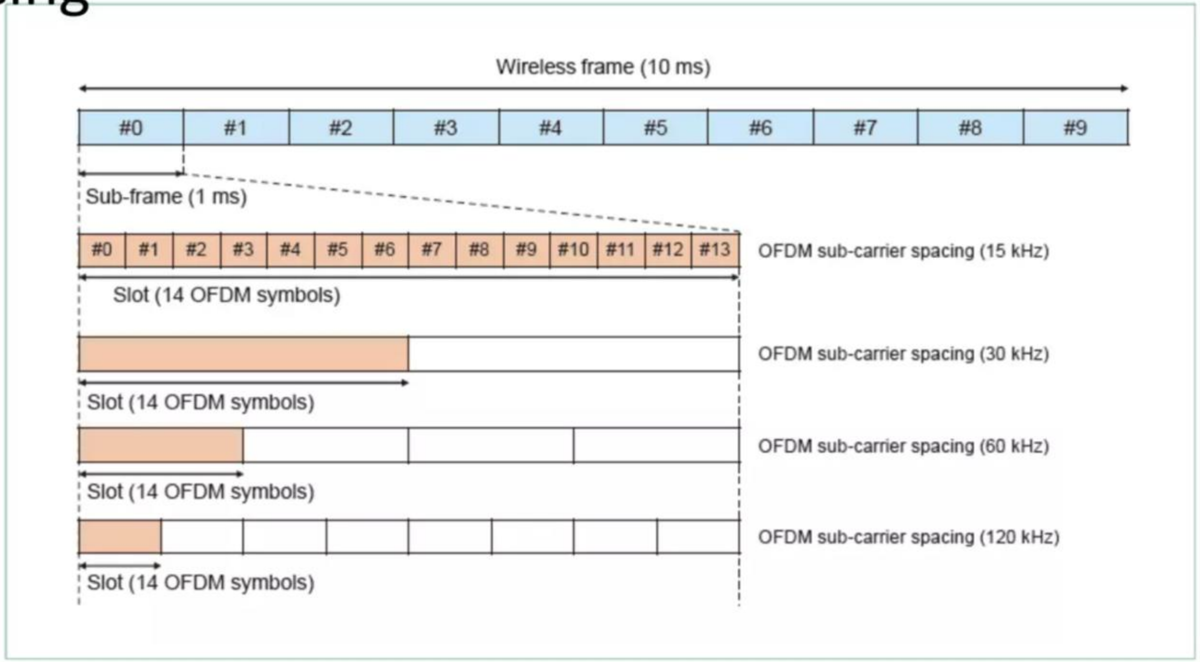
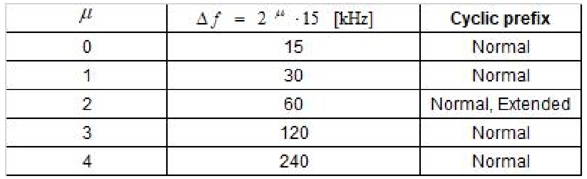
5G NR Radio Frame

- The 5G NR Radio Frame is in units of 10ms
- Subframes are defined in units of 1ms
- Slots are defines as 14 OFDM Symbols and their time interval depends on sub-carrier spacing





μ	$\Delta f = 2^{\mu} \cdot 15$ [kHz]	Cyclic prefix
0	15	Normal
1	30	Normal
2	60	Normal, Extended
3	120	Normal
4	240	Normal

Source: NTT Docomo

5G NR Logical ,Transport and Physical Channels Mapping

Logical Channel Definition: Medium Access Control (MAC) Layer of NR provides services to the Radio Link Control (RLC) Layer in the form of logical channels. A logical channel is defined by the type of information it carry and is generally differentiated as a control channel, used for transmission of control and configuration information or as a traffic channel used for the user data.

List of Logical Channels for NR:

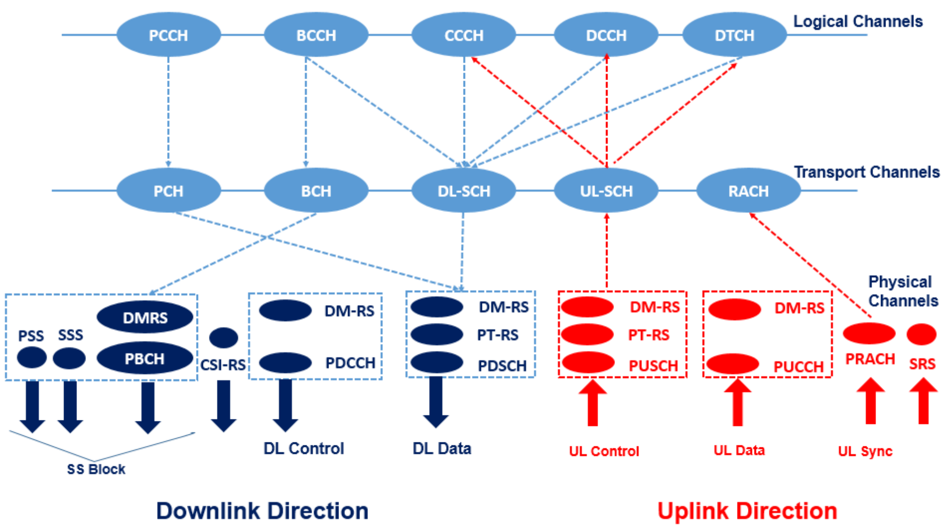
- **Broadcast Control Channel** (BCCH): It is used for transmitting system information from the network to UEs in a cell coverage.
- **Paging Control Channel** (PCCH): This is used to page the UEs whose location at cell level is not known to the network.
- **Common Control Channel** (CCCH): It is used for transmission of control information to UEs with respect to Random Access
- **Dedicated Control Channel** (DCCH): It is used for transmission of control information to/from a UE. This channel is used for individual configuration of UEs such as setting different parameters for different layers.
- **Dedicated Traffic Channel** (DTCH): It is used for transmission of user data to/from a UE. This is the logical channel type used for transmission of all unicast uplink and downlink user data.

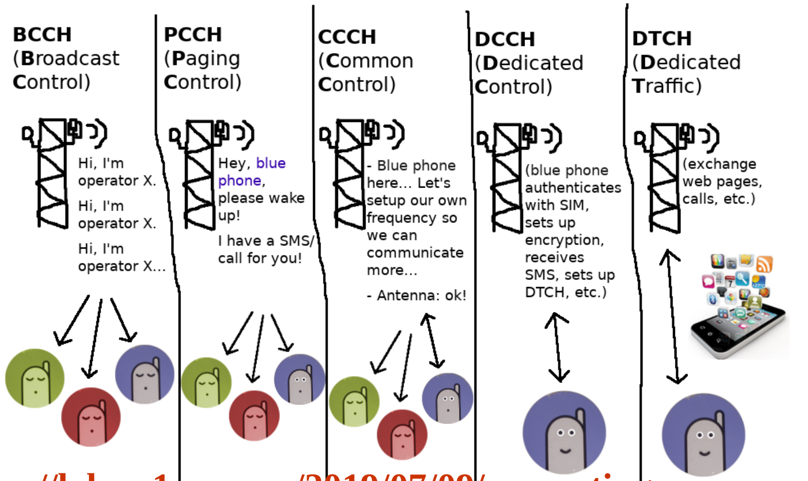
Transport Channel Definition: A transport channel is defined by how and with what characteristics the information is transmitted over the radio interface. From the physical layer, the MAC layer uses services in the form of transport channels. Data on a transport channel are organized into transport blocks.

List of Transport Channels for NR:

- **Broadcast Channel** (BCH) : It is used for transmitting the BCCH system information, more specifically Master Information Block (MIB). It has a fixed transport format, provided by the specifications.
- **Paging Channel** (PCH): This channel is used for transmission of paging information from the PCCH logical channel. The PCH supports discontinuous reception (DRX) to allow the device to save battery power by waking up to receive the PCH only at predefined time instants.
- **Downlink Shared Channel** (DL-SCH) : This is the main transport channel used for transmitting downlink data in NR. It supports key all NR features such as dynamic rate adaptation and channel aware scheduling, HARQ and spatial multiplexing. DL-SCH is also used for transmitting some parts of the BCCH system info which is not mapped to the BCH. Each device has a DL-SCH per cell it is connected to. In slots where system information is received there is one additional DL-SCH from the device perspective.
- **Uplink Shared Channel** (UL-SCH): This is the uplink counterpart to the DLSCH that is, the uplink transport channel used for transmission of uplink data.
- **Random-Access Channel** (RACH): RACH is also a transport channel, although it does not carry transport blocks.

Logical, Transport and Physical Channel Mapping

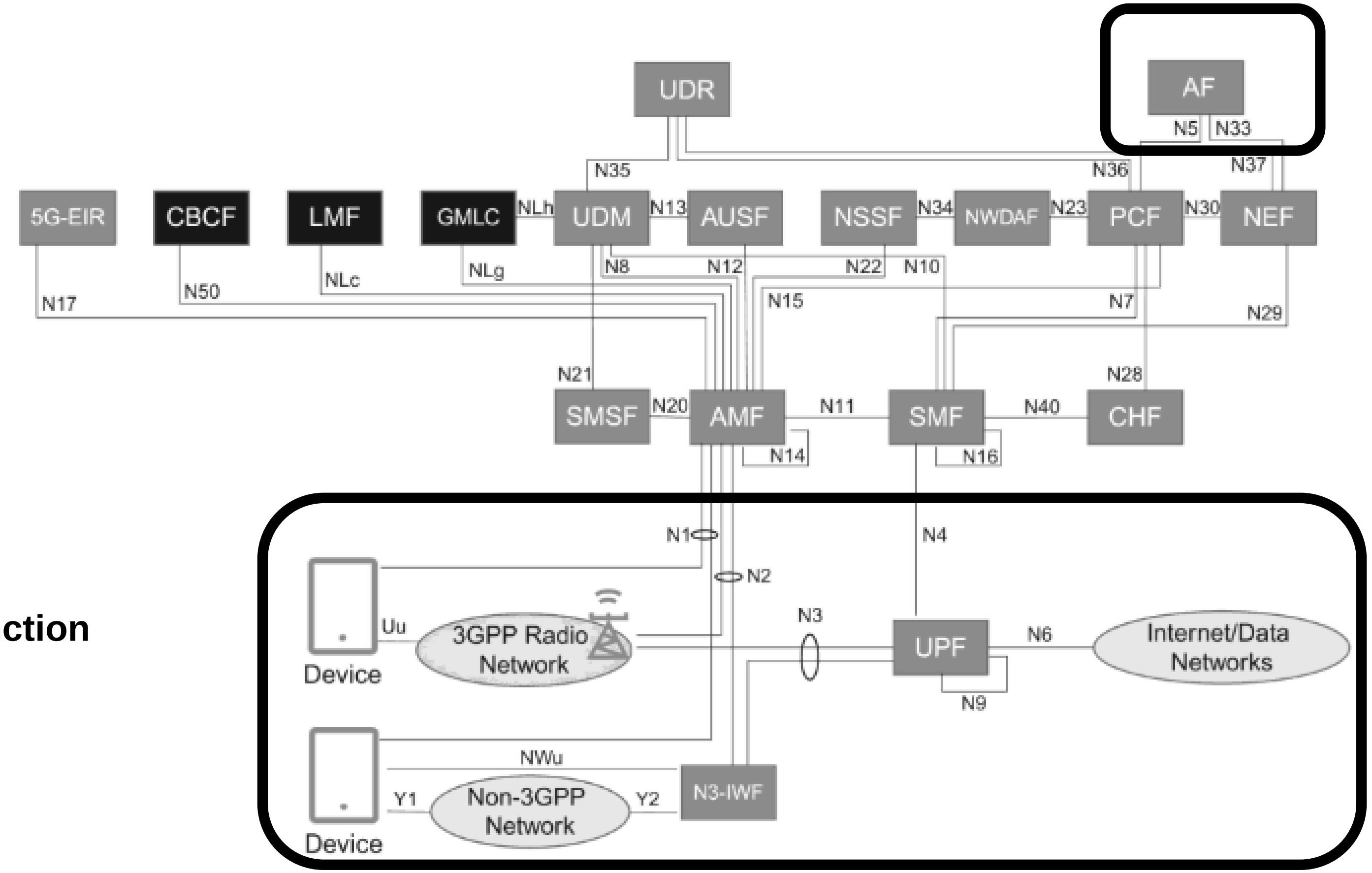



BCCH (Broadcast Control)
Hi, I'm operator X.
Hi, I'm operator X.
Hi, I'm operator X...
PCCH (Paging Control)
Hey, blue phone, please wake up!
I have a SMS/ call for you!
CCCH (Common Control)
- Blue phone here... Let's setup our own frequency so we can communicate more...
- Antenna: ok!
DCCH (Dedicated Control)
(blue phone authenticates with SIM, sets up encryption, receives SMS, sets up DTCH, etc.)
DTCH (Dedicated Traffic)
(exchange web pages, calls, etc.)

https://labs.p1sec.com/2019/07/09/presenting-qcsuper-a-tool-for-capturing-your-2g-3g-4g-air-traffic-on-qualcomm-based-phones/

The 5G System architecture

- References points representation
  - shows the interaction that exist between the NF services in the network
  - functions described by point-to-point reference point (e.g. N11)
  - between any two network functions (e.g. AMF and SMF)



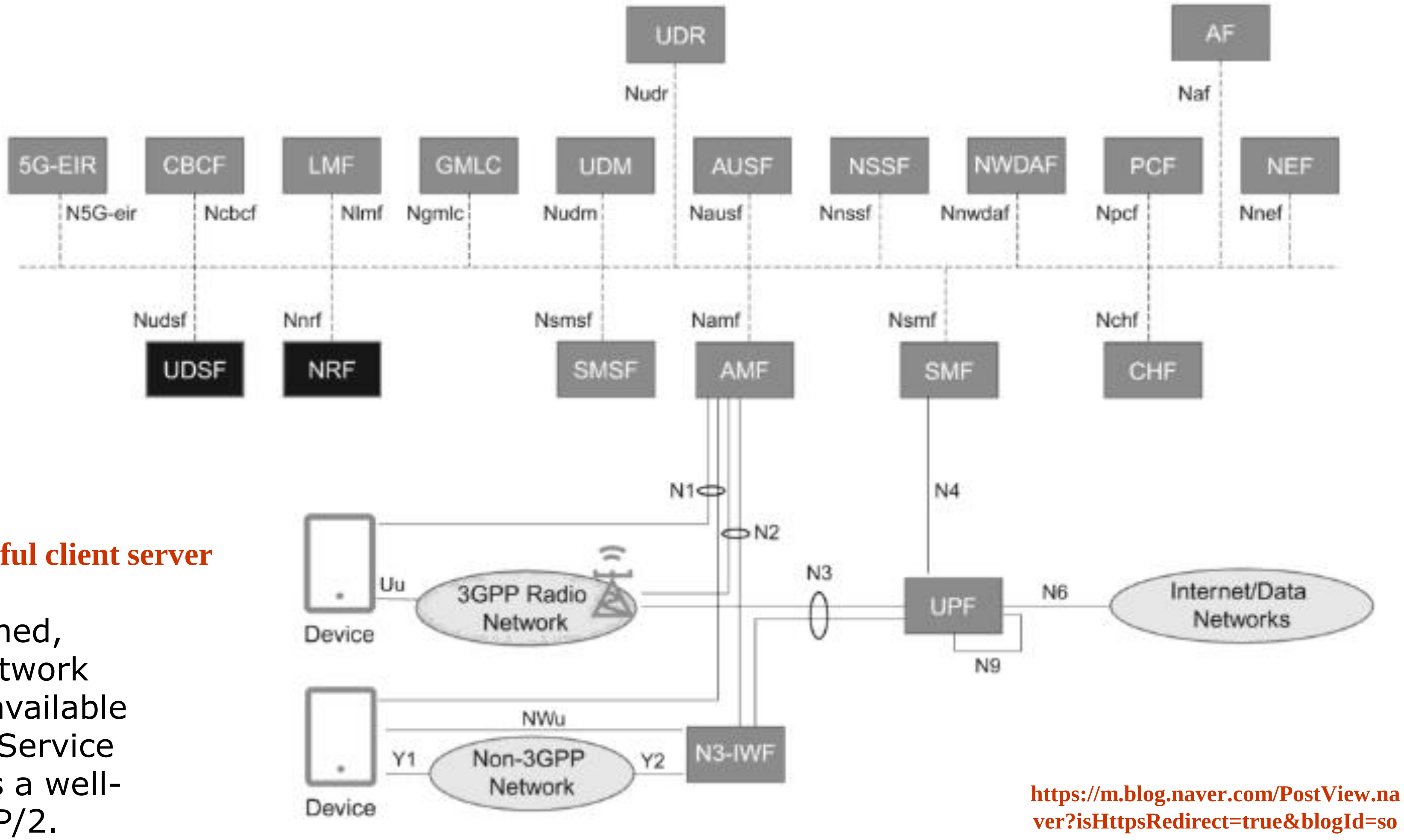
AF:	Application Function
AUSF:	Authentication Server Function
AMF:	Core Access and Mobility Management Function
DN:	Data Network
LMF:	Location Management Function
NEF:	Network Exposure Function
NRF:	Network Repository Function
NSSF:	Network Slice Selection Function
PCF:	Policy Control Function
SMF:	Session Management Function
UDM:	User Data Management
UPF:	User Plane Function

https://m.blog.naver.com/PostView.naver?isHttpsRedirect=true&blogId=song_sec&logNo=222025295180

https://infohub.delltechnologies.com/p/the-5g-core-network-demystified/

The 5G System architecture

Service based representation where **network functions (e.g. AMF) within the control plane enables other authorized network functions to access their services**



