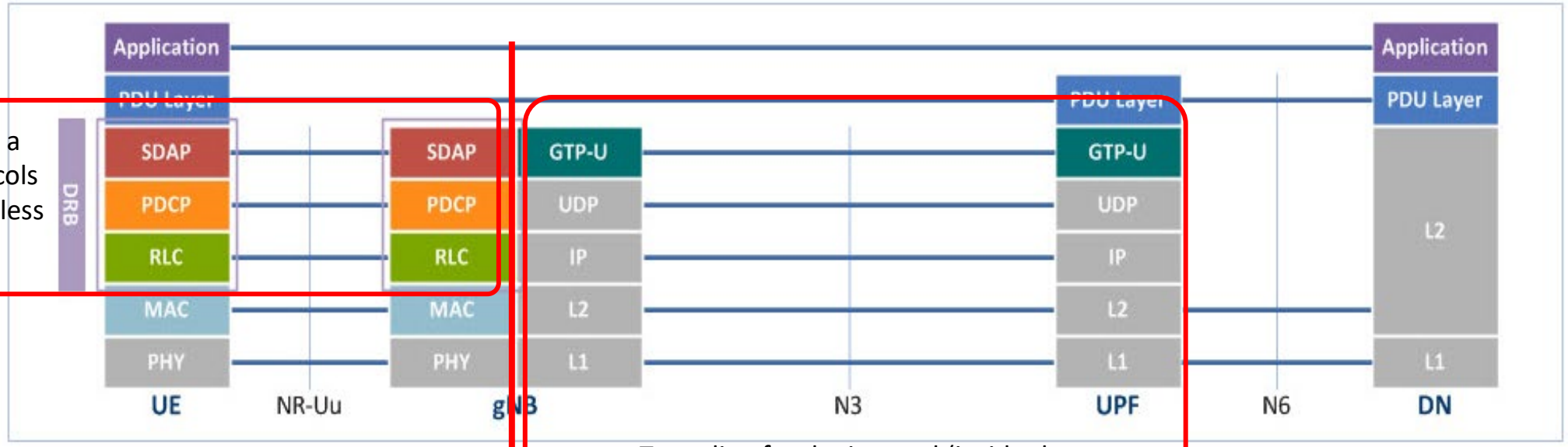
TS 23.501	System architecture for the 5G System (5GS)
TS 23.502	Procedures for the 5G System (5GS)

Understanding the 5G Protocol stack

Protocol stacks support Reception and Send process

- Different protocols can be used (gNB case) depending on the source / destination

The radio part includes a set of additional protocols for controlling the wireless link (SDAP/PDCP/RLC).

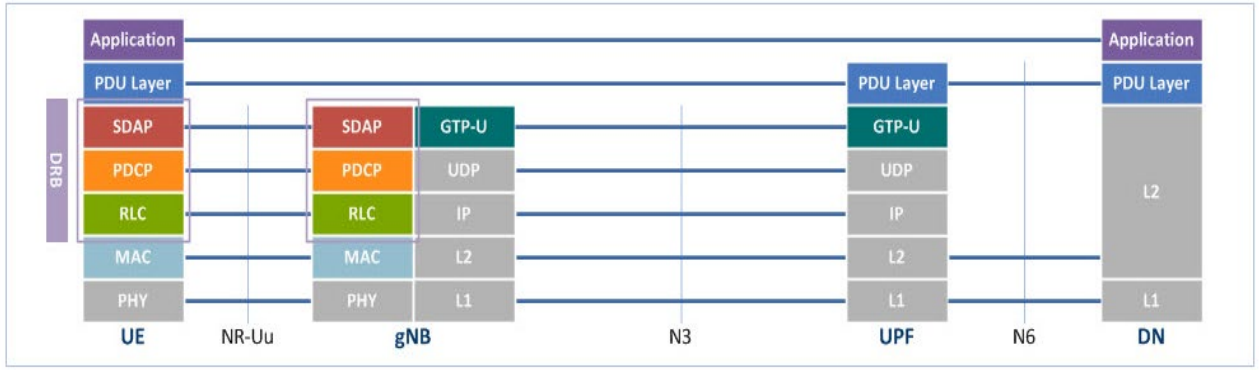


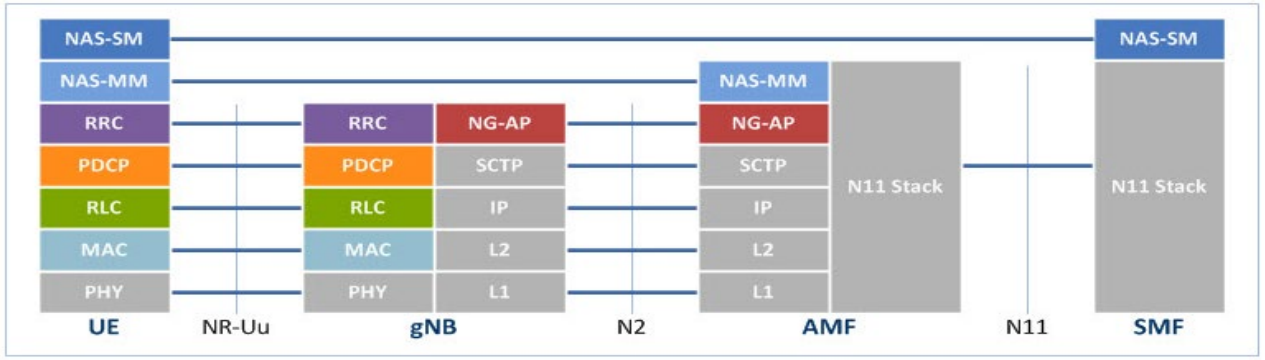
Tunneling for the internal (inside the operator's network) communications
-**GTP tunneling**-

Understanding the 5G Protocol stack

Protocol stacks support Reception and Send process

- Different protocols can be used (UE, gNB, AMF etc case) depending on the type of data exchanged





