EURECOM

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5G Core Network

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MobSys

INTRODUCTION

5G Introduction - definition

- 5G is an end-to-end ecosystem to enable a fully mobile and connected society
  - empowers value creation towards customers and partners, through existing and emerging use cases,
  - delivered with consistent experience, and enabled by sustainable business models.
  - support vertical use-cases

5G key challenges

5G key Challenges

- **x1000** data **volume** / geographical area
- **x10** lower **energy** consumption
- Very **shot service creation time** cycle (i.e. minutes)
- **Very short latency**
- Very **dense deployments of wireless** links
- **Scalable & Cognitive** management framework for fast deployment
- **OPEX reduction** management framework for fast deployment
- Multi domain virtualized networks and services
- **Complete network convergence** (fixed, backhaul, satellite)

Why?

Broadband access in dense areas	Broadband access everywhere	Higher user mobility	Massive Internet of Things
PERVASIVE VIDEO 	50+ MBPS EVERYWHERE 	HIGH SPEED TRAIN 	SENSOR NETWORKS 

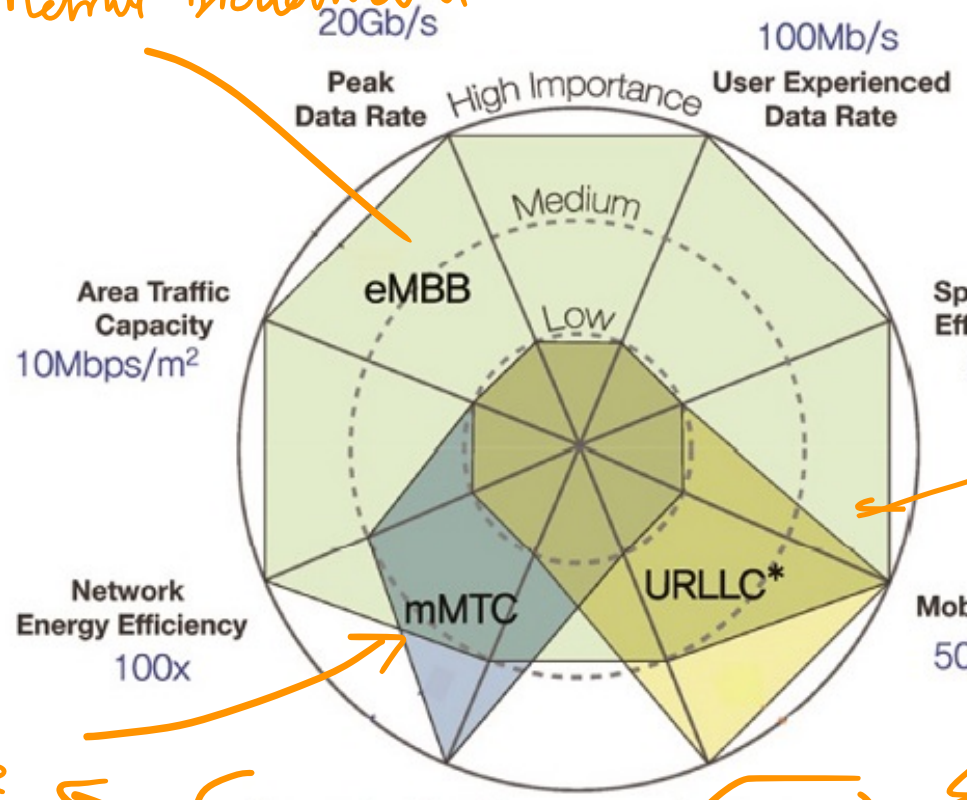
Challenge	**Data Rate**	**UBIQUITOUS COVERAGE QUALITY**	**Mobility**	**Connectivity Density**
Other Usecases	Cloud Service Smart Office AR/VR	Ultra-low Cost networks	Moving HotSpots Remote Computing	Smart wearables Smart Grid Mobile video surveillance

Why?

Extreme real-time communications	Lifeline communications	Ultra-reliable communications	Broadcast-like services
TACTILE INTERNET	NATURAL DISASTER	E-HEALTH SERVICES	BROADCAST SERVICES
			

Challenge	**Latency**	**Availability**	**Reliability** **Latency**	**Reachability** **Connectivity**
Other Usecase	Industry automation	Earthquakes	Automated driving Collaborative robots Remote operation Public safety	News / information Reginal and national services

5G Services


20Gb/s
Peak
Data Rate
High Importance
100Mb/s
User Experienced
Data Rate
Medium
Low
eMBB
Area Traffic
Capacity
10Mbps/m²
Spectrum
Efficiency
3x
mMTC
URLLC*
Network
Energy Efficiency
100x
Mobility
500km/h
Connection Density
10⁶devices/km²
Latency
1msec

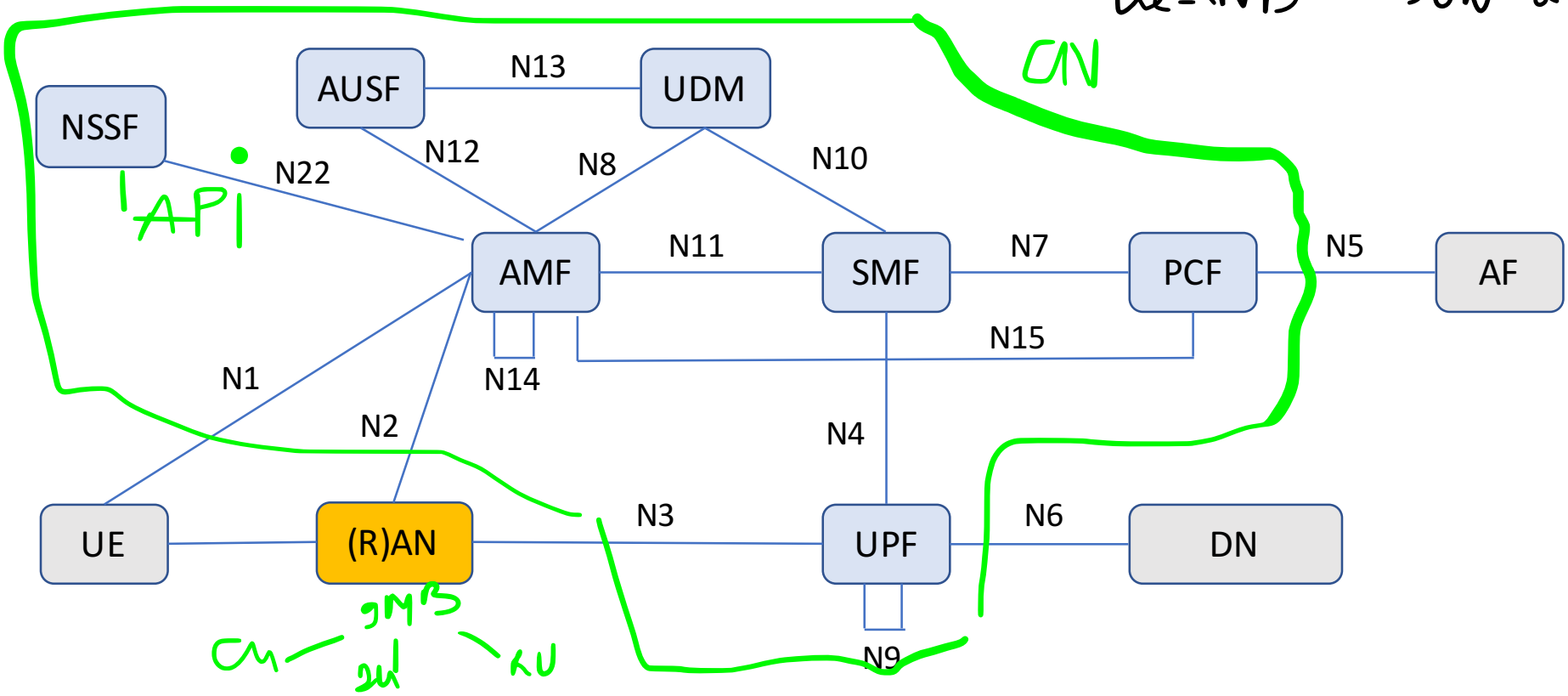
5G vs LTE: Main Physical Layer Differences

	LTE	5G
Use cases	Mobile broadband access (MTC later)	More use cases: eMBB, mMTC, uRLLC
Latency	around 10 ms	< 1ms
Band	Below 6 Ghz	Up to 60 Ghz
Bandwidth	Up to 20 Mhz	Up to 100 Mhz below 6Ghz Up to 400 Mhz above 6 Ghz
Subcarrier spacing	Fixed	Variable
Freq allocation	UEs need to decode the whole bandwidth	Use of bandwidth parts

IoT

5G ARCHITECTURE CORE NETWORK

5G Architecture (Point to point)



AUSF: Authentication Server Function

AF: Application Function

AMF: Acces and Mobility Management Function

DN: Data Network

NSSF: Network Slice Selection Function

SMF: Session Management Function

PCF: Policy Control Function

UDM: Unified Data Management

UPF: User Plane Function

Relation between the 4G and 5G equipments

5G: Divide the monolithic element into smaller Network Function Block

AMF: Access and Mobility management Function
SMF: Session Management Function

User Plane

P-GW

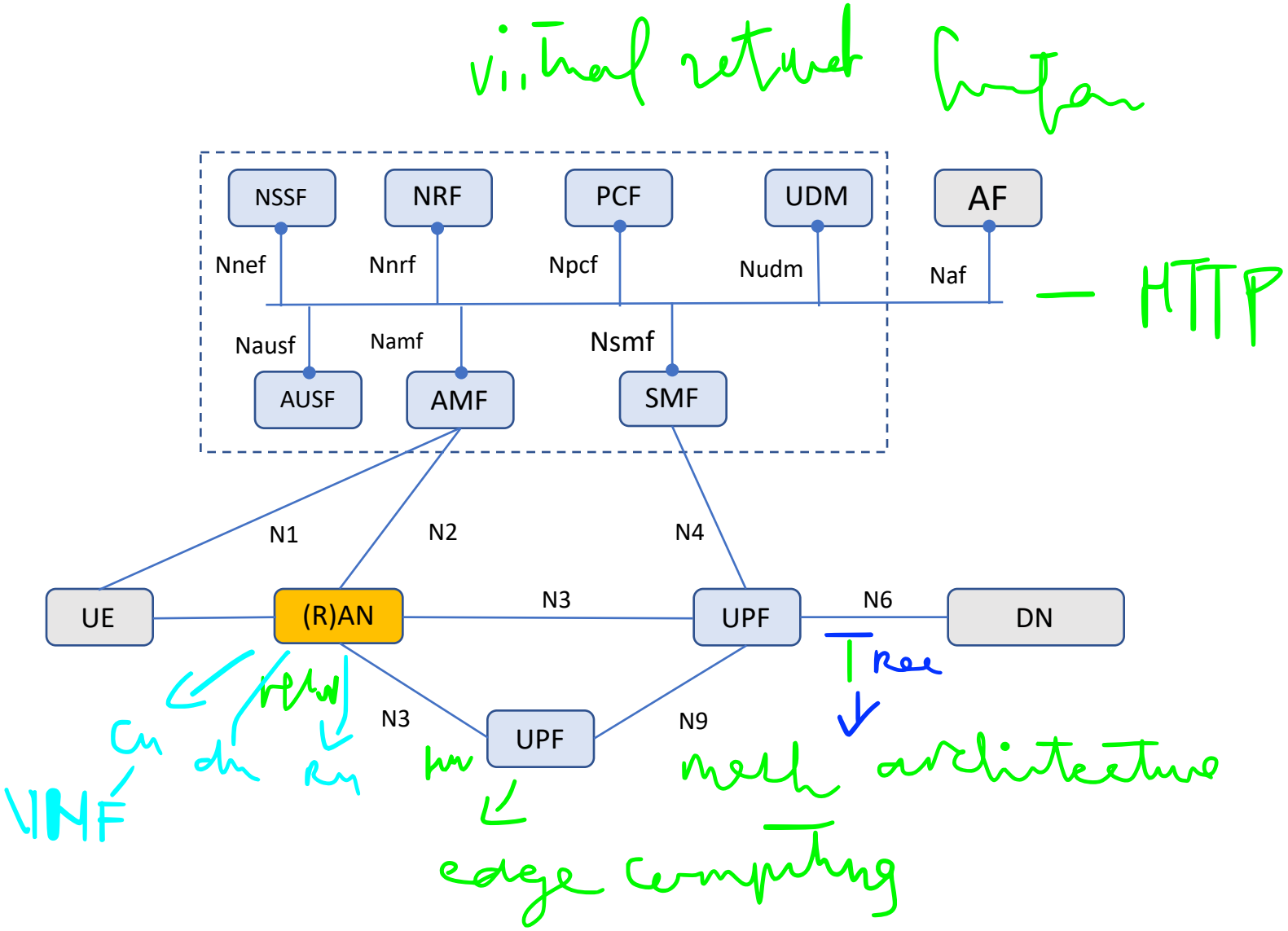
SMF: Session Management Function - P/SGW-C
UPF: User Plane Function - P/SGW-U

Vector

AUSF: Authentication Service Function
UDM: Unified Data Management
UDR: Unified Data Repository

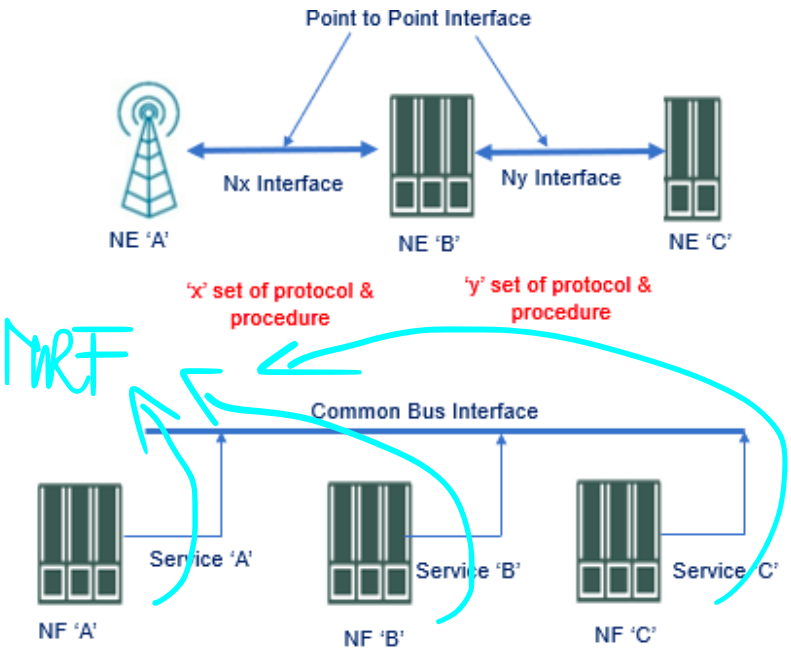
data base

5G Architecture service-based (communication bus)



