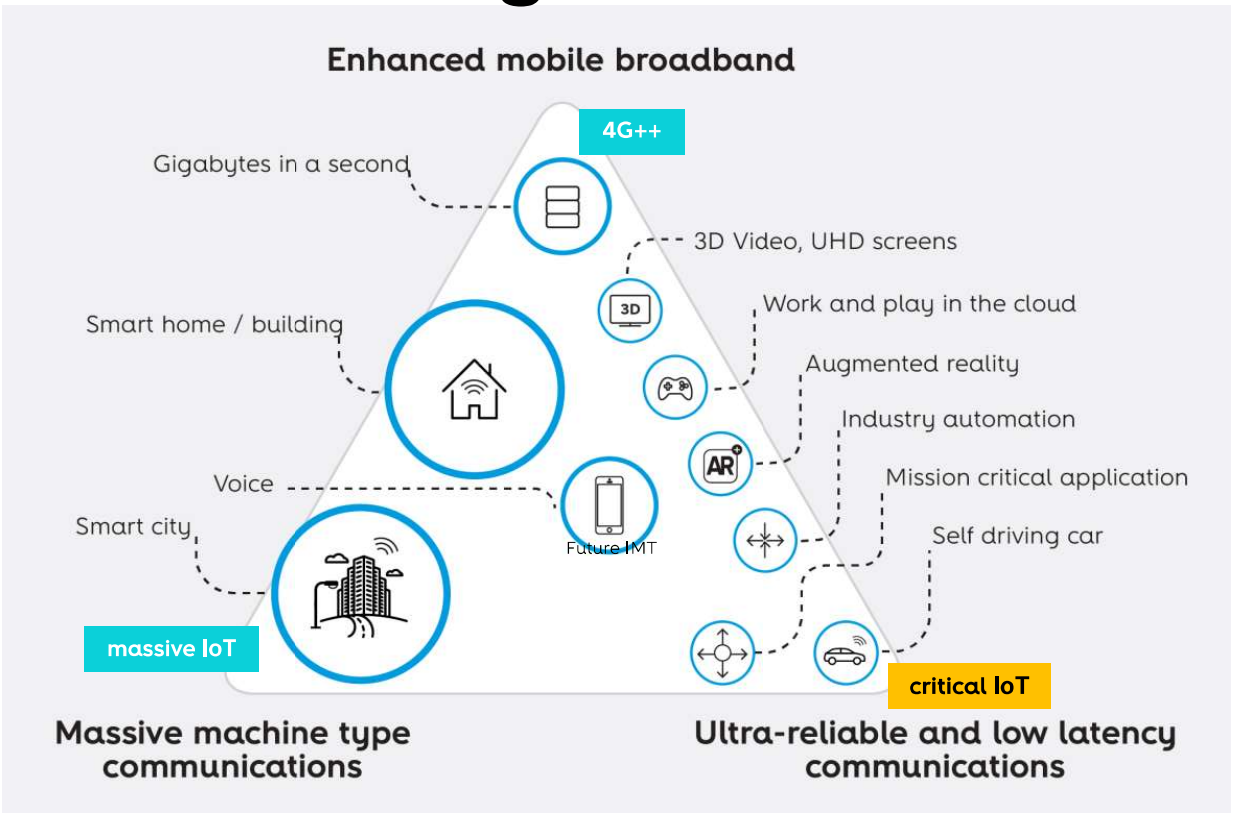
5G

"Enabling a seamlessly connected society in the 2020 timeframe and beyond that brings together people along with things, data, applications, transport systems and cities in a smart networked communications environment"

ITU-R (*International Telecommunication Union*)

5G organization of ‘Usage Scenarios’



A trillion of devices with different needs	GB transferred in an instant	Mission-critical wireless control and automation

5G will power a **new generation of services and applications** in the areas of:

Enhanced Mobile BroadBand (eMBB)
Make it faster!

Massive Machine Type Communications (mMTC)
Make it massive!

Ultra-Reliable, Low Latency Communications (URLCC)
Make it trustable and responsive!

All with a single, unified technology

…while driving down the cost per managed bit

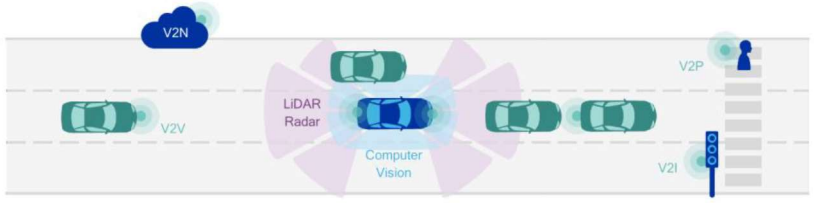
Example of verticals:
5GAA (5G Automotive Association)

http://5gaa.org/

"Develop, test and promote communications solutions, initiate their standardization and accelerate their commercial availability and global market penetration to address society's connected mobility and road safety needs with applications such as autonomous driving, ubiquitous access to services and integration into smart city and intelligent transportation"

Vehicle to anything (V2x) communications:

- Vehicle to Vehicle (V2V)
- Vehicle to Network (V2N)
- Vehicle to Infrastructure (V2I)
- Vehicle to Pedestrian (V2P)

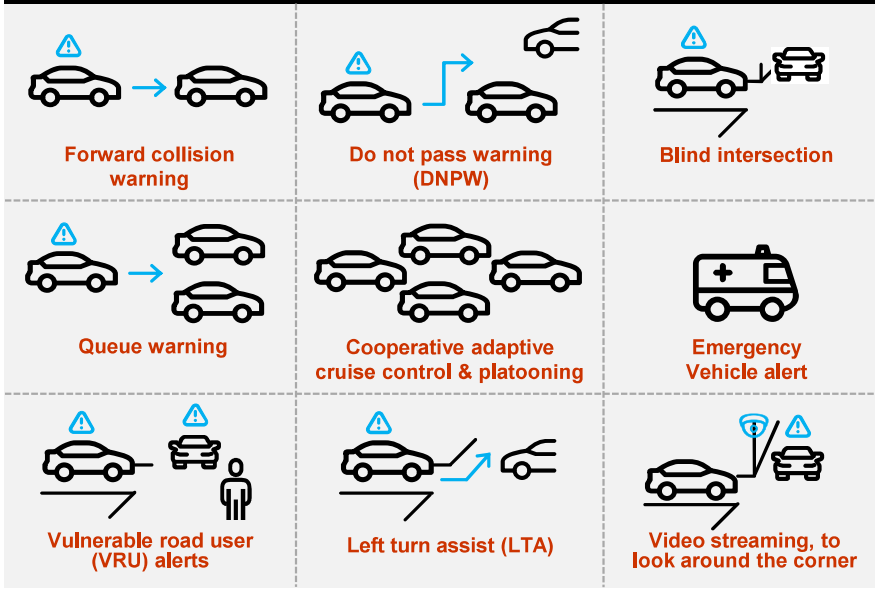


MEMBERS

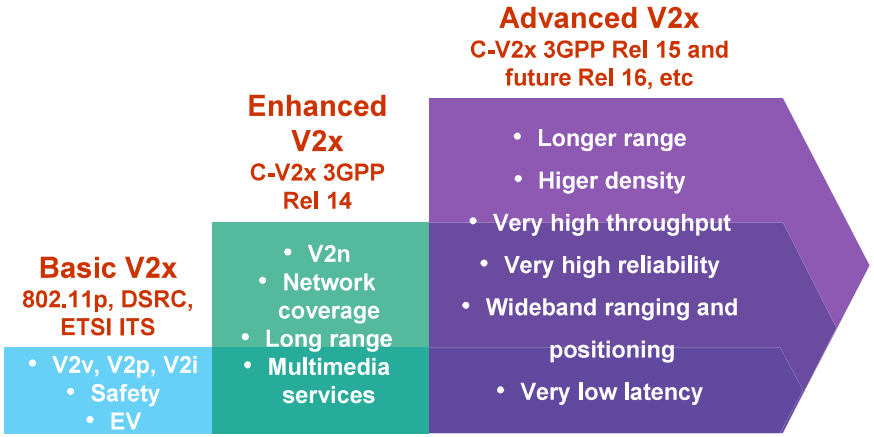
V2x Use Cases

Adapted from Qualcomm

V2x enables a broad set of use cases



3GPP V2x evolutionary support



Source: 5G Americas Whitepaper, "Cellular V2x Communications towards 5G", Mar'18

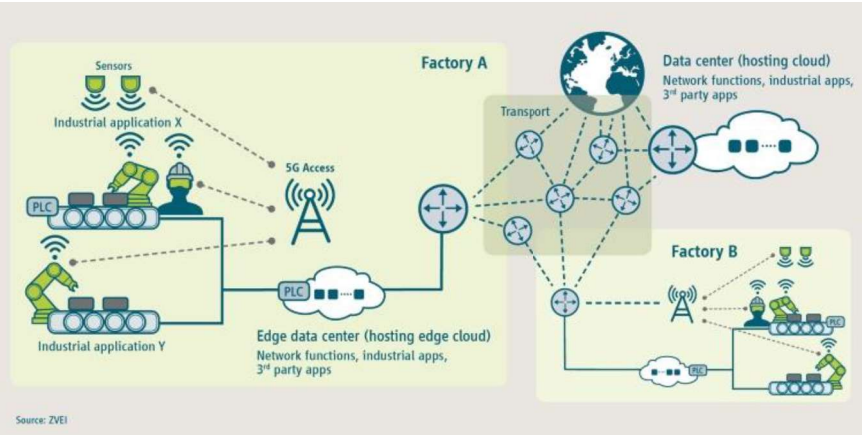
Communication scenario description	Max end-to-end latency (ms)	Reliability (%)
Information exchange between a UE supporting V2X application and a V2X Application Server	5	99.999
Cooperative driving for vehicle platooning Information exchange between a group of UEs supporting V2X application.	10	99.99
Emergency trajectory alignment between UEs supporting V2X application.	3	99.999
Sensor information sharing between UEs supporting V2X application	3	99.999

3GPP TS 22.186

Example of verticals: 5G-ACIA

https://www.5g-acia.org/

"5G-ACIA ensures the best possible applicability of 5G technology and 5G networks for the manufacturing and process industries by addressing, discussing and evaluating relevant technical, regulatory and business aspects."



Source: 5G-ACIA, "5G for Connected Industries and Automation", Whitepaper, Apr'18

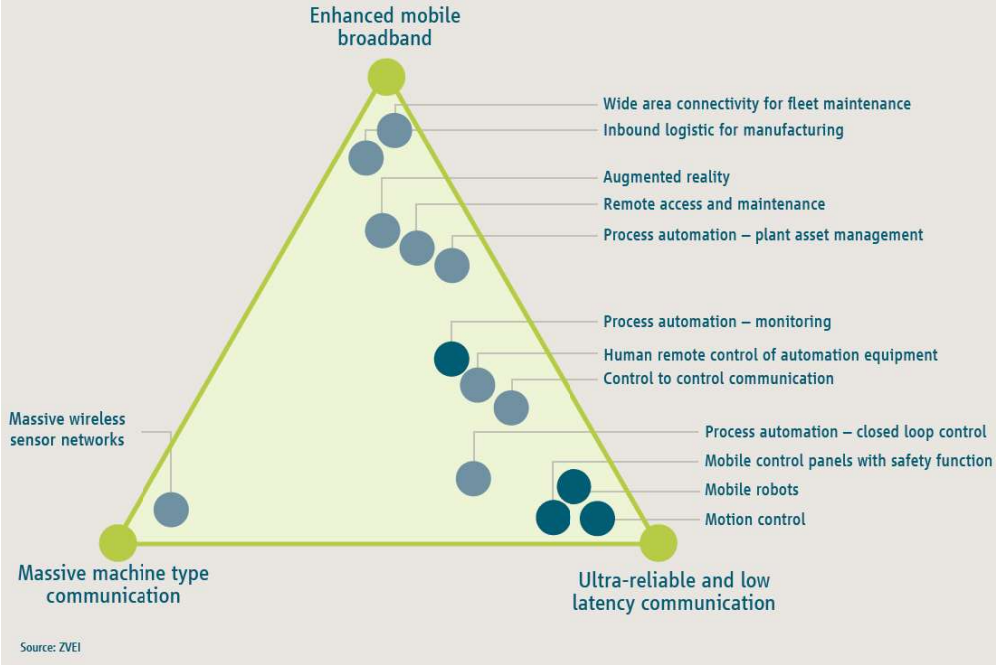
5G ACIA

5G Alliance for Connected Industries and Automation

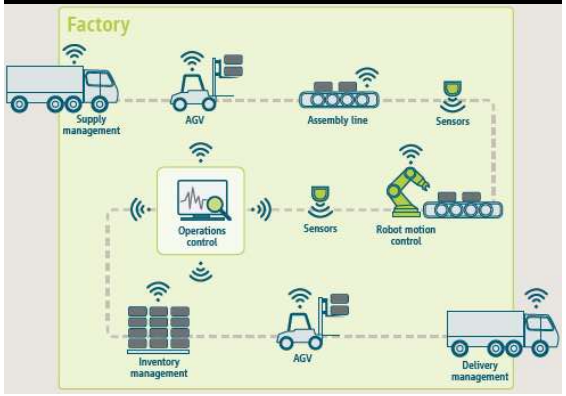
Industry use cases

- 5G in the private domain

Overview of selected industrial use cases and arrangement according to their basic service requirements (5G-ACIA)



Exemplary application areas of 5G in the factory of the future (5G-ACIA)



Selected use cases requirements (5G-ACIA)

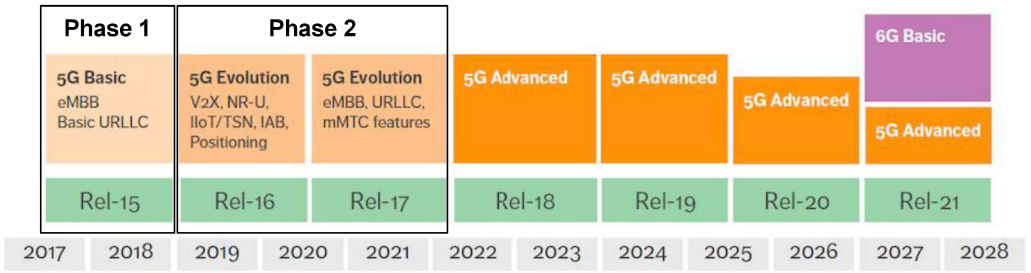
Use case (high level)		Availability	Cycle time	Typical payload size	# of devices	Typical service area
Motion control	Printing machine	>99.9999%	< 2 ms	20 bytes	>100	100 m x 100 m x 30 m
	Machine tool	>99.9999%	< 0.5 ms	50 bytes	~20	15 m x 15 m x 3 m
	Packaging machine	>99.9999%	< 1 ms	40 bytes	~50	10 m x 5 m x 3 m
Mobile robots	Cooperative motion control	>99.9999%	1 ms	40-250 bytes	100	< 1 km²
	Video-operated remote control	>99.9999%	10 – 100 ms	15 – 150 kbytes	100	< 1 km²
Mobile control panels with safety functions	Assembly robots or milling machines	>99.9999%	4-8 ms	40-250 bytes	4	10 m x 10 m
	Mobile cranes	>99.9999%	12 ms	40-250 bytes	2	40 m x 60 m
Process automation (process monitoring)		>99.99%	> 50 ms	Varies	10000 devices per km²	

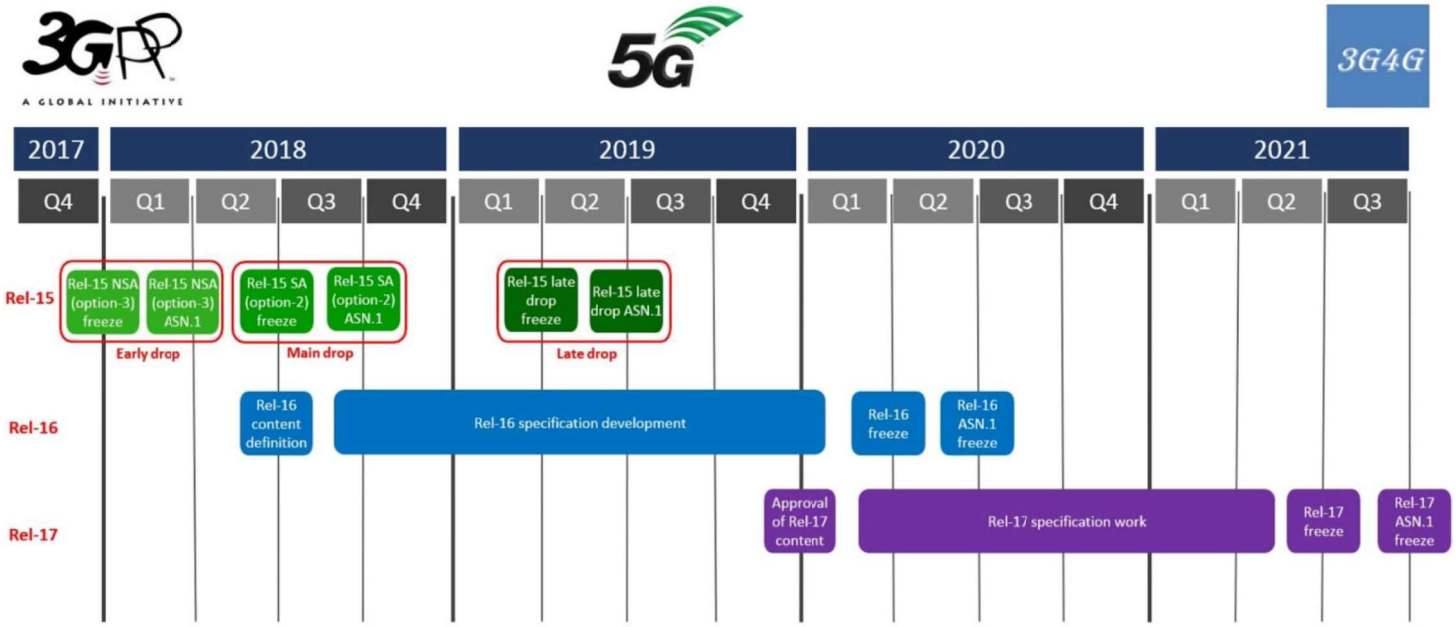
Service unavailability <31,5s / Year

Cycle time shall be measured from command execution to feedback received ➔ 5G latency < half the cycle time