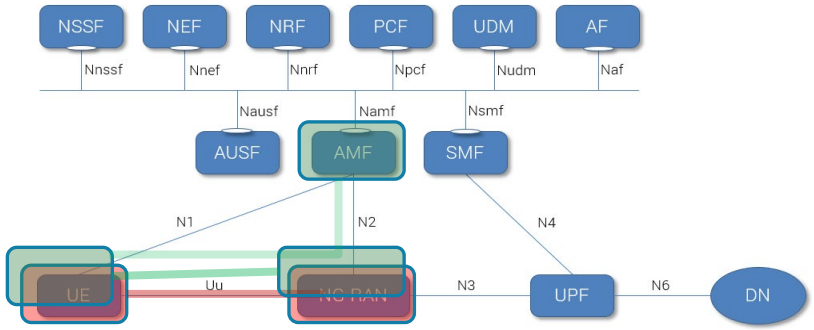
User Plane

- Type of data is the user's actual data
- The set of communicating nodes includes nodes outside the operator's network e.g., the internet / data network

Control Plane

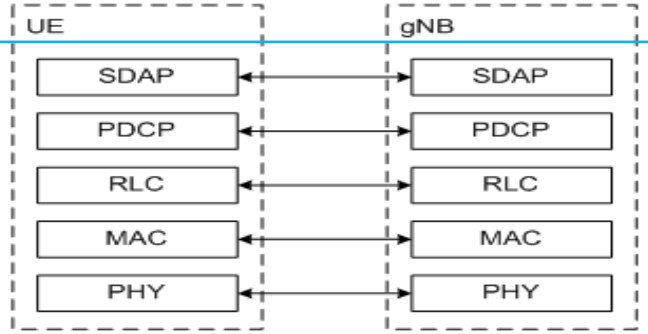
- Type of data is signaling or controlling message
- All the communicating nodes are internal to the operator's network

5G New Radio (Protocol Stack)

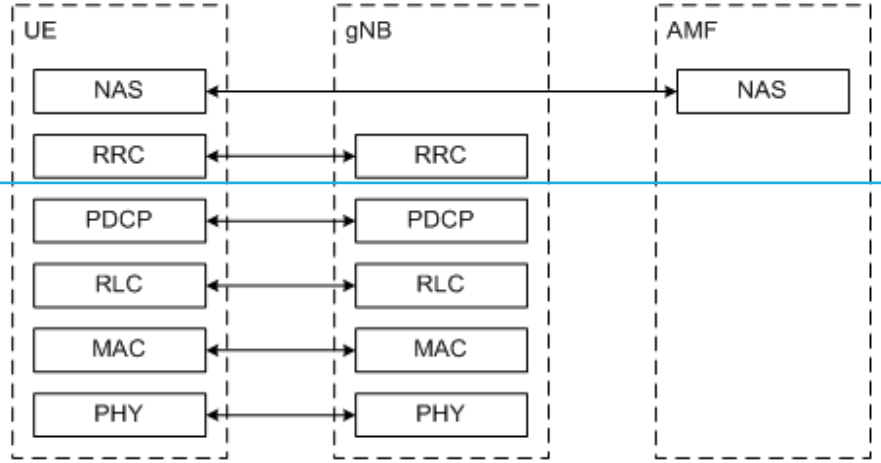


Layer 3

Layer 2



User Plane



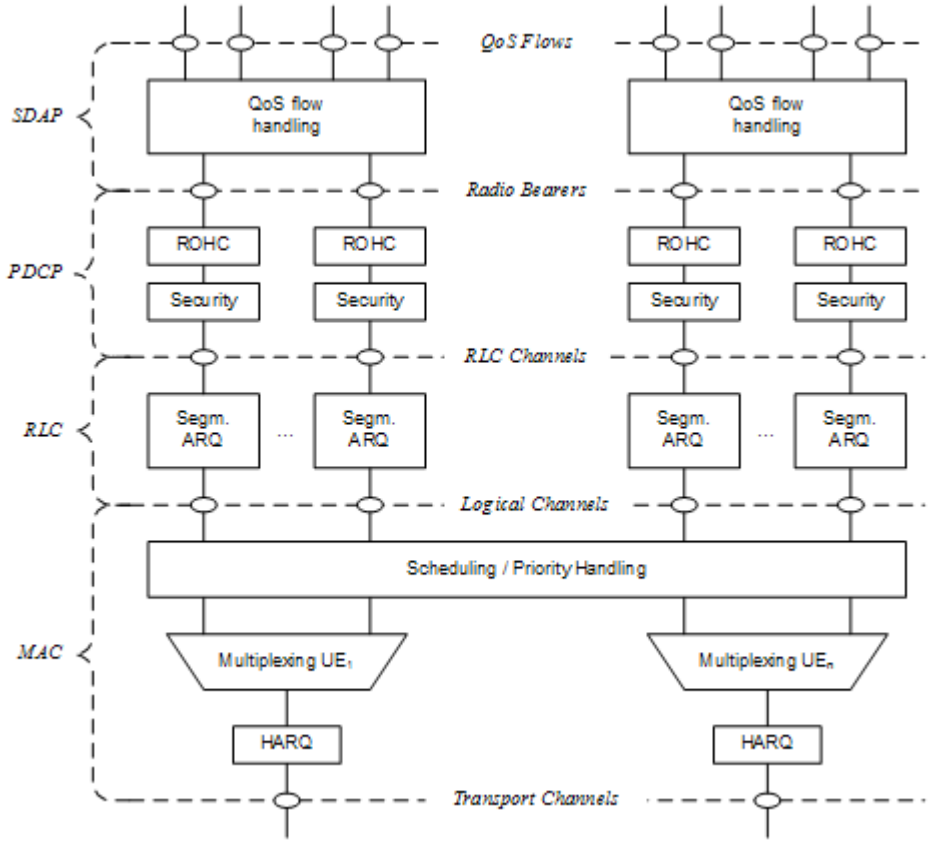
Control Plane

*3GPP has released specification 38.300 V1

5G New Radio (Protocol Stack – Layer 2)

The layer 2 of NR is split into the following sub layers:

- Service Data Adaptation Protocol (SDAP)
- Packet Data Convergence Protocol (PDCP)
- Radio Link Control (RLC)
- Medium Access Control (MAC)



PHY

Frequency bands: 700 MHz, 2 GHz, 3400 – 3800 MHz και 26 GHz

Frequency Range 1 (FR1), including sub-6 GHz frequency bands
Frequency Range 2 (FR2), including frequency bands in (24–100GHz)