Advantages of a service-based architecte

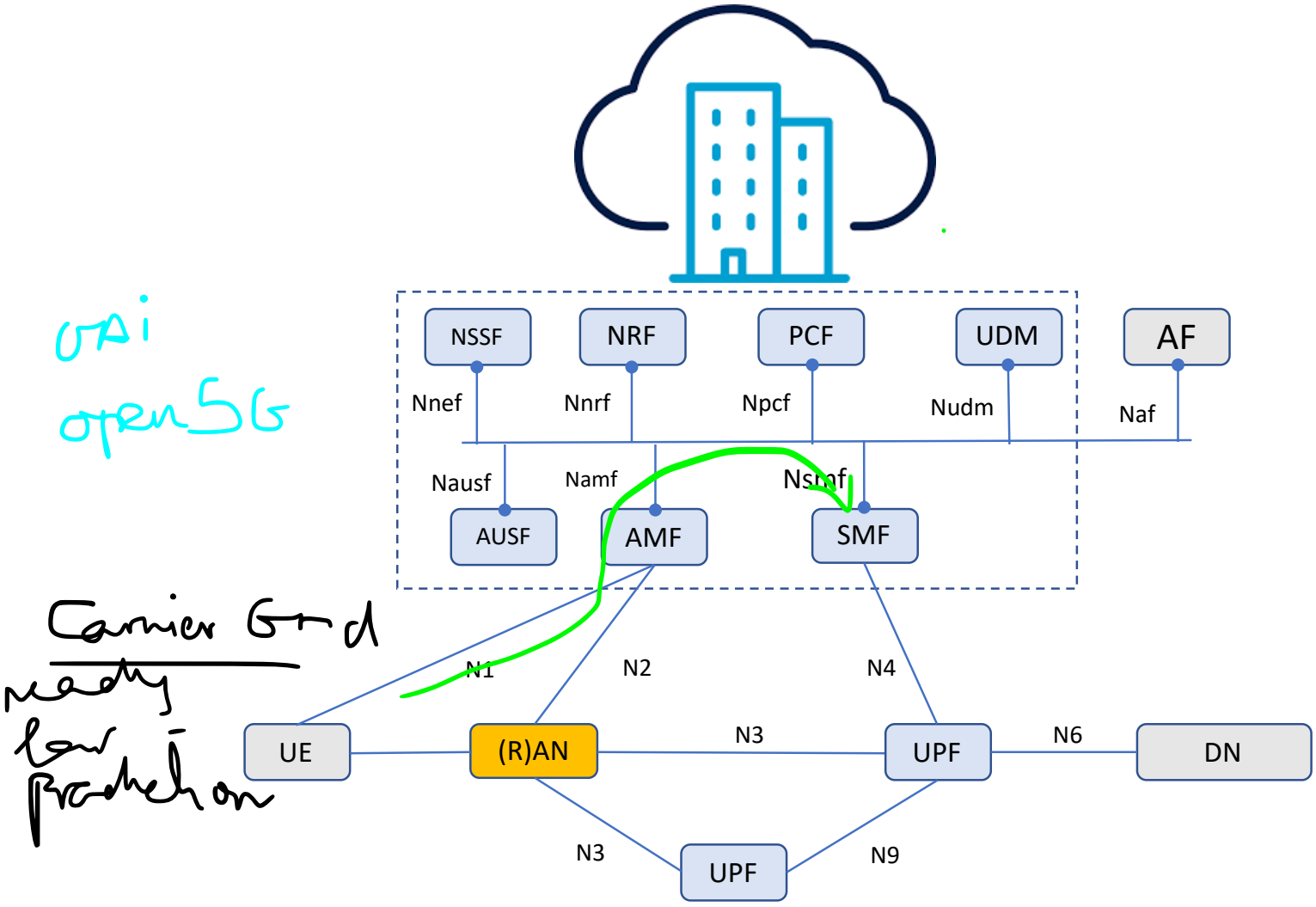
- Service-based architecture is based on a set of Network Functions (NFs)
- Communication among NFs to be like a service mesh functions rather than serial chaining,
- NFs provides services to other NFs Service Base Interface (SBI)
- Reference Point interface is replaced by a common bus to connect all NFs
- Advantages
  - Reduction in dependency between each interface
  - Independent scaling of each function.
  - Agility of having new features and services across network functions is increased.



Network Function

- Network Function (NF) – a functional building block within a network infrastructure, which has well-defined external interfaces and a well-defined functional behavior.
  - In practical terms, a Network Function is often a physical or a virtual appliance.
- Enable stateless NF by separating the control from the data
  - In 5G, Unified Data Repository (UDR)
- Network Function Virtualization (NFV) is about separating software running network functions from hardware
  - Run Virtual Network Function (VNF) over commercial-off-the-shelf (COTS) hardware
  - VNF can run on top of a Virtual Machine (VM), container (Linux container - LXC, or Docker)
  - VNFs are hosted in public or private cloud

Virtual 5G Core Network



Access and Mobility management Function (AMF)

- The AMF functions:
  - Termination of RAN control plane interface (N2) and NAS (N1)
  - Ciphering and integrity protection of NAS messages
  - Registration management
  - Connection management
  - Mobility management
  - Transport of session messages between UE and SMF
  - Access authentication and authorization

Session Management Function (SMF)

- The SMF functions:
  - Handle session management (session establish, modification, and release)
  - UE IP address allocation and management
  - Selection and control of UPF User Plane Function
  - Traffic steering configuration at UP to route traffic to the proper destination
  - Termination of interfaces toward Policy Control Function (PCF)
  - Control part of policy enforcement and QoS

Authentication Service Function (AUSF) and Unified Data Management (UDM)

- AUSF: Performs authentication process with the user terminals
- UDM:
  - Generation of 3GPP authentication and key agreement (AKA) authentication credentials
  - User identification handling
  - Access authorization based on subscription data
  - UE's serving NF registration management
  - Subscription management and SMS management
  - Use data stored in the Unified Data Repository (UDR)
    - A stateful form stores data locally to where the UDM is running.
    - A stateless form stores data in a unified data repository (UDR).
  - No storage is needed; the UDM implements only the application logic.

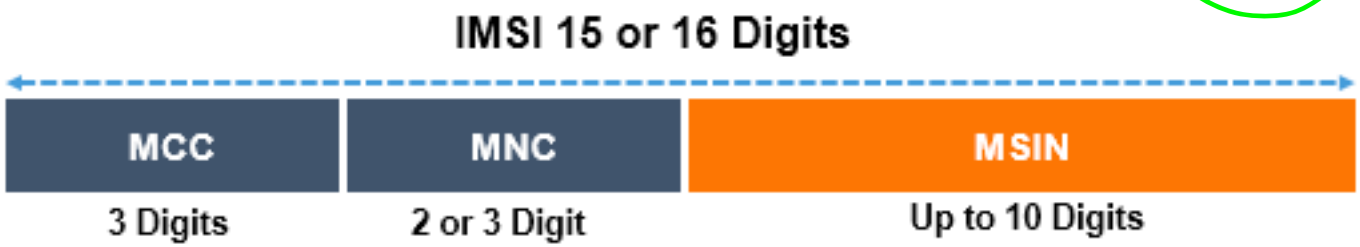
subscribers database

User Plan Function (UPF)

- The UPF functions:
  - Packet routing and 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
  - QoS handling for user plane (packet filtering, gating, and UL/DL rate enforcement)
  - Uplink traffic verification (SDF to QoS flow mapping)

UE Identifier: SUbscription Permanent Identifier (SUPI)

- Each subscriber in the 5G system is assigned a 5G SUPI
- SUPI value is provisioned in USIM and UDM (UDR)
- SUPI can be
  - An IMSI (International Mobile Subscriber Identity)
  - NAI (Network Access Identifier) NAI (Network Access Identifier) as defined in RFC 4282 based user identification
- SUPI is a string of 15 digits



UE Identifier: Subscription Concealed Identifier (SUCI)

- SUCI is a privacy preserving identifier containing the concealed SUPI.
- A UE generates a SUCI using a ECIES-based protection scheme with the public key of the Home Network that was securely provisioned to the USIM during the USIM registration.
- Only the MSIN part of the SUPI gets concealed by the protection scheme
  - The home network identifier i.e. MCC/MNC are transmitted in plain-text.

SUCI format

Subscription Concealed Identifier - SUCI

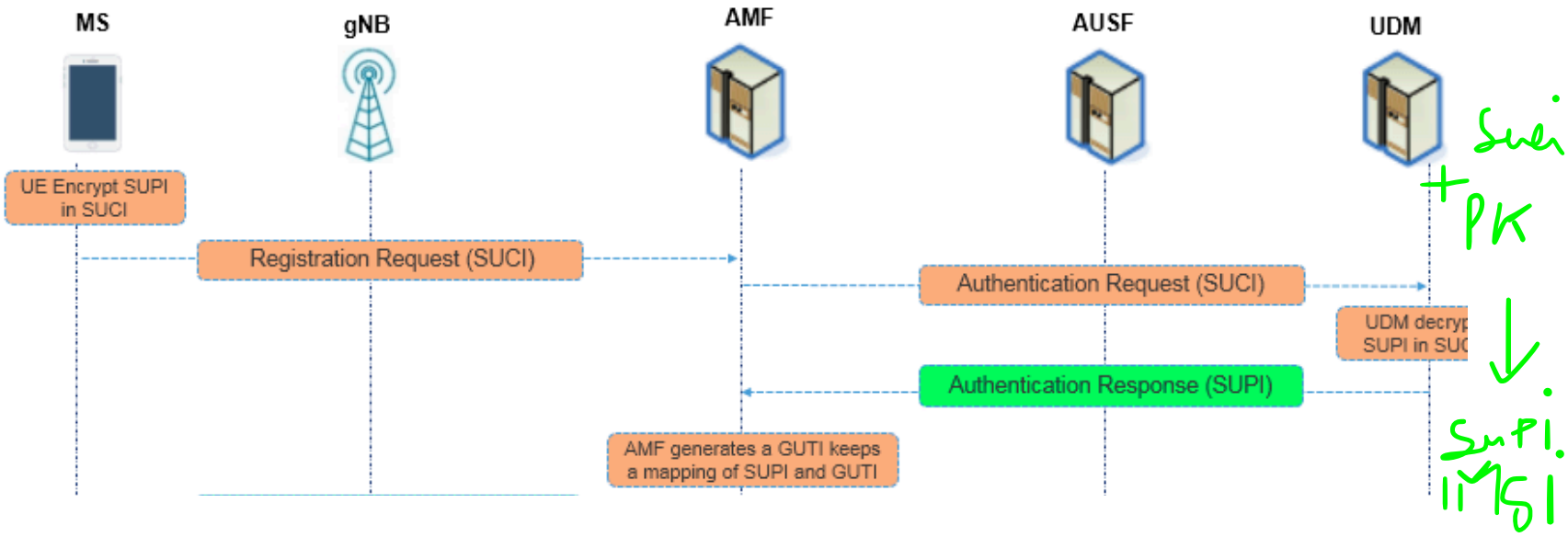
SUCI Type	Home Network identifier	Routing Indicator	Protection Scheme	Home Network Public Key ID	Protection Scheme Output
Value 0-7	Value Depend on SUPI Type	1-4 Digits	Value 0-15	Value 0-255	Output Depend on Scheme used

- SUPI Type: consisting in a value in the range 0 to 7. It identifies the type of the SUPI concealed in the SUCI. The following values are defined
  - 0: IMSI
  - 1: Network Access Identifier (NAI)
  - 2 to 7: spare values for future use.
- Home Network Identifier: identifying the home network of the subscriber. When the SUPI Type is an IMSI, the Home Network Identifier is composed of MCC and MNC. When the SUPI type is a Network Access Identifier, the Home Network Identifier consists of a string of characters with a variable length representing a domain name. e.g. user@toperator.com
- Routing Indicator: It is consist of 1 to 4 decimal digits assigned by the home network operator and provisioned within the USIM.
- Protection Scheme Identifier: It is consist of a value in the range of 0 to 15 and represented with 4 bits
  - null-scheme 0x0
  - Profile <A> 0x1
  - Profile <B> 0x2
- Home Network Public Key Identifier: It is consist of a value in the range 0 to 255. It represents a public key provisioned by the HPLMN and it is used to identify the key used for SUPI protection. In case of null-scheme being used, this data field shall be set to the value as 0
- Protection Scheme Output : It is consist of a string of characters with a variable length or hexadecimal digits, dependent on the used protection scheme

UE Identifie: 5G Global Unique Temporary Identifier (GUTI)

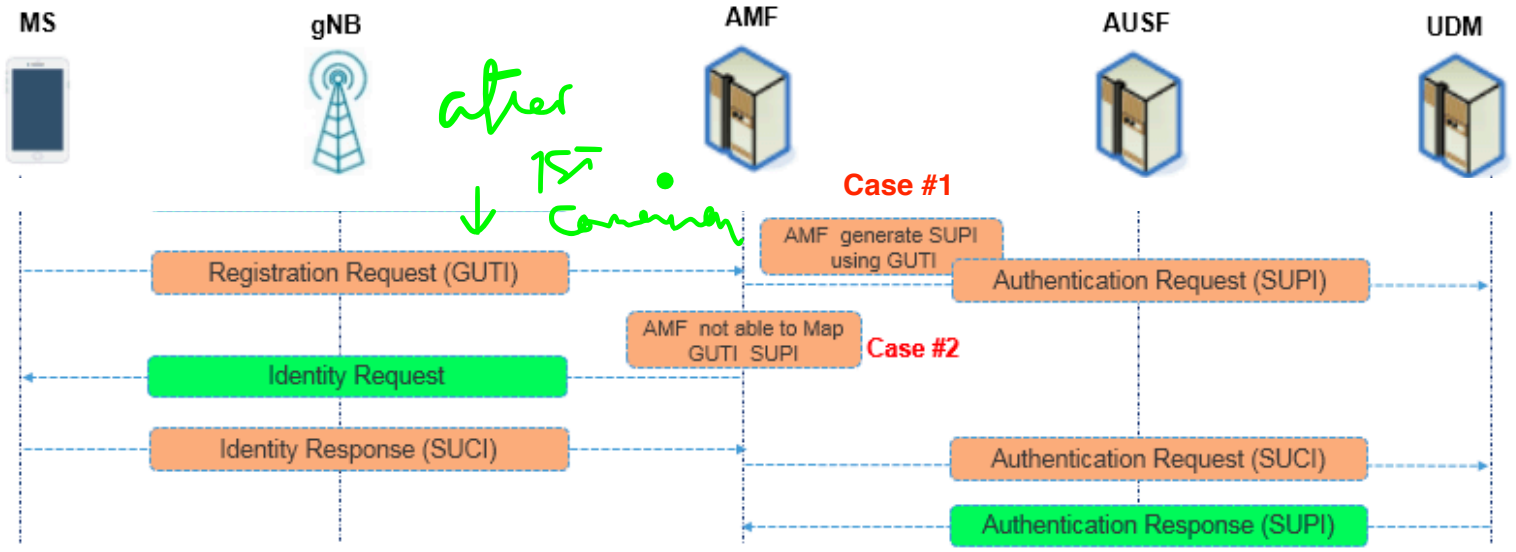
- 5G Globally Unique Temporary Identifier (GUTI) is allocated by an AMF to the UE that is common in both 3GPP and non 3GPP access.
- A UE can use the same 5G-GUTI for accessing 3GPP access security context within the AMF
- The AMF may assign a new 5G-GUTI to the UE at any time
- The 5G-GUTI comprises a GUAMI and 5G-TMSI
  - GUAMI identifies the assigned AMF
  - 5G-TMSI identifies the UE uniquely within AMF

