5th Generation Cellular Network, Cellular Network

Vahid Shah-Mansouri, Fall 1397
school of ECE, University of Tehran

Where is 5G?

- 5G is in R&D phase in some parts and ready to market it some others.
- Various research/standardization groups are working towards making it possible.
  - ITU
  - 5GPPP
  - NGMN
- High level goals:
  - Support various QoS requirements,
  - Better and faster service provisioning,
  - Flexibility and programmability,
  - Support multi-tenancy
  - Lower CAPEX and OPEX
  - …

5G Goals

- 5G aim is to achieve tighter service QoS levels
- 5G networks are conceived as extremely **flexible** and **highly programmable** *E2E connect-and-compute infrastructures* that are application- and service-aware, as well as time-, location- and context-aware.

- To achieve 5G goals, we need to
  - change the network functions,
    - Many new technologies and protocols are
  - change the way we preform the functions,
    - Softwarizations
    - Virtualizations
    - Central control

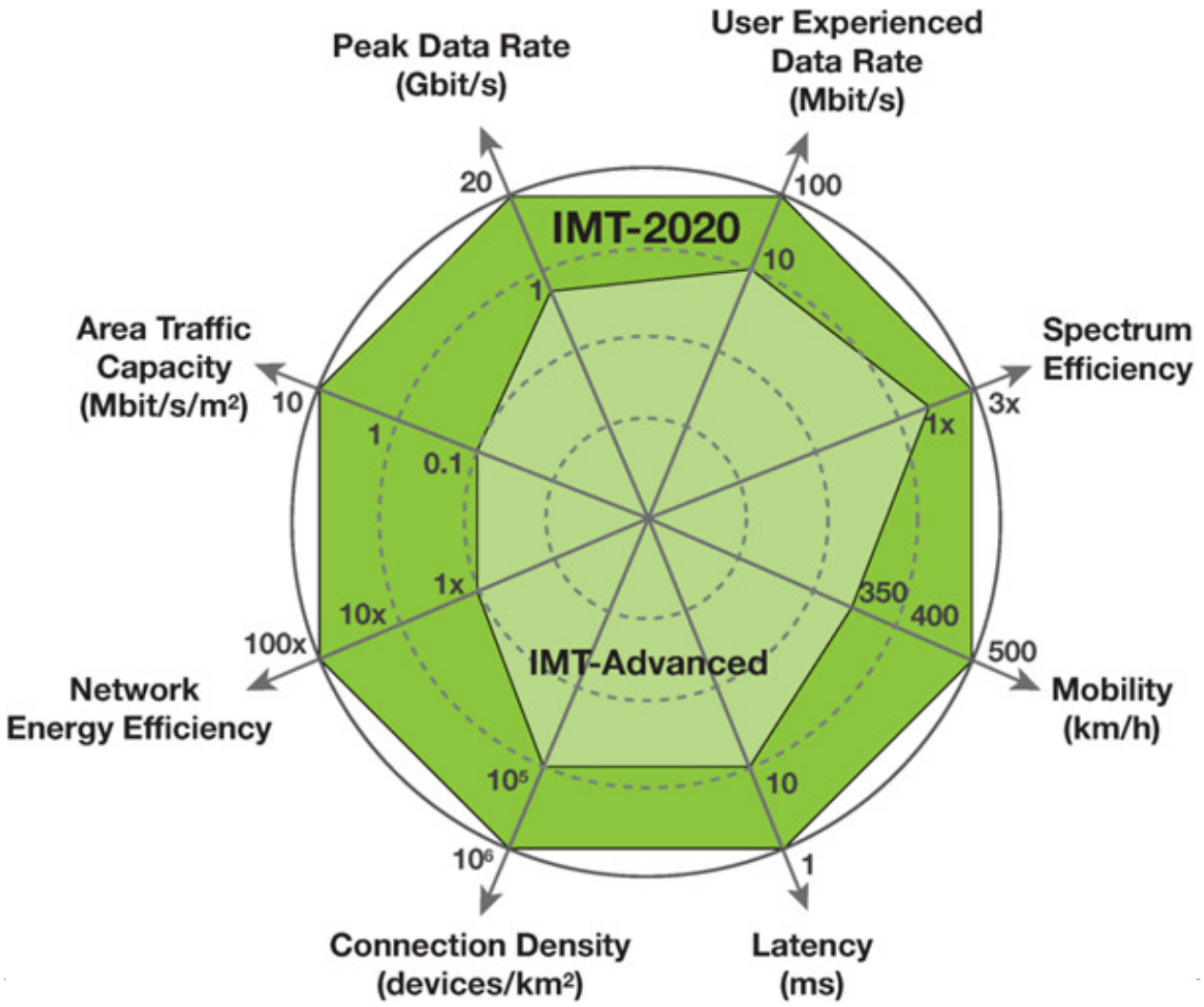
5G Contributing Technologies

- Radio access network:
  - NB-IoT
  - Ultra-dense RAN
  - mmWave communications
  - Cloud RAN
  - Heterogeneous RANs
  - Software defined
- Core network:
  - Software defined networking
  - Network function virtualization
  - Network Slicing
  - Central management orchestration
  - Service chaining
  - Function separation

IMT 2020

- The term was coined in 2012 by the International Telecommunication Union radio communication Sector.
- It means International Mobile Telecommunication system with a target date set for 2020.
- In September 2015, ITU-R has finalized its vision of the 5G mobile broadband connected society.
- Their goal is to describe the services and their attributes.

IMT-Advanced to IMT-2020 Enhancements



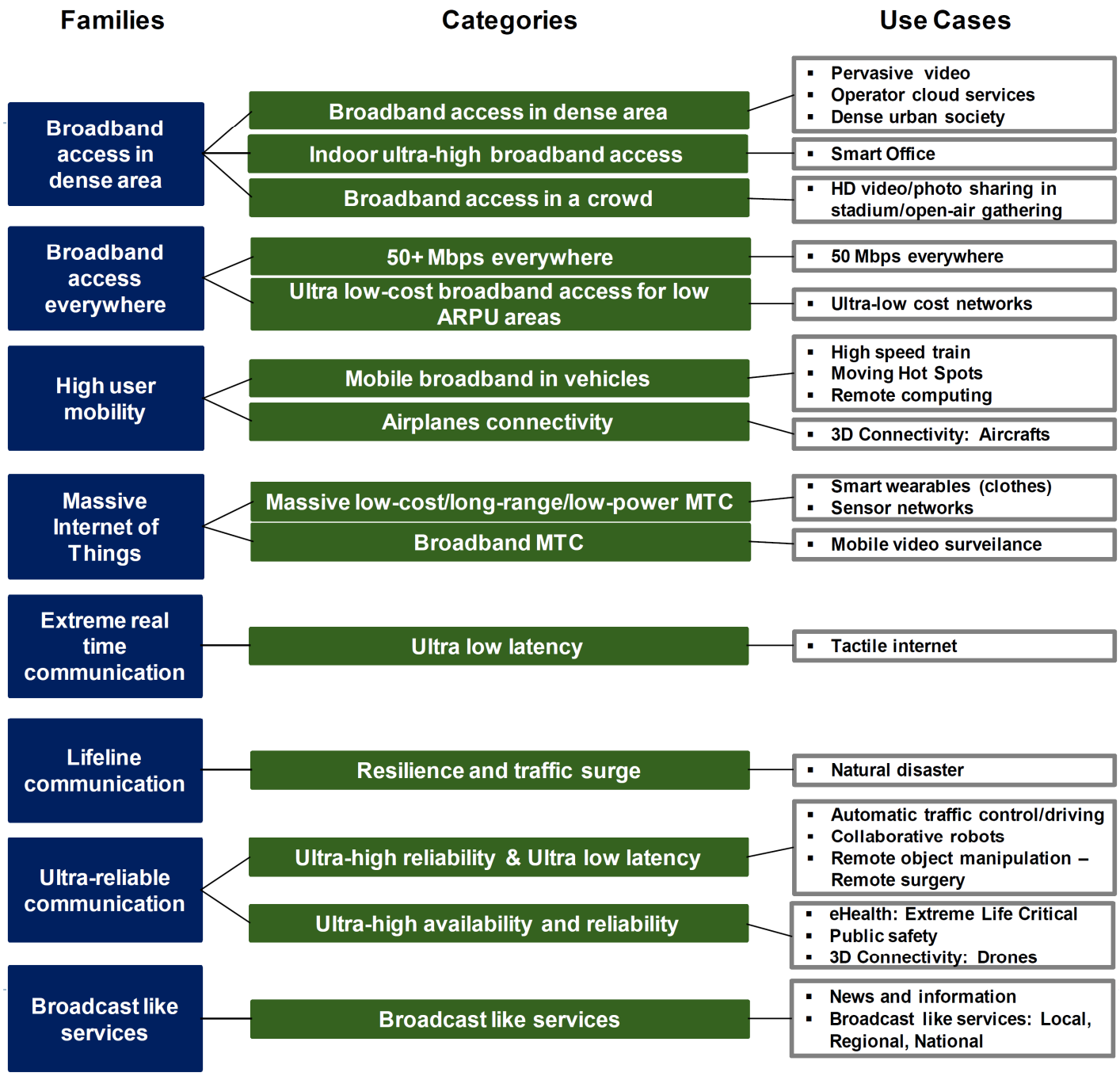
NGMN

- The Next Generation Mobile Networks (NGMN) Alliance is a mobile telecommunications association of mobile operators, vendors, manufacturers and research institutes. It was founded by major mobile operators in 2006 as an open forum to evaluate candidate technologies to develop a common view of solutions for the next evolution of wireless networks.
- The vision of the NGMN Alliance is to expand the communications experience by providing a truly integrated and cohesively managed delivery platform that brings affordable mobile broadband services to the end user with a particular focus on 5G while accelerating the development of LTE-Advanced and its ecosystem.