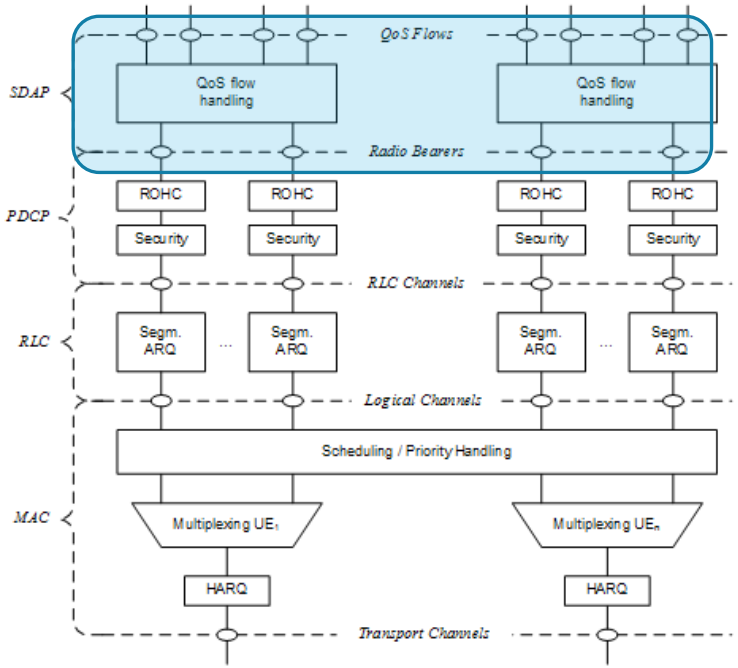
Bandwidth: up to 100MHz (20MHz was in 4G)

5G New Radio (Protocol Stack – Layer 2)

SDAP (Service Data Adaptation Protocol)

- ***New protocol introduced in 5G-NR***
- **Mapping** between a QoS flow and a data radio bearer
- **Marking** QoS flow ID (QFI) in both DL and UL packets

(This protocol is transparent for the control plane flows)



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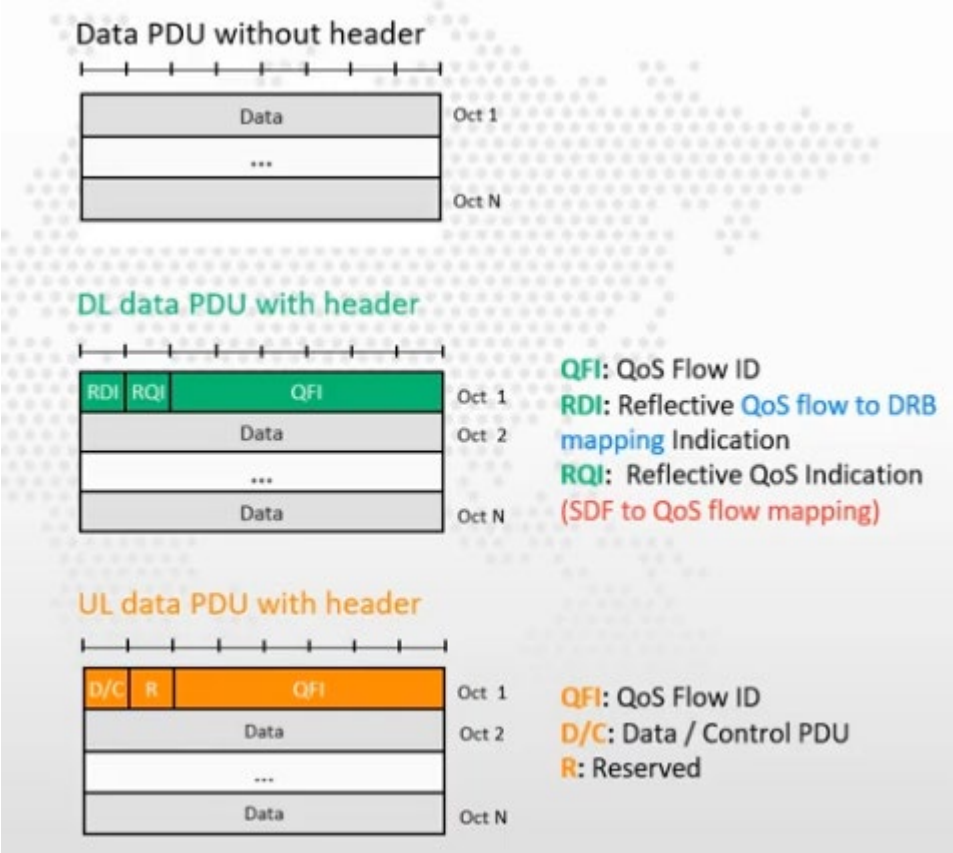


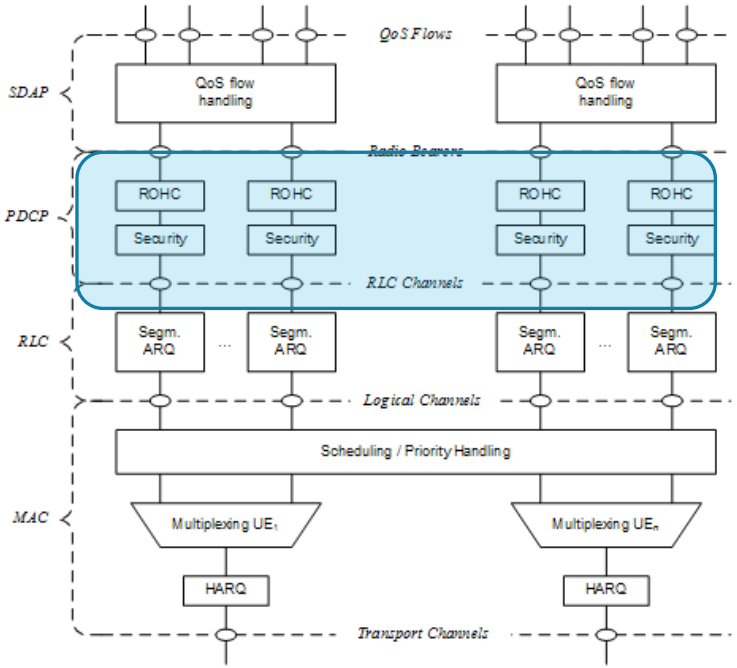
5G New Radio (Protocol Stack – Layer 2)

PDCP (Packet Data Convergence Protocol)

- Sequence Numbering
- Header compression and decompression: ROHC
- Transfer of user data
- Reordering and Duplicate detection
  - (if in order delivery to layers above PDCP is required)
- ***PDCP PDU routing (in case of split bearers)***
- Retransmission of PDCP SDUs
- Ciphering and Deciphering
- PDCP SDU discard
- PDCP re-establishment and data recovery for RLC AM
- Duplication of PDCP PDUs

(subset of the functionality for the Control plane flows)

- Sequence Numbering;
- Ciphering, deciphering and integrity protection;
- Transfer of control plane data;
- Duplicate detection;
- Duplication of PDCP PDUs.