NFs follow the web-based approach using RESTful client server communication

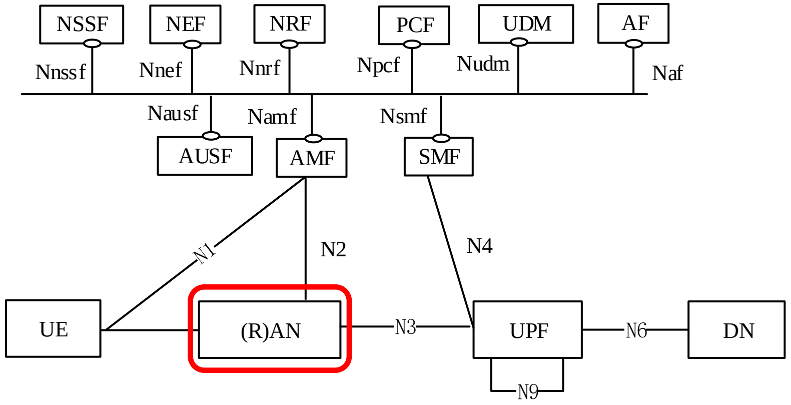
Network Functions are self-contained, independent and reusable. Each Network Function service exposes and makes available its functionality (services) through a Service Based Interface (SBI), which employs a well-defined REST interface using HTTP/2.

https://m.blog.naver.com/PostView.naver?isHttpsRedirect=true&blogId=song_sec&logNo=222025295180

RAN

Radio Access Network (RAN)

- **Radio Resources Management (RRM)**
- **Control, Dynamic allocation of resources to UEs in both uplink and downlink (scheduling)**
- **Selection of an AMF at UE attachment**
- **Routing of User Plane data towards UPF(s)**
- **Routing of Control Plane information towards AMF**
- **Connection setup and release**
- **Scheduling and transmission of paging messages and system broadcast information**
- **Measurement and measurement reporting configuration for mobility and scheduling**
- **Transport level packet marking in the uplink**
- **Session Management**
- **Support of Network Slicing**
- **QoS Flow management and mapping to data radio bearers**



(3GPP TS 23.501)

AMF, SMF and PCF

Access and Mobility Management Function (AMF)

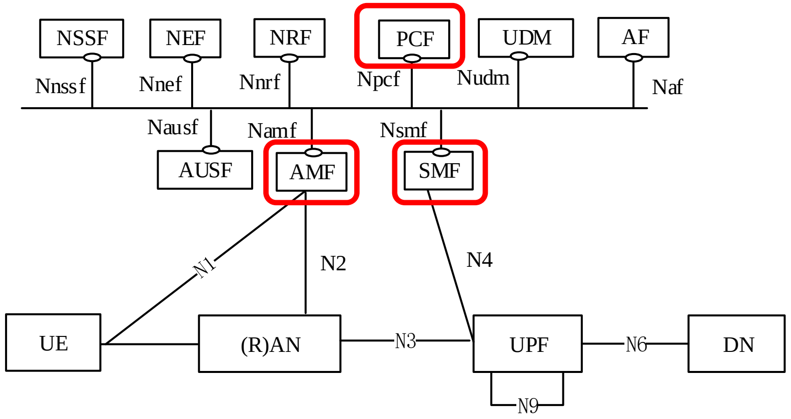
- Termination of NAS (Non-Access Stratum) signalling
- NAS ciphering & integrity protection
- Registration management
- Connection management
- Mobility management
- Access authentication and authorization
- Security context management

Session Management Function (SMF)

- Session management (establishment, modification, release)
- UE IP address allocation & management
- UPF selection and configuration for QoS and traffic steering
- DHCP functions
- Lawful intercept functions
- Charging data collection and support of charging interfaces

Policy Control Function (PCF)

- Supports unified policy framework to govern network behaviour
- Provides policy rules to Control Plane function(s) to enforce them
- Accesses subscription information relevant for policy decisions in a Unified Data Repository (UDR)



(3GPP TS 23.501)

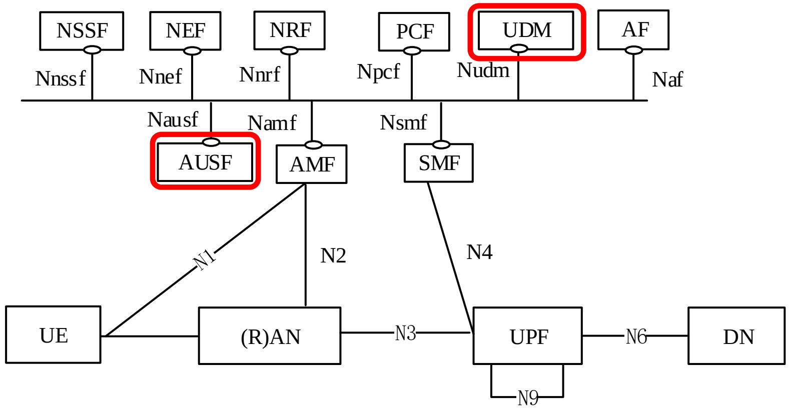
AUSF and UDM

Authentication Server Function (AUSF)

- Acts as an authentication server for 3GPP access and untrusted non-3GPP access

Unified Data Management (UDM)

- Generation of 3GPP Authentication and Key Agreement (AKA) credentials
  - User Identification handling
  - Access authorization based on subscription data
  - Lawful Intercept functionality
  - Subscription management



(3GPP TS 23.501)

NEF, NRF and NSSF

Network Slice Selection Function (NSSF)

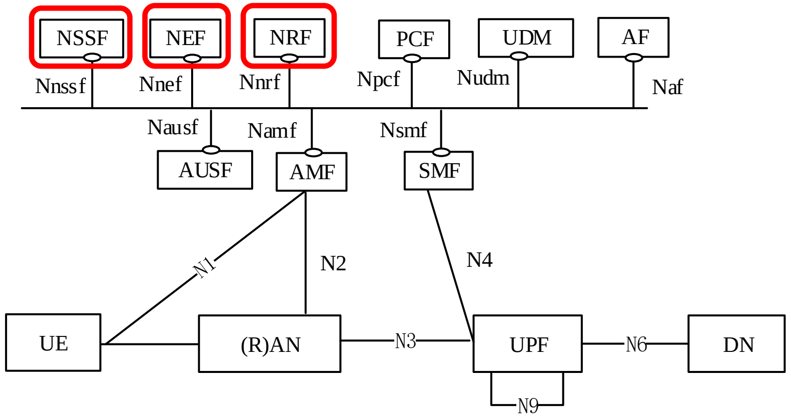
- Selecting of the Network Slice instances serving the UE
- Determining the Allowed NSSAI (*Network Slice Selection Assistance Information*)
- Determining the AMF set to be used to serve the UE

Network Exposure function (NEF)

- Exposure of capabilities and events
- Secure provision of information from external application to 3GPP network
- Translation of internal/external information

NF Repository function (NRF)

- Supports service discovery function
- Maintains the NF profile of available NF instances and their supported services

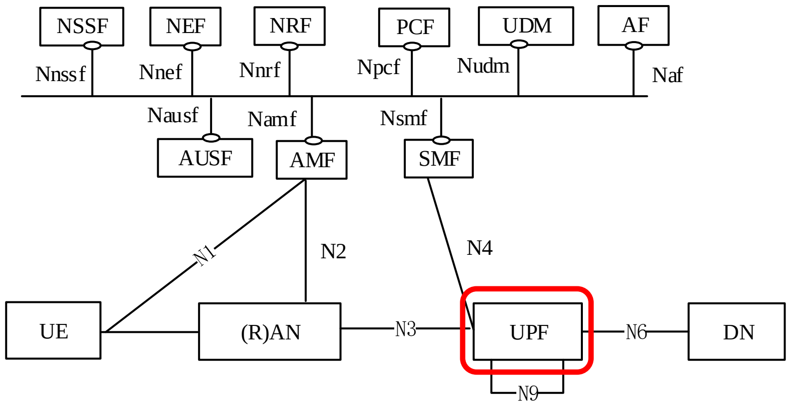


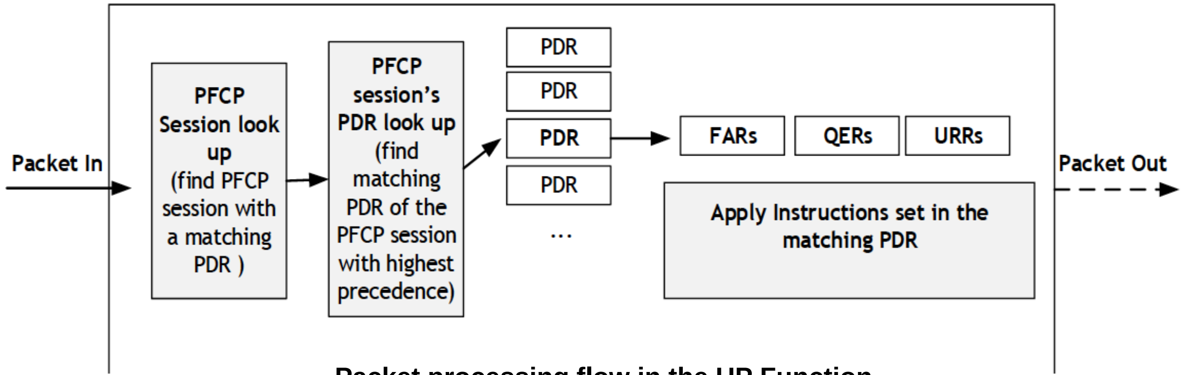
(3GPP TS 23.501)

UPF

User Plane Function (UPF)

- Packet routing & forwarding
- Anchor point for Intra-/Inter-RAT mobility
- External PDU session point of interconnect to Data Network
- Packet inspection and User plane part of Policy rule enforcement
- Lawful intercept (UP collection)
- Traffic usage reporting
- Uplink classifier (ULCL) to support routing traffic flows to a data network
- QoS handling for user plane, e.g. packet filtering, gating, UL/DL rate enforcement
- Transport level packet marking in the uplink and downlink
- Downlink packet buffering and downlink data notification triggering




Packet In
PFCP Session look up (find PFCP session with a matching PDR)
PFCP session's PDR look up (find matching PDR of the PFCP session with highest precedence)
PDR
PDR
PDR
PDR
...
FARs
QERs
URRs
Apply Instructions set in the matching PDR
Packet Out

Packet processing flow in the UP Function

Sent from SMF to UPF in PFCP

Packet Detection Rule *(PDR)*: This rule instructs the UPF how to detect incoming user data traffic (PDUs) and how to classify the traffic. The PDR contains Packet Detection Information (e.g., IP filters) used in the traffic detection and classification. There are separate PDRs for uplink and downlink.

QoS Enforcement Rule *(QER)*: This rule contains information on how to enforce QoS, e.g., bit rate parameters.

Usage Reporting Rule *(URR)*: This rule contains information on how the UPF shall measure (e.g., count) packets and bytes and report the usage to the SMF. The URR also contains information on events that shall be reported to SMF.

Forwarding Action Rule *(FAR)*: This rule contains information for how a packet (PDU) shall be forwarded by the UPF, e.g., towards the Data Network in uplink or towards RAN in downlink.

https://www.sciencedirect.com/topics/computer-science/user-data-traffic

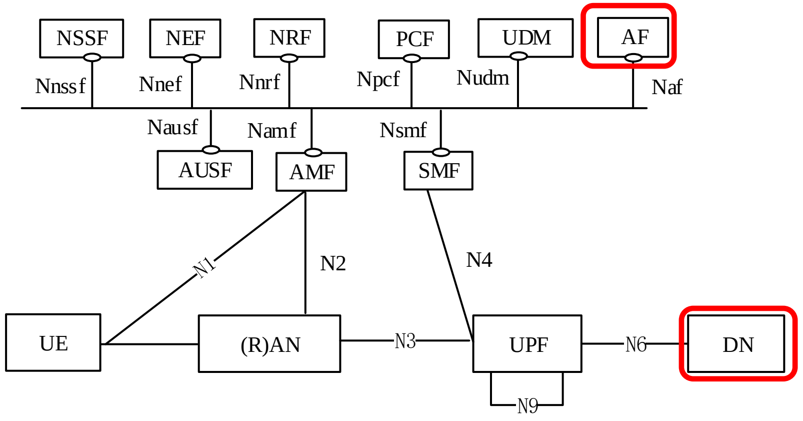
AF and DN

Application Function (AF)

- Application influence on traffic routing
- Accessing Network Exposure Function
- Interacting with the Policy framework for policy control

Data Network (DN)

- Operator services
- Internet access
- 3rd party services
- May be a Local Area Data Network (LADN):
  - a DN that is accessible by the UE only in specific locations, that provides connectivity to a specific **Data Network Name (DNN)**, and whose availability is provided to the UE.