Pictures from: 5G-ACIA, "5G for Connected Industries and Automation", Whitepaper, Apr'18

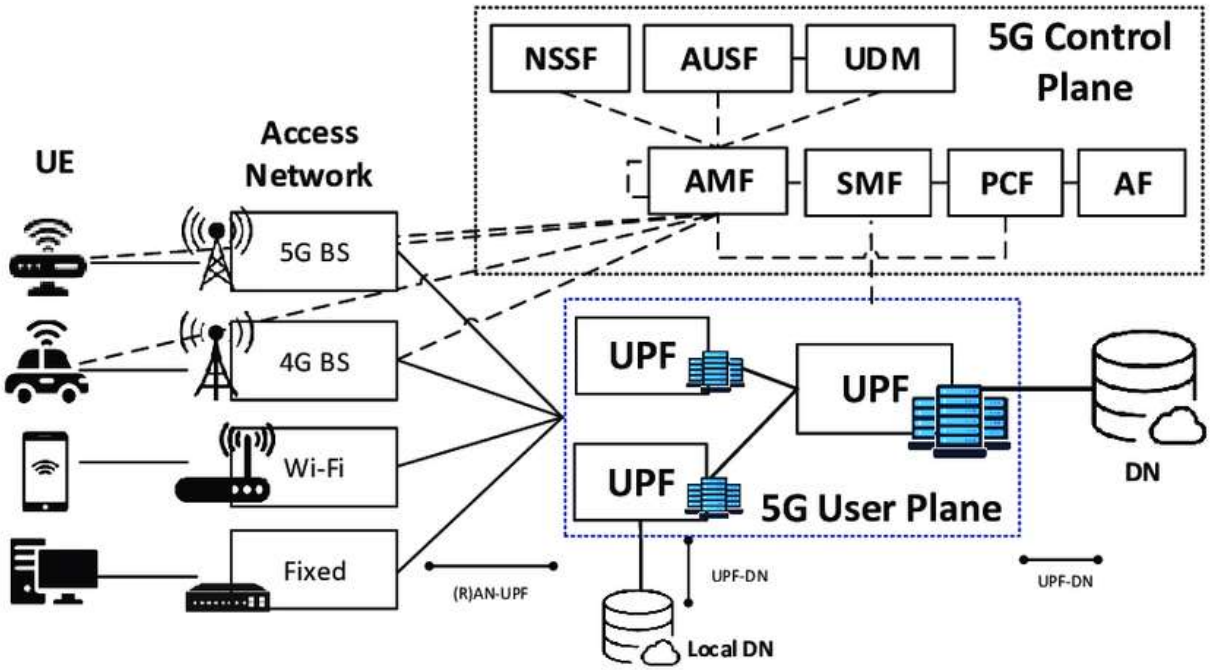
5G roadmap





Designed by 3G4G, based on roadmap from 3GPP, July 2019

5G System



5G System:

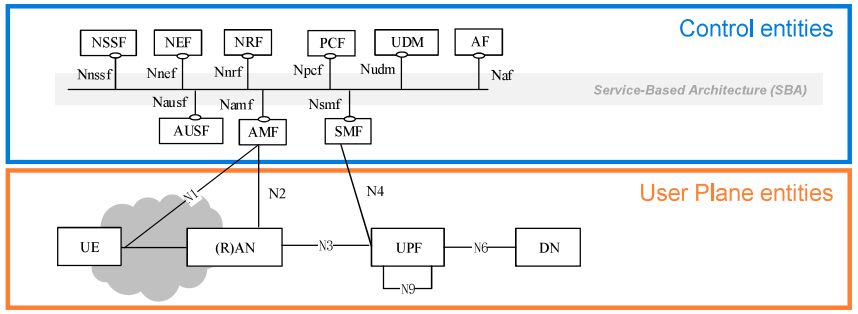
1. UEs
2. 5G RAN
3. 5G Core

Control and user planes separation

Microservices (5G Core)

Multi-access

5G System arch. and functional modules (parcial)



3GPP TS 23.501 V0.3.1 (2017-03)

- **Separate the User Plane (UP) functions from the Control Plane (CP) functions**
- **Modularize the function design**, e.g. to enable flexible and efficient network slicing
- **Define procedures** (i.e. the set of interactions between network functions) **as services**
- Enable each Network Function to interact with other NF directly if required (**direct interaction**)
- **Minimize dependencies between the Access Network (AN) and the Core Network (CN)**
- Support a **unified authentication framework**
- Support **"stateless" NFs**, where the "compute" resource is decoupled from the "storage" resource
- Support **capability exposure**
- Support **concurrent access to local and centralized services.** To support low latency services and access to local data networks, **UP functions can be deployed close to the Access Network**

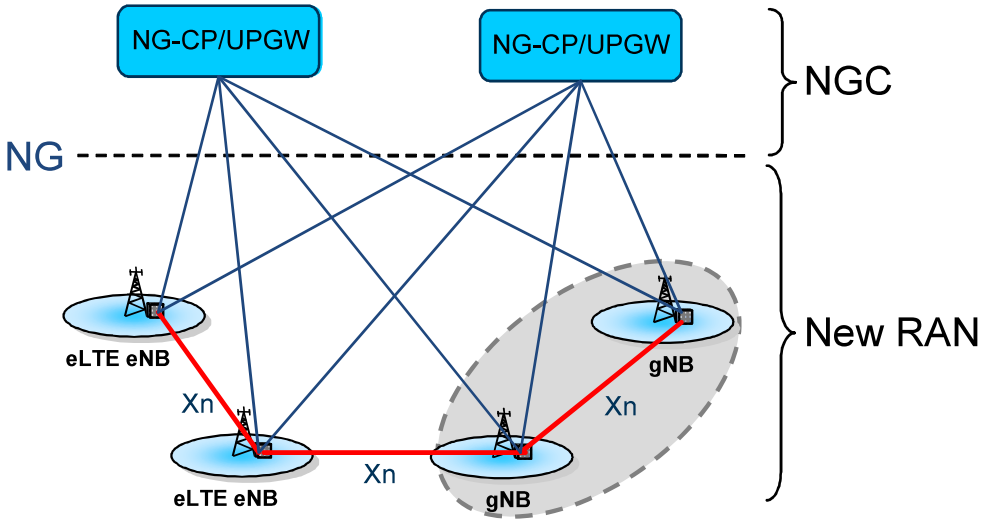
1. Network Slice Selection Function (NSSF)
2. Network Exposure Function (NEF)
3. NF Repository Function (NRF)
4. Policy Control Function (PCF)
5. Unified Data Management (UDM)
6. Application Function (AF)

7. Authentication Server Function (AUSF)
8. Access and Mobility Management Function (AMF)
9. Session Management Function (SMF)

10. Unified Data Repository (UDR)
11. Unstructured Data Storage Function (UDSF)
12. 5G-Equipment Identity Register (5G-EIR)
13. Security Edge Protection Proxy (SEPP)
14. Network Data Analytics Function (NWDAF)

1. User Equipment (UE)
2. (Radio) Access Network ((R)AN)
3. User Plane Function (UPF)
4. Data Network (DN)

5G: a New Radio is required



NGC: Next Generation Core
NG-CP: *Next Generation Control Plane*
UPGW: *User Plane GateWay*

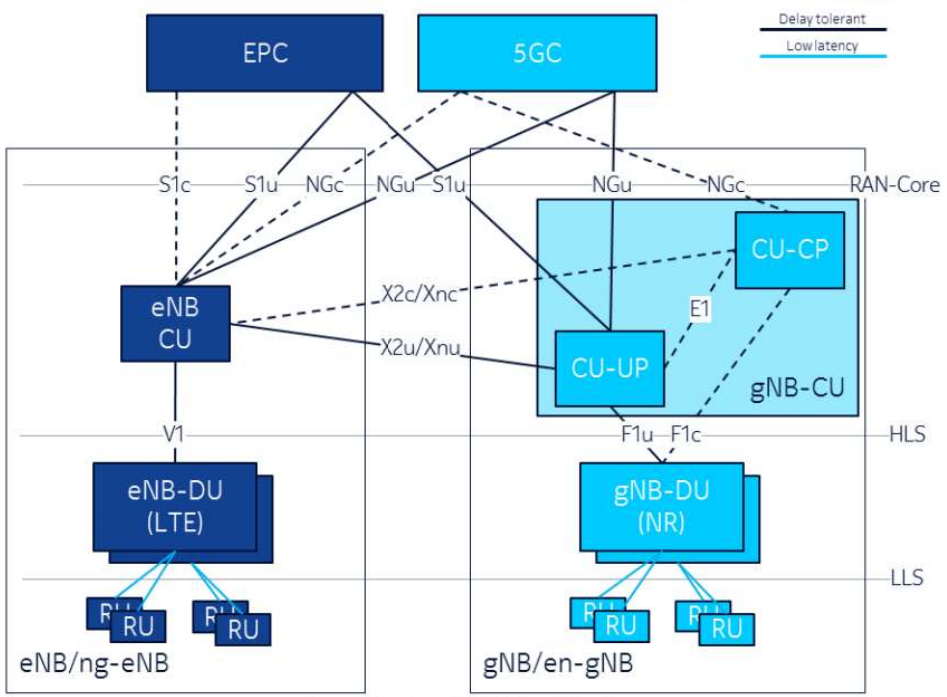
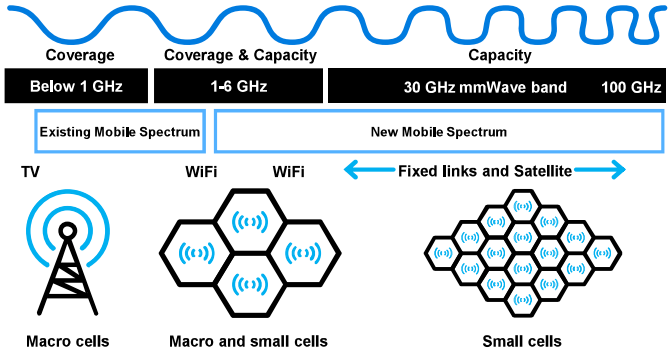
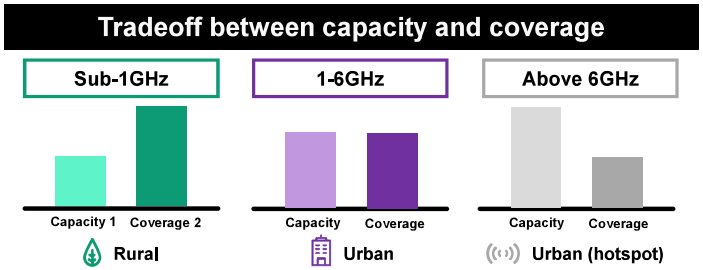
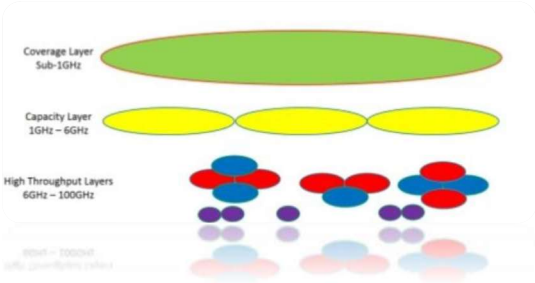


Figure 3: Overall RAN architecture

Larger spectrum usage to cover all applications



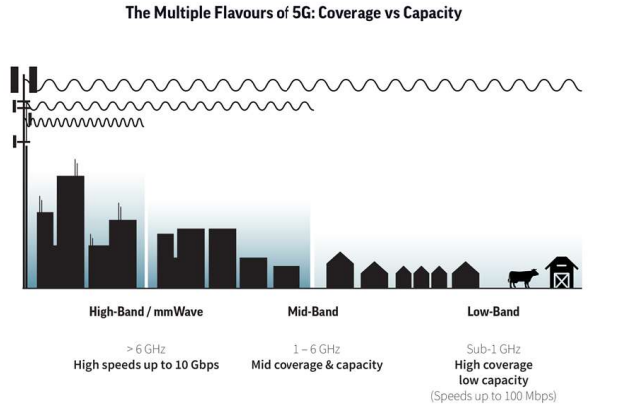




Universal coverage (10's of Mb/s) of reliable connectivity

Urban coverage with dense small cells (1-3 Gb/s) e.g. mobile Gb/s society, smart cities, option for connected highways

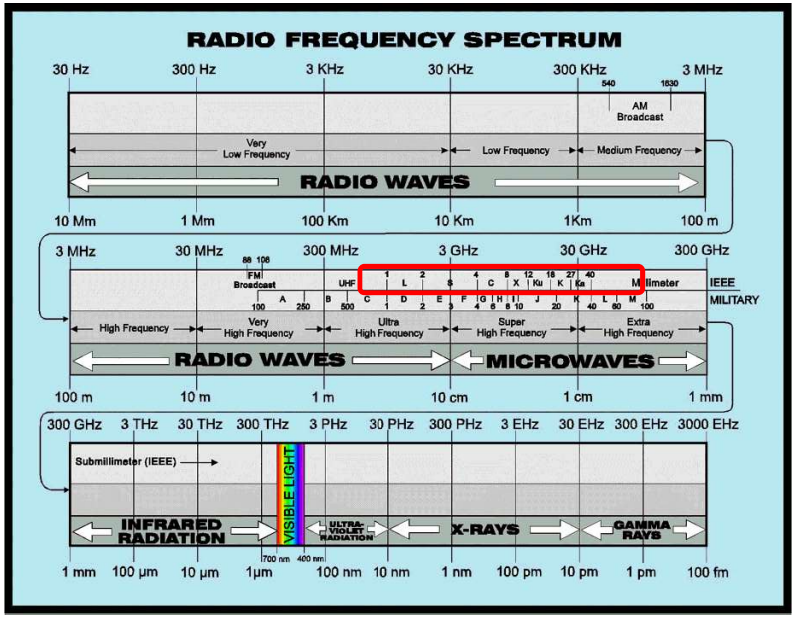
Hot spots coverage (up to 10 Gb/s) e.g. fixed wireless access, railway stations, sport events, smart factories,



5G-NR to operate on a larger spectrum range
- Expanding to lower freqs. for coverage and penetration
- Expanding to higher freqs. for capacity and low latency

5G Spectrum

http://donsnotes.com/tech/em-spectrum.html



RADIO SPECTRUM POLICY GROUP, "STRATEGIC ROADMAP TOWARDS 5G FOR EUROPE"
"Opinion on spectrum related aspects for next-generation wireless systems (5G)", Nov/16

http://rspg-spectrum.eu/wp-content/uploads/2013/05/RPSG16-032-Opinion_5G.pdf

- **<1GHz (e.g. 700MHz)**
  to "enable nationwide and indoor 5G coverage" — < 1GHz
- **3400-3800 MHz GHz**
  - **>100MHz (400MHz) of continuous spectrum**
  to "put Europe at the forefront of the 5G deployment" — > 1GHz, < 6GHz
- **24.25-27.5 GHz**
  "pioneer band for earlier implementation in Europe"
- **31.8-33.4 GHz**
  "looks a promising band which could be made available" — > 6GHz
- **40.5-43.5 GHz**
  "is a viable option for 5G in the longer term"

IMT frequencies usage between 24.25 and 86GHz will be analysed at the ITU-T WRC'19 (Nov/19)