5G New Radio (Protocol Stack – Layer 2)

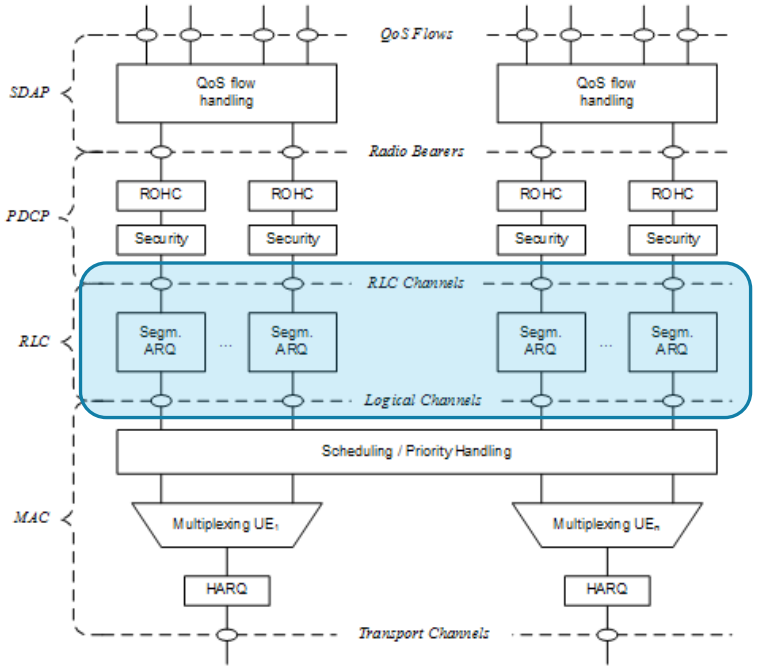
RLC (Radio Link Control)

Acknowledge Mode (AM) **Un-ack Mode (UM)**

- RLC Header Added : Yes
- Buffering: Buffering done both at Transmission and Reception
- Functionality: Segmentation done at TX and Reassembly at RX side
- Radio Bearers or Info usage: SRB1/SRB2/SRB3 and DRBs
- Feedback Mechanism (ARQ): Feedback mechanism

Transparent Mode (TM)

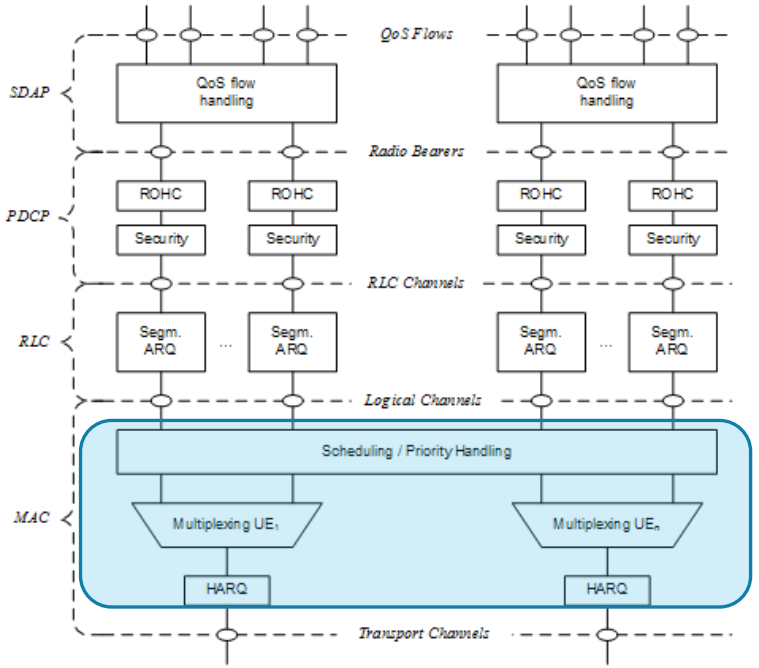
- Radio Bearers or Info usage: SRB0



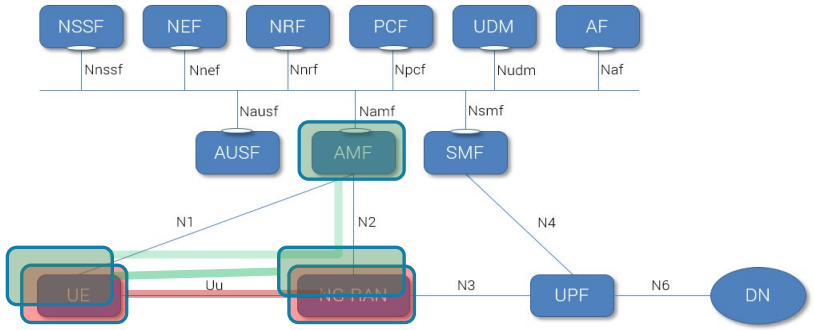
5G New Radio (Protocol Stack – Layer 2)

MAC (Media Access Control)

- 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**
- Priority handling between UEs by means of dynamic scheduling
- Priority handling between logical channels of one UE by means of **logical channel prioritization**
- Padding

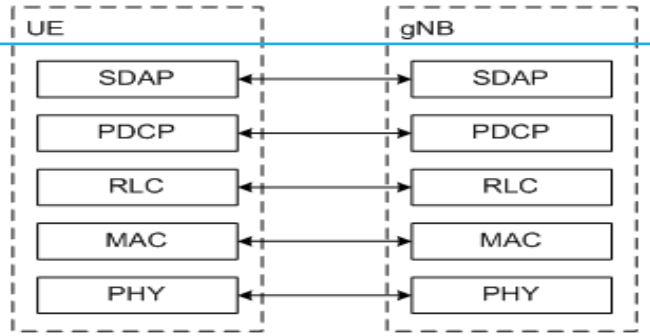


5G New Radio (Protocol Stack)