(3GPP TS 23.501)

Data storage

Unstructured Data Storage Function (UDSF)

Unified Data Repository (UDR)

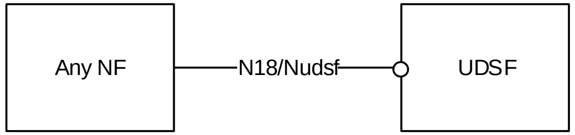


Figure 4.2.5-1: Data storage architecture for unstructured data from any NF (3GPP TS 23.501)

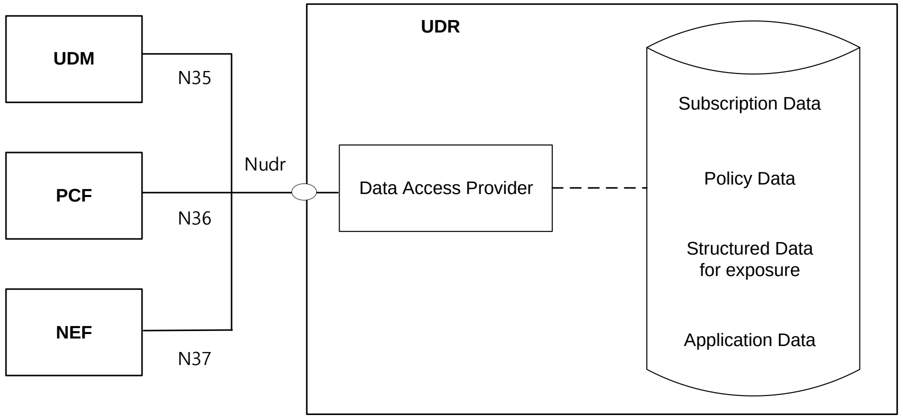
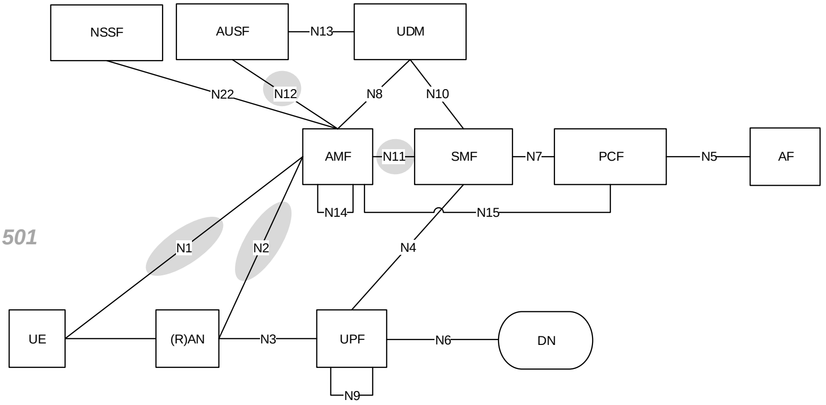


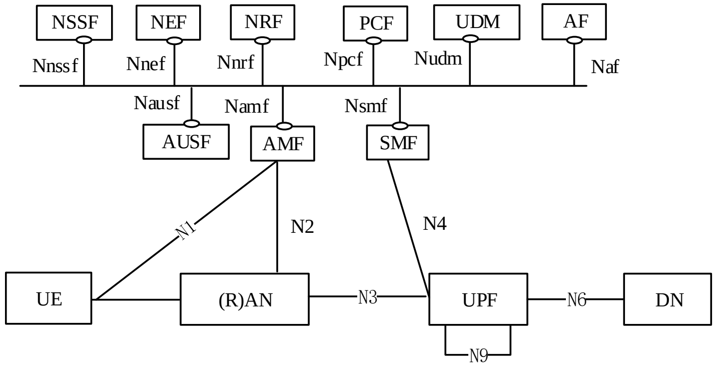
Figure 4.2.5-2: Data storage architecture (3GPP TS 23.501)

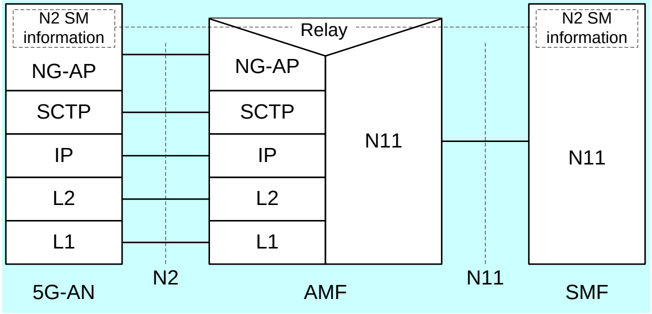
(3GPP TS 23.501)

Protocol stacks: Control Plane

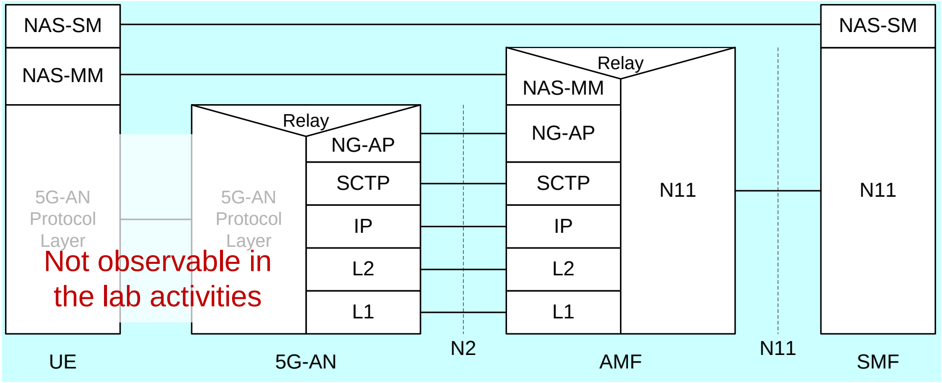
Source: 3GPP TS 23.501



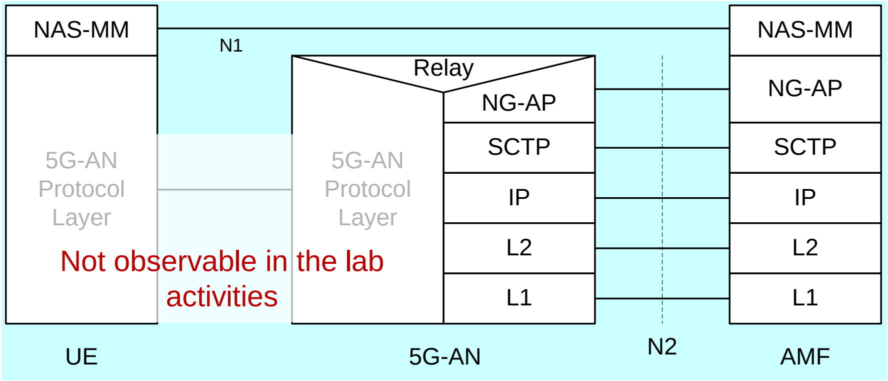




SCTP: Stream Control Transmission Protocol
PFCP: Packet Forwarding Control Protocol
NG-AP: NG Application Protocol
NAS-MM: NAS Mobility Management
NAS-SM: NAS Session Management
NAS: Non-Access-Stratum