NGMN-Use Cases

Broadband Access in Dense Areas	Broadband Access Everywhere	Higher User Mobility	Massive Internet of Things
• Pervasive Video • Smart Office • Operator Cloud Services • HD Video/Photo Sharing in Stadium/Open-Air Gathering	• 50+ Mbps Everywhere • Ultra-low Cost Networks	• High Speed Train • Remote Computing • Moving Hot Spots • 3D Connectivity: Aircrafts	• Smart Wearables (Clothes, Watches, etc.) • Sensor Networks • Mobile Video Surveillance
Extreme R/T Communications	**Lifeline Communication**	**Ultra-reliable Communications**	**Broadcast-like Services**

• Tactile Internet
  • Robotic control
  • Manufacturing
  • remote medical care
  • autonomous cars
	• Natural Disaster
	  • Earthquakes
	  • Tsunamis
	  • Floods
	  • hurricanes
		• Collaborative Robots:
		• eHealth: Extreme Life Critical
		• Remote Object Manipulation: Remote Surgery
		• 3D Connectivity: Drones
			• News and Information
			• Local Broadcast-like Services
			• Regional Broadcast-like Services
			• National Broadcast-like Services


Families
Categories
Use Cases
Broadband access in dense area
Broadband access in dense area
Indoor ultra-high broadband access
Broadband access in a crowd
Pervasive video
Operator cloud services
Dense urban society
Smart Office
HD video/photo sharing in stadium/open-air gathering
Broadband access everywhere
50+ Mbps everywhere
Ultra low-cost broadband access for low ARPU areas
50 Mbps everywhere
Ultra-low cost networks
High user mobility
Mobile broadband in vehicles
Airplanes connectivity
High speed train
Moving Hot Spots
Remote computing
3D Connectivity: Aircrafts
Massive Internet of Things
Massive low-cost/long-range/low-power MTC
Broadband MTC
Smart wearables (clothes)
Sensor networks
Mobile video surveilance
Extreme real time communication
Ultra low latency
Tactile internet
Lifeline communication
Resilience and traffic surge
Natural disaster
Ultra-reliable communication
Ultra-high reliability & Ultra low latency
Ultra-high availability and reliability
Automatic traffic control/driving
Collaborative robots
Remote object manipulation – Remote surgery
eHealth: Extreme Life Critical
Public safety
3D Connectivity: Drones
Broadcast like services
Broadcast like services
News and information
Broadcast like services: Local, Regional, National

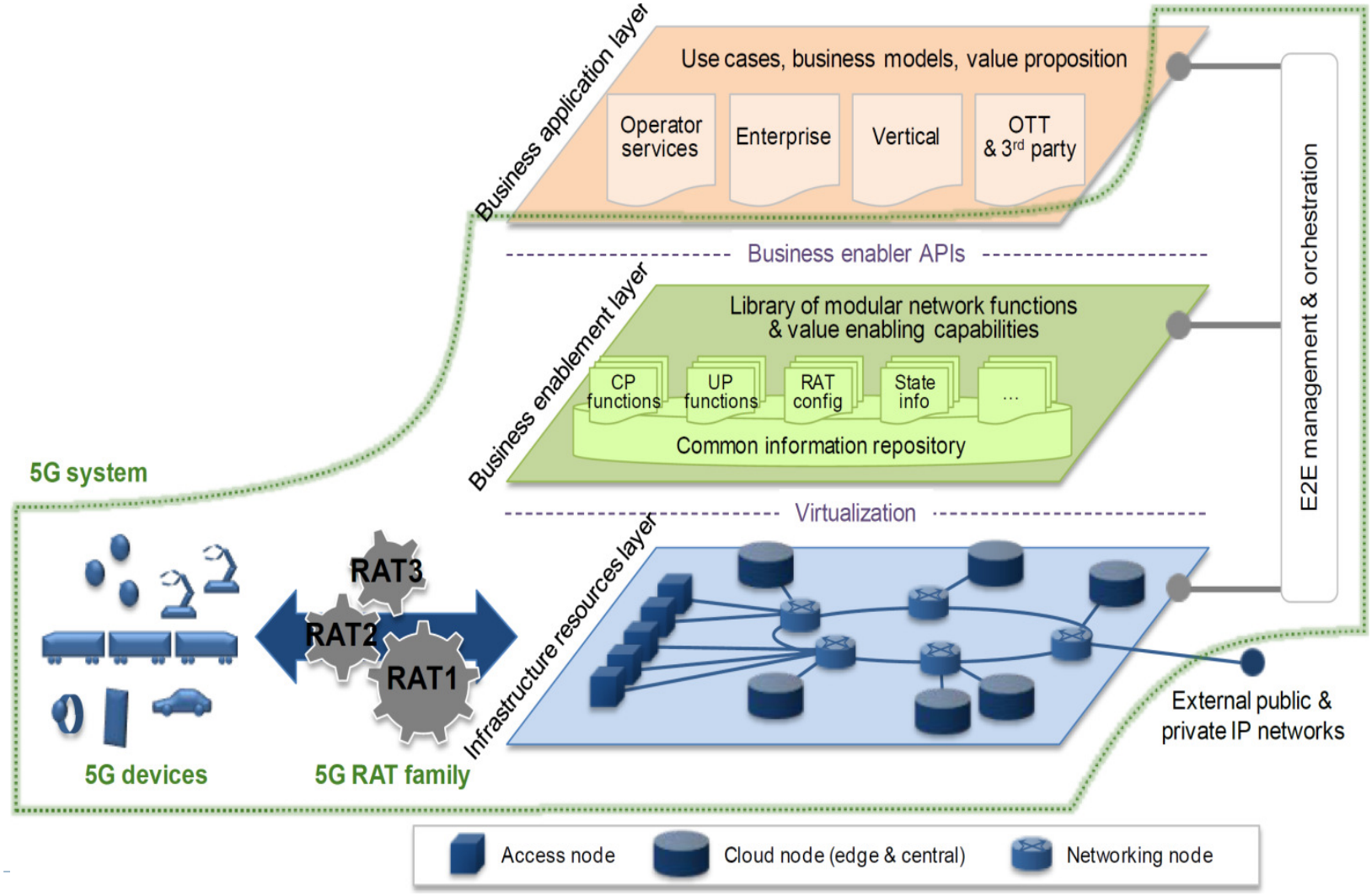
NGMN Provided Requirements

Use case category	User Experienced Data Rate	E2E Latency	Mobility
Broadband access in dense areas	DL: 300 Mbps UL: 50 Mbps	10 ms	On demand, 0-100 km/h
Indoor ultra-high broadband access	DL: 1 Gbps, UL: 500 Mbps	10 ms	Pedestrian
Broadband access in a crowd	DL: 25 Mbps UL: 50 Mbps	10 ms	Pedestrian
50+ Mbps everywhere	DL: 50 Mbps UL: 25 Mbps	10 ms	0-120 km/h
Ultra-low cost broadband access for low ARPU areas	DL: 10 Mbps UL: 10 Mbps	50 ms	on demand: 0-50 km/h
Mobile broadband in vehicles (cars, trains)	DL: 50 Mbps UL: 25 Mbps	10 ms	On demand, up to 500 km/h
Airplanes connectivity	DL: 15 Mbps per user UL: 7.5 Mbps per user	10 ms	Up to 1000 km/h
Massive low-cost/long-range/low-power MTC	Low (typically 1-100 kbps)	Seconds to hours	on demand: 0-500 km/h
Broadband MTC	See the requirements for the Broadband access in dense areas and 50+Mbps everywhere categories		
Ultra-low latency	DL: 50 Mbps UL: 25 Mbps	<1 ms	Pedestrian
Resilience and traffic surge	DL: 0.1-1 Mbps UL: 0.1-1 Mbps	Regular communication: not critical	0-120 km/h
Ultra-high reliability & Ultra-low latency	DL: From 50 kbps to 10 Mbps; UL: From a few bps to 10 Mbps	1 ms	on demand: 0-500 km/h
Ultra-high availability & reliability	DL: 10 Mbps UL: 10 Mbps	10 ms	On demand, 0-500 km/h
Broadcast like services	DL: Up to 200 Mbps UL: Modest (e.g. 500 kbps)	<100 ms	on demand: 0-500 km/h

NGMN Provided Requirements

Use case category	Connection Density	Traffic Density
Broadband access in dense areas	200-2500 /km^2	DL: 750 Gbps / km2 UL: 125 Gbps / km2
Indoor ultra-high broadband access	75,000 / km^2 (75/1000 m^2 office)	DL: 15 Tbps/ km2 (15 Gbps / 1000 m2) UL: 2 Tbps / km2 (2 Gbps / 1000 m2)
Broadband access in a crowd	150,000 / km^2 (30.000 / stadium)	DL: 3.75 Tbps / km2 (DL: 0.75 Tbps / stadium) UL: 7.5 Tbps / km2 (1.5 Tbps / stadium)
50+ Mbps everywhere	400 / km^2 in suburban 100 / km^2 in rural	DL: 20 Gbps / km2 in suburban UL: 10 Gbps / km2 in suburban DL: 5 Gbps / km2 in rural UL: 2.5 Gbps / km2 in rural
Ultra-low cost broadband access for low ARPU areas	16 / km^2	16 Mbps / km^2
Mobile broadband in vehicles (cars, trains)	2000 / km^2 (500 active users per train x 4 trains, or 1 active user per car x 2000 cars)	DL: 100 Gbps / km^2 (25 Gbps per train, 50 Mbps per car) UL: 50 Gbps / km^2 (12.5 Gbps per train, 25 Mbps per car)
Airplanes connectivity	80 per plane 60 airplanes per 18,000 km^2	DL: 1.2 Gbps / plane UL: 600 Mbps / plane
Massive low-cost/long-range/low-power MTC	Up to 200,000 / km^2	Non critical
Broadband MTC	See the requirements for the Broadband access in dense areas and 50+Mbps everywhere categories	
Ultra-low latency	Not critical	Potentially high
Resilience and traffic surge	10,000 / km^2	Potentially high
Ultra-high reliability & Ultra-low latency* (*) the reliability requirement for this category is described in Section 4.4.5	Not critical	Potentially high
Ultra-high availability & reliability* (*) the reliability requirement for this category is described in Section 4.4.5	Not critical	Potentially high
Broadcast like services	Not relevant	Not relevant

