5G Core - Architecture, concepts and Call Flows

Image: 3GPP

Agenda

- Introduction - Why and How ?
- 5G Timeline
- 5GC Deployment Architectures - SA and NSA
- 5G Core Architecture - Enabling Technologies
- 5G Core Architecture - SBA and Point-to-Point
- 5G Core elements
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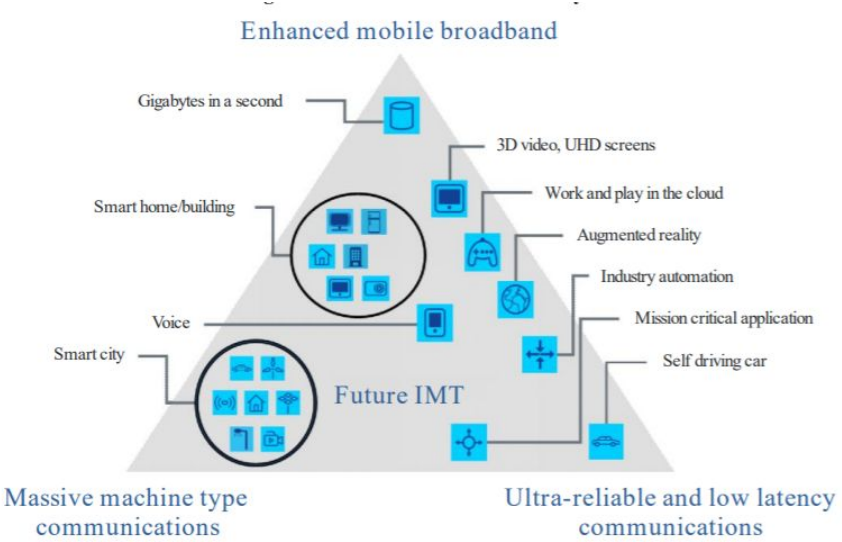
  - SMF - Session Management Function
  - UPF - User Plane Function
    - QoS in 5G
  - NRF - Network Repository Function
  - UDM - Unified Data Management Function
  - AUSF, EIR
  - PCF - Policy Control Function
  - NSSF - Network Slicing Selection Function
    - Network Slicing
- Identifiers in 5G Core
- Security in 5GC
- Interworking with 4G EPC
- Network Functions and Services
- Call Flows

Quizzes are inserted at the end of sections to help you test your understanding of concepts before moving on.

Section 1 - Introduction

Why do we need 5G ?

- New Use cases other than just Mobile Broadband
  - eMBB (enhanced Mobile Broadband)
  - URLCC (ultra-reliable low-latency communications)
  - mMTC (massive machine type communications)



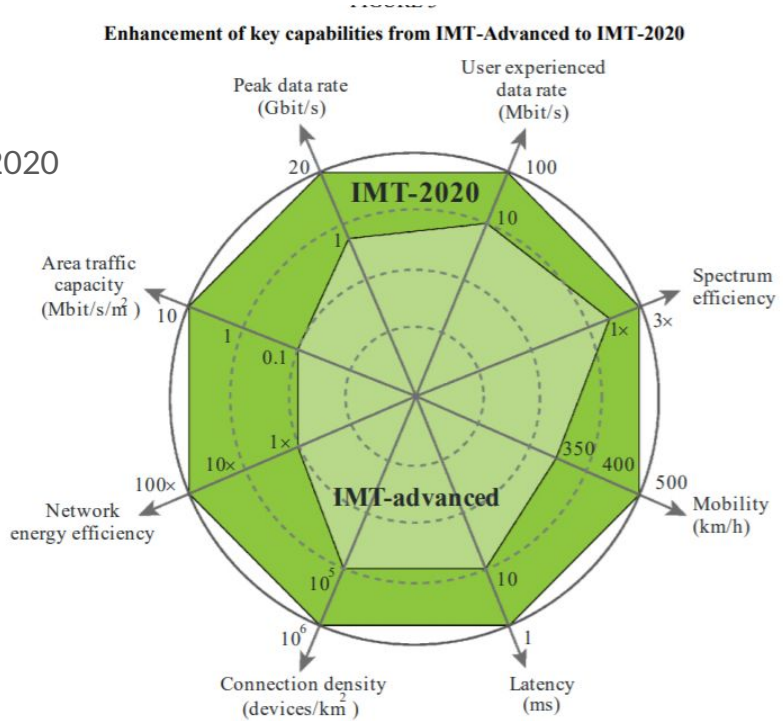
Source - ITU

Why do we need 5G ?

- IMT-advanced drove the design of LTE, LTE advanced and LTE-AP.
- IMT-2020 drives the design of 5G and beyond.
- Comparison of various metrics between IMT-advanced and IMT-2020
- Significant differences between both technologies.

Metrics for comparison:

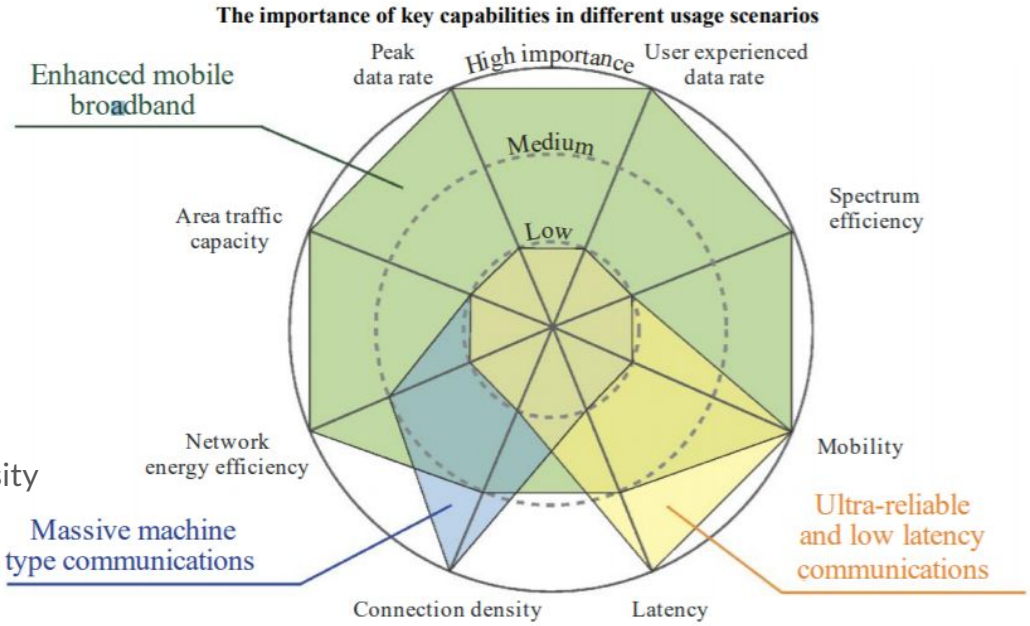
- Peak Data Rate
- User Exp Data Rate
- Area traffic Capacity
- Network efficiency
- Connection density
- Mobility
- Latency
- Spectrum efficiency



Source - ITU

5G requirements

- As seen before the main use cases for 5G are - eMBB, URLCC and mMTC
- Some observations worth noting:
  - eMBB - High importance on
    - Peak data rate
    - Area traffic capacity
    - Network efficiency
    - Spectrum efficiency
    - Mobility
  - Latency
    - High importance on Mobility
    - High importance on Latency
  - mMTC
    - High importance on connection density



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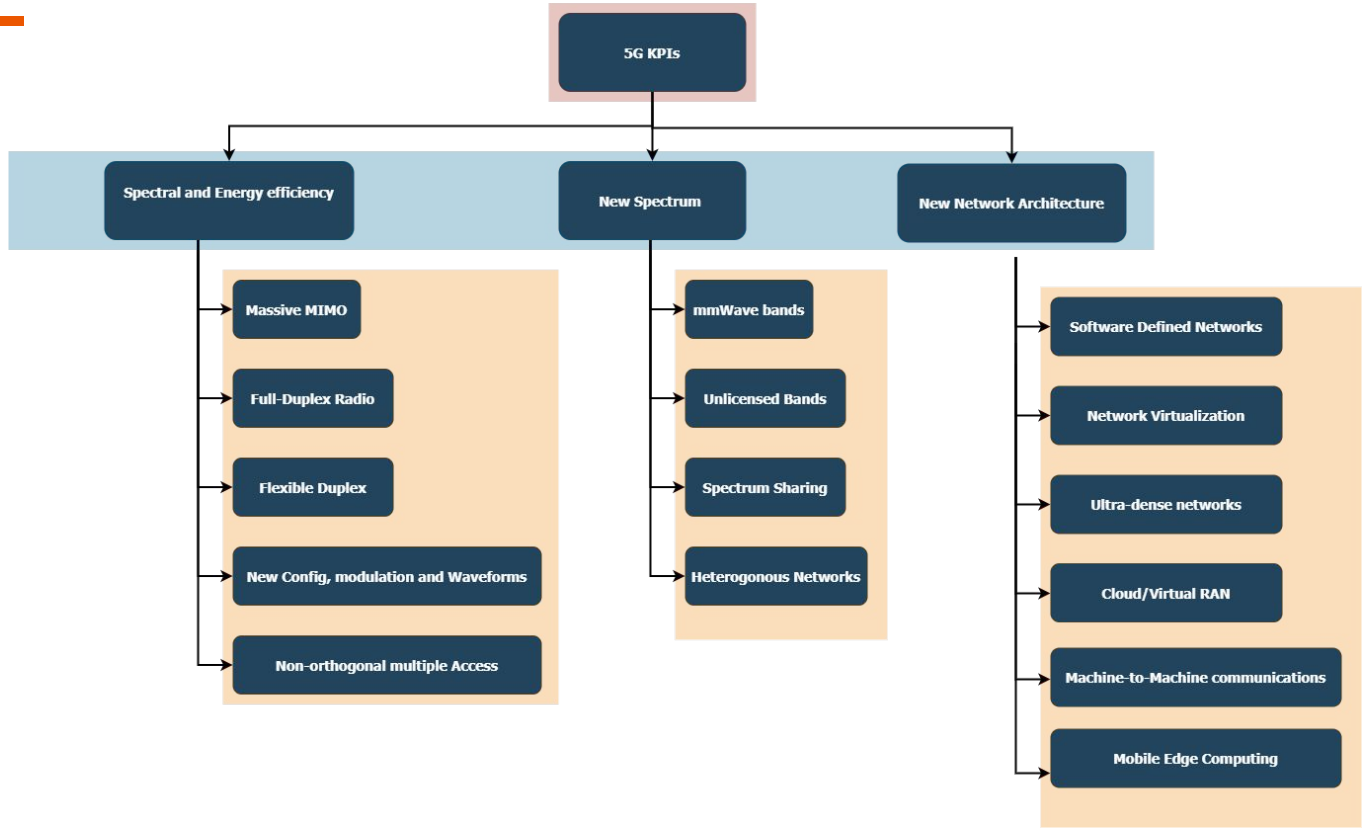
Enabling 5G technologies > How ?



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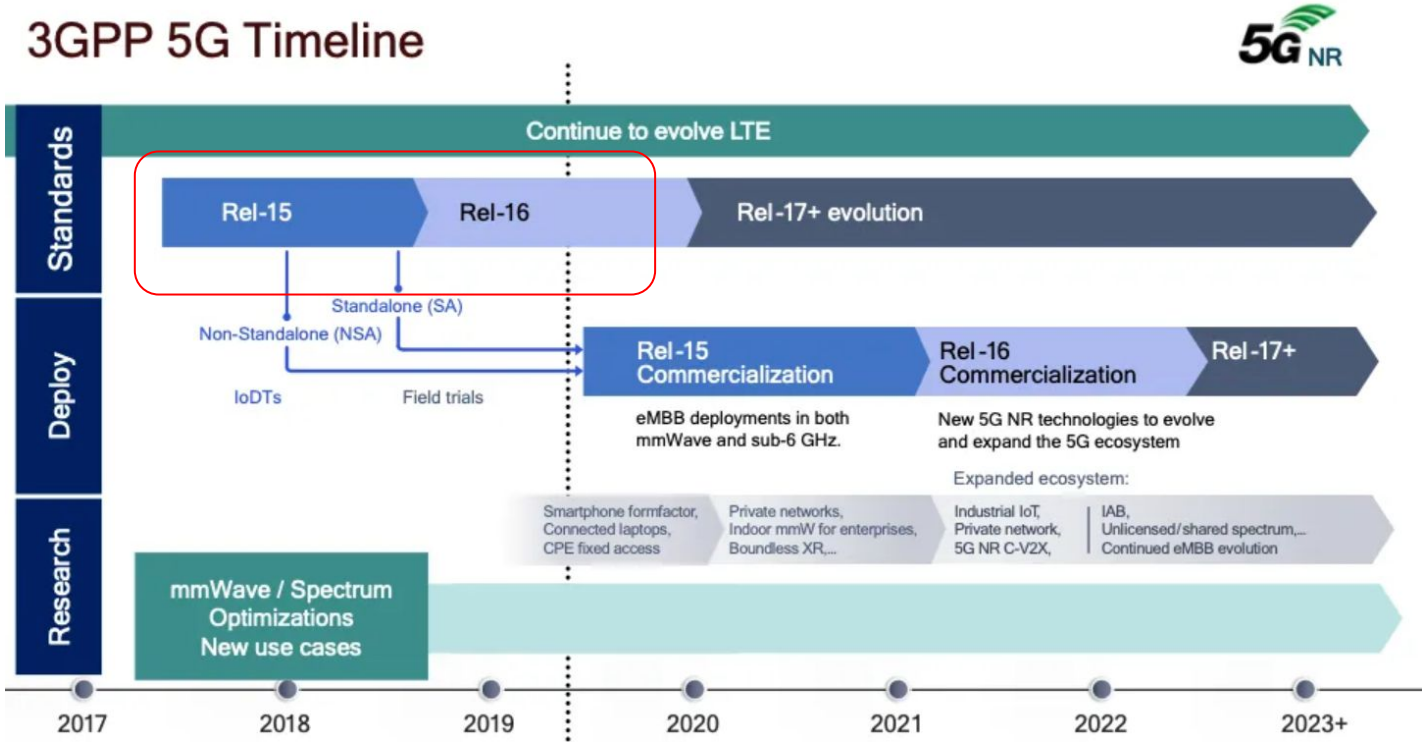
Section 2 - 5G Timeline

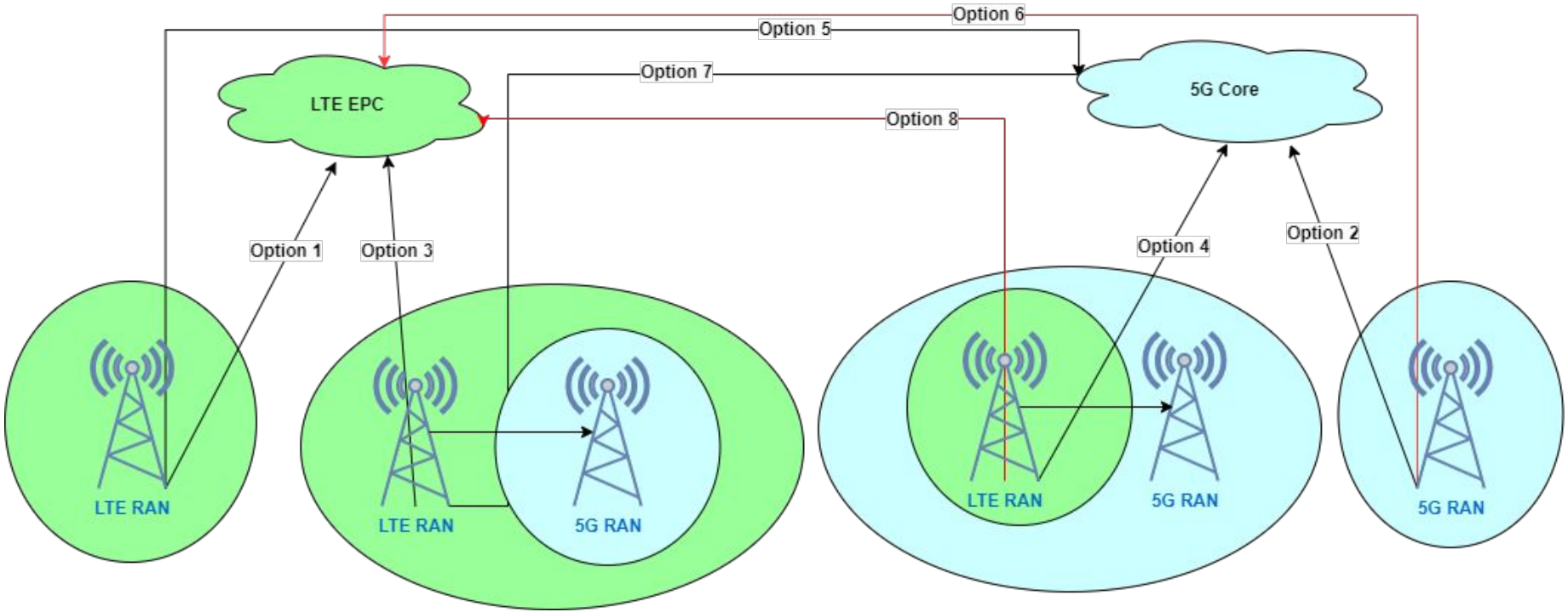
3GPP Progress



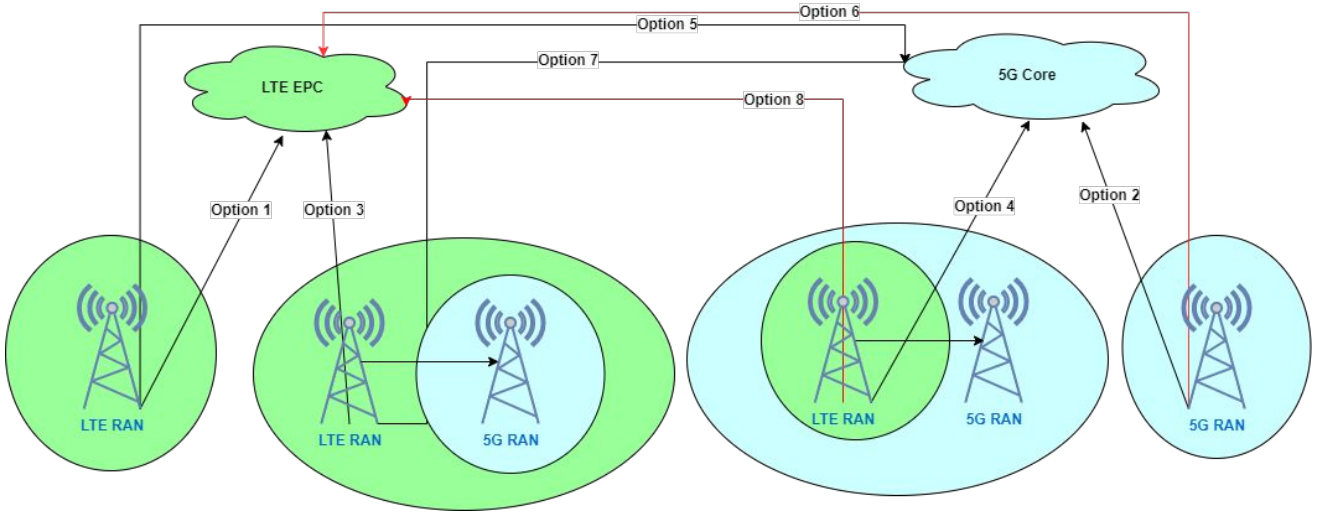
Section 3 - 5G Architectures - SA and NSA