5G Identity Exchange between UE and Network



First time registration

5G Identity Exchange between UE and Network



Subsequent registration

Control plane protocols

NG-AP

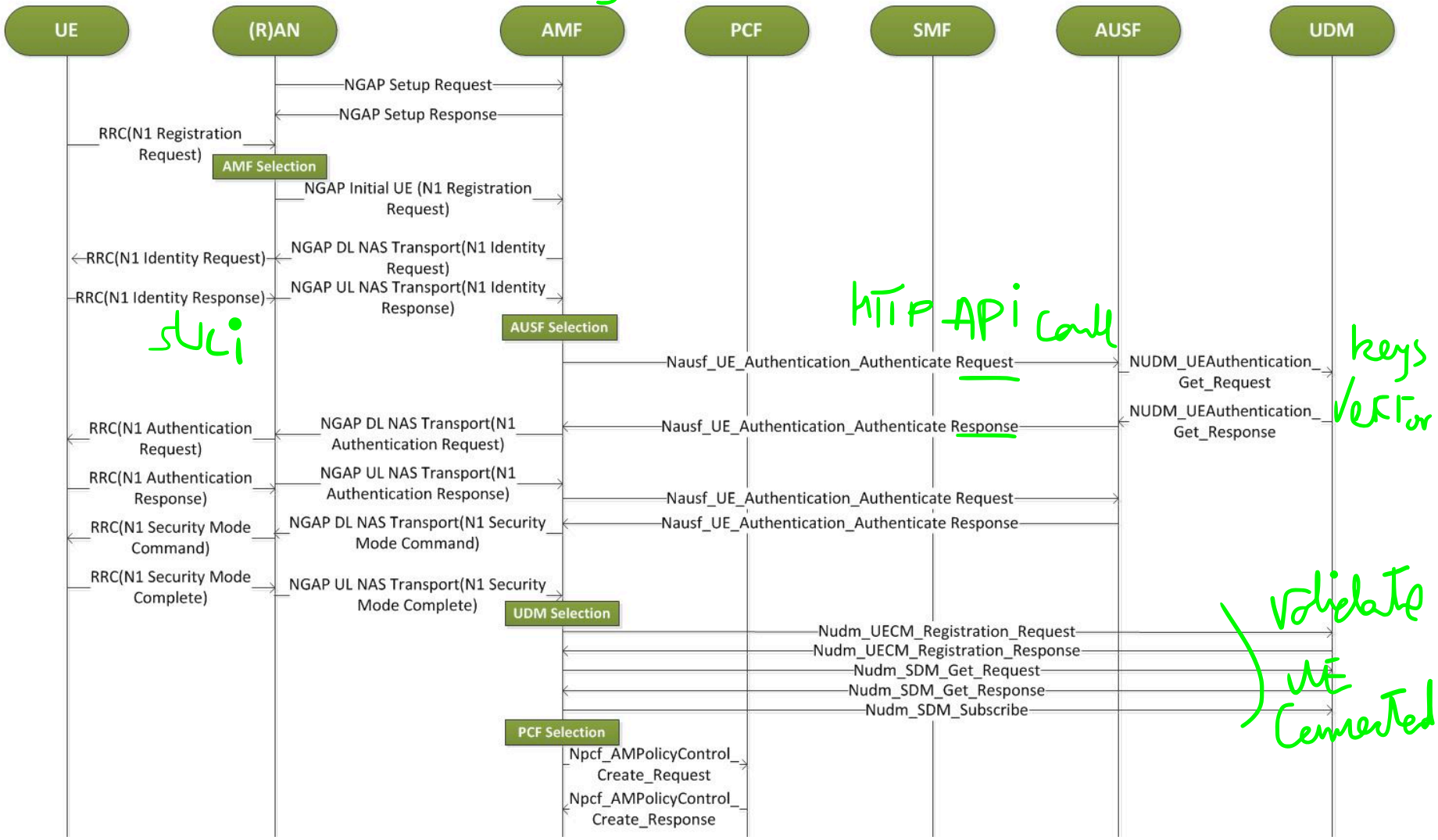
Carry the NAS-MM & NAS-SM
↳ AMF

- Similar to S1AP of 4G
- NGAP protocol is used over the N2 interface
- For each UE, a NGAP connection needs to be created, regardless of the number of PDU sessions of the UE.
- N2 interface supports the separation of AMF and other functions such as SMF
- Using the SCTP protocol, the NG application protocol enables message exchange between the 5G access node and the AMF over the N2 interface.

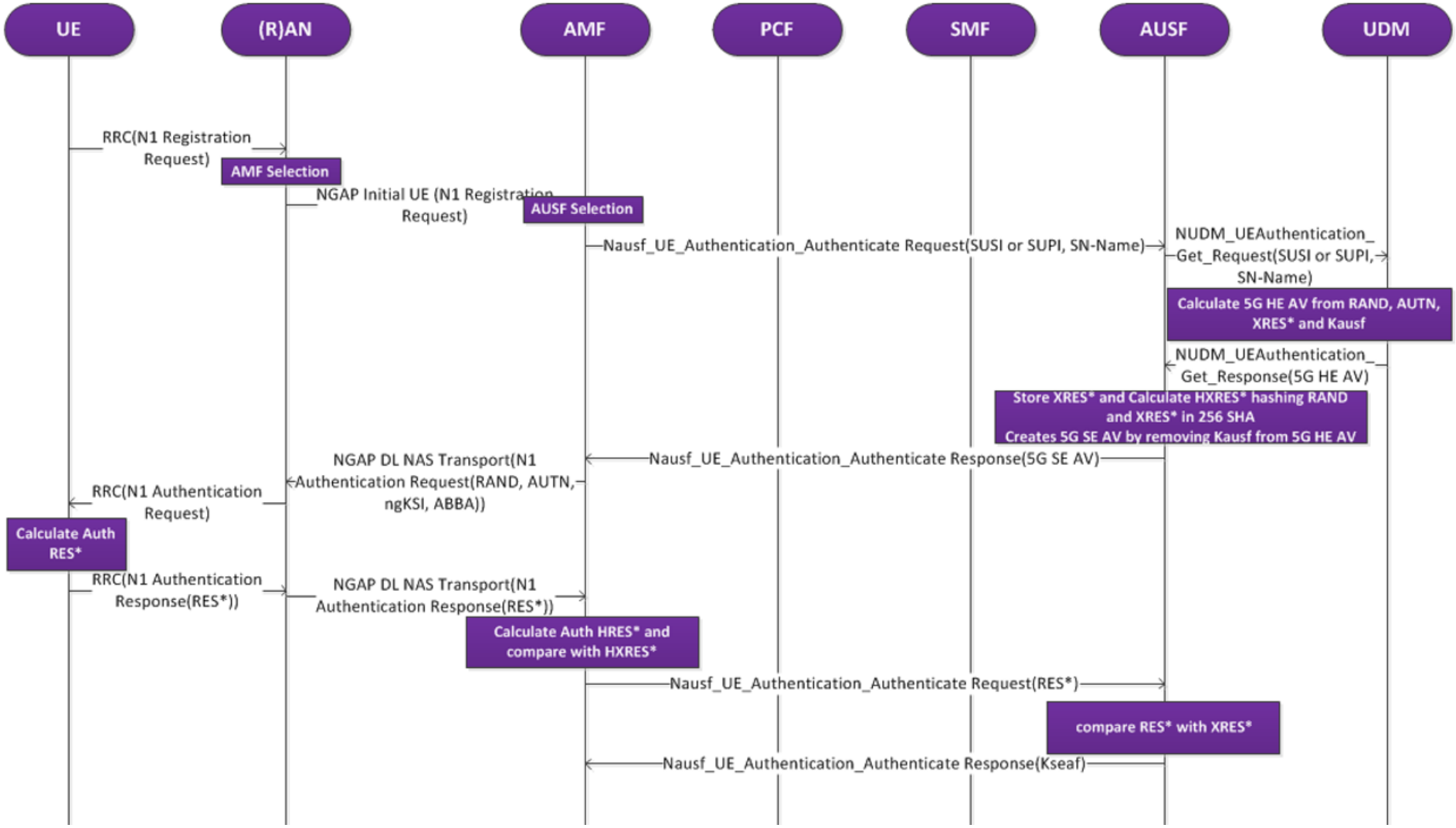
5G NAS

- A NAS connection over N1 is used to connect a UE to the AMF
  - Registration management and connection management functions
  - Transport of NAS mobility and session management (NAS-MM and NAS-SM) components
- NAS-MM mobility
  - Support NAS procedures that terminate at the AMF
  - ex. handling registration and connection management state machines and procedures of the UE, including NAS transport.
  - Security for NAS messages is provided using the security context established between the UE and the AMF.
  - It is possible to send other types of NAS messages (e.g., NAS SM) along with NAS-MM messages by supporting NAS transport of different types of payload or messages that do not terminate at the AMF.

Registration procedures



Authentication procedure



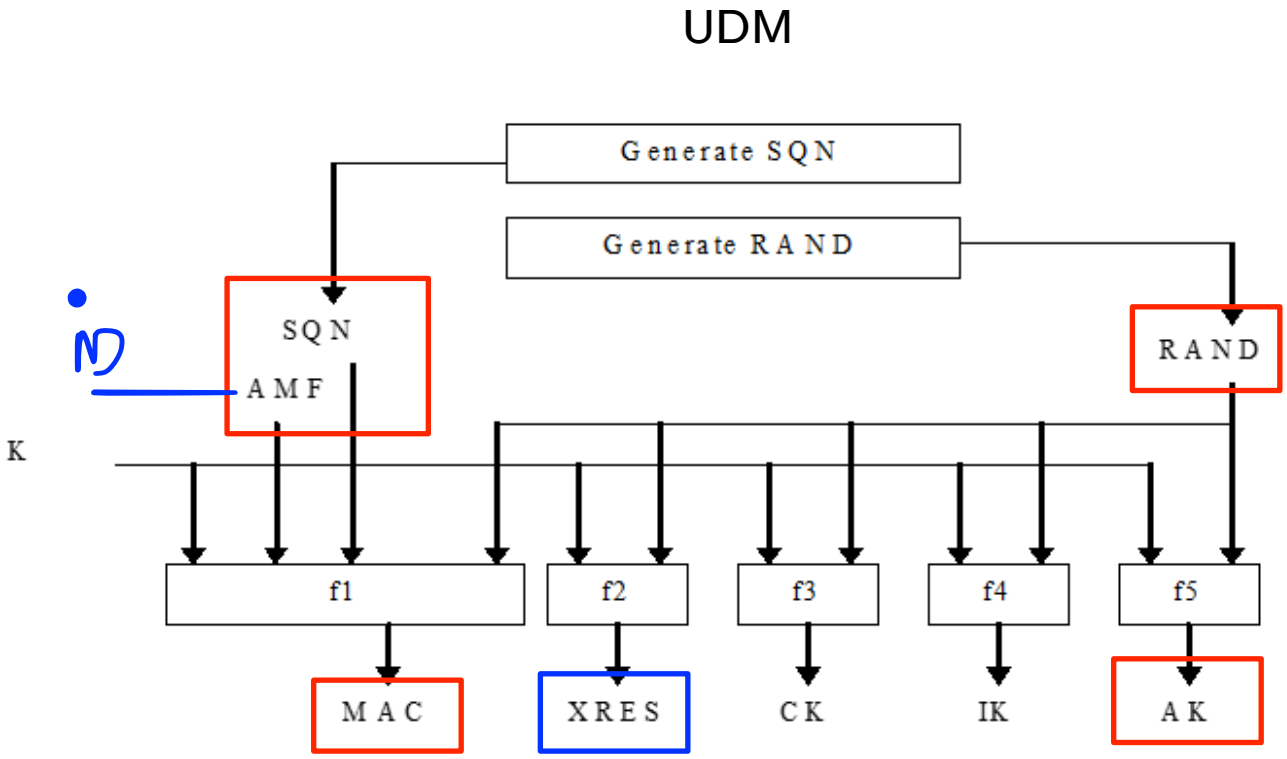
5G AKA

(Authentication and Key Agreement) algorithm

	UE	gNB	AMF	AUSF	UDM
Pre-Shared Keys	K				K
	OP				OP
Generated parameters	SQN				SQN, RAND
Derived keys for 5G AV for authentication	IK				IK
	CK				CK
	RES				XRES
	MAC				XMAC
	RES*				AUTN
				Kseaf	Kausf
				HXRES*	XRES*
			HRES*		

- UDM generates the 5G Authentication Vector (AUTN) and forwards it to the UE (AUSF/AMF)
  - Way for UE to derive the IK, CK, RES, RES*, MAC
- AUSF authenticates the UE