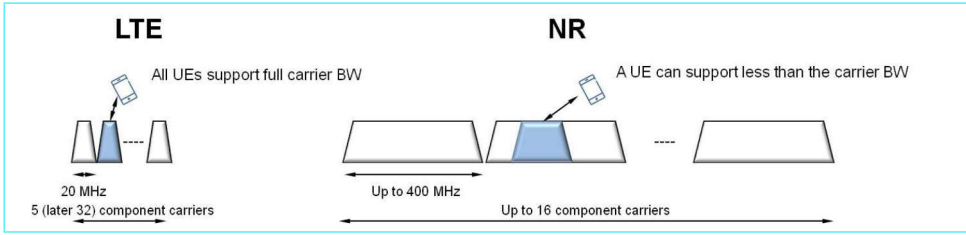
	Quantidade de frequência adquerida						
	Dense Air	Dixarobil	MEO	NOS	NOWO	VODAFONE	TOTAL
700 MHz	0	0	10 MHz	20 MHz	0	20 MHz	**50 MHz**
900 MHz	0	10 MHz	4 MHz	4 MHz			**18 MHz**
1800 MHz	0	10 MHz	0	0	20 MHz	0	**30 MHz**
2,1 GHz	0	0	0	10 MHz	0	0	**10 MHz**
2,6 GHz	0	35 MHz	0	0	10 MHz	0	**45 MHz**
3,6 GHz	40 MHz	40 MHz	90 MHz	100 MHz	40 MHz	90 MHz	**400 MHz**
Total	**40 MHz**	**95 MHz**	**104 MHz**	**134 MHz**	**70 MHz**	**110 MHz**	**553 MHz**

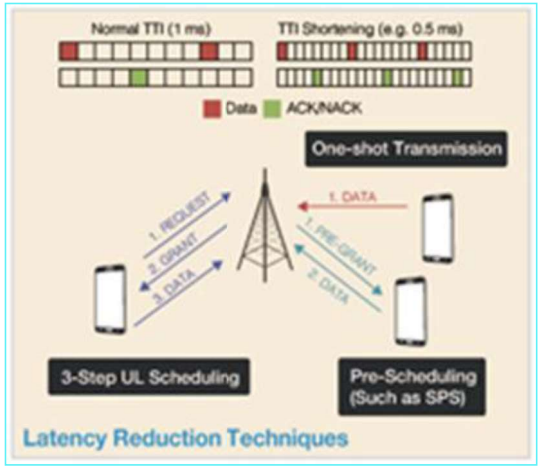
2021 PT Auction results

5G-NR main characteristics

- **Operation from low to very high bands: 0.4 – 100Ghz**
  - Including standalone operation in unlicensed bands
- **Up to 400 MHz component-carrier bandwidth (20 MHz for LTE)**
  - Up to 100MHz in <6GHz
  - Up to 400MHz in >6GHz
- **Up to 16 component carriers**
- **Set of different numerologies for optimal operation in different frequency ranges**
- **Native support for Low Latency**
  - Shortened *Transmission Time Interval* (TTI)
- **Native support for Ultra Reliability (Multiple diversity mechanisms)**
- **Flexible and modular RAN architecture: split fronthaul, split control- and user-plane**
- **Support for devices connecting directly, with no network (D2D, V2X)**
- **Native end-to-end support for Network Slicing**
- **New channel coding**
  - LDPC for data channel, Polar coding for control channel

Workshop on 3GPP submission towards IMT-2020, Brussels, October 24/25, 2018
"NR Physical Layer Design: Physical layer structure, numerology and frame structure"
Havish Koorapaty 3GPP TSG RAN WG1 vice-chairman (Ericsson)





http://developer.samsung.com/sd2_images/progra m/content/mtech_5g09.jpg (adapted)

4G/LTE:
- **Turbo codes** for **data** channels
- **TBCCs** (Tail-Biting Convolutional Codes) for **control** channels

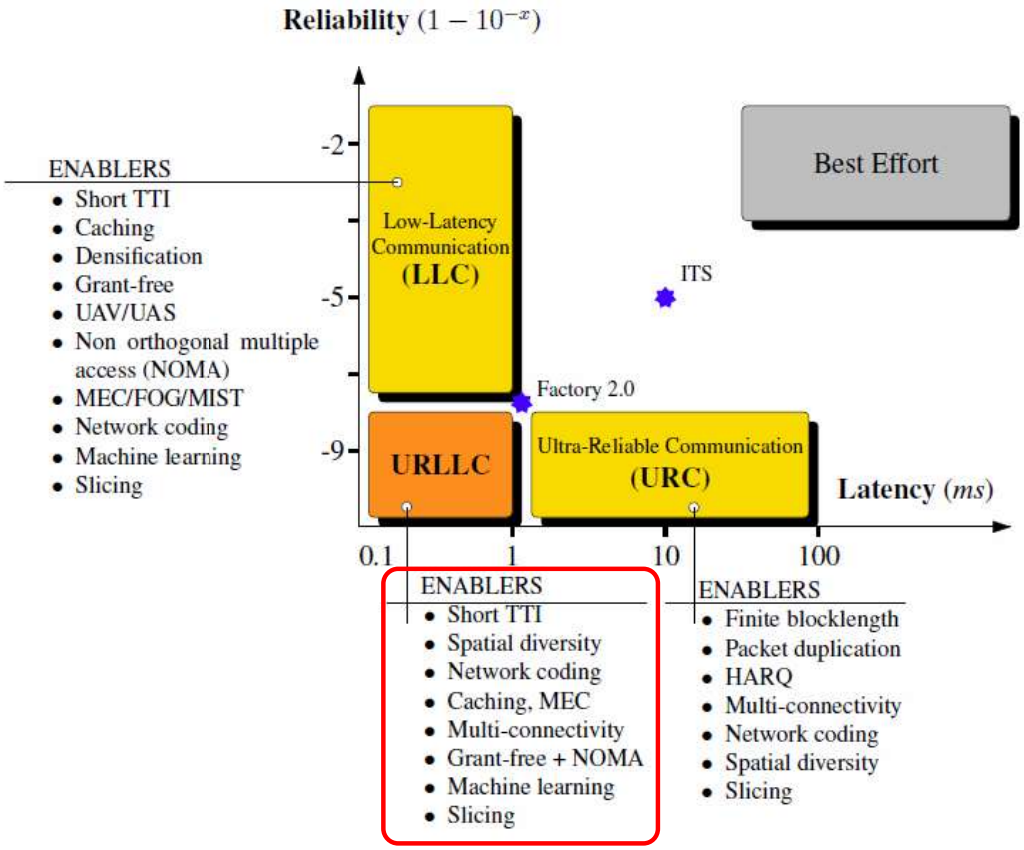
LDPC (*Low-Density Parity-Check*):
- **Improved performance**: block error rate (BLER) around or below 10^{-5} for all code sizes and code rates
- Reduced decoding complexity and **improved decoding latency** (lower overall latency)
- Better **area throughput efficiency** and **higher peak throughput**

URLLC: The Ultra Reliability versus Low Latency challenge

Answering two conflicting requirements:
- **Low latency and ultra-high reliability**

Release 16 objective:
- **0.5-1ms one-way latency**
- **Reliability of up to 99.9999%**

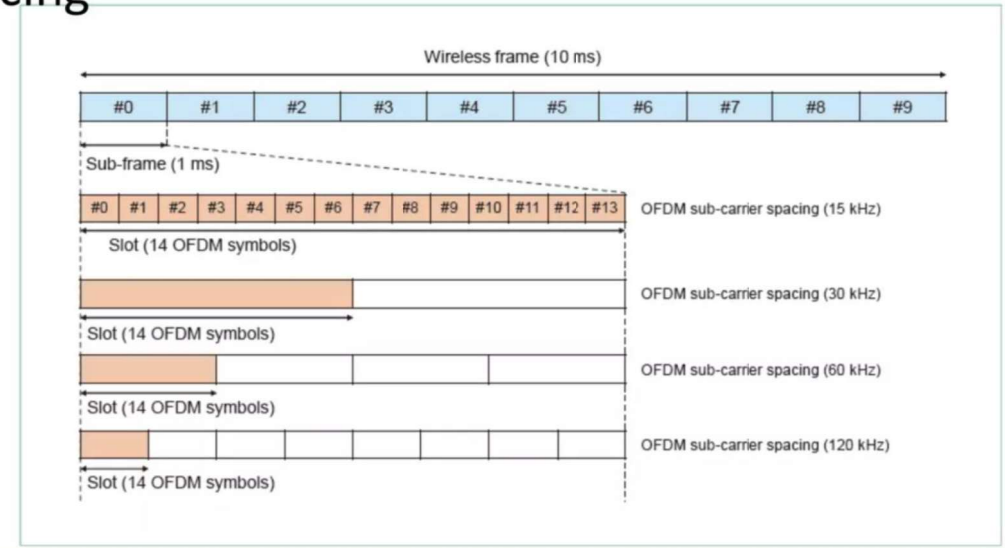
Retransmissions (e.g. HARQ) and packet duplications in time (e.g. PDCP duplications) are useless, considering the low latency budget



"Ultra-Reliable and Low-Latency Wireless Communication: Tail, Risk and Scale"
Mehdi Bennis, Senior Member IEEE, M'erouane Debbah, Fellow IEEE, and H. Vincent Poor, Fellow IEEE

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:

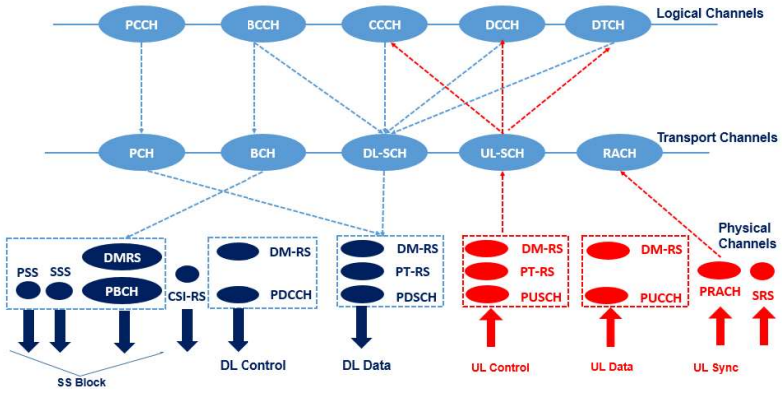
- **Broadcast Control Channel** (BCCH): It is used for transmitting system information from the network to UEs in a cell coverage.
- **Paging Control Channel** (PCCH): This is used to page the UEs whose location at cell level is not known to the network.
- **Common Control Channel** (CCCH): It is used 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.

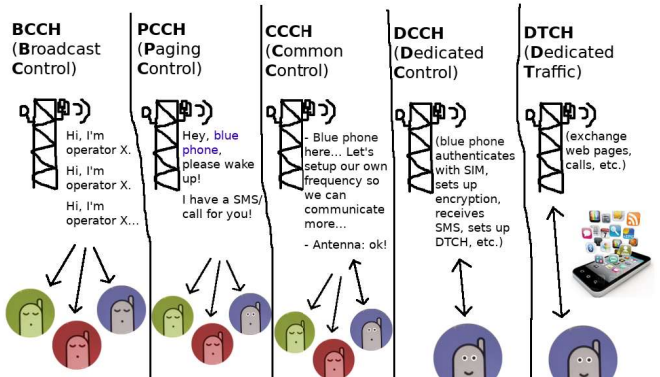
Transport Channel Definition: A transport channel is defined by how and with what characteristics the information is transmitted over the radio interface. From the physical layer, the MAC layer uses services in the form of transport channels. Data on a transport channel are organized into transport blocks.

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

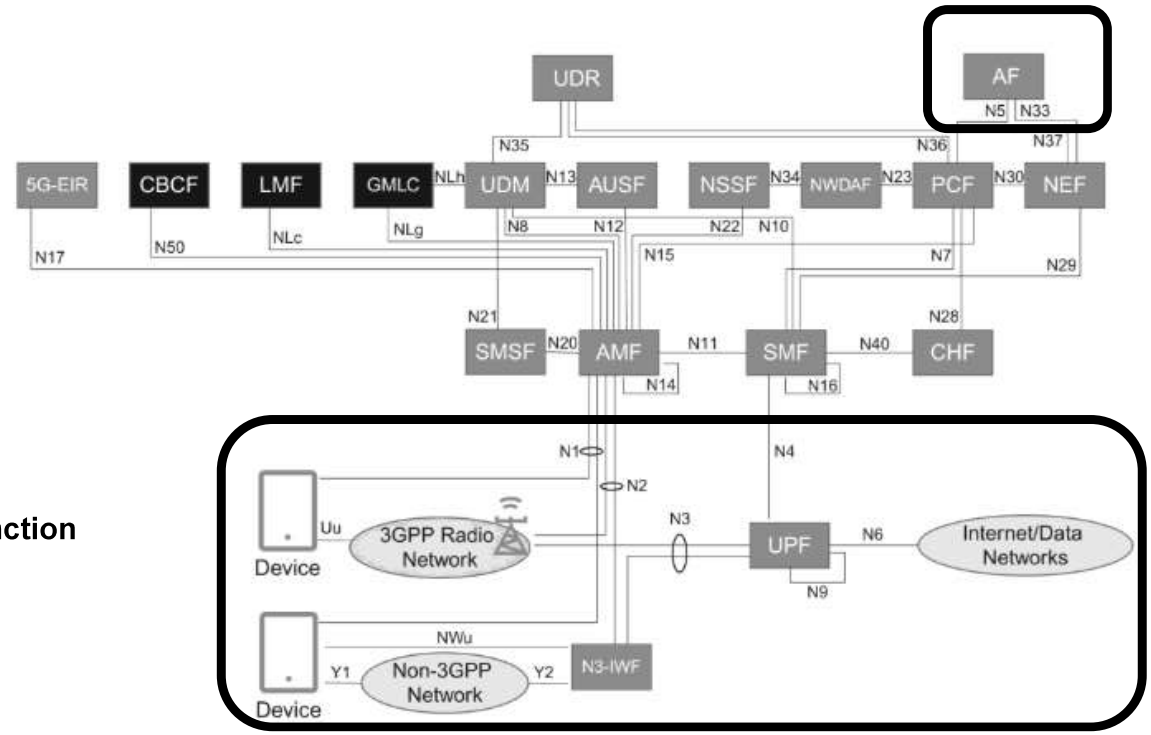




https://labs.p1sec.com/2019/07/09/presenting-qcsuper-a-tool-for-capturing-your-2g-3g-4g-air-traffic-on-qualcomm-based-phones/

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)**



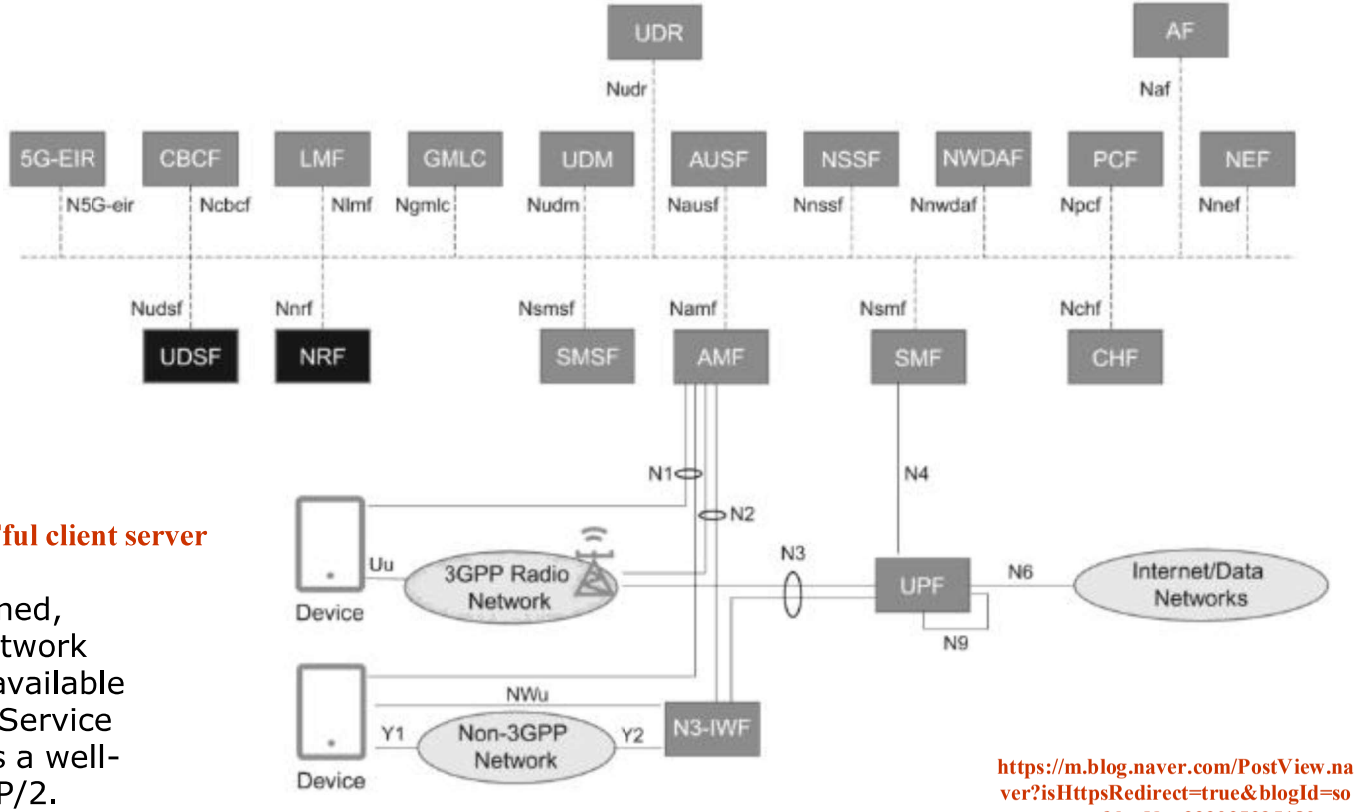
AF: Application Function
AUSF: Authentication Server Function
AMF: Core Access and Mobility Management Function
DN: Data Network
LMF: Location Management Function
NEF: Network Exposure Function
NRF: Network Repository Function
NSSF: Network Slice Selection Function
PCF: Policy Control Function
SMF: Session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

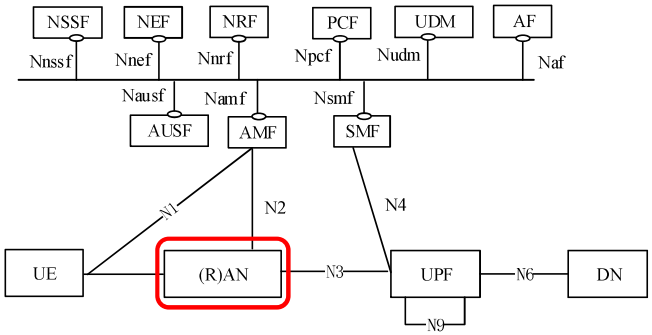
Network Functions are self-contained, independent and reusable. Each Network Function service exposes and makes available its functionality (services) through a Service Based Interface (SBI), which employs a well-defined REST interface using HTTP/2.

