EURECOM

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A journey in the 5G core network

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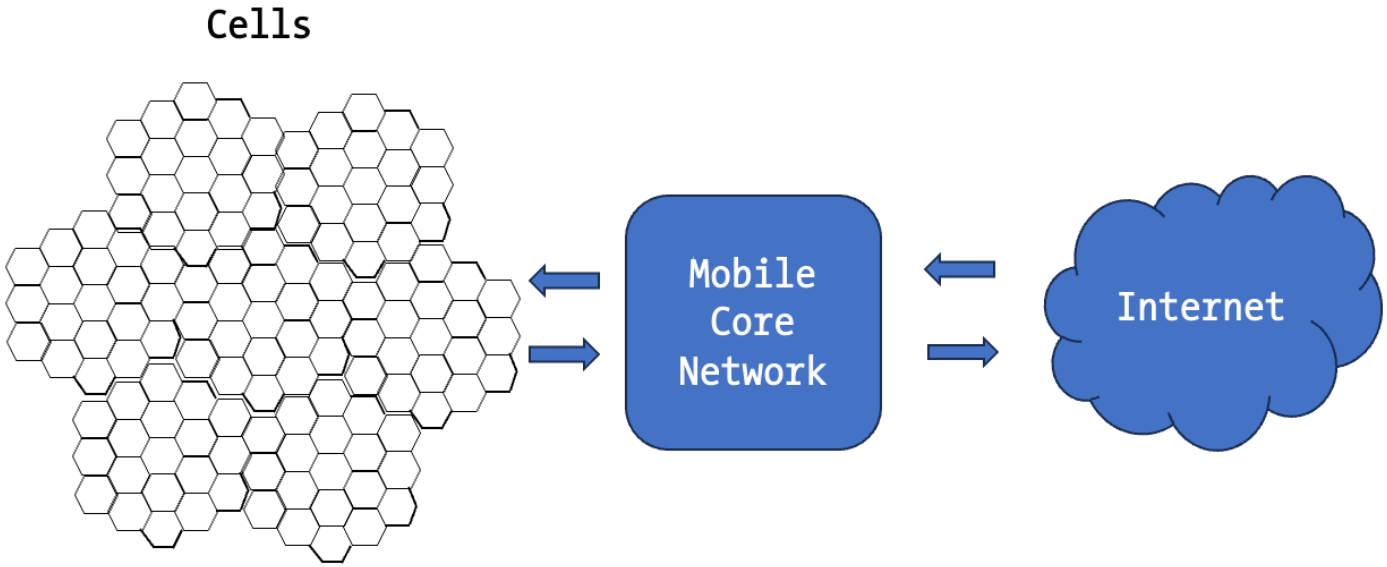
- Agenda
  - Introduction
  - 4G and LTE
  - 5G

1. General Introduction

Core network definition

- A Mobile Core Network (MCN) is the central part of a mobile telecommunications network that manages and controls mobile devices' connectivity, data transfer, and communication services.
- It acts as the backbone of mobile networks, ensuring seamless connectivity between mobile users, external networks (like the Internet), and other telecom services.



Mobile Core Network functions

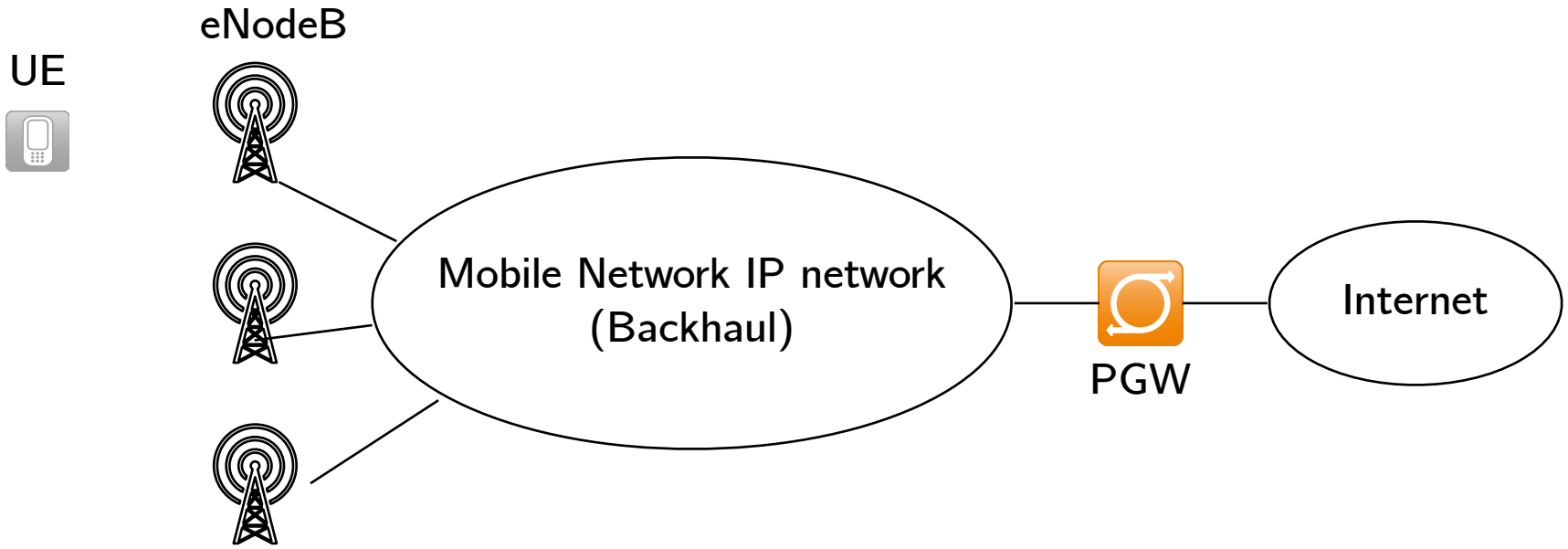
- Authentication & Security – Ensures that only authorized users can access the network.
- Mobility Management – Tracks users as they move between different locations and ensures continuous connectivity.
- Call & Session Management – Manages voice calls, SMS, and data sessions.
- Data Routing & Internet Access – Directs mobile data to and from external networks, including the internet.
- Quality of Service (QoS) Management – Prioritizes network traffic to ensure optimal performance for users.
- Billing & Charging – Tracks data usage and call duration for billing purposes.

Evolution of the core network technologies

- Circuit-Switched Core (Used in 2G/3G) – Primarily handles voice calls.
- Packet-Switched Core (Used in 3G/4G) – Handles data traffic over IP networks.
- Evolved Packet Core (EPC) (Used in 4G LTE) – Unifies voice and data over an IP-based network.
- 5G Core (5GC) – Introduces cloud-native, software-defined networking (SDN) and network slicing for advanced capabilities.

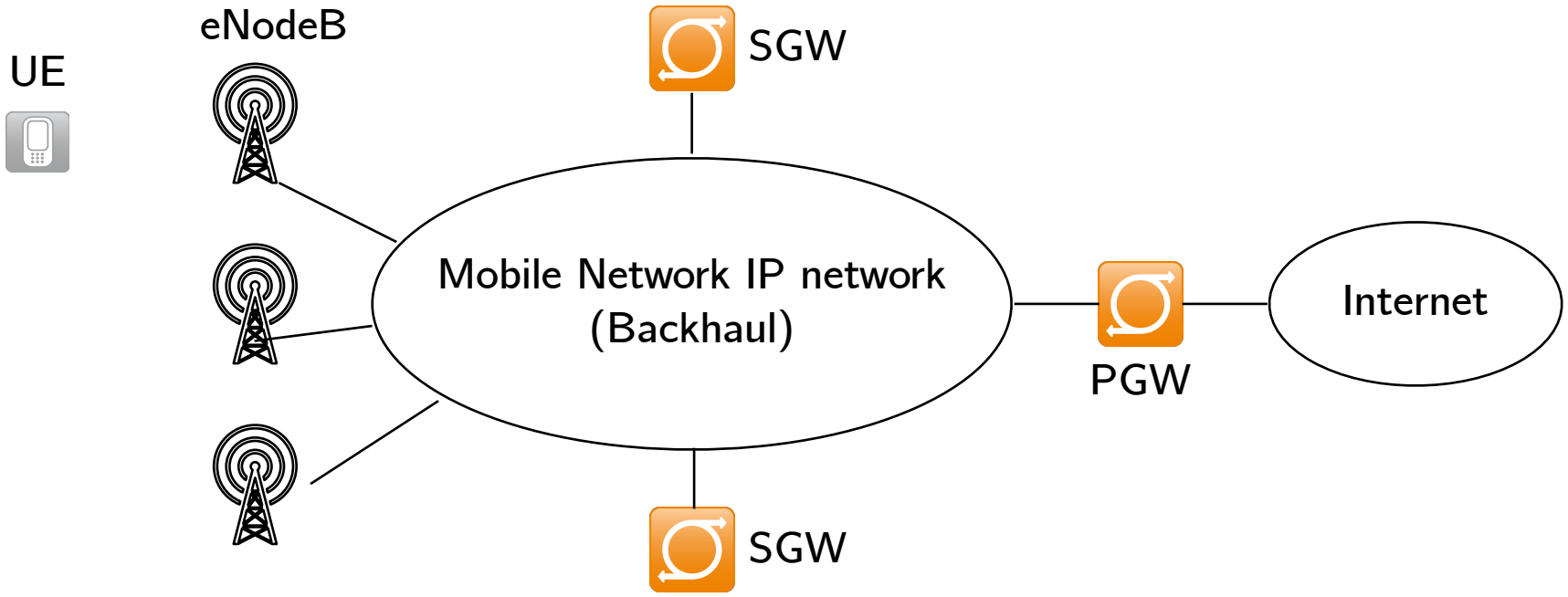
2. 4G and LTE

All IP architecture



- No mobility management in the Internet
- All data packets towards a mobile users have to pass by the PGW (Packet Gateway)

All IP architecture

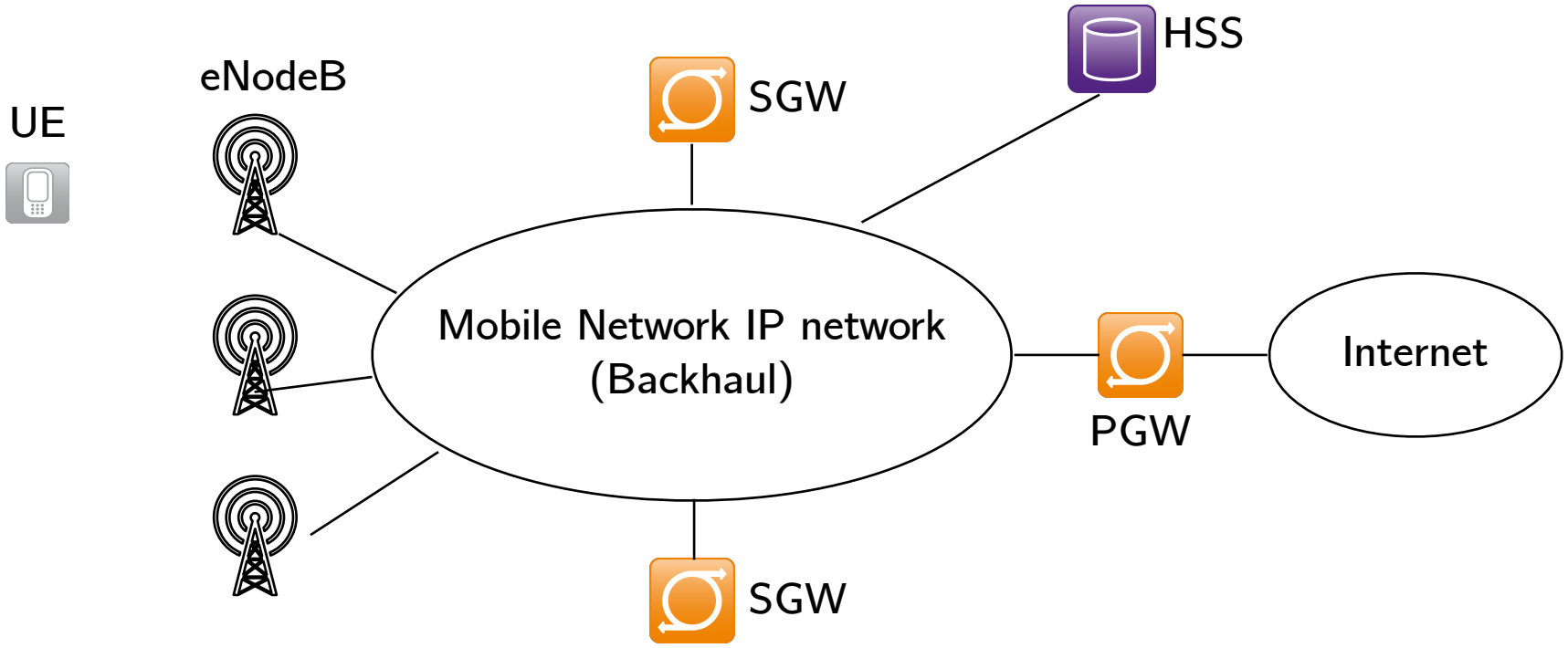


- Need to reduce the load on the PGW in case of mobility
- Introduction of the Serving Gateway
  - It covers a certain regions (number of eNodeB)
  - It is an intermediary node between the PGW and UEs

PGW and SGW

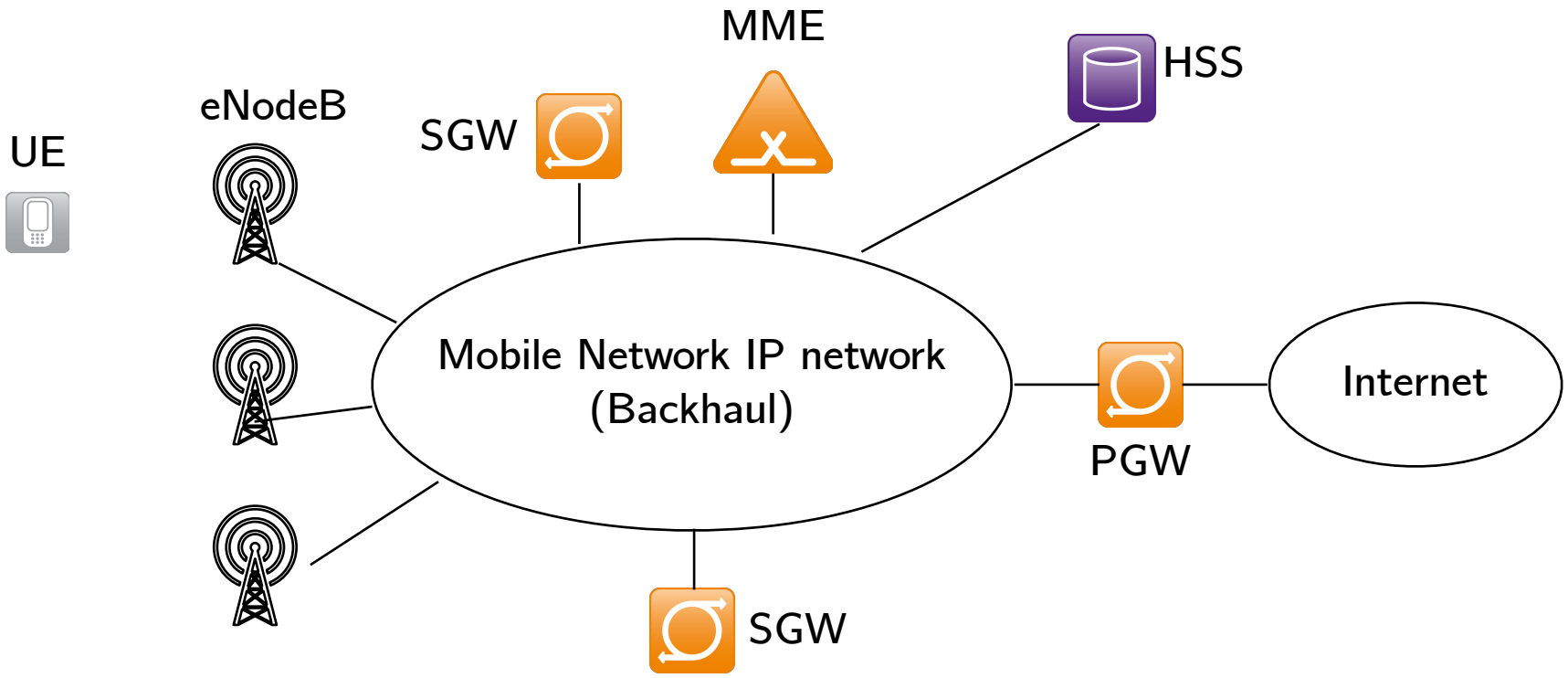
- S-GW (Serving GateWay) routes and forwards user data packets, acts as a user plane mobility anchor during inter-eNodeB handovers and between LTE and other 3GPP technologies. For idle state UE, the S-GW terminates the DL data path and triggers paging when the DL data arrives for the UE.
  - It manages and stores UE contexts and performs replication of the user traffic in case of lawful interception.
- P-GW (Packet Data network GateWay) provides connectivity between the UE and external packet data networks, it provides the entry and exit point of traffic for the UE. A UE may have simultaneous connectivity with more than one P-GW for accessing multiple Packet Data Networks.
  - The P-GW performs policy enforcement, packet filtering for each user, charging support, lawful interception and packet screening. The P-GW also acts as the anchor for inter technology handovers.

Control procedures: authentication, autorisation



- Home Subscriber Server (HSS)
  - Data base including information on the subscribers (IMSI, secret key, location, etc.)

Control procedures: authentication, autorisation

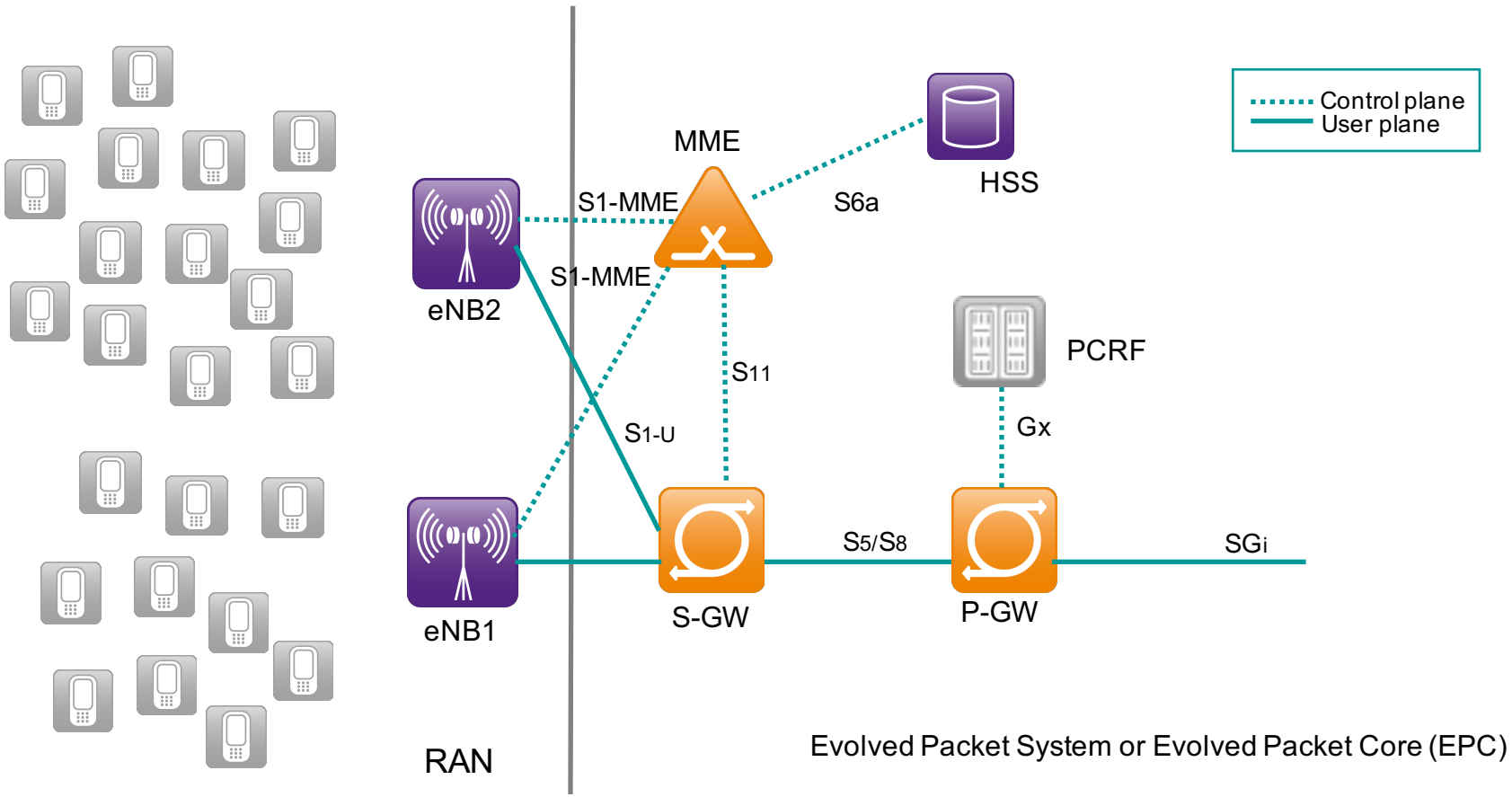


- HSS can be accessed directly by eNodeBs
- Mobility Management Element (MME)
  - Manage authentication, autorisation, mobility, data plane traffic establishment, etc.

MME

- MME is the key control-node for the LTE access-network.
  - Idle mode UE tracking and paging procedures.
  - bearer activation / deactivation process
  - responsible for choosing the S-GW (see below) for the UE at the initial attach and at time of intra-LTE handover involving Core Network node relocation.
  - authenticating the user (in conjunction with the HSS).
- NAS (Non-Access Stratum) signalling terminates at the MME which is also responsible for the generation and allocation of temporary identities to the UEs.
- The MME is the termination point in the network for ciphering/integrity protection for NAS signalling and handles security key management.
- Lawful interception of signalling is also a function provided by the MME. The MME provides the control plane function for mobility between LTE and 2G/3G access networks and interfaces with the home HSS for roaming UEs.