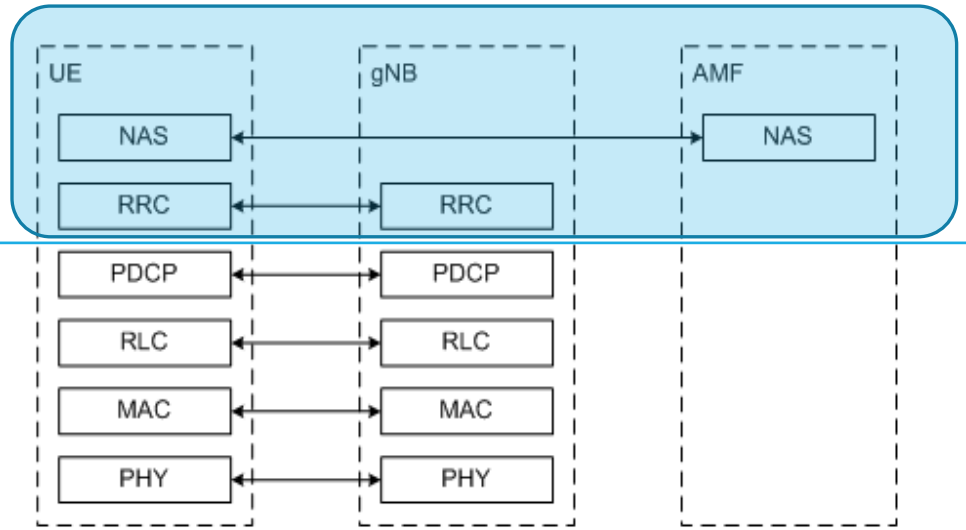


Layer 3

Layer 2



User Plane



Control Plane

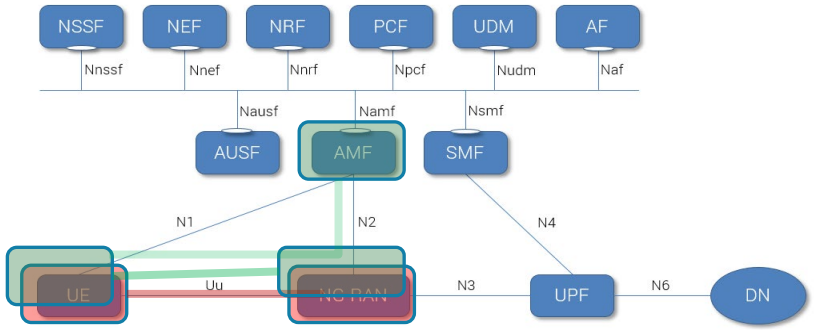
*3GPP has released specification 38.300 V1

5G New Radio (Protocol Stack – Layer 3)

The main services and functions of the NAS/RRC sub layer 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 Signaling 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.

5G New Radio (Protocol Stack)



Layer 3

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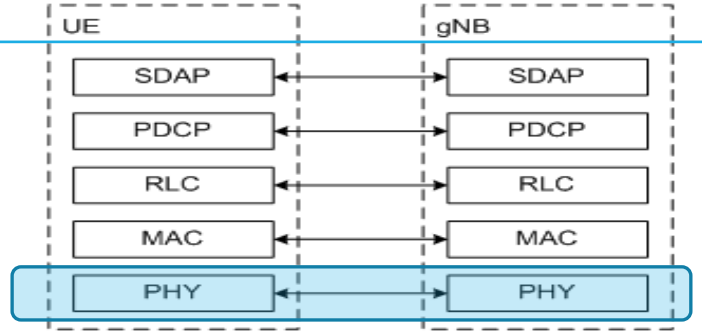
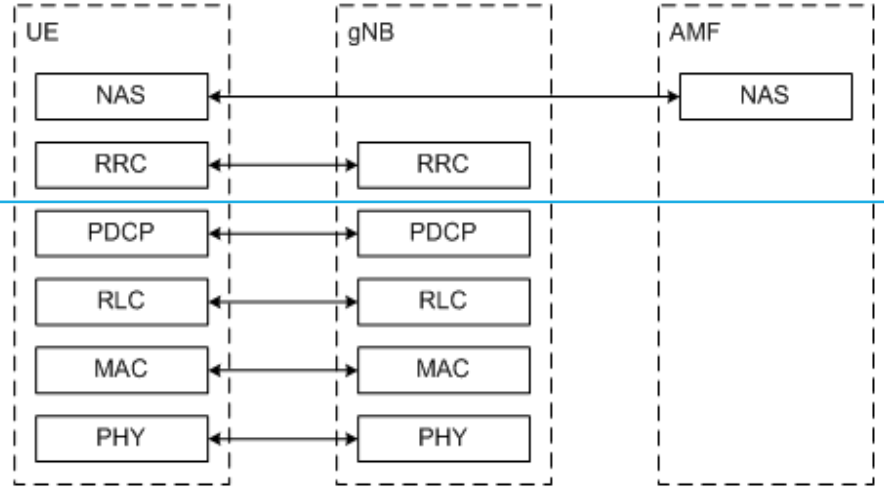