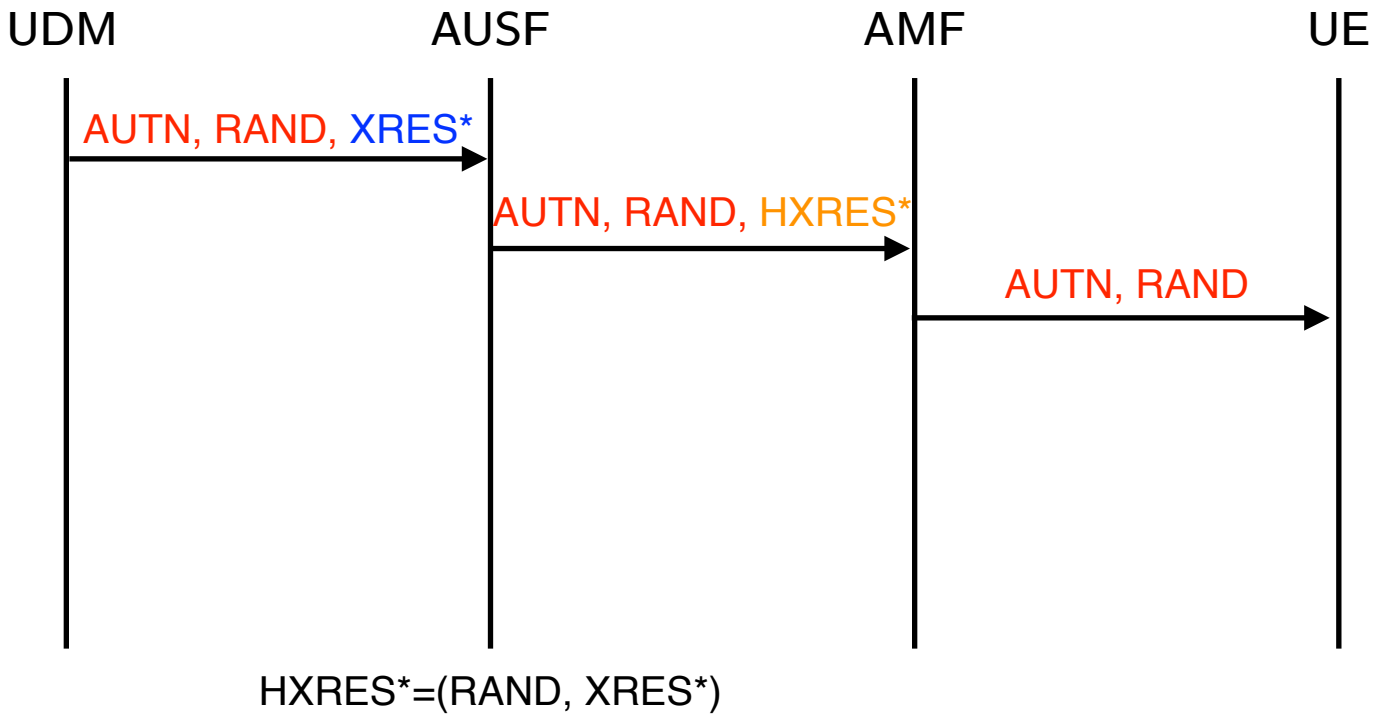
5G AKA: UDM and UE



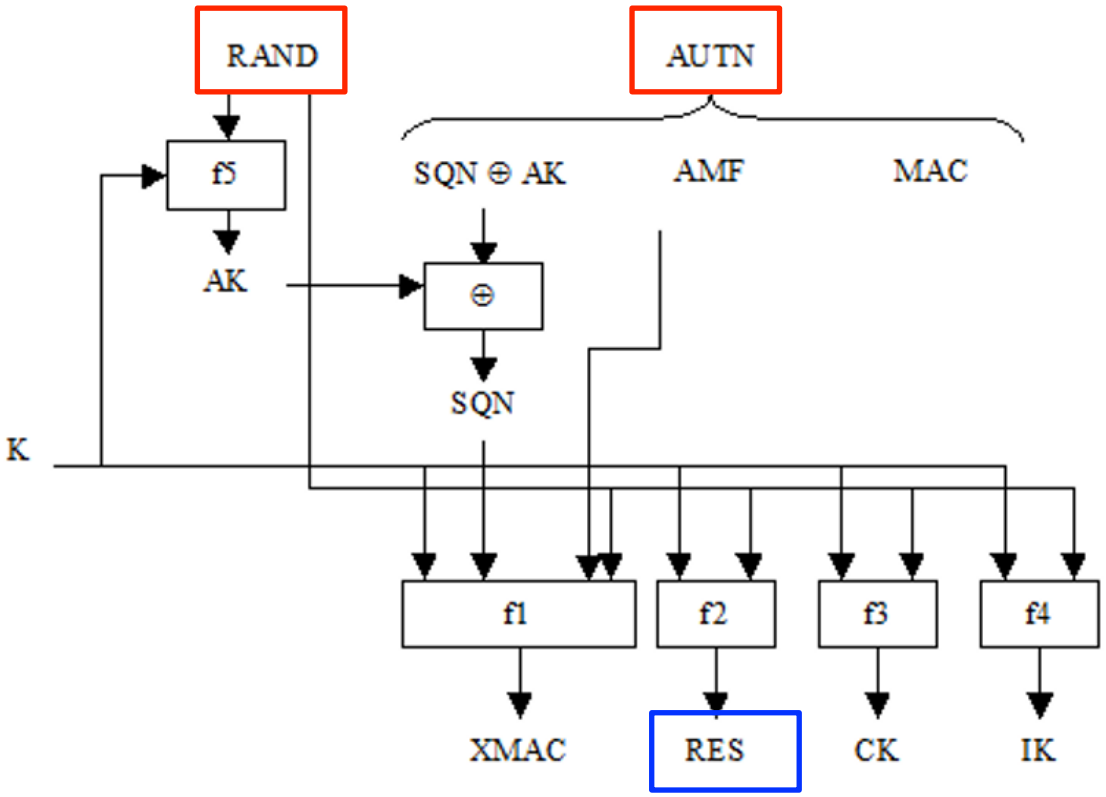
AUTN = (SQN+AK, RAND, MAC, AMF) (in Red) to UE

Generate XRES* from XRES (in Blue) to AUSF

Frome UDM to UE



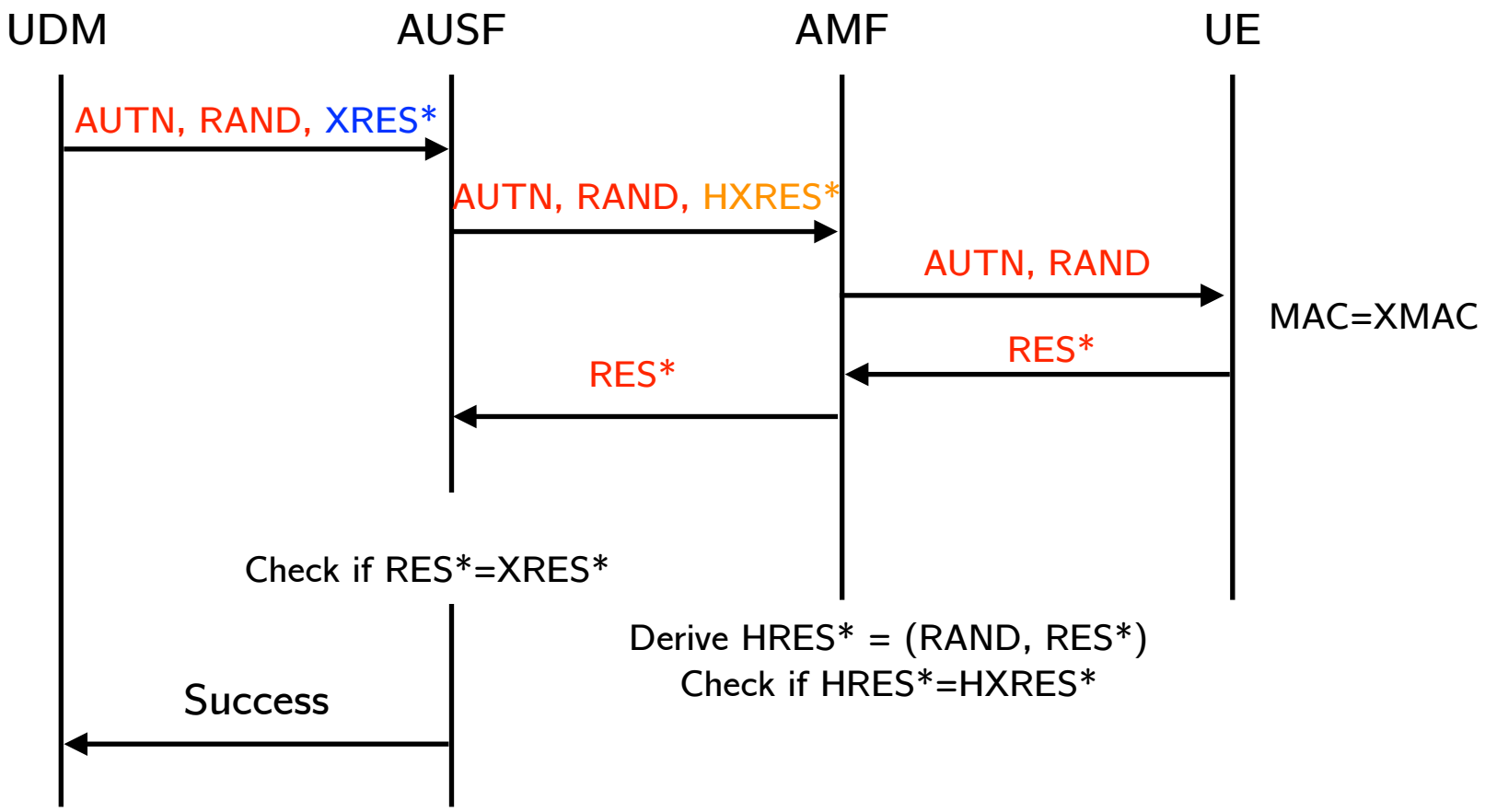
5G AKA: UDM and UE



Check if the received MAC in AUTN = XMAC, otherwise error

Generate RES* from RES (in Blue) to AUSF (via AMF)

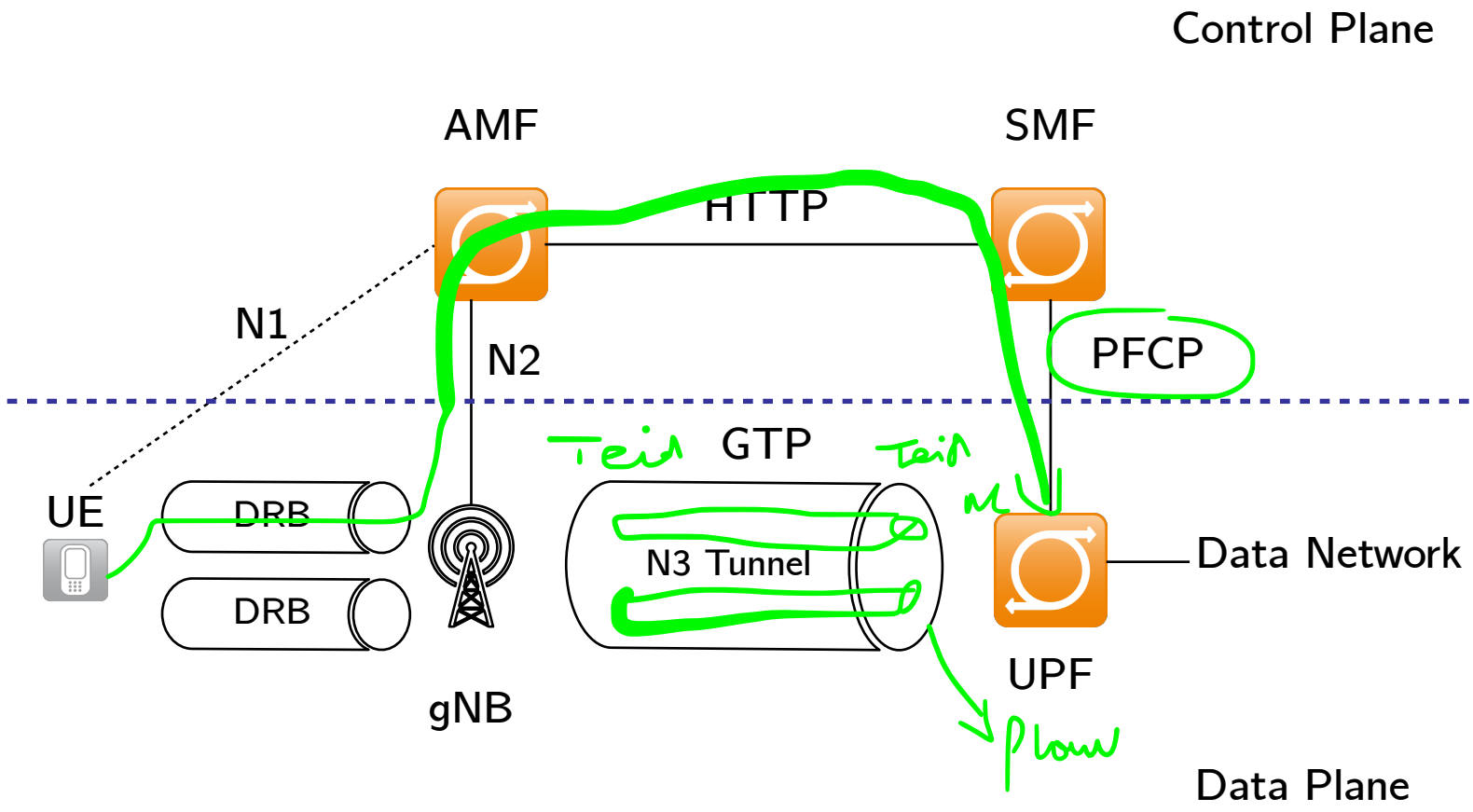
Frome UE to AUSF



Packet Data Unit (PDU) session or connectivity

- 5GC supports PDU connectivity service
  - Provides exchange of PDUs between a UE and a data network
    - PDU could be an IPv4/IPv6, Ethernet or Unstructured (IOT data)
  - PDU connectivity service is supported through PDU sessions established upon the request of a UE.
  - To establish a PDU session and access the PDN, UE must establish user plane and control plane over the NG-RAN and the 5GC network interfaces to the PDN.
- Connection/Session management
  - Establish and release a signaling connection between a UE and the AMF over N1
- The signaling connection is used to enable NAS signaling exchange between the UE and the CN,
  - Including both access network signaling connection between the UE and the access node and the N2 connection for this UE between AN and the AMF.

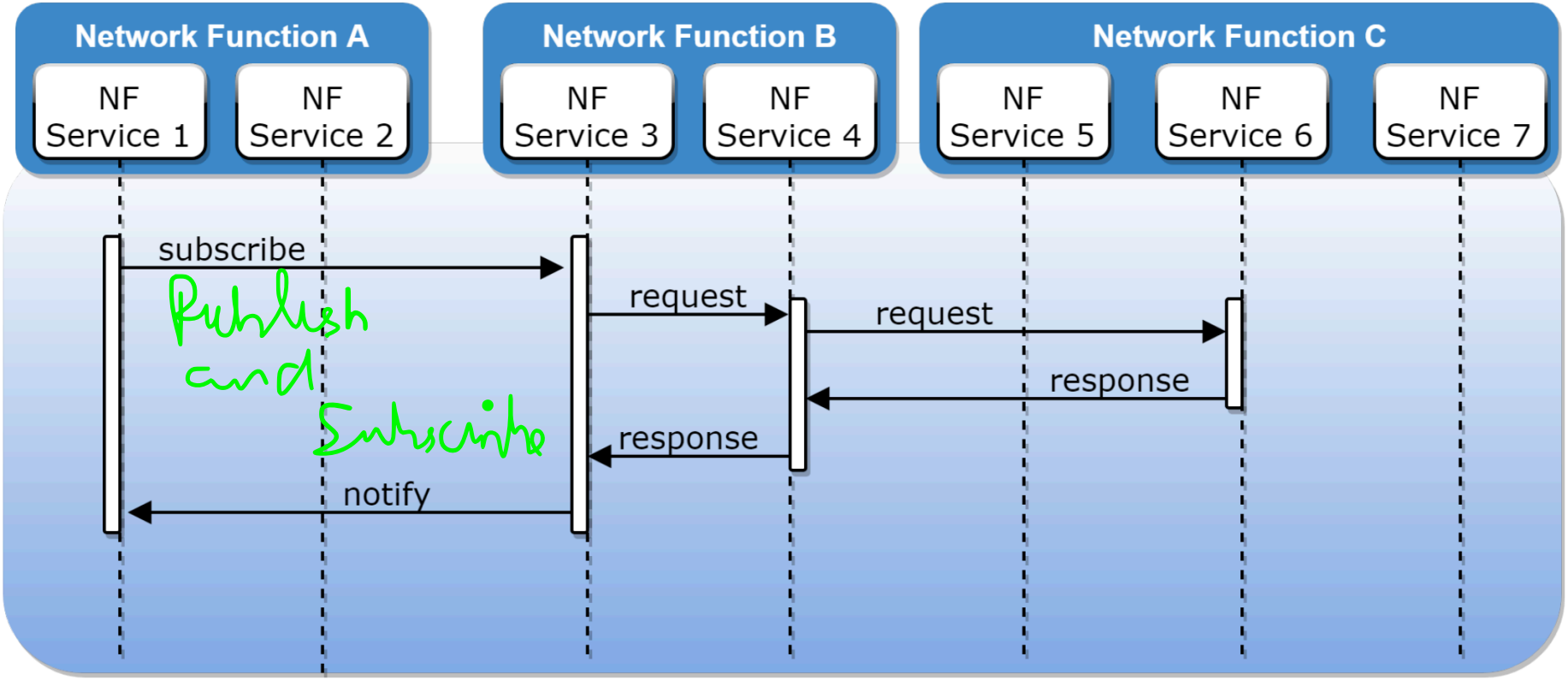
PDN Session


Control Plane
AMF
SMF
HTTP
N1
N2
PFCP
GTP
Teid
Teid
UE
DRB
DRB
N3 Tunnel
Data Network
UPF
gNB
Flow
Data Plane