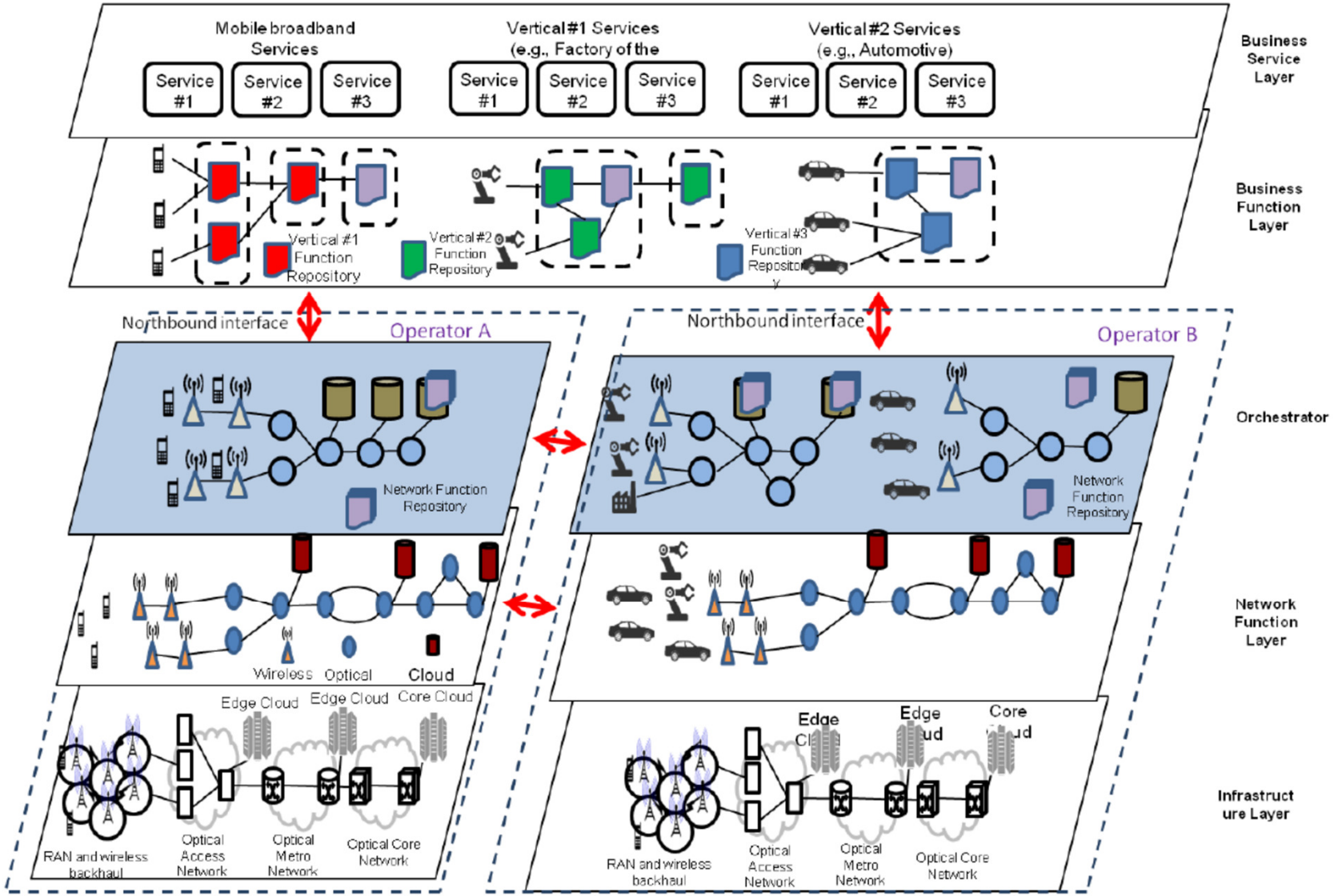
5G High Level Architecture (NGMN View)



5GPPP

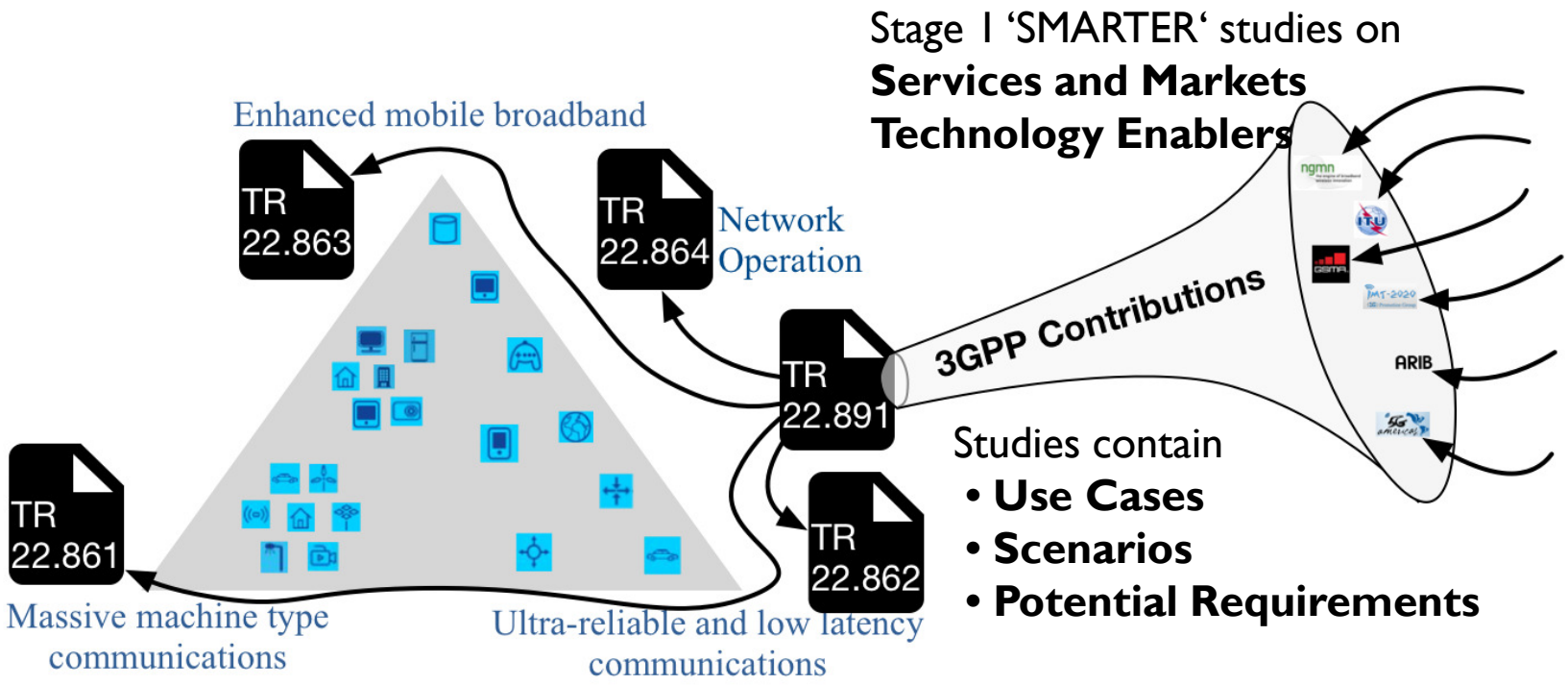
- The 5G Infrastructure Public Private Partnership (5G PPP) has been initiated by the EU Commission and industry manufacturers, telecommunications operators, service providers, SMEs and researchers.
- The 5G PPP will deliver solutions, architectures, technologies and standards for the ubiquitous next generation communication infrastructures of the coming decade.
- In broad strokes, the 5GPPP will be organised in three or four stages, covering:
  - 2014-2016: research
  - 2016-2017: optimisation
  - 2019-2020: large-scale trials

5G High Level Architecture (5GPP View)