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



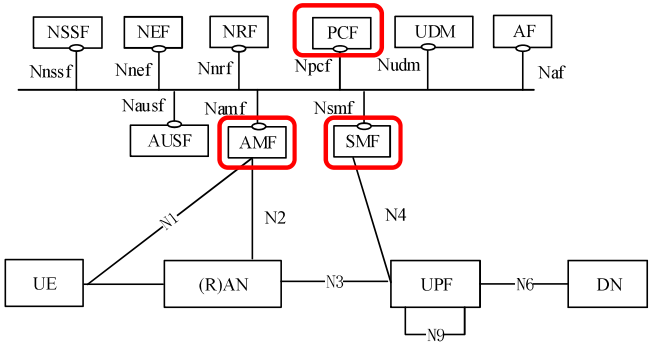
(3GPP TS 23.501)

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)

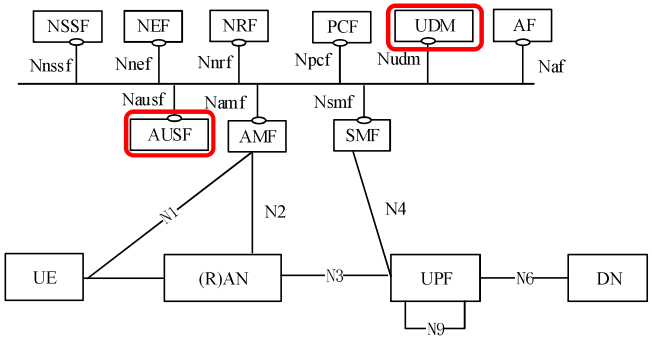
AUSF and UDM

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)

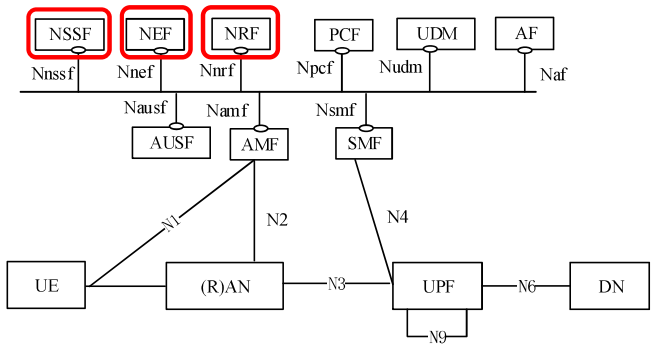
- Selecting of the Network Slice instances serving the UE
- Determining the Allowed NSSAI (*Network Slice Selection Assistance Information*)
- Determining the AMF set to be used to serve the UE

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

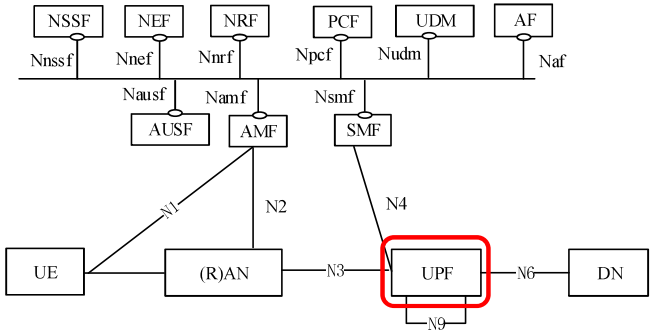


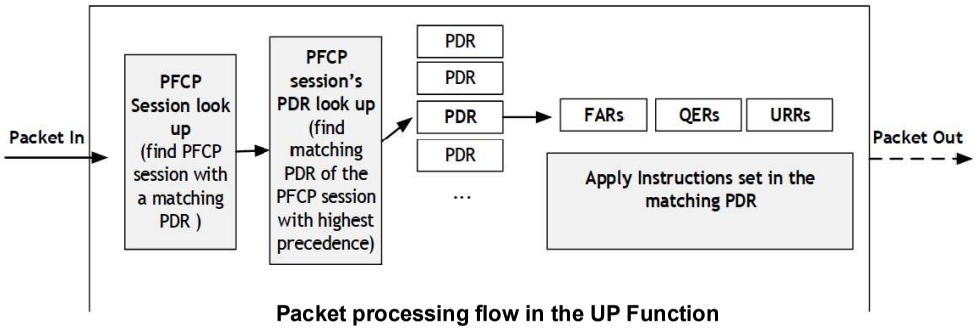
(3GPP TS 23.501)

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 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

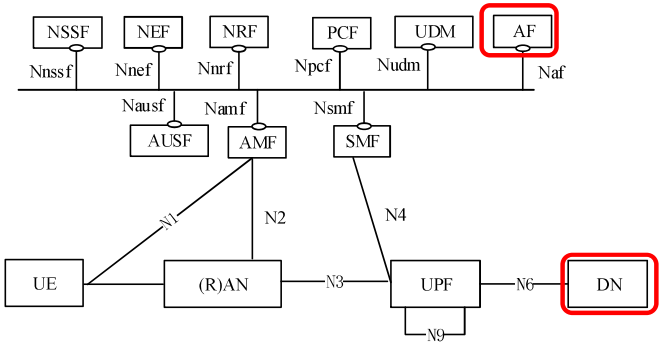
AF and DN

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)

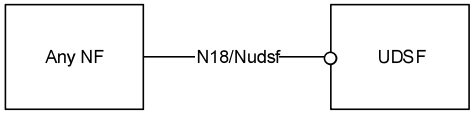


Figure 4.2.5-1: Data storage architecture for unstructured data from any NF (3GPP TS 23.501)

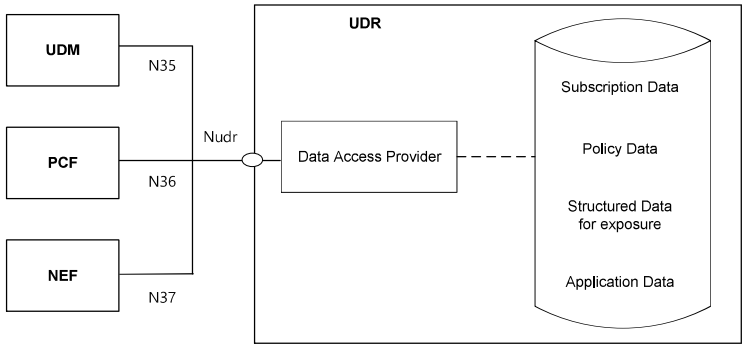
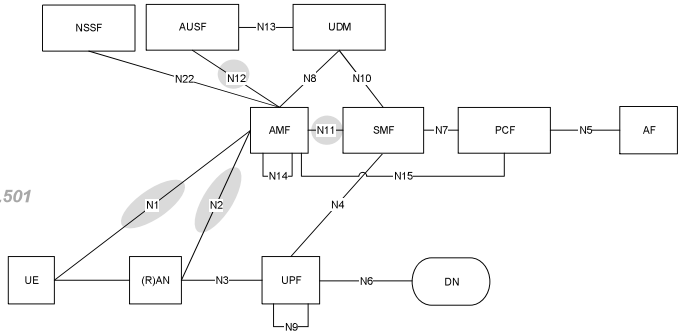


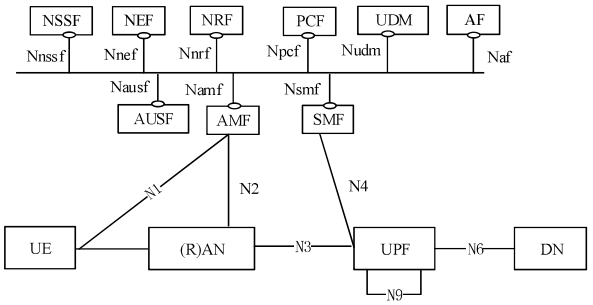
Figure 4.2.5-2: Data storage architecture (3GPP TS 23.501)

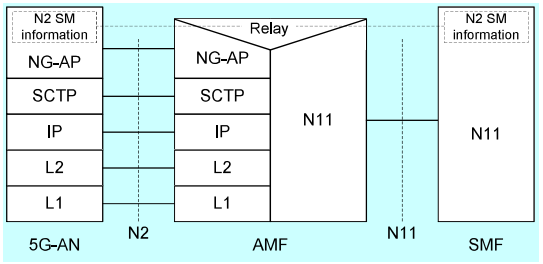
(3GPP TS 23.501)

Protocol stacks: Control Plane

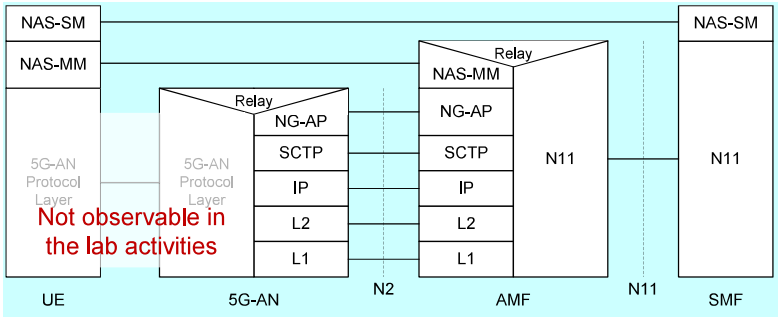


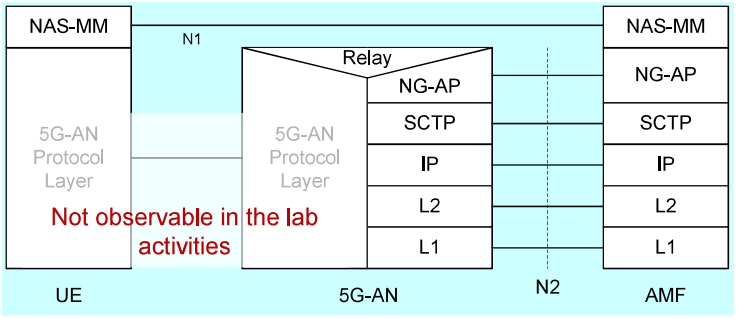
Source: 3GPP TS 23.501



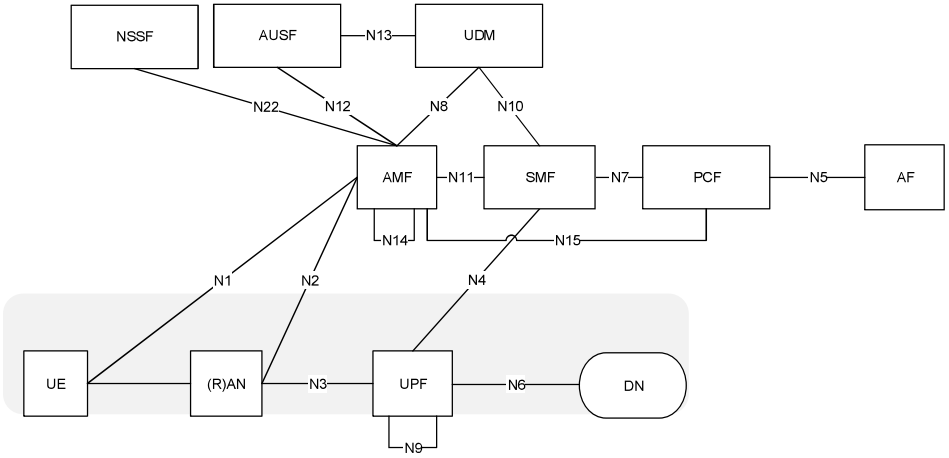


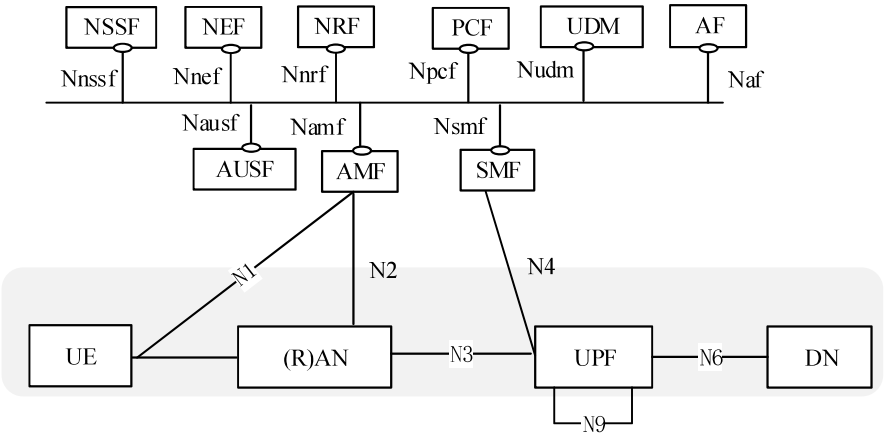
SCTP: Stream Control Transmission Protocol
PFCP: Packet Forwarding Control Protocol
NG-AP: NG Application Protocol
NAS-MM: NAS Mobility Management
NAS-SM: NAS Session Management
NAS: Non-Access-Stratum