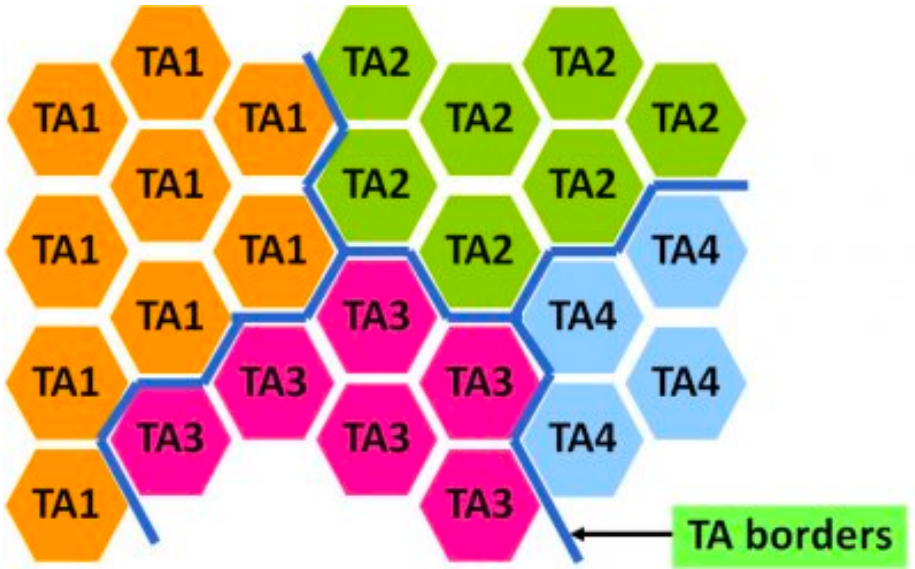
Interfaces


Control plane
User plane
MME
HSS
S1-MME
S6a
S1-MME
eNB2
PCRF
S11
Gx
S1-U
eNB1
S-GW
S5/S8
P-GW
SGi
RAN
Evolved Packet System or Evolved Packet Core (EPC)

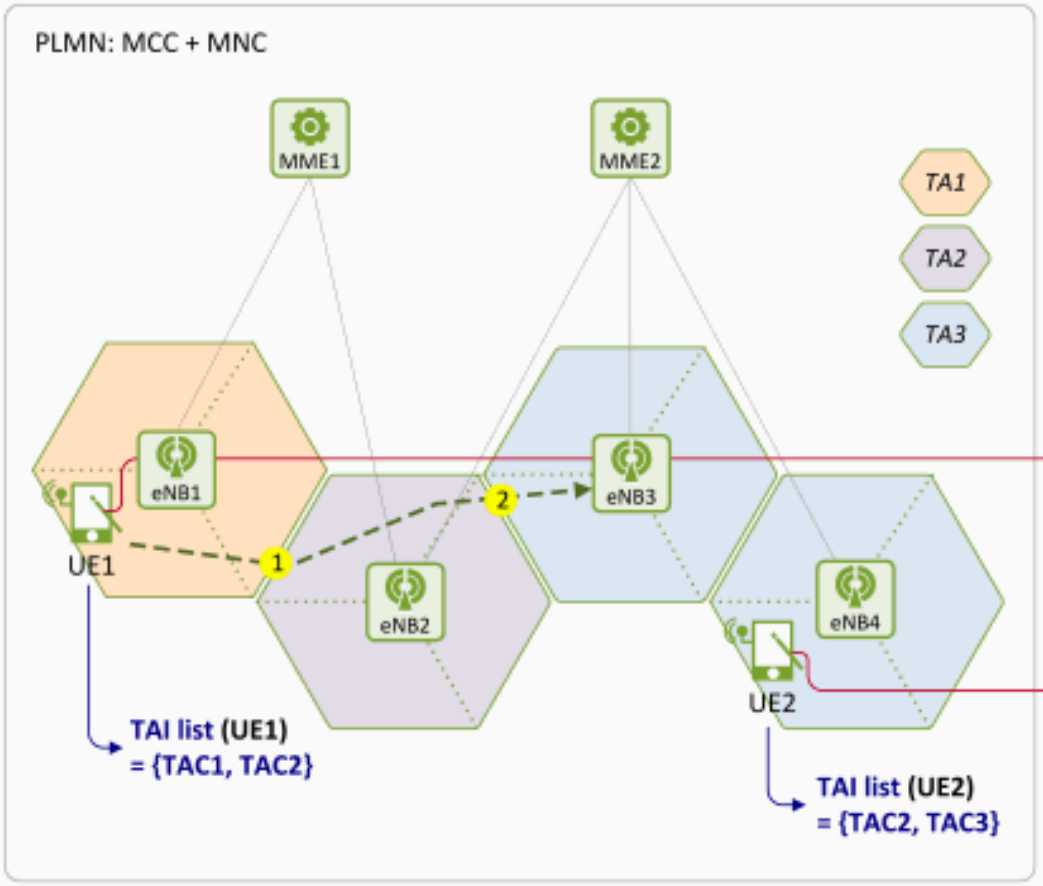
Tracking Area (TA)

TA concept

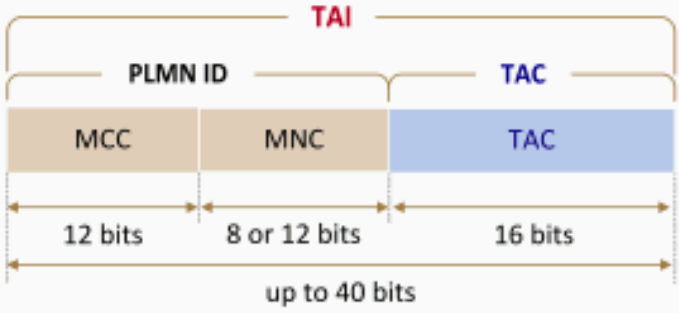
- Group cells into TAI
- A UE under the TAI does not update the MME about its location
  - An update is sent only to a new TAI
- MME tracks UE in Idle mode in the last known TA
  - Paging request to all eNBs belonging to this area



Tracking Area Identity (TAI)



- TAI Format



3. 5G

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 

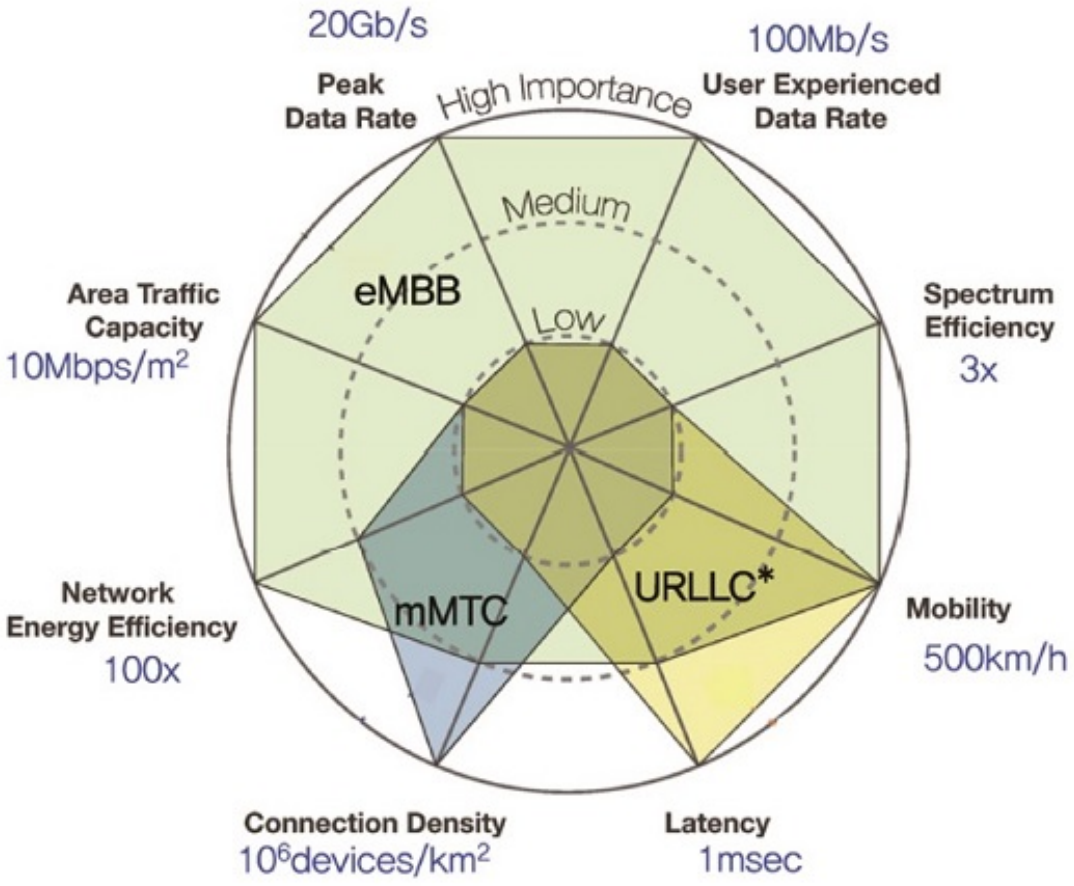
Challenge	**Data Rate**	**UBIQUITOUS COVERAGE QUALITY**	**Mobility**	**Connectivity Density**
Other Usecases	Cloud Service Smart Office AR/VR	Ultra-low Cost networks	Moving HotSpots Remote Computing	Smart wearables Smart Grid Mobile video surveillance

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

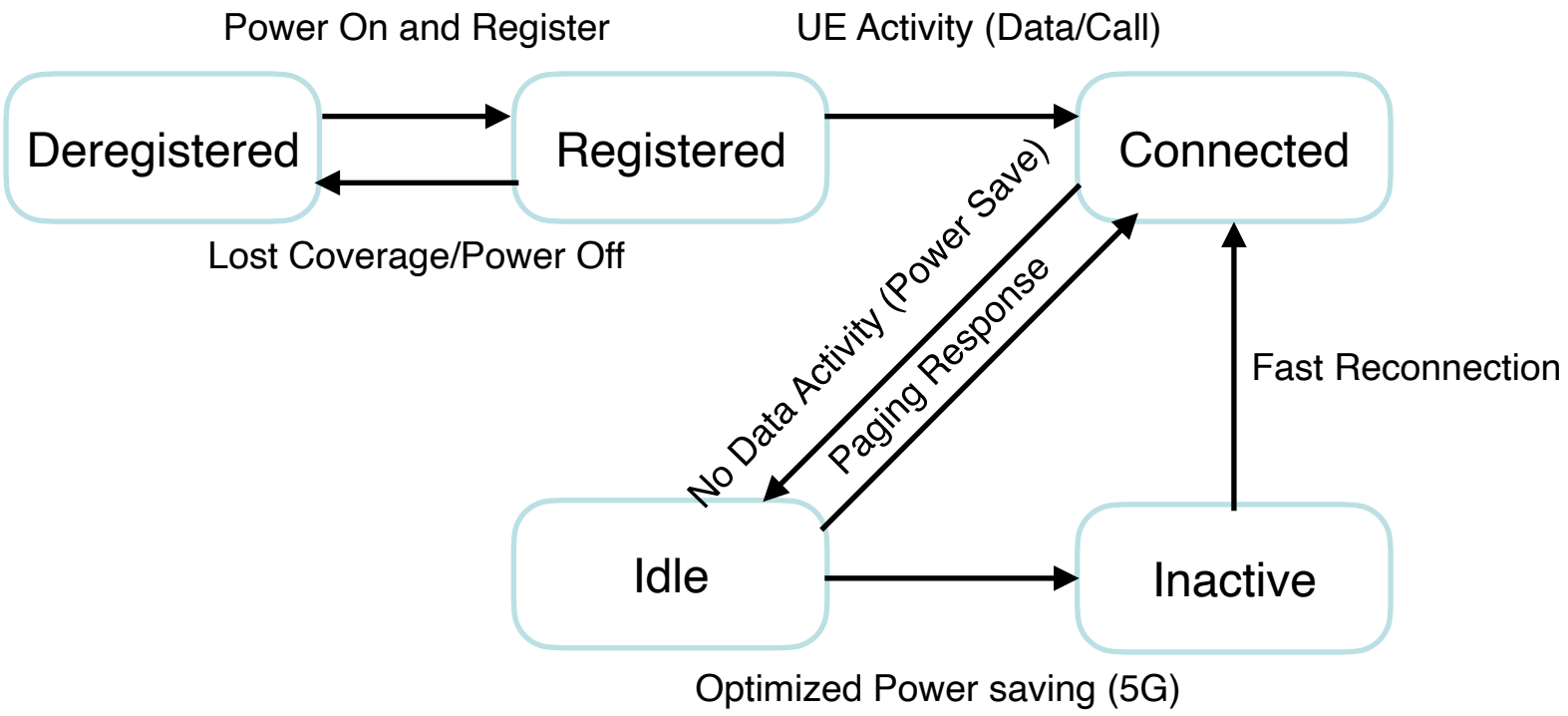

20Gb/s
Peak
Data Rate
High Importance
100Mb/s
User Experienced
Data Rate
Medium
Low
eMBB
Area Traffic
Capacity
10Mbps/m²
Spectrum
Efficiency
3x
mMTC
URLLC*
Network
Energy Efficiency
100x
Mobility
500km/h
Connection Density
10⁶devices/km²
Latency
1msec

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

5G UE States

UE states


Power On and Register
UE Activity (Data/Call)
Deregistered
Registered
Connected
Lost Coverage/Power Off
No Data Activity (Power Save)
Paging Response
Fast Reconnection
Idle
Inactive
Optimized Power saving (5G)

Differences between IDLE and INACTIVE states

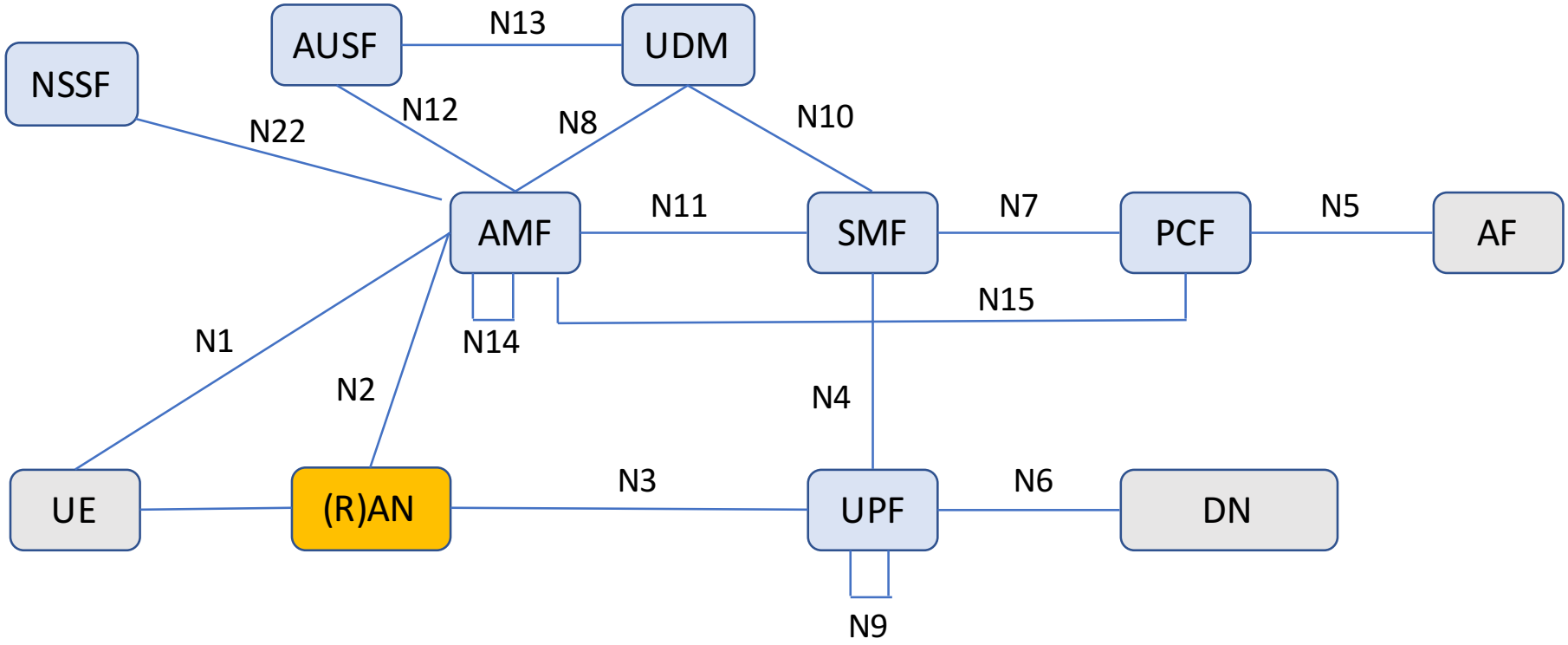
Feature	Idle (RRC-IDLE)	Inactive (RRC-INACTIVE)
Power Consumption	🟢 Low	🟢 Lower
Wake-up Time	⚠️ Longer (requires full connection setup)	✅ Faster (network retains context)
Location Updates	🔄 Tracking Area updates (TAU)	✅ Cell-level awareness
Network Paging	📶 Network-wide Paging	📶 More localized paging (faster response)
Latency on Data Request	⏳ Higher (needs full reconnection)	⚡ Lower (fast reconnection)
Battery Efficiency	🔋 Moderate	🔋 High (optimized for IoT & intermittent traffic)
Ideal Use Case	Long standby periods with minimal network interaction	Frequent but intermittent data exchange

UE Status Summary

State	Registered with 5GC?	Connection to Network?	Data Transfer?	Network Location Awareness	Power Consumption	Wake-Up Mechanism
Deregistered	❌ No	❌ No	❌ No	❌ Unknown	❌ Off or No Signal	🔄 User action (turn on)
Registered	✅ Yes	⏳ Depends on CM state	⏳ Possible	🔄 TA (Idle) / Cell (Connected)	🔄 Medium	🔄 Paging / UE Activity
Connected	✅ Yes	✅ Yes	✅ Yes	✅ Cell level	🔴 High	❌ Always Active
Idle	✅ Yes	❌ No	❌ No	🔄 Tracking Area (TA)	🟢 Low	📶 Paging from Network
Inactive	✅ Yes	⚠️ Semi-connected	❌ No	✅ Cell-level in RAN Paging Area	🟢 Low	📶 Fast Paging

5G Core network architecture

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

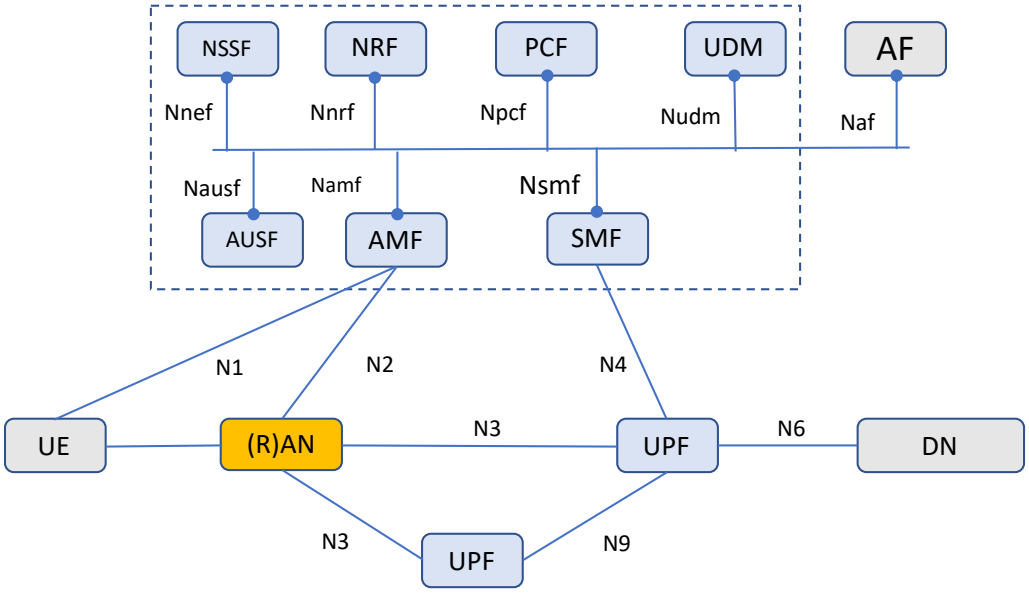
5G: Divide the monolithic element into smaller Network Function Block

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

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

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

5G Architecture service-based (communication bus)



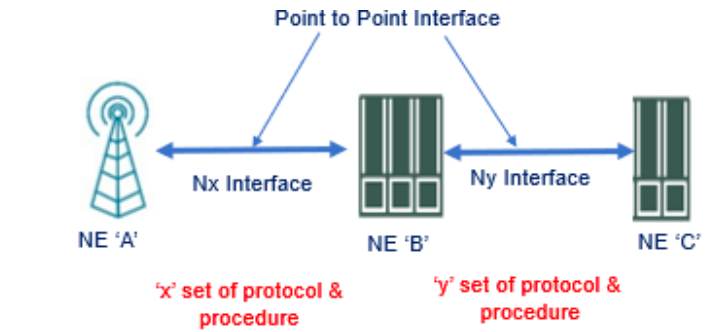
- No more point-to-point interface; Service-based using HTTPv2, Cloud-native
- Separation of the Control plane and data plane => SDN

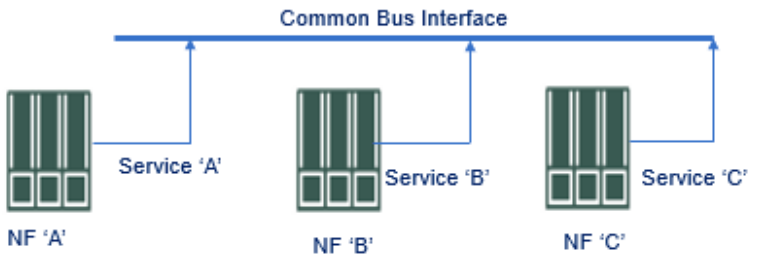
Advantages:

- Reduction in dependency between each interface
- Independent scaling of each function.
- Agility of having new features and services across network functions is increased.

Service-based architecture

- 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.