NAS-SM

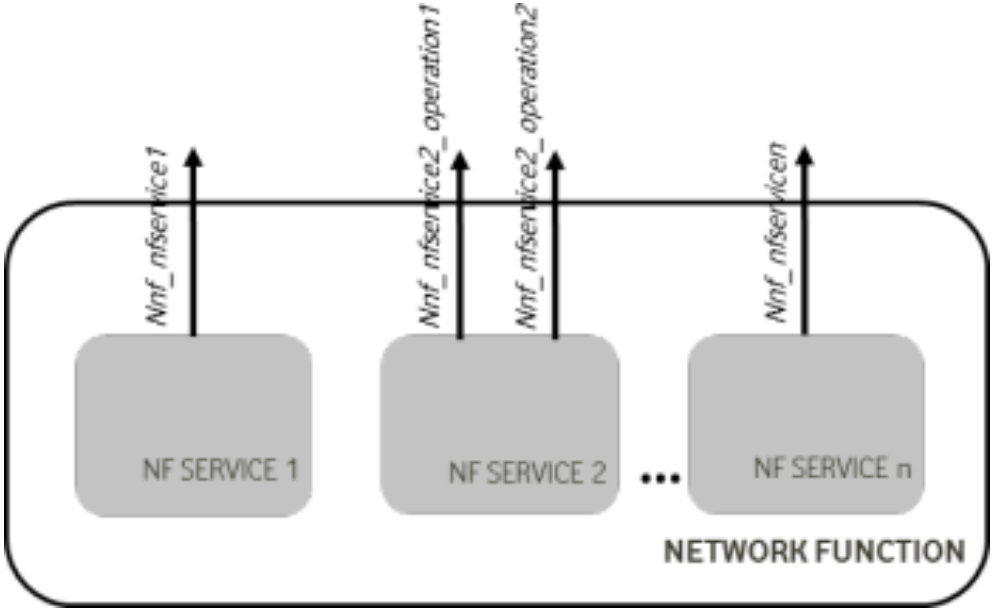
- Control the session management functions between the UE and the SMF
- The session management message is created and processed in the NAS-SM layer of UE and the SMF
- The content of the NAS-SM message is transparent to the AMF
- The NAS-MM layer creates a NAS-MM message, including security header, indicating NAS transport of SM signaling.
- The receiving NAS-MM forwards the message the SMF

Network Function Network Service



Request/Response based on HTTP

Example of exposed services (SMF)

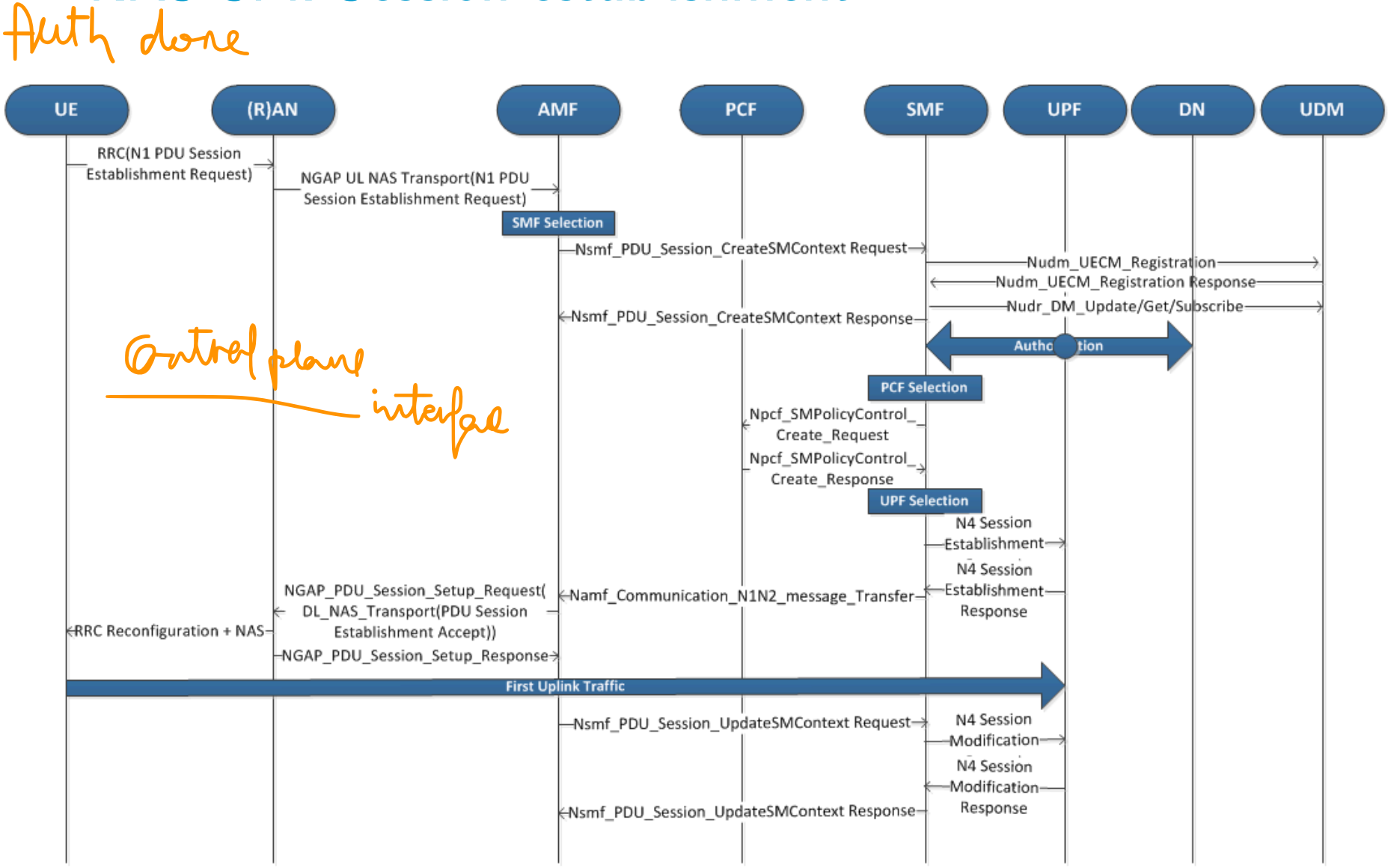


Service Name	Description
Nsmf_PDUSession	This service manages the PDU Sessions and uses the policy and charging rules received from the PCF. The service operations exposed by this NF service allows the consumer NFs to handle the PDU Sessions.
Nsmf_EventExposure	This service exposes the events happening on the PDU Sessions to the consumer NFs.
Nsmf_NIDD	This service is used for NIDD transfer between SMF and another NF.