User Plane



Control Plane

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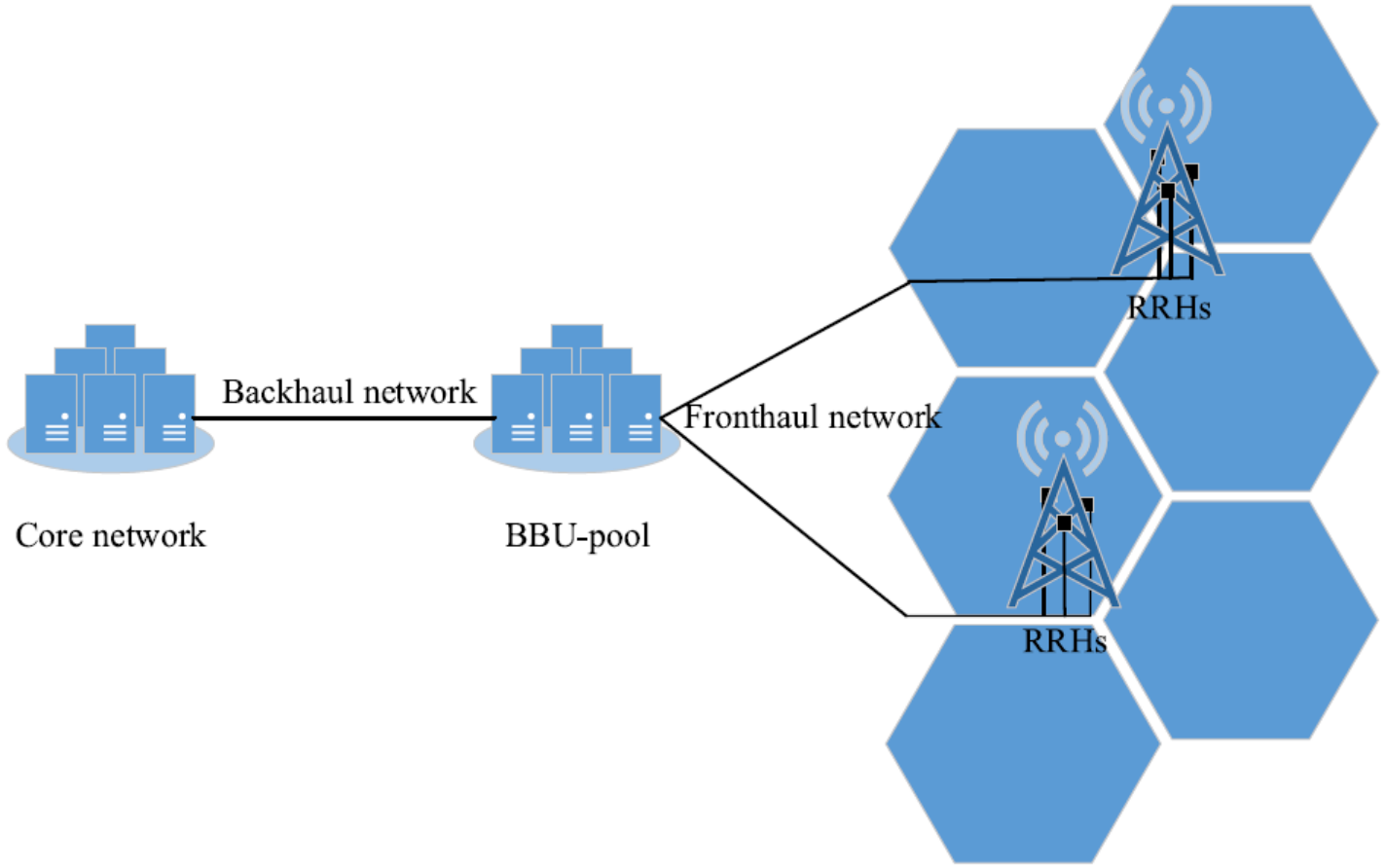
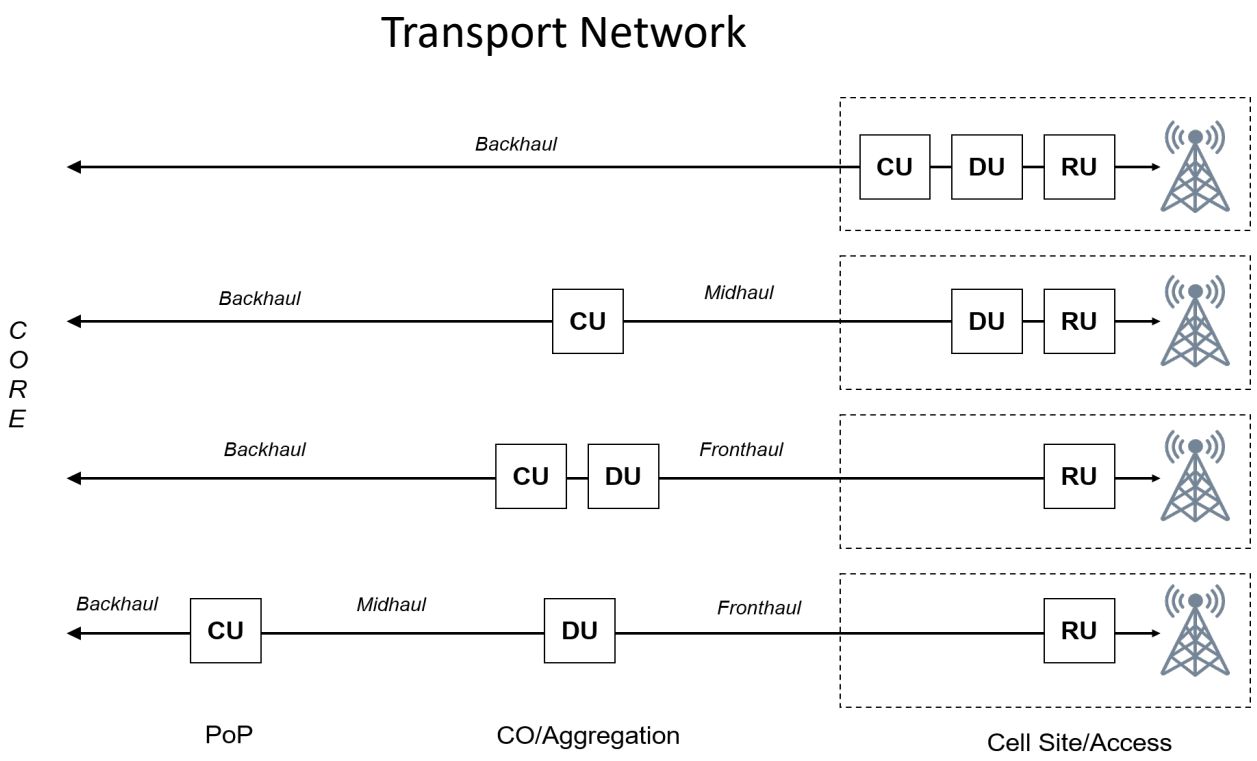
Functional Split