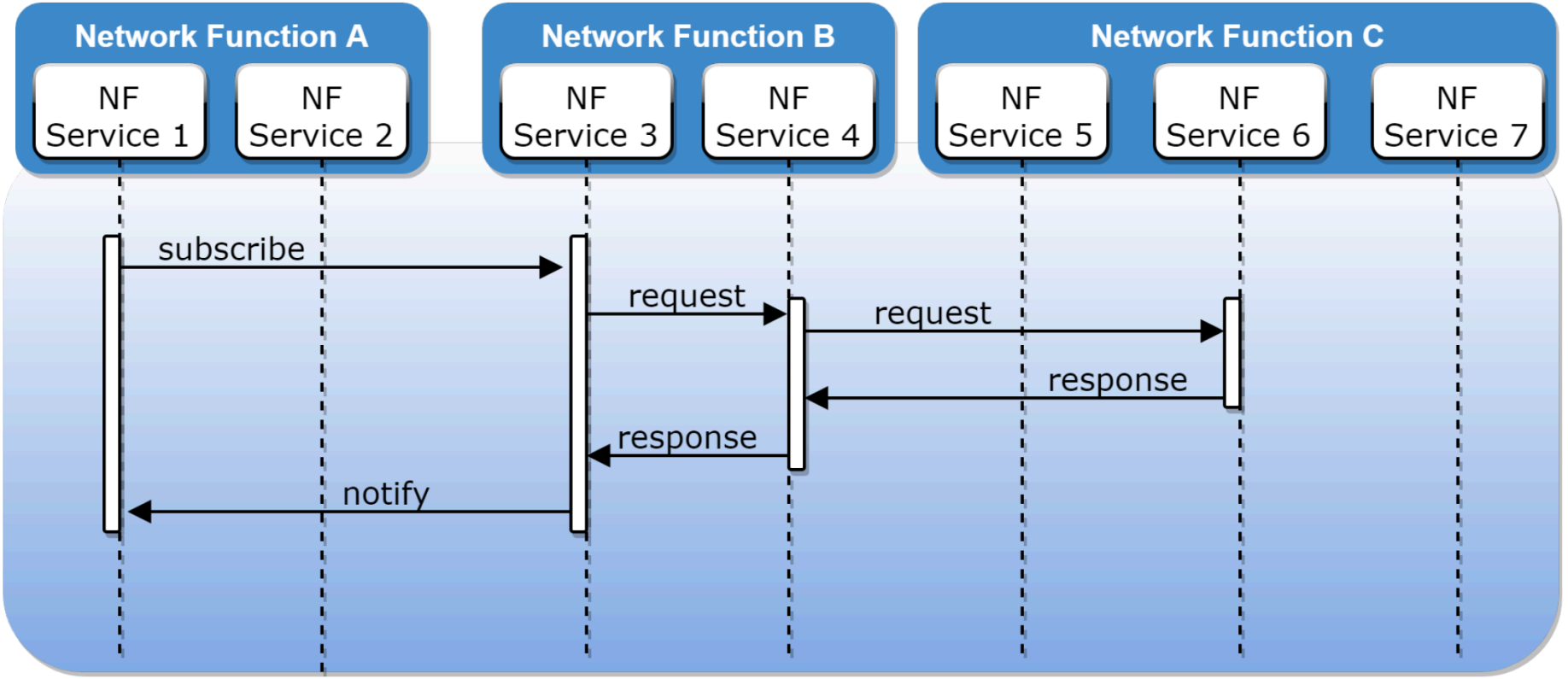




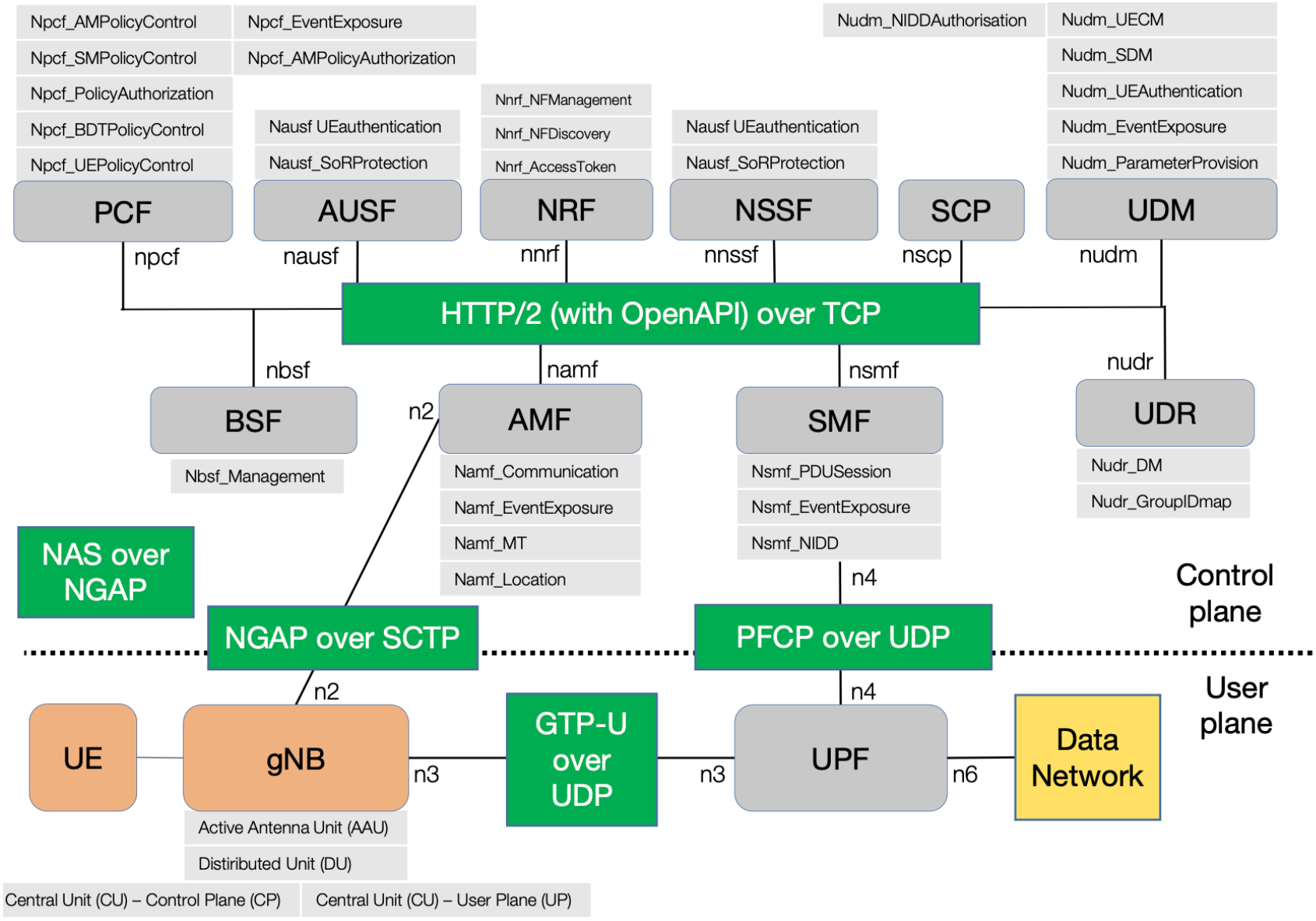
Network Function

- 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

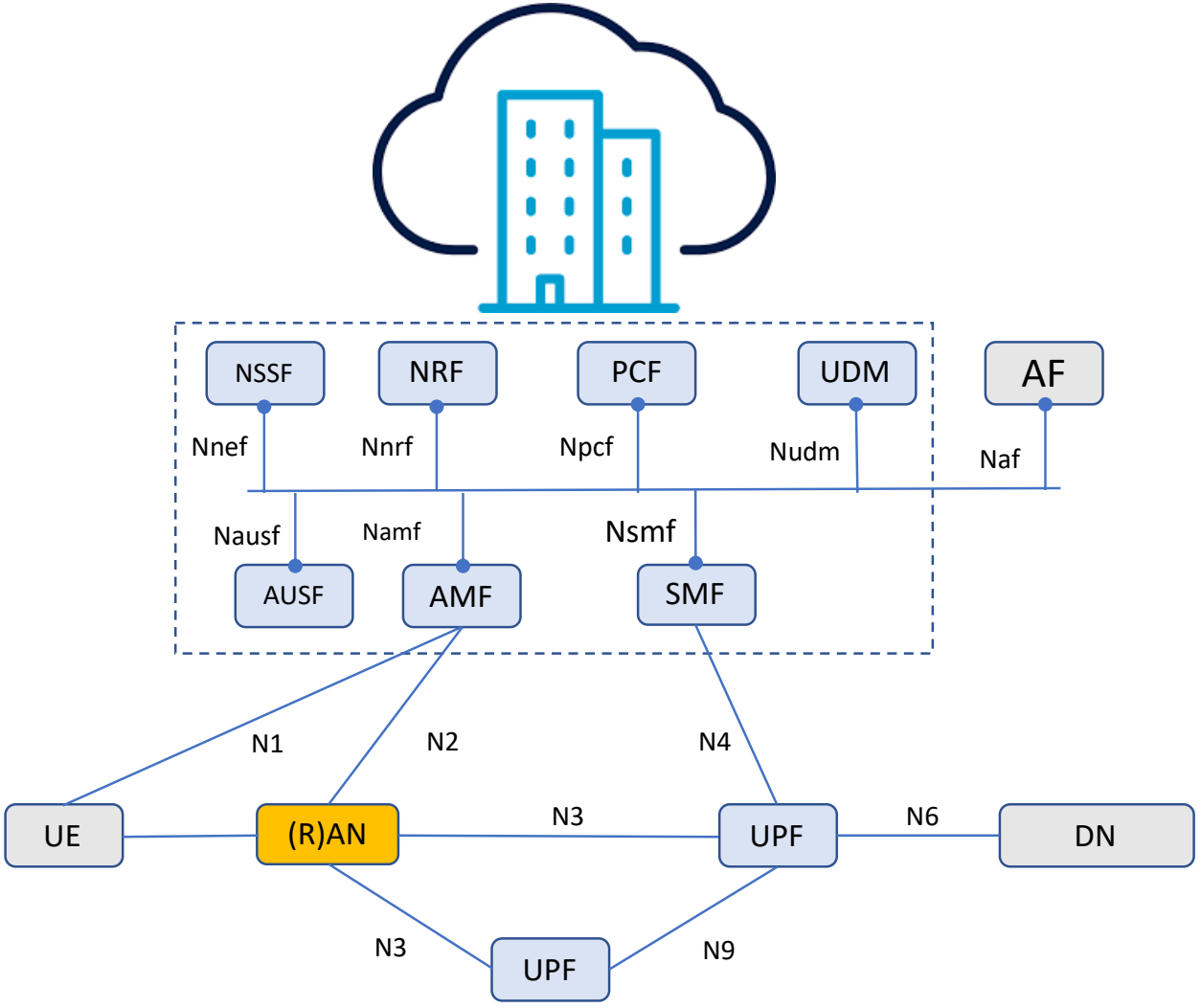
Network Function Network Service



Request/Response based on HTTP


Npcf_AMPolicyControl
Npcf_EventExposure
Npcf_SMPolicyControl
Npcf_AMPolicyAuthorization
Npcf_PolicyAuthorization
Npcf_BDTPolicyControl
Npcf_UEPolicyControl
PCF
npcf
Nausf UEauthentication
Nausf_SoRProtection
AUSF
nausf
Nnrf_NFManagement
Nnrf_NFDiscovery
Nnrf_AccessToken
NRF
nnrf
Nausf UEauthentication
Nausf_SoRProtection
NSSF
nnssf
SCP
nscp
Nudm_NIDDAuthorisation
Nudm_UECM
Nudm_SDM
Nudm_UEAuthentication
Nudm_EventExposure
Nudm_ParameterProvision
UDM
nudm
HTTP/2 (with OpenAPI) over TCP
nbsf
BSF
Nbsf_Management
n2
namf
AMF
Namf_Communication
Namf_EventExposure
Namf_MT
Namf_Location
nsmf
SMF
Nsmf_PDUSession
Nsmf_EventExposure
Nsmf_NIDD
nudr
UDR
Nudr_DM
Nudr_GroupIDmap
NAS over NGAP
NGAP over SCTP
n4
PFCP over UDP
Control plane
User plane
n2
n4
UE
gNB
n3
GTP-U over UDP
n3
UPF
n6
Data Network
Active Antenna Unit (AAU)
Distiributed Unit (DU)
Central Unit (CU) – Control Plane (CP)
Central Unit (CU) – User Plane (UP)

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
  - 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)

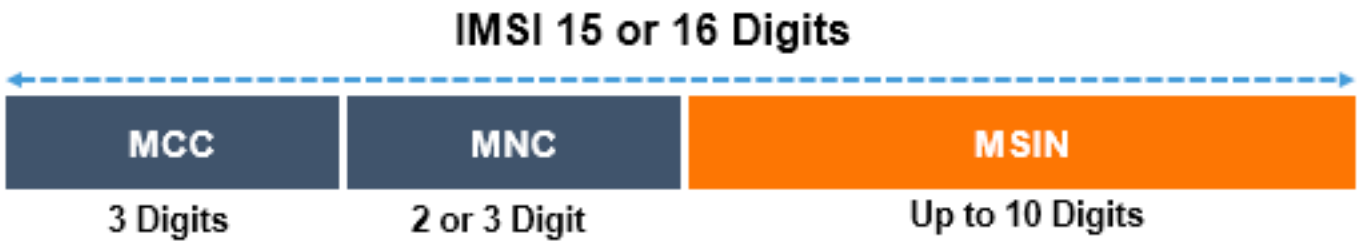
- AUSF: Performs authentication process with the user terminals
- UDM:
  - Generation of 3GPP authentication and key agreement (AKA) authentication credentials
  - User identification handling
  - Access authorization based on subscription data
  - UE's serving NF registration management
  - Subscription 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.

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



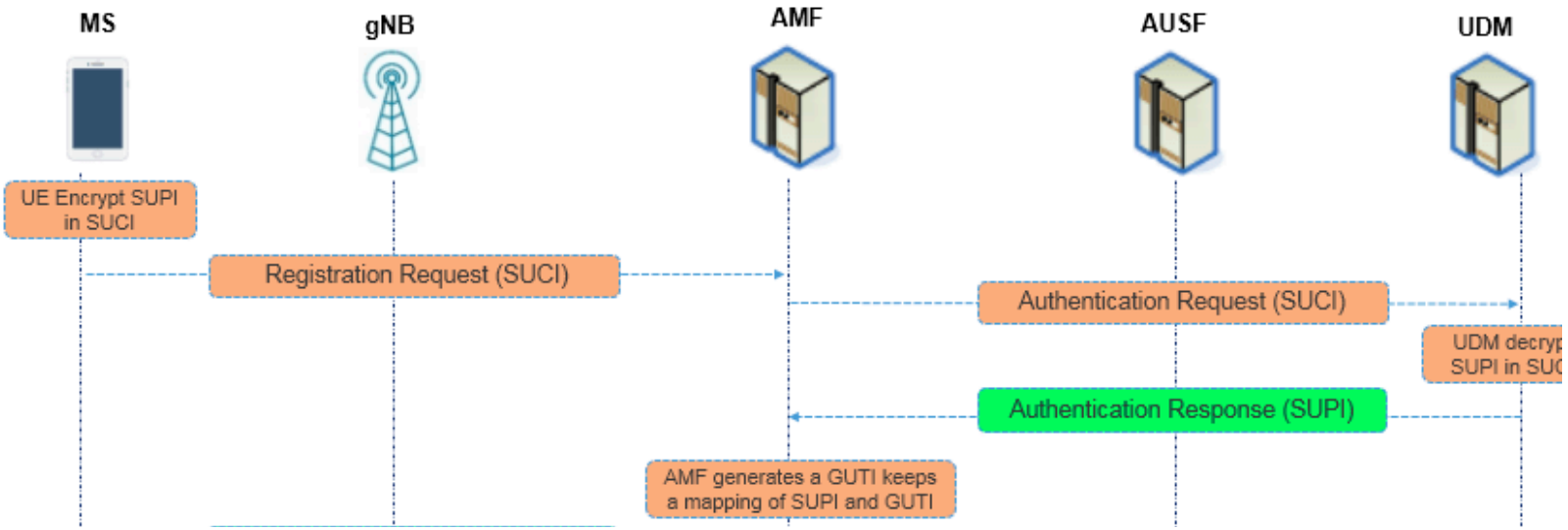
UE Identifier: Subscription Concealed Identifier (SUCI)

- 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.

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

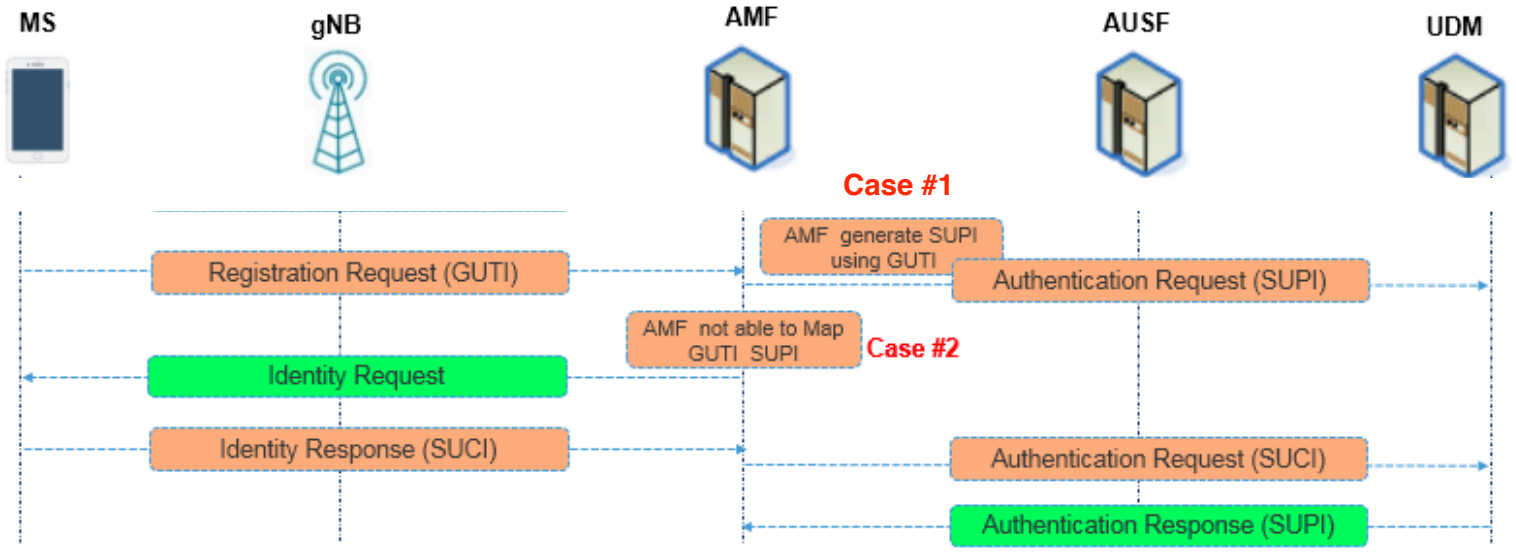
- 5G Globally Unique Temporary Identifier (GUTI) is allocated by an AMF to the UE that is common in both 3GPP and non 3GPP access.
- A UE can use the same 5G-GUTI for accessing 3GPP access security context within the AMF
- The AMF may assign a new 5G-GUTI to the UE at any time
- The 5G-GUTI comprises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

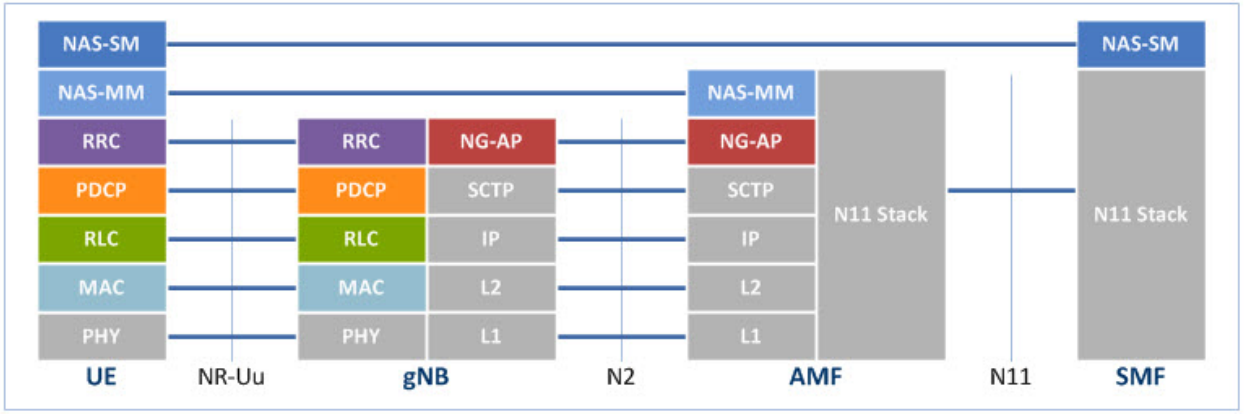
5G Identity Exchange between UE and Network

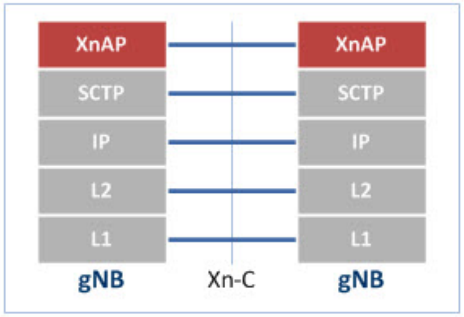


Subsequent registration

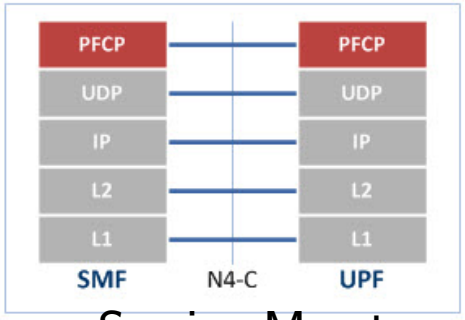
Control plane protocols

Registration &
Session Mgmt

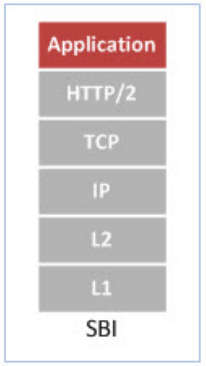




Handover Mgmt



Session Mgmt



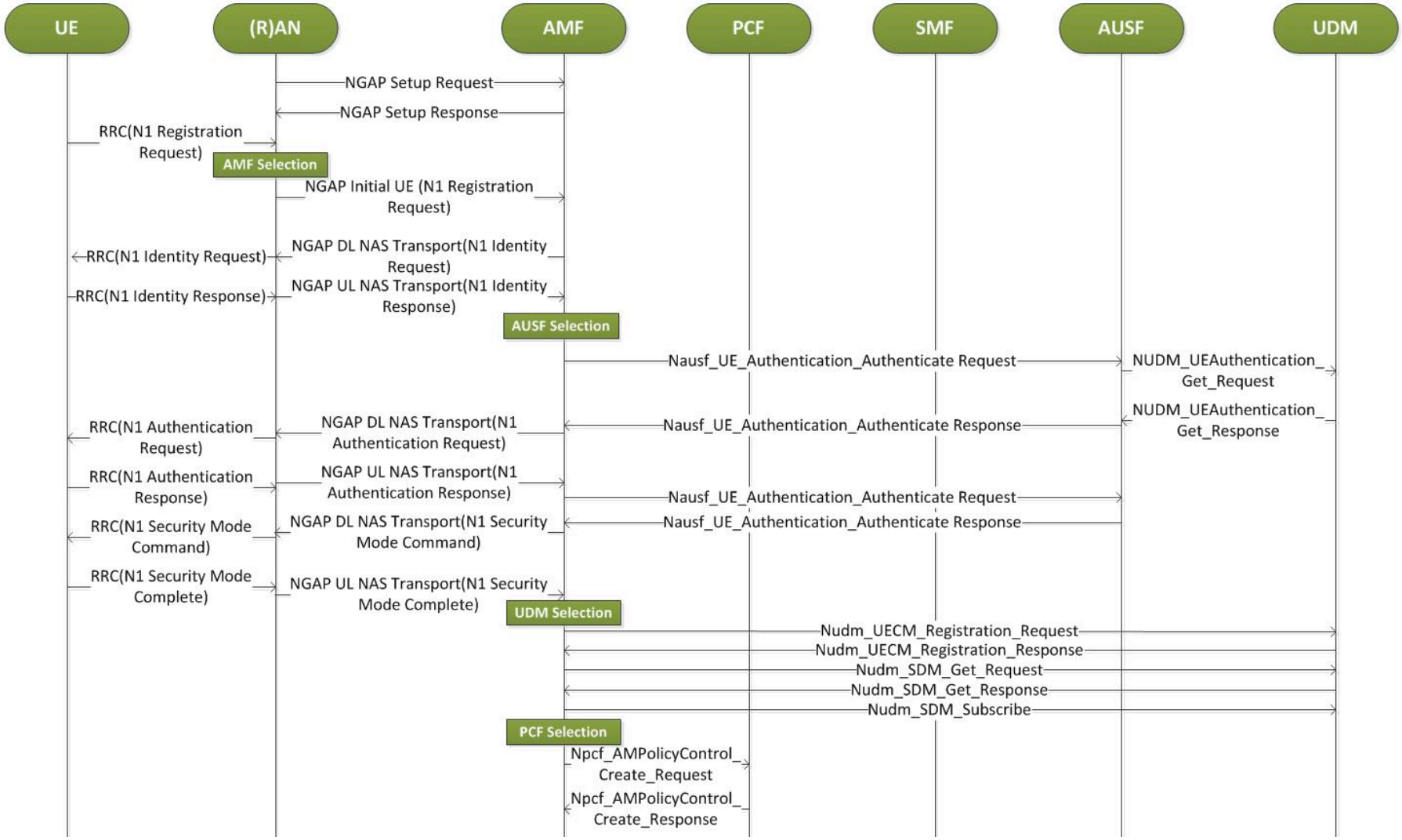
NG-AP

- 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.