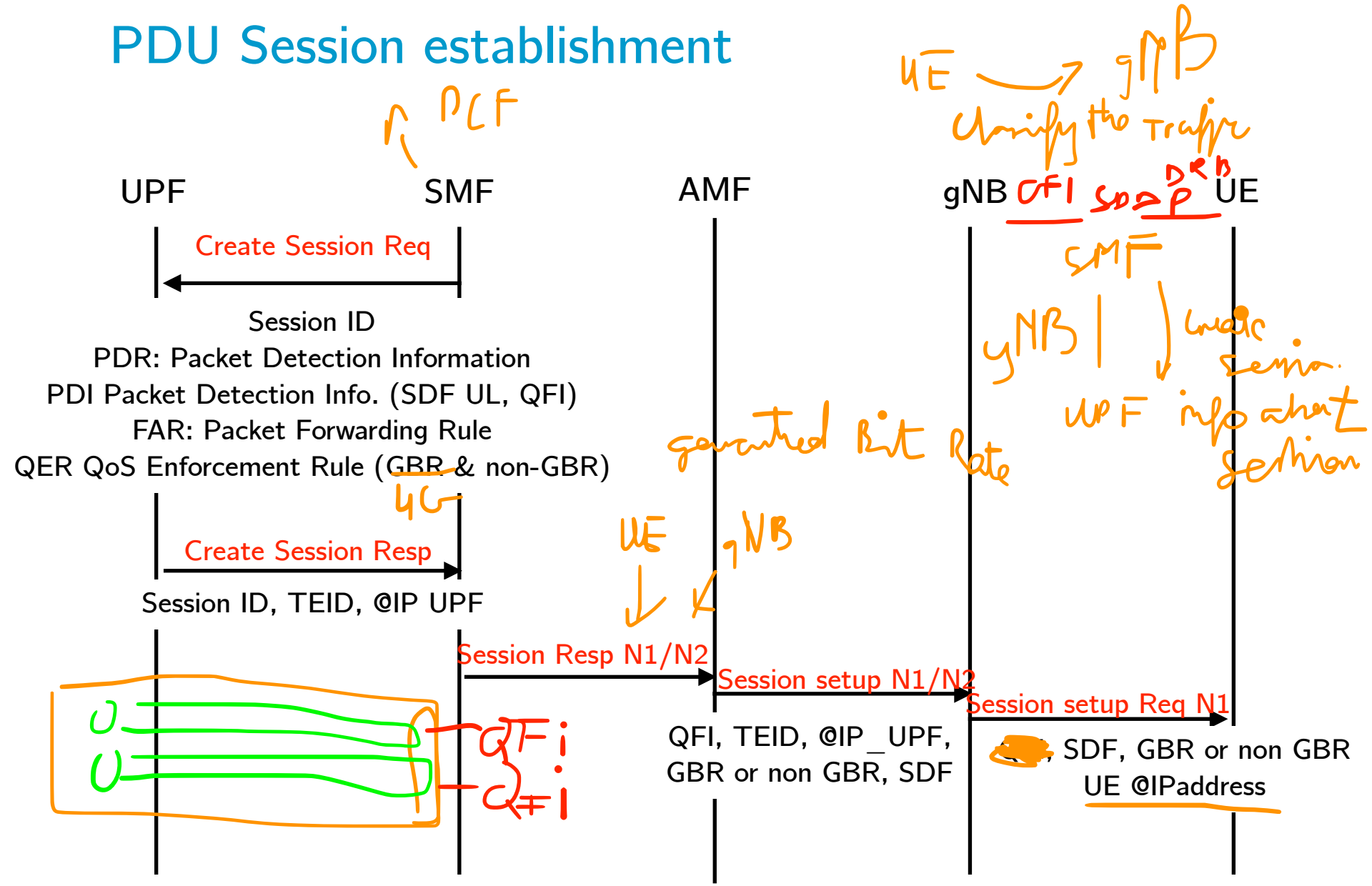
Req / Resp

Event based PIS

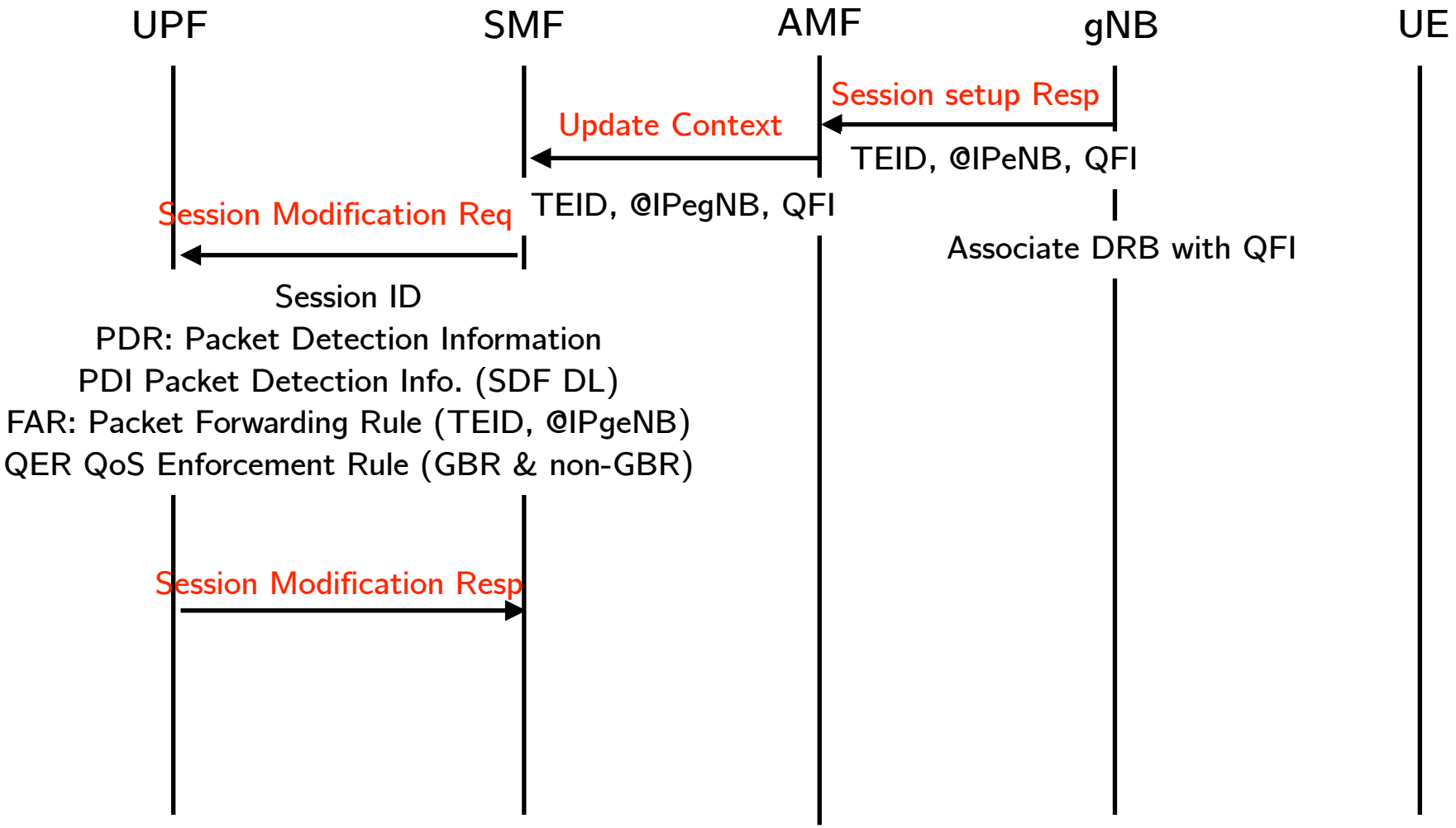
NAS-SM: Session establishment



PDU Session establishment



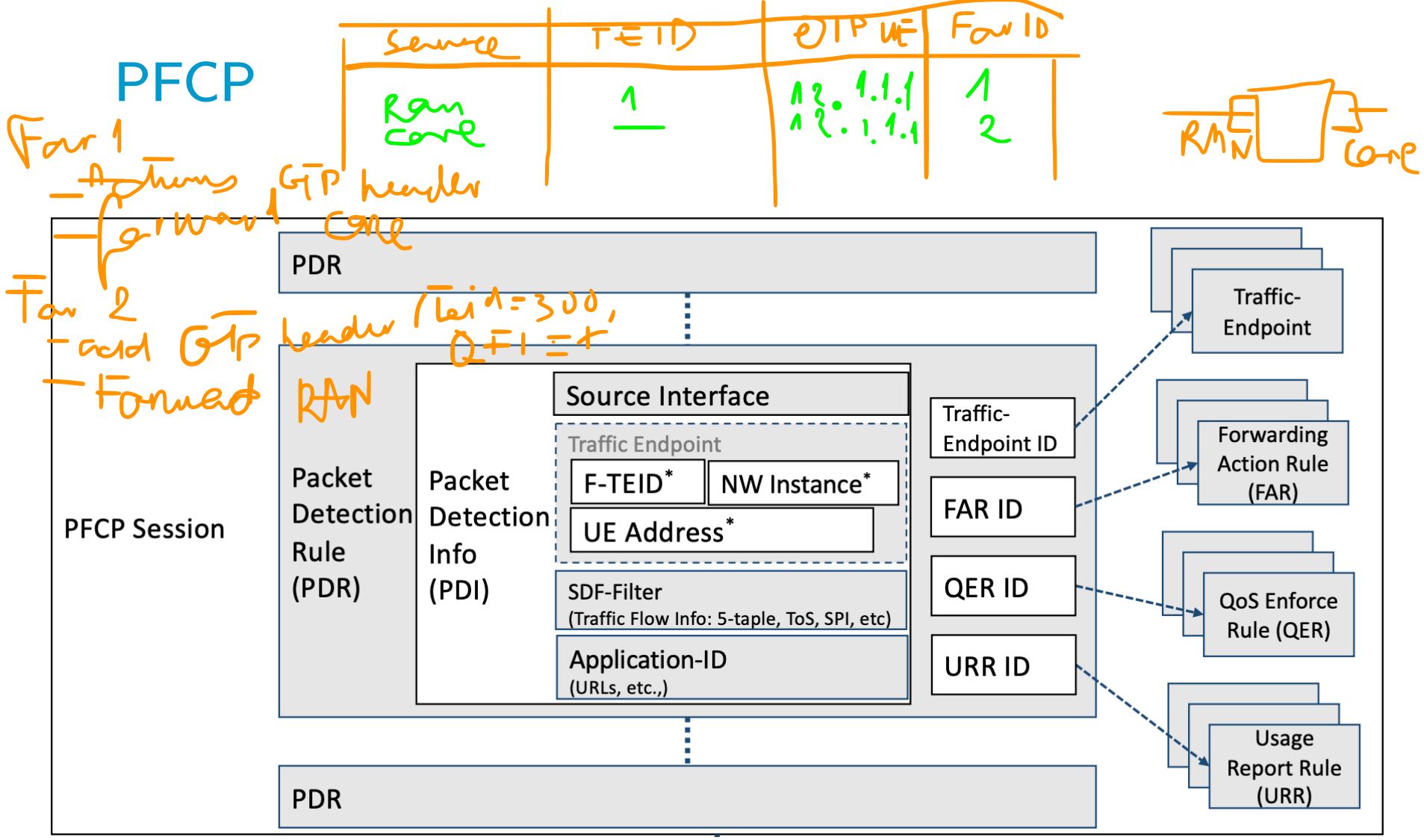
PDU Session establishment



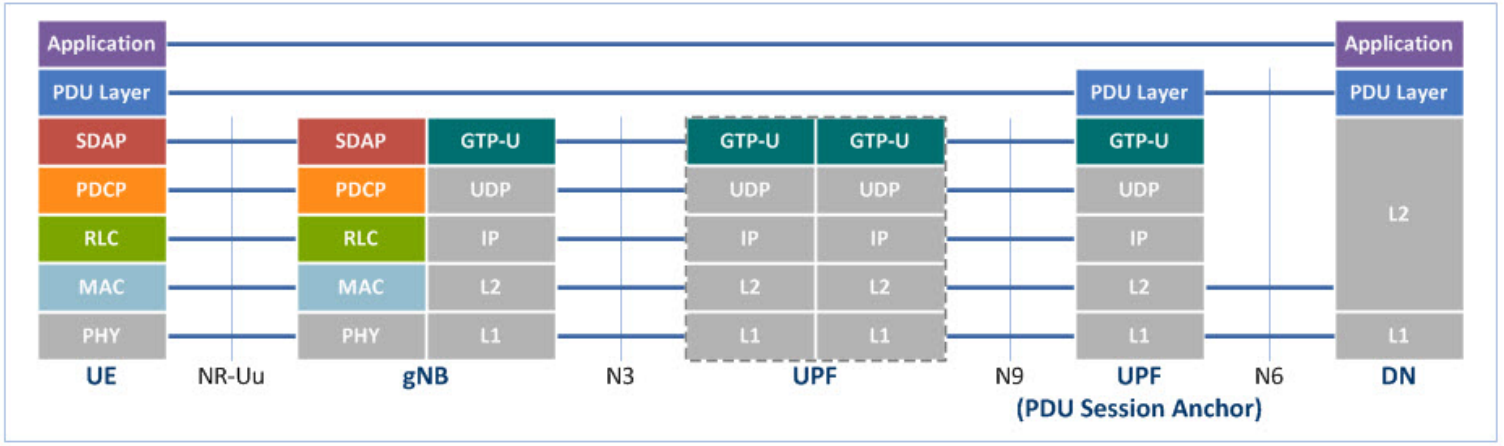
Packet Forwarding Control Protocol (PFCP)

- PFCP sessions, established with the UP, define how packets are:
  - Identified (Packet Detection Rule / PDR),
  - Forwarded (Forwarding Action Rules / FARs),
  - Processed (Buffering Action Rules / BARs),
  - Marked (QoS Enforcement Rules / QERs),
  - Reported (Usage Reporting Rules / URRs).

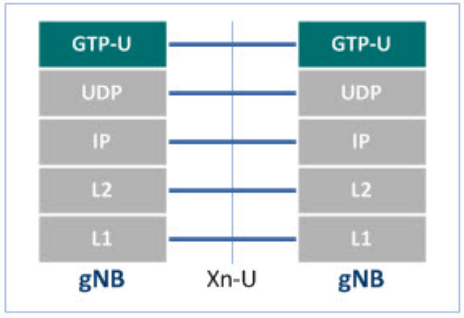
PFCP

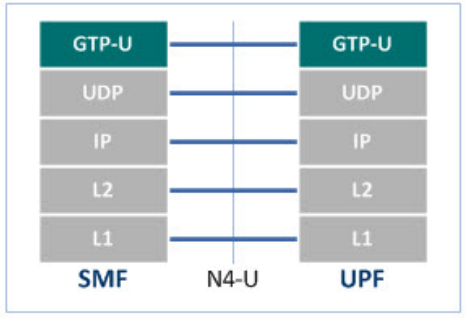

Source
TEID
GTP UE
Far ID
Ran
Core
1
1
2
RAN
Core
Far 1
Forward
GTP header
Core
Far 2
Add GTP header (Teid=300, QFI=1)
Forward
RAN
PFCP Session
PDR
Packet Detection Rule (PDR)
Packet Detection Info (PDI)
Source Interface
Traffic Endpoint
F-TEID*
NW Instance*
UE Address*
SDF-Filter
(Traffic Flow Info: 5-taple, ToS, SPI, etc)
Application-ID
(URLs, etc.,)
Traffic-Endpoint ID
FAR ID
QER ID
URR ID
Traffic-Endpoint
Forwarding Action Rule (FAR)
QoS Enforce Rule (QER)
Usage Report Rule (URR)
PDR

5G user plane

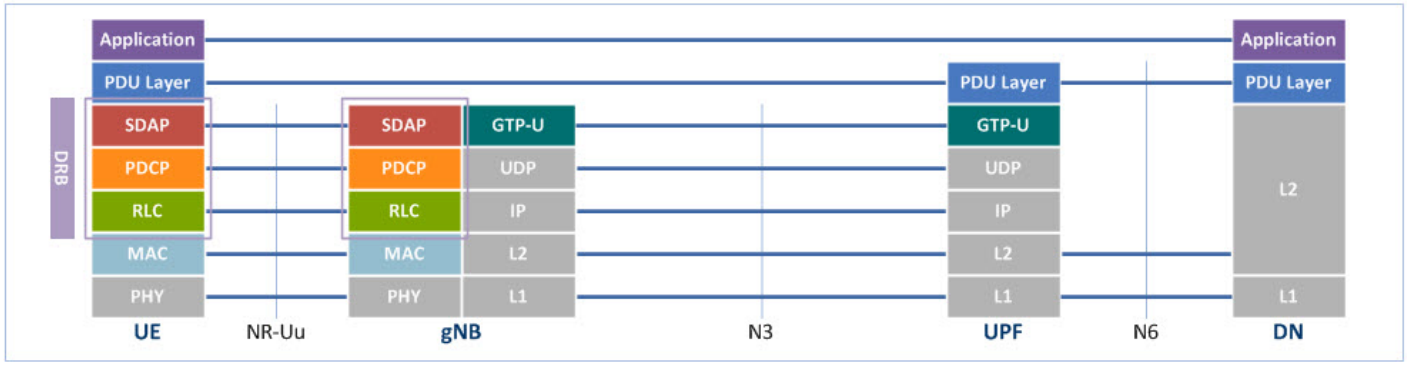


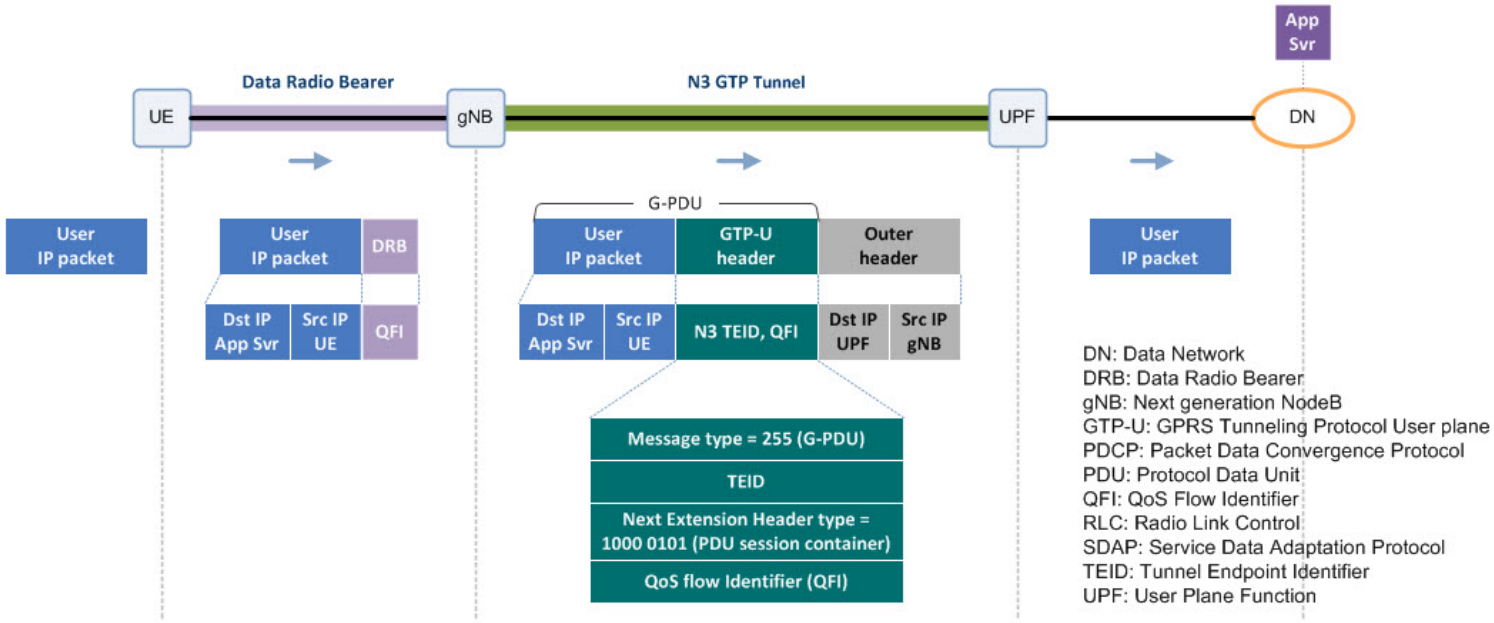
PDU Layer: IP, Ethernet, etc.





5G User plane





DN: Data Network
DRB: Data Radio Bearer
gNB: Next generation NodeB
GTP-U: GPRS Tunneling Protocol User plane
PDCP: Packet Data Convergence Protocol
PDU: Protocol Data Unit
QFI: QoS Flow Identifier
RLC: Radio Link Control
SDAP: Service Data Adaptation Protocol
TEID: Tunnel Endpoint Identifier
UPF: User Plane Function

QoS

- In 4G LTE QoS is enforced at the EPS bearer level, while in 5G it is enforced at the QoS flow level
- in 4G LTE uses EPS bearers each assigned an EPS bearer ID, while 5G uses QoS Flow Id (QFI)

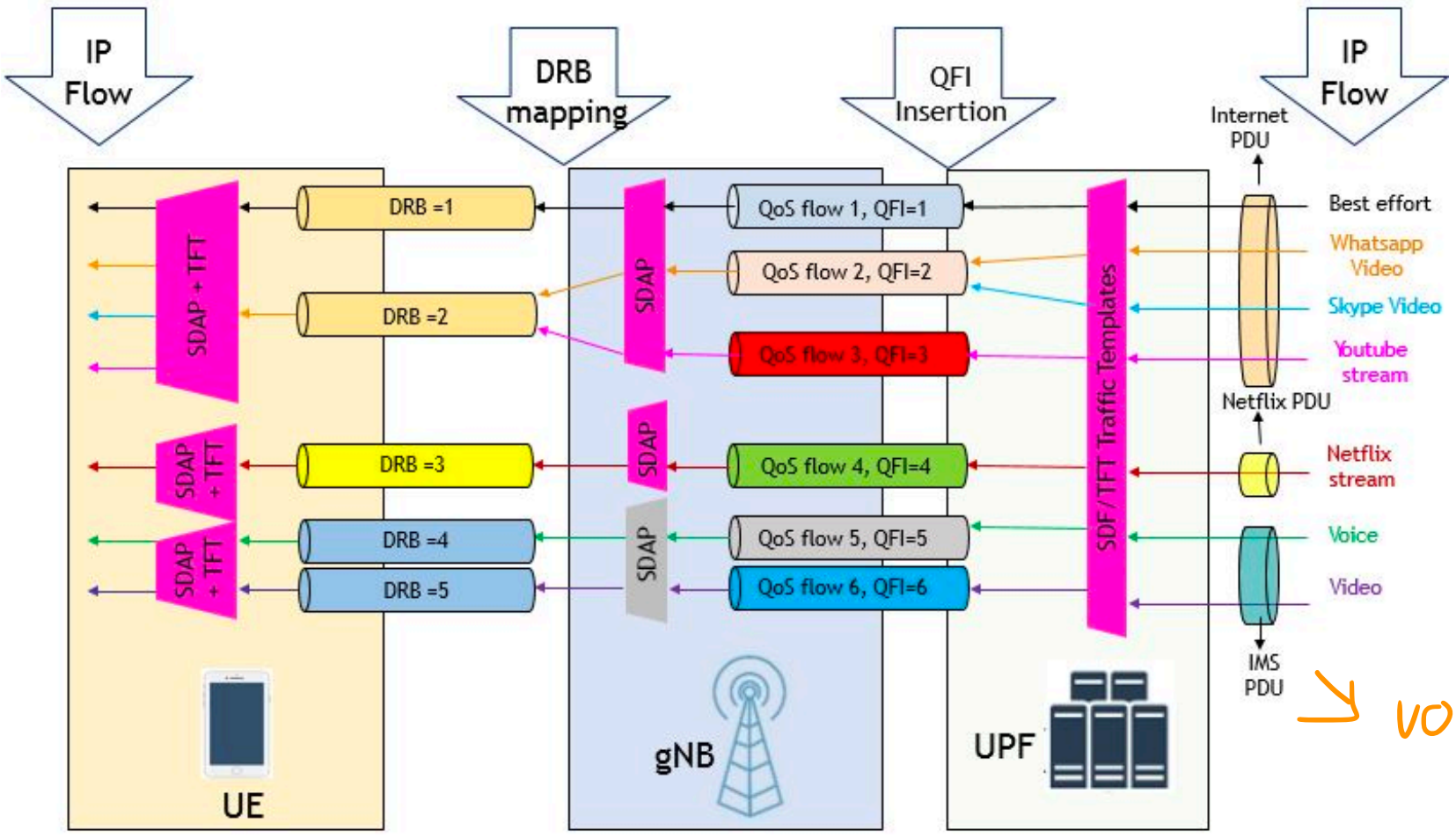
Parameter	5G	4G LTE
QoS Identifier	5G QoS Identifier - 5QI	Quality Class Indicator - QCI
IP Flow: UE to UPF/P-GW flow	QoS Flow	EPS Bearer
Flow/Bearer identifier	QoS Flow Identifier - QFI	EPS Bearer ID- EBI
Reflective QoS	Reflective QoS Indicator - RQI	N/A