5G Deployment Architectures

Many options to Choose from. 5G gives MNOs a lot of flexibility



5G Deployment Architectures



Access Network	LTE only	NR only	LTE with NR for user plane only	NR with LTE for user plane only
EPC Core Network	Option 1 (4G)	Option 6	Option 3	Option 8
5G Core Network	Option 5	Option 2 (Stand-Alone)	Option 7	Option 4

5G Deployment Architectures

Per 3GPP TR 21.915, Two deployment options are defined for 5G:

1. The “Non-Stand Alone” (NSA) architecture, where the 5G Radio Access Network (AN) and its New Radio (NR) interface is used in conjunction with the existing LTE and EPC infrastructure Core Network (respectively 4G Radio and 4G Core), thus making the NR technology available without network replacement. In this configuration, only the 4G services are supported, but enjoying the capacities offered by the 5G New Radio (lower latency, etc). The NSA is also known as “E-UTRA-NR Dual Connectivity (EN-DC)” or “Architecture Option 3”.
2. The “Stand-Alone” (SA) architecture, where the NR is connected to the 5G CN. Only in this configuration, the full set of 5G Phase 1 services are supported.

Benefits of 5G NSA:

- deliver high-speed connectivity to consumers with 5G-enabled devices
- leverage existing network investments in transport and mobile core

Benefits of 5G SA:

- MNOs can launch new enterprise 5G services such as smart cities, and smart factories
- It is fully virtualized, cloud-native architecture (CNA), which introduces new ways to develop, deploy and manage services
- The architecture enables end to end slicing to logically separate services
- Automation drives up efficiencies while driving down the cost of operating the networks.
- By standardizing on a cloud-native approach, MNOs can also rely on best of breed innovation from both vendors and the open-source communities
- By choosing a cloud-native microservices-based architecture, MNOs can also decide on a variety of deployment models such as on-prem private cloud, public cloud, or hybrid to meet their business objectives

Section 4 - 5G Core Architecture - Enabling Technologies

5G Core Architecture - Enabling Techs

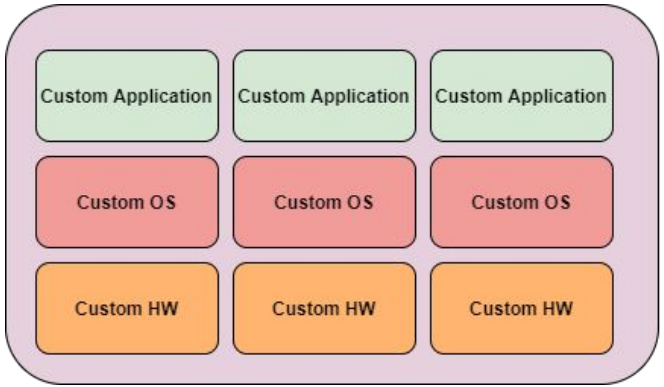
5G Core Architecture embraces the following new technologies (we will discuss these over the next few sections).

- Virtualization
- Cloud Native
- Containers
- Microservices, and
- Automation and Orchestration

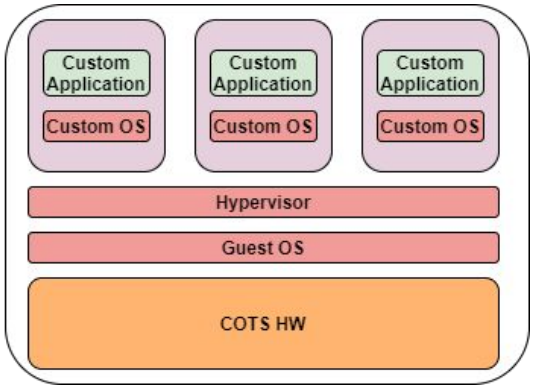
These concepts are not new and have been driving the success of IT/DevOps for many years. Let us look at that them briefly.

Virtualization

- Traditionally Mobile core application software runs on proprietary hardware. This HW is deployed OEMs/Vendors specifically for custom applications.
- Such HW is optimized for speed and performance and has a fixed capacity. Capacity increases often require HW swaps or adding additional HW resources (CPU, memory, storage).
- The current model does not scale well and is not cost effective.
- Virtualization enables running applications on virtual machines, which run on COTS HW. This enables the decoupling of application and HW and therefore offers great flexibility at a significantly reduced cost.



Traditional Architecture



VM Based Architecture

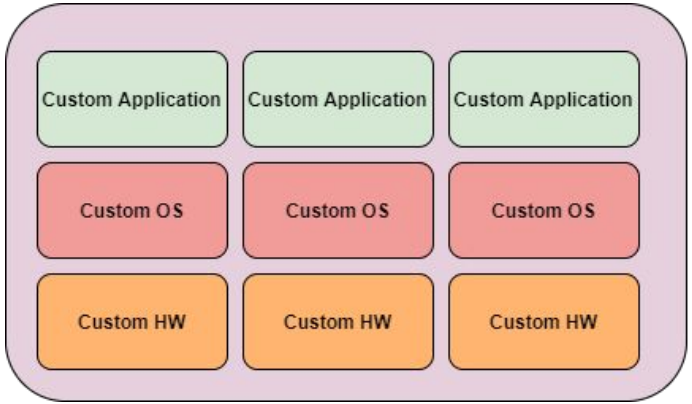
Cloud Native

- Cloud Native architectures have gained a lot of attention lately as operators try to follow the same architecture principles as followed by hyperscalers like Amazon, Google etc.
- Cloud Native is not a single concept but instead is a set of principles. Some of these are:
  - Infrastructure agnostic - Apps don’t depend on HW and resources.
  - Software decomposition and Life Cycle Management - Apps run in smaller and manageable pieces unlike a monolithic application.
  - Resiliency - due to distributed nature of applications impact of local maintenance or faults is isolated to local instances and does not affect overall functionality.
  - Orchestration and Automation - Apps can be managed using orchestrators like Kubernetes or OpenStack. Turn-up/down, scaling and maintenance (upgrades, logging etc.) of apps is all automated.

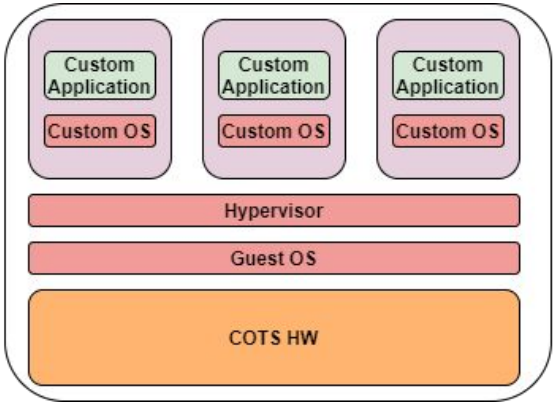
Containers

Containers vs VMs: Key Takeaways

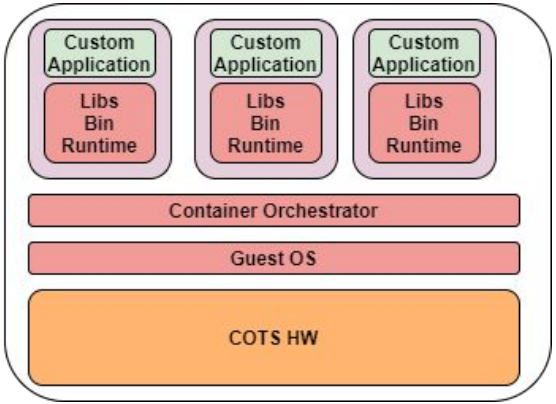
- Containers are independent hosts for applications that use a single, stripped-down version of an operating system to run.
- Virtual machines use a full version of an operating system.
- Containers run a virtualized workload, processed by an application broken up into microservices, making them more lightweight and flexible than a VM.
- VMs can run a full, unaltered application, orchestrated by a hypervisor.
- Both can scale up and down quickly and easily.



Traditional Architecture



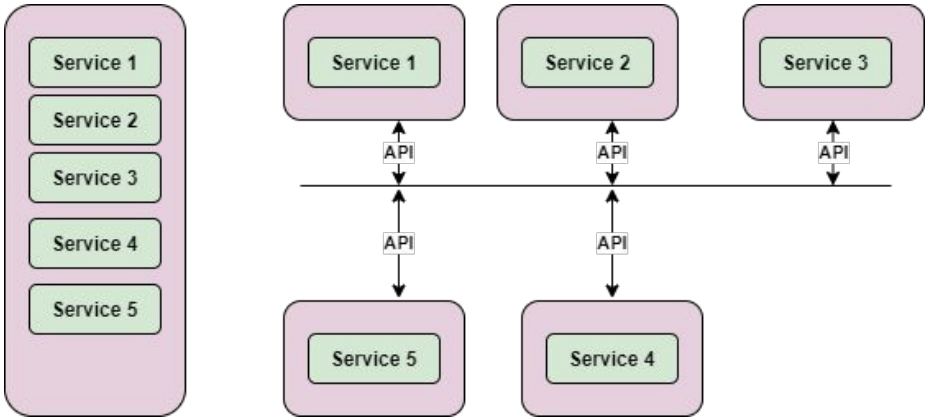
VM Based Architecture



Container Based Architecture

Microservices

- Refers to an architectural and organizational approach to software development where application is composed of smaller independent services that interact with each other over well defined APIs.
- Form the basis for service based architecture (SBA).
- Several benefits:
  - Components have a limited scope and therefore changes can be made quickly and efficiently.
  - Instances can be added, removed on demand adding ease of scalability.
  - Independent software upgrades
  - Ease of debugging due to limited scope of components.