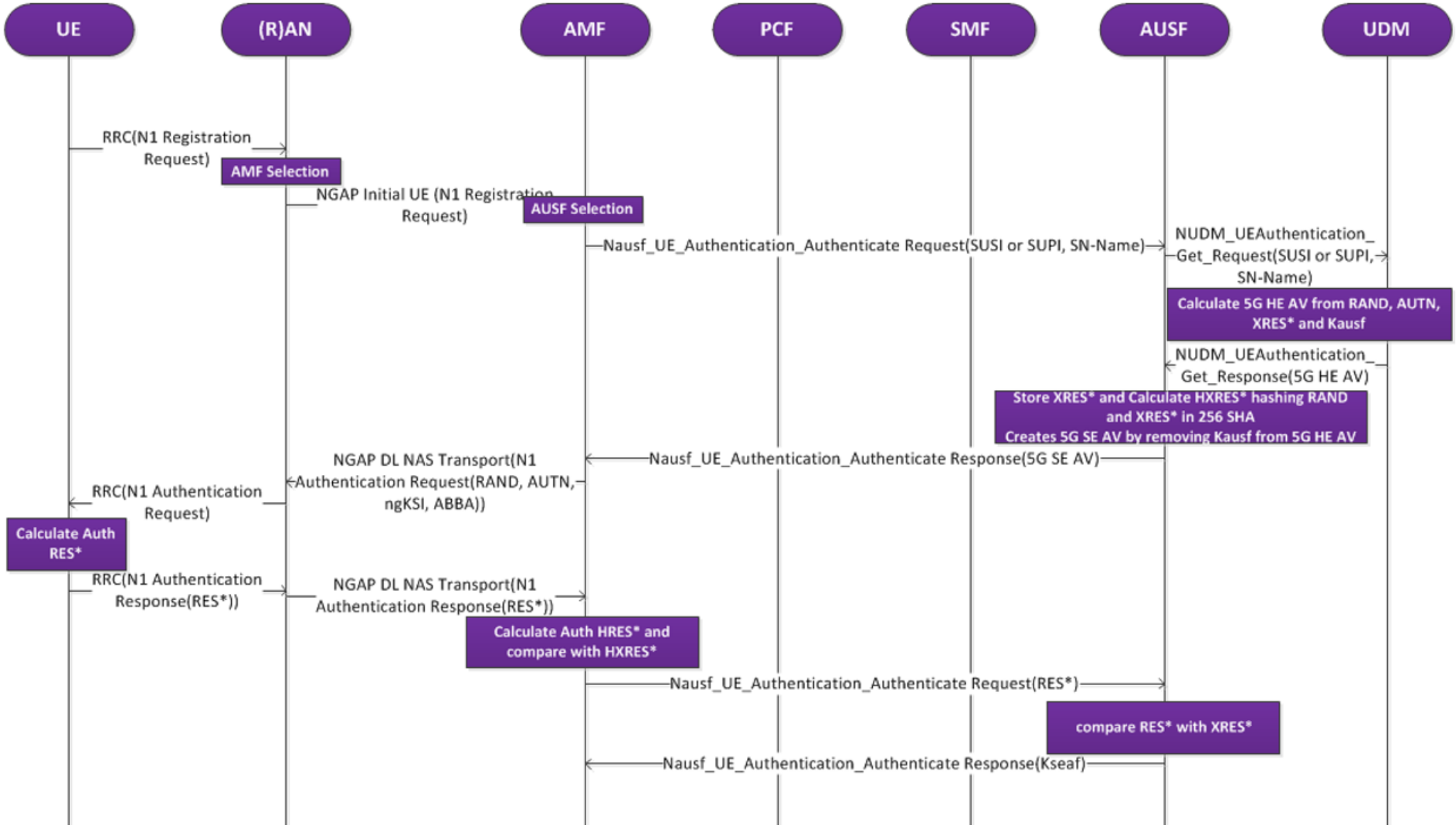
5G NAS

- 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
  - 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

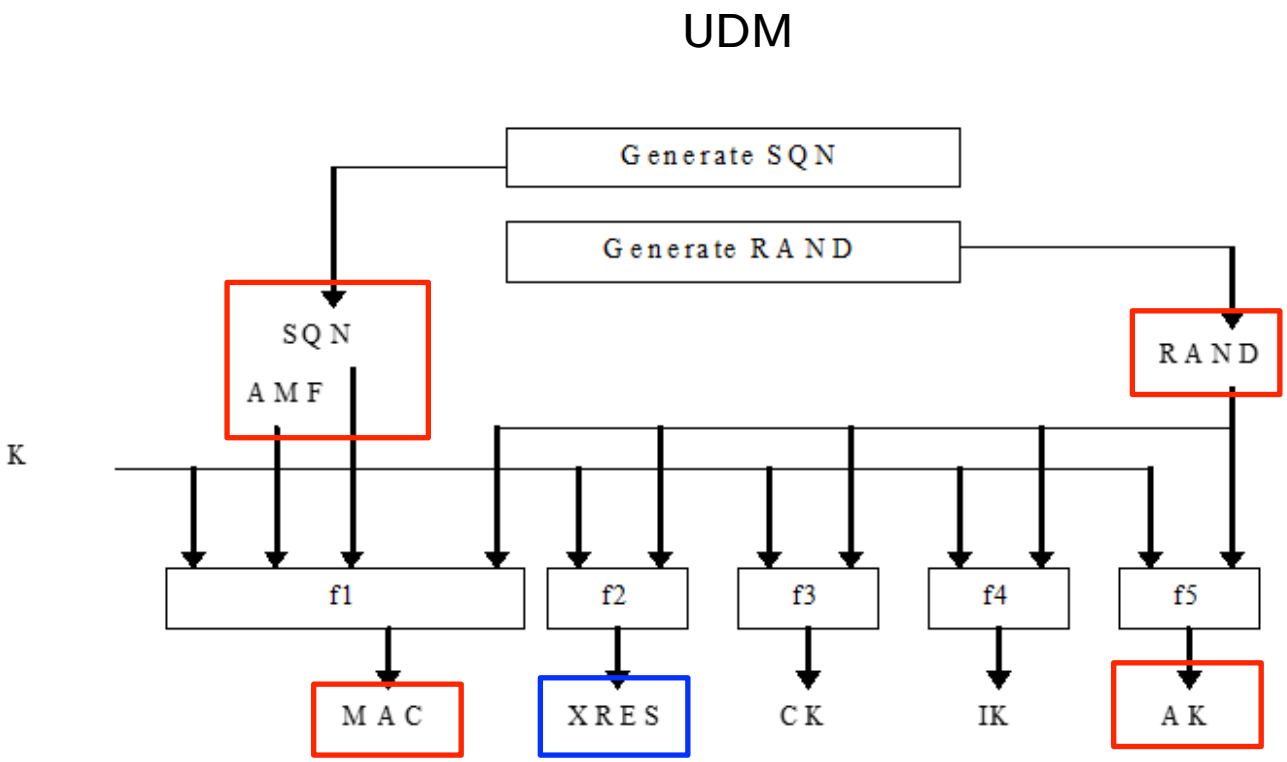


5G AKA

	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

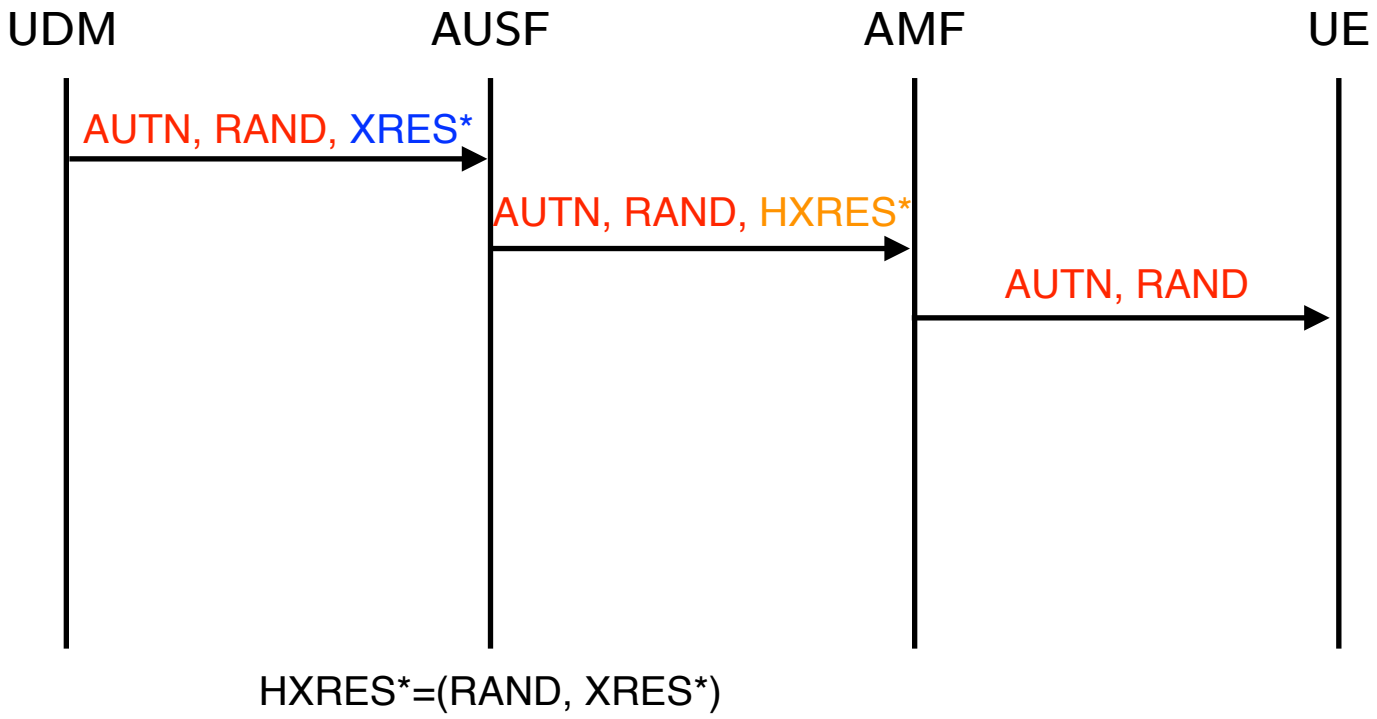
5G AKA: UDM and UE



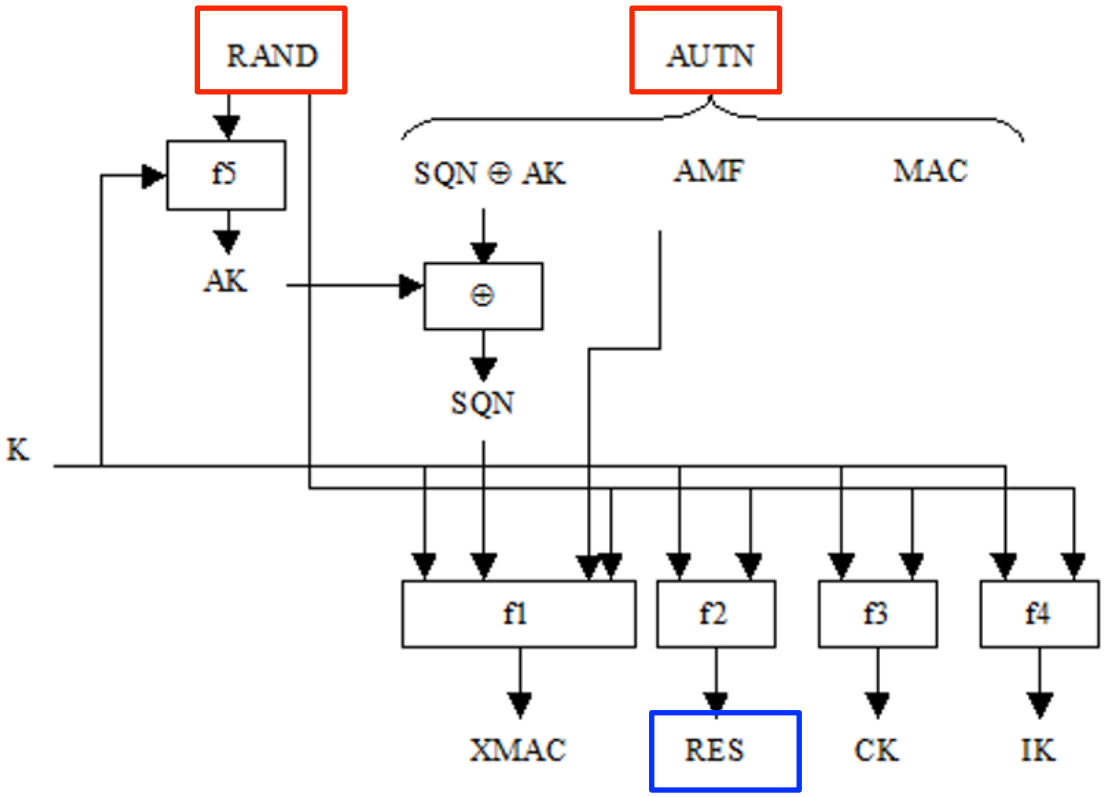
AUTN = (SQN+AK, RAND, MAC, AMF) (in Red) to UE

Generate XRES* from XRES (in Blue) to AUSF

Frome UDM to UE



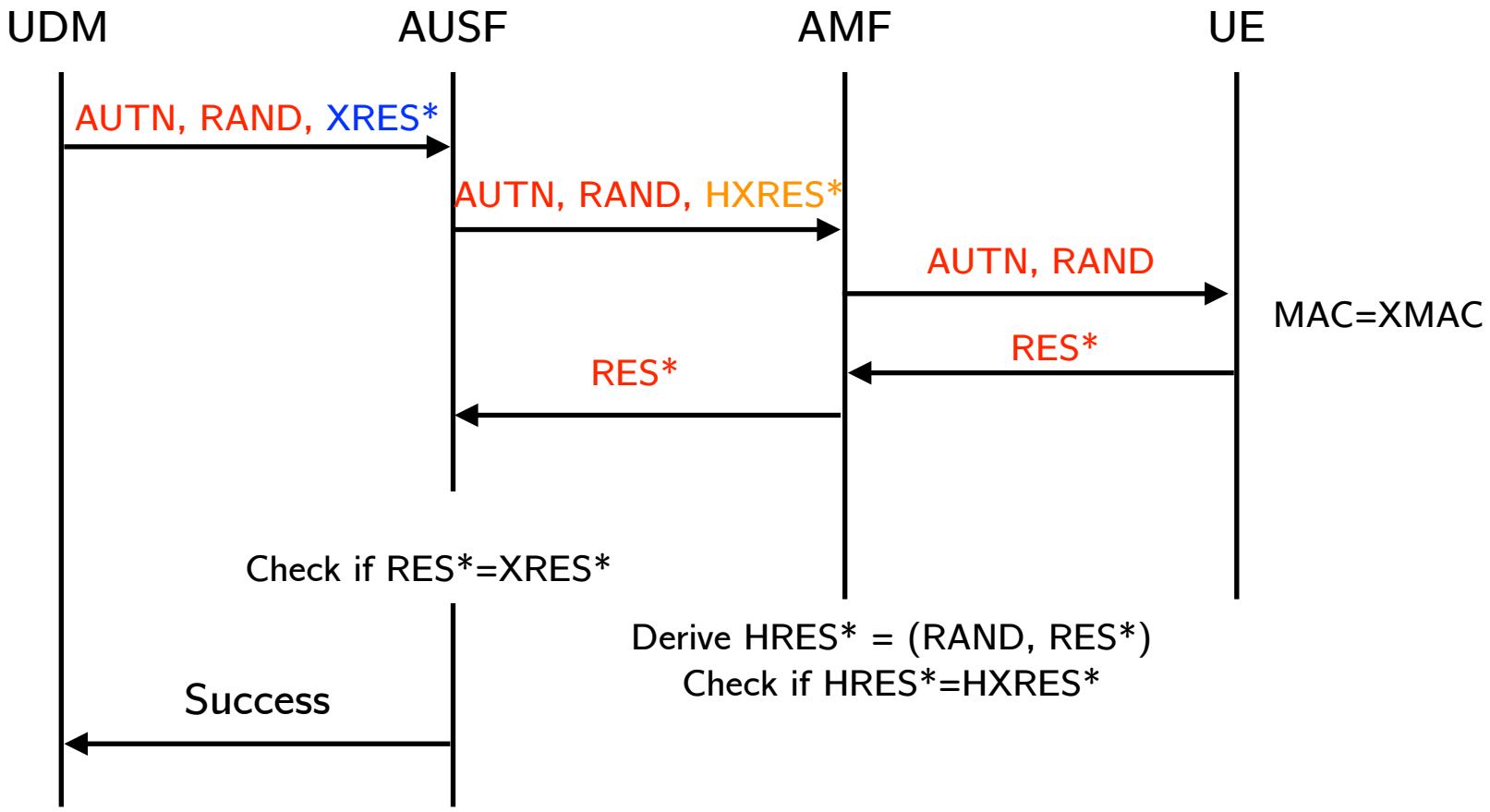
5G AKA: UDM and UE



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

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

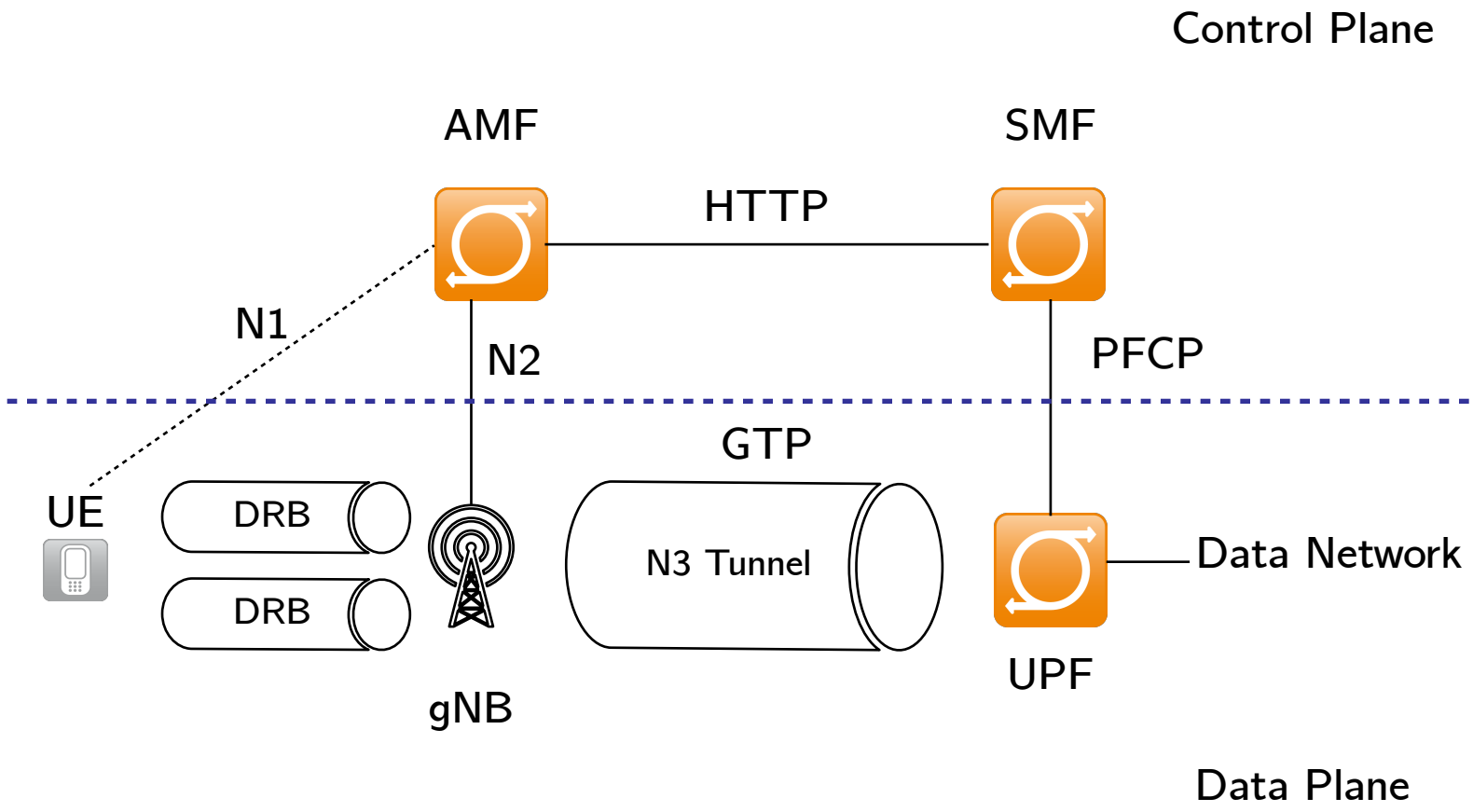
From UE to AUSF



Packet Data Unit (PDU) session or connectivity

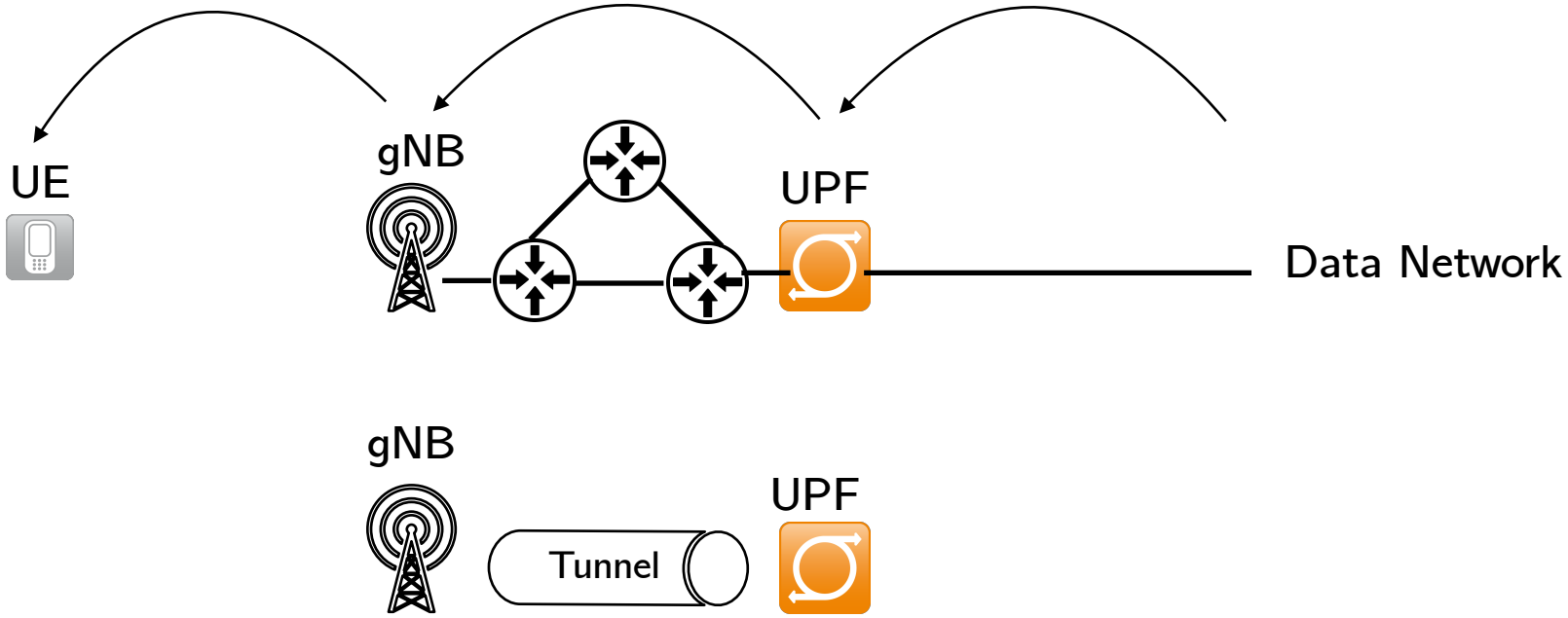
- 5GC supports PDU connectivity service
  - Provides exchange of PDUs between a UE and a data network
    - PDU could be an IPv4/IPv6, Ethernet or Unstructured (IOT data)
  - PDU connectivity service is supported through PDU sessions established upon the request of a UE.
  - To establish a PDU session 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 the access network signaling connection between the UE and the access node and the N2 connection for this UE between AN and the AMF.