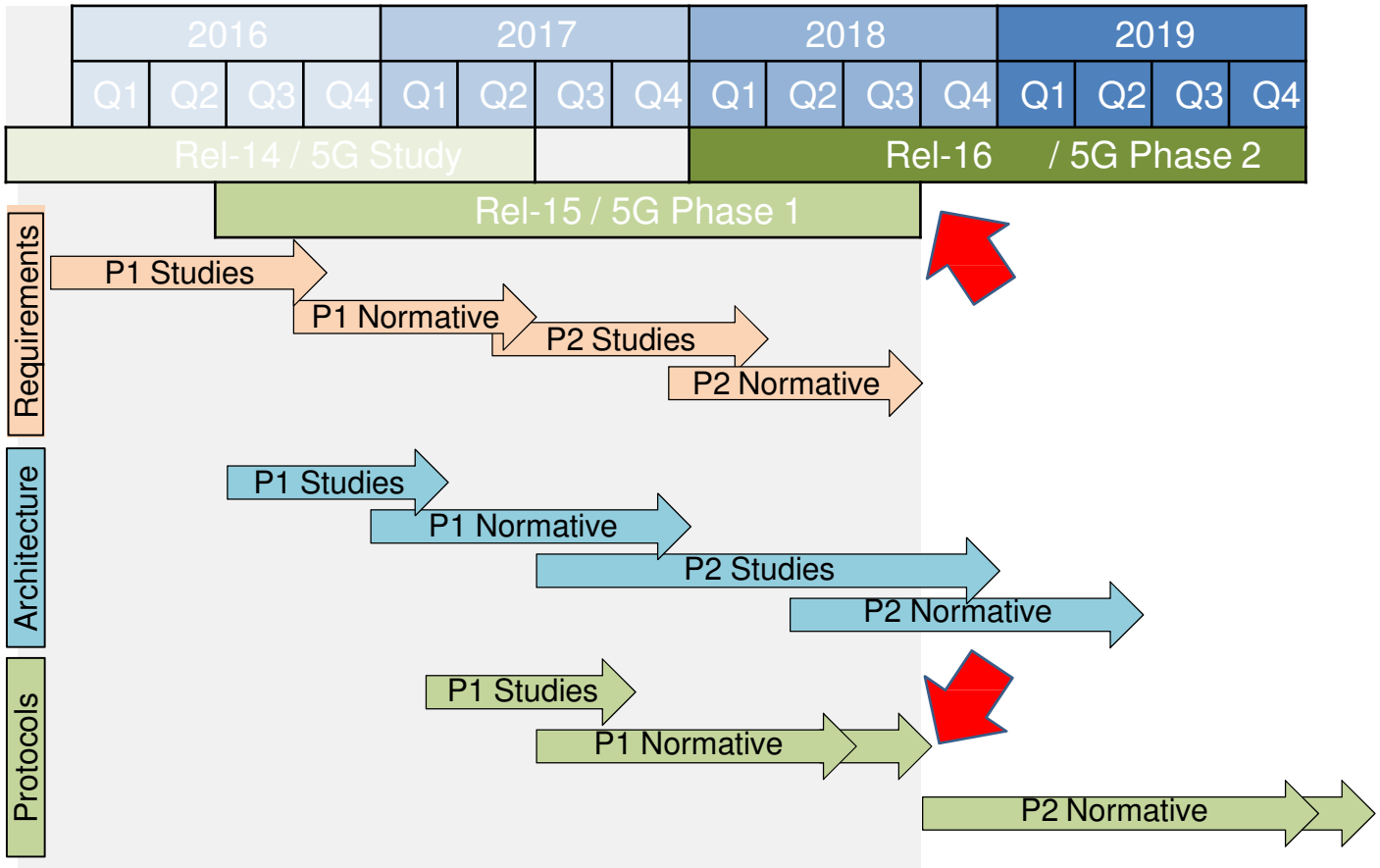


3GPP Standards for 5G

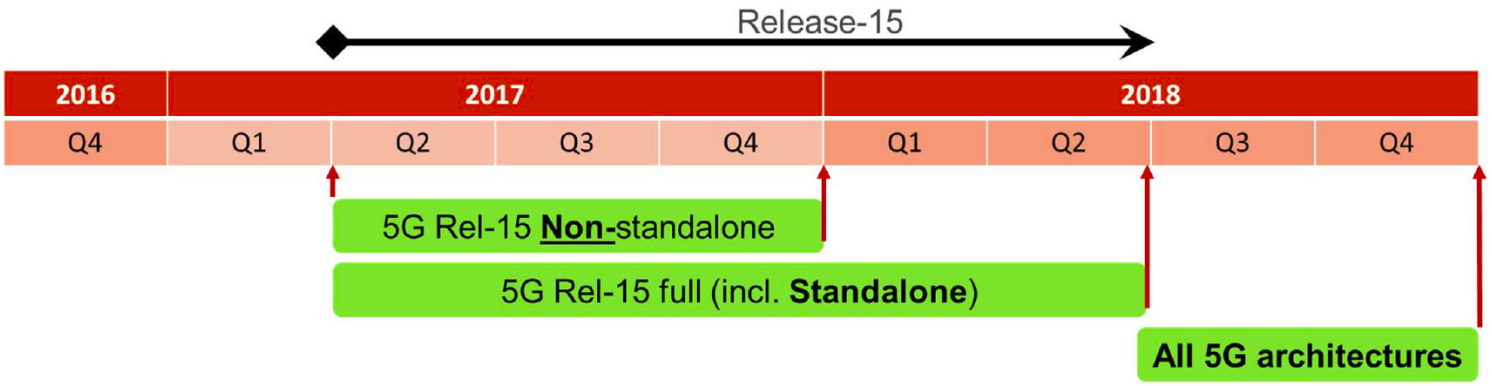
Services in Rel. 14



5G Standardization Timeline



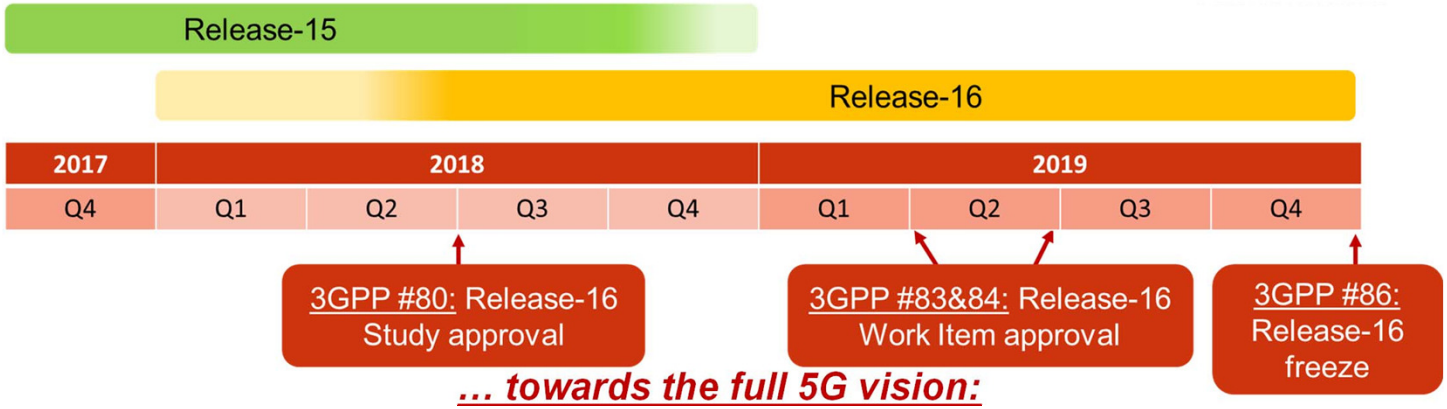
5G Phase 1 – Rel. 15



- Licensed bands between 600MHz – 39 GHz
- LTE-Anchored 5G (NSA), and Standalone (SA) 5G
- Basic URLLC support
- Massive MIMO
- Flexible RAN architecture
- Fulfills IMT2020 criteria

- 5G Core Network
  - Network Slicing
  - Service Based Architecture for the Control Plane
  - Designed for scalability & virtualization
- Orchestration and management network and radio functions
- 5G Media

5G Phase 2 – Rel. 16



... towards the full 5G vision:

- MBMS,
- Satellite support,
- V2X support – autonomous driving
- Enhanced MIMO
- Support for Unlicensed bands
- Factory automation and other use cases supported
- Support of higher bands (>52.6 GHz)
- Additional accesses (Wireline Wireless Convergence, Satellite...)

3GPP 5G Design Criteria

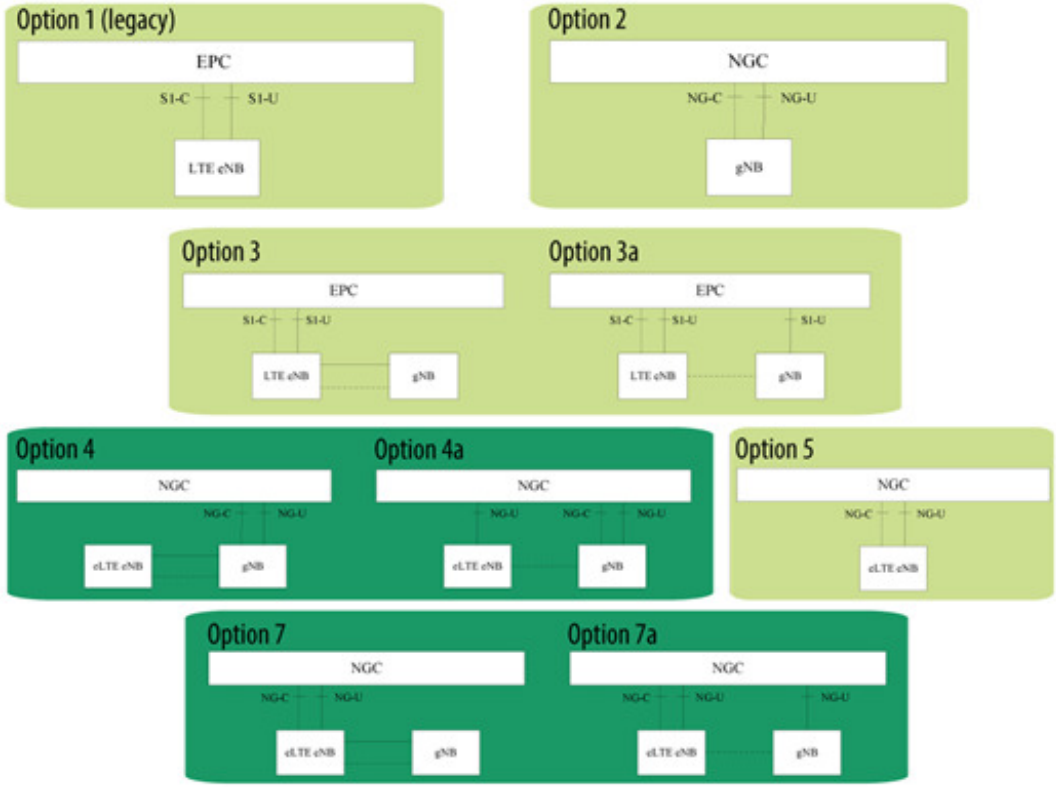
- Separate the User Plane (UP)
- Modularize the function design.
- Define procedures
- Direct interaction of Network Functions.
- Minimize dependencies between the Access Network and the Core Network.
- Multiple choices for AN.
- Unified authentication framework.
- "stateless" NFs, where the "compute" resource is decoupled from the "storage" resource.
- Support capability exposure.
- User plane functions close to the Access Network.

Main Components

- As with the previous generations, 3GPP is defining
  - a new 5G core network, referred to as 5GC,
  - as well as a new radio access technology called 5G "New Radio" (NR).
- Unlike previous generations that required that both access and core network of the same generation to be deployed, with 5G it is possible to integrate elements of different generations in different configurations, namely:
  - Standalone using only one radio access technology and
  - Non-Standalone combining multiple radio access technologies.