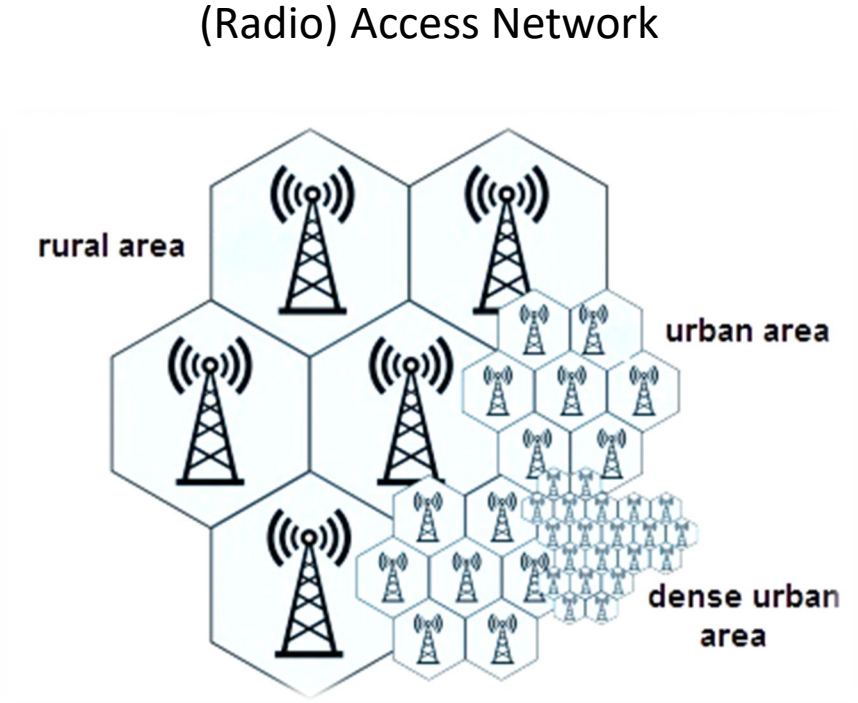
- The main challenge refers to the layer of the RAN protocol stack where the split is performed



*A Survey of the Functional Splits Proposed for 5G Mobile Crosshaul Networks, IEEE Comm Surveys & Tutorials 2019

Horizontal view
Understanding the topology of a Mobile network





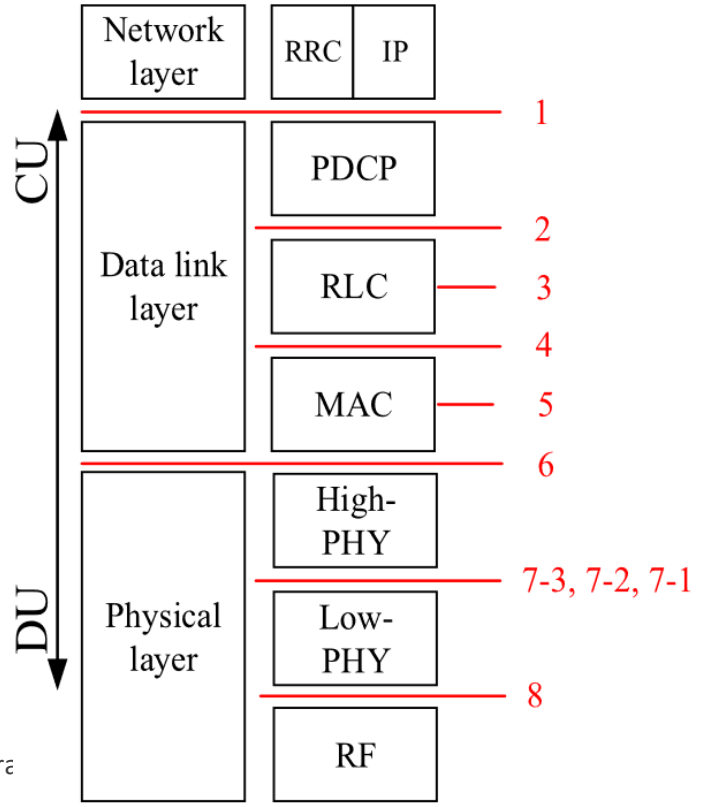
Functional Split

Functional split options w.r.t the RAN layers

- Data link layer options
- Physical layer options

Definition of the interfaces by 3GPP: TR 38 801*

Other definitions: eCPRI**, NGMN***



*Study on new radio access technology: Radio access architecture and interfaces, V14.0.0 (2017–03),” 3GPP, Sophia Antipolis, Fra