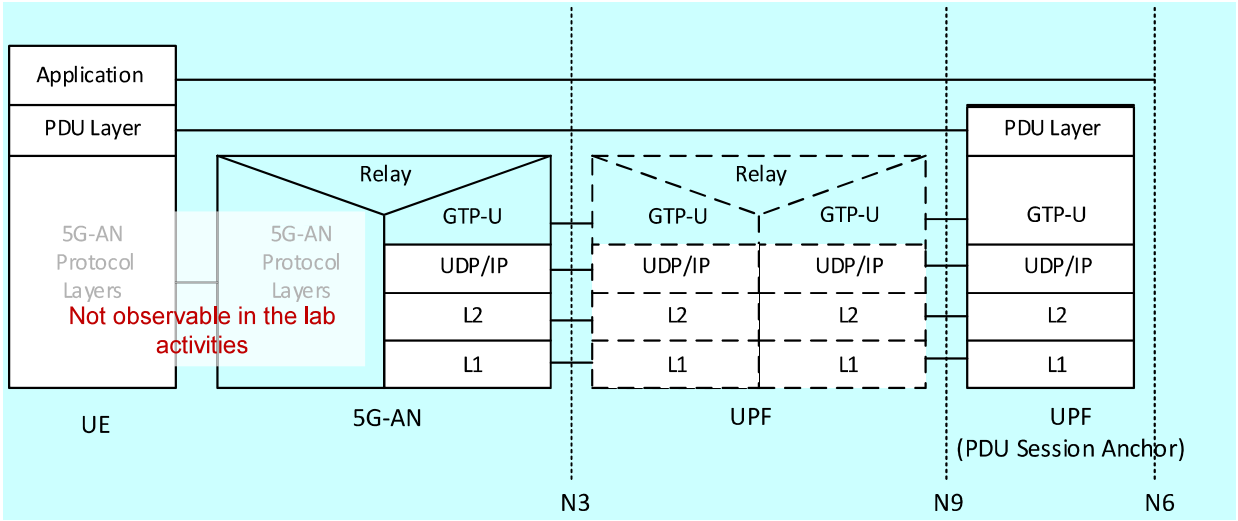




Protocol stacks: User Plane



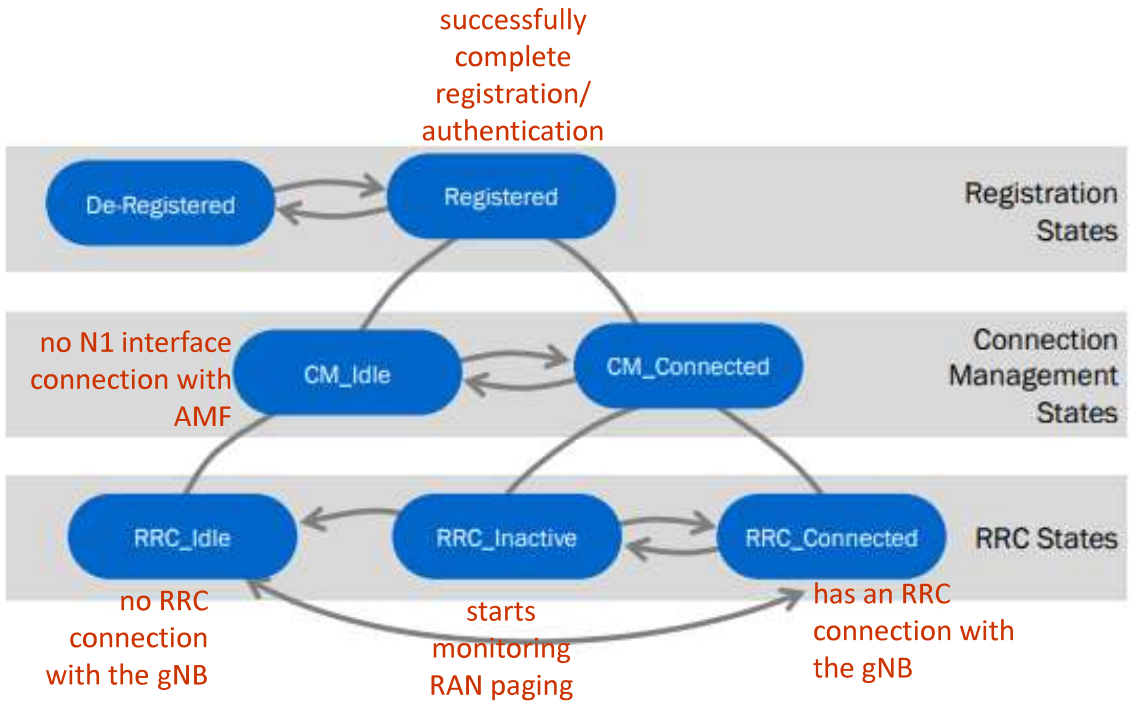


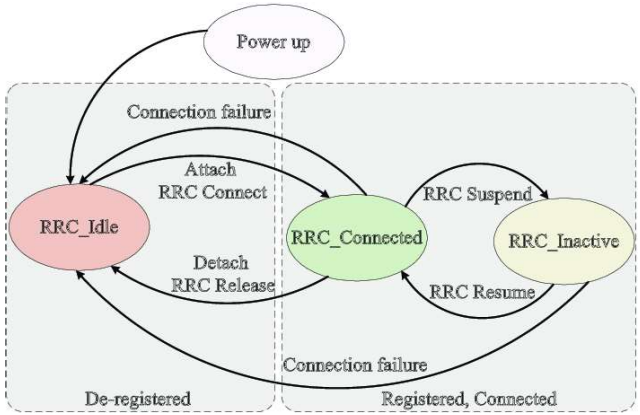


GTP: GPRS Tunnelling Protocol

Source: 3GPP TS 23.501

UE states in 5G



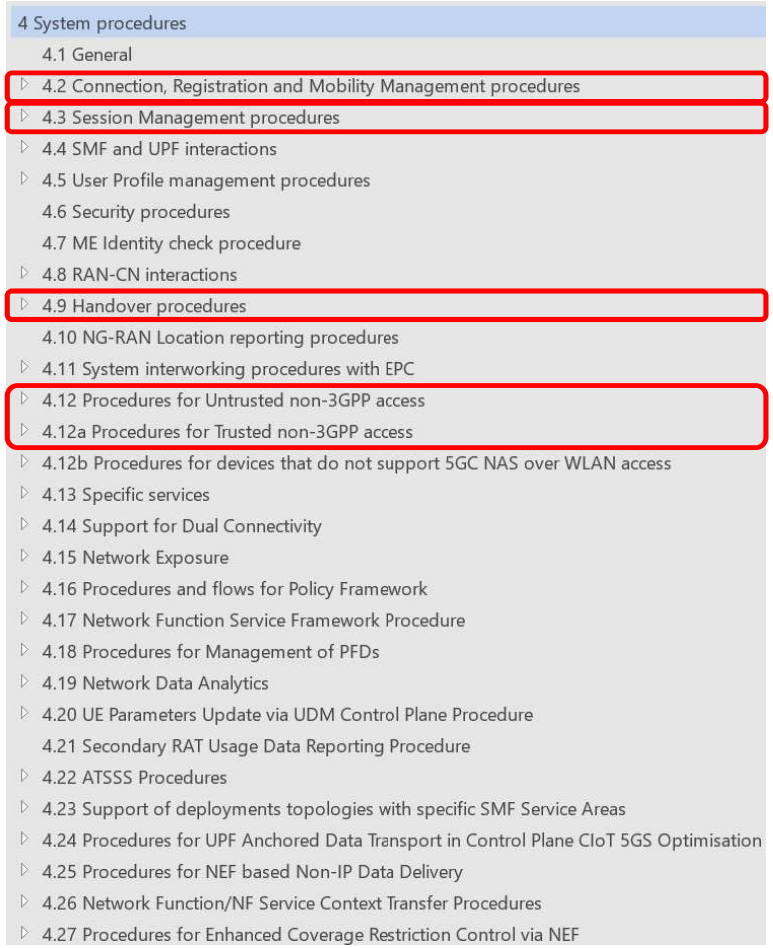


https://www.researchgate.net/figure/UE-state-machine-and-state-transitions-in-5G-78_fig3_350202251

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

5G Procedures

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



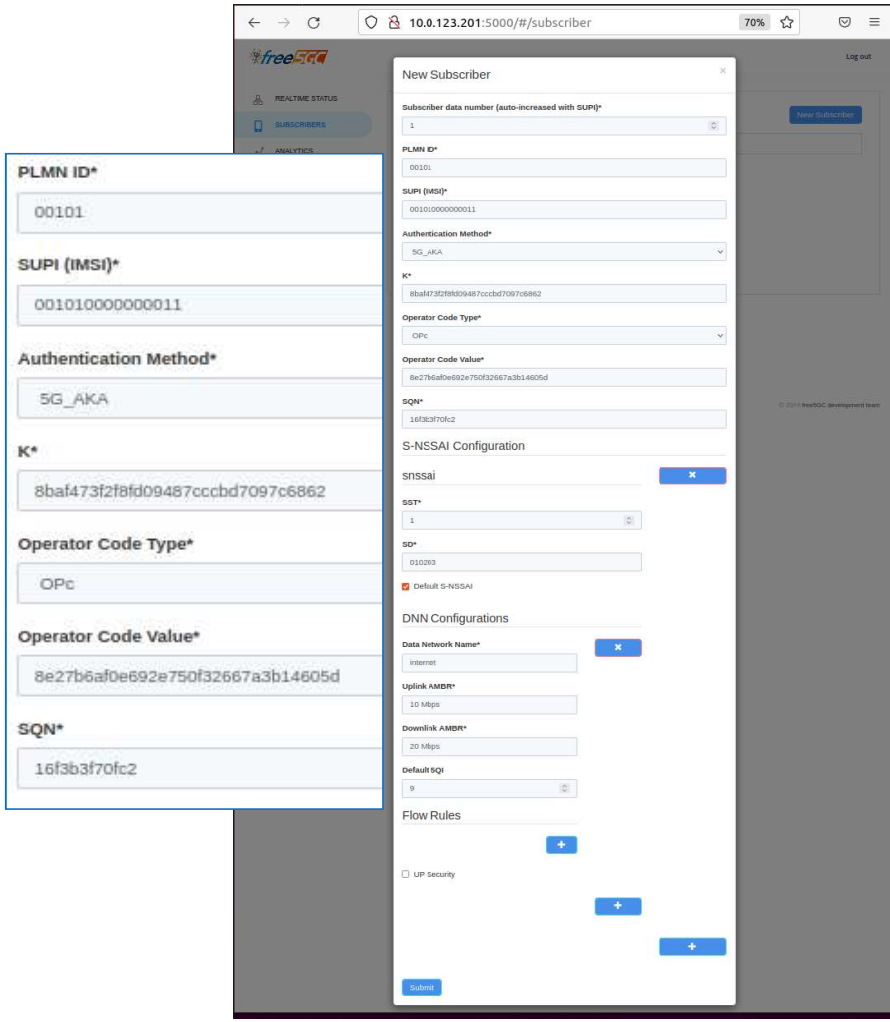
- **Connection, Registration and Mobility Management procedures**
- **Session Management**
  - **PDU Session Establishment**
  - **PDU Session Modification**
  - **PDU Session Release**
  - **Session continuity, service continuity and UP path management**
- **Handover procedures**
- **Procedures for 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*

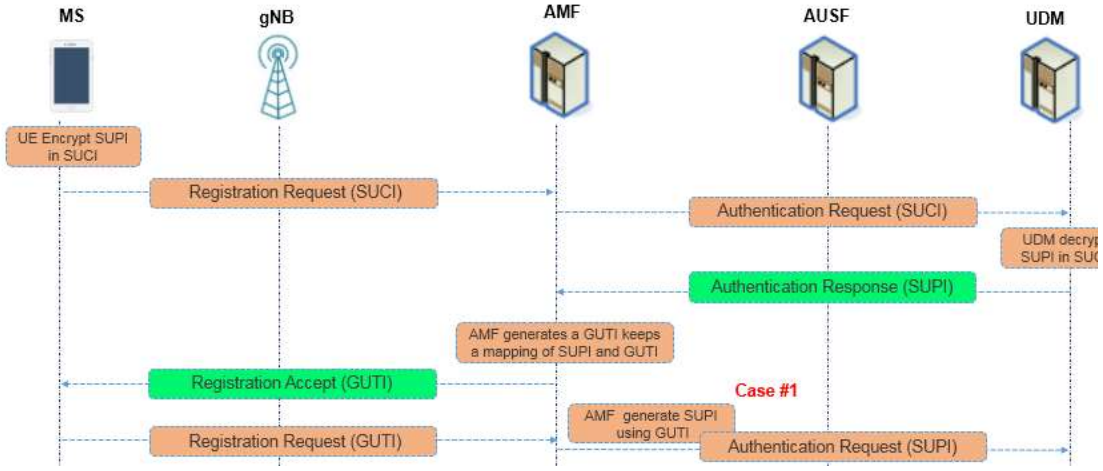
Free5GC subscriber creation example



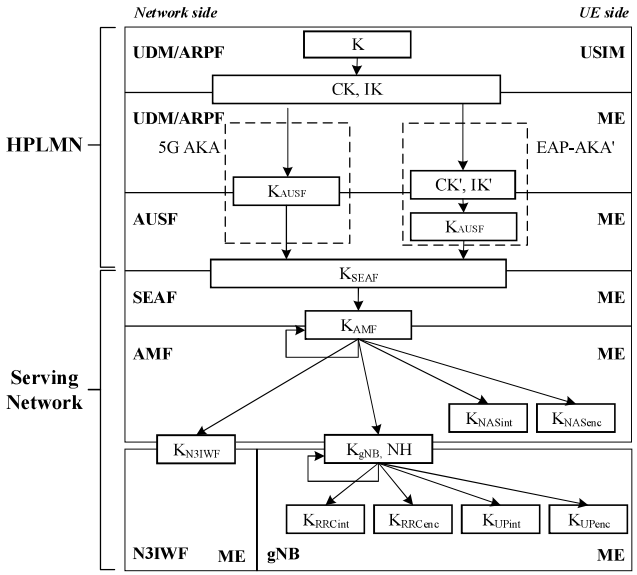
Authentication process

- **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**

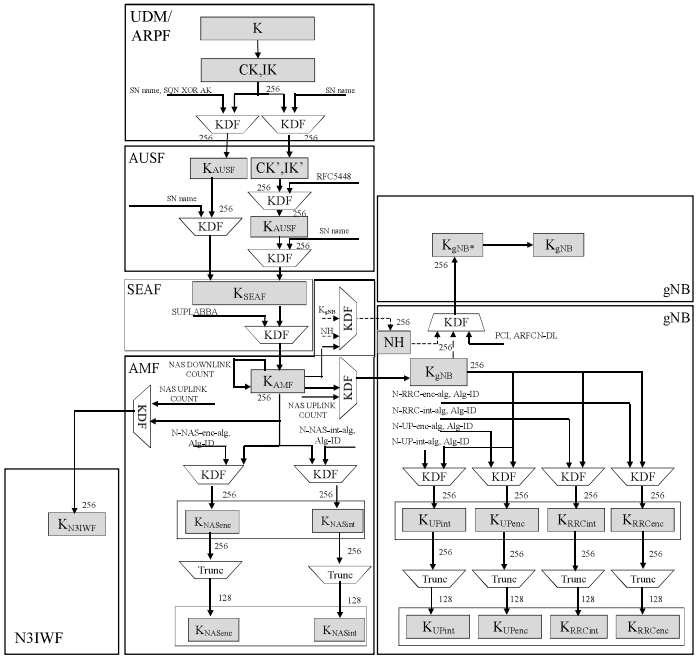
- **Primary authentication offers two mechanisms:**
  - ***(1) 5G Authentication and Key Agreement* (5G AKA): no EAP encapsulation**
  - ***(2) Extensible Authentication Protocol AKA'* (EAP-AKA')**



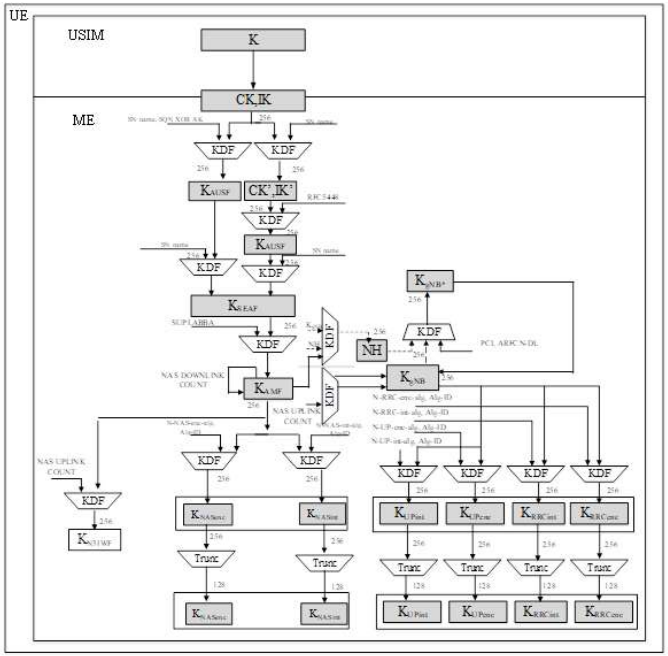
Keys generationm from K



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



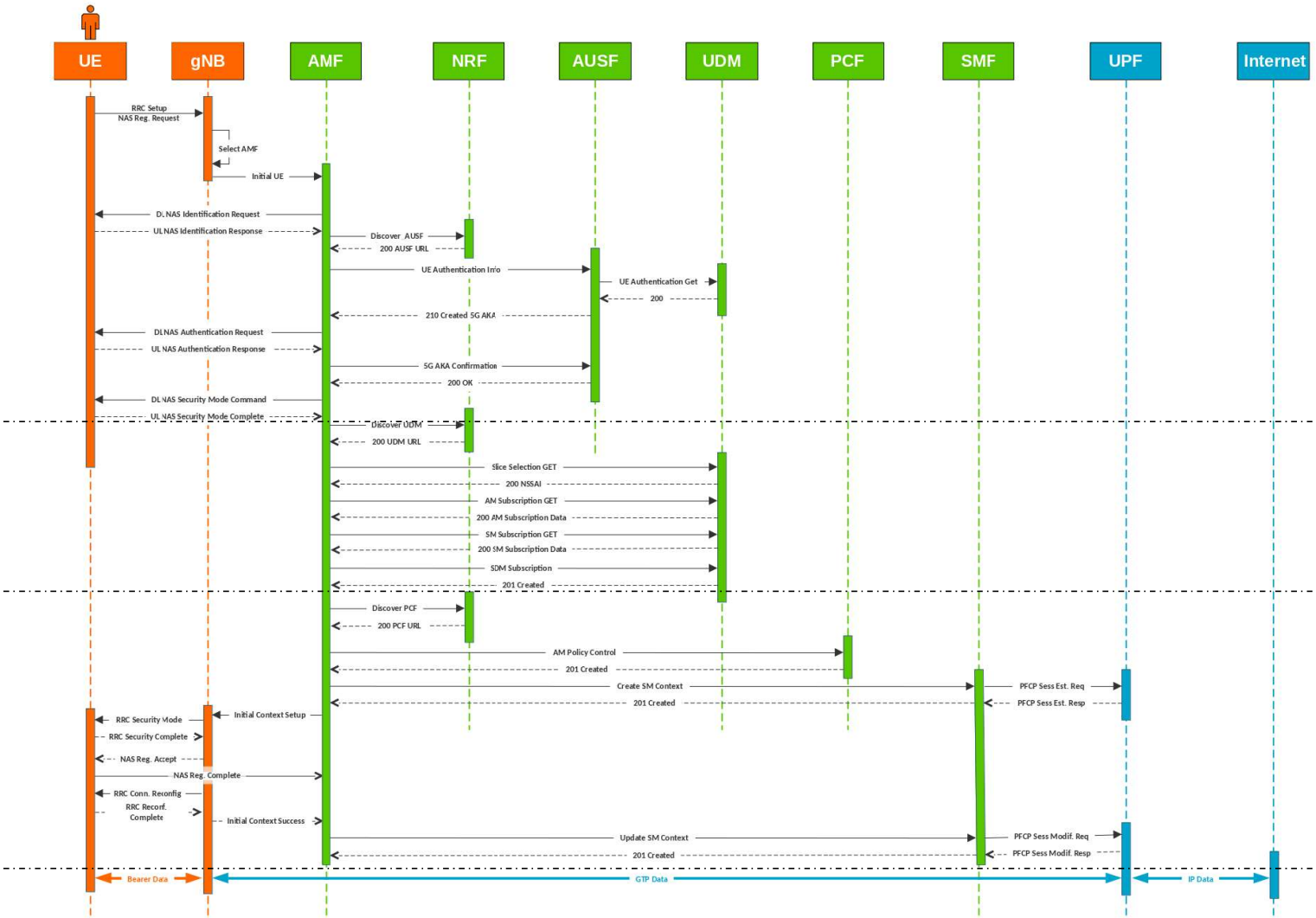
3GPP, TS 33.501, Figure 6.2.2-1: Key distribution and key derivation scheme for 5G for network nodes