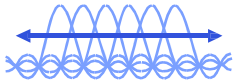
5G Adoption Architecture Options

- Stand alone (SA)
  - SA scenario uses only one radio access technology (5G NR or the evolved LTE (Long Term Evolution) radio cells) and the core networks are operated alone.
- non-standalone (NSA)
  - NSA scenario combines NR radio cells and LTE radio cells using dual-connectivity to provide radio access and the core network may be either EPC (Evolved Packet Core) or 5GC



5G New Radio

Scalable OFDM- based air interface



Scalable OFDM numerology

Efficiently address diverse spectrum, deployments/services

Flexible slot-based framework

Self-contained slot structure

Key enabler to low latency, URLLC and forward compatibility

Advanced channel coding

Multi-Edge LDPC and CRC-Aided Polar

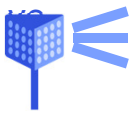
Efficiently support large data blocks and a reliable control channel

Massive MIMO

Reciprocity-based MU-MIMO

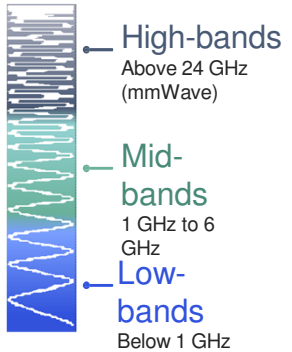
Efficiently utilize a large number of antennas to

Mobile mmWa



Beamforming and beam-tracking

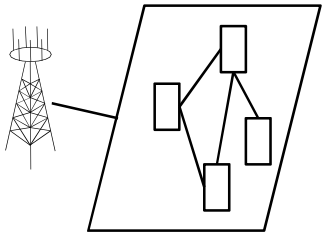
Enables wide mmWave bandwidths for extreme capacity and throughput



Diverse spectrum

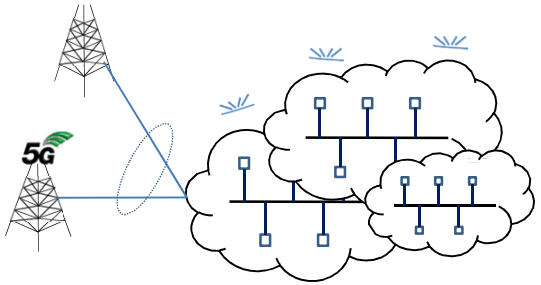
Getting the most out of a wide array of spectrum bands/types

Transformation of the Core Network



- Functional entities
- Single Core
- Dedicated protocols

5G



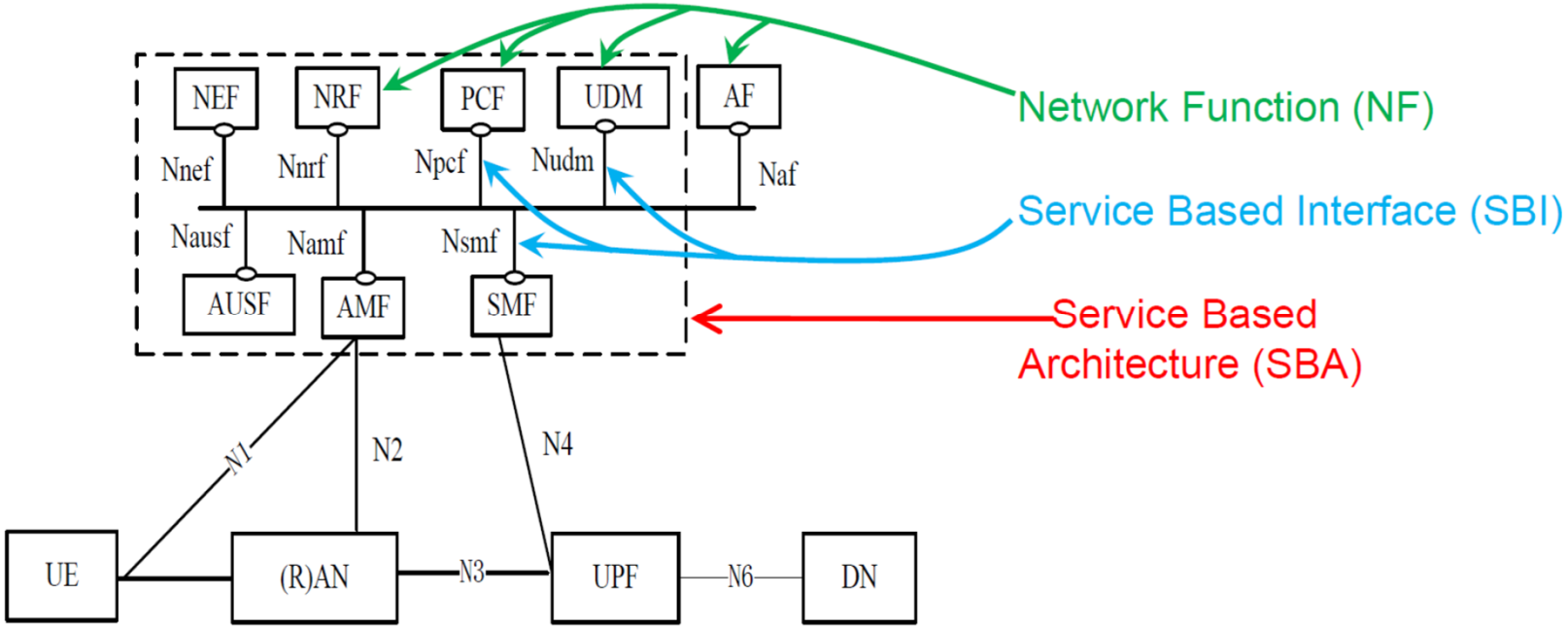
- Service Based (SBA/SBI/NAPS)
- Virtualization & Slicing
- Softwarization / Cloudification
- Application Programming Interfaces
- Harmonized protocols (HTTP…)

- Exposure to 3rd Parties
- Backward & Forward Compatibility

Goals of SBA

- Modularity & Reusability
  - The network is composed of modularized services, also known as Microservices.
  - Services can be reused among different network functions.
- Cloud-Native
  - Continuous delivery, shrinking testing and integration timescales (moving towards continuous integration) which reduces the time to market for installing bug fixes, and rolling out new features.
  - Containerization, allowing individual services updated/extended with minimal impact to other services
- Extensibility
  - Service based interfaces can be easily extended without introducing new reference points
  - Traffic can be easily balanced or offloaded by deployment new NF service instance.
- Openness
  - Together with some control functions (i.e. authentication), service based interface can be
  - easily exposed to external users, such as 3rd-party application providers.

Service Based Architecture in Core

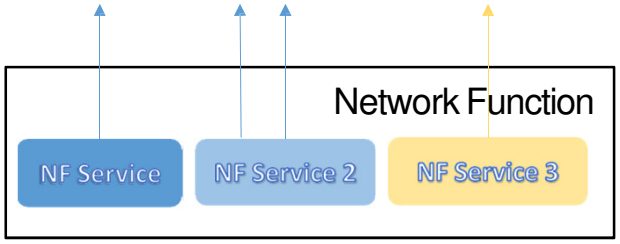


Network Function Service

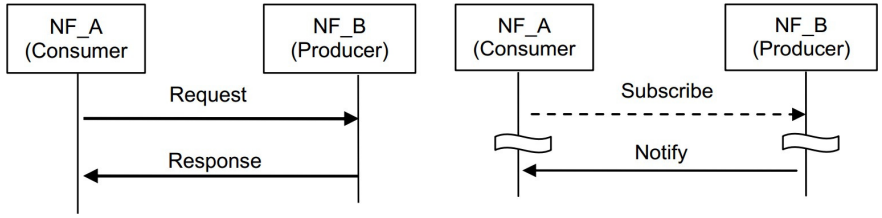
- Each network function is composed of several network function services.
- An NF service is
  - a capability
  - exposed by an NF (NF Service Producer)
  - to other authorized NF (NF Service Consumer)
  - through a service-based interface.
- NF services are derived from the system procedures that describe end to end functionality.
- System procedures can be described by a sequence of NF service invocations.
- A Control Plane Network function (NF) within the 5G Core network may expose its capabilities as services via its service based interface.

Network Function Services

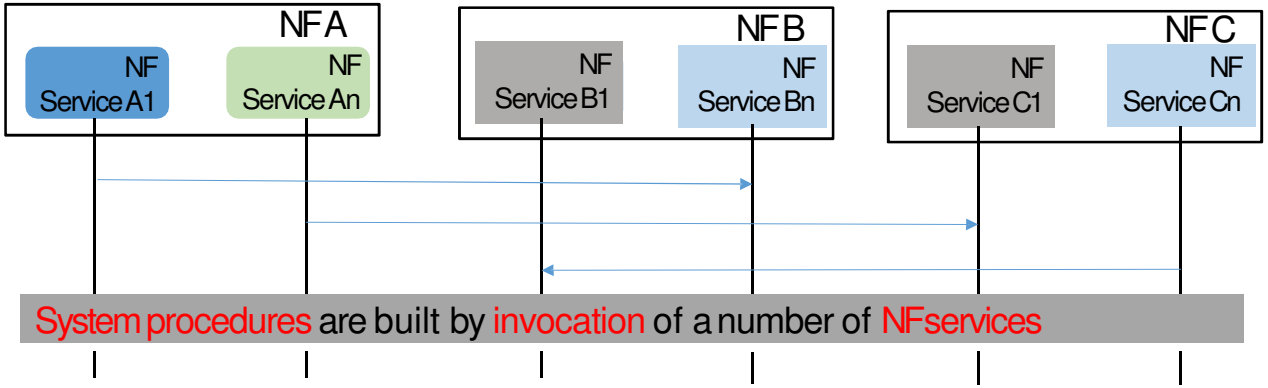
Service-based Architecture = “Network function service” +”Service-based interface”



An NF service is one type of capability exposed by an NF (NF Service Producer) to other NF (NF Service Consumer)



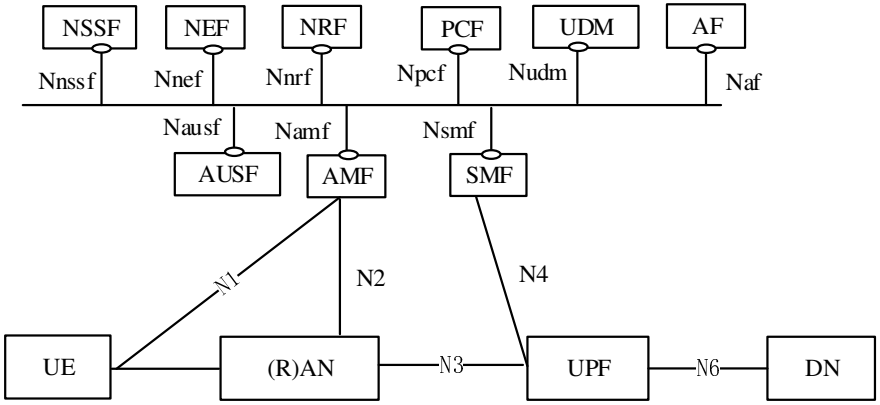
Two types of primitive operations: “Request & Response” And “Subscribe-Notify”