Packet Data Network (PDN) session



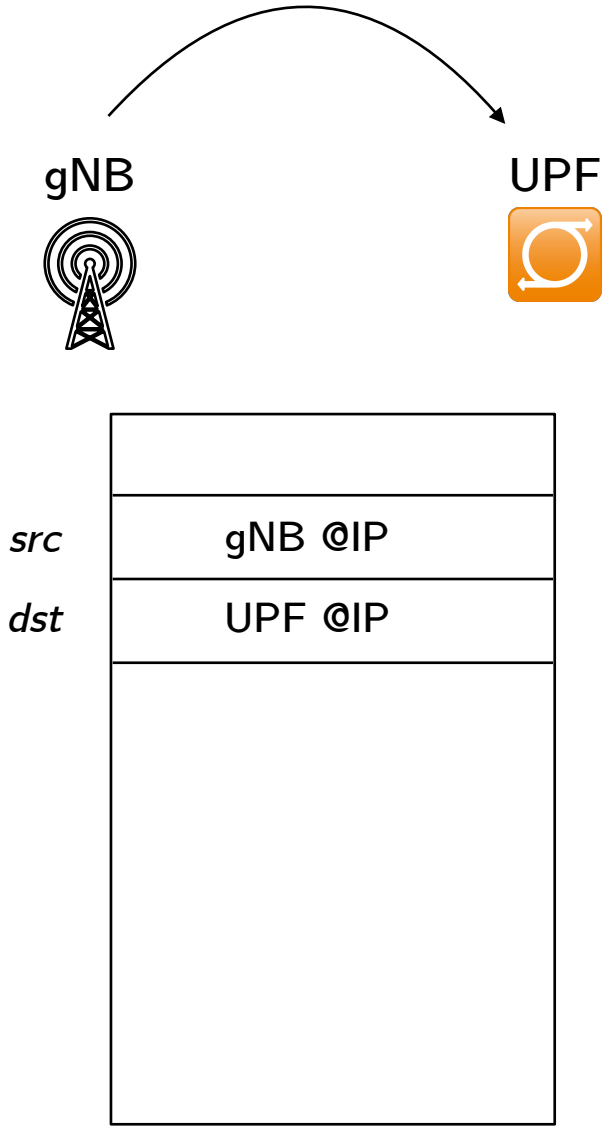
Tunneling concept

- Whatever the network topology, a packet always goes from the gNB and UPF, like having a tunnel between the gNB and UPF

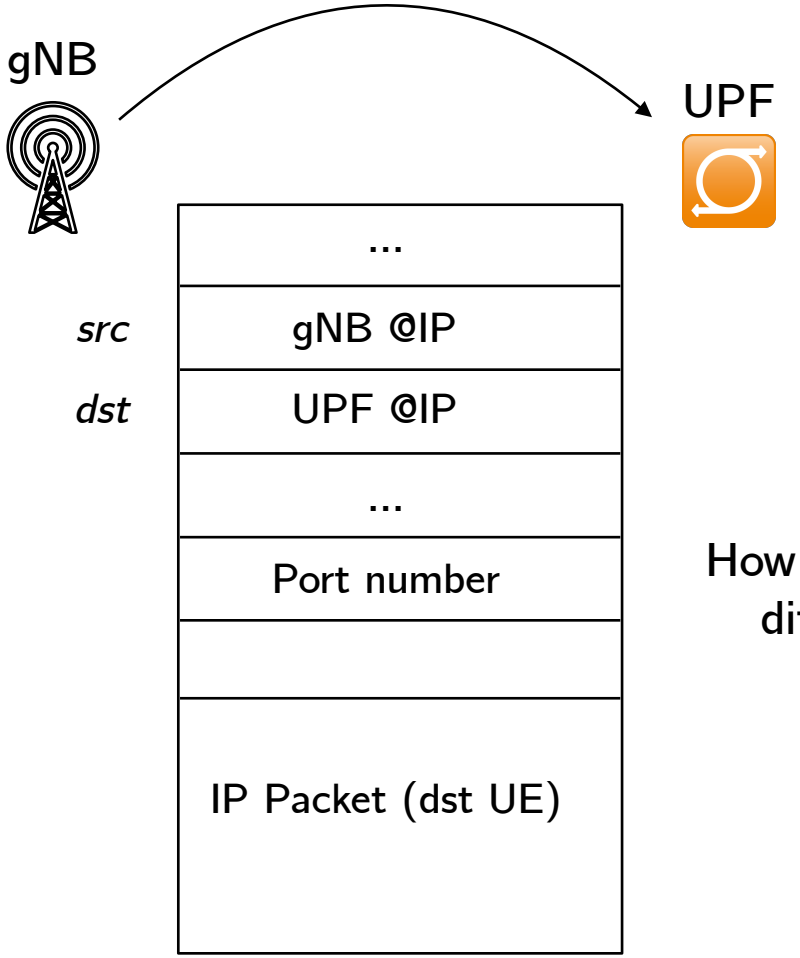


Layer 4 protocol

- The gNB always sends received packets to the UPF
  - It is not aware of what happen after the UPF
- A need for a transport protocol
  - TCP: too complex
  - UDP: simple. The reliability needs to be handled by the higher layers
- UDP
  - Between gNB and UPF,



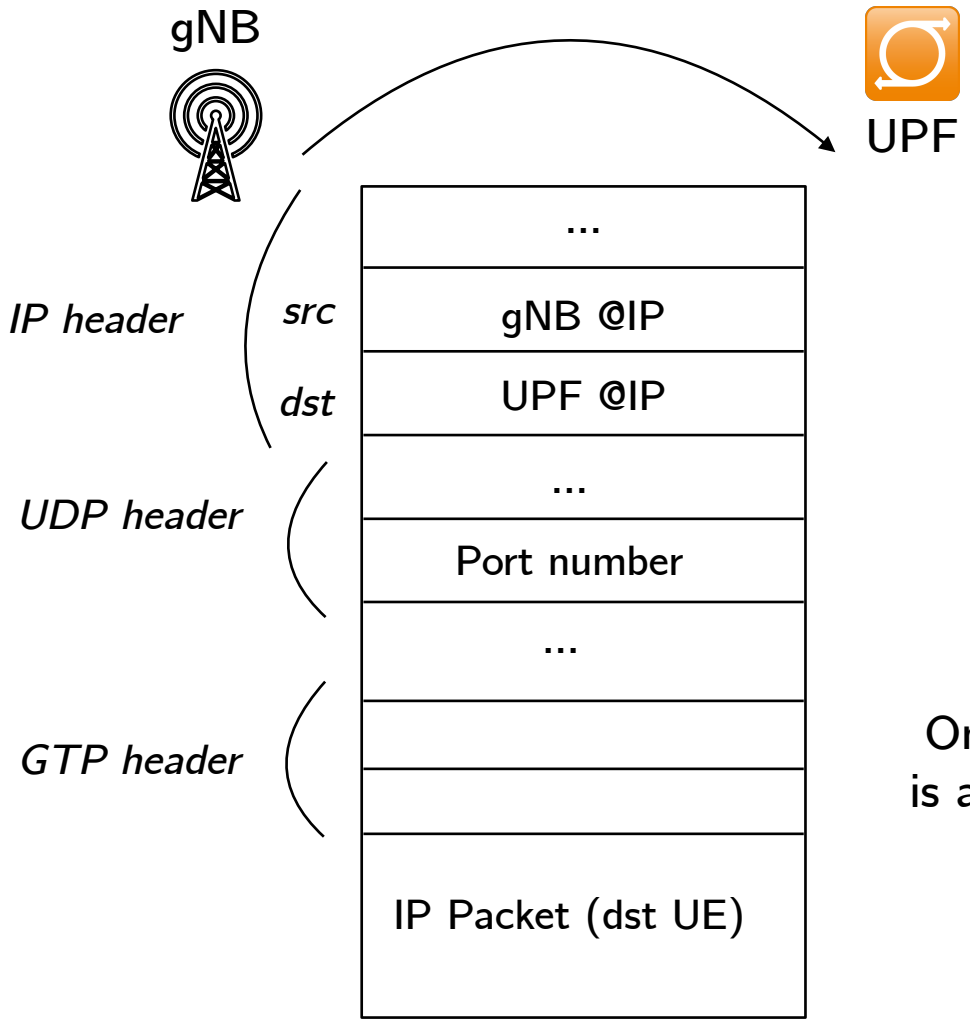
New layer



IPv4? IPv6?
How to avoid handling different format?

- An additional layer (new protocol, new format)
  - GTP, GPRS Tunneling protocol

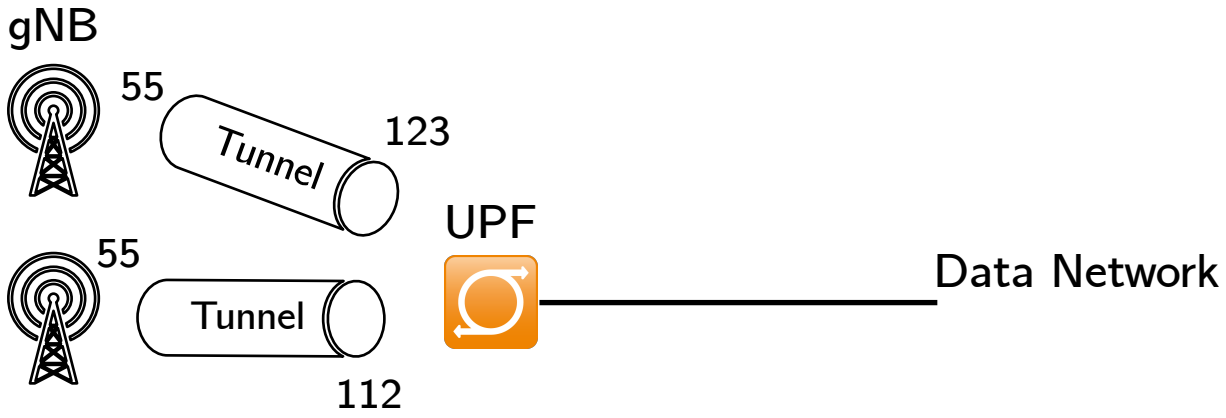
GTP-U



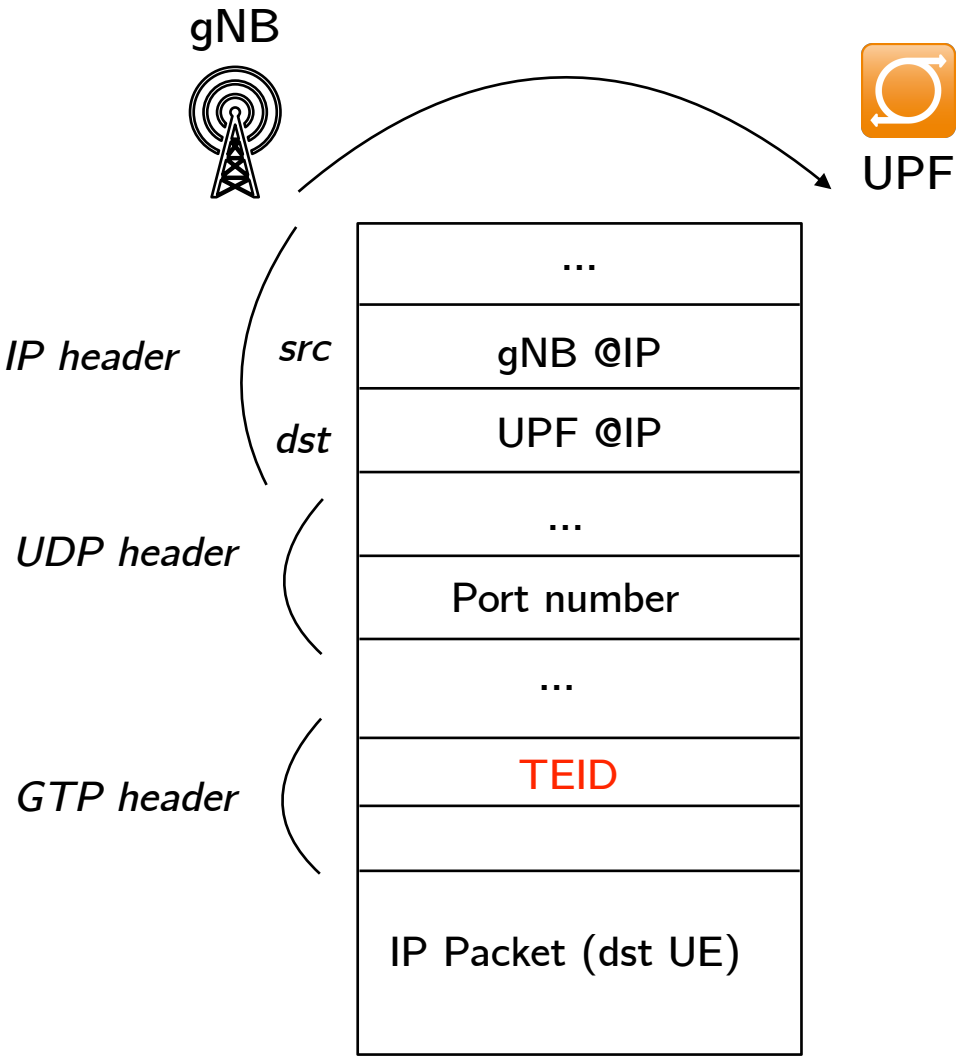
Only the GTP header
is analyzed by the UPF

GTP-U

- GTP-U runs on top of UDP
  - Simplicity by report to TCP. For reliability, it is end-to-end
  - Tunnel Endpoints Identifier (TEID) 32 bits to identify the end point of a tunnel
  - Each tunnel is identified by a pair of TEID
  - Configured by SMF via PFCP protocol

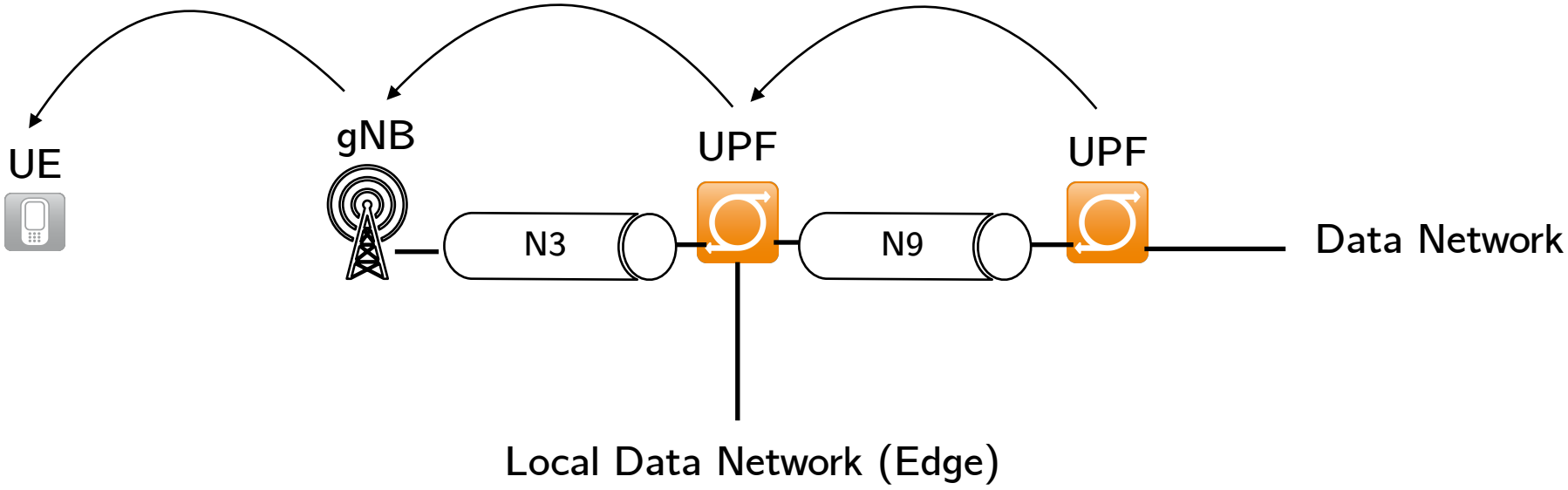


GTP-U



Only the GTP header is analyzed by the UPF and gNB

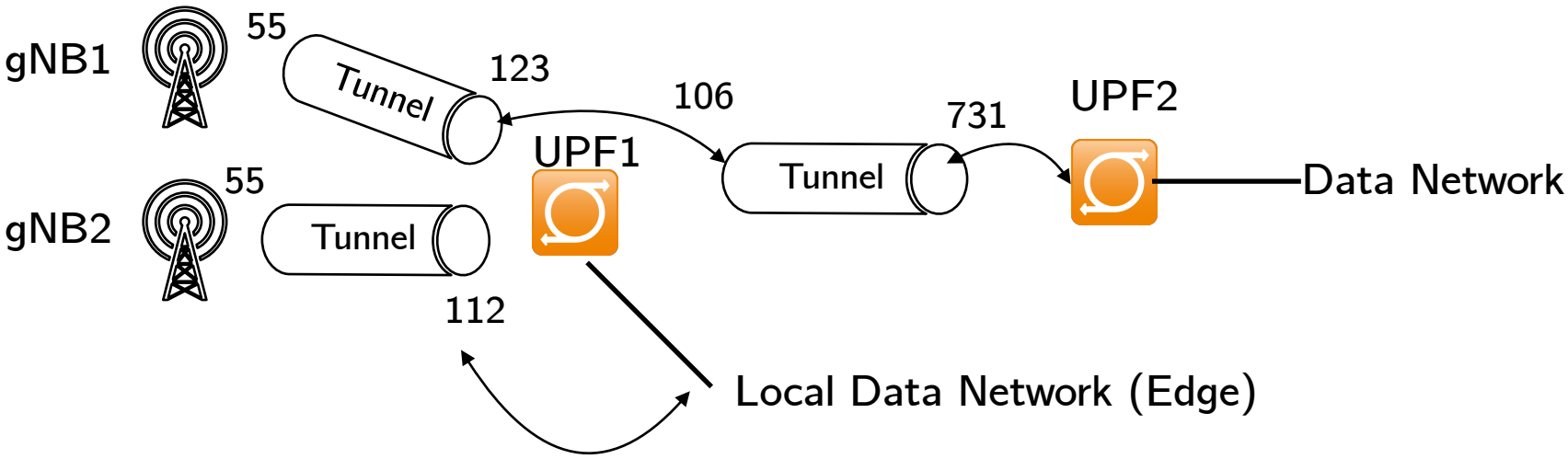
More advanced topology (Edge offload)



GTP-U TEID management

UPF1 Table

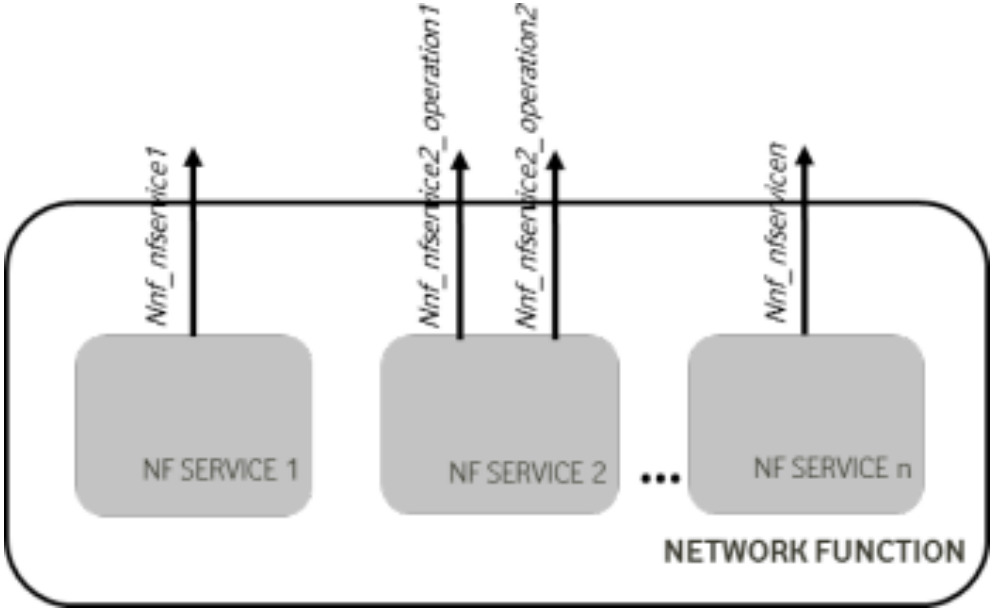
TEID	IPdst	Action	IPdst (Peer)	TEID	Port
106	-	Fwd	gNB2	55	N3
112	-	Decapsulate/Fwd	-	-	Edge
123	-	Fwd	UPF2	731	N9
-	@UE	Encapsulate/Fwd	gNB2	55	N3