Monolithic Architecture

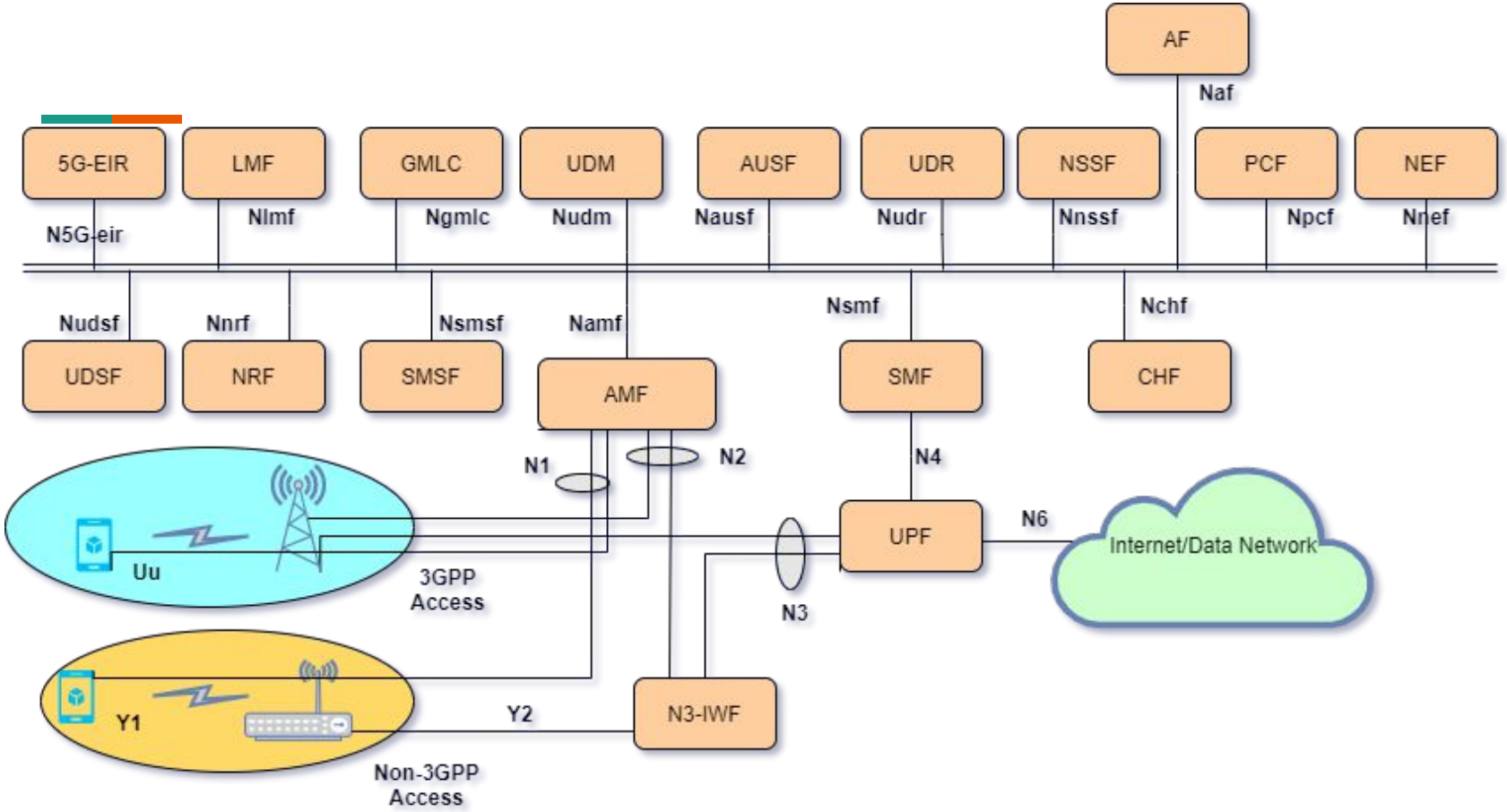
Microservices based Architecture

Automation

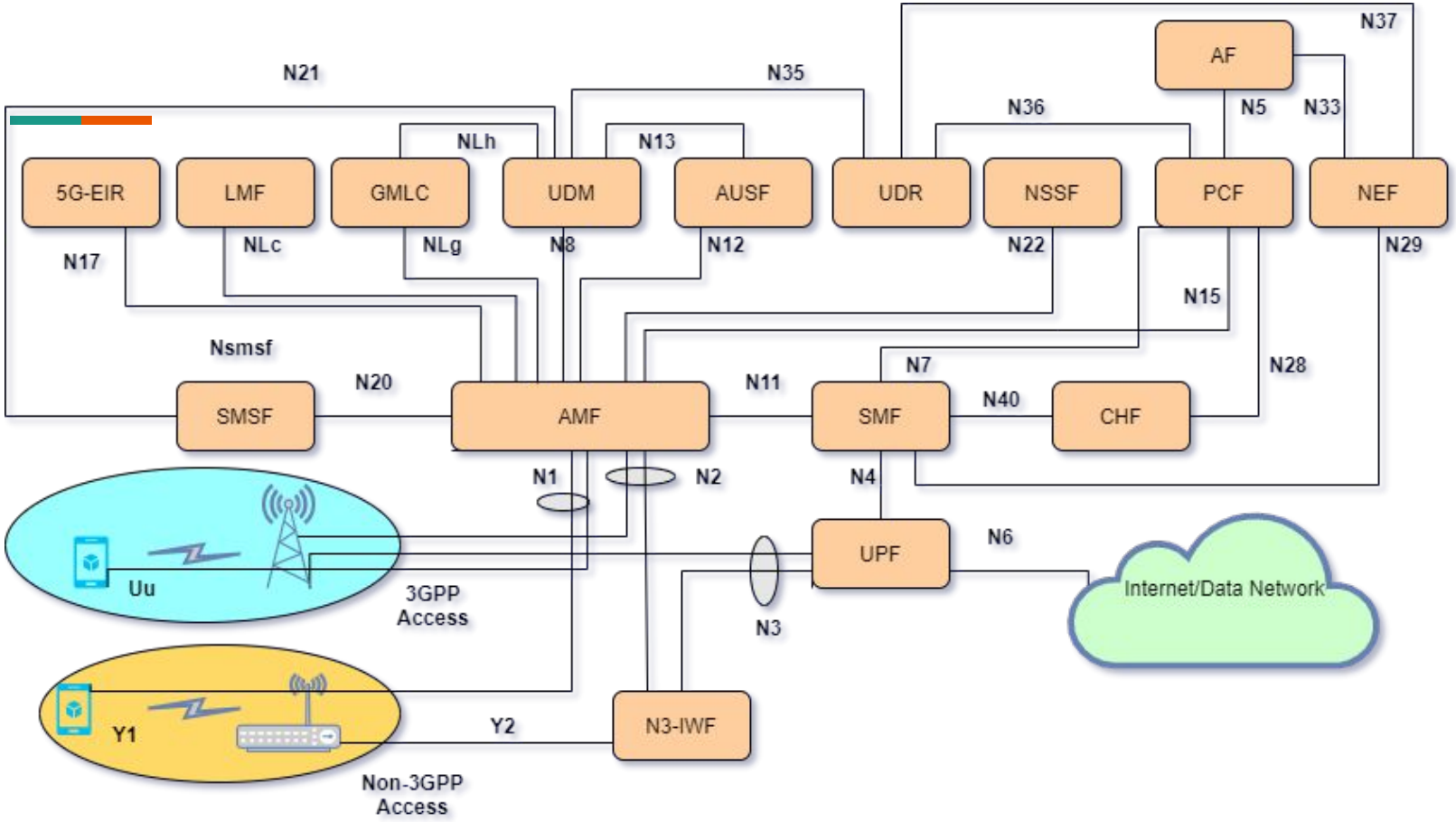
- 5G needs to support rapid scaling up/down and life cycle management of network applications (turn up/down, upgrade, logging etc.)
- Automation technologies for orchestration can help achieve these goals.
- So far SON (self-optimizing networks) capabilities have been leverage on the RAN side. For example - Automatic Neighbor relations.
- Operators have seen accelerated roll out times, simplified network upgrades, fewer dropped calls, improved call setup success rates among other positive impacts. Therefore there is a great deal of interest to implement SON/automation on the core side as well.
- 5G is a unique architecture that is service-based and built on top of microservices. This offers a unique opportunity to leverage automation to manage life cycle of applications and infrastructure resources. Such capabilities are essential for supporting 5G use cases that demand varying demands/requirements.
- Machine learning and artificial intelligence will become further integrated across all aspects of mobile systems in the near future.

Section 5 - 5G Core Architecture

5G Core Elements - SBA based depiction

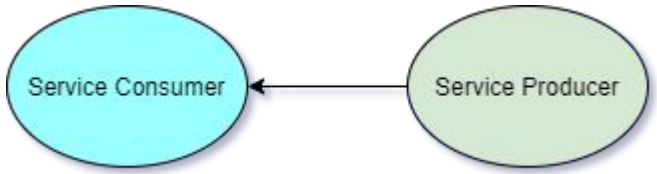


5G Core Elements - Point-to-Point Interface



Some noteworthy points re the 5G Core Architecture

- 5G Core architecture is a service-based architecture. SBA can be understood in terms of “service producer” and “service consumer”.



- 2 ways of representing the architecture: SBA based and Point-to-Point
- All interactions among network services are based on HTTP/Rest APIs
- Both these architecture representations look complex at first but over time all the elements will make sense. Use both architecture diagrams as reference as you go through the course.

Section 6 - 5G Core Elements

Access and Mobility Function (AMF)

AMF - Access and Mobility Function

- AMF interacts with NG-RAN over N2 interface.
- AMF interacts with UE over N1 interface for authentication, registration, handovers. Also responsible for paging of idle mode UEs.
- One UE is connected to one AMF at a time.
- AMF relays all session management-related signalling between the SMF (session management function) and UE.
- Relays all SMS messages between UE and SMSF (SMS function)
- Relay for Location service messages between UE and LMF (Location management function)
- Unlike 4G UEs in 5G have a specific interface between UE and AMF -> known as N1
- Relay for messages between UE and PCF (Policy Control Function)
- Includes security functionality for authentication, authorization of UEs (in cooperation with AUSF and UDM)
- Responsible for deriving Keys for integrity and Ciphering - RRC and User plane.
- In many ways it is similar to MME in 4G
- Interfaces with MME in 4G for context transfer when interworking with EPC is deployed.

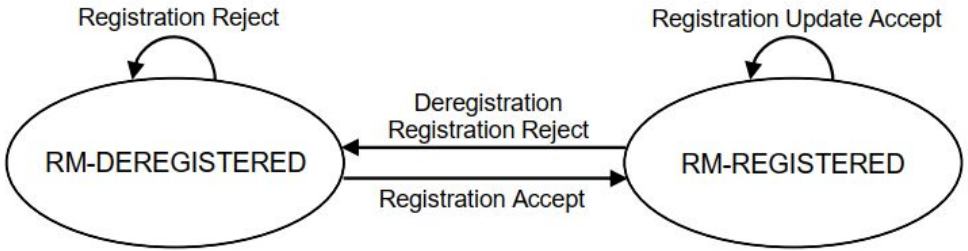
Registration Mgmt. States

In the **RM-DEREGISTERED** state, the UE is not registered with the network. The UE context in AMF holds no valid location or routing information for the UE so the UE is not reachable by the AMF. However, some parts of UE context may still be stored in the UE and the AMF e.g. to avoid running an authentication procedure during every Registration procedure.

In the **RM-REGISTERED** state, the UE shall:

- perform Mobility Registration Update procedure if the current TAI of the serving cell (see TS 37.340 [31]) is not in the list of TAIs that the UE has received from the network in order to maintain the registration and enable the AMF to page the UE;

- perform Periodic Registration Update procedure triggered by expiration of the periodic update timer to notify the network that the UE is still active.



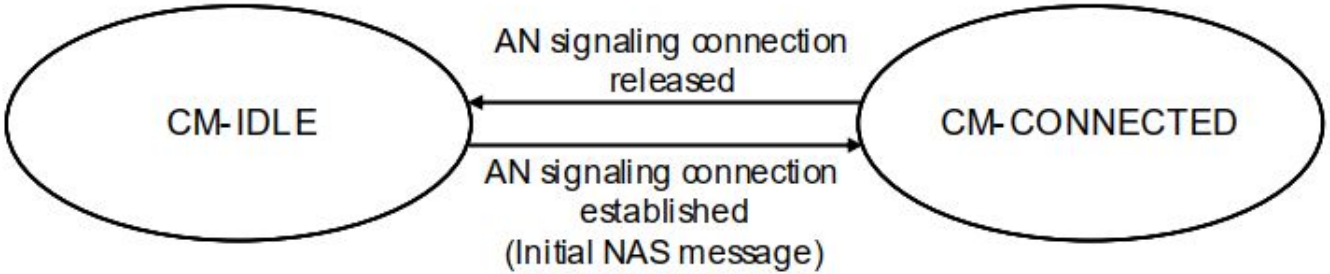
Connection Mgmt. States

- in **CM-IDLE** state has no NAS signalling connection established with the AMF over N1. The UE performs cell selection/cell reselection according to radio conditions.
- There are no AN signalling connection, N2 connection and N3 connections for the UE in the CM-IDLE state.
- If the UE is both in CM-IDLE state and in RM-REGISTERED state, the UE shall:
    - Respond to paging by performing a Service Request procedure, unless the UE is in MICO mode.
    - perform a Service Request procedure when the UE has uplink signalling or user data to be sent
- When the UE state in the AMF is RM-REGISTERED, UE information required for initiating communication with the UE shall be stored. The AMF shall be able to retrieve stored information required for initiating communication with the UE using the 5G-GUTI.

Connection Mgmt. States

- in **CM-CONNECTED** state has a NAS signalling connection with the AMF over N1. A NAS signalling connection uses an RRC Connection between the UE and the NG-RAN and an NGAP UE association between the AN and the AMF for 3GPP access.
- A UE in CM-CONNECTED state can be in RRC Inactive state. When the UE is in **RRC Inactive** state the following applies:
  - UE reachability is managed by the RAN, with assistance information from core network;
  - UE paging is managed by the RAN.
  - UE monitors for paging with UE's CN (5G S-TMSI) and RAN identifier

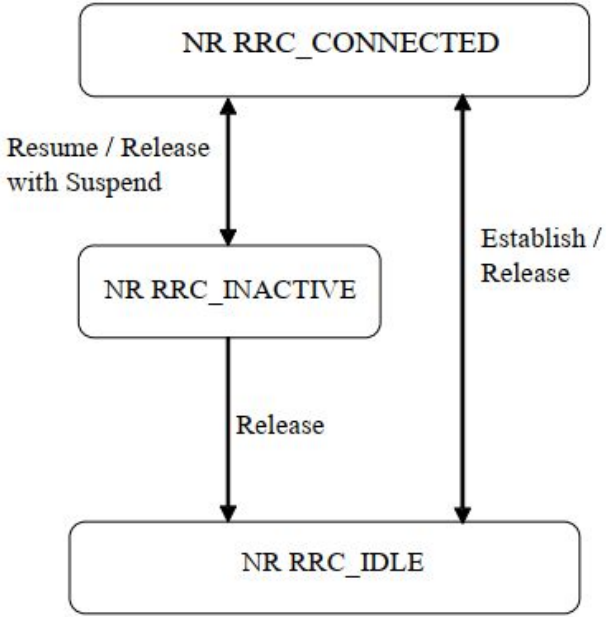
3 states in RRC unlike 4G.



RRC States

- **RRC_INACTIVE**:

- A UE specific DRX may be configured by upper layers or by RRC layer;
- UE controlled mobility based on network configuration;
- The UE stores the UE Inactive AS context;
- A RAN-based notification area is configured by RRC layer;
- The UE:
  - Monitors Short Messages transmitted with P-RNTI over DCI - Monitors a Paging channel for CN paging using 5G-S-TMSI and RAN paging using full I-RNTI;
  - Performs neighbouring cell measurements and cell (re-)selection;
  - Performs RAN-based notification area updates periodically and when moving outside the configured
  - RAN-based notification area;
  - Acquires system information and can send SI request (if configured)



Session Management Function (SMF)

SMF - Session Management Function

- SMF of the 5G system has the responsibility for setup of the connectivity for the UE towards Data Networks, as well as managing the user plane for that connectivity.
- SMF manages the establishment, modification and release of sessions. It can allocate IP addresses to UEs depending on the type of request - v4, v4v6 or v6 etc.
- SMF communicates indirectly with UE through AMF that relays session-related information messages.
- Compared to EPS - SMF resembles MME and SGW in some aspects.
- SMF interacts with other network elements using SB interfaces. It selects and controls the User plane Function (UPF)
- SMF also interacts with Policy control Function (PCF) to retrieve policies for a UE. They are then configured in the UPF
- SMF also collects charging data - offline and online.
- Downlink Data Notification for Idle UEs

User Plane Function (UPF)

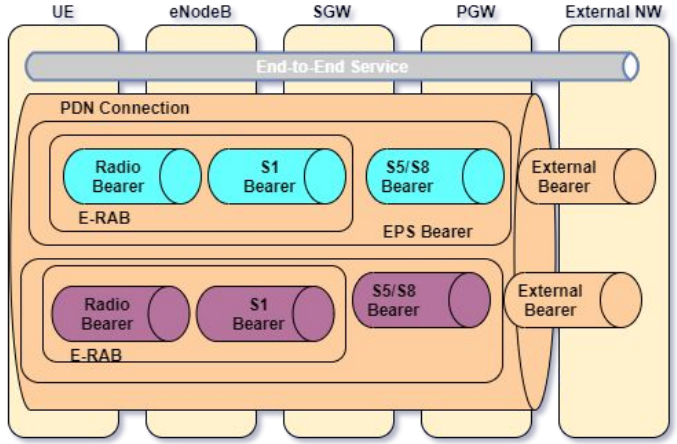
UPF - User Plane Function

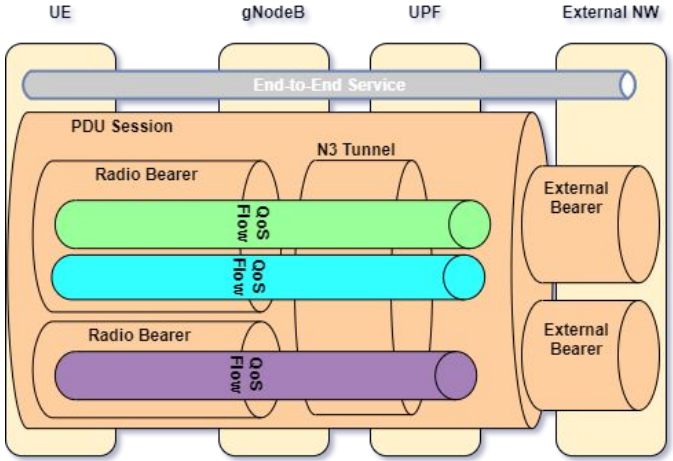
- UPF processes and forwards user data. It is controlled by SMF.
- Connects with external IP networks and acts as an anchor for UEs towards external networks, hiding the mobility.
- Generates charging data records and traffic usage records, which can be sent to SMF.
- Capable of performing packet inspections and apply configured policies - gating, redirection of traffic, applying data rate limitations.
- Buffering of downlink data for Idle mode UEs.
- UPF can be deployed in series unlike in 4G.
- UPF applies QoS policies on packets in Downlink direction. More on QoS in the next section.
- Compared to EPS, UPF resembles SGW and PGW in some respects.

QoS in 5G

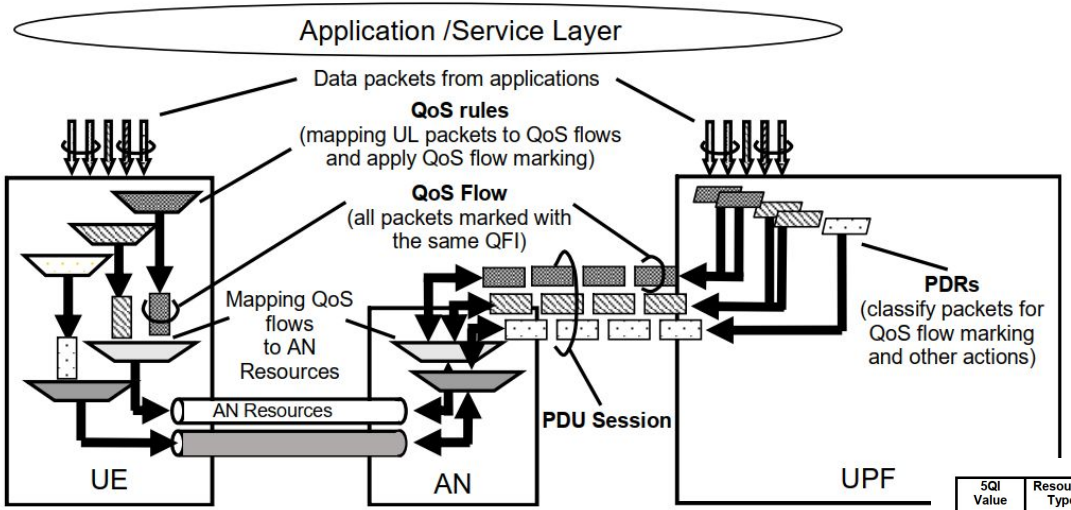
5G QoS

- In 5G QoS framework is based on QoS Flows which is the finest granularity of QoS differentiation.
- Each QoS Flow is identified by a QoS Flow ID.
- NG-RAN can map multiple QoS Flow IDs to one Radio Bearer or can have a 1:1 relationship. It depends on NG-RAN implementation.
- In 4G we had a 1:1 relationship between QCI and EPS bearers.
- 3GPP has standardized QoS Flow IDs like QCI for various services. More on this later.
- Also notice there is one N3 tunnel between eNB and UPF unlike multiple S5/S8 bearers in LTE.