System procedures are built by invocation of a number of NF services

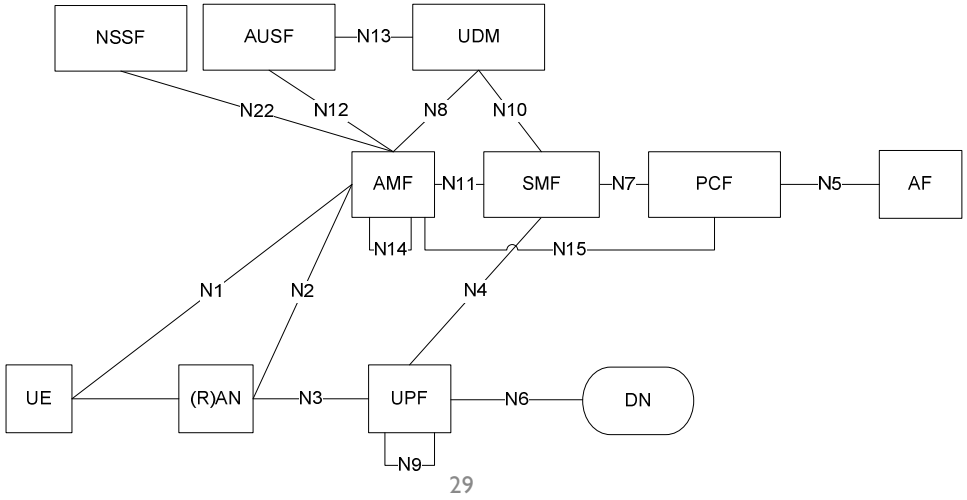
NF Services is expected to be self-contatined, reusable and use management schemes independently of other NF services offered by the same Network Functions (e.g. for scaling, healing, etc.

Service-Based Interfaces and Reference Points



Service-based representation

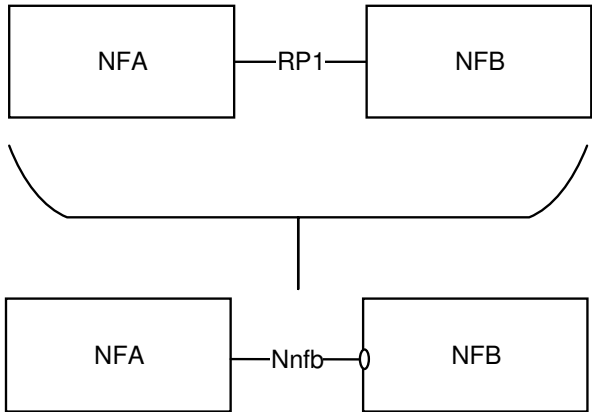
Reference point representation

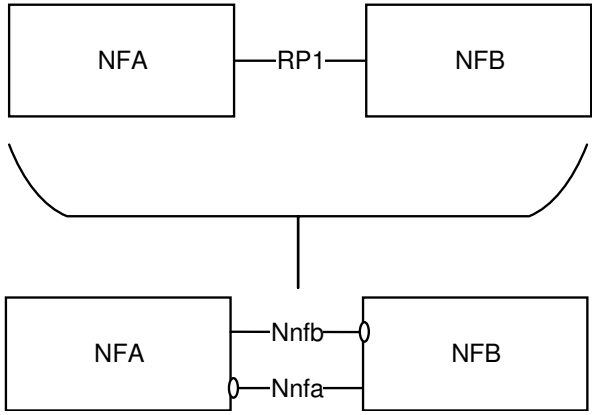


29

Service-Based Interfaces and Reference Points

- Service-Based Interfaces and Reference Points are two different ways to model interactions between architectural entities.
- A Reference Point is a conceptual point at the conjunction of some non-overlapping network functions.
- A reference point can be replaced by one or more service-based interfaces.

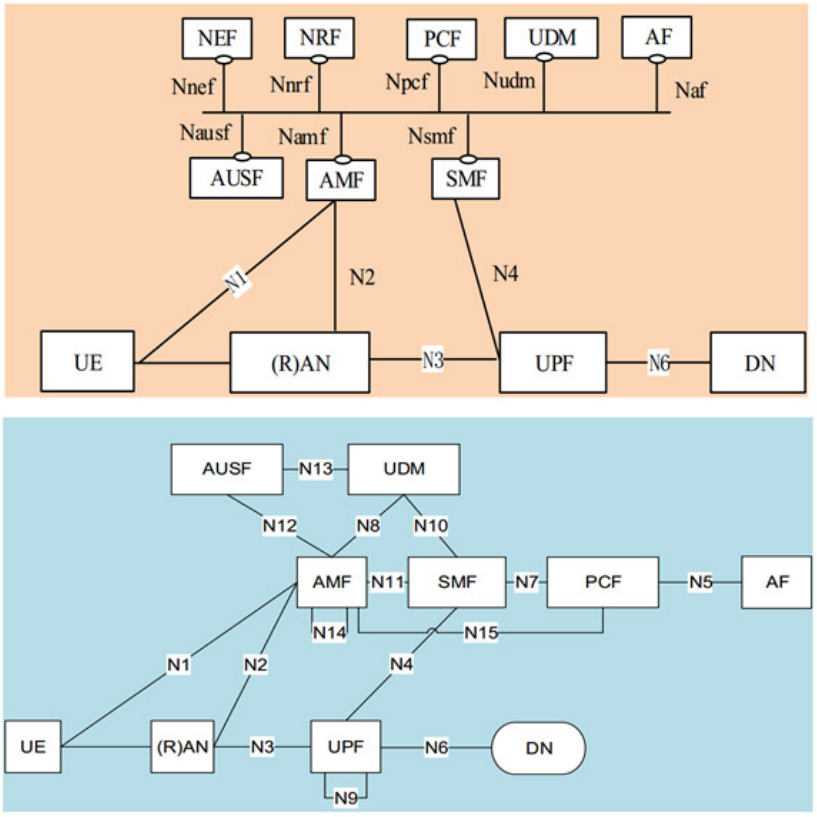




Access and Mobility Management function (AMF)

- Functions of MME, SGW-C, and PGW-C are divided between AMF and SMF.
- AMF:

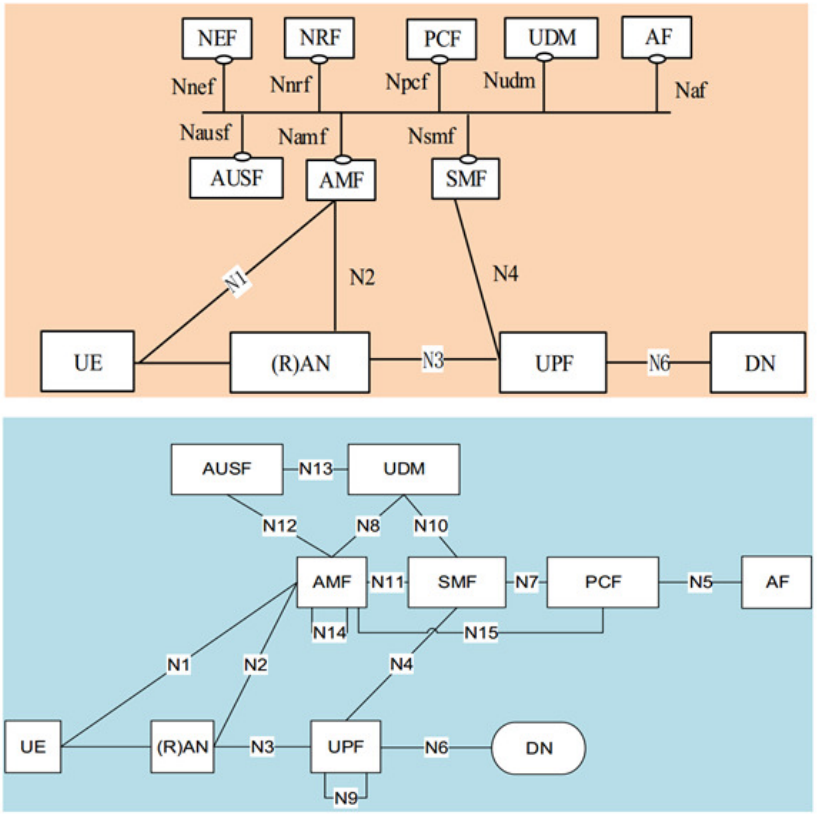
  Termination of NAS signalling, NAS ciphering & integrity protection, registration management, connection management, mobility management, access authentication and authorization, security context management.
- One AMF supports all UE requests.
- Different UEs may have different AMFs.
- Either UE knows its AMF or request is sent to the default AMF.



Session Management function (SMF)

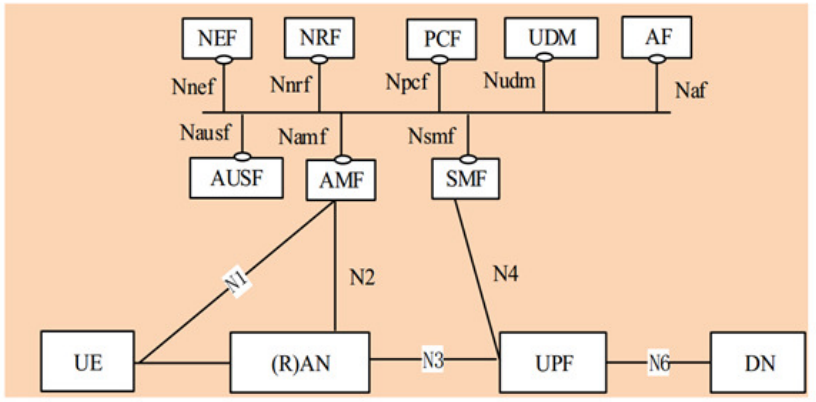
- SMF Functions
  - Session management
    - establishment, modification, release,
  - UE IP address allocation & management,
  - DHCP functions,
  - termination of NAS signalling related to session management,
  - DL data notification,
  - traffic steering configuration for UPF for proper traffic routing.