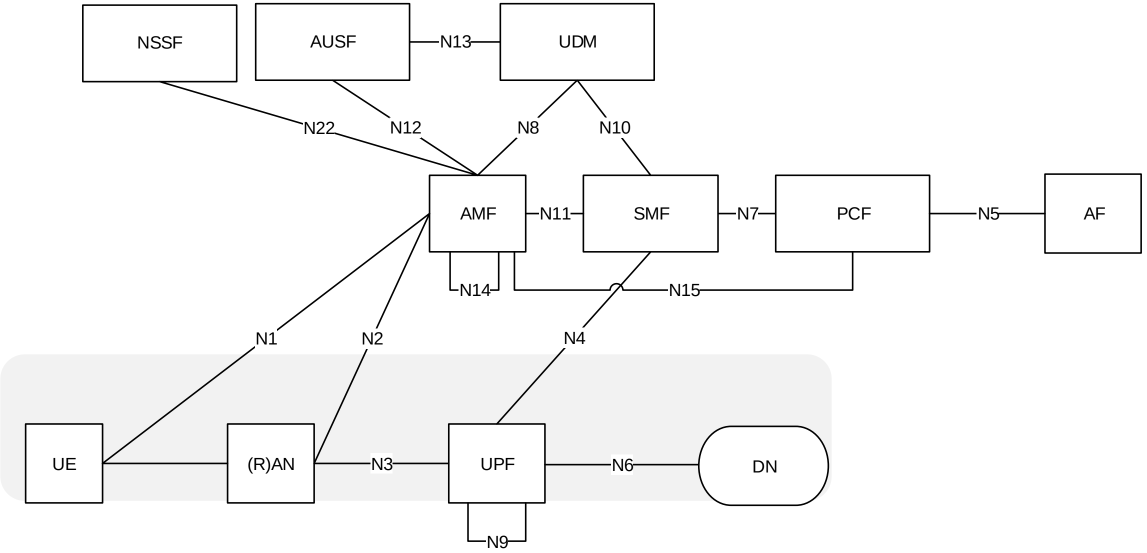


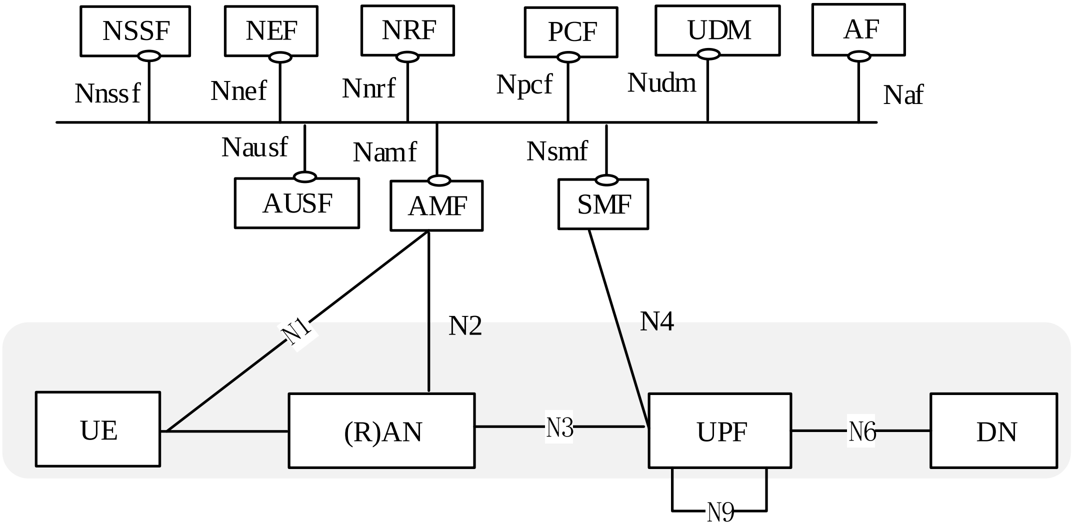
Not observable in the lab activities

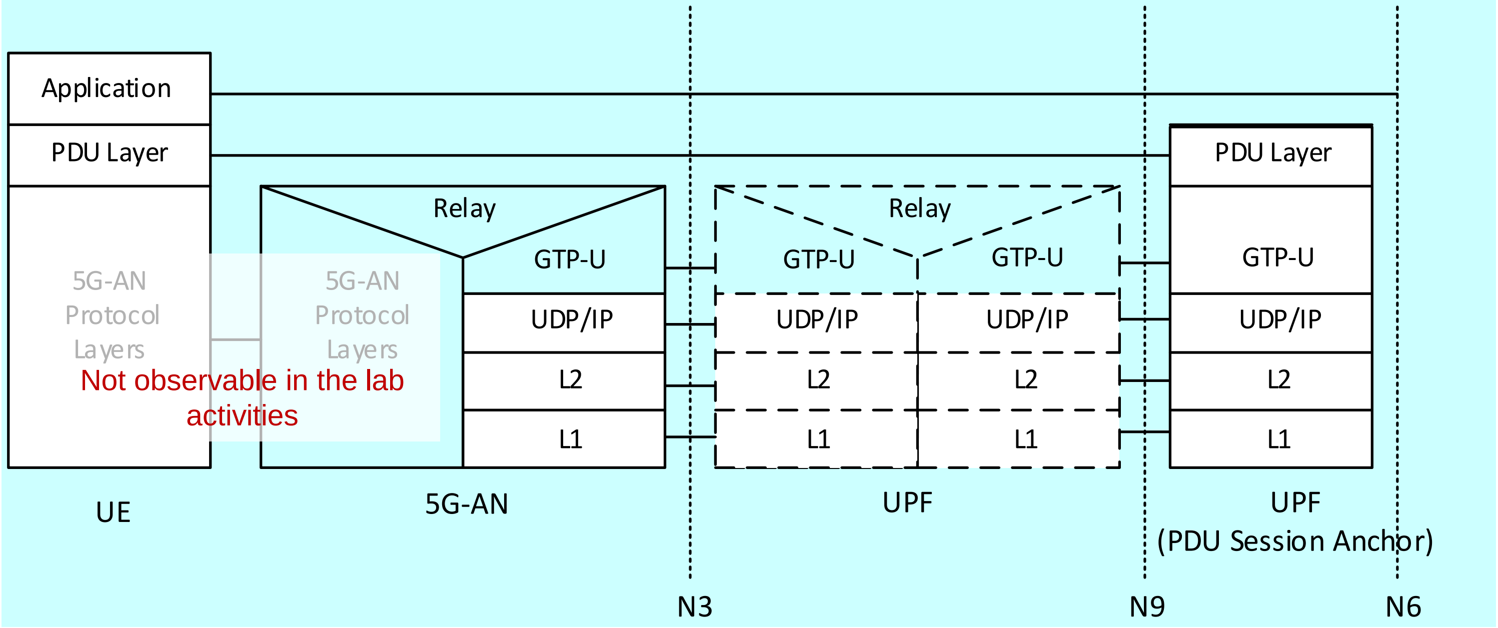


Not observable in the lab activities

Protocol stacks: User Plane





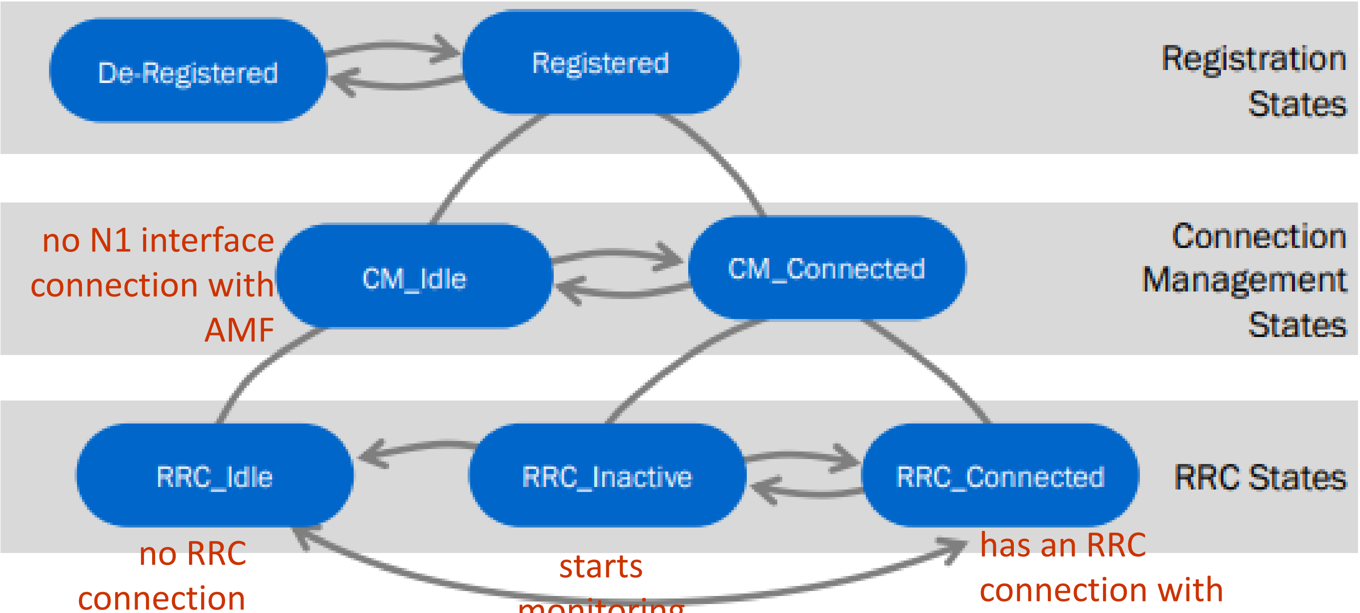


Not observable in the lab activities

GTP: GPRS Tunnelling Protocol

Source: 3GPP TS 23.501

UE states in 5G



successfully complete registration/ authentication

no N1 interface connection with AMF

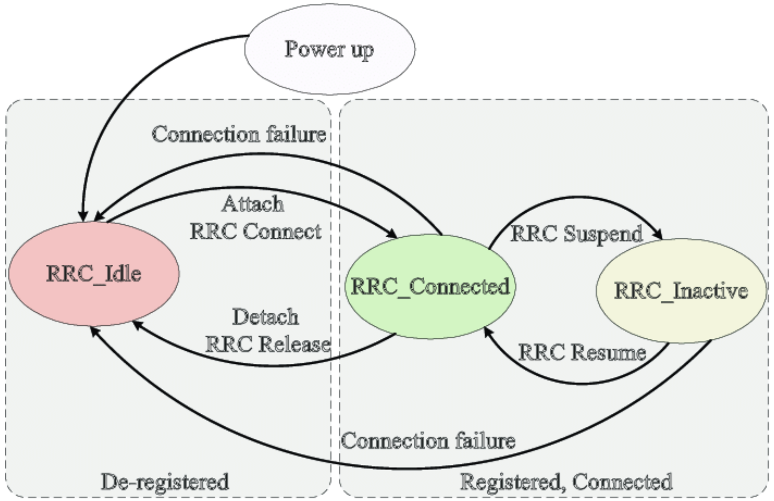
no RRC connection with the gNB

starts monitoring RAN paging

has an RRC connection with the gNB

Between UE and 5G Core

Between UE and gNB

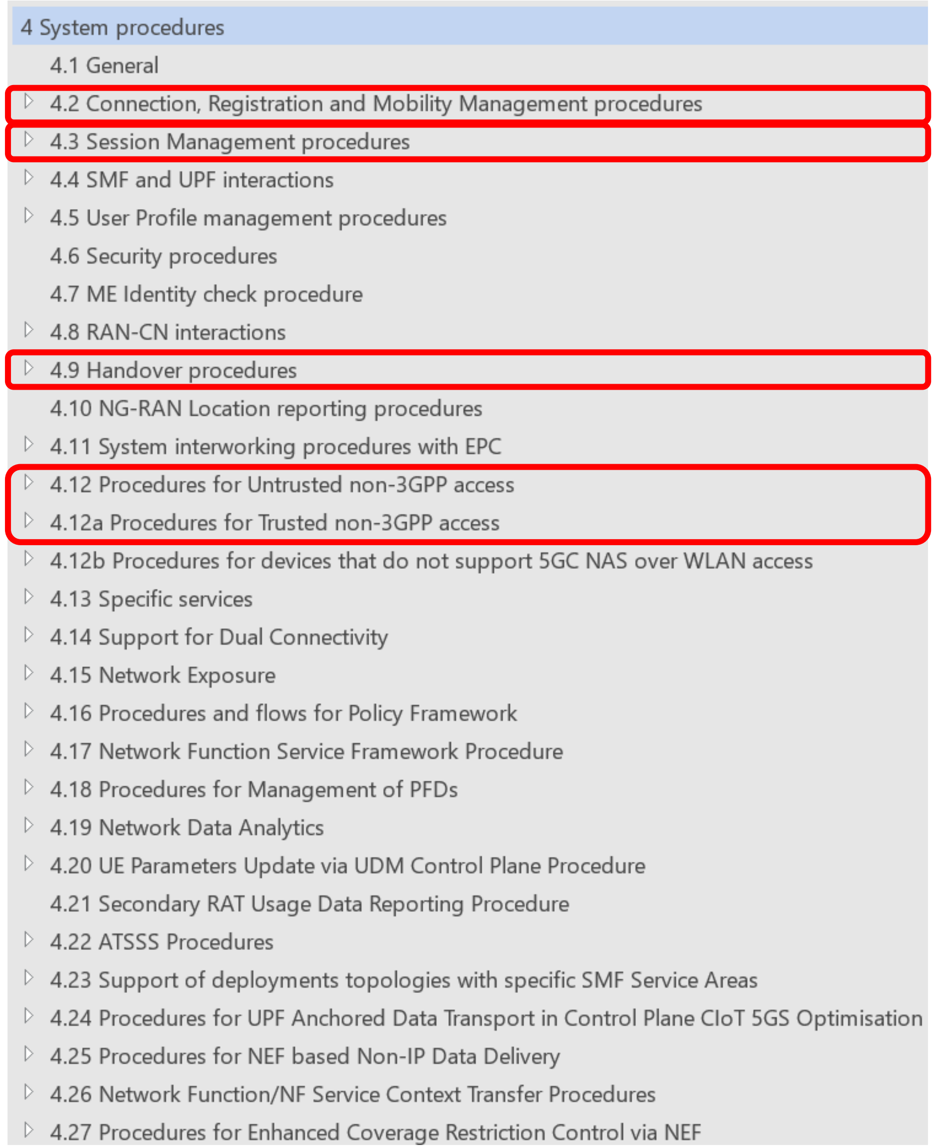


https://www.researchgate.net/figure/UE-state-machine-and-state-transitions-in-5G-78_fig3_350202251

https://www.linkedin.com/pulse/5g-ue-states-5g-myapekshatelecom/

5G Procedures

3GPP, TS 23.502, “Procedures for the 5G System (5GS)”



4 System procedures

4.1 General

4.2 Connection, Registration and Mobility Management procedures

4.3 Session Management procedures

4.4 SMF and UPF interactions

4.5 User Profile management procedures

4.6 Security procedures

4.7 ME Identity check procedure

4.8 RAN-CN interactions

4.9 Handover procedures

4.10 NG-RAN Location reporting procedures

4.11 System interworking procedures with EPC

4.12 Procedures for Untrusted non-3GPP access

4.12a Procedures for Trusted non-3GPP access

4.12b Procedures for devices that do not support 5GC NAS over WLAN access

4.13 Specific services

4.14 Support for Dual Connectivity

4.15 Network Exposure

4.16 Procedures and flows for Policy Framework

4.17 Network Function Service Framework Procedure

4.18 Procedures for Management of PFDs

4.19 Network Data Analytics

4.20 UE Parameters Update via UDM Control Plane Procedure

4.21 Secondary RAT Usage Data Reporting Procedure

4.22 ATSSS Procedures

4.23 Support of deployments topologies with specific SMF Service Areas

4.24 Procedures for UPF Anchored Data Transport in Control Plane CIoT 5GS Optimisation

4.25 Procedures for NEF based Non-IP Data Delivery

4.26 Network Function/NF Service Context Transfer Procedures

4.27 Procedures for Enhanced Coverage Restriction Control via NEF

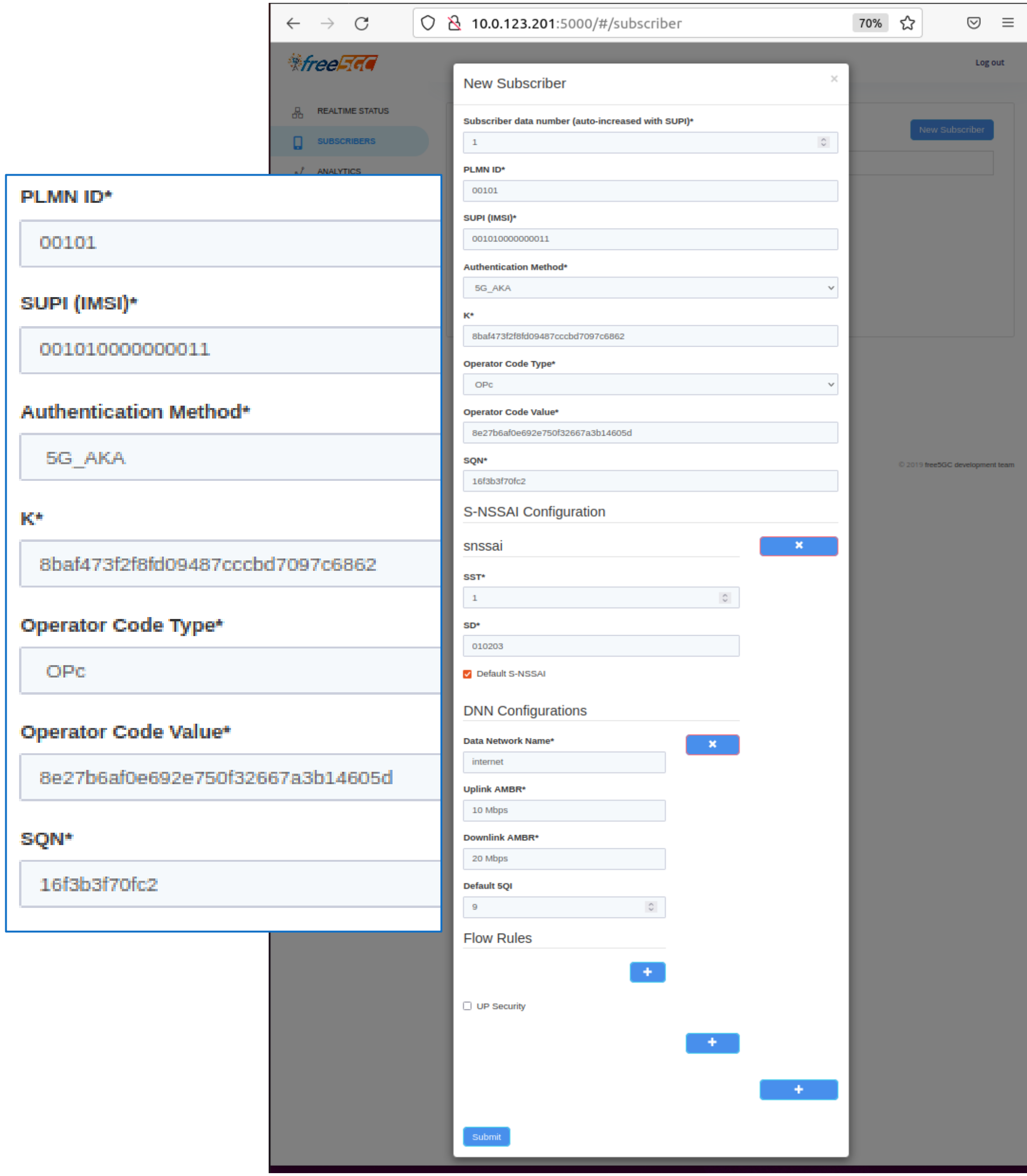
- **Connection, Registration and Mobility Management procedures**
- **Session Management**
  - **PDU Session Establishment**
  - **PDU Session Modification**
  - **PDU Session Release**
  - **Session continuity, service continuity and UP path management**
- **Handover procedures**
- **Procedures for Trusted/Untrusted non-3GPP access**

5G Security Parameters

- Auth Method
  - 5G-AKA or EAP-AKA’
- K: Long term 128 bit authentication key
  - Provisioned in the USIM (UE) and Operator (UDR)
- Operator Code Type:
  - OP: is an identifier assigned to a particular mobile network operator
  - OPc: Derived Operator Code, from OP value but unique for each USIM
- OP/OPc: Operator Code
  - Specific operator key parameters for Milenage and TUAK algorithms
- OPv: Operator Key
  - Value for OP or OPc
- SQN: Sequence Number
  - Used during the keys generation

- PLMN ID: MCC + MNC
- SUPI: *Subscription Permanent Identifier* (not exchanged)
  - IMSI (PLMN ID+MSIN):
  - NAI
- SUCI: *Subscriber Concealed Identifier*
  - Identifier used during the authentication process, avoiding SUPI exchange
- GUTI: *5G Globally Unique Temporary Identity*
  - Used in 5G as a means to keep the subscriber’s IMSI confidential
- MSIN: *Mobile Subscriber Identification Number*

Free5GC subscriber creation example



New Subscriber

Subscriber data number (auto-increased with SUPI)*: 1

PLMN ID*: 00101

SUPI (IMSI)*: 001010000000011

Authentication Method*: 5G_AKA

K*: 8baf473f2f8fd09487cccbd7097c6862

Operator Code Type*: OPc

Operator Code Value*: 8e27b6af0e692e750f32667a3b14605d

SQN*: 16f3b3f70fc2

S-NSSAI Configuration

snssai

SST*: 1

SD*: 010203

☑ Default S-NSSAI

DNN Configurations

Data Network Name*: internet

Uplink AMBR*: 10 Mbps

Downlink AMBR*: 20 Mbps

Default 5QI: 9

Flow Rules

☐ UP Security

Submit

PLMN ID*: 00101

SUPI (IMSI)*: 001010000000011

Authentication Method*: 5G_AKA

K*: 8baf473f2f8fd09487cccbd7097c6862

Operator Code Type*: OPc

Operator Code Value*: 8e27b6af0e692e750f32667a3b14605d

SQN*: 16f3b3f70fc2

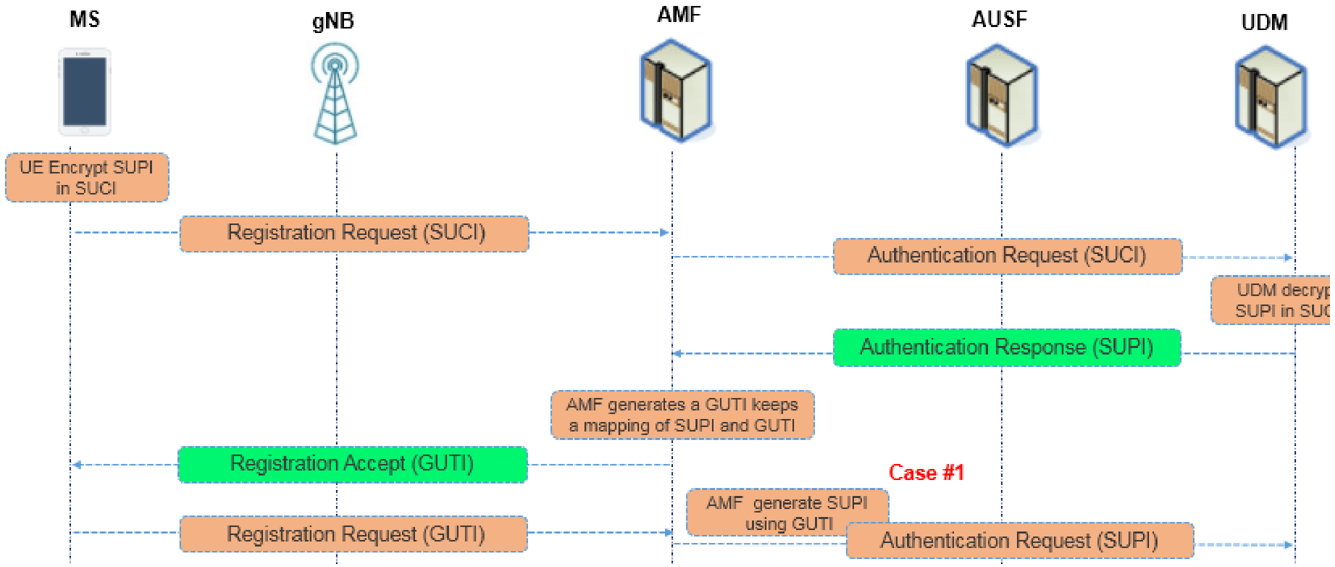
Authentication process

- **Primary authentication:**
  - **Mutual authentication between the UE and the network and provide keying material that can be used between the UE and the serving network in subsequent security procedures**