5G QoS

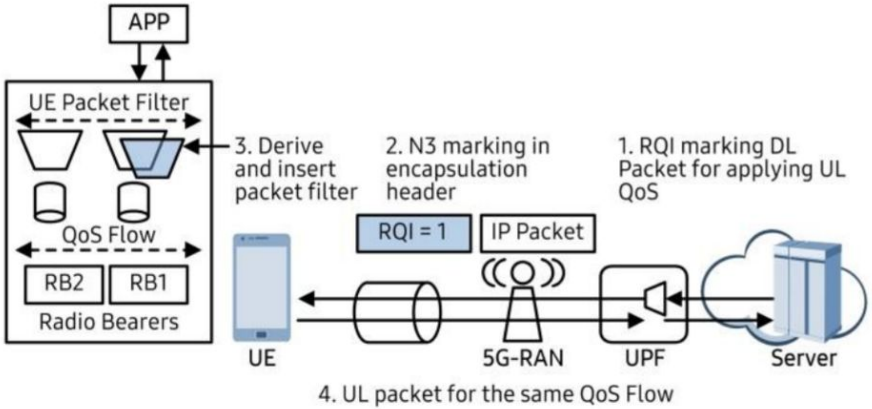


Refer to 3GPP Spec - 23.501 - Table 5.7.4-1

5QI Value	Resource Type	Default Priority Level	Packet Delay Budget	Packet Error Rate	Default Maximum Data Burst Volume (NOTE 2)	Default Averaging Window	Example Services
1	GBR (NOTE 1)	20	100 ms	10^{-2}	N/A	2000 ms	Conversational Voice
2		40	150 ms	10^{-3}	N/A	2000 ms	Conversational Video (Live Streaming)
3		30	50 ms	10^{-3}	N/A	2000 ms	Real Time Gaming, V2X messages Electricity distribution – medium voltage, Process automation - monitoring
4		50	300 ms	10^{-6}	N/A	2000 ms	Non-Conversational Video (Buffered Streaming)
65		7	75 ms	10^{-2}	N/A	2000 ms	Mission Critical user plane Push To Talk voice (e.g., MCPTT)
66		20	100 ms	10^{-2}	N/A	2000 ms	Non-Mission-Critical user plane Push To Talk voice
67		15	100 ms	10^{-3}	N/A	2000 ms	Mission Critical Video user plane

5G Reflective QoS

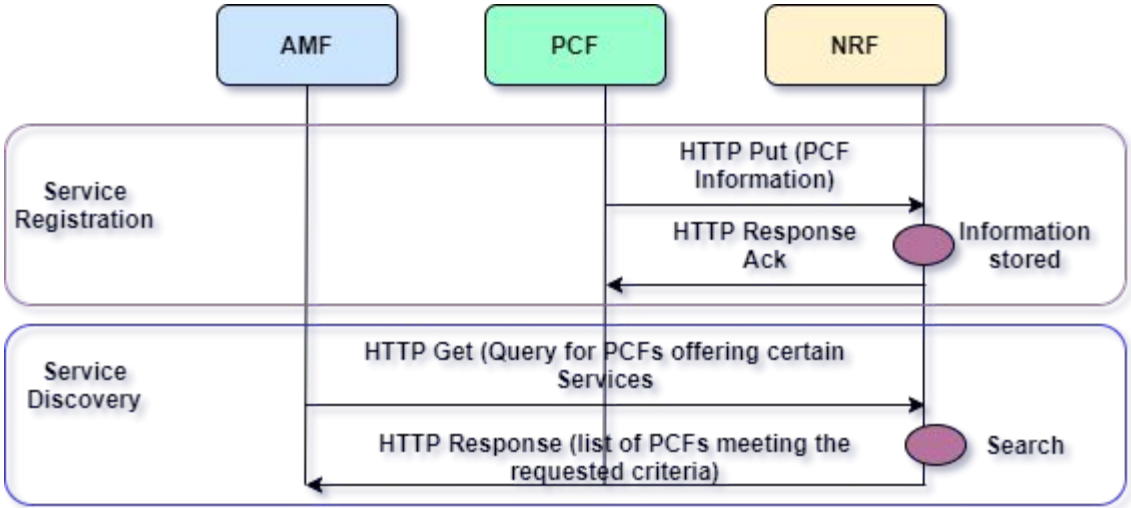
- Reflective QoS was introduced in 5G to minimize signalling. At a high level the UE mirrors the mapping of QFIs based on packets received in Downlink from UPF.
- RQoS requires support from UE.
- RQoS is useful for applications where header values in packets change frequently - HTTP.
- RQoS is controlled/enabled on a per packet basis by using RQI indicator in the encapsulation header on N3 reference point along with QFI, and a reflection QoS Timer



Network Repository Function (NRF)

NRF - Network Repository Function

- NRF is a repo of the profiles of NFs that are available in the network. Purpose of NRF is to allow service consumer to discover and select suitable service producers i.e., without defining a static mapping.
- When a new instance of NF is deployed or changed example - scaling up or down, the NRF is updated with details like - NF Type, address, capacity, supported services and addresses for each running instance.
- This information is provided to the consumer during the discovery process.



Unified Data Management (UDM)

UDM - Unified Data Management

- Frontend for Unified Data Repo (UDR). UDR stores all the user subscription information.
- UDM uses subscription data to perform access authorization, registration management and reachability for terminating events like SMS.
- When UE attaches to 5GC UDM performs the checks like - barring and restrictions like roaming.
- UDM generates auth credentials used during auth process.
- Performs conversion of SUCI (Subscriber concealed Identity) to SUPI (Subscriber Private Identity). More on this later.
- UDM keeps track of which AMF is serving a user.
- UDM is always located in Home PLMN.
- Compared to EPC UDM is similar to HSS in some aspects.

Unified Data Repository (UDR), AUSF and EIR

UDR - Unified Data Repository

- Repo for all subscription related information and all data related to various type of network and user policies.
- UDR storage and access to data is offered as services to other network functions like UDM, PCF (Policy control Function) and NEF (network exposure function)

AUSF - Authentication Server Function

- Handling of authentication in the home network based on information received from UE.

5G - EIR (Equipment ID Registry)

- Checks whether Device has been blacklisted or not.
- Optional element

Policy Control Function (PCF)

PCF - Policy Control Function

- PCF provides policy control for sessions management related functionality, for access and mobility related functionality.
- PCF interacts with application functions (AFs) and SMF to provide authorized QoS and charging control for service data flows, PDU session related policy control and event reporting for PDU sessions.
- PCF interacts with AMF for access and mobility policy control that includes Frequency selection priority, a parameter used by NG-RAN to differentiate the treatment of different UEs.
- PCF can also interact with UE via NAS (AMF) to update discovery and selection policies for non 3GPP networks, session continuity mode selection policy, network slice selection policy, data name selection policy and more.

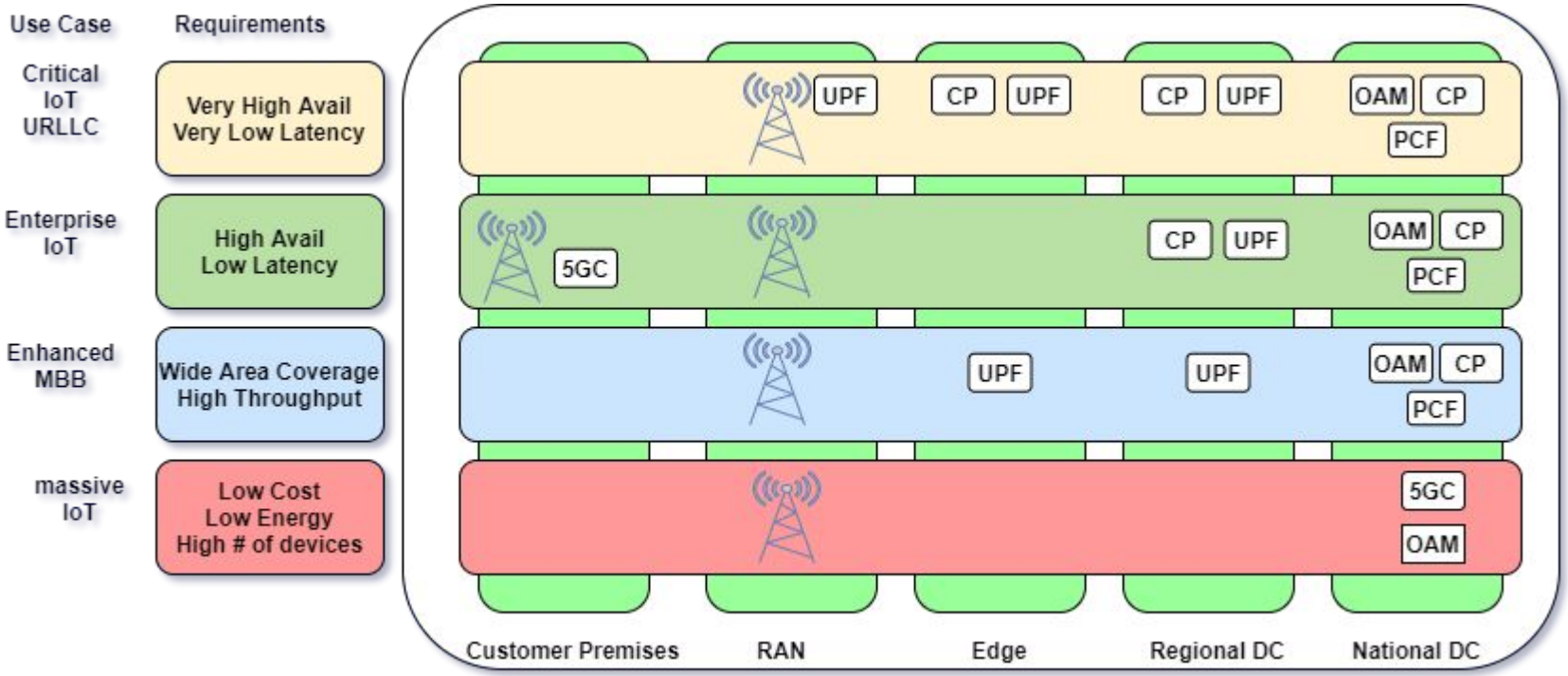
Network Slice Selection Function (NSSF)

Network Slicing

NS - Network Slicing

- Traditional and their one size fits all approach needs to be adapted for 5G since 5G use cases are quite different compared to legacy.
- In 5G services/use cases (eMBB, URLLC, mMTC) define network requirements/capabilities and at any given time we may have multiple of these services running.
- So instead of using a monolithic architecture 5G needs to have the ability to run various logical networks (“slices”) with varying capabilities.

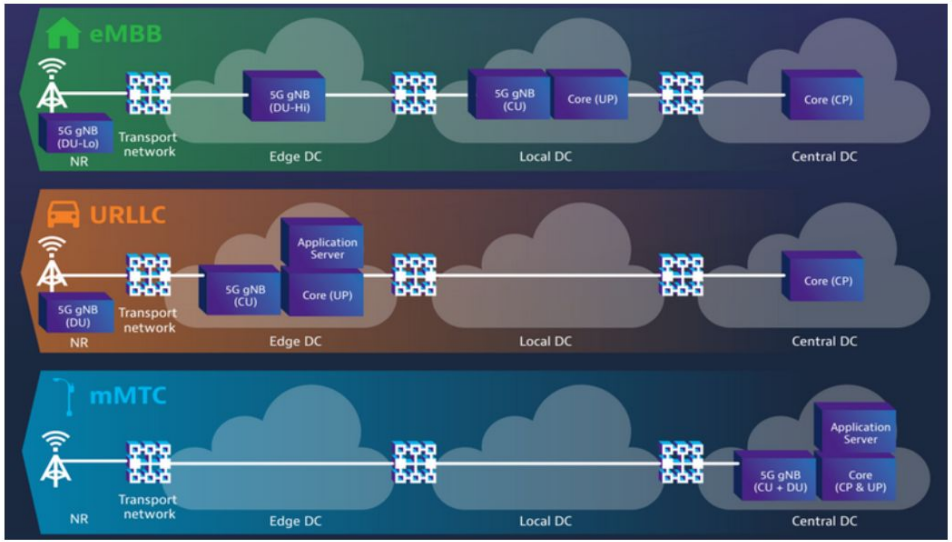
NS - Network Slicing



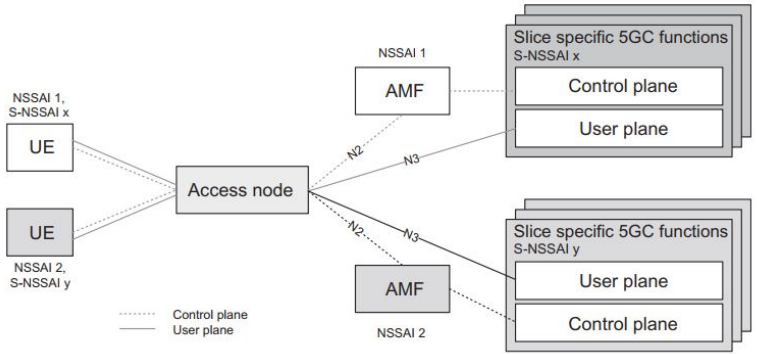
NS - Network Slicing

- The combination of SDN and NFV enables dynamic, flexible deployment and on-demand scaling of NFs, which are necessary for the development of the 5G packet core network.
- Such characteristics have also encouraged the development of network slicing and service function chaining. From a UE perspective, slicing a network is to group devices with similar performance requirements (transmission rate, delay, throughput, etc.) into a slice.
- From network perspective, slicing a network is to divide an underlying physical network infrastructure into a set of logically isolated virtual networks. This concept is considered as an important feature of a 5G network, which is standardized by 3GPP.

NS - Network Slicing - 2 Flavors



Use Case specific Network Slices

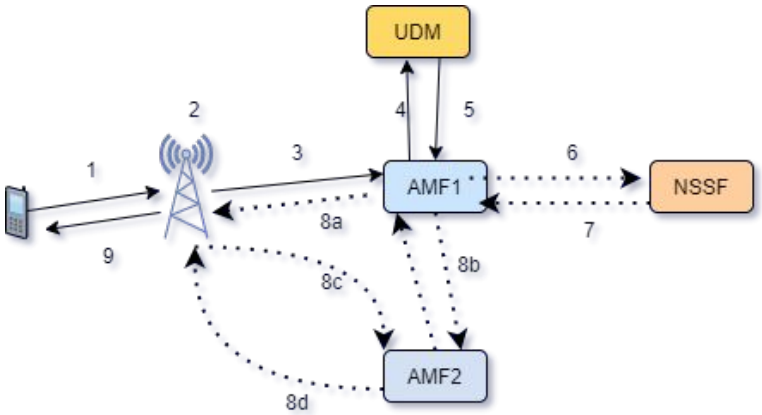


UE specific Network Slices

Network Slice Selection Function (NSSF)

- NSSF selects the (set of) network slice instances for the UE and the set of AMFs that should serve the UE.
- AMF may be dedicated to one or a set of network slices and the NSSF knows all the slices in the network and assists the AMF with cross slice selection functionality.