NAS-SM

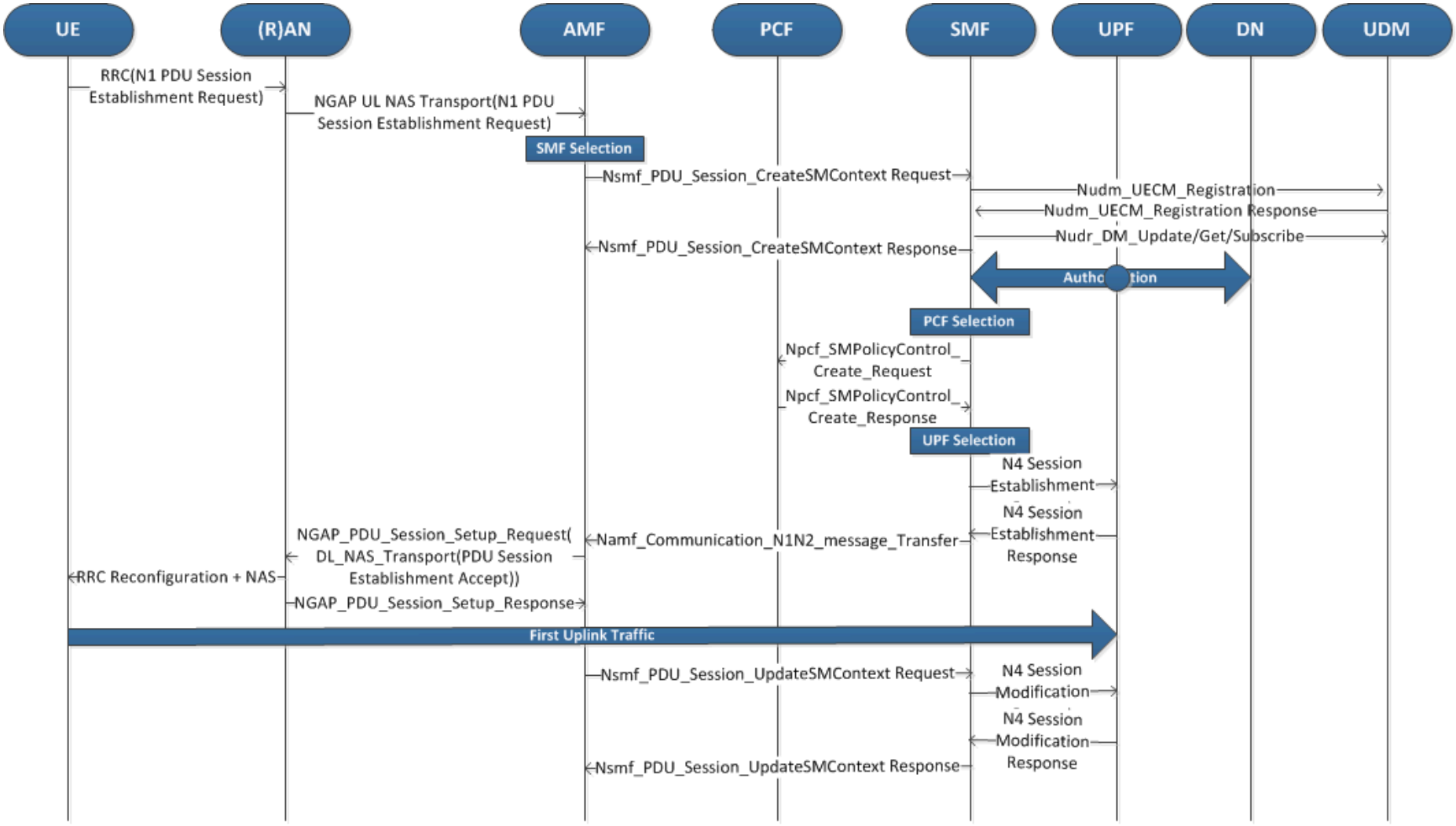
- Control the session management functions between the UE and the SMF
- The session management message is created and processed in the NAS-SM layer of UE and the SMF
- The content of the NAS-SM message is transparent to the AMF
- The NAS-MM layer creates a NAS-MM message, including security header, indicating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

Example of exposed services (SMF)

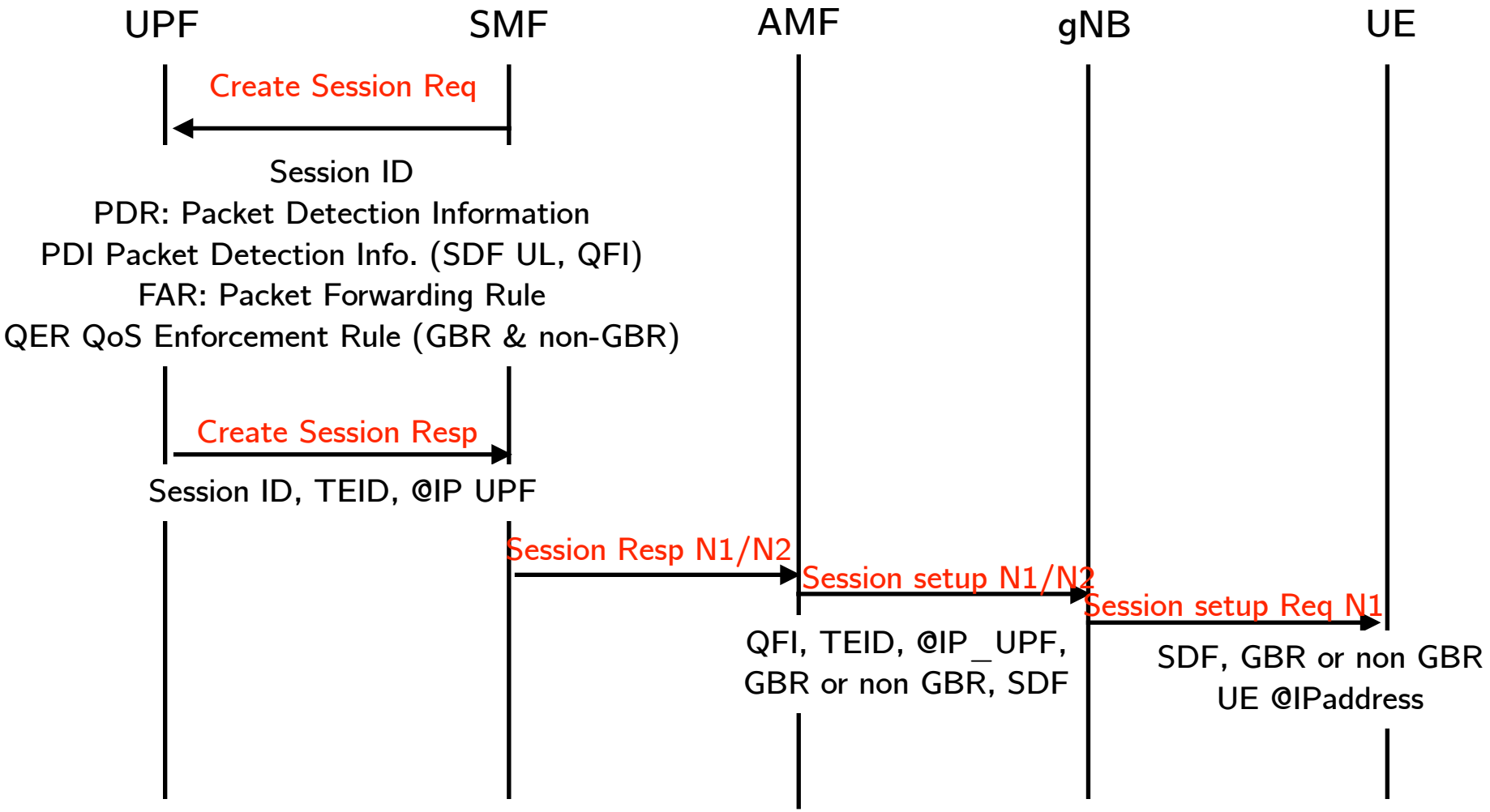


Service Name	Description
Nsmf_PDUSession	This service manages the PDU Sessions and uses the policy and charging rules received from the PCF. The service operations exposed by this NF service allows the consumer NFs to handle the PDU Sessions.
Nsmf_EventExposure	This service exposes the events happening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

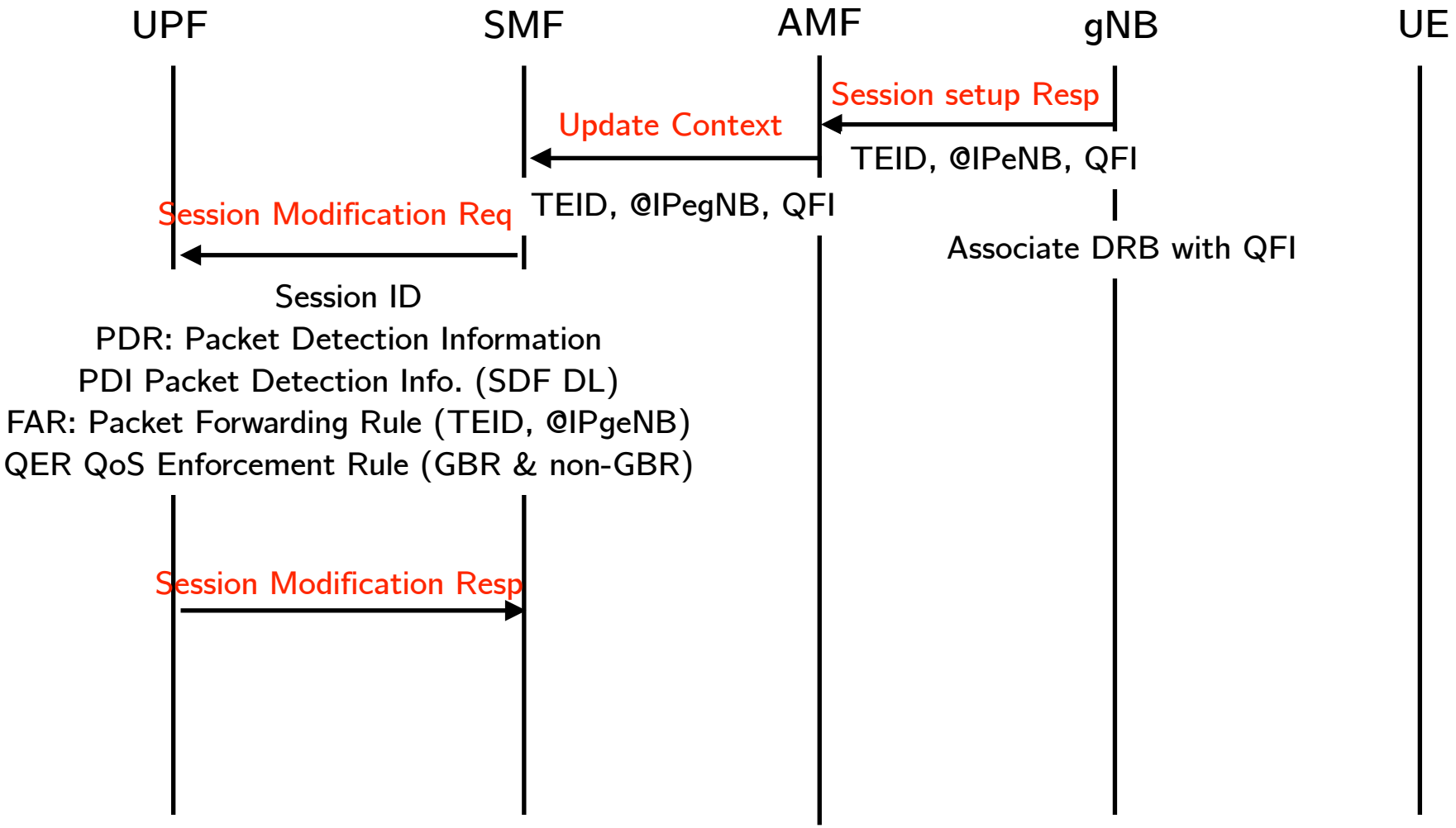
NAS-SM: Session establishment



PDU Session establishment



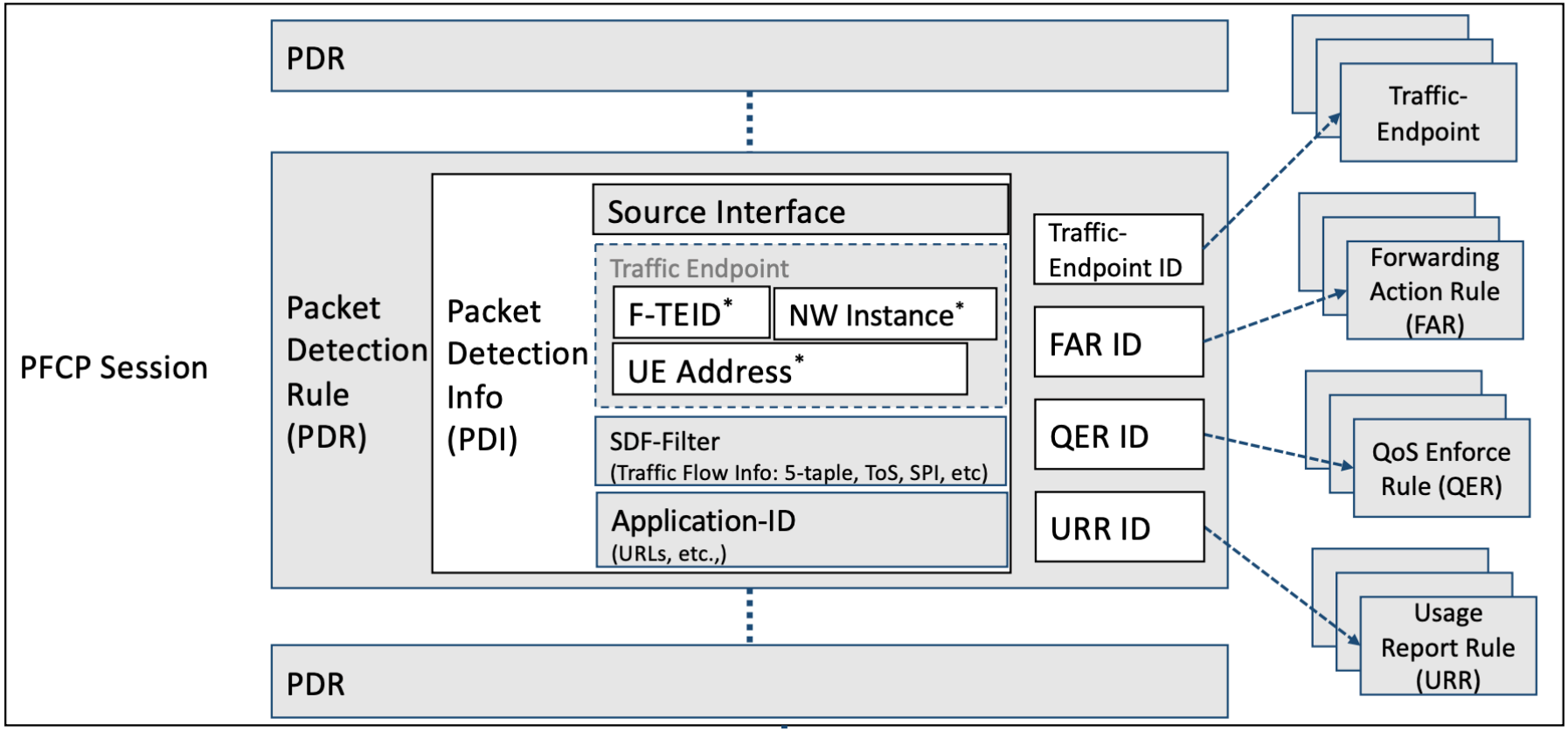
PDU Session establishment



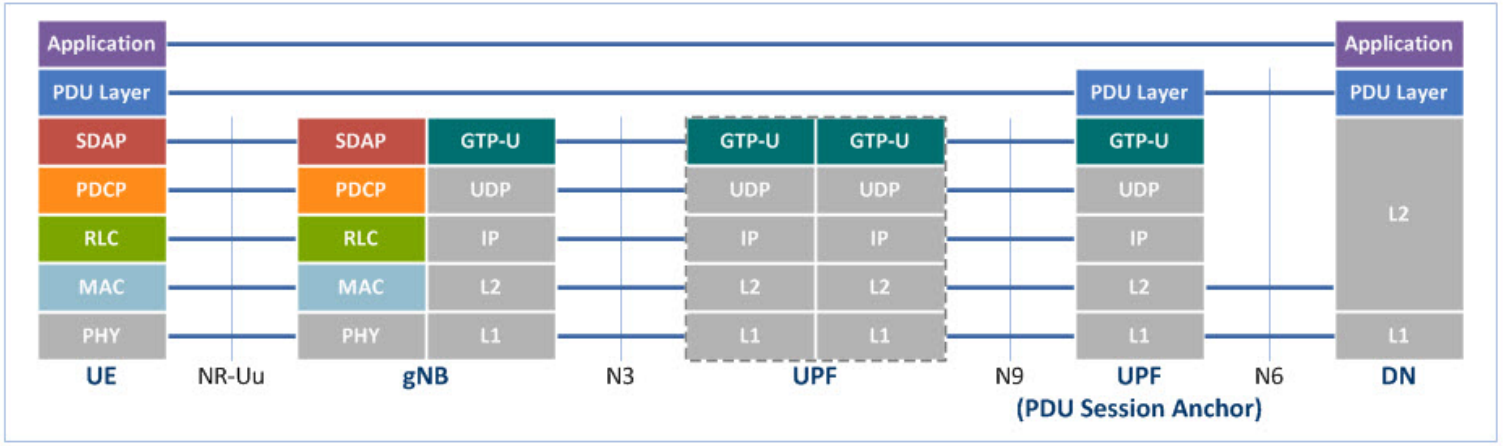
Packet Forwarding Control Protocol (PFCP)

- 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).

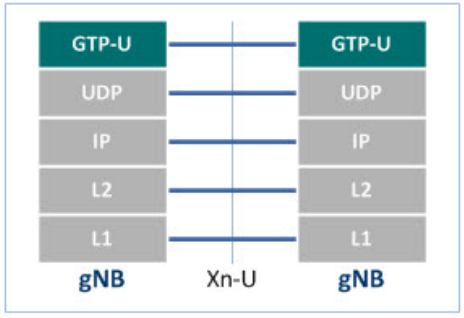
PFCP

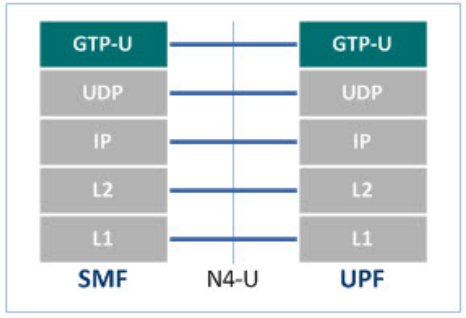

PFCP Session
PDR
Packet Detection Rule (PDR)
Packet Detection Info (PDI)
Source Interface
Traffic Endpoint
F-TEID*
NW Instance*
UE Address*
SDF-Filter
(Traffic Flow Info: 5-taple, ToS, SPI, etc)
Application-ID
(URLs, etc.,)
Traffic-Endpoint ID
FAR ID
QER ID
URR ID
Traffic-Endpoint
Forwarding Action Rule (FAR)
QoS Enforce Rule (QER)
Usage Report Rule (URR)
PDR

5G User plane

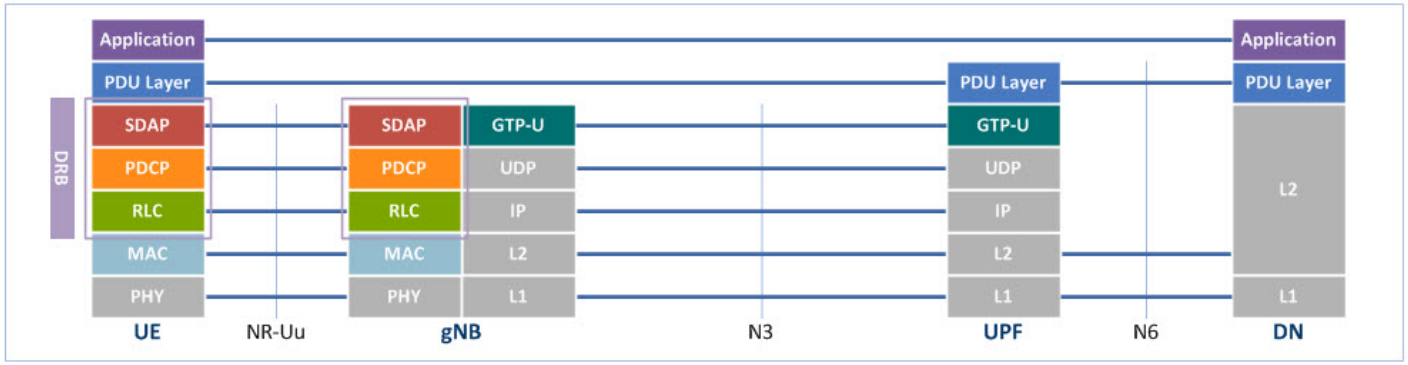


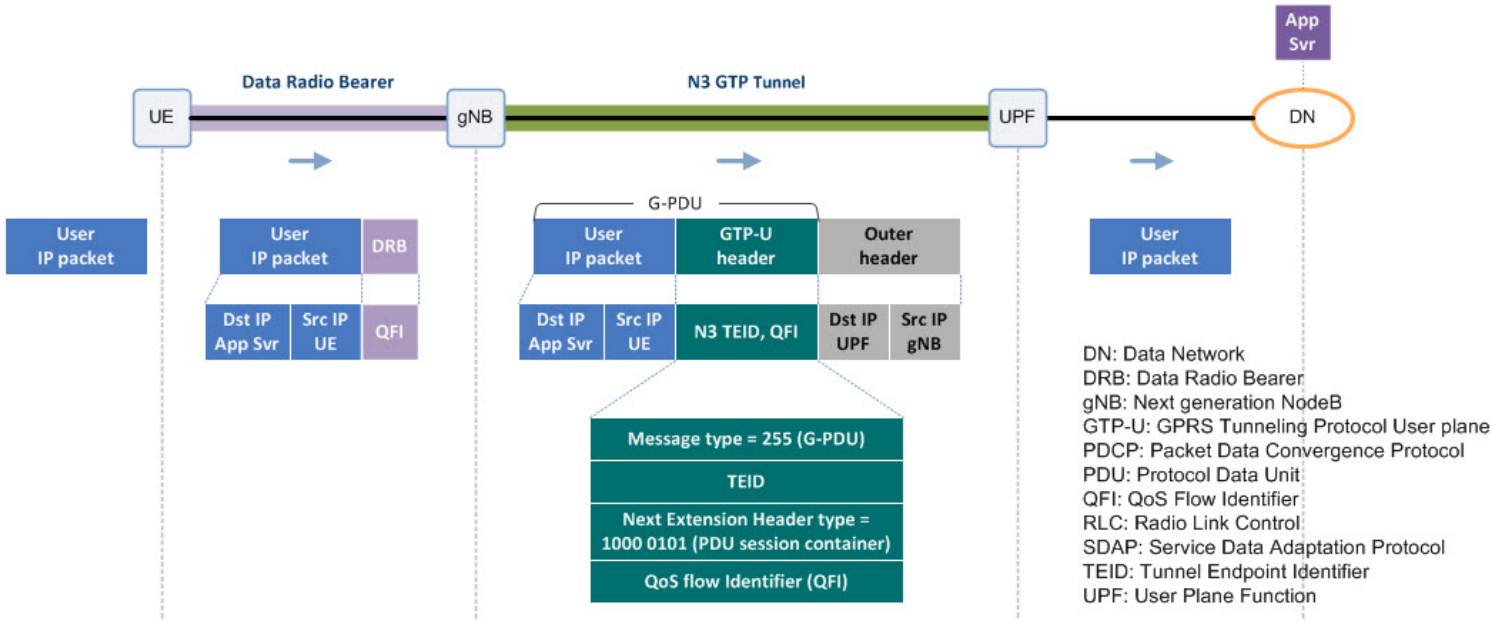
PDU Layer: IP, Ethernet, etc.