QoS profile of a QoS flow

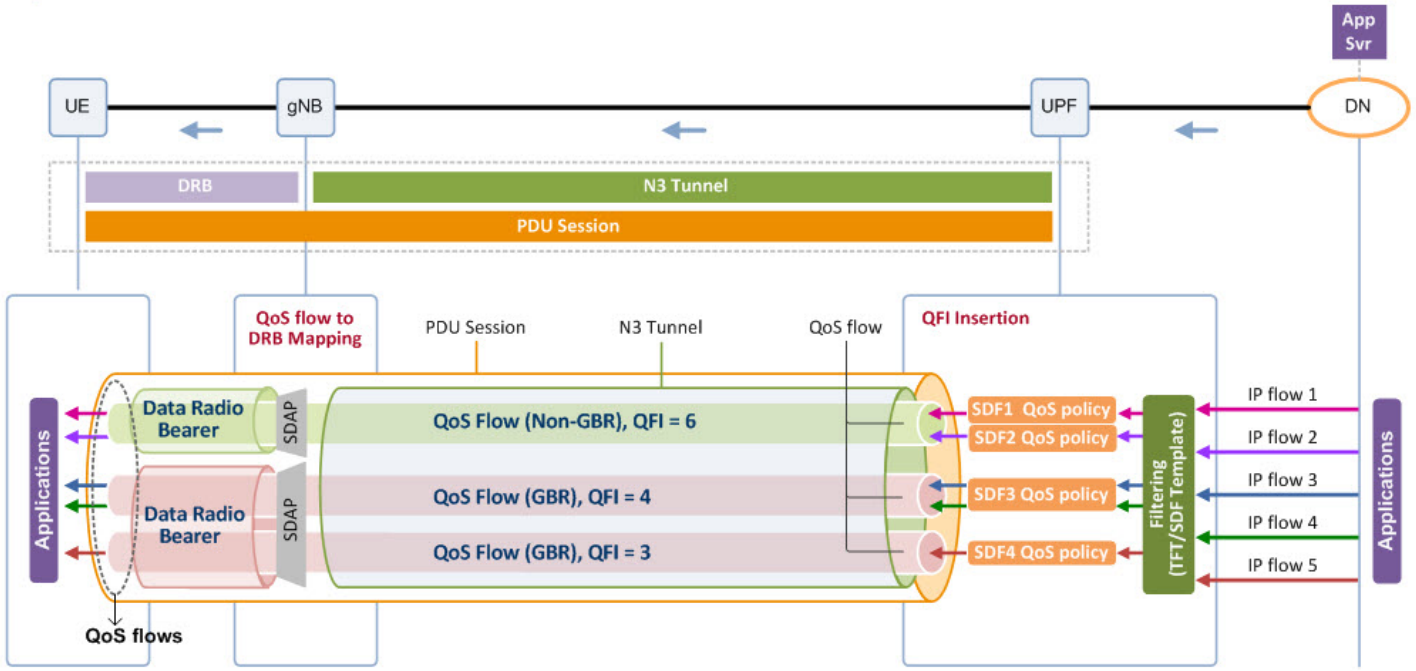
- 5G QoS identifier
- ARP
- If GBR, for uplink and downlink
  - Guaranteed flow bit rate (GFBR)
  - Maximum flow bit rate (MFBR)
- If non-GBR
  - Newly defined Reflective QoS attribute (RQA)

5QI Value	Resource Type	Default Priority Level	Packet Delay Budget (ms)	Packet Error Rate	Default Maximum Data Burst Volume (Bytes)	Default Averaging Window (ms)	Example Services
1	GBR	20	100	10^{-2}	N/A	2000	Conversational Voice
2		40	150	10^{-3}	N/A	2000	Conversational Video (Live Streaming)
3		30	50	10^{-3}	N/A	2000	Real-time Gaming, V2X Messages, Electricity Distribution, Process Automation
4		50	300	10^{-6}	N/A	2000	Non-Conversational Video (Buffered Streaming)
65		7	75	10^{-2}	N/A	2000	Mission-critical User-plane Push-to-Talk Voice
66		20	100	10^{-2}	N/A	2000	Non-mission-critical User-plane Push-to-Talk Voice
67		15	100	10^{-3}	N/A	2000	Mission-critical Video
75		—	—	—	—	—	—
5	Non-GBR	10	100	10^{-6}	N/A	N/A	IMS Signaling
6		60	300	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	10^{-3}	N/A	N/A	Voice, Video (Live Streaming) Interactive Gaming
8		80	300	10^{-6}	N/A	N/A	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
9		90					
69		5	60	10^{-6}	N/A	N/A	Mission-critical Delay Sensitive Signaling
70		55	200	10^{-6}	N/A	N/A	Mission-critical Data
79		65	50	10^{-2}	N/A	N/A	V2X Messages
80		68	10	10^{-6}	N/A	N/A	Low-latency eMBB Applications, Augmented Reality
82	Delay Critical GBR	19	10	10^{-4}	255	2000	Discrete Automation
83		22	10	10^{-4}	1354	2000	Discrete Automation
84		24	30	10^{-5}	1354	2000	Intelligent Transport Systems
85		21	5	10^{-5}	255	2000	Electricity Distribution

5G QoS


IP Flow
DRB mapping
QFI Insertion
IP Flow
Internet PDU
DRB =1
DRB =2
DRB =3
DRB =4
DRB =5
SDAP + TFT
SDAP + TFT
SDAP + TFT
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
VoIP
UE
gNB
UPF

QoS differentiation



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

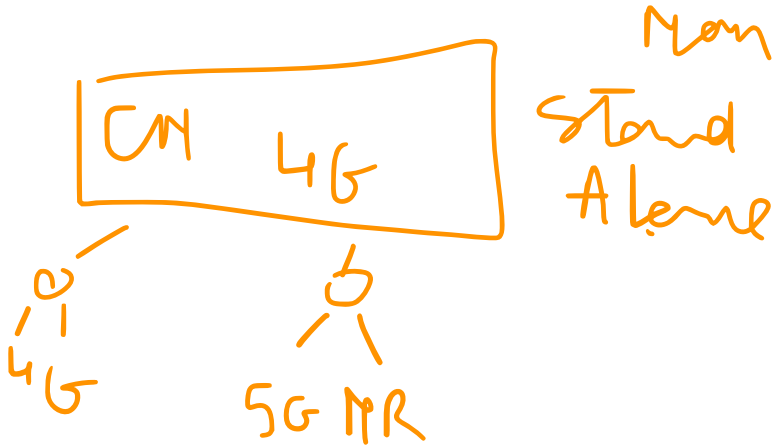
QoS Flow type		QoS Flow parameters
GBR flow	Non-GBR flow	5QI
		ARP
		RQA
		GFBR
		MFBR
		Notification Control
		Maximum Packet Loss Rate

5QI
Resource Type*
Default Priority Level
PDB
PER
Default Maximum Data Burst Volume
Default Averaging Window

* GBR, non-GBR or delay critical GBR

DEPLOYMENT

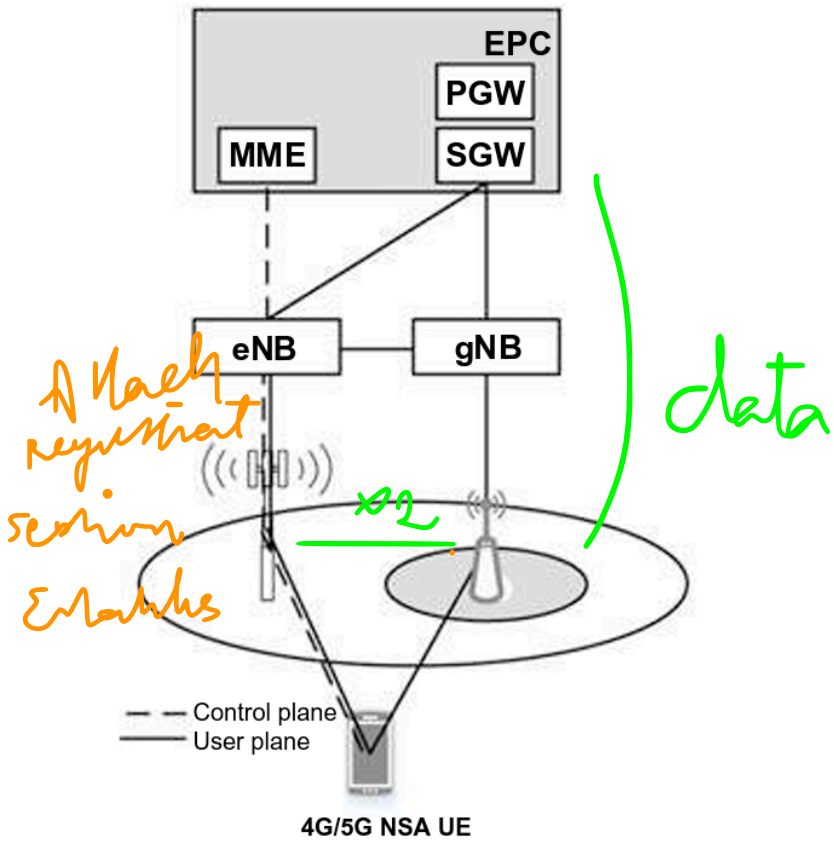
Deployment of 5G



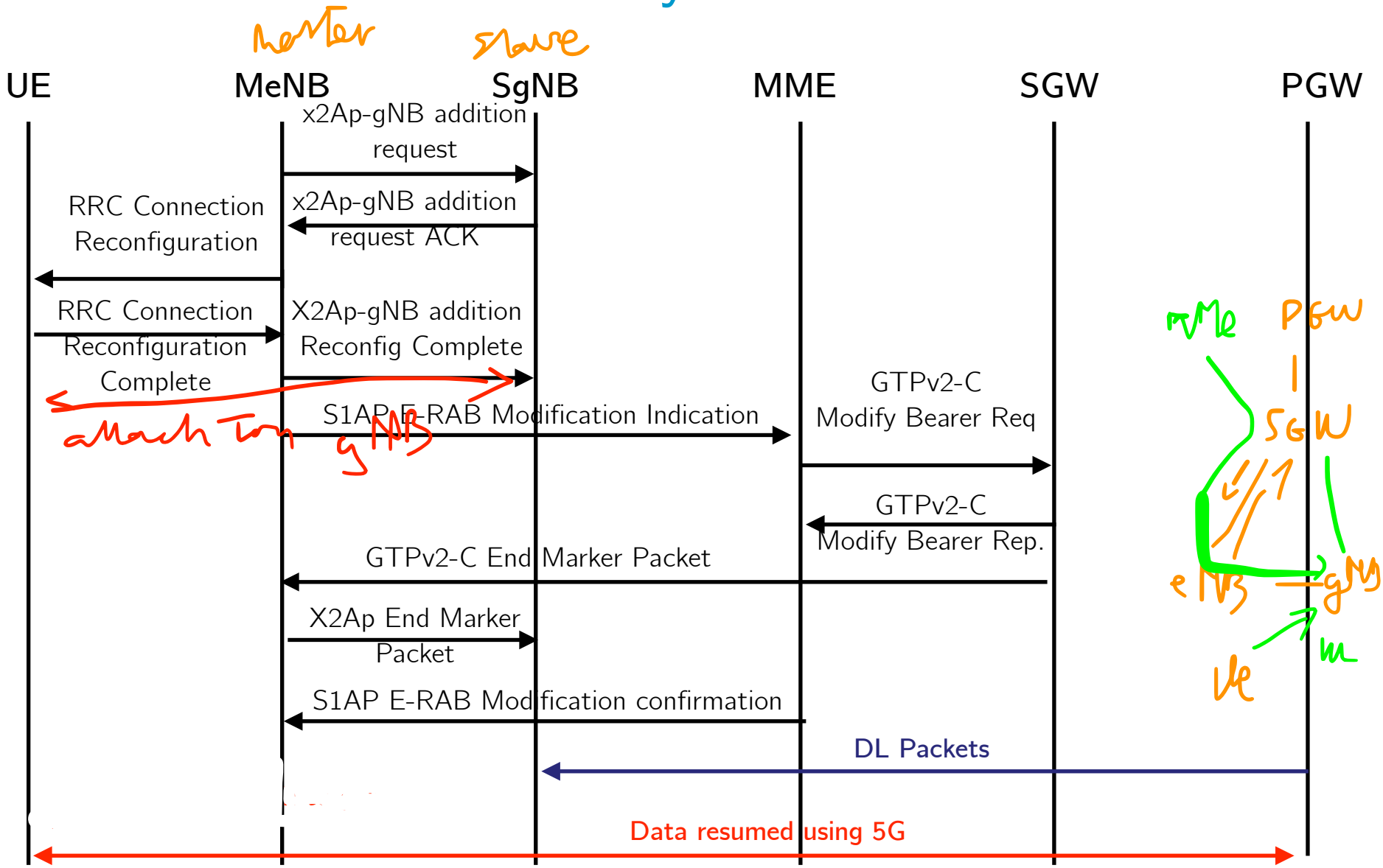
- Two modes
  - Non-Standalone (NSA): an intermediate step where the 5G NR is deployed while using the 4G CN
  - Standalone (SA): 5G NR and 5G CN

Non-Standalone (NSA): Dual connectivity

- UE has dual connectivity 4G and 5G
  - Control plane via 4G, only data plane via 5G.
- UE starts by being connected to the 4G
  - Registration, authentication and EPS bearer establishment
  - UE requests 5G connectivity
  - Handover between eNB and gNB (as an X2 handover)