1. UE sends requested S-NSSAI in the Reg Message.
2. gNB selects AMF or sends to default AMF.
3. Selected AMF processes Reg request.
4. AMF requests UDM for subscription info.
5. UDM responds with Subscription info. AMF verifies if it can serve the UE for the specific NS. if not then it proceeds with Steps 6-7
6. AMF1 queries NSSF to find AMF that can serve the UE.
7. NSSF responds with AMF set.
8. AMF1 can either a) send a NAS reroute request to gNB asking it to send the re request to AMF2
   b) send the request directly to AMF2
   c) AMF2 processes Reg request
9. AMF2 sends Reg Accept message to UE



Section 7 - Identifiers in 5G Core

SUPI - Subscription Permanent Identity

- A globally unique 5G Subscription Permanent Identifier (SUPI) shall be allocated to each subscriber in the 5G System and provisioned in the UDM/UDR
- SUPI may either contain IMSI or network-specific identifier (used for private networks)
- In order to enable roaming scenarios, the SUPI shall contain the address of the home network (e.g. the MCC and MNC in the case of an IMSI based SUPI)
- For interworking with the EPC, the SUPI allocated to the 3GPP UE shall always be based on an IMSI to enable the UE to present an IMSI to the EPC
- SUPI is never transmitted unlike LTE due to security concerns.
- SUPI is protected over radio interface using the Subscription Concealed Identifier (SUCI)

SUCI - Subscription Concealed Identity

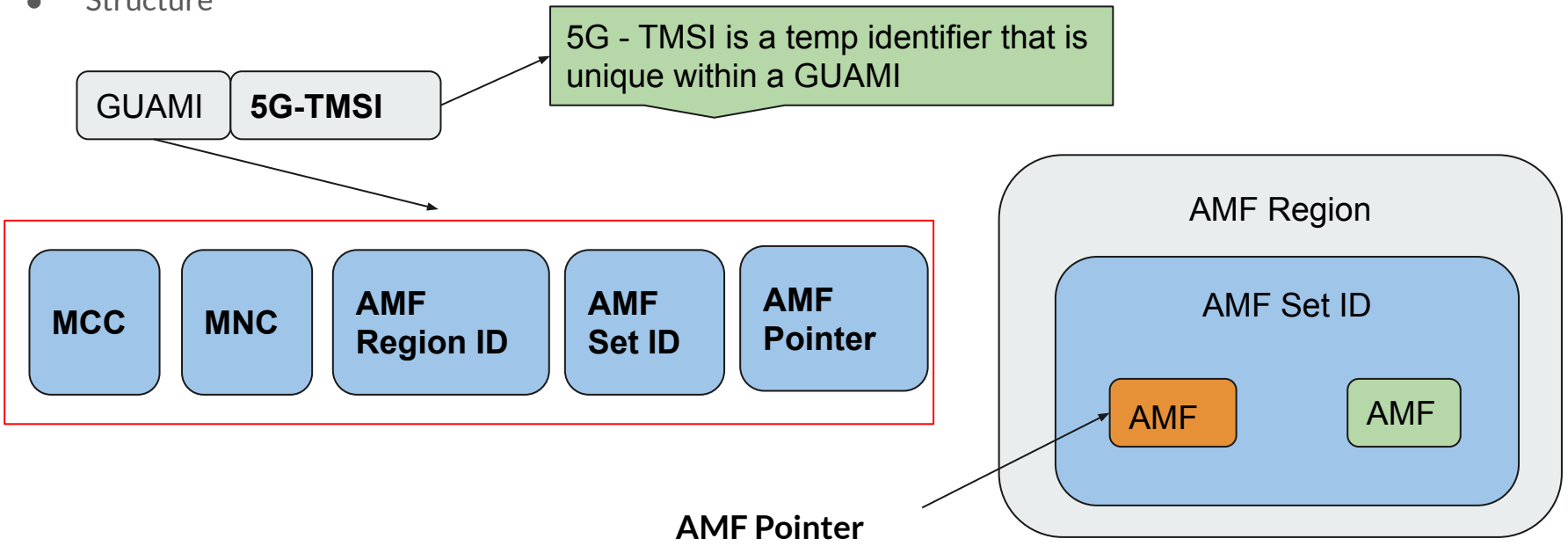
- SUCI is a privacy preserving identifier containing the concealed SUPI.
- SUCI is a one-time use subscription identifier and a different SUCI is generated after SUCI has been used.
- The UE shall generate a SUCI using a protection scheme with the raw public key, i.e. the Home Network Public Key, that was securely provisioned in control of the home network.
- Both UE and Home Network can derive the SUPI from SUCI and vice versa.
- The UE shall construct a scheme-input from the subscription identifier part of the SUPI as follows:
    - For SUPIs containing IMSI, the subscription identifier part of the SUPI includes the MSIN of the IMSI as defined in TS 23.003 .
    - For SUPIs taking the form of a NAI, the subscription identifier part of the SUPI includes the "username" portion of the NAI (Network Access Identifier) as defined in NAI RFC 7542..

PEI - Permanent Equipment Identifier

- PEI is allocated to each 5G UE.
- PEI represents either:
  - IMEI - International Mobile Station Equipment Identity or
  - IMEISV - International Mobile Station Equipment Identity and Software Version number
- Same as EPS

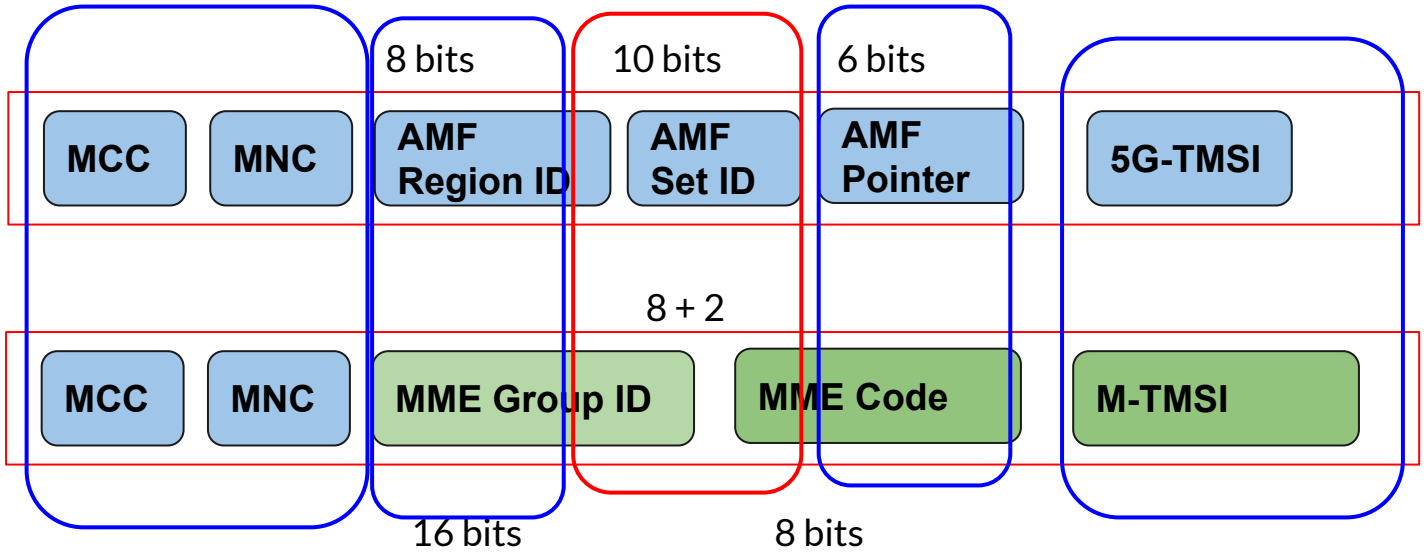
5G GUTI

- 5G GUTI is assigned to UE by the AMF as part of registration procedure.
- 5G GUTI can be re-assigned by AMF anytime (Same as in EPS)
- Structure



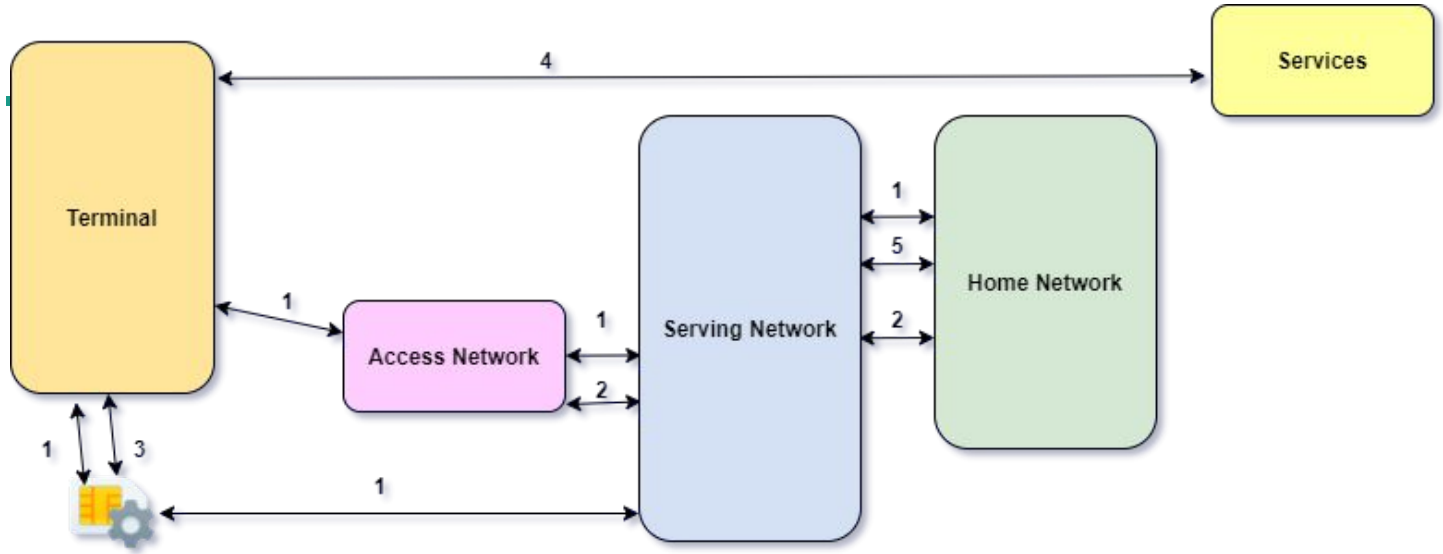
5G GUTI <-> 4G-GUTI

- 5G Coverage is not going to be ubiquitous at the beginning to we can expect devices to switch between 4G and 5G anytime the RF conditions change.
- In the Single registration mode the UE can be attached to one network - 4G or 5G.
- During the switch however the UE identifies itself using the GUTI (4G or 5G) . 3GPP introduces a mapping between the GUTIs to assist the UE to perform the conversion. The sent GUTI is used by the MME/AMF to fetch the context from AMF/MME.



Section 8 - Security in 5G

Security Aspects



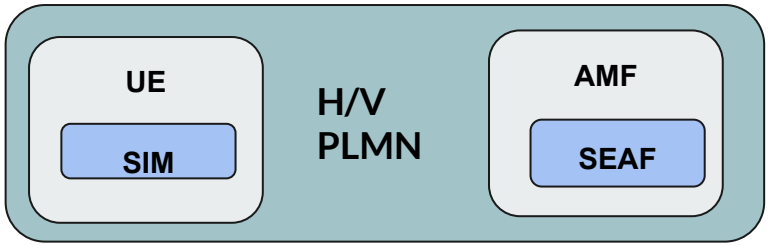
1. Network Access Security - Secure access to network by user. Integrity + Ciphering
2. Network Domain Security - Secure Inter NF communication.
3. User Domain Security - USIM <-> ME security
4. Application Domain Security - Security for Apps running using the 5G PDU Session.
5. SBA domain Accuracy - Inter NF communication + roaming

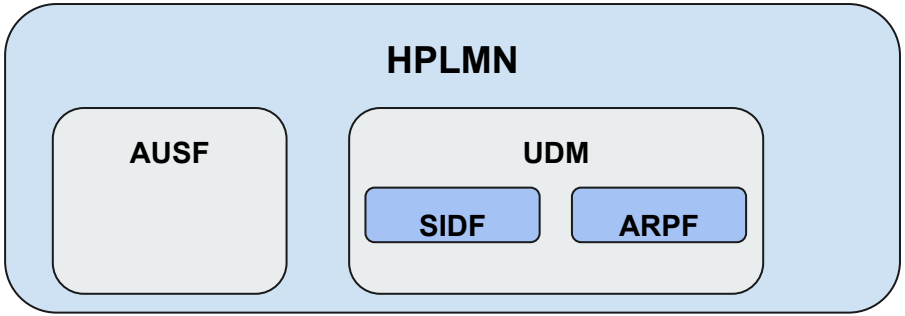
Access Security

- Network Access Security
  - Compared to 4G the 5GS supports NAS based authentication procedures across both 3GPP and non-3GPP access.
  - SUCI is used across all access types.
  - On lower layer non-3GPP used IPSEC and 3GPP uses RRC + NAS integrity and Ciphering.
  - 5G is more flexible when it comes to authentication alternatives - SIM based + certificate based. However there is more roam here for 3GPP given the enterprise applications.
  - New Security entities in 5G - AUSF, SEAF (security Anchor Function), ARPF (Authentication credential repository and processing function), SIDF (Subscriber Identifier De-concealing Function)

Access Security

- ARPF (Authentication Repository and Processing Function)
  - Stores user credentials - Keys and SUPI
  - ARPF can be located in UDM or UDR - Open to implementation.
- AUSF (Authentication Server Function)
  - Defined as a standalone NF
  - Located in HPLMN
  - Responsible for authentication using information provided by UE and UDM/ARPF
- SEAF (Security Anchor Function)
  - Functionality provided by AMF
  - Responsible for handling authentication in VPLMN
- SIDF (Subscription Identifier De-concealing Function)
  - Converts SUCI to SUPI
  - Located in HPLMN

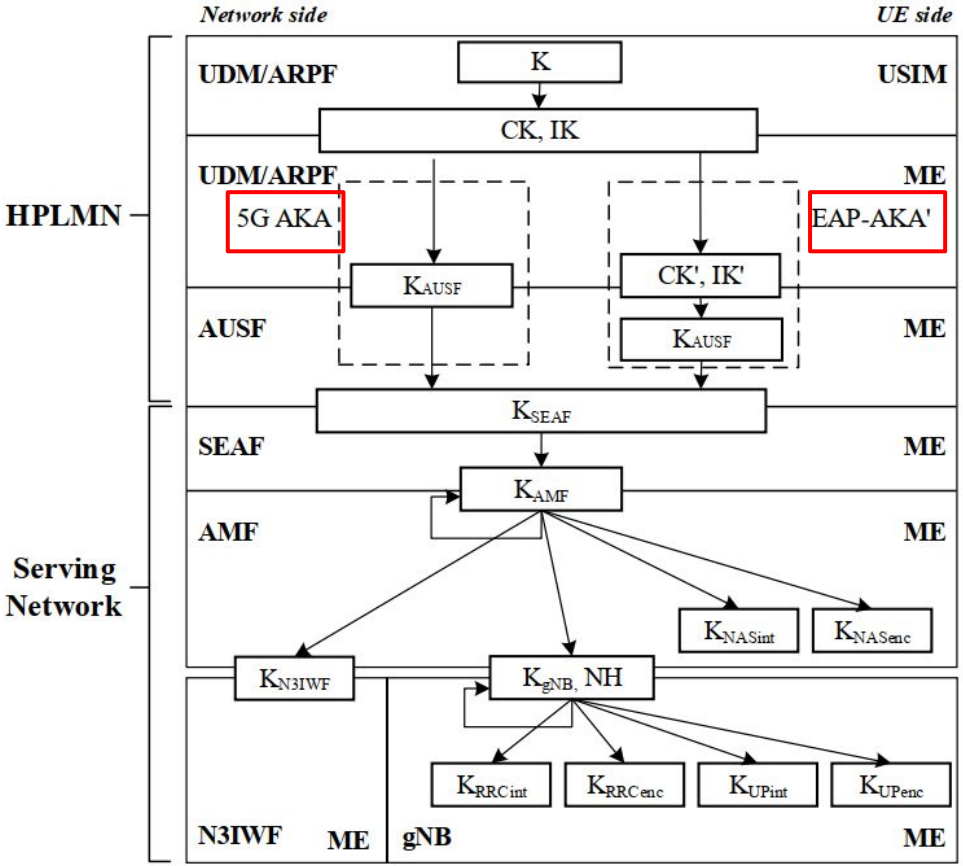




Comparison with 4G

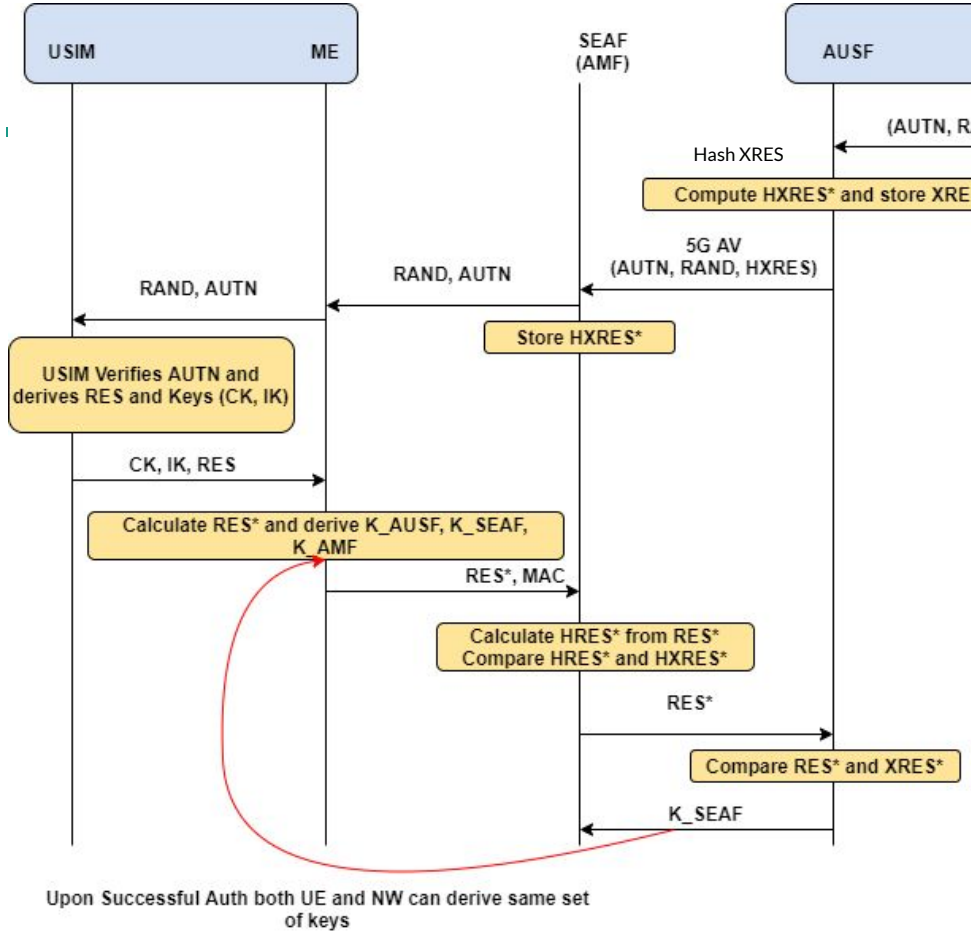
- Improved privacy protection since SUPI/IMSI is not transmitted OTA
- Optional integrity protection of user plane traffic
- Improved HPLMN control over authentication. 5G enables VPLMN and HPLMN to take part in authentication more actively.
- Improved capabilities to use non-SIM based credentials -> useful for enterprise/private networks
- Additional configurability of security - UDM decides Integrity + Ciphering security requirements rather than eNB.
- 5G supports NAS based authentication even for non-3GPP access.
- 2 primary modes for authentication - AKA and EAP-AKA’

Key Hierarchy



Refer to Spec - 3GPP TS 33.501 for details re Key derivations

Authentication Process



This ensure separate keys are used in different networks -> different from 4G

For details re Key Derivation look up 3GPP 33.501

A.4 RES* and XRES* derivation function

When deriving RES* from RES, RAND, and serving network name in the UE and when deriving XRES* from XRES, RAND, and the serving network name in the ARPF, the following parameters shall be used to form the input S to the KDF.