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)

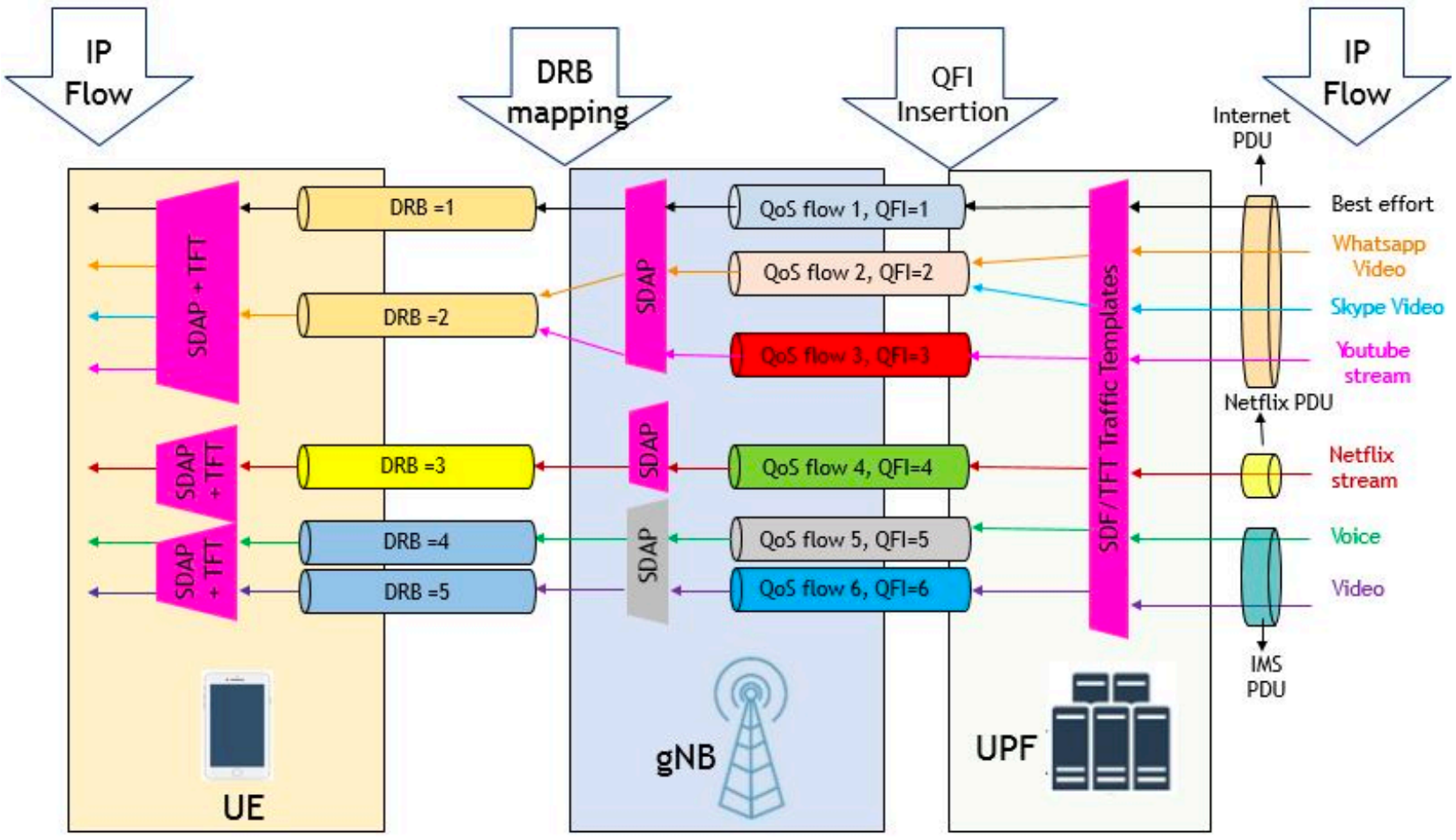
Parameter	5G	4G LTE
QoS Identifier	5G QoS Identifier - 5QI	Quality Class Indicator - QCI
IP Flow: UE to UPF/P-GW flow	QoS Flow	EPS Bearer
Flow/Bearer identifier	QoS Flow Identifier - QFI	EPS Bearer ID- EBI
Reflective QoS	Reflective QoS Indicator - RQI	N/A

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

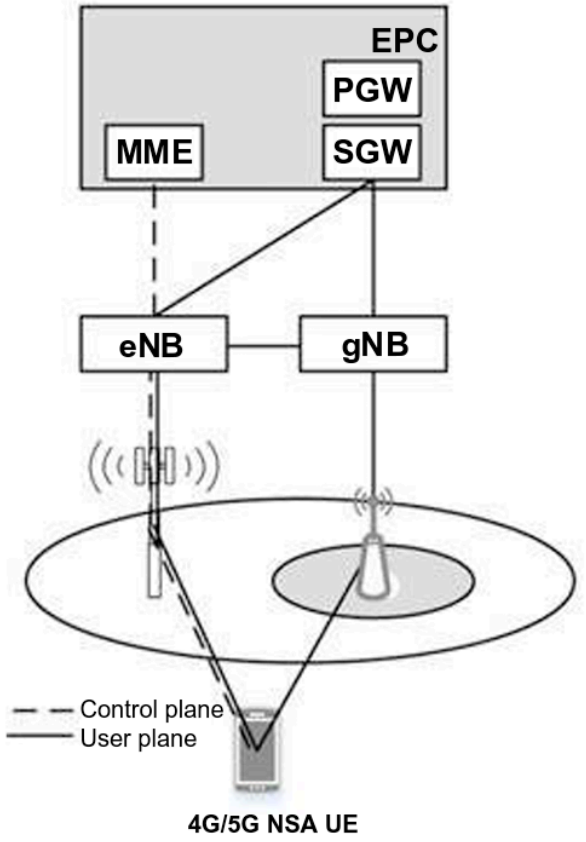
5G Deployment

Deployment of 5G

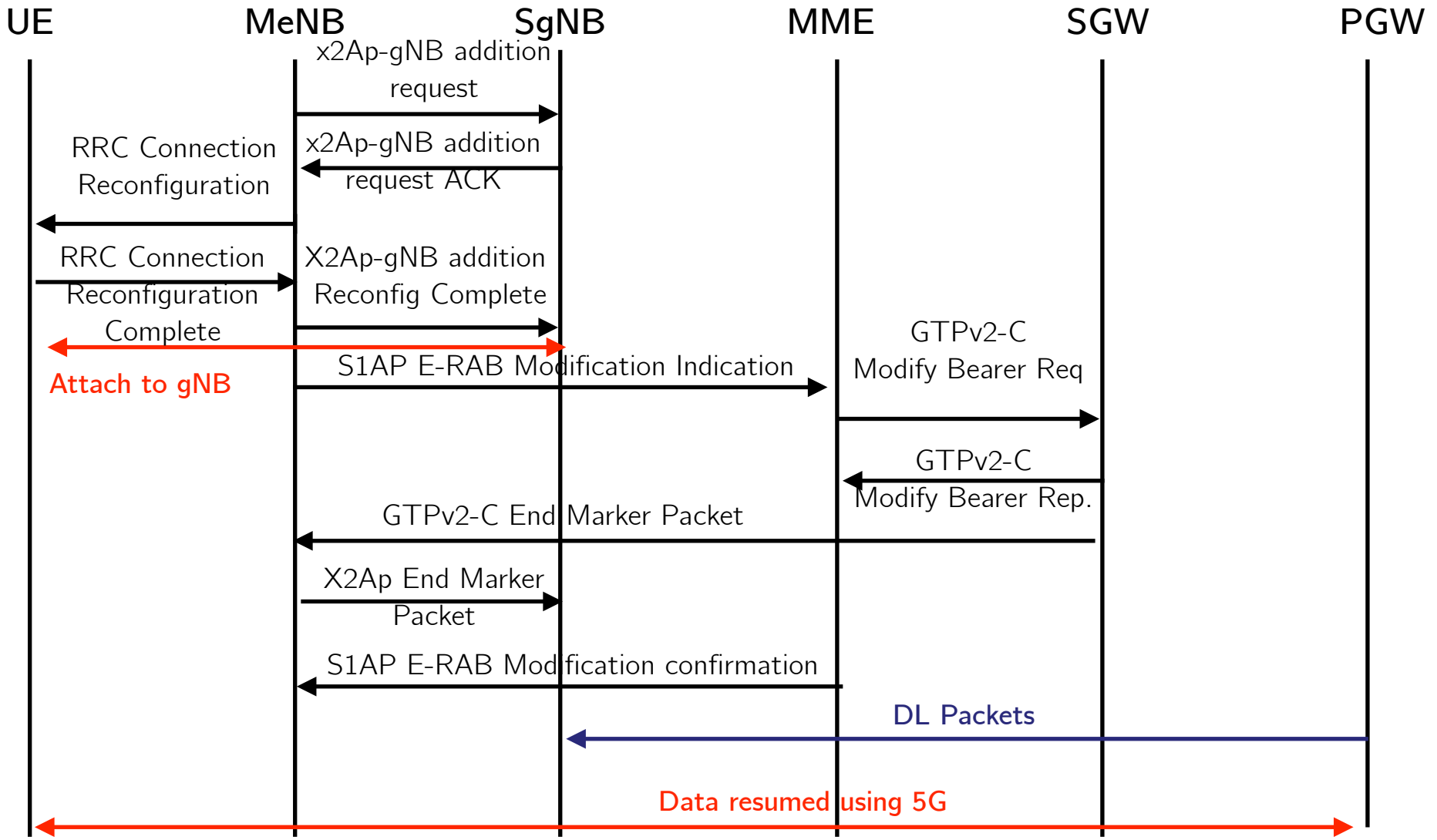
- Two modes
  - Non-Standalone (NSA): an intermediate step where the 5G NR is deployed while using the 4G CN
  - Standalone (SA): 5G NR and 5G CN

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



SA deployment

free

PRESS RELEASE

Paris, September 18, 2024

Free – France's first telco to offer 5G SA on a national scale

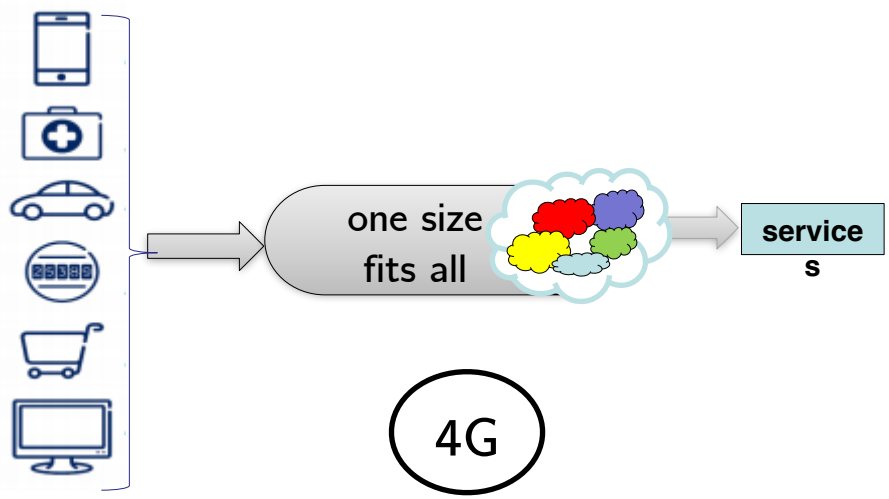
5G StandAlone : Orange « répond » à Free avec sa 5G+ home

Il ne s'est même pas passé 12 h pour qu'Orange réponde à Free sur l'arrivée de la 5G SA pour les clients. Si Free la propose à ses clients mobiles sur la bande des 3,5 GHz au niveau national, Orange se limite aux box 5G, avec une nouvelle offre « 5G+ home » qui sera lancée le 10 octobre.

Network Slicing

4G limitation

4G One size fits all no more efficient!!



4G limitation

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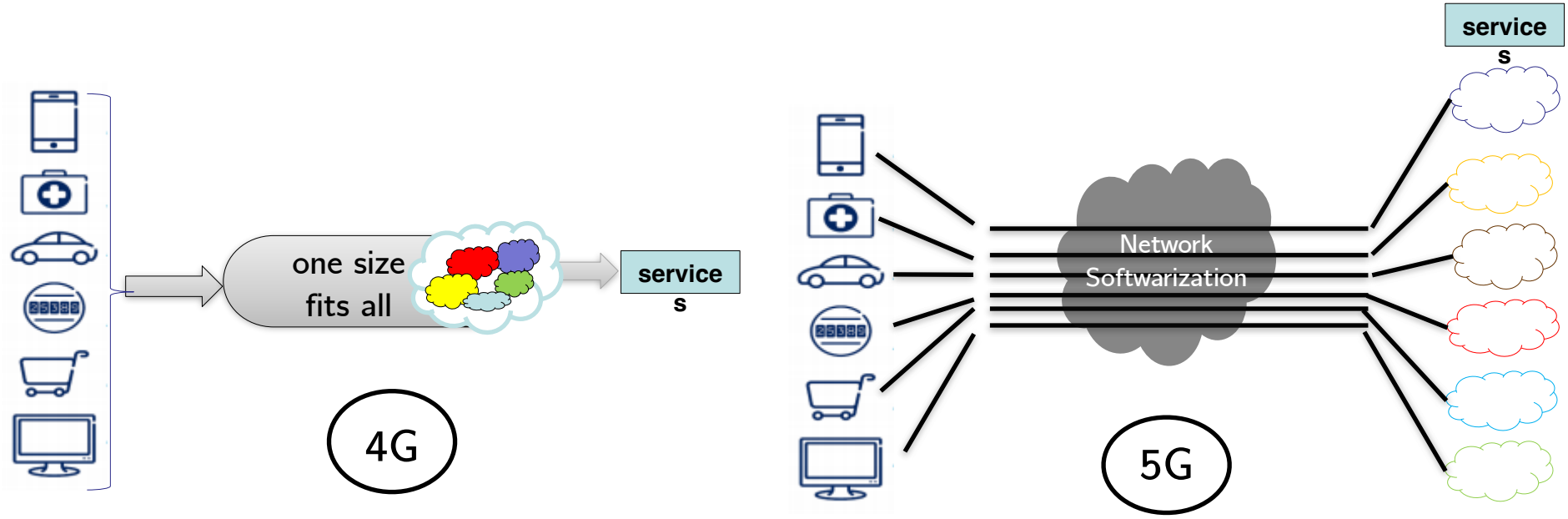
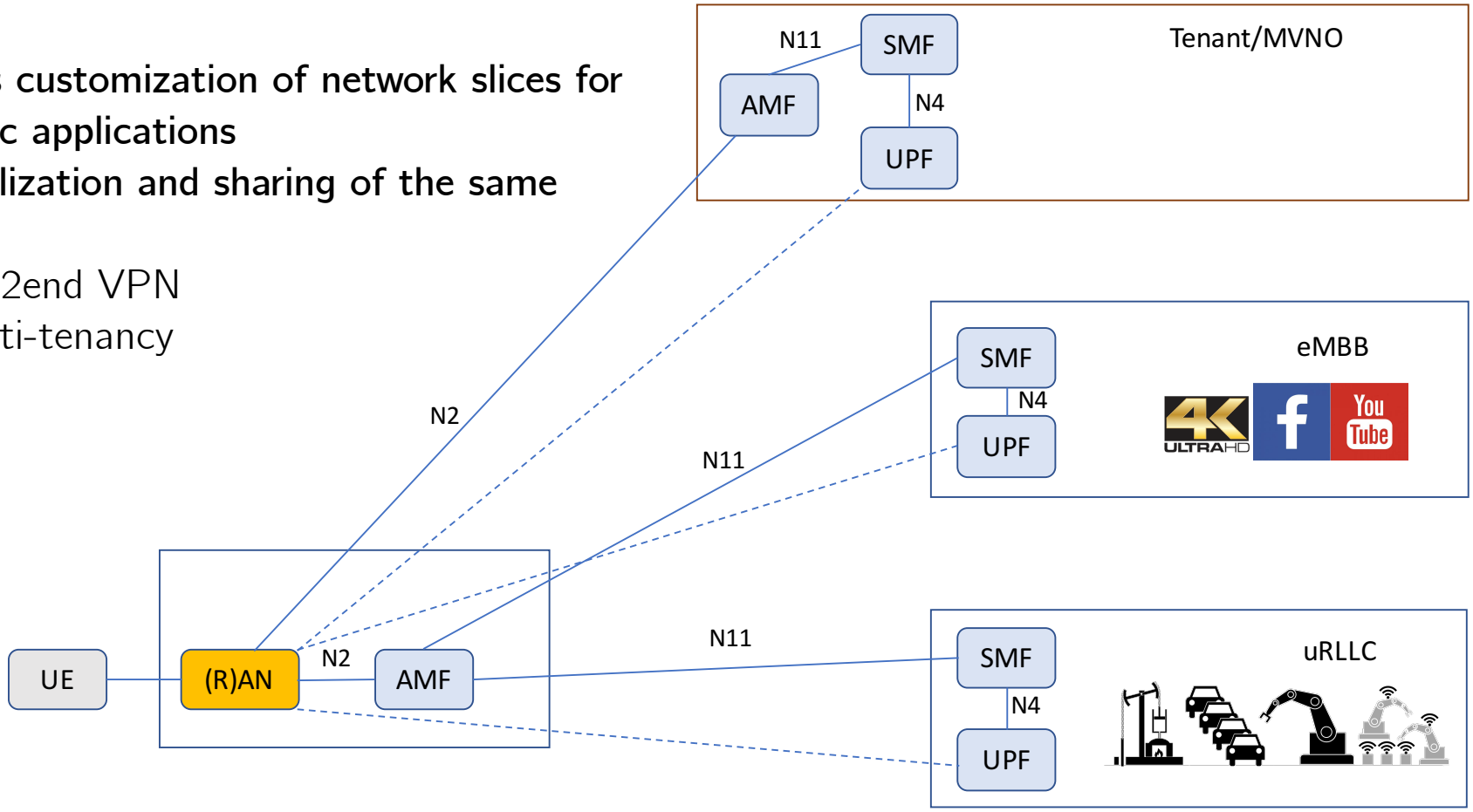


5G Network Slicing

- Allows customization of network slices for specific applications
- Virtualization and sharing of the same infra.
  - End2end VPN
  - Multi-tenancy



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 functions

Network Registry Function (NRF)

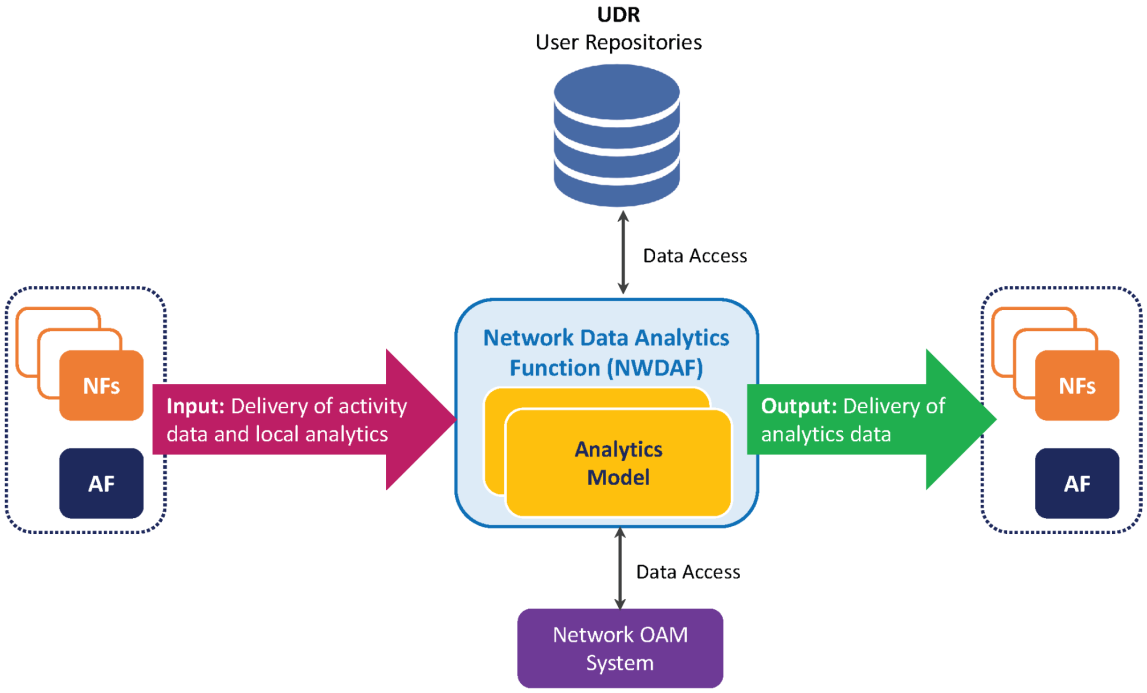
- The NRF is one of the main key components of the 5G Service Based Architecture.
- The NRF maintains an updated repository of all the 5G elements available in the operator's network along with the services provided by each of the elements in the 5G core that are expected to be instantiated, scaled, 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].