5G NSA dual connectivity



5G NETWORK SLICING

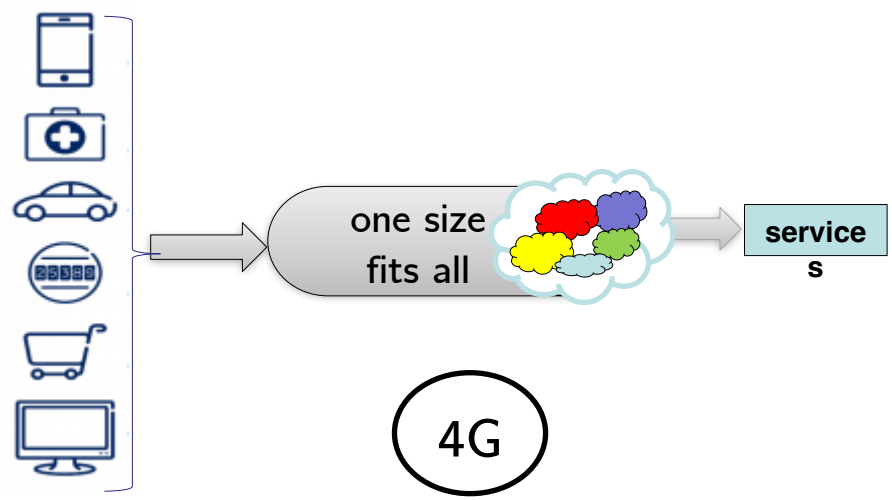
eMBB

URLLC

mMTC

4G limitation

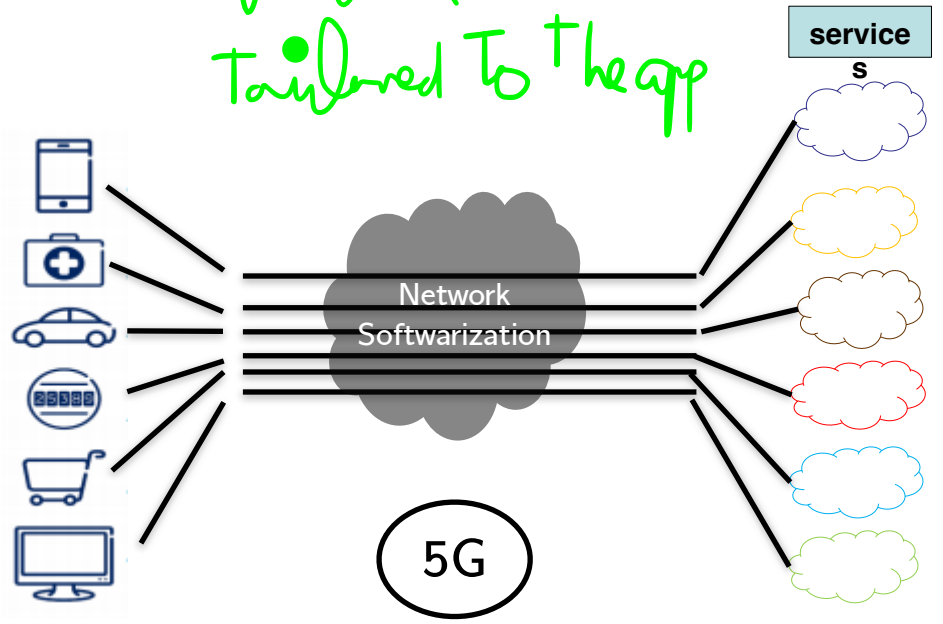
4G One size fits all no more efficient!!



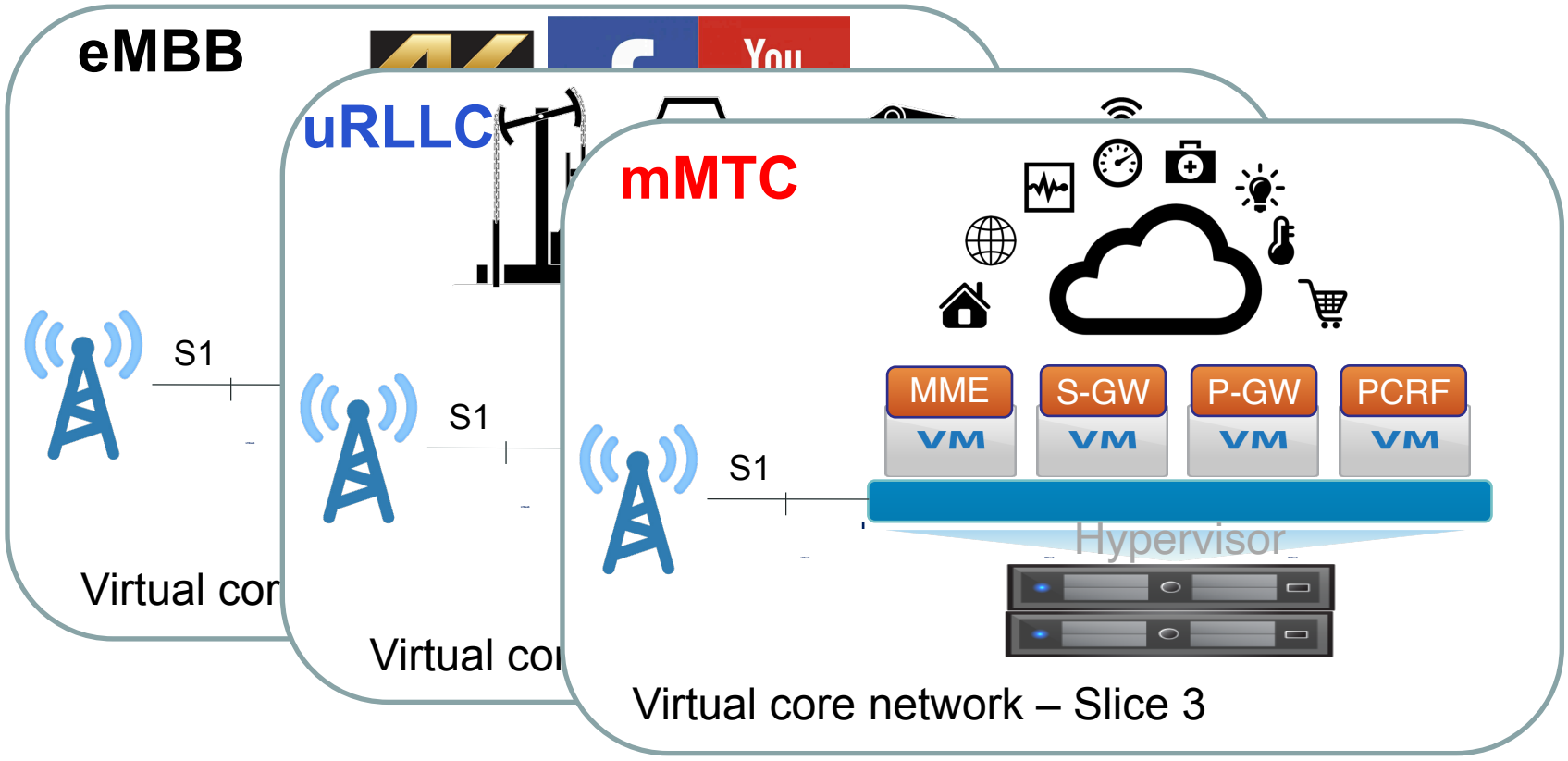
Network Slicing

virtual network instance

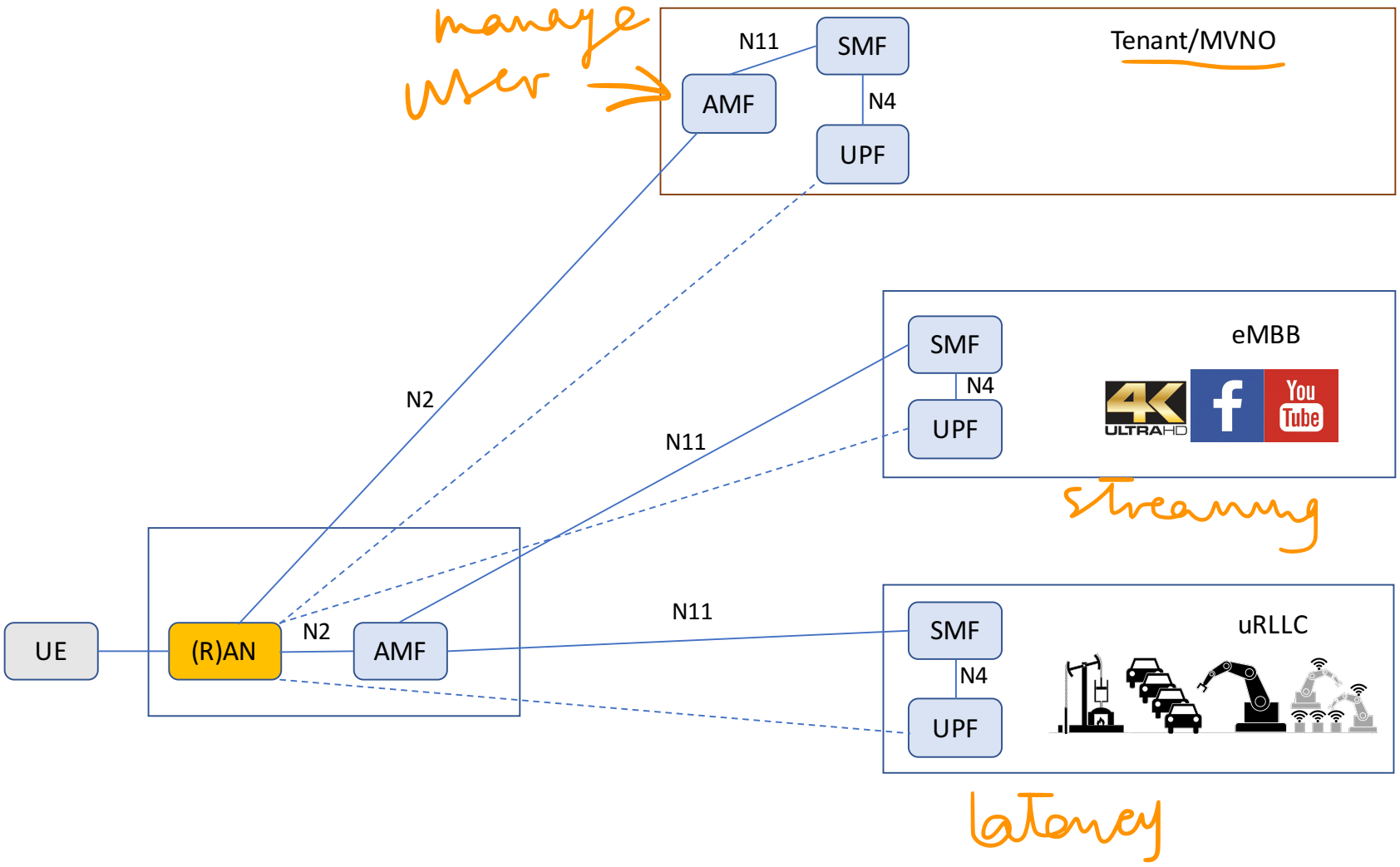
Tailored To the app



Each service a dedicated mobile network



5G Network Slicing



Network Slice Selection Function (NSSF)

- Selects the set of NSIs (Network Slice Instance) to serve a UE
- Determines the allowed NSSAI (Network Slice Selection Assistance Information)
- Determines the AMF set to serve the UE or a list of candidate AMF

Network Slice Identification

- UE sends a NSSAI (network slice selection assistance information), a vector of max 8 S-NSSAI value selecting the Slice Instances
- An S-NSSAI is comprised of:
  - A Slice/Service type (SST), which refers to the expected Network Slice behavior in terms of features and services;
  - A Slice Differentiator (SD), which is optional information that complements the Slice/Service type(s) to differentiate amongst multiple Network Slices of the same Slice/Service type

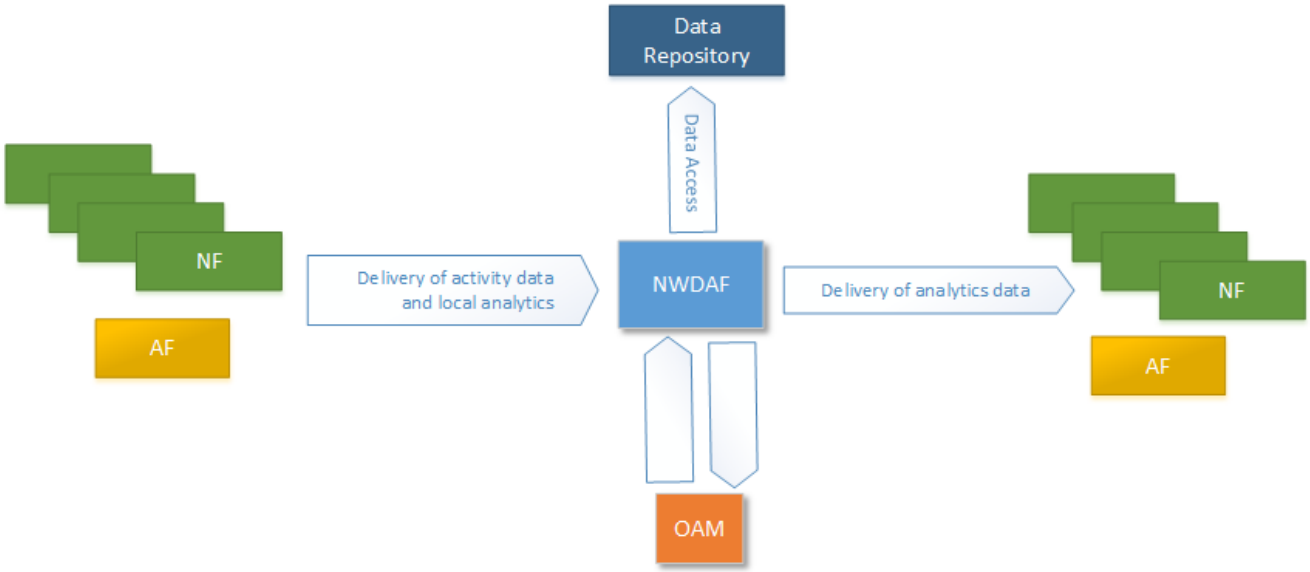
Slice/Service type	SST Value
eMBB	1
URLLC	2
MMTC	3

OTHER 5G CORE NETWORK FUNCTION

Network Data Analytics Function (NWDAF)

- Data collection and analytic
- NWDAF can provide network slice-level data analytics (e.g., load-level information) to PCF and NSSF
  - PCF uses that data in its policy decisions
  - NSSF may use the load level information provided by NWDAF for slice selection
  - Other examples:
    - Current status of UE (Battery, CPU, Memory, etc.)
    - RAN congestion level
    - Subscription information

NWDAF



Service Name	Description
Nnwdaf_AnalyticsSubscription	This service enables the NF service consumers to subscribe/unsubscribe for different type of analytics from NWDAF.
Nnwdaf_AnalyticsInfo	This service enables the NF service consumers to request and get different type of analytics information from NWDAF.

Network Registry Function (NRF)

- The NRF is one of the main key components of the 5G Service Based Architecture.
- The NRF maintains an updated repository of all the 5G elements available in the operator's network along with the services provided by each of the elements in the 5G core that are expected to be instantiated, scaled, and terminated without or minimal manual intervention.
- The NRF supports discovery mechanisms that allow 5G elements to discover each other and get updated status of the desired elements.
- The NRF supports the following functions:
  - Maintains the profiles of the available NF instances and their supported services in the 5G core network
  - Allows consumer NF instances to discover other providers NF instances in the 5G core network
  - Allows NF instances to track the status of other NF instances

Service Name	Description
Nnrf_NFManagement	Provides support for register, deregister and update service to NF, NF services. Provide consumers and SCP with notifications of newly registered/updated/deregistered NF along with its NF services.
Nnrf_NFDiscovery	Enables one NF service consumer or SCP to discover a set of NF instances with specific NF service or a target NF type. Also enables one NF service or SCP to discover a specific NF service.
Nnrf_AccessToken	Provides OAuth2 2.0 Access Tokens for NF to NF authorization as defined in TS 33.501 [29].