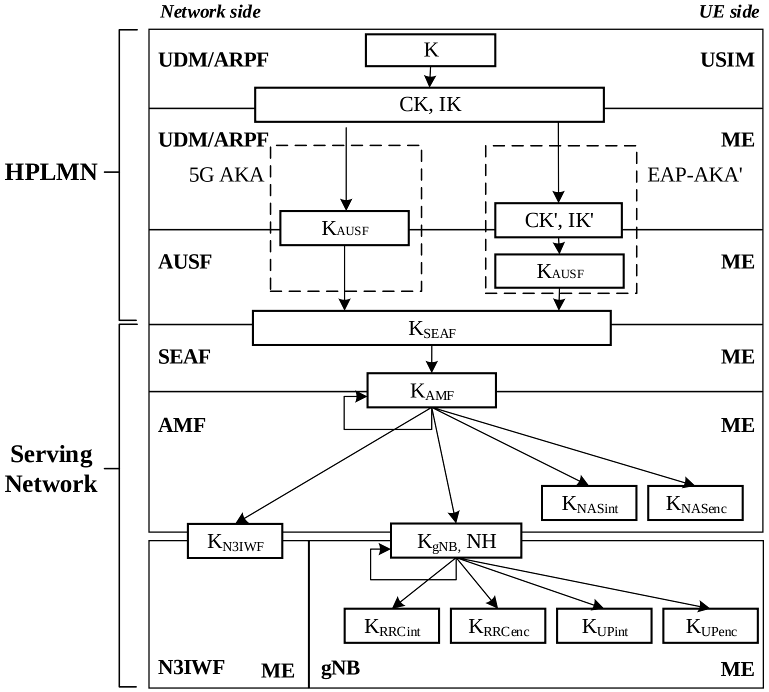
- **Primary authentication offers two mechanisms:**

  (1) *5G Authentication and Key Agreement* (5G AKA): no EAP encapsulation

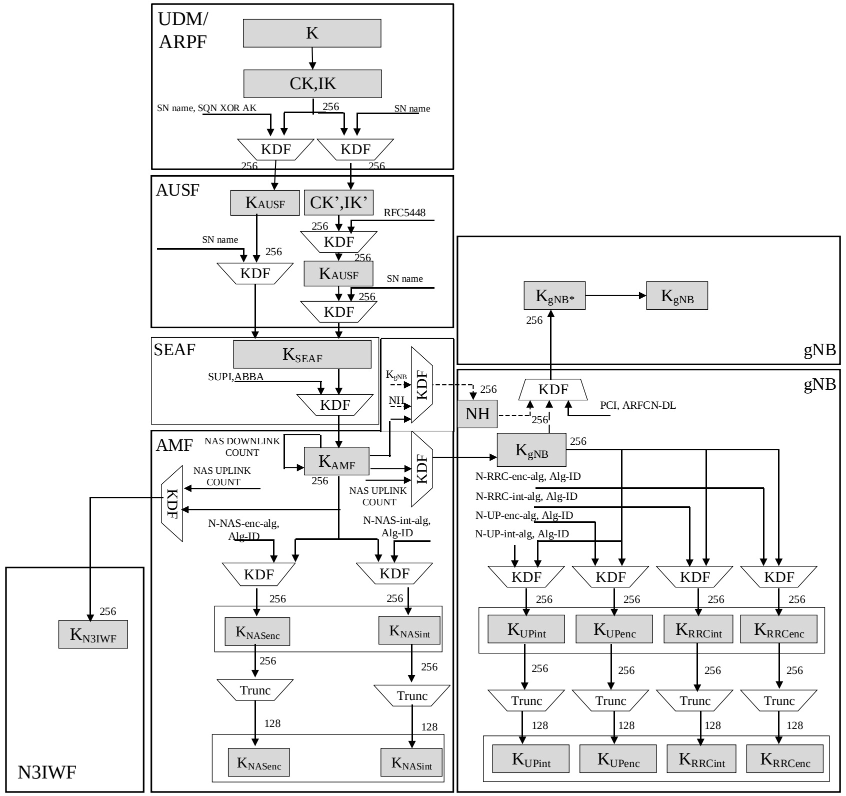
  (2) *Extensible Authentication Protocol AKA'* (EAP-AKA')


MS
gNB
AMF
AUSF
UDM
UE Encrypt SUPI in SUCI
Registration Request (SUCI)
Authentication Request (SUCI)
UDM decryp SUPI in SUC
Authentication Response (SUPI)
AMF generates a GUTI keeps a mapping of SUPI and GUTI
Registration Accept (GUTI)
Case #1
AMF generate SUPI using GUTI
Registration Request (GUTI)
Authentication Request (SUPI)

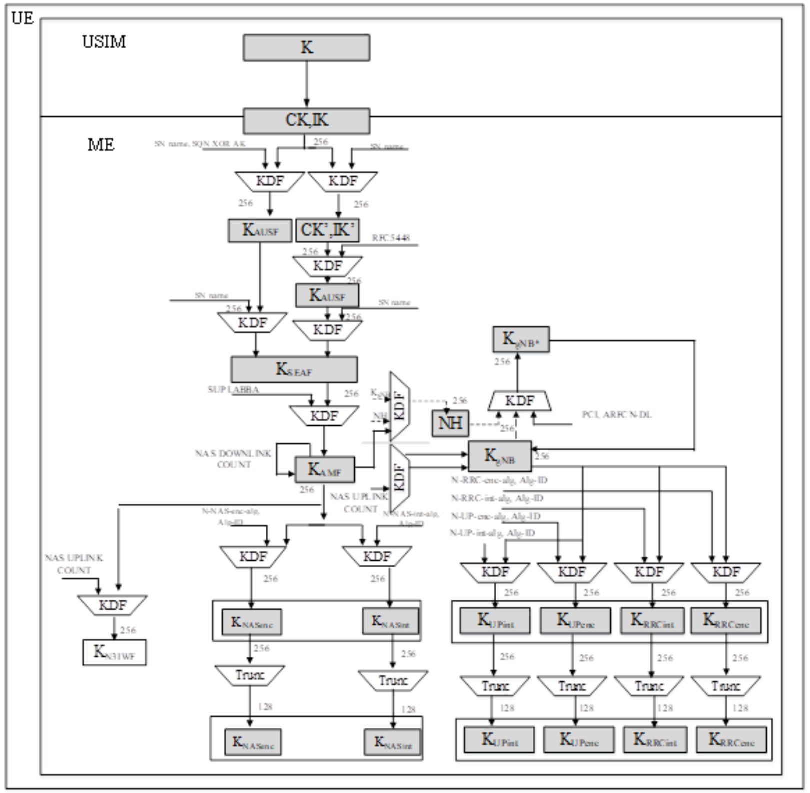
Keys generationm from K



3GPP, TS 33.501, Figure 6.2.1-1: Key hierarchy generation in 5GS



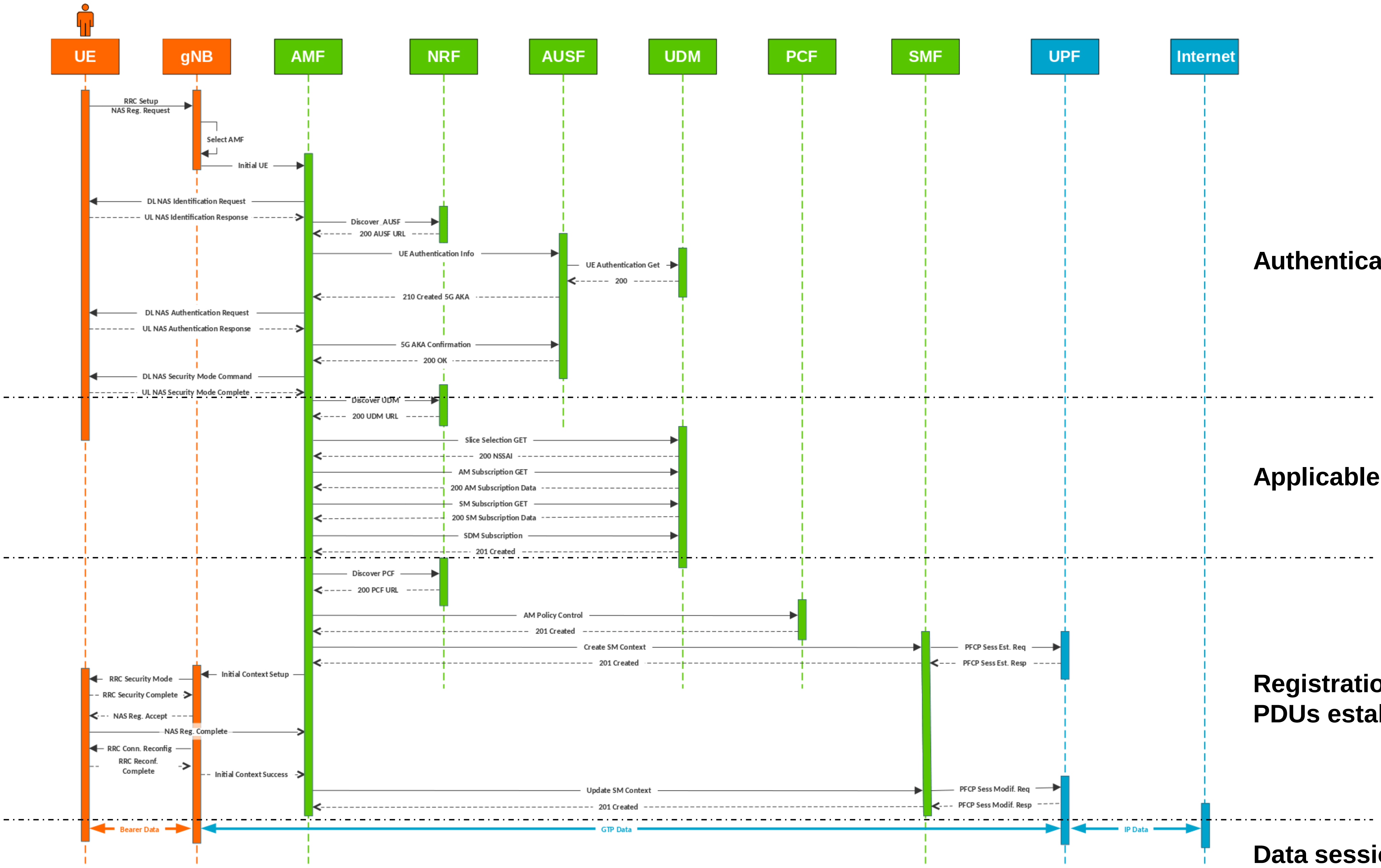
3GPP, TS 33.501, Figure 6.2.2-1: Key distribution and key derivation scheme for 5G for network nodes



3GPP, TS 33.501, Figure 6.2.2-2: Key distribution and key derivation scheme for 5G for the UE

CK: cipher key
IK: integrity keyb

5G Standalone Registration



UE
gNB
AMF
NRF
AUSF
UDM
PCF
SMF
UPF
Internet

RRC Setup
NAS Reg. Request
Select AMF
Initial UE
DL NAS Identification Request
UL NAS Identification Response
Discover_AUSF
200 AUSF URL
UE Authentication Info
UE Authentication Get
200
210 Created 5G AKA
DL NAS Authentication Request
UL NAS Authentication Response
5G AKA Confirmation
200 OK
DL NAS Security Mode Command
UL NAS Security Mode Complete

Authentication

Discover UDM
200 UDM URL
Slice Selection GET
200 NSSAI
AM Subscription GET
200 AM Subscription Data
SM Subscription GET
200 SM Subscription Data
SDM Subscription
201 Created

Applicable Slices selection

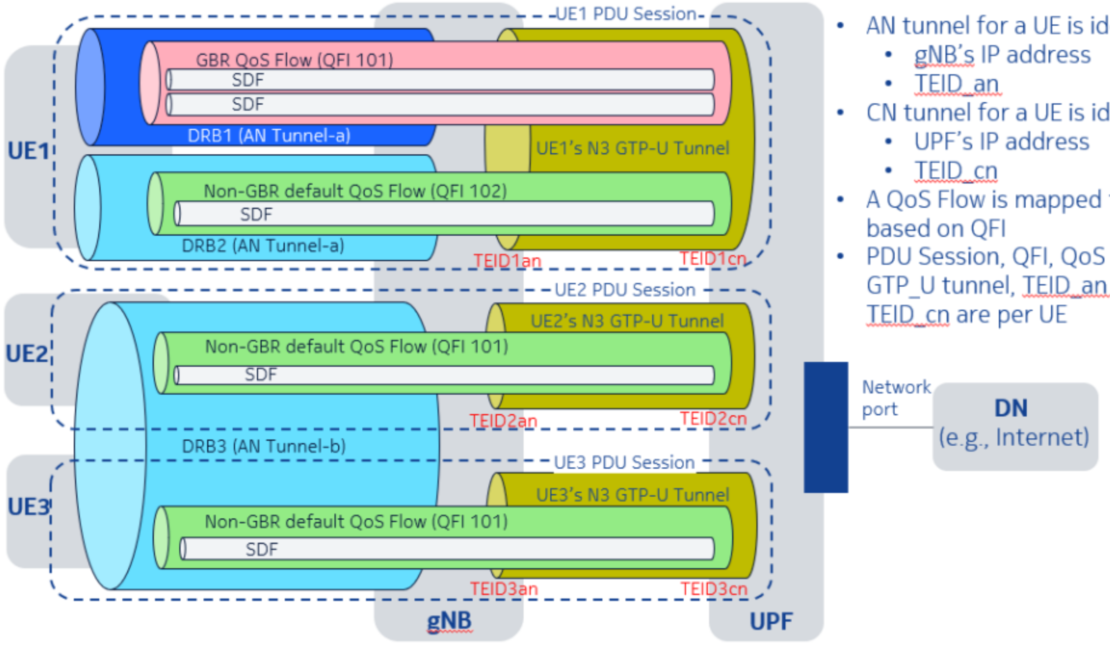
Discover PCF
200 PCF URL
AM Policy Control
201 Created
Create SM Context
PFCP Sess Est. Req
201 Created
PFCP Sess Est. Resp
Initial Context Setup
RRC Security Mode
RRC Security Complete
NAS Reg. Accept
NAS Reg. Complete
RRC Conn. Reconfig
RRC Reconf. Complete
Initial Context Success
Update SM Context
PFCP Sess Modif. Req
201 Created
PFCP Sess Modif. Resp