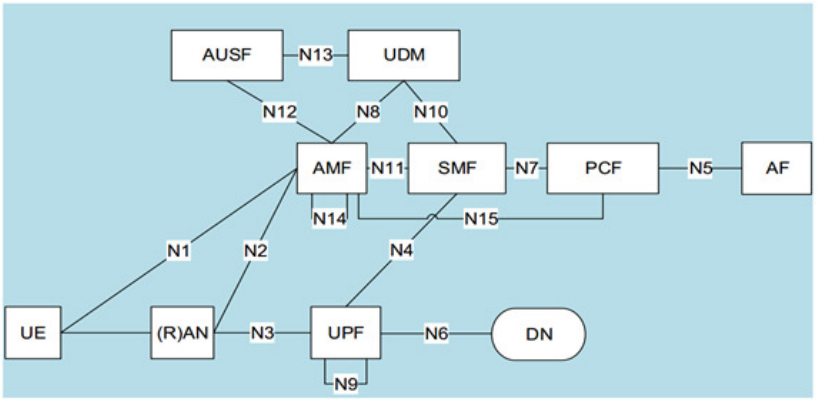
There can be several SMF for each UE, each for a slice.



User plane function (UPF)

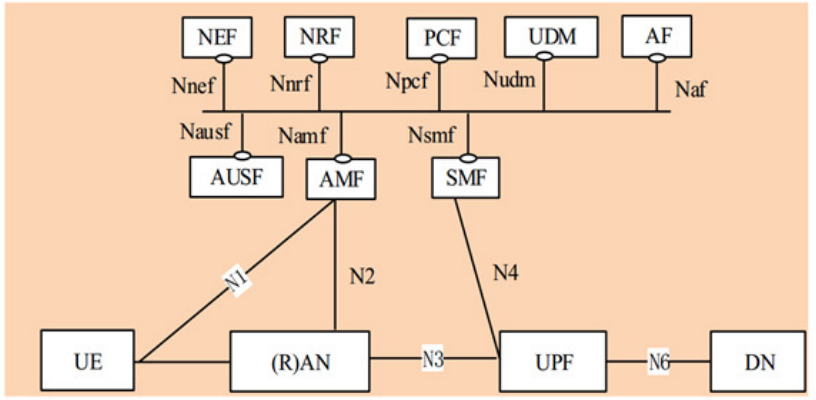
- Replaces S/PGW
- Anchor point for Intra-/Inter-RAT mobility (when applicable).
- External PDU Session point of interconnect to Data Network.
- Packet routing & forwarding.
- Packet inspection.
- User Plane part of policy rule enforcement.
- Lawful intercept (UP collection).
- Traffic usage reporting.
- QoS handling for user plane, e.g. UL/DL rate enforcement, Reflective QoS marking in DL.
- Uplink Traffic verification (SDF to QoS Flow mapping).
- …

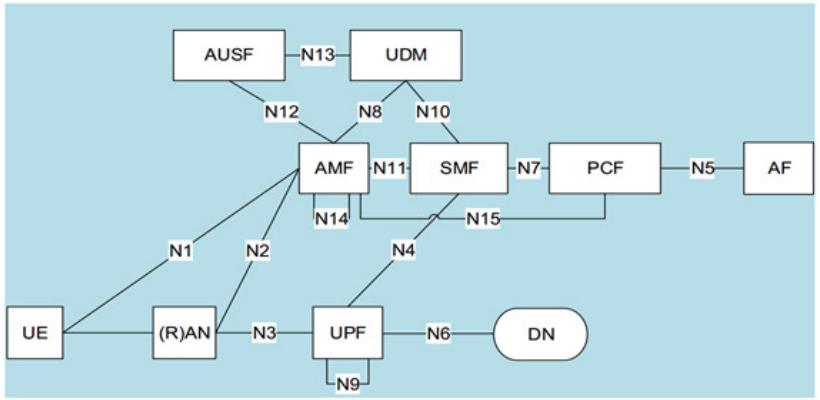




NF Repository (NRF) Function

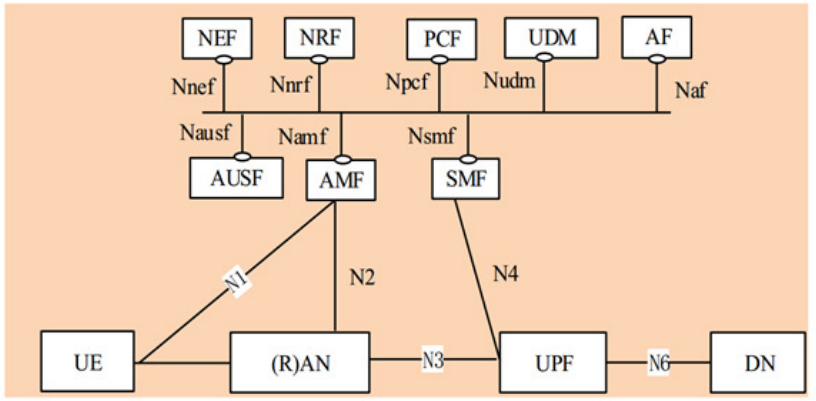
- Control plane function communicate with each other through NRF over service based interface (using http 2.0 transport).
- The NRF provides service discovery between individual NFs.
- It maintains profiles of network function instances and their supported services.
- The SMF discovery and selection request is initiated by the AMF when a request to establish a data session is received from the UE.
- The NRF is used to assist the discovery and selection of the correct SMF.
- In a network slice content, the AMF queries the NRF to select an SMF that is part of a network slice instance based on S-NSSAI, UE subscription profile and operator policy when the UE requests a session to be set up.

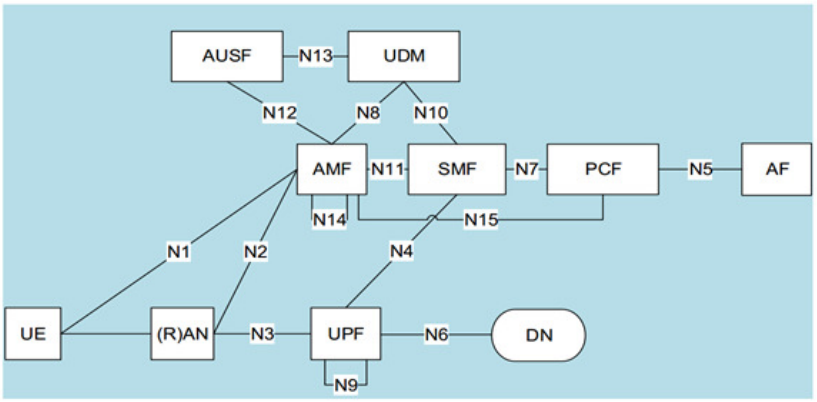




Policy Control Function (PCF)

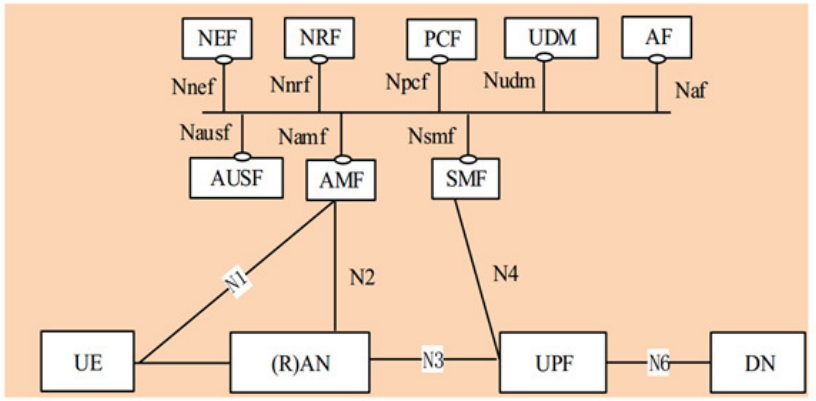
- Similar to PCRF.
- It supports
  - unified policy framework,
  - providing policy rules to CP functions,
  - access subscription information for policy decisions in UDR.

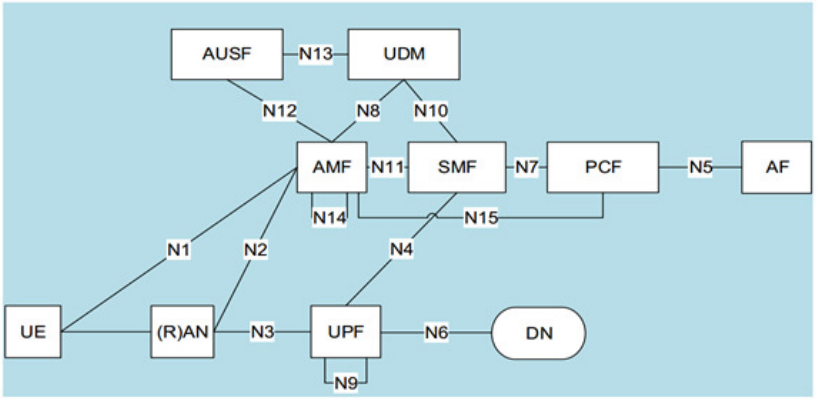




Unified Data Management (UDM)