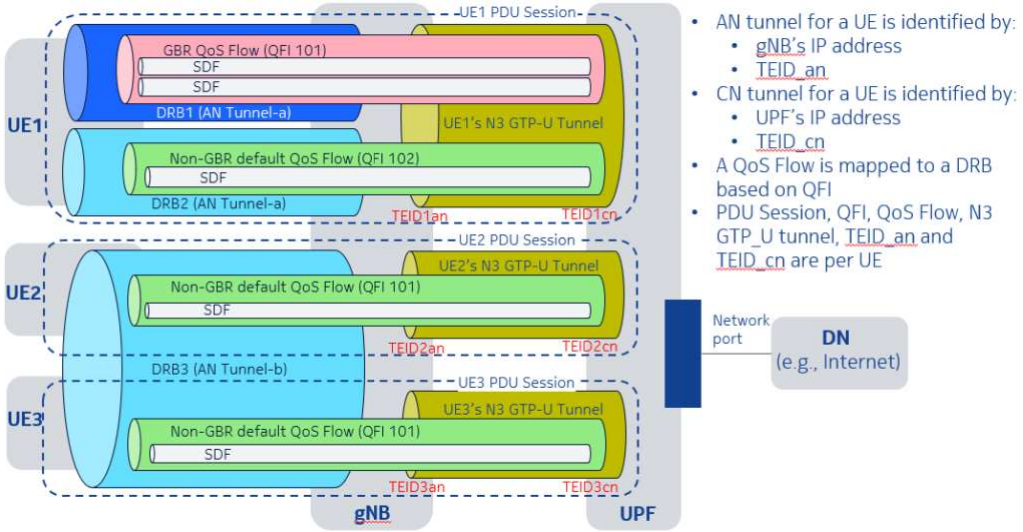
3GPP, TS 33.501, Figure 6.2.2-2: Key distribution and key derivation scheme for 5G for the UE

CK: cipher key
IK: integrity keyb

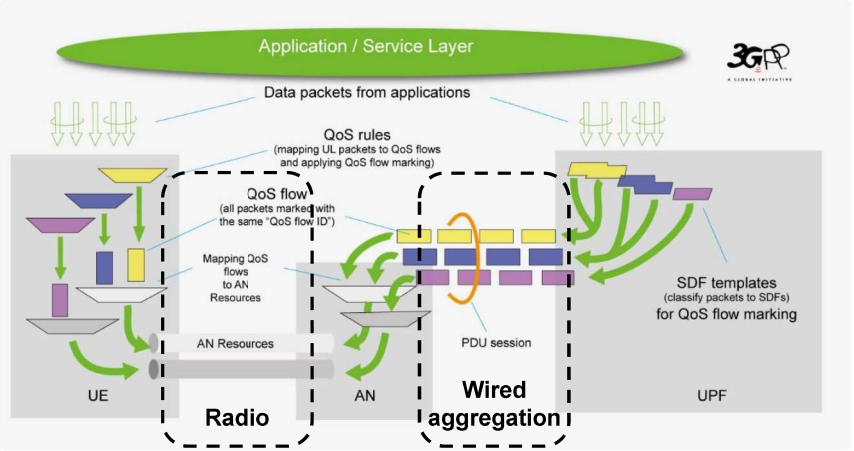
5G Standalone Registration



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



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	

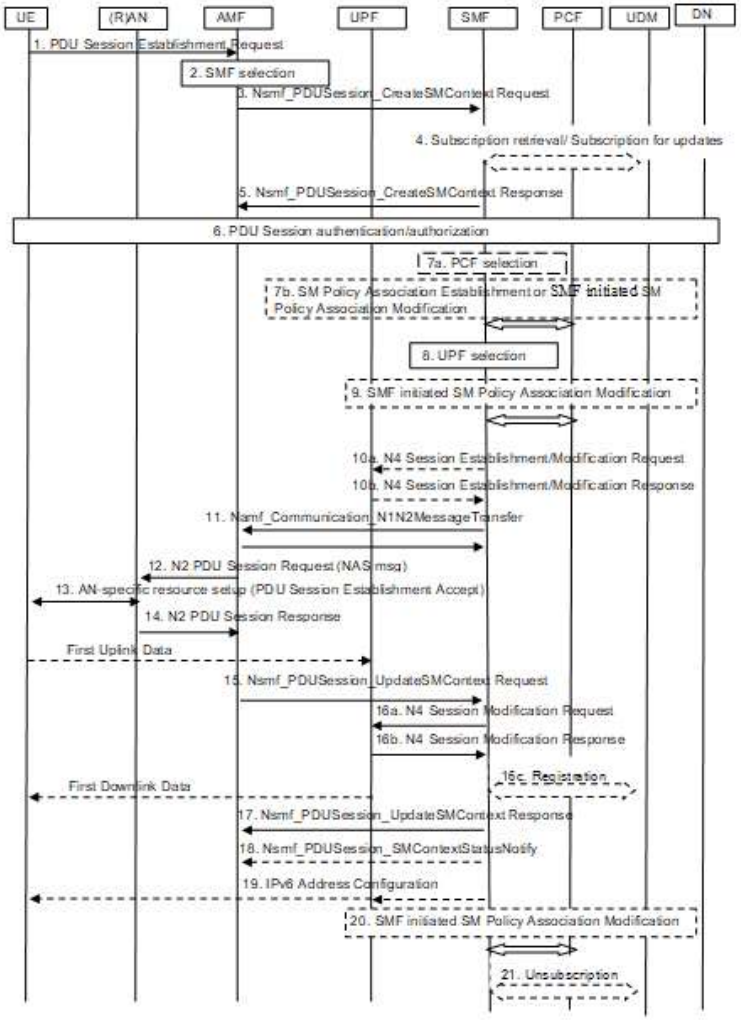
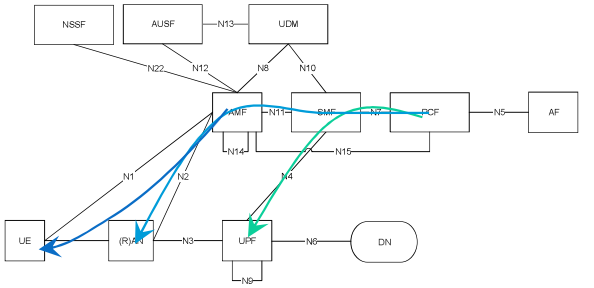
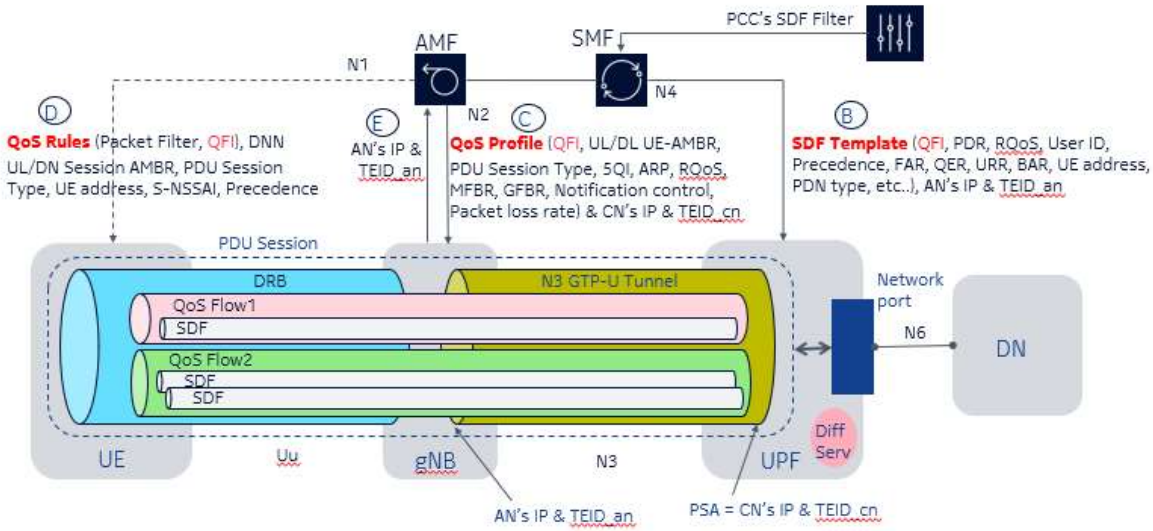


Figure 4.3.2.2.1-1: UE-requested PDU Session Establishment for non-roaming and roaming with local breakout

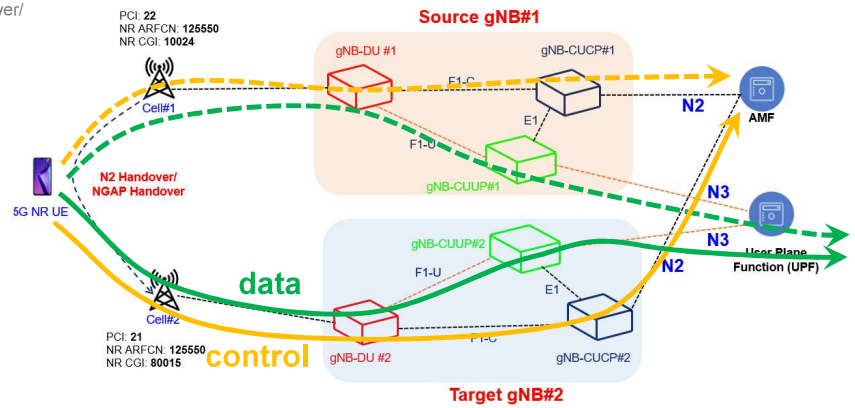
QoS protocols' flows



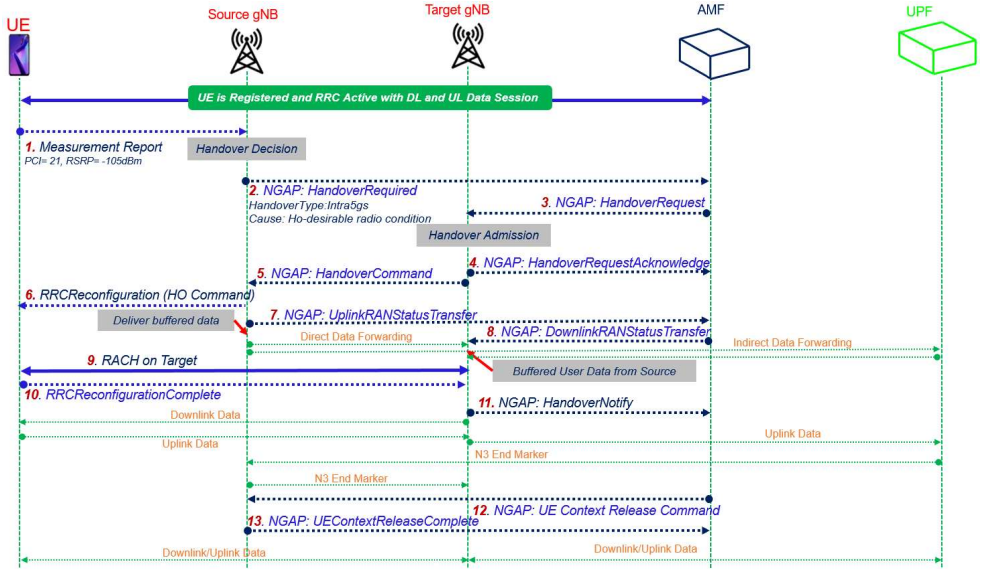


Inter gNB mobility in 5G

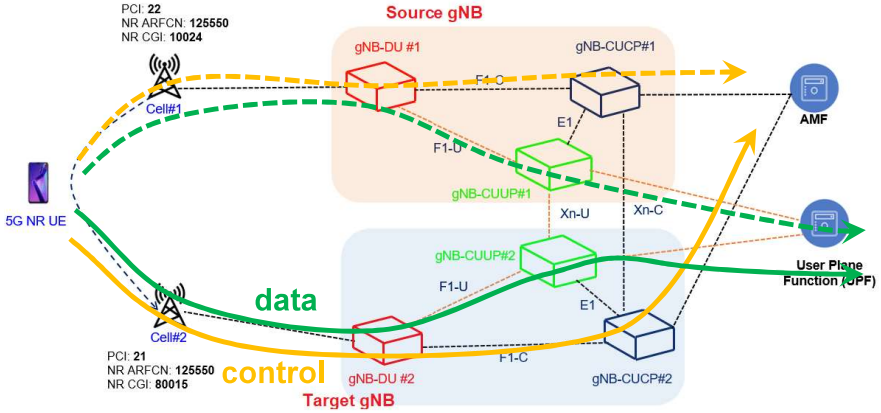
https://www.techplayon.com/5g-sa-inter-gnb-handover-n2-or-ngap-handover/

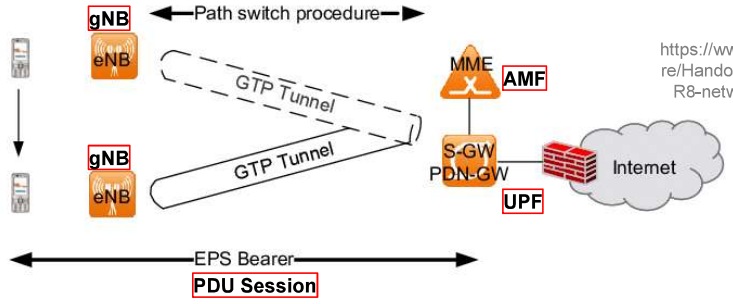


https://www.techplayon.com/5g-sa-inter-gnb-handover-n2-or-ngap-handover/



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

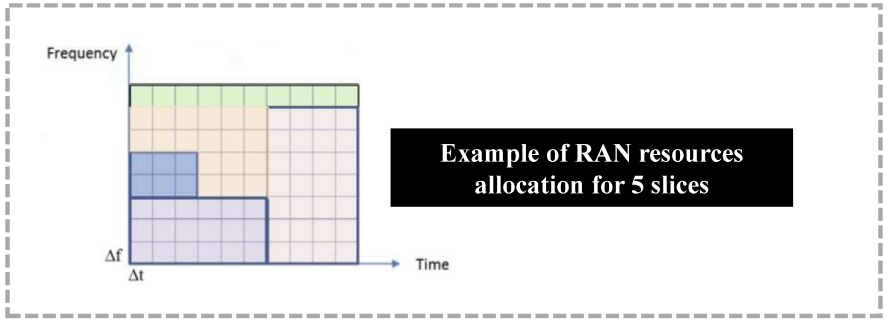
Network Slice definition (TR 23.799): ***complete logical network (providing Telecommunication Services and Network Capabilities) including AN and CN***

Slicing enables the creation of distinct logical networks:
- **Of the same type (different businesses)**
- **Providing differentiated behaviour (different services)**