Registration & PDUs establishment

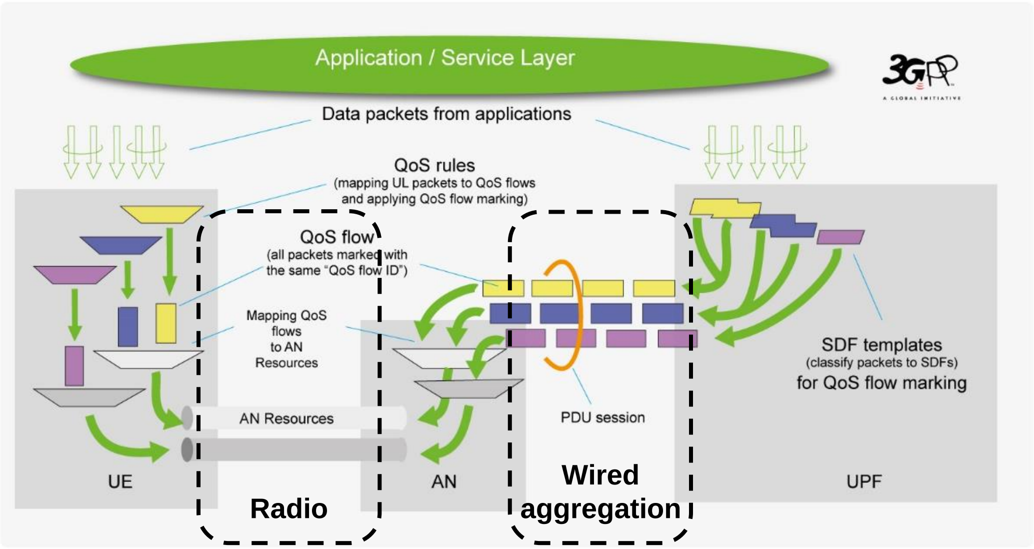
Bearer Data
GTP Data
IP Data

Data session

QoS Model



- 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


Application / Service Layer
3GPP
A GLOBAL INITIATIVE
Data packets from applications
QoS rules
(mapping UL packets to QoS flows and applying QoS flow marking)
QoS flow
(all packets marked with the same "QoS flow ID")
Mapping QoS flows to AN Resources
AN Resources
SDF templates
(classify packets to SDFs)
for QoS flow marking
PDU session
UE
AN
UPF
Radio
Wired aggregation

The QoS profile of a QoS flow contains QoS parameters:
For each QoS flow:

- A 5G QoS Identifier (5QI)
- An Allocation and Retention Priority (ARP)

In case of a GBR QoS flow only:

- Guaranteed Flow Bit Rate (GFBR) for both uplink and downlink
- Maximum Flow Bit Rate (MFBR) for both uplink and downlink
- Maximum Packet Loss Rate for both uplink and downlink

In case of Non-GBR QoS only:

- Reflective QoS Attribute (RQA): the RQA, when included, indicates that some (not necessarily all) traffic carried on this QoS flow is subject to reflective quality of service (RQoS) at NAS

Standardized 5QI to QoS characteristics mapping

5QI Value	Resource Type	Priority Level	Packet Delay Budget	Packet Error Rate	Default Averaging Window	Example Services
1	GBR	20	100 ms	10^{-2}	TBD	Conversational Voice
2		40	150 ms	10^{-3}	TBD	Conversational Video (Live Streaming)
3		30	50 ms	10^{-3}	TBD	Real Time Gaming, V2X messages
4		50	300 ms	10^{-6}	TBD	Non-Conversational Video (Buffered Streaming)
65		7	75 ms	10^{-2}	TBD	Mission Critical user plane Push To Talk voice (e.g., MCPTT)
66		20	100 ms	10^{-2}	TBD	Non-Mission-Critical user plane Push To Talk voice
75		25	50 ms	10^{-2}	TBD	V2X messages
5	Non-GBR	10	100 ms	10^{-6}	N/A	IMS Signalling
6		60	300 ms	10^{-6}	N/A	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
7		70	100 ms	10^{-3}	N/A	Voice, Video (Live Streaming) Interactive Gaming
8		80	300 ms	10^{-6}	N/A	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file
9		90			N/A	sharing, progressive video, etc.)
69		5	60 ms	10^{-6}	N/A	Mission Critical delay sensitive signalling (e.g., MC-PTT signalling)
70		55	200 ms	10^{-6}		Mission Critical Data (e.g. example services are the same as QCI 6/8/9)
79		65	50 ms	10^{-2}	N/A	V2X messages
					N/A	

Release 16 87 3GPP TS 23.502 V16.4.0 (2020-03)

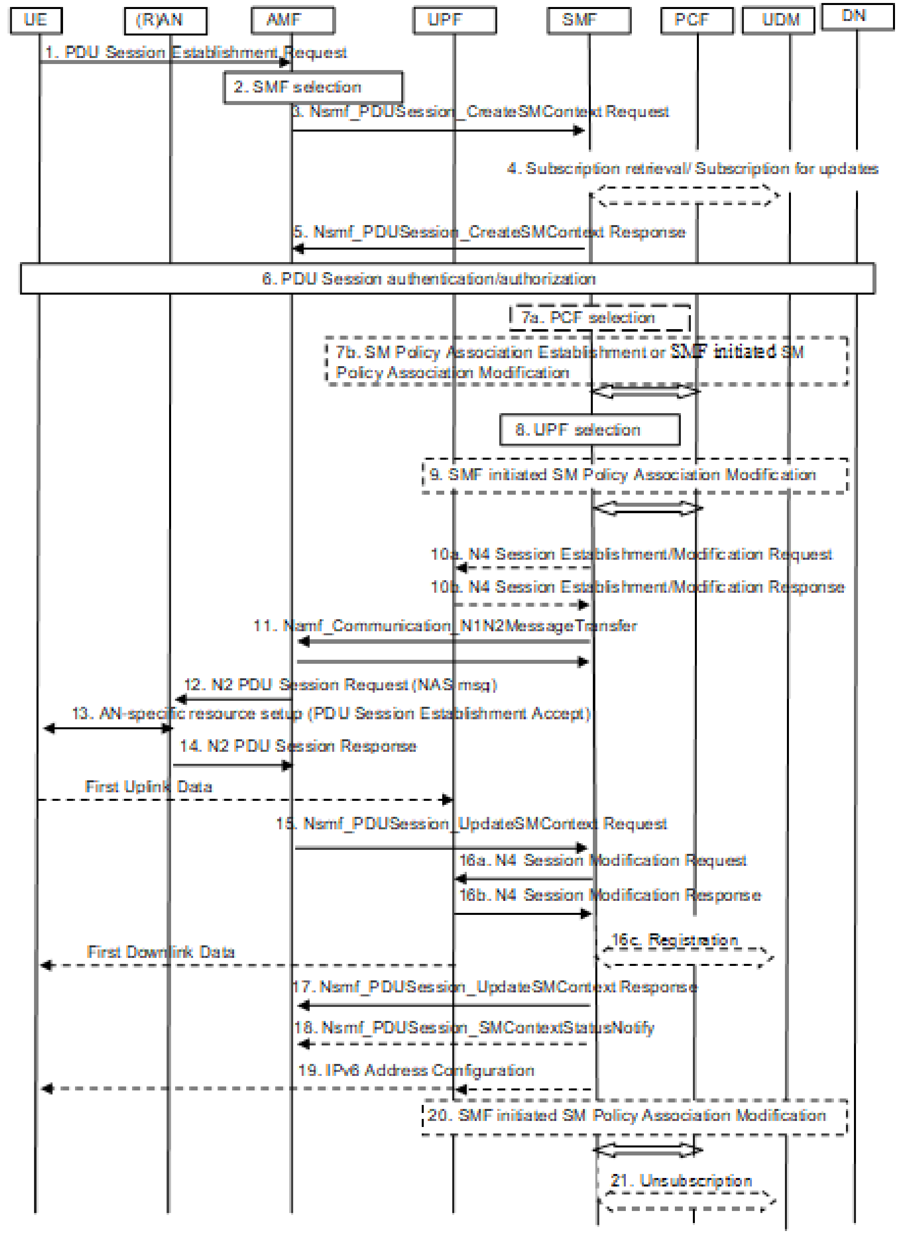
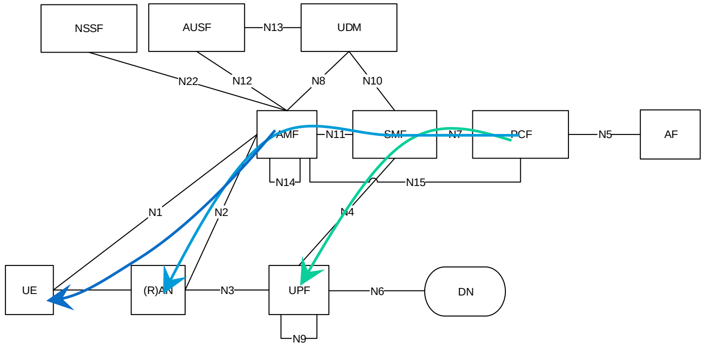
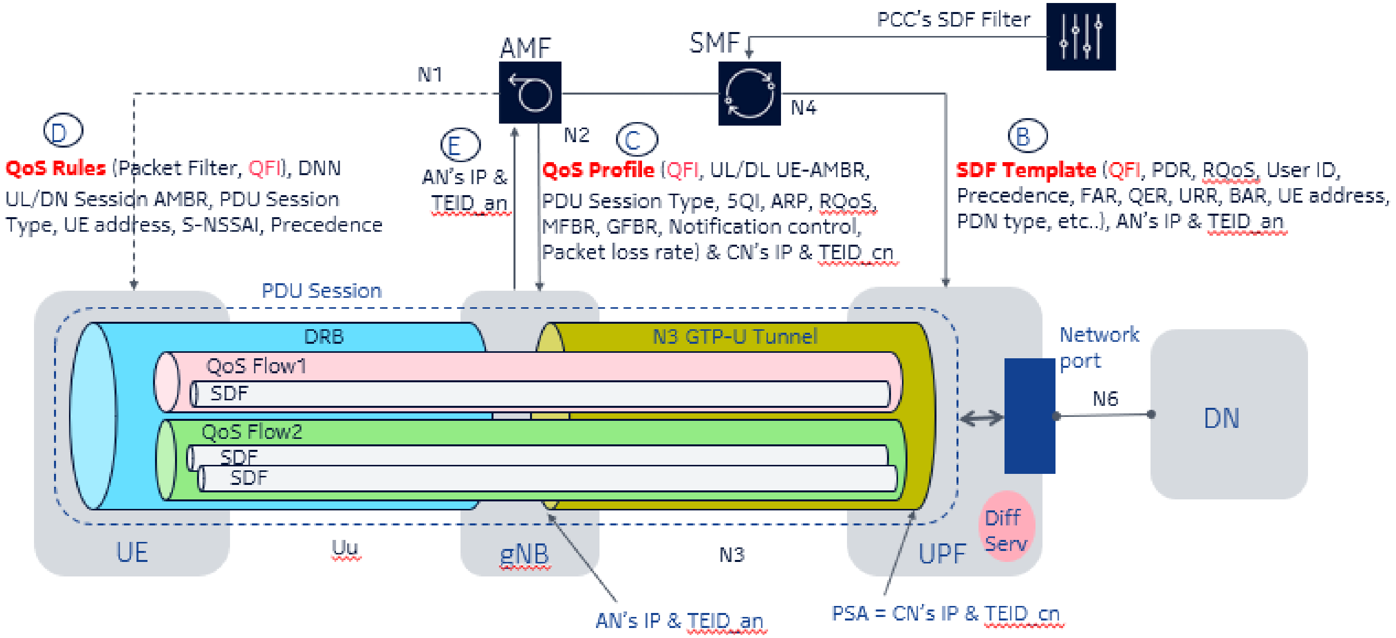

UE
(R)AN
AMF
UPF
SMF
PCF
UDM
DN
1. PDU Session Establishment Request
2. SMF selection
3. Nsmf_PDUSession_CreateSMContext Request
4. Subscription retrieval/ Subscription for updates
5. Nsmf_PDUSession_CreateSMContext Response
6. PDU Session authentication/authorization
7a. PCF selection
7b. SM Policy Association Establishment or SMF initiated SM Policy Association Modification
8. UPF selection
9. SMF initiated SM Policy Association Modification
10a. N4 Session Establishment/Modification Request
10b. N4 Session Establishment/Modification Response
11. Namf_Communication_N1N2MessageTransfer
12. N2 PDU Session Request (NAS msg)
13. AN-specific resource setup (PDU Session Establishment Accept)
14. N2 PDU Session Response
First Uplink Data
15. Nsmf_PDUSession_UpdateSMContext Request
16a. N4 Session Modification Request
16b. N4 Session Modification Response
16c. Registration
First Downlink Data
17. Nsmf_PDUSession_UpdateSMContext Response
18. Nsmf_PDUSession_SMContextStatusNotify
19. IPv6 Address Configuration
20. SMF initiated SM Policy Association Modification
21. Unsubscription

Figure 4.3.2.2.1-1: UE-requested PDU Session Establishment for non-roaming and roaming with local breakout

QoS protocols' flows





QoS Rules (Packet Filter, QFI), DNN UL/DN Session AMBR, PDU Session Type, UE address, S-NSSAI, Precedence

AN's IP & TEID_an

QoS Profile (QFI, UL/DL UE-AMBR, PDU Session Type, 5QI, ARP, RQoS, MFBR, GFBR, Notification control, Packet loss rate) & CN's IP & TEID_cn

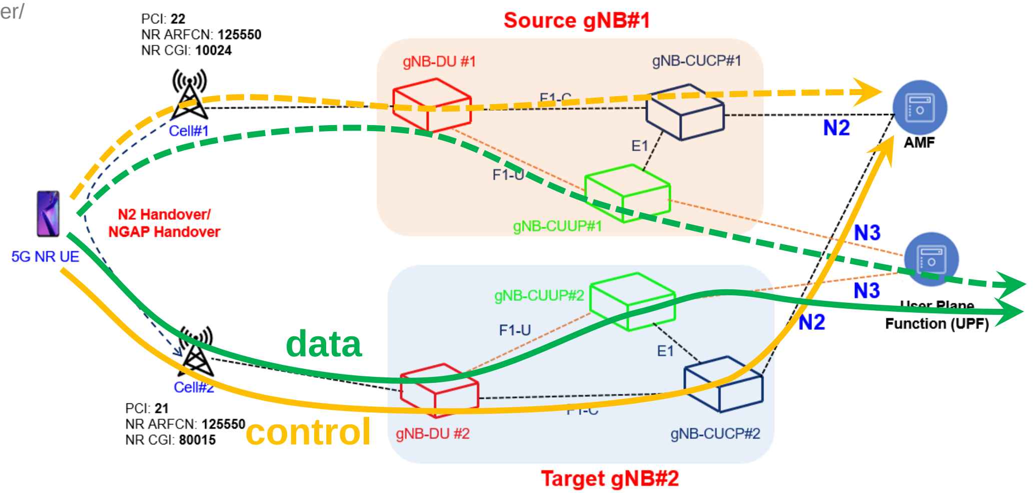
SDF Template (QFI, PDR, RQoS, User ID, Precedence, FAR, QER, URR, BAR, UE address, PDN type, etc..), AN's IP & TEID_an