- FC = 0x6B,
- P0 = serving network name,
- L0 = length of the serving network name (variable length as specified in 24.501 [35]),
- P1 = RAND,
- L1 = length of RAND (i.e. 0x00 0x10),
- P2 = RES or XRES,
- L2 = length RES or XRES (i.e. variable length between 0x00 0x04 and 0x00 0x10).

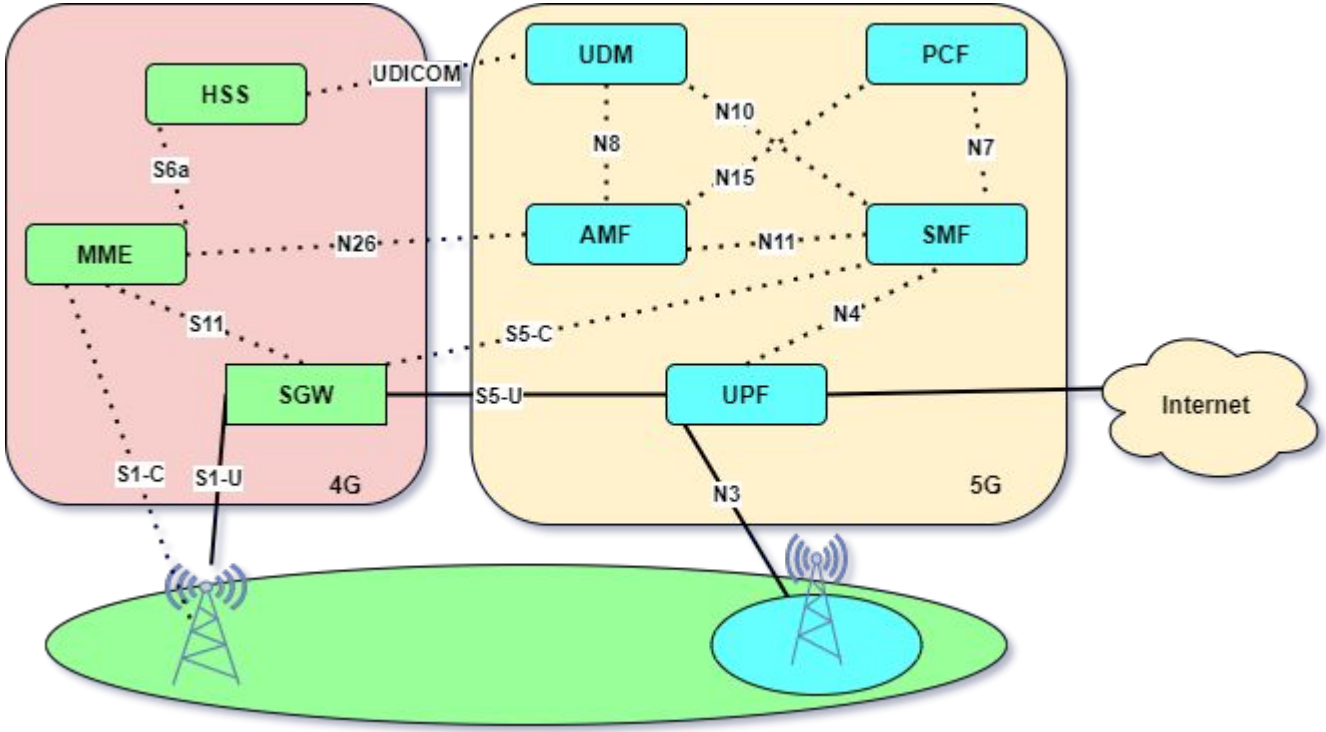
The input key KEY shall be equal to the concatenation CK || IK of CK and IK.

The serving network name shall be constructed as specified in clause 6.1.1.4.

The (X)RES* is identified with the 128 least significant bits of the output of the KDF.

Section 9 - Interworking between 5G and 4G Core

4G - 5G Interworking



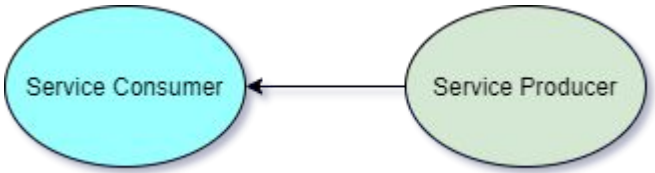
4G - 5G Interworking

- To ensure successful interworking with appropriate EPS functionality, only one PGW-C + SMF is allocated per APN to the UE, and this is enforced by the HSS+UDM. HSS+UDM sends the PGW-C + SMF FQDN per APN to the MME.
- As discussed before when the UE has been registered in one system and moves to the other, the UE has no native UE ID for the target system. Therefore UE maps the temp ID of the source system to the target system. 4G GUTI <-> 5G-GUTI
- When moving from 5GS -> EPS, UE includes GUMMEI in RRC as a native GUMMEI. In addition UE states that 4G -GUTI has been mapped from 5G-GUTI
- When moving from EPS -> 5G, UE includes GUAMI in RRC as a native GUAMI. Also it mentions 5G-GUTI has been mapped from 4G-GUTI.

Section 10 - Services and Service Operations

Network Services

- As we saw before in the SBA - 5GC NFs offer their capabilities to other 5G Core network functions as NF services. These services are accessed using SBA interfaces like Restful APIs.
- Now we will look at some of the Key NFs in 5GC and their associated services. This will help us when we look at Call flows in 5GC.



AMF Services

AMF Services

- AMF acts as service producer for 4 services:
  - Namf_Communication -> this is the main service and has many sub service operations.
    - Enables other NFs like SMF, PCF to communicate with UE and of NG-RAN via the AMF.
    - Enables One AMF to fetch UE contexts from other AMFs
    - Allows for subscription to status changes
  - Namf_EventExposure
    - Allows other NFs to subscribe to events such as UE reachability, mobility changes etc.
  - Namf_MT
    - Allows other NFs to ensure UE is reachable.
  - Namf_Location
    - Allows NFs to get location of UE

AMF Services

3GPP TS 23.502

Table 5.2.2.1-1: List of AMF Services

Service Name	Service Operations	Operation Semantic	Known Consumer(s)
Namf_Communication	UEContextTransfer	Request/ Response	Peer AMF
	CreateUEContext	Request/ Response	Peer AMF
	ReleaseUEContext	Request/ Response	Peer AMF
	RegistrationStatusUpdate	Request/ Response	Peer AMF
	N1MessageNotify	Subscribe / Notify	PCF, LMF, Peer AMF
	N1N2MessageSubscribe		PCF
	N1N2MessageUnSubscribe		PCF
	N1N2MessageTransfer	Request/ Response	SMF, SMSF, PCF, LMF
	N1N2TransferFailureNotification	Subscribe / Notify	SMF, SMSF, PCF, LMF
	N2InfoSubscribe	Subscribe / Notify	NOTE 1
	N2InfoUnSubscribe		NOTE 1
	N2InfoNotify		AMF, LMF
	EBIAssignment	Request/Response	SMF
	AMFStatusChangeSubscribe	Subscribe / Notify	SMF, PCF, NEF, SMSF, UDM
	AMFStatusChangeUnSubscribe	Subscribe / Notify	SMF, PCF, NEF, SMSF, UDM
Namf_EventExposure	Subscribe	Subscribe / Notify	NEF, SMF, UDM, NWDAF
	Unsubscribe	Subscribe / Notify	NEF, SMF, UDM, NWDAF
	Notify	Subscribe / Notify	NEF, SMF, UDM, NWDAF
Namf_MT	EnableUEReachability	Request/Response	SMSF, SMF
	ProvideDomainSelectionInfo	Request/Response	UDM
Namf_Location	ProvidePositioningInfo	Request/Response	GMLC
	EventNotify	Subscribe / Notify	GMLC
	ProvideLocationInfo	Request/Response	UDM
	CancelLocation	Request/Response	GMLC

AMF Services - Examples

Namf_Communication_UEContextTransfer service operation

Service operation name: Namf_Communication_UEContextTransfer

Description: Provides the UE context to the consumer NF.
Input, Required: 5G-GUTI or SUPI, Access Type, Reason.
Input, Optional: Integrity protected message from the UE that triggers the context transfer.
Output, Required: The UE context of the identified UE or only the SUPI and an indication that the Registration

Namf_Communication_RegistrationStatusUpdate service operation

Service operation name: Namf_Communication_RegistrationStatusUpdate
Description: This service operation is used by the consumer NF to inform the AMF that a prior UE context transfer has resulted in the UE successfully registering with it. The UE context is marked inactive in the AMF.
Input, Required: 5G-GUTI, Status.
Input, Optional: PDU Session ID(s) (indicates the PDU Session(s) to be released), PCF ID (indicates that the PCF ID that handles the AM Policy association has changed)

new AMF to old AMF: Namf_Communication_RegistrationStatusUpdate (PDU Session ID(s) to be released due to slice not supported . If the AMF has changed the new AMF informs the old AMF that the registration of the UE in the new AMF is completed by invoking the Namf_Communication_RegistrationStatusUpdate service operation.

SMF Services

SMF services

- SMF Provides 2 services
  - Nsmf_PDUSession service
  - Nsmf_EventExposure Service

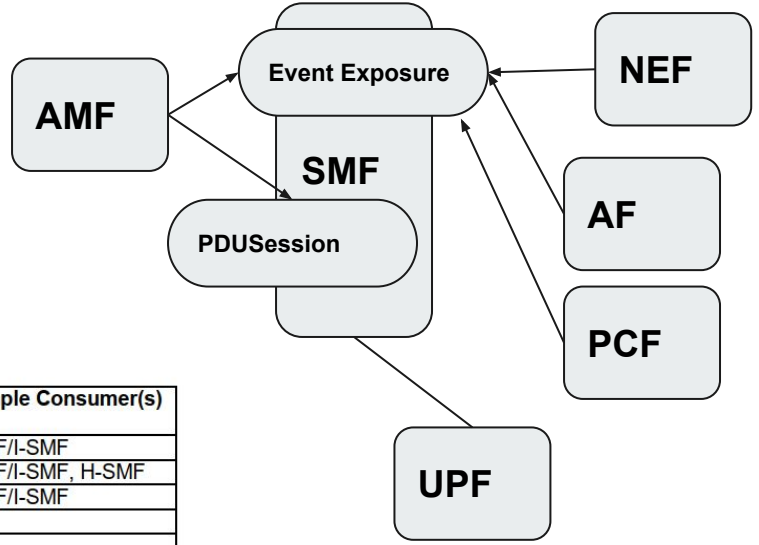


Table 5.2.8.1-1: NF services provided by the SMF

Service Name	Service Operations	Operation Semantics	Example Consumer(s)
Nsmf_PDUSession	Create	Request/Response	V-SMF/I-SMF
	Update	Request/Response	V-SMF/I-SMF, H-SMF
	Release	Request/Response	V-SMF/I-SMF
	CreateSMContext	Request/Response	AMF
	UpdateSMContext	Request/Response	AMF
	ReleaseSMContext	Request/Response	AMF
	SMContextStatusNotify	Subscribe/Notify	AMF
	StatusNotify	Subscribe/Notify	V-SMF/I-SMF
	ContextRequest	Request/Response	AMF, I-SMF, SMF
	ContextPush	Request/Response	SMF
	SendMOData	Request/Response	AMF
	TransferMOData	Request/Response	V-SMF/I-SMF
	TransferMTData	Request/Response	SMF, H-SMF
Nsmf_EventExposure	Subscribe	Subscribe/Notify	NEF, AMF, NWDAF
	Unsubscribe		NEF, AMF, NWDAF
	Notify		NEF, AMF, NWDAF
	AppRelocationInfo		AF
Nsmf_NIDD	Delivery	Request/Response	NEF

- UE IP address or Prefix change.
- PDU Session Release.
- UP path change.
- Change of Access Type.
- PLMN change

SMF services

Nsmf_PDUSession_CreateSMContext service operation

- used by the AMF to create an AMF-SMF association to support a PDU Session. The AMF provides the SUPI, DNN, AMF ID and other parameters needed by the SMF to create the PDU session including the N1 SM message from the UE.
- The SMF responds with a SM Context ID, PDU Session ID and any N1 SM messages for transfer to the UE and/or N2 messages to be transferred to the NG-RAN

Nsmf_PDUSession_UpdateSMContext service operation

- allows the AMF to update the AMF-SMF association to support a PDU Session and/or to provide SMF with N1 or N2 SM information received from the UE or from the NG-RAN. The AMF includes the SM Context ID to identify the context in the SMF and N1 SM message, N2 message information or other parameters depending on the reason for update request .

Nsmf_PDUSession_ReleaseSMContext service operation

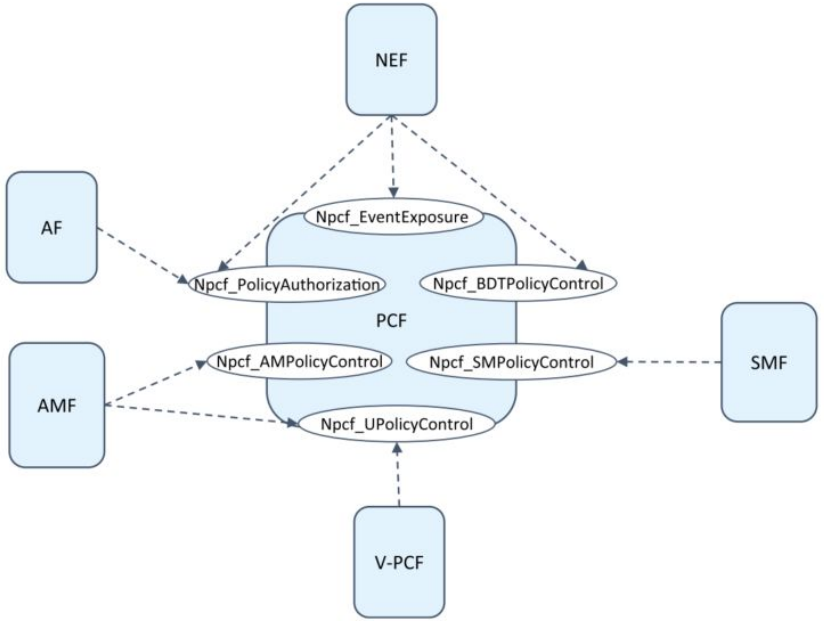
- used by the AMF to release the AMF-SMF association when the PDU Session is being released

PCF Services

PCF services

- PCF Provides 6 services

Service Name	Service Operations	Operation Semantics	Example Consumer (s)
Npcf_AMPolicyControl	Create	Request/Response	AMF
	Update	Request/Response	AMF
	UpdateNotify	Subscribe/Notify	AMF
	Delete	Request/Response	AMF
Npcf_Policy Authorization	Create	Request/Response	AF, NEF
	Update	Request/Response	AF, NEF
	Delete	Request/Response	AF, NEF
	Notify	Subscribe/Notify	AF, NEF, NWDAF
	Subscribe		AF, NEF, NWDAF
	Unsubscribe		AF, NEF, NWDAF
Npcf_SMPolicyControl	Create	Request/Response	SMF
	UpdateNotify	Subscribe/Notify	SMF
	Update	Request/Response	SMF
	Delete	Request/Response	SMF
Npcf_BDTPolicyControl	Create	Request/Response	NEF
	Update	Request/Response	NEF
	Notify		NEF
Npcf_UEPolicyControl	Create	Request/Response	AMF, V-PCF
	Update	Request/Response	AMF, V-PCF
	UpdateNotify	Subscribe/Notify	AMF, V-PCF
	Delete	Request/Response	AMF, V-PCF
Npcf_EventExposure	Subscribe	Subscribe/Notify	NEF, NWDAF
	Unsubscribe		
	Notify		



PCF services

- **Npcf_AMPolicyControl** service provides Access Control, network selection and Mobility Management related policies and UE Route Selection Policies to the AMF.
- **Npcf_Policy Authorization** authorizes and creates policies on request from an AF related to the PDU Session to which the AF session is bound to.
- **Npcf_SMPolicyControl** provides PDU session related policies to the SMF.
- **Npcf_BDTPolicyControl**, PCF service provides background data transfer policy to the NEF.
- **Npcf_UEPolicyControl** PCF service provides the management of UE Policy Association to the NF consumers.
- **Npcf_EventExposure** allows other NFs subscribe to notifications of PCF related events.