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

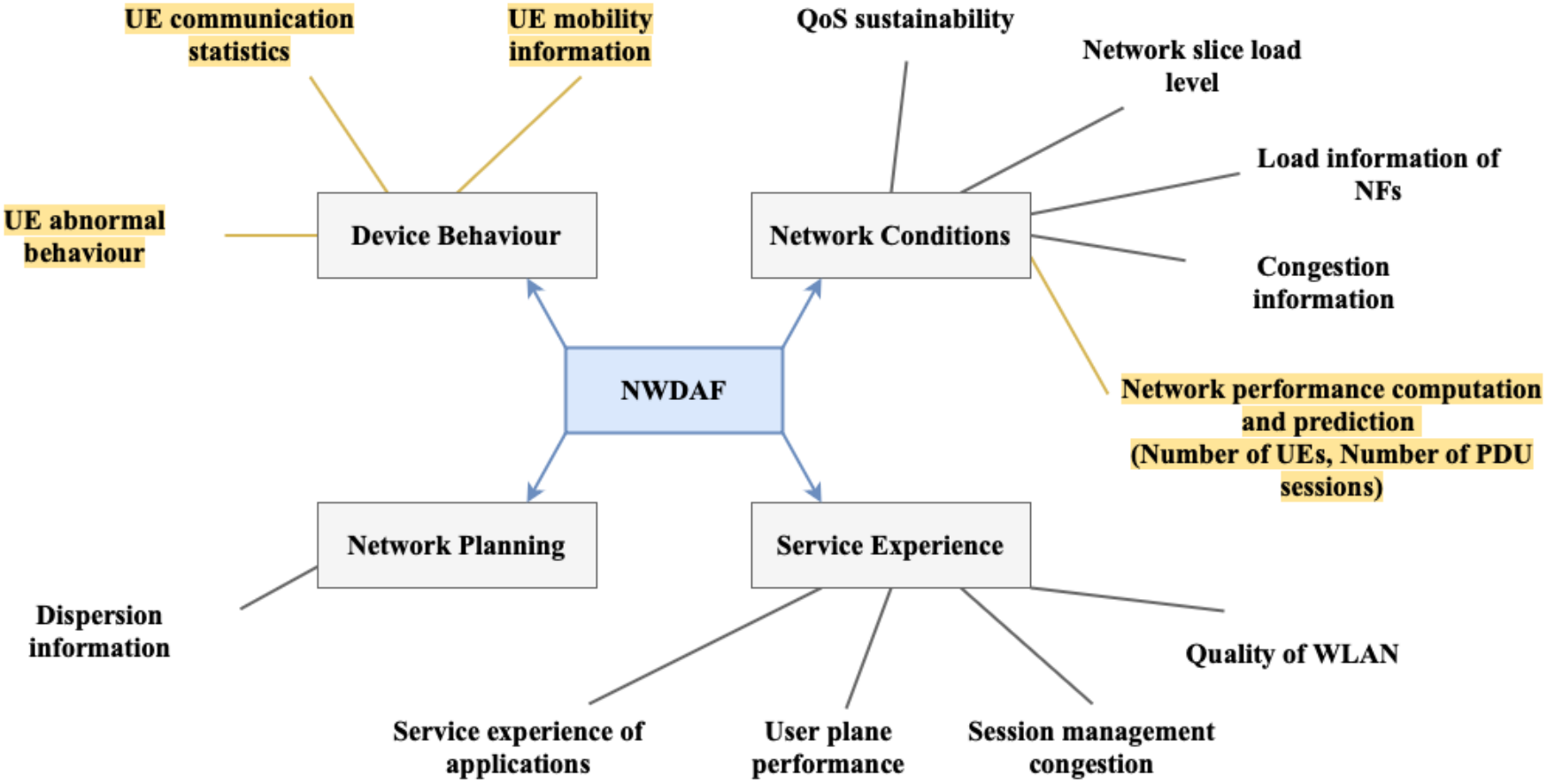
NWDAF



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.

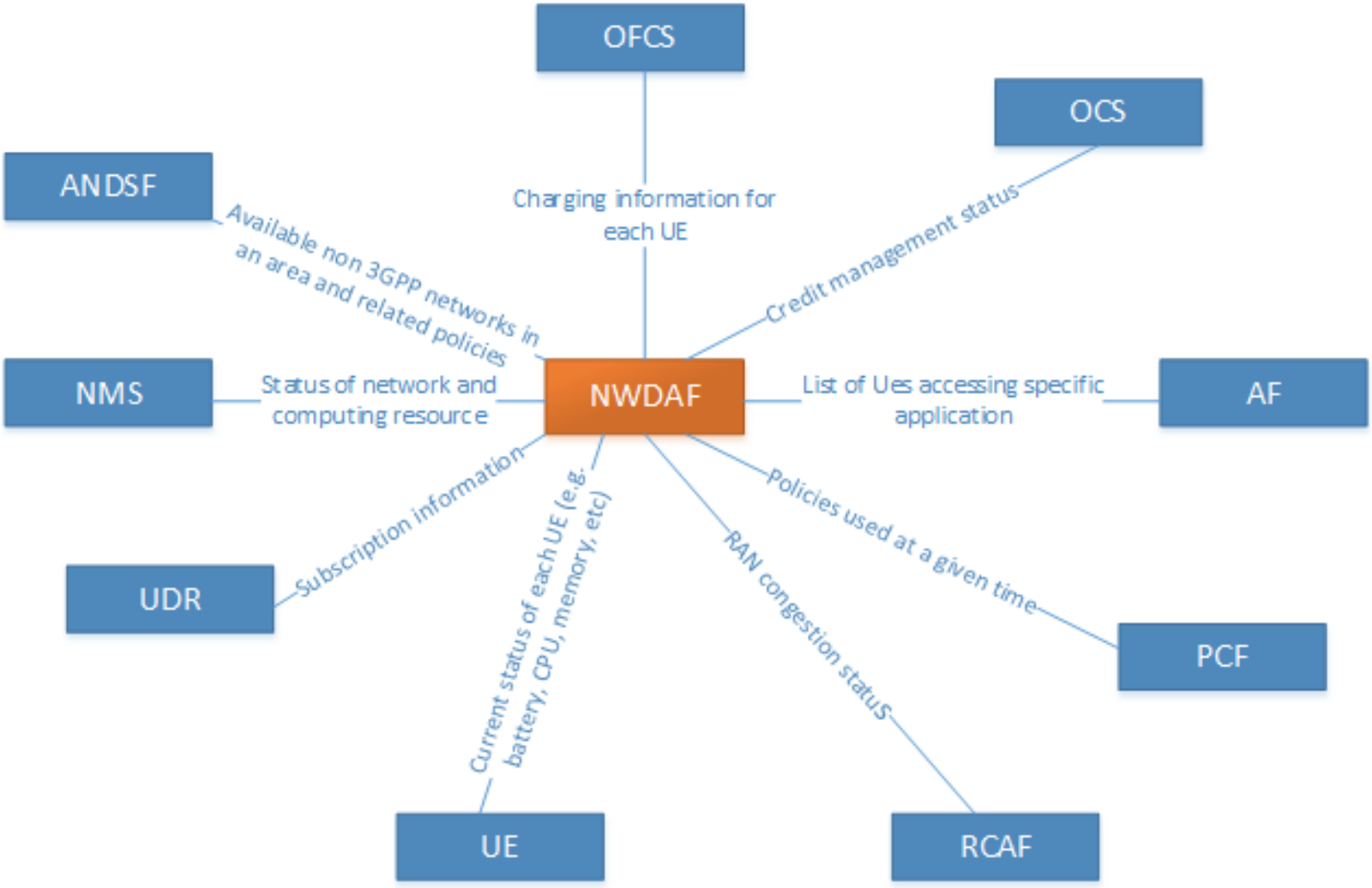
Malik, S., Khan, M. A., El-Sayed, H., Khan, J., & Ullah, O. (2022). Implanting Intelligence in 5G Mobile Networks—A Practical Approach. Electronics, 11(23), 3933.

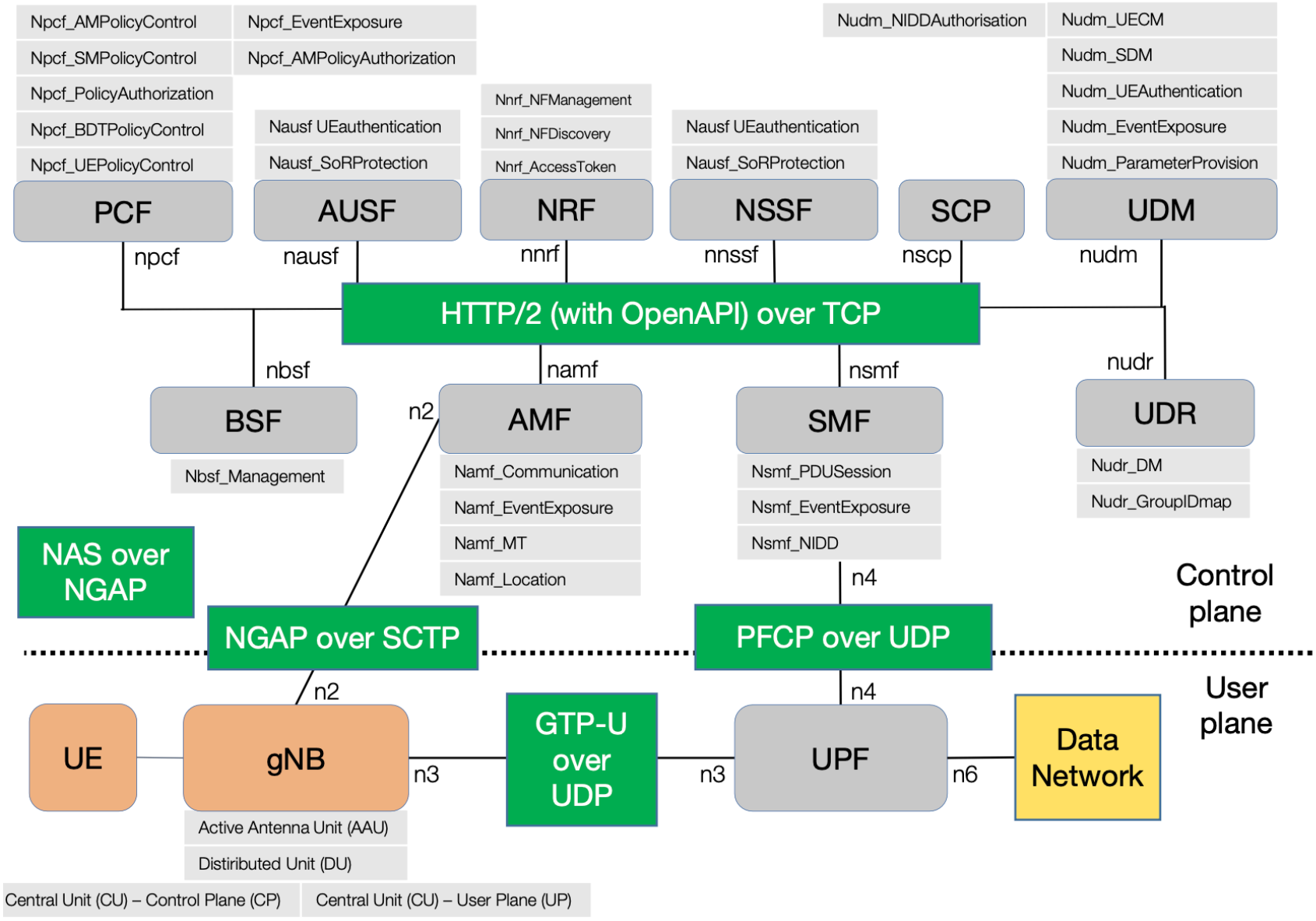
NWDAF functions



3GPP. Technical Specification Group Core Network and Terminals; 5G System; Network Data Analytics Services; tech. rep. 29.520. Version 17.10.0. 2023

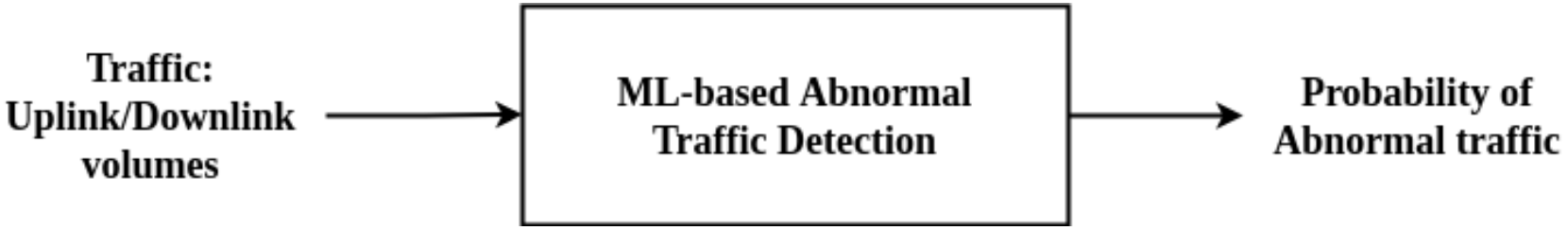
NWDAF provisioning




Npcf_AMPolicyControl
Npcf_EventExposure
Npcf_SMPolicyControl
Npcf_AMPolicyAuthorization
Npcf_PolicyAuthorization
Npcf_BDTPolicyControl
Npcf_UEPolicyControl
PCF
npcf
Nausf UEauthentication
Nausf_SoRProtection
AUSF
nausf
Nnrf_NFManagement
Nnrf_NFDiscovery
Nnrf_AccessToken
NRF
nnrf
Nausf UEauthentication
Nausf_SoRProtection
NSSF
nnssf
SCP
nscp
Nudm_NIDDAuthorisation
Nudm_UECM
Nudm_SDM
Nudm_UEAuthentication
Nudm_EventExposure
Nudm_ParameterProvision
UDM
nudm
HTTP/2 (with OpenAPI) over TCP
nbsf
BSF
Nbsf_Management
n2
namf
AMF
Namf_Communication
Namf_EventExposure
Namf_MT
Namf_Location
nsmf
SMF
Nsmf_PDUSession
Nsmf_EventExposure
Nsmf_NIDD
nudr
UDR
Nudr_DM
Nudr_GroupIDmap
NAS over NGAP
NGAP over SCTP
n4
PFCP over UDP
Control plane
User plane
n2
n4
UE
gNB
n3
GTP-U over UDP
n3
UPF
n6
Data Network
Active Antenna Unit (AAU)
Distiributed Unit (DU)
Central Unit (CU) – Control Plane (CP)
Central Unit (CU) – User Plane (UP)

NWDAF use-case: abnormal traffic detection

- Abnormal Traffic: the NWDAF clients can subscribe to the ''abnormal_behaviour'' event and exception ID ''unexpected_large_rate_flow'' to receive periodic updates on the probability of abnormal traffic



- Data pattern differs from UE to other -> no generalization on data pattern -> no labeled dataset
- The ML-model will learn only the normal Uplink/Downlink pattern from historical data
  - It then will detect abnormal traffic -> AutoEncoder Architecture

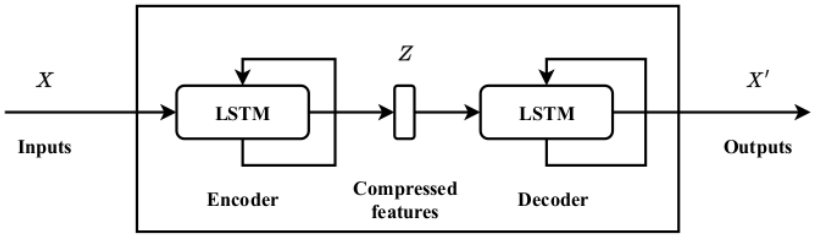
NWDAF use-case: abnormal traffic detection

- Encoding: X is compressed into a lower-dimensional space $Z = \sigma\left(WX + b\right)$
- Decoding: decode Z to X′ that is similar to the input dimension

$$X' = \sigma'\left(W'Z + b'\right)$$

- The loss function is

$$\mathrm{MAE} = \frac{\sum_{i=1}^{n} |x_i' - x_i|}{n} = \frac{\sum_{i=1}^{n} |e_i|}{n}$$



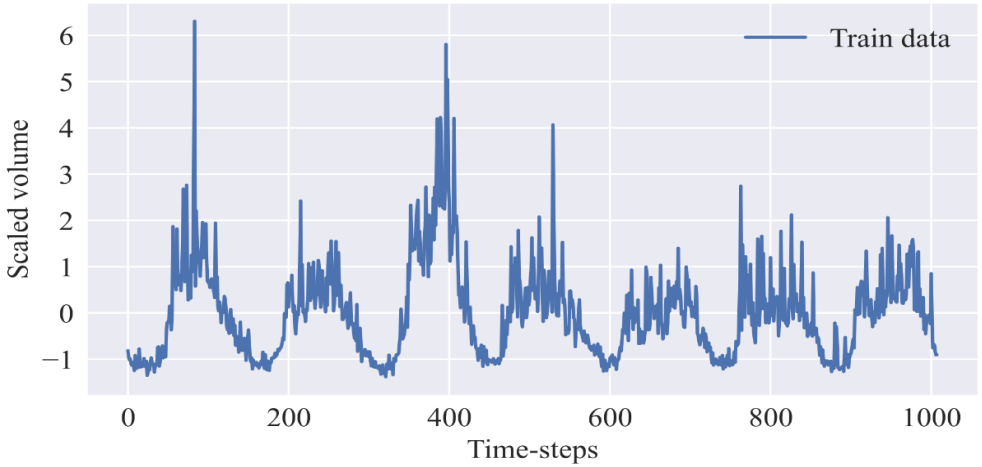
- The traffic anomaly probability is

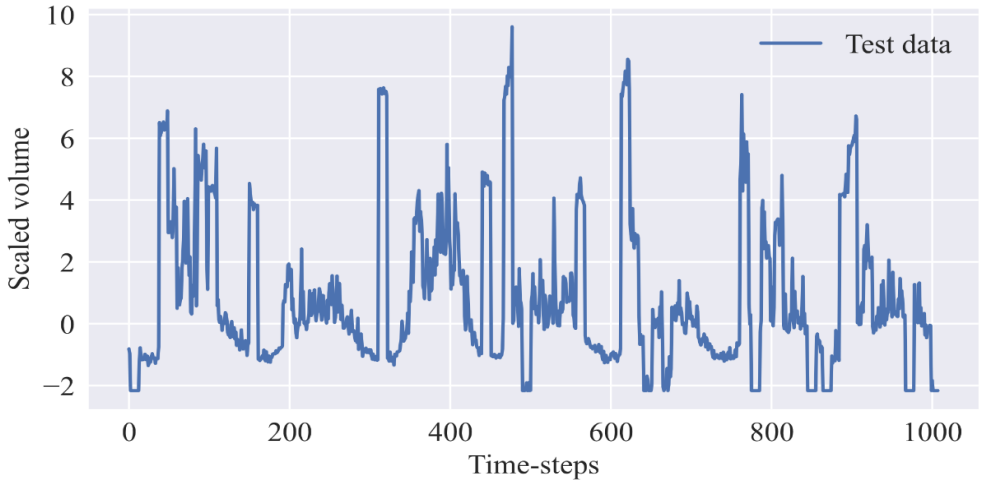
$$p = \min(\alpha \times |\beta' - \beta|, 1)$$

α controls the impact of the distances scale.
β is the average train MAE.
β' is the test MAE.

NWDAF use-case

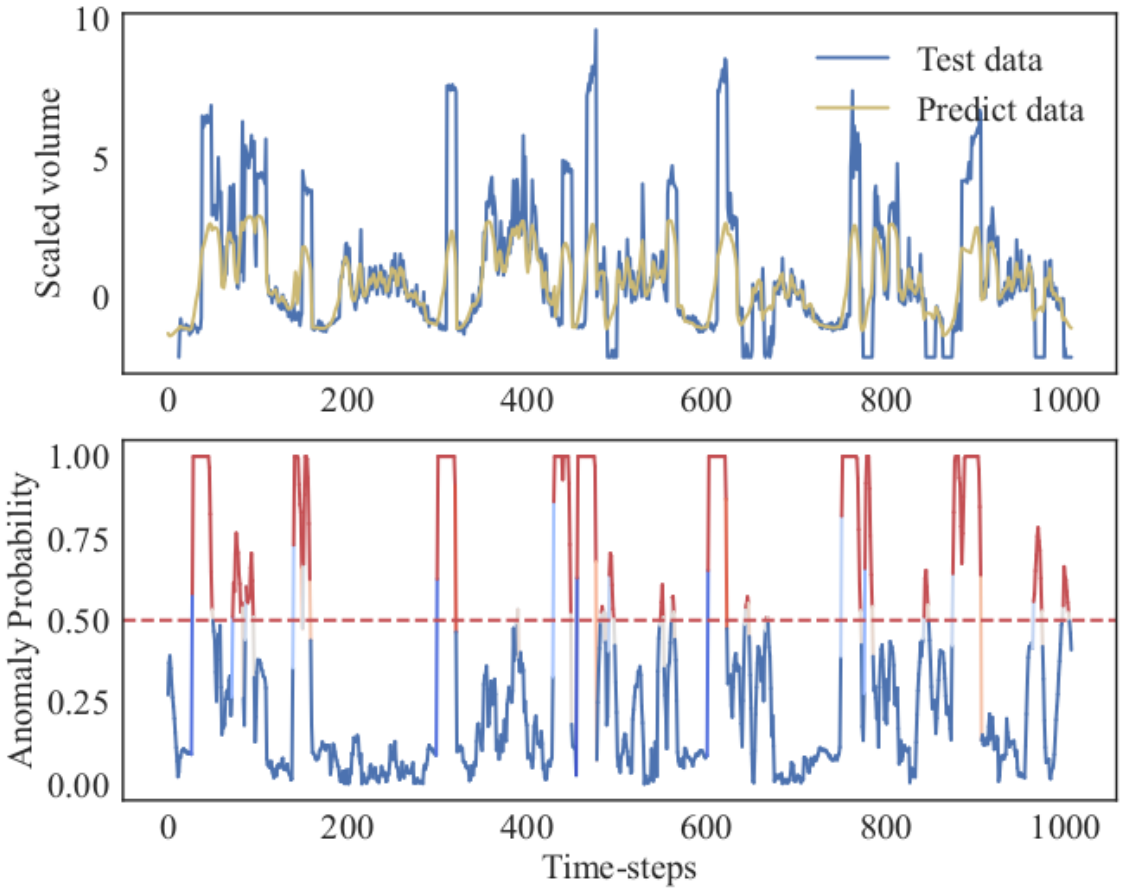
- We trained LSTM-based model using Milano Dataset
- We injected some anomalies in the pattern by introducing long traffic flows





NWDAF use-case

- The distance between input and generated data correlates with the anomaly probability.
- The probabilities increase as the generated data diverges from the input data.
- The anomaly probability threshold is set to 0.5



https://www.youtube.com/watch?v=kI9GuJeW0es