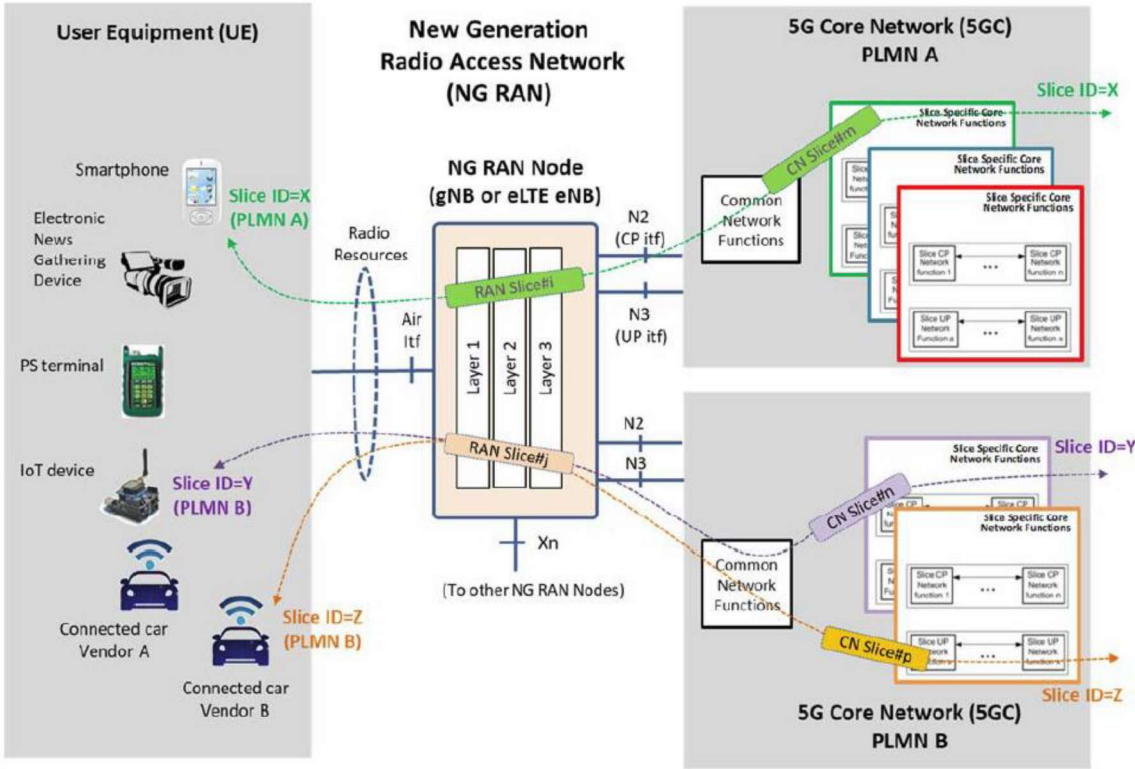
5G supports end-to-end slicing (radio and core)
- **Resources isolation between services**
- **Customized functions and/or capacities, according to SLA**

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)

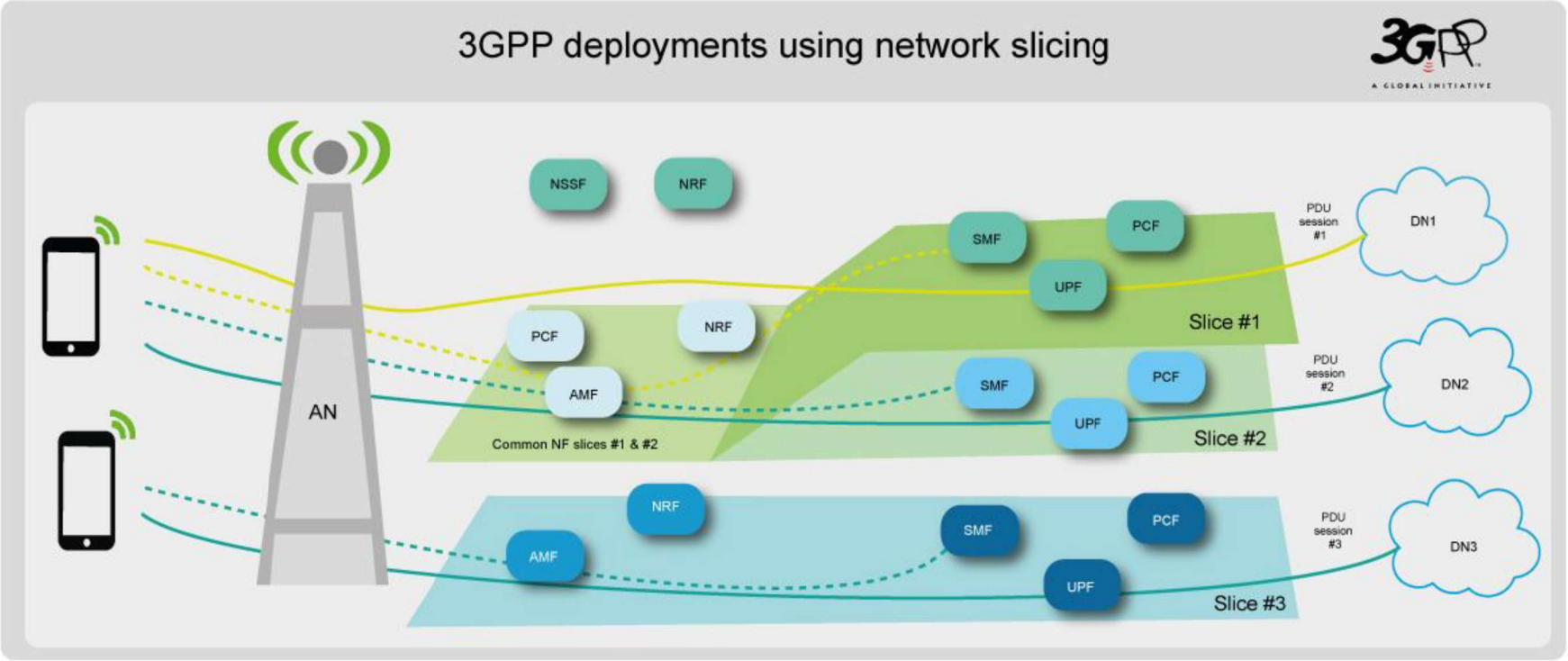


Example of RAN resources allocation for 5 slices



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

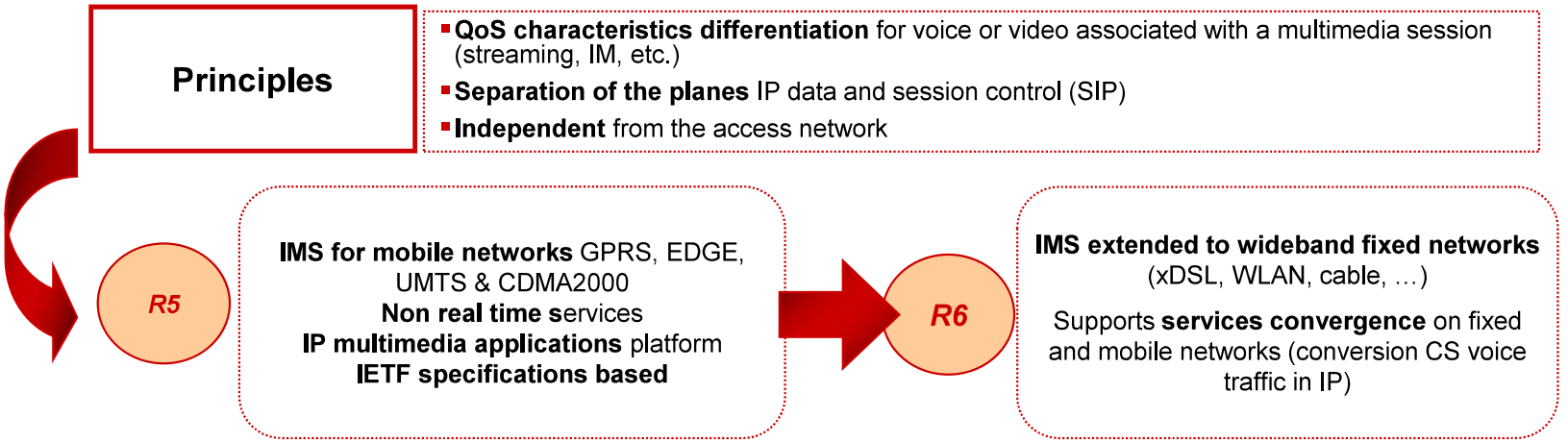


https://www.3gpp.org/news-events/3gpp-news/sys-architecture

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



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

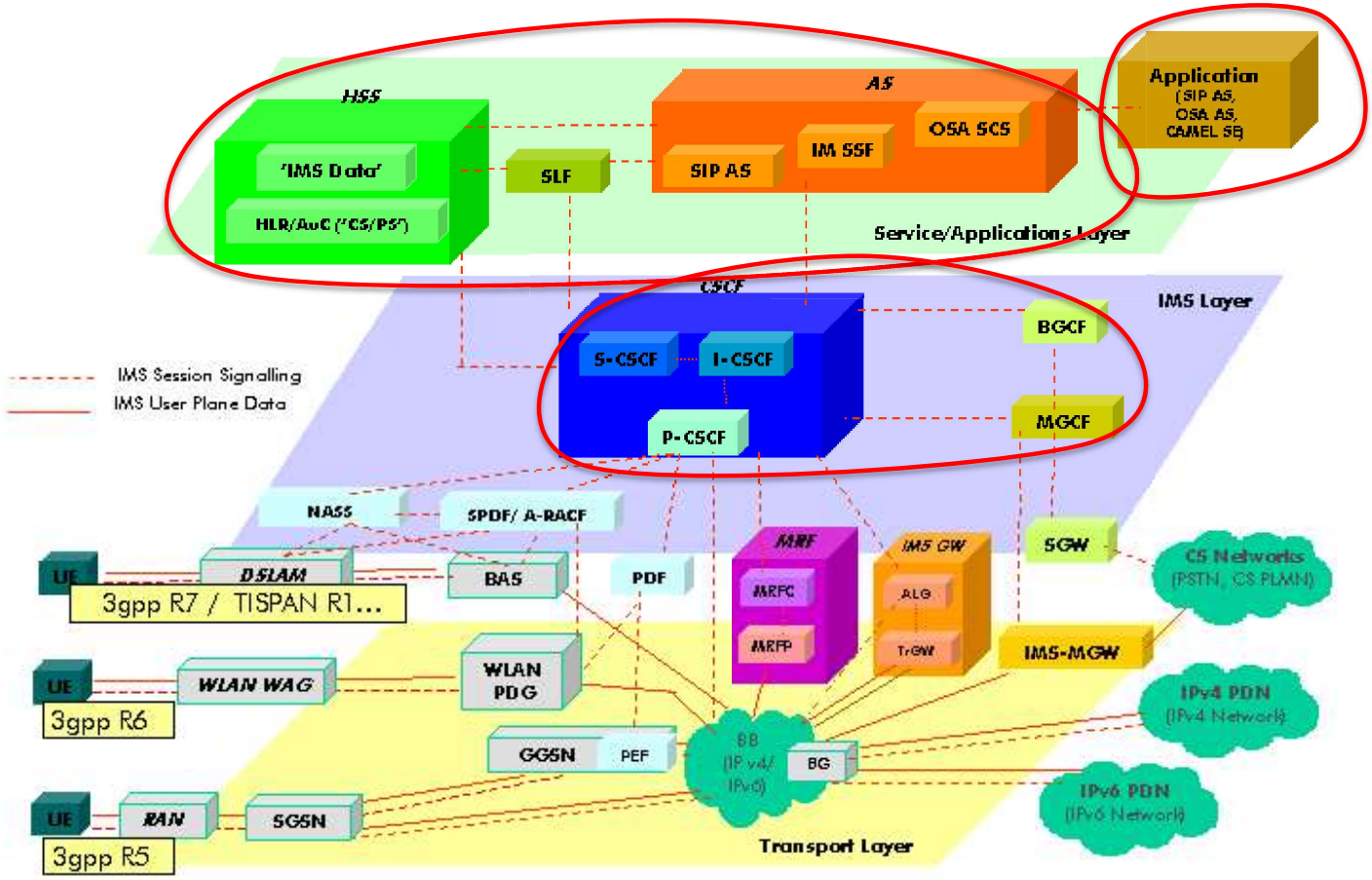
- Defined in IETF RFC 3261
  - "… an application-layer control (signaling) protocol for creating, modifying, and terminating sessions with one or more participants. These sessions include Internet telephone calls, multimedia distribution, and multimedia conferences."
- SIP is to the Internet what SS#7 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

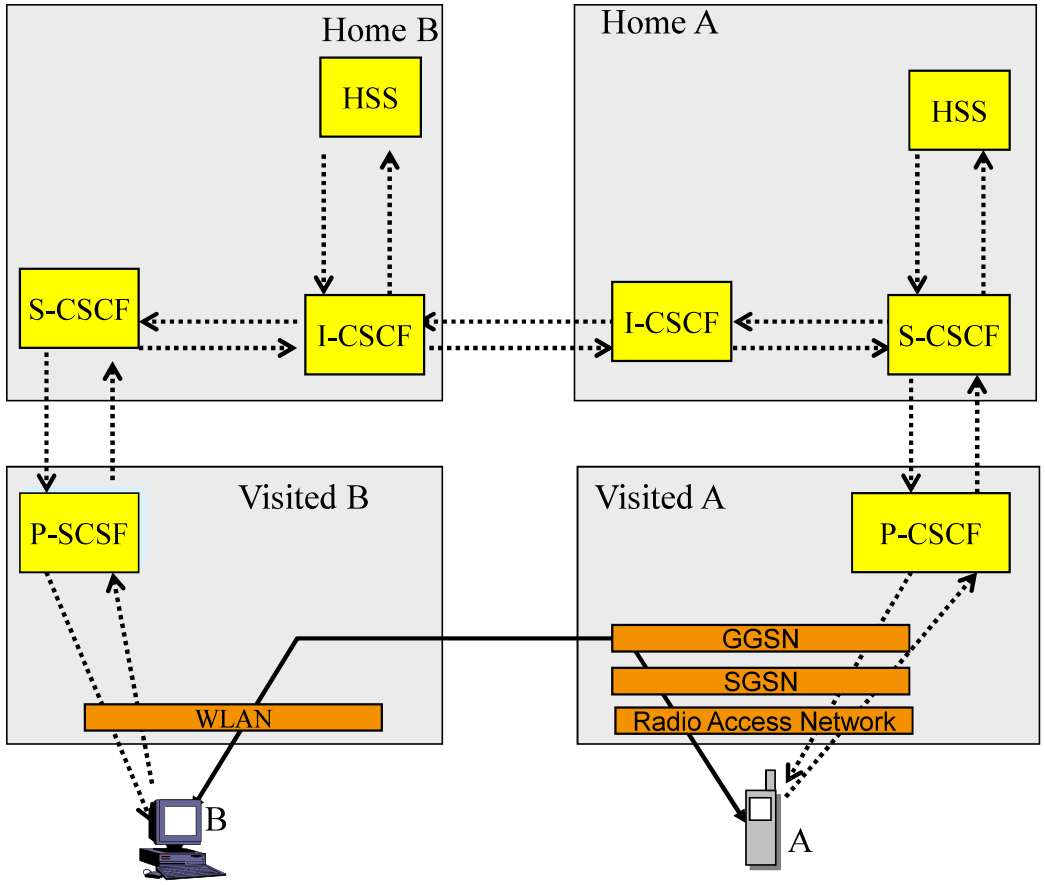
- IMS is an advanced infrastructure enabling services. But the services are in the end points or peers (calls, etc.), not in the IMS
- Application Servers (AS) are the key part to endow IMS with services
- AS offered services enjoy all IMS advantages
- AS interact – using SIP - with the S-CSCF (which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

Where is IMS ?