AN's IP & TEID_an

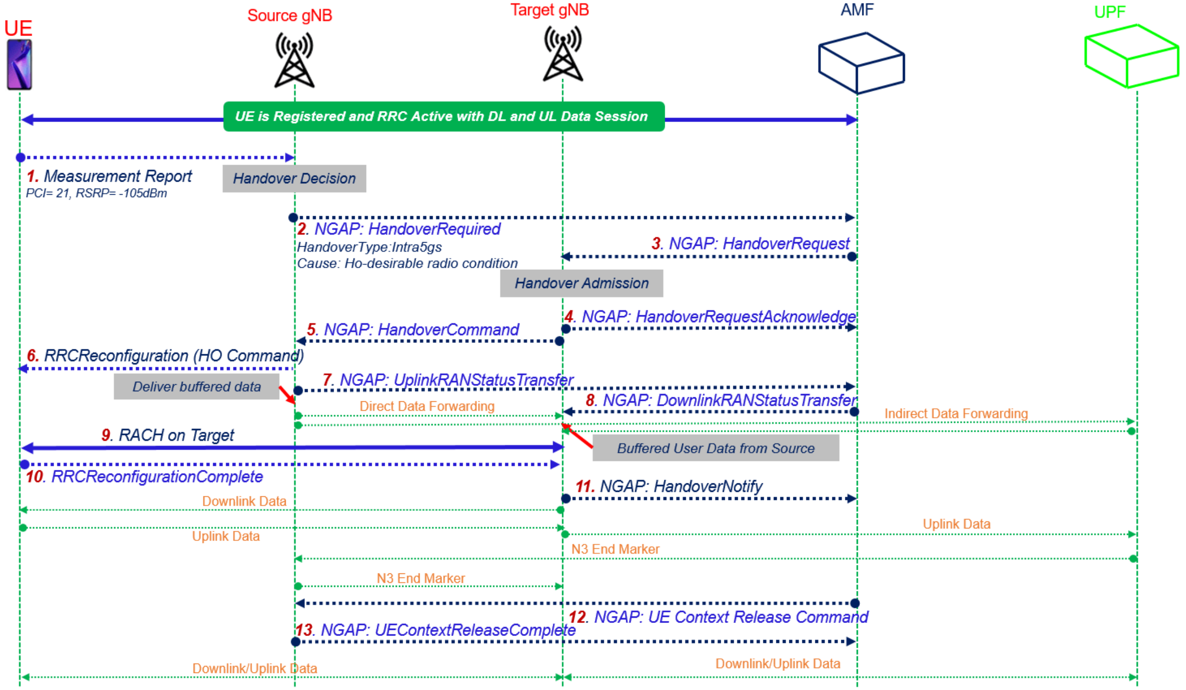
PSA = CN's IP & TEID_cn

Inter gNB mobility in 5G

https://www.techplayon.com/5g-sa-inter-gnb-handover-n2-or-ngap-handover/

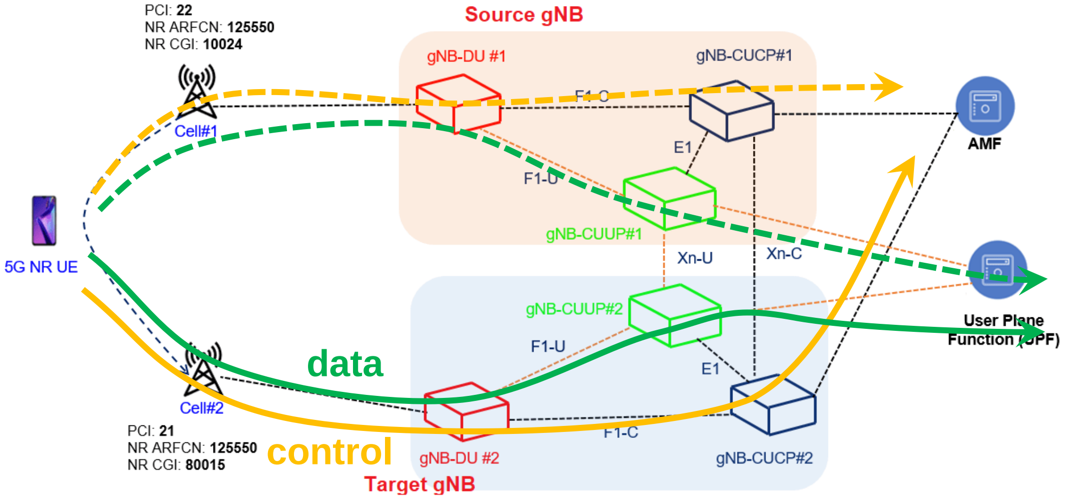


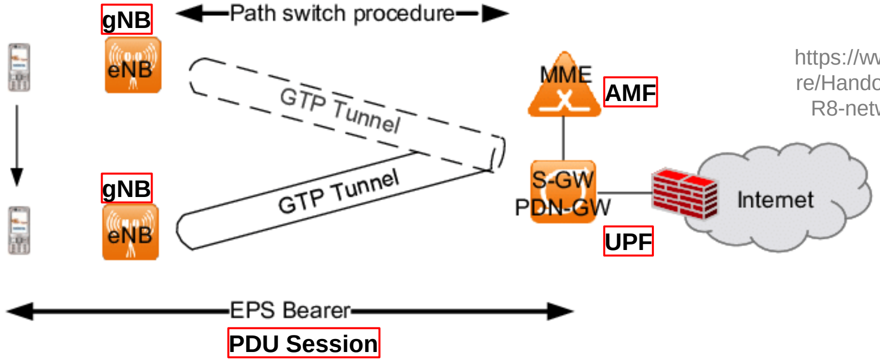
https://www.techplayon.com/5g-sa-inter-gnb-handover-n2-or-ngap-handover/



UE
Source gNB
Target gNB
AMF
UPF
UE is Registered and RRC Active with DL and UL Data Session
1. Measurement Report
PCI= 21, RSRP= -105dBm
Handover Decision
2. NGAP: HandoverRequired
HandoverType:Intra5gs
Cause: Ho-desirable radio condition
3. NGAP: HandoverRequest
Handover Admission
4. NGAP: HandoverRequestAcknowledge
5. NGAP: HandoverCommand
6. RRCReconfiguration (HO Command)
Deliver buffered data
7. NGAP: UplinkRANStatusTransfer
Direct Data Forwarding
8. NGAP: DownlinkRANStatusTransfer
Indirect Data Forwarding
9. RACH on Target
Buffered User Data from Source
10. RRCReconfigurationComplete
11. NGAP: HandoverNotify
Downlink Data
Uplink Data
Uplink Data
N3 End Marker
N3 End Marker
12. NGAP: UE Context Release Command
13. NGAP: UEContextReleaseComplete
Downlink/Uplink Data
Downlink/Uplink Data

https://www.techplayon.com/5g-sa-inter-gnb-hanodver-xn-handover/





https://www.researchgate.net/figure/Handover-procedure-in-3GPP-R8-networks_fig1_224264314

5G Slicing

Network Slice definition (TR 23.799): ***complete logical network (providing Telecommunication Services and Network Capabilities) including AN and CN***

Slicing enables the creation of distinct logical networks:

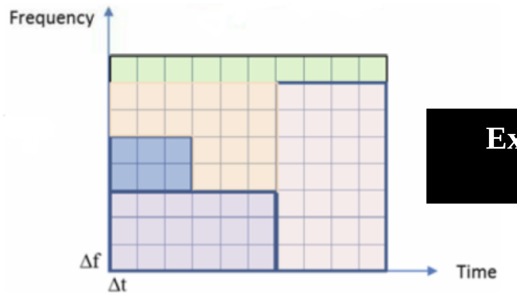
- **Of the same type (different businesses)**
- **Providing differentiated behaviour (different services)**

5G supports end-to-end slicing (radio and core)

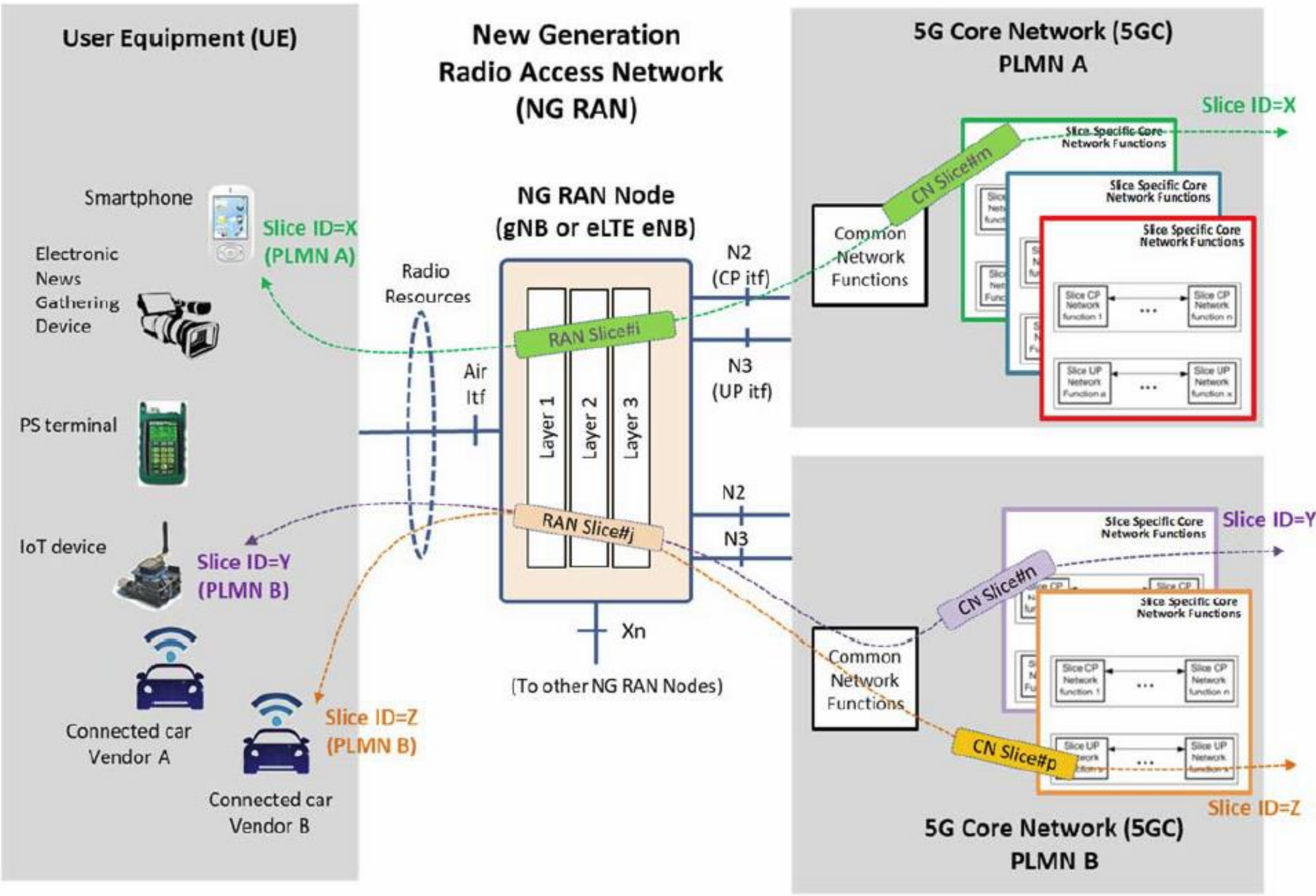
- **Resources isolation between services**
- **Customized functions and/or capacities, according to SLA**

Each terminal (UE) may connect simultaneously to max 8 slices (no limit for the number of slices in the core)

Takes benefit of NVF for easy slices creation and management (LCM)



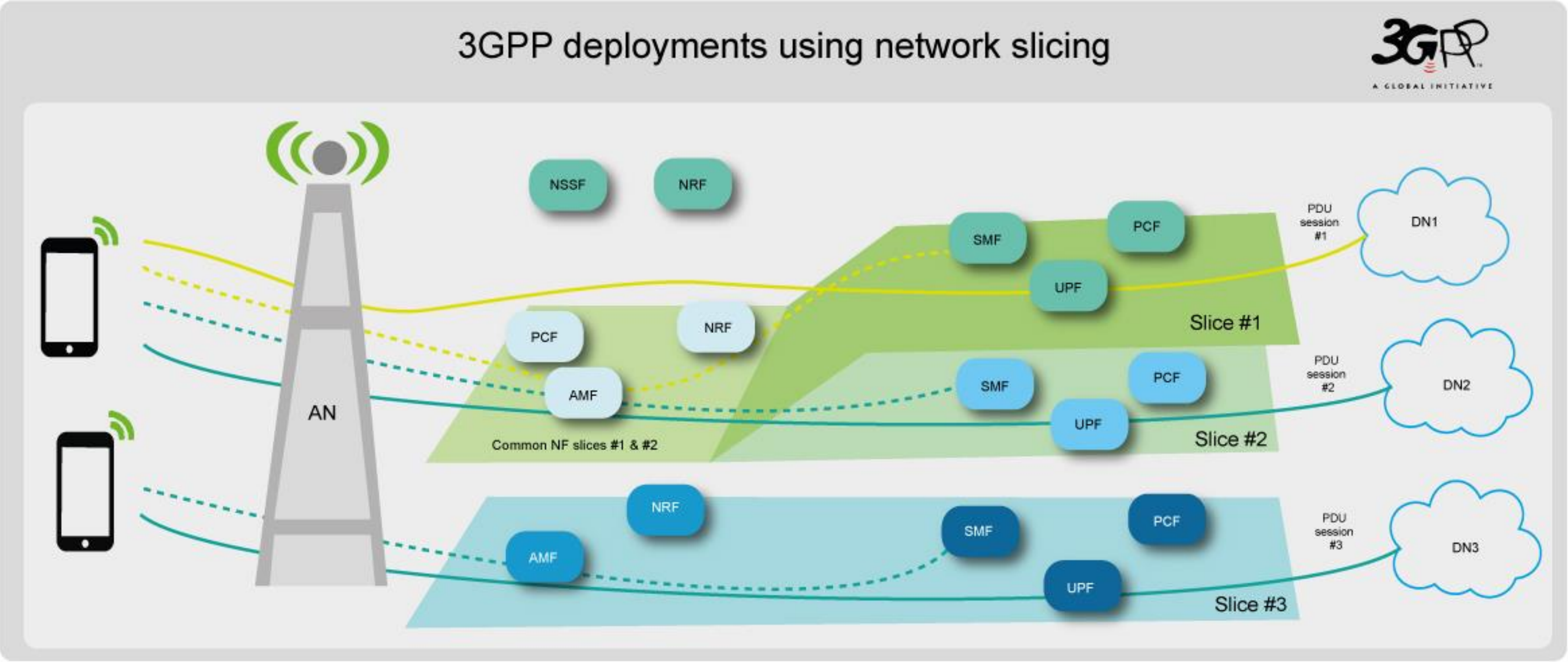
Example of RAN resources allocation for 5 slices



5G Americas, *NetWork Slicing for 5G networks & services*, Nov/16

On 5G Radio Access Network Slicing: Radio Interface Protocol Features and Configuration, R. Ferrús

5G Slicing



https://www.3gpp.org/news-events/3gpp-news/sys-architecture

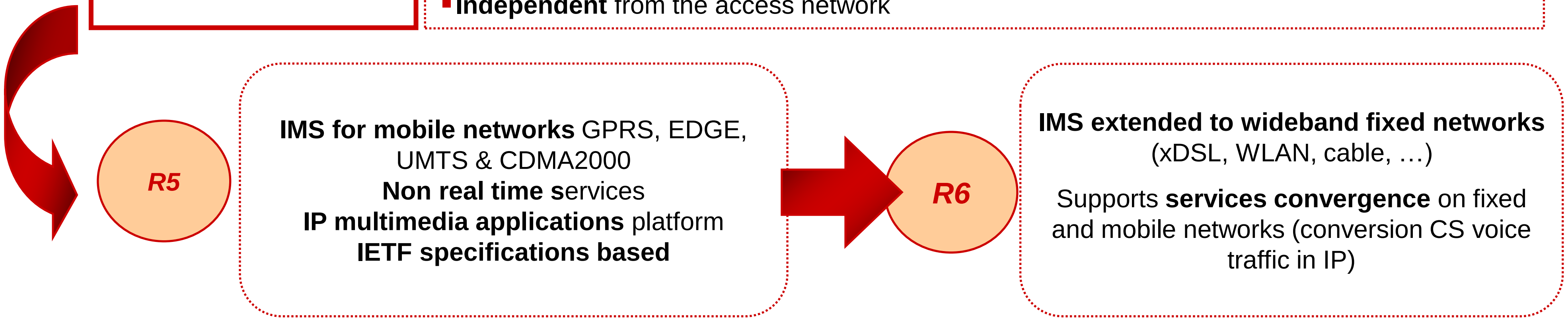
APN → DNN (Data Network Name)

- https://www.mpirical.com/blog/the-evolution-of-mobile-communication
- https://telecompedia.net/5g-core-network-overview/
- https://telecompedia.net/5g-nr-frequency-bands/