PCF services

- **Npcf_AMPolicyControl service**
  - allows the AMF to create modify and delete per UE AM Policy Associations with the PCF.
  - Policy information per UE can may contain access and mobility related policy information as well as Policy Control Request Trigger conditions
  - When the AMF detects that a Policy Control Request Trigger condition is met is will contact the PCF that may provide updated access and mobility related policy information and Policy Control Request Trigger conditions
  - also allows the PCF to send new AM policies for an established AM Policy Association

- **Npcf_SMPolicyControl service**
  - allows the SMF to create modify and delete per UE SM Policy Associations with the PCF
  - PCF may provide the SMF with policy information per UE that may include PDU session related policy information as well as Policy Control Request Trigger conditions
  - When the SMF detects that a Policy Control Request Trigger condition is met is will contact the PCF that may provide updated PDU session related policy information and Policy Control Request Trigger conditions.
  - also allows the PCF to send new PDU Session policies for an established SM Session Policy Association

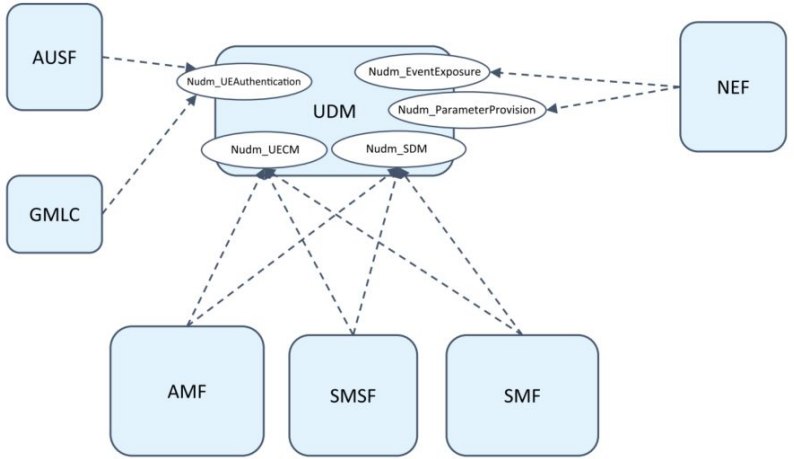
UDM Services

UDM Services

- UDM Provides 5 services

Table 5.2.3.1-1: NF services provided by UDM

NF service	Service Operations	Operation Semantics	Example Consumer(s)
Subscriber Data Management (SDM)	Get	Request/Response	AMF, SMF, SMSF, NEF
	Subscribe	Subscribe/Notify	AMF, SMF, SMSF, NEF
	Unsubscribe	Subscribe/Notify	AMF, SMF, SMSF, NEF
	Notification	Subscribe/Notify	AMF, SMF, SMSF, NEF, GMLC
	Info	Request/Response	AMF, NEF
UE Context Management (UECM)	Registration	Request/Response	AMF, SMF, SMSF
	DeregistrationNotification	Subscribe/Notify	AMF
	Deregistration	Request/Response	AMF, SMF, SMSF
	Get	Request/Response	NEF, SMSF, GMLC, NWDAF
	Update	Request/Response	AMF, SMF
	PCscfRestoration	Subscribe/Notify	AMF, SMF
UE Authentication	Get	Request/Response	AUSF
	ResultConfirmation	Request/Response	AUSF
EventExposure	Subscribe	Subscribe/Notify	NEF (NOTE), NWDAF
	Unsubscribe		NEF (NOTE), NWDAF
	Notify		NEF (NOTE), NWDAF
Parameter Provision	Update	Request/Response	NEF, AMF
	Create	Request/Response	NEF
	Delete	Request/Response	NEF
	Get	Request/Response	NEF
NIDDAuthorisation	Get	Request/Response	NEF
	UpdateNotify	Subscribe/Notify	NEF



UDM Services

- **Nudm_UEContextManagement** service
  - used for UE context management and allow NFs like the AMF, SMF and SMSF to register and deregister with UDM and can provide the NFs with information related to UE's e.g., a UE's serving NF identifier, UE status, etc .
- **Nudm_SubscriberDataManagement** service
  - used to manage subscription data and enables NFs like AMF and SMF to retrieve user subscription data and allows the UDM to provided updates of subscriber data
- **Nudm_UEAuthentication** service
  - provides authentication subscriber data to the e.g., AMF
- **Namf_EventExposure** service allows NFs to subscribe to events and can provides monitoring indication of the events to the subscribed NF consumer
- **Nudm_ParameterProvision** service is used to provision information which can be used for the UE in 5GS

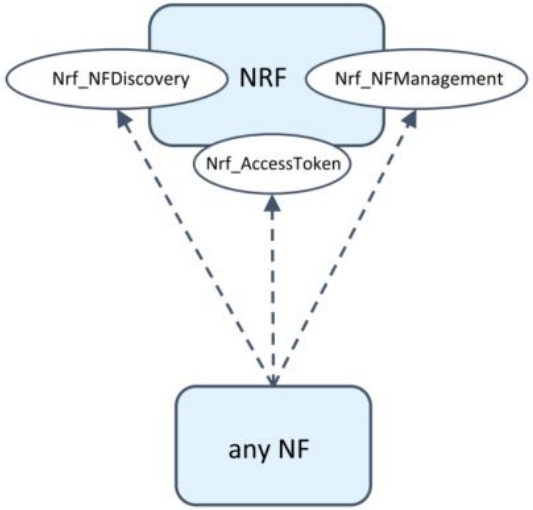
NRF Services

NRF Services

- NRF and its services are key enablers in a service based architecture.
- NRF centralizes and automates the configuration required for NF/NF services to discover, select and connect to peer NF/NF services with the correct capabilities.
- NRF provides three services:
  - Nnrf_NFManagement,
  - Nnrf_NFDiscovery, and
  - Nnrf_ Access Token

Table 5.2.7.1-1: NF services provided by the NRF

Service Name	Service Operations	Operation Semantics	Example Consumer(s)
Nnrf_NFManagement	NFRegister	Request/Response	AMF, SMF, UDM, AUSF, NEF, PCF, SMSF, NSSF, UPF, BSF, CHF, NWDAF, P-CSCF, HSS, UDR, SCP
	NFUpdate	Request/Response	AMF, SMF, UDM, AUSF, NEF, PCF, SMSF, NSSF, UPF, BSF, CHF, NWDAF, P-CSCF, HSS, UDR, SCP
	NFDeregister	Request/Response	AMF, SMF, UDM, AUSF, NEF, PCF, SMSF, NSSF, UPF, BSF, CHF, NWDAF, P-CSCF, HSS, UDR, SCP
	NFStatusSubscribe	Subscribe/Notify	AMF, SMF, PCF, NEF, NSSF, SMSF, AUSF, CHF, NRF, NWDAF, I-CSCF, S-CSCF, IMS-AS, SCP, UDM
	NFStatusNotify		AMF, SMF, PCF, NEF, NSSF, SMSF, AUSF, CHF, NWDAF, I-CSCF, S-CSCF, IMS-AS, SCP, UDM
	NFStatusUnSubscribe		AMF, SMF, PCF, NEF, NSSF, SMSF, AUSF, CHF, NRF, NWDAF, I-CSCF, S-CSCF, IMS-AS, SCP, UDM
Nnrf_NFDiscovery	Request	Request/Response	AMF, SMF, PCF, NEF, NSSF, SMSF, AUSF, CHF, NRF, NWDAF, I-CSCF, S-CSCF, IMS-AS, SCP, UDM, AF (NOTE 2)
Nnrf_AccessToken	Get	Request/Response	AMF, SMF, PCF, NEF, NSSF, SMSF, AUSF, UDM, NWDAF, I-CSCF, S-CSCF, IMS-AS, HSS



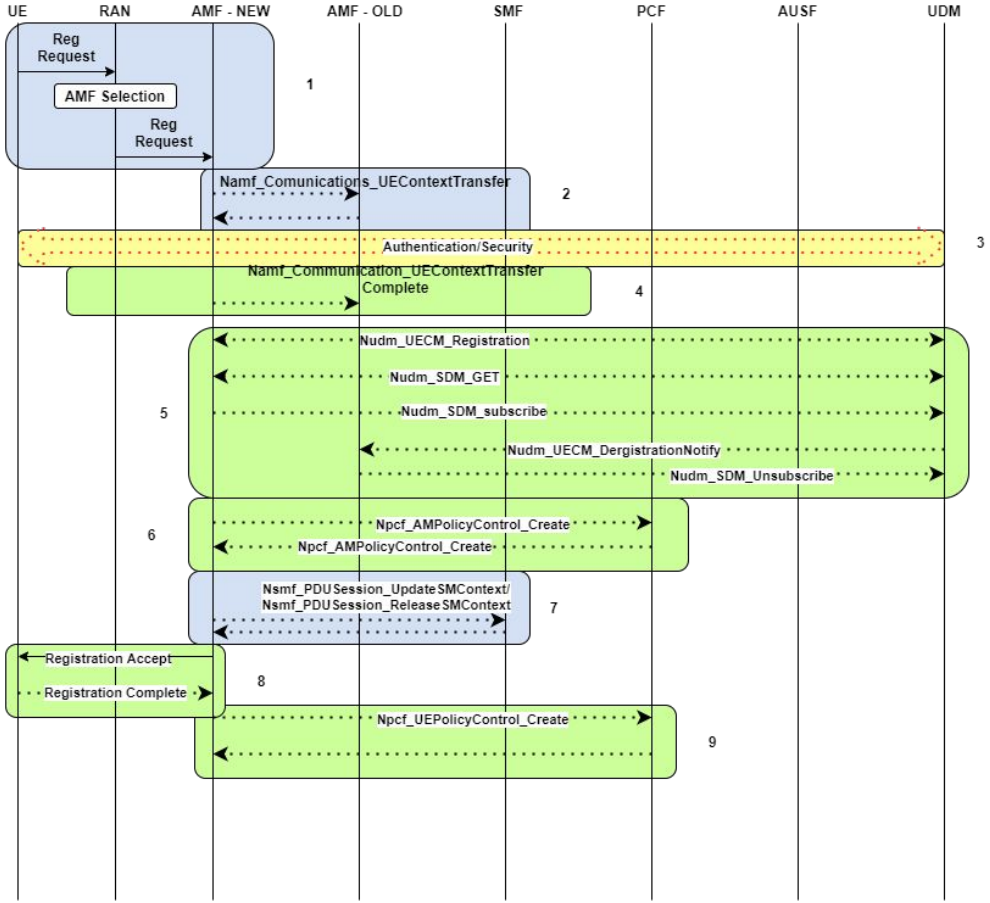
NRF Services

- **Nnrf_NFManagement** Service
  - enables NFs to register and manage their NF services and capabilities in the NRF
- **Nnrf_NFDiscovery** Service
  - allows NFs/NF Services to discover NFs/NF Services that match provided criteria
- **Nnrf_AccessToken** Service
  - allows the NFs to request Auth2.0 access tokens that can be used to access services from other NFs

Section 11 - Call Flows

Registration procedure

- Registration is the first procedure UE performs after power ON. Other scenarios where Reg procedure is used -
  - Initial Reg
  - Periodic Reg -> similar to periodic TAU
  - Mobility Reg -> similar to TAU
  - Emergency Reg -> used by UE when it wants to use emergency service
- Note the difference and similarities between usage of TAU and Reg Procedure.
- We will review the steps in detail now



Registration procedure

1. UE sends the Registration request to RAN. Reg requests includes some key details. If temporary identities (5G-TMSI or GUAMI) are included and the RAN can map these to a valid AMF, RAN forwards the request to that AMF. Else it sends it to default AMF. AMF selection can be based on S-NSSAI as well.

IEI	Information Element	Type/Reference	Presence	Format	Length
	Extended protocol discriminator	Extended Protocol discriminator 9.2	M	V	1
	Security header type	Security header type 9.3	M	V	1/2
	Spare half octet	Spare half octet 9.5	M	V	1/2
	Registration request message identity	Message type 9.7	M	V	1
	5GS registration type	5GS registration type 9.11.3.7	M	V	1/2
	ngKSI	NAS key set identifier 9.11.3.32	M	V	1/2
	5GS mobile identity	5GS mobile identity 9.11.3.4	M	LV-E	6-n
C-	Non-current native NAS key set identifier	NAS key set identifier 9.11.3.32	O	TV	1
10	5GMM capability	5GMM capability 9.11.3.1	O	TLV	3-15
2E	UE security capability	UE security capability 9.11.3.54	O	TLV	4-10
2F	Requested NSSAI	NSSAI 9.11.3.37	O	TLV	4-74
52	Last visited registered TAI	5GS tracking area identity 9.11.3.8	O	TV	7
17	S1 UE network capability	S1 UE network capability	O	TLV	4-15

Registration procedure

2. In case new AMF is selected (e.g., UE registers in an area not served by the old AMF), and the UE provided a GUAMI containing identity of the old AMF, the new AMF retrieves the UE context from the old AMF

Field	Description
5G-GUTI	
Reason	
Registration Request	Integrity protected message from the UE that triggers the context transfer.

Response

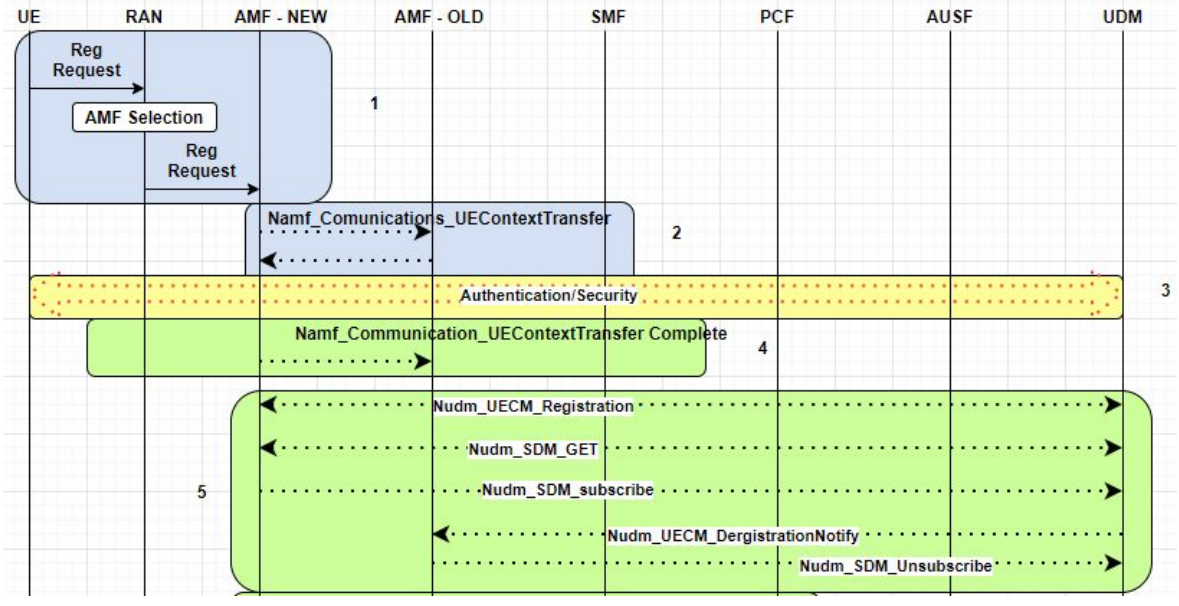
Field	Description
SUPI	SUPI (Subscription Permanent Identifier) is the subscriber's permanent identity in 5GS.
SUPI-unauthenticated-indicator	This indicates whether the SUPI is unauthenticated.
GPSI	The GPSI(s) of the UE. The presence is dictated by its storage in the UDM.
5G-GUTI	5G Globally Unique Temporary Identifier.
PEI	Mobile Equipment Identity
Internal Group ID-list	List of the subscribed internal group(s) that the UE belongs to.
UE Specific DRX Parameters	UE specific DRX parameters.
UE MM Network Capability	Indicates the UE MM network capabilities.
5GMM Capability	Includes other UE capabilities related to 5GCN or interworking with EPS.
Events Subscription	List of the event subscriptions by other CP NFs. Indicating the events being subscribed as well as any information on how to send the corresponding notifications

Registration procedure

3. Authentication is carried out as described before.

4. In case a new AMF is selected it lets the old AMF know that it is taking over.

5. New AMF registers as serving AMF for the UE in the specific access technology using Nudm_UECM service. The AMF also requests subscription data and subscribes to subscription data updates using Nudm_SDM service. UDM notifies the old AMF that it is deregistered in the UDM.