**Common Public Radio Interface: http://www.cpri.info/downloads/eCPRI_v_1_1_2018_01_10.pdf

***Further study on critical C-RAN technologies, version 1.0,” NGMN, Frankfurt, Germany, White Paper, Mar. 2015

Functional Split

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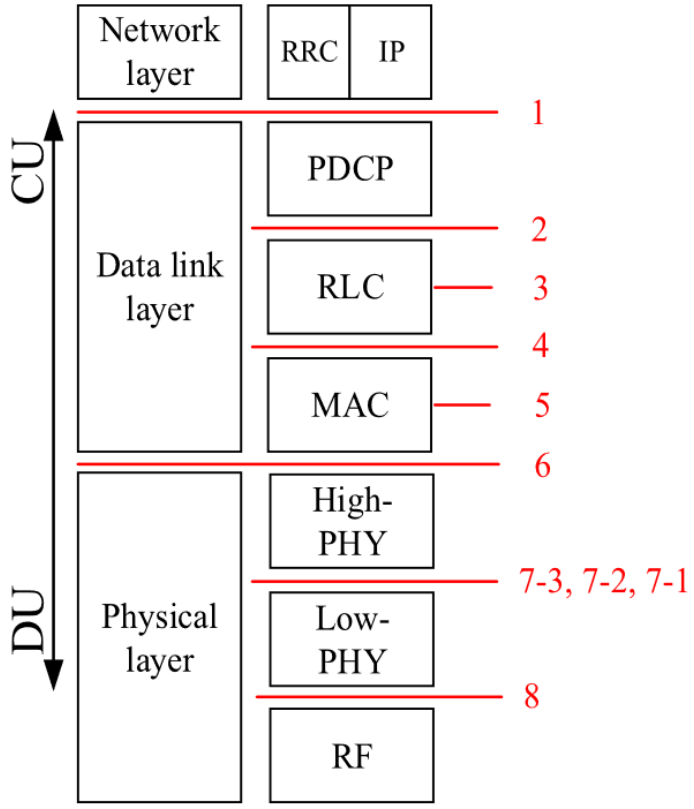
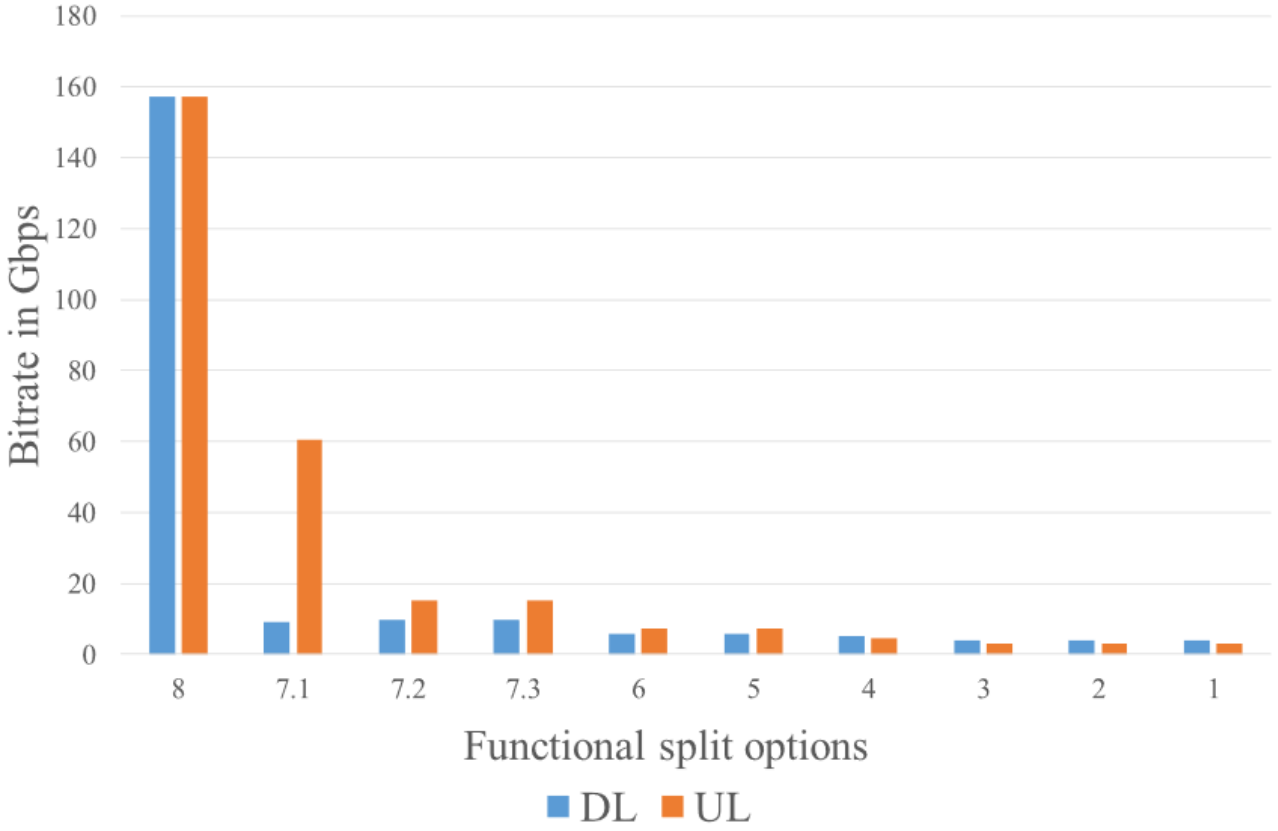
OVERVIEW OF THE MAX NUMBER OF DUS SUPPORTED BY DIFFERENT SIZES OF FRONTHAUL CAPACITY

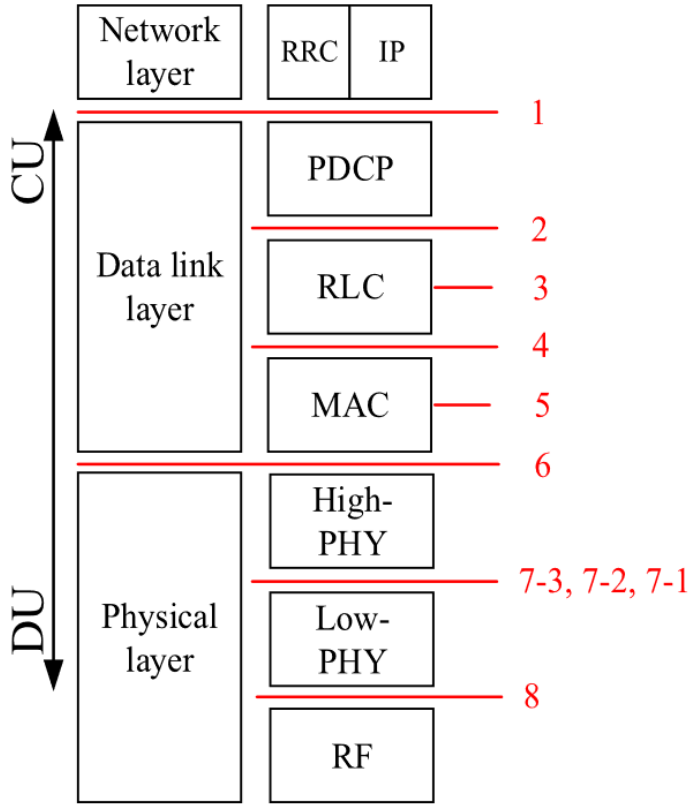
	Option 8	Option 7-1	Option 7-2	Option 7-3	Option 6	Option 5	Option 4	Option 3	Option 2	Option 1
Gb E	0	0	0	10	20	20	20	20	20	20
10 Gb E	5	10	135	235	220	135	230	235	240	240
100 Gb E	40	100	1355	2395	2210	2330	2395	2405	2405	2410

*A Survey of the Functional Splits Proposed for 5G Mobile Crosshaul Networks, IEEE Comm Surveys & Tutorials 2019



Functional Split





M. Agiwal, A. Roy, and N. Saxena, "Next generation 5G wirelessnetworks: A comprehensive survey,"IEEE Commun. Surveys Tuts.,vol. 18, no. 3, pp. 1617–1655, 3rd Quart., 2016.

Take-aways

- API exposure is performed with CAPIF support
- QoS Enforcement
  - QFI concept
  - Network slice selection during the PDU session set up
- 5G New Radio (NR)
  - Deployment options: SA / NSA
  - SDAP protocol is added to realize filtering of 5G quality flows to DRB
  - The protocols stack is Slitted to allow central management of radio flows (concept of functional split)