IMS - IP Multimedia Subsystem

Principles

- **QoS characteristics differentiation** for voice or video associated with a multimedia session (streaming, IM, etc.)
- **Separation of the planes** IP data and session control (SIP)
- **Independent** from the access network



R5

IMS for mobile networks GPRS, EDGE, UMTS & CDMA2000
Non real time services
IP multimedia applications platform
IETF specifications based

R6

IMS extended to wideband fixed networks (xDSL, WLAN, cable, …)

Supports **services convergence** on fixed and mobile networks (conversion CS voice traffic in IP)

Advantages

- **Introduction of multimedia services** with **QoS** management
- **Integration** with other networks (WLANs, fixed, CDMA2000, …)
- **Flexible billing**: billing / service, connectivity, QoS, time, destination

Drawbacks

- **Implementation of many equipments, softwares, interfaces, protocols**, which may cause integration, interworking and optimisation problems
  - –Ex.: S-**CSCF** (*Call Status Control Function*); SIP **AS** (*SIP Application Server*); OSA **SCS** (*Service Capability Server*); IM-SSF (*Inter-working Module*); CSE (*Camel Service Environment*); **HSS** *(Home Subscriber Server)*
- **Security and QoS** with Internet interconnection

IMS – Key Architectural Principals

- Border Functions
  - Access and Network Border Security
  - QoS and Admission Control
  - Media and Signaling Adaptation

- Core Functions
  - Subscriber Management – Registration
  - Session Switching – Set-up and tear-down of session legs, Session state maintenance, Application Server invocation
  - Session Routing – Breakout to external networks
  - Centralized Provisioning – Subscriber and Routing data

- Application Functions
  - Access to legacy applications
  - Native SIP Applications
  - Service Brokering

SIP Protocol

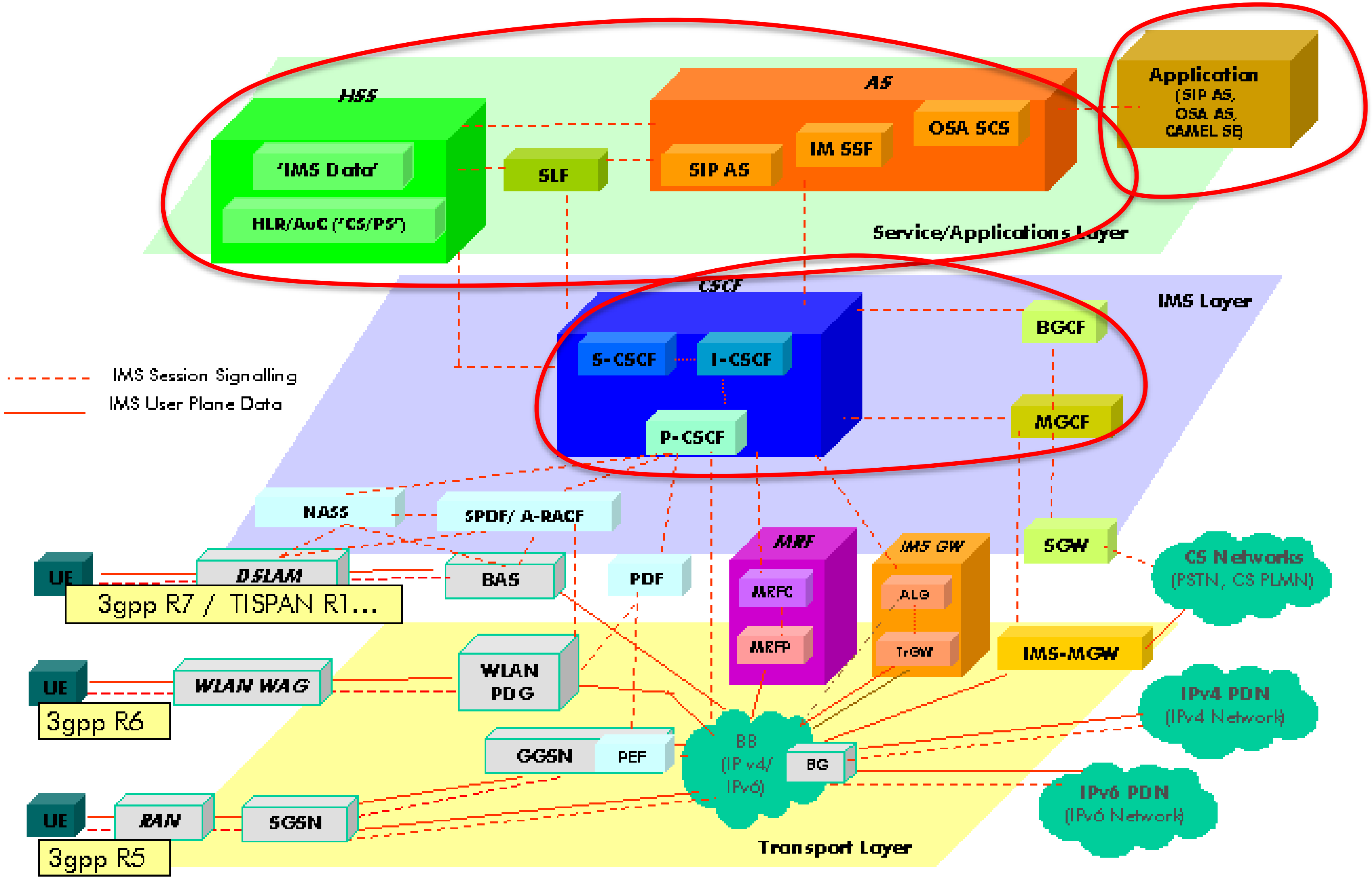
- Defined in IETF RFC 3261
  - "… an application-layer control (signaling) protocol for creating, modifying, and terminating sessions with one or more participants. These sessions include Internet telephone calls, multimedia distribution, and multimedia conferences."
- SIP is to the Internet what SS#7 is to telephony
- In IMS, SIP is extended to include extra functionality
  - E.g. 3GPP TS 23.228
- At the core of IMS there are several SIP proxies:
  - I-CSCF, S-CSCF, P-CSCF
  - The Call Session Control function (CSCF) is the heart of the IMS architecture
  - The main functions of the CSCF:
    - provide session control for terminals and applications using the IMS network
    - secure routing of the SIP messages,
    - subsequent monitoring of the SIP sessions and communicating with the policy architecture to support media authorization.
    - responsibility for interacting with the HSS.

- Serving - CSCF
  - Controls the user's SIP Session
  - very few per domain
  - Located in the home domain
  - Is a SIP registrar (and proxy)
- Proxy – CSCF
  - IMS contact point for the user's SIP signaling
  - Several in a domain
  - Located in the visited domain
  - Terminals must know this proxy (e.g. DHCP used)
  - Compresses and decompresses SIP messages
  - Secures SIP messages
  - Assures correctness of SIP messages
- Interrogating – CSCF
  - domain's contact point for inter-domain SIP signaling
  - one or more per domain
  - In case there are more than one S-CSCFs in the domain, locates which S-CSCF is serving a user

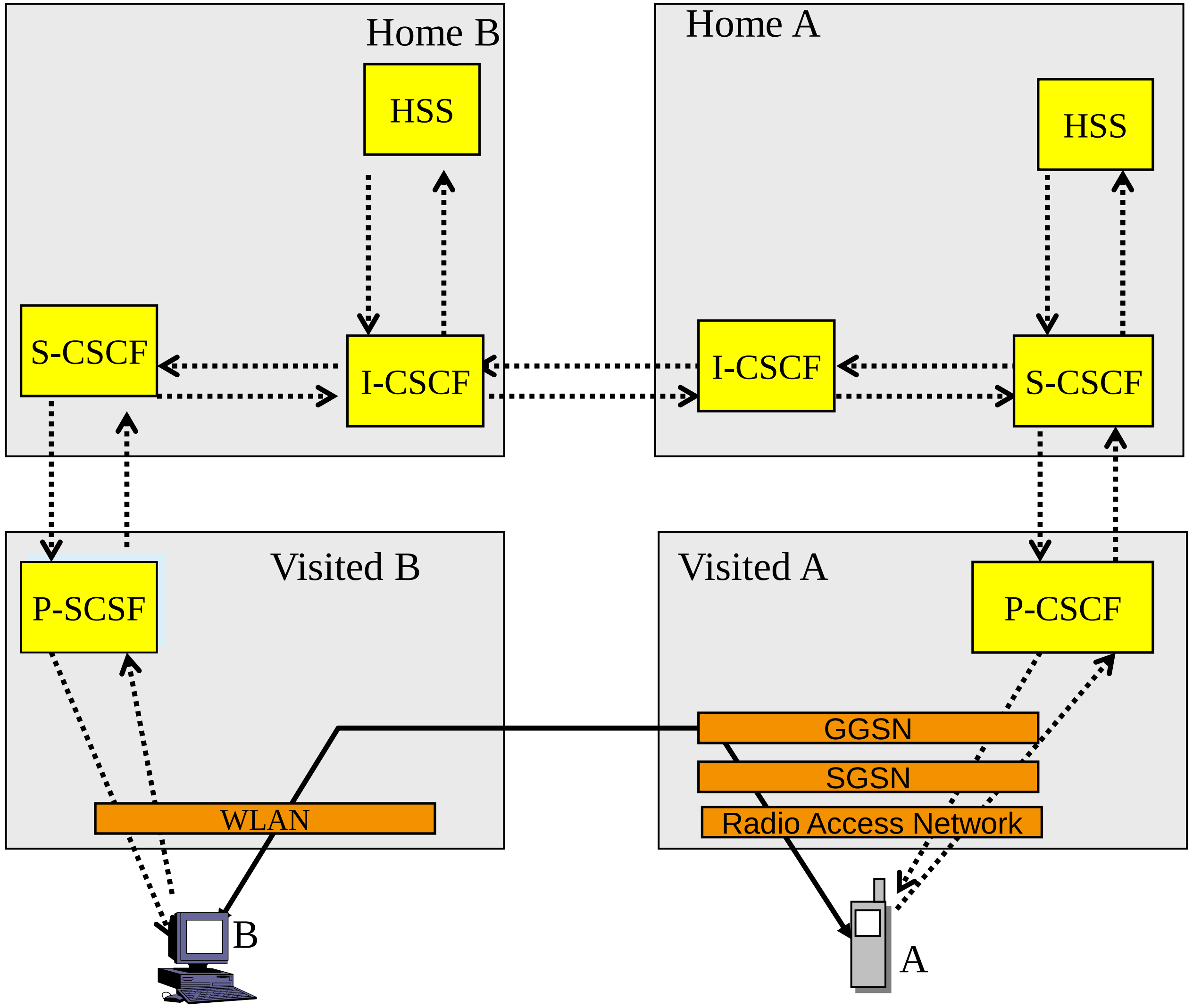
Services in IMS

- IMS is an advanced infrastructure enabling services. But the services are in the end points or peers (calls, etc.), not in the IMS
- Application Servers (AS) are the key part to endow IMS with services
- AS offered services enjoy all IMS advantages
- AS interact – using SIP - with the S-CSCF (which controls user’s SIP session)
- AS can behave as another SIP proxy or as a SIP UA (terminal)

Where is IMS ?

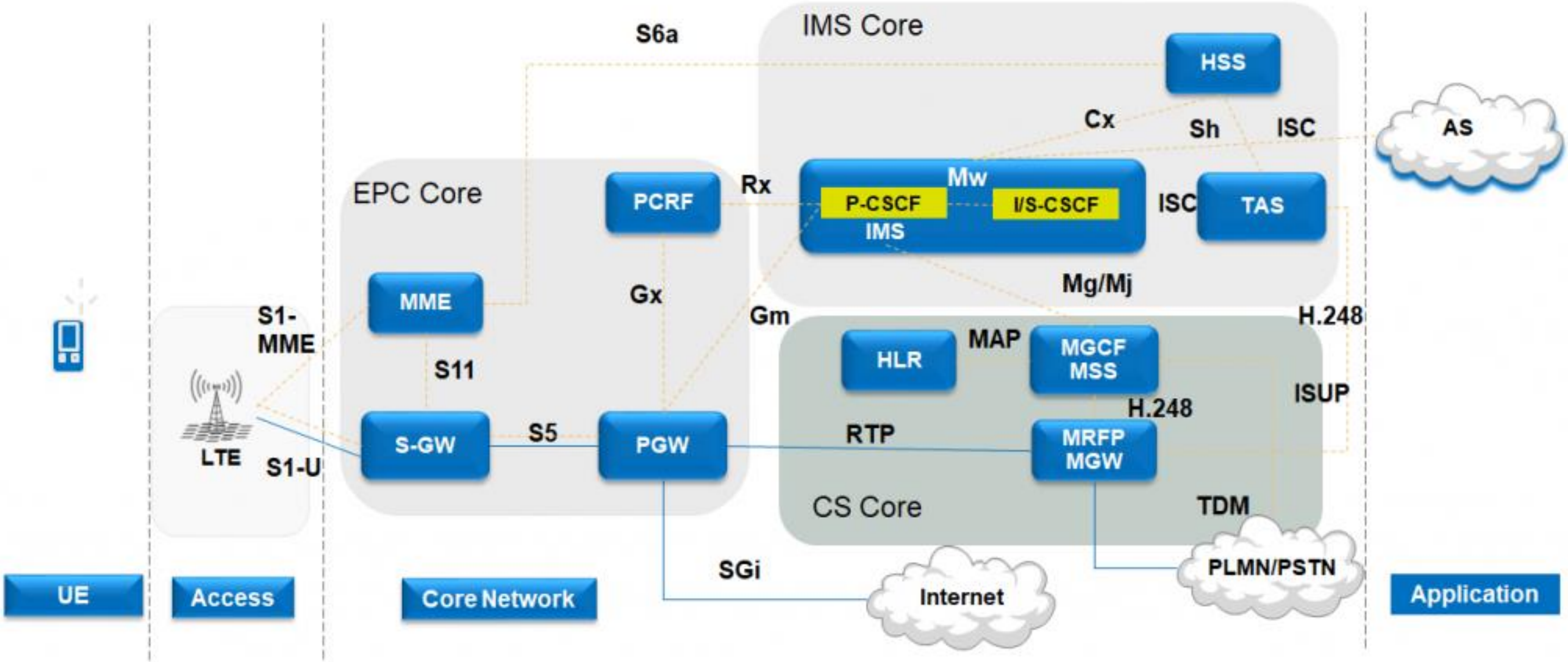

HSS
'IMS Data'
HLR/AuC ("CS/PS")
SLF
AS
SIP AS
IM SSF
OSA SCS
Application
(SIP AS,
OSA AS,
CAMEL SE)
Service/Applications Layer
CSCF
S-CSCF
I-CSCF
P-CSCF
BGCF
MGCF
IMS Layer
IMS Session Signalling
IMS User Plane Data
NASS
SPDF/ A-RACF
UE
DSLAM
BAS
PDF
MRF
MRFC
MRFP
IMS GW
ALG
TrGW
SGW
CS Networks
(PSTN, CS PLMN)
IMS-MGW
3gpp R7 / TISPAN R1...
UE
WLAN WAG
WLAN
PDG
3gpp R6
GGSN
PEF
BB
(IP v4/
IPv6)
BG
IPv4 PDN
(IPv4 Network)
IPv6 PDN
(IPv6 Network)
UE
RAN
SGSN
3gpp R5
Transport Layer

UMTS IMS: basic call flow



Non-GPRS access Networks (e.g. WLAN) comes in release 6

VoLTE Network Architecture



https://cafetele.com/volte-architecture/