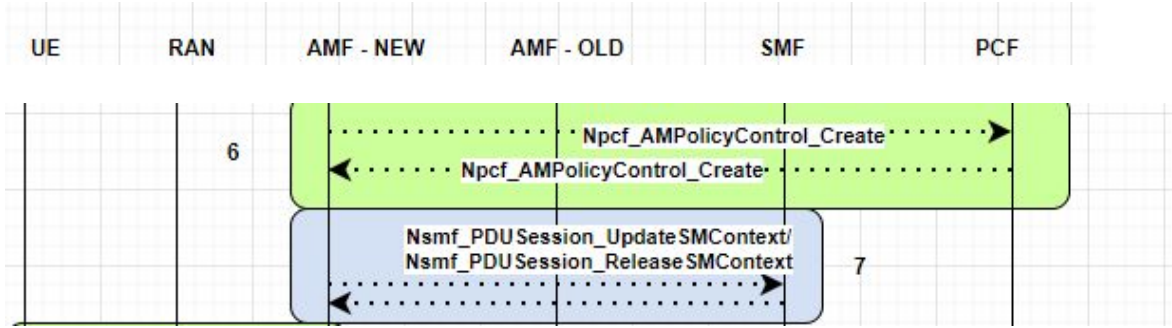


Registration procedure

6. In case access and mobility management policies are deployed, AMF initiates establishment of the AMF policy association with the PCF and retrieves the AM policies.

7. If the UE has indicated that it wants to active UP connection for existing PDU sessions, AMF invokes the Nsmf_PDUSession_UpdateSMContext service operation for those sessions. If there is a mismatch between the UE and AMF PDU session state, the AMF invokes the Nsmf_PDUSession_releaseSMContext procedure for the affected SMFs.

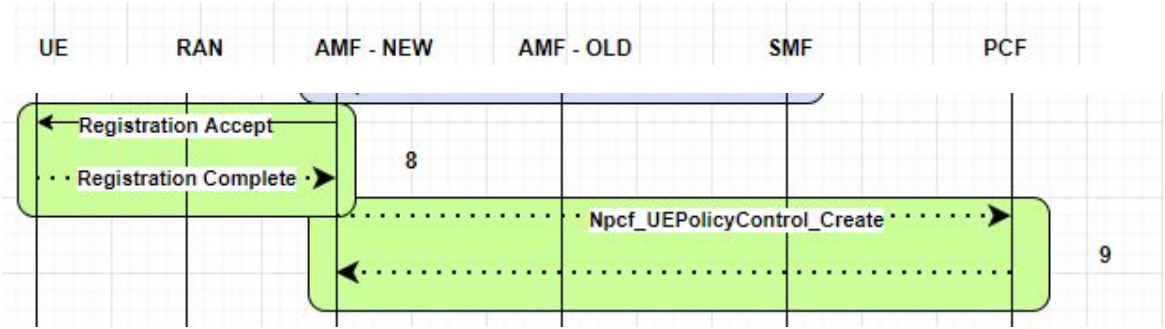
Input	Presence
SUPI	Required
Operation Type	• UP activate • UP deactivate • UP To Be Switched
PDU Session ID	Optional
N1 SM container received from the UE	Optional
N2 SM information received from the AN	Optional
Serving GW Address(es) and Serving GW DL TEID(s) for data forwarding during HO from 5GS to EPS.	Optional
UE location information	Optional
AN type	Optional
UE Time Zone	Optional
H-SMF identifier/address	Optional
EBI(s) to be revoked, PDU Session(s) to be re-activated	Optional
Direct Forwarding Flag	Optional
ARP list	Optional
S-NSSAI	Optional
Data Forwarding Tunnel (setup/release)	Optional
UE presence in LADN service area	Optional
Target ID	Optional
Target AMF ID	Optional
GUAMI	Optional
Backup AMF(s) (if NF Type is AMF)	Optional



Registration procedure

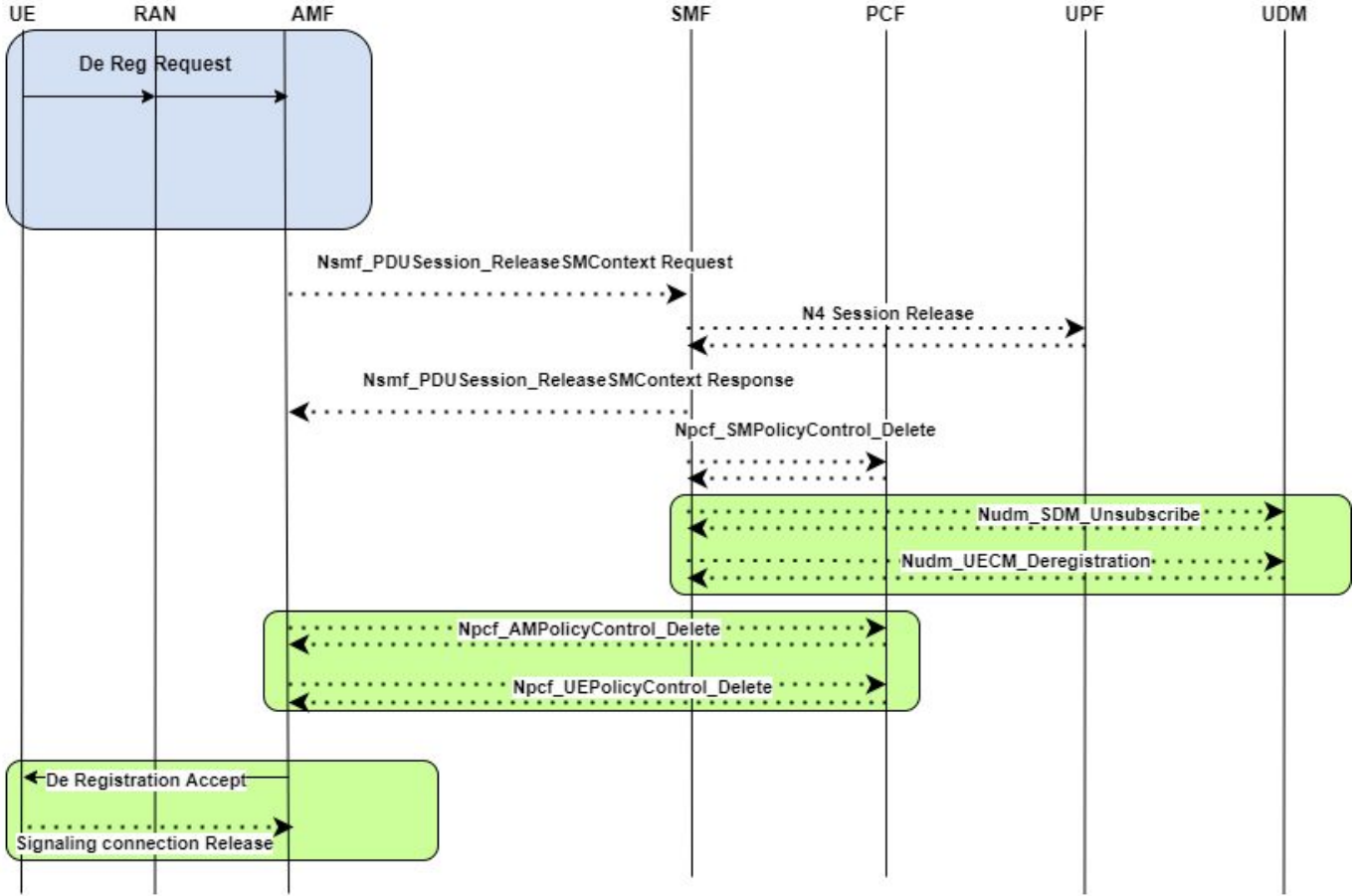
8. If Registration is successful thus far, AMF sends a Reg Accept message to the UE and the UE can send a Reg Complete as ACK.

9. In case UE policies are deployed the AMF initiates establishment of the UE policy association with PCF. This allows PCF to provide UE policies to the UE.



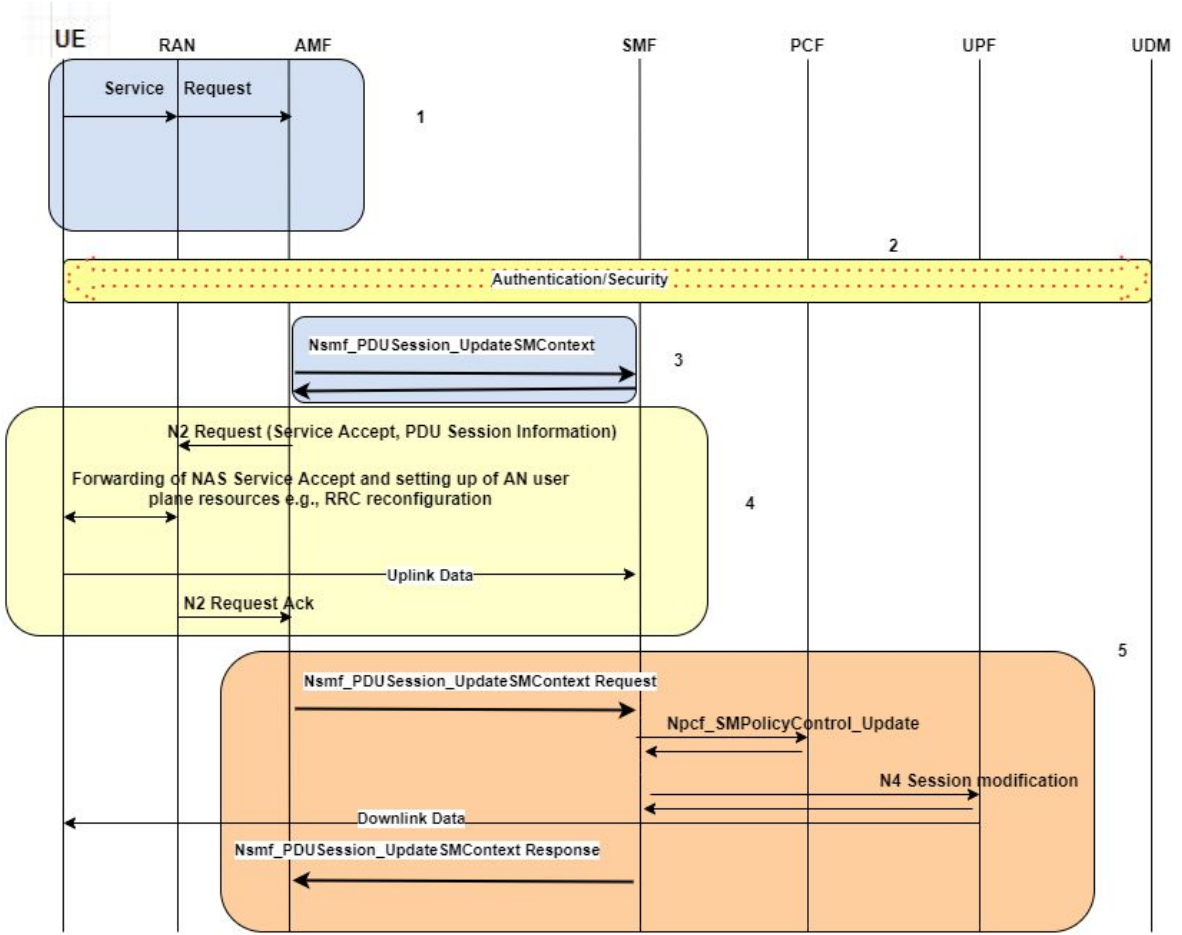
More details can be found in - 3GPP TS 23.502

De Registration procedure



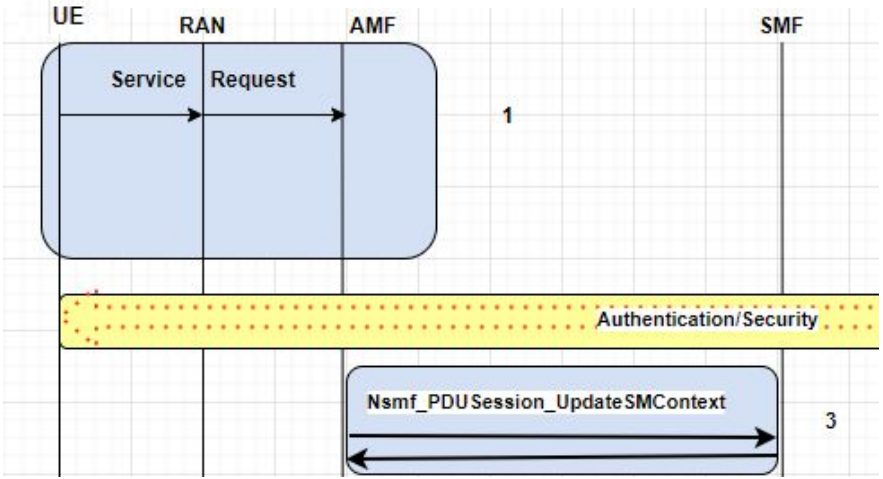
Service Request

- SR is used by UE to establish secure connection with AMF.
- Process transitions UE from ECM-Idle to ECM-Connected mode
- 2 variants -
  - UE triggered
  - Network triggered



UE - Triggered Service Request

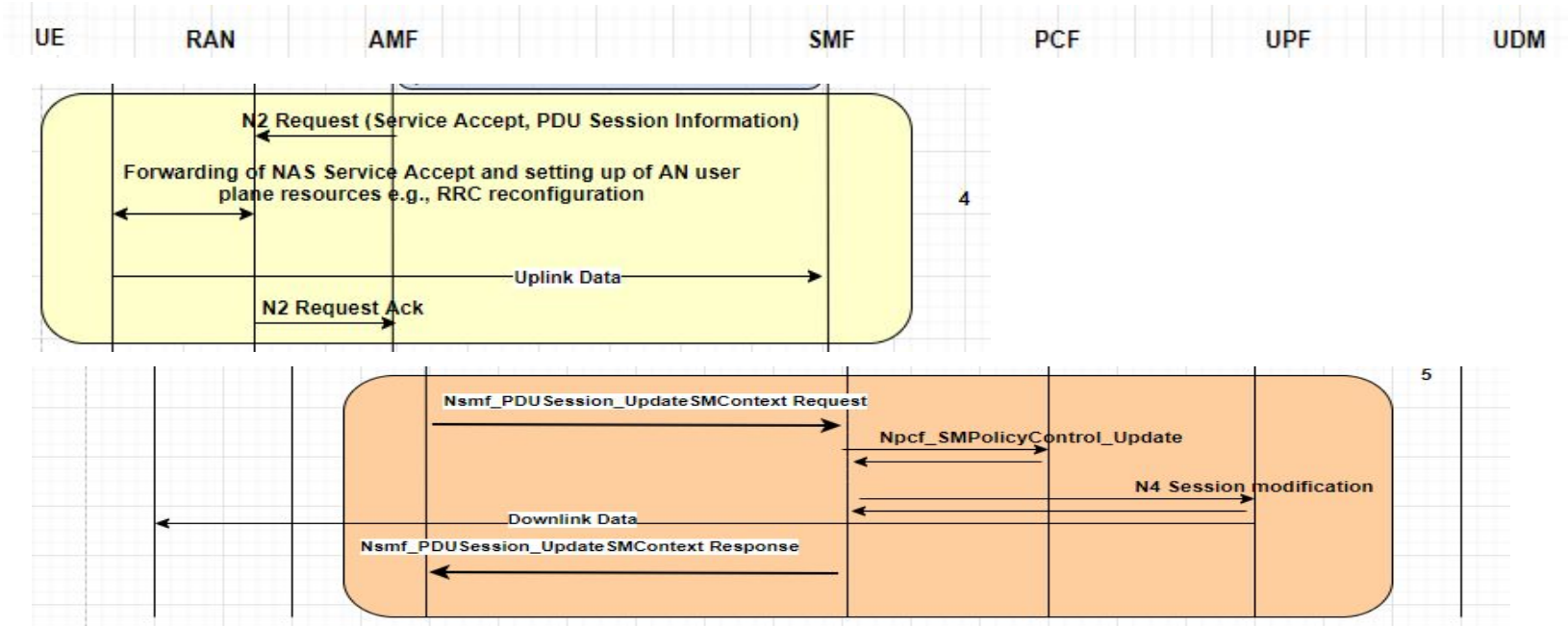
1. UE sends a NAS Service Request Message to AMF via the RAN. If the UE wants to establish User plane connections for one or more existing PDU sessions, the UE includes information to the AMF about the PDU session IDs for these sessions.
2. Network may optionally authenticate the subscriber.
3. If the UE indicated in 1. That UP sessions need to be resumed, the AMF notifies each involved SMF serving the corresponding PDU session. In the simplest case the SMF can reply to this message with the UPF tunnel end point identifiers (needed by RAN to send uplink data).
   In more complex scenarios we can have UPF selection procedures as well in case UE has moved out of serving area (initial)



UE - Triggered Service Request

4. AMF sends a NAS: Service Accept message to the RAN. For User plane AMF also sends the PDU session information the RAN including UPF tunnel end point identifiers. RAN configures the radio bearers for UE using RRC Reconfiguration messaging. UE responds back with RRC Reconfig Complete + NAS Message - Service Accept.

5. AMF notifies each involved SMF/UPF about the RAN tunnel end point identifiers - Needed for Downlink data delivery. If PCF has subscribed to UE location information, SMF notifies PCF about the new UE location.



Network Triggered Service Request