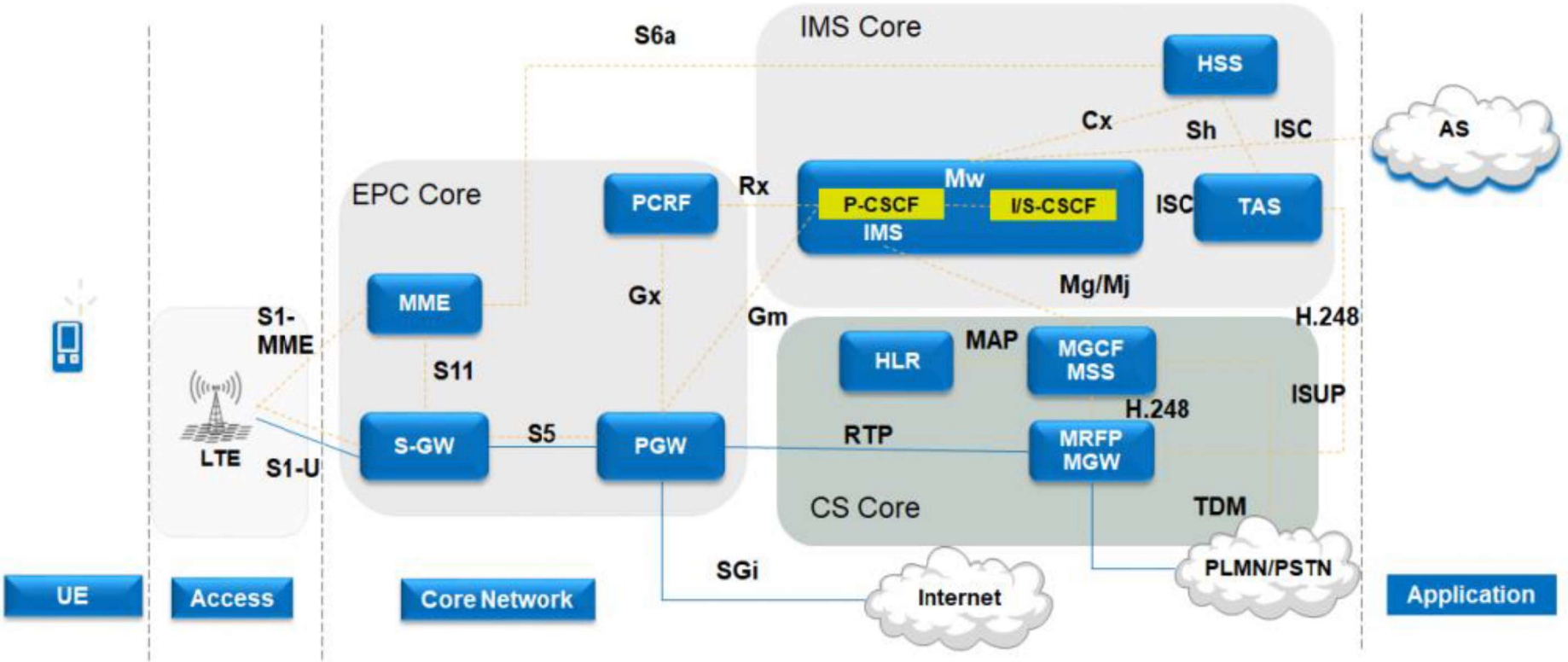

HSS
'IMS Data'
HLR/AuC ('CS/PS')
SLF
AS
SIP AS
IM SSF
OSA SCS
Application
(SIP AS,
OSA AS,
CAMEL SE)
Service/Applications Layer
IMS Layer
CSCF
S-CSCF
I-CSCF
P-CSCF
BGCF
MGCF
IMS Session Signalling
IMS User Plane Data
NASS
SPDF/ A-RACF
MRF
MRFC
MRFP
IMS GW
ALG
TrGW
SGW
CS Networks
(PSTN, CS PLMN)
IMS-MGW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

UMTS IMS: basic call flow

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



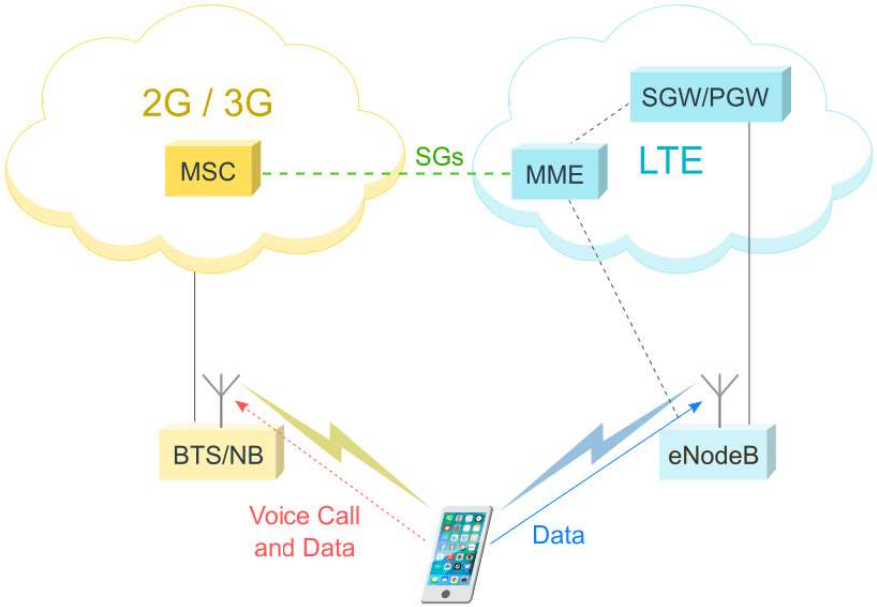
VoLTE Network Architecture



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

Voice: CSFB or VoLTE

https://yatebts.com/solutions_and_technology/csfb-to-volte-evolution/



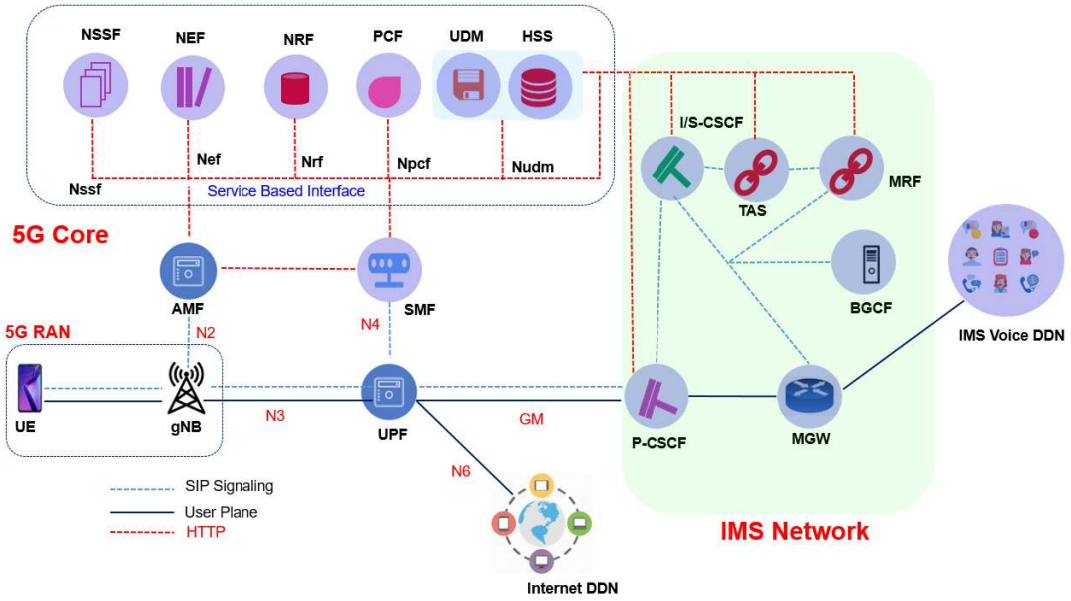
https://www.mpirical.com/blog/delivering-5g-voice-services

Feature	CSFB	VoLTE
Easy of Deployment	Challenging, but not as difficult as VoLTE	Numerous major challenges to overcome
Economic Considerations	Minor	Major
LTE Coverage Requirements	Low	High
Call Setup Time	Approx. 3-7 secs	Approx. 2-4 secs
Voice Quality	Acceptable	HD Voice
Lifespan	2G and 3G limited life	IMS forms basis for 5G voice and beyond

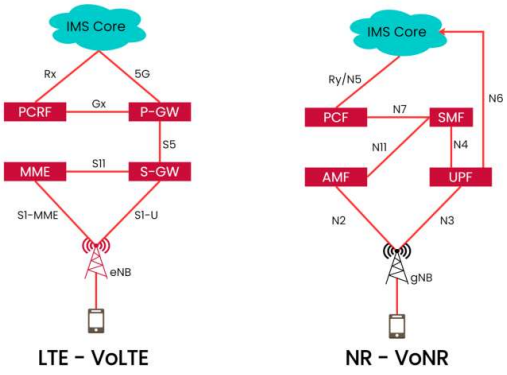
CSFB (Circuit Switch Fallback) is a technology that supports voice and SMS services in 4G networks using the 2G/3G systems.

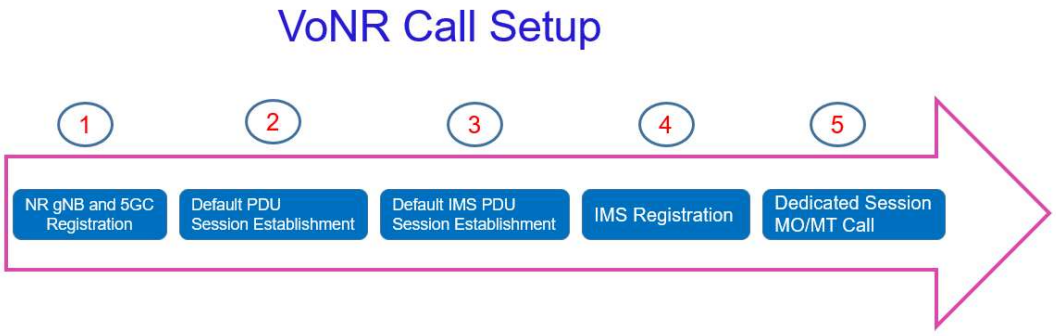
VoLTE (Voice over LTE), on the other hand, means that a call is made through a 4G network (Making calls over IP).

Example: VoNR

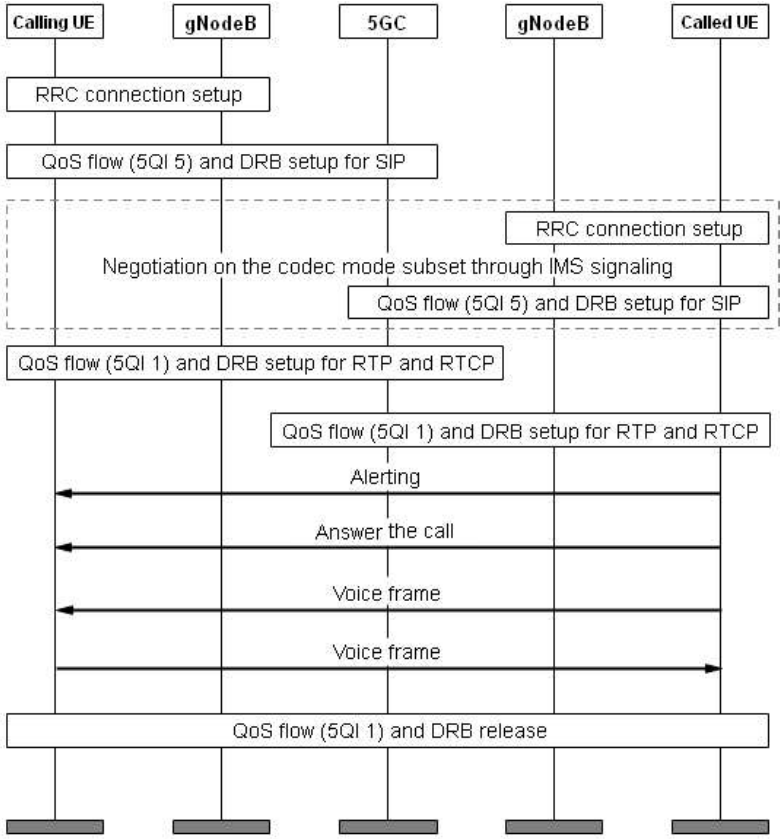


- Main componentes: 5G RAN, 5G Core, IMS
- Establishement of specific PDU sessions
- QoS

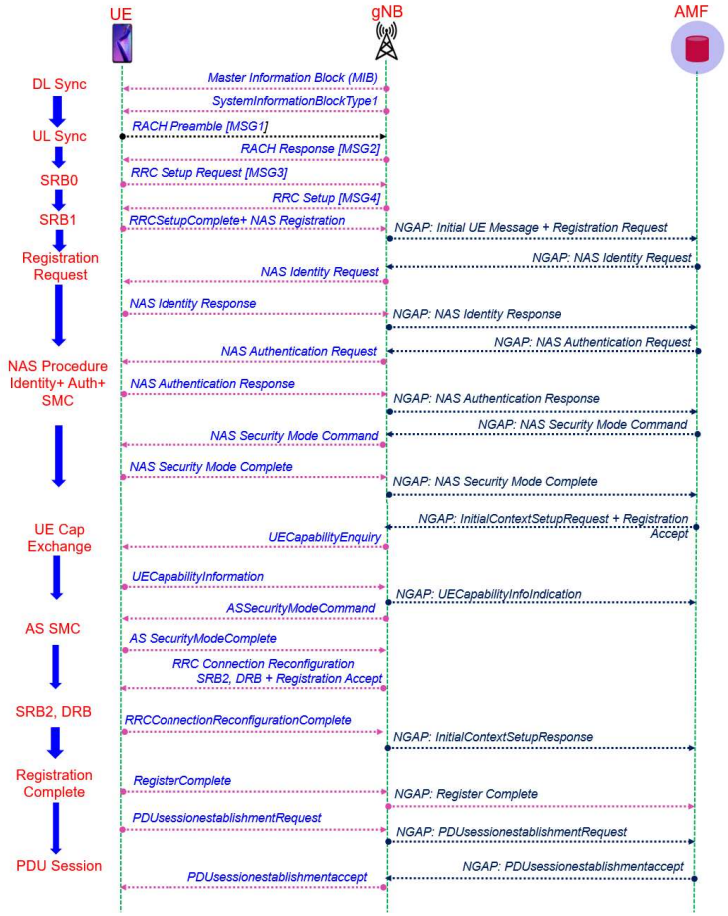




VoNR Call Flow

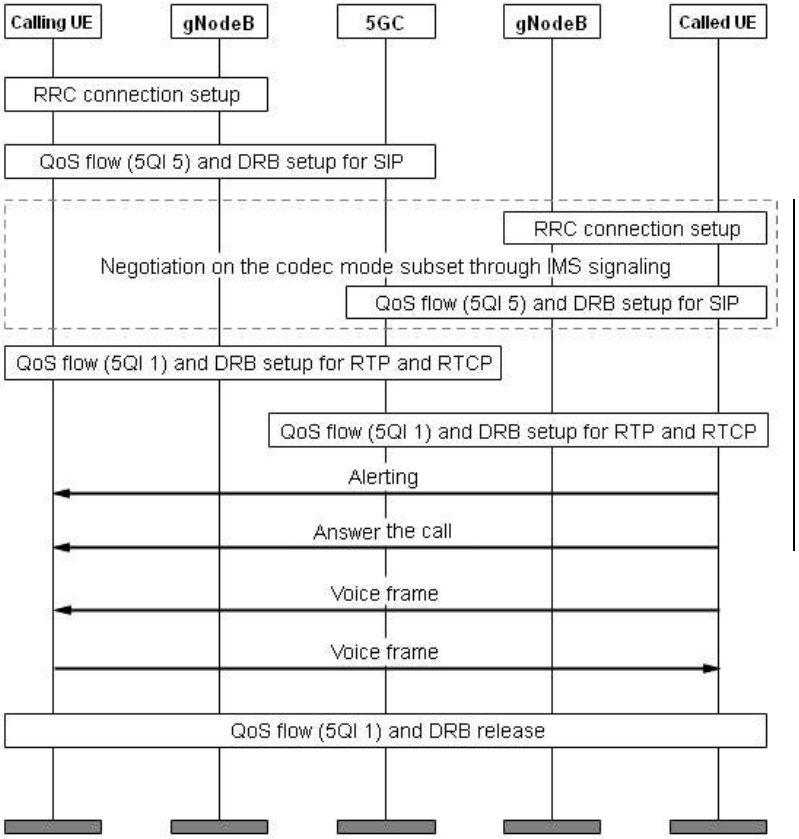


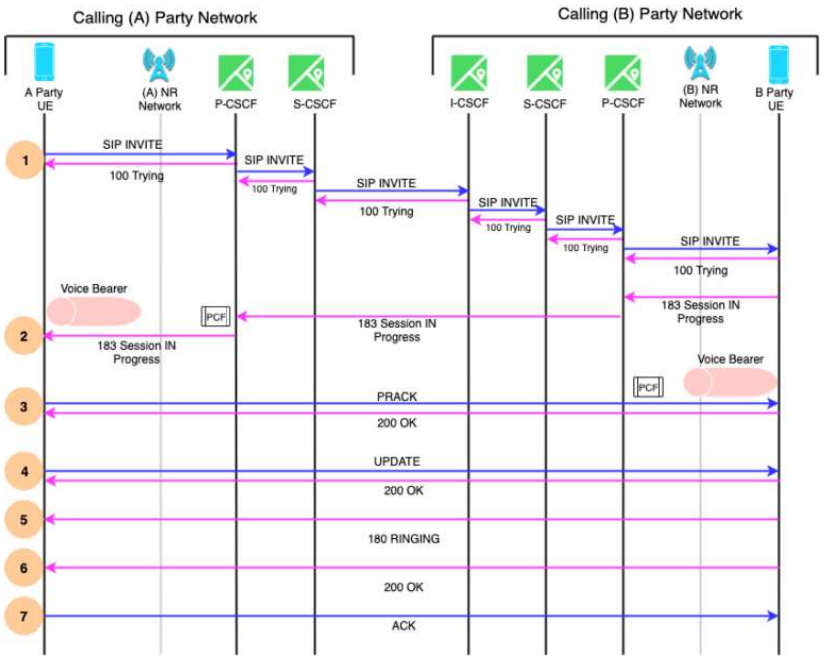
https://www.5gworldpro.com/blog/2021/05/30/voice-over-nr-call-flow/



https://www.techplayon.com/5g-nr-sa-registration-attach-call-flow/

VoNR Call Flow





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