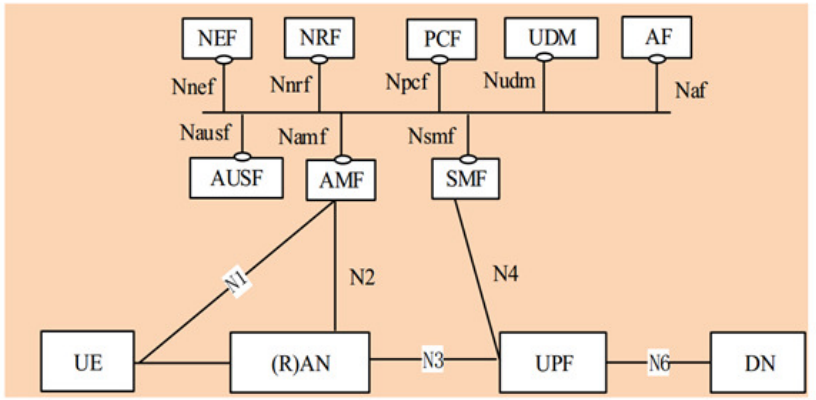
- Replaces SSH.
- Generation of 3GPP AKA Authentication Credentials.
- User Identification Handling (e.g. storage and management of SUPI for each subscriber in the 5G system).
- Access authorization based on subscription data (e.g. roaming restrictions).
- Subscription management.
- …

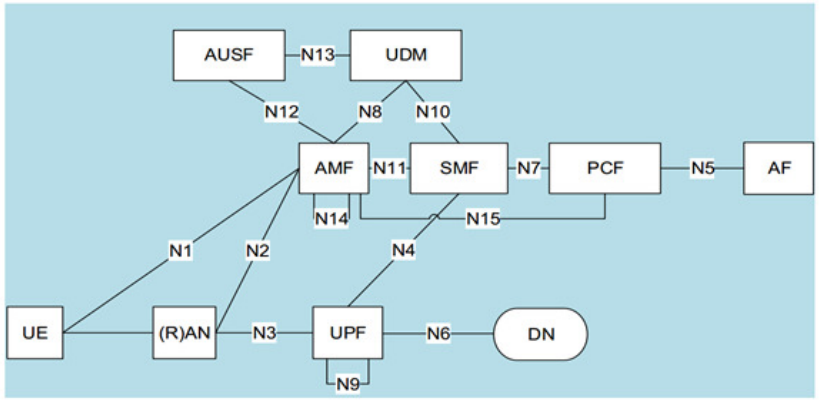




Slice Selection Function (NSSF)

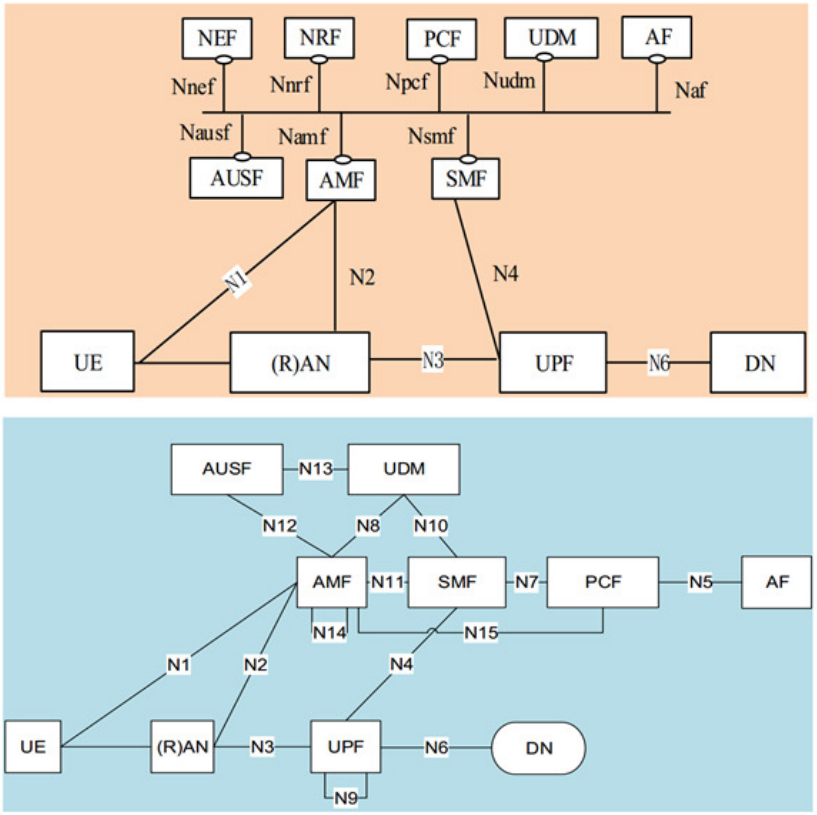
- selecting of the Network Slice instances to serve the UE, determining the allowed NSSAI, determining the AMF set to be used to serve the UE.





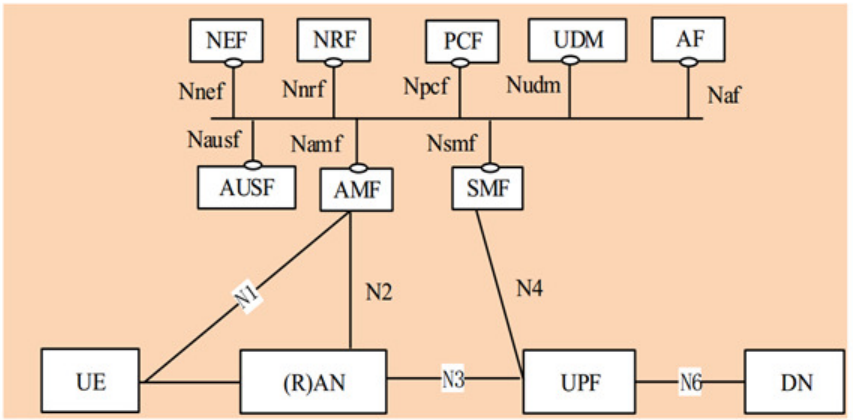
Network Exposure Functions (NEF)

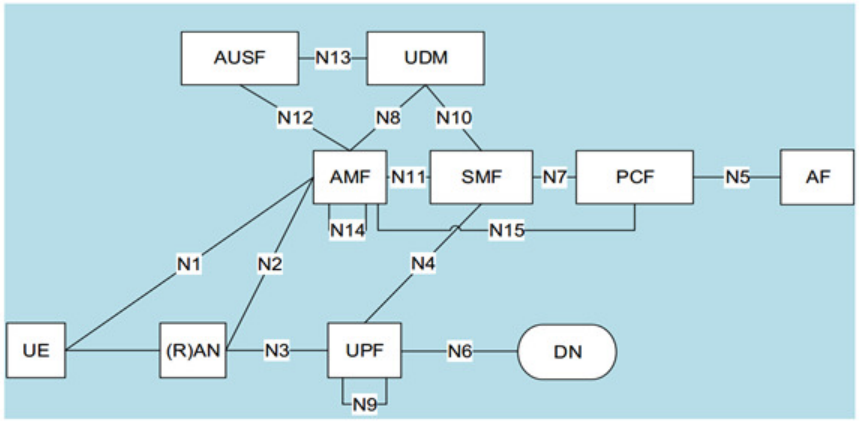
- 3GPP NFs expose capabilities and events to other NFs via NEF.
- The Network Exposure Function receives information from other network functions (based on exposed capabilities of other network functions).
- NEF stores the received information as structured data using a standardized interface to a Unified Data Repository (UDR).
- The stored information can be accessed and "re-exposed" by the NEF to other network functions and Application Functions, and used for other purposes such as analytics.



Application Function (AF)

- AF interacts with the 3GPP Core Network in order to provide services, for example to support:
  - Application influence on traffic routing,
  - Accessing Network Exposure Function,
  - Interacting with the Policy framework for policy control,
- AFs trusted by the operator can be allowed to interact directly with relevant Network Functions.
- AFs not allowed by the operator to access directly the Network Functions shall use the external exposure framework via the NEF to interact with relevant Network Functions.
- The functionality and purpose of Application Functions are only defined in this specification with respect to their interaction with the 3GPP Core Network.





Network Data Analytics Function (NWDAF)

- NWDAF represents operator managed network analytics logical function.
- NWDAF provides **slice specific** network data analytics to a NF.
- NWDAF provides network analytics information
  - i.e., load level information
  - NWDAF is not required to be aware of the current subscribers using the slice.

Automatic Selection

UE (re)selection of PLMN, N3IWF, RAN

AMF Selection by RAN

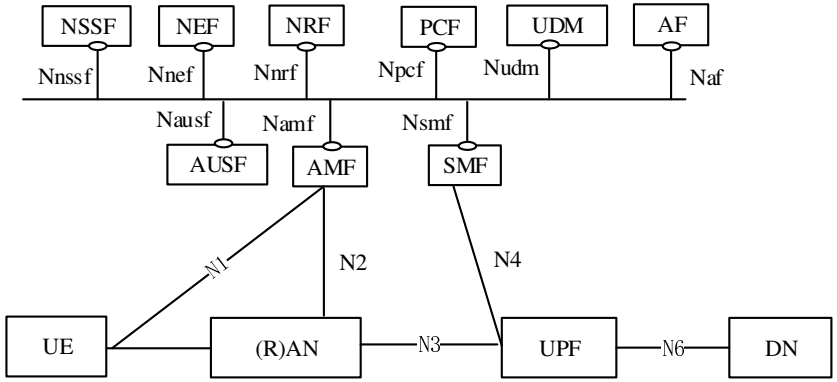
Slice/AMF Selection by AMF

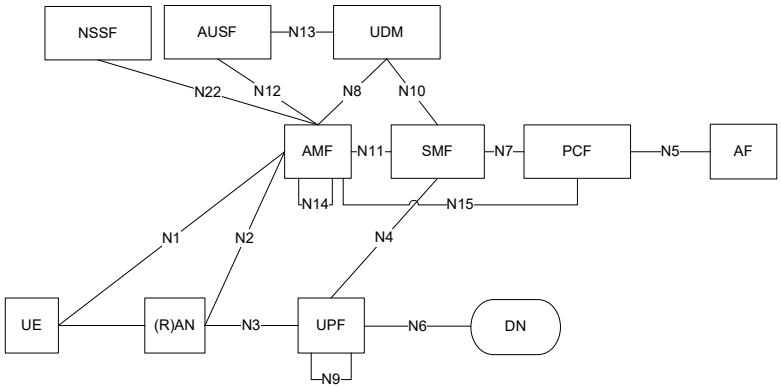
AUSF Selection by AMF

SMF selection by AMF

UPF Selection by SMF

PCE Selection by AMF (UE) and SMF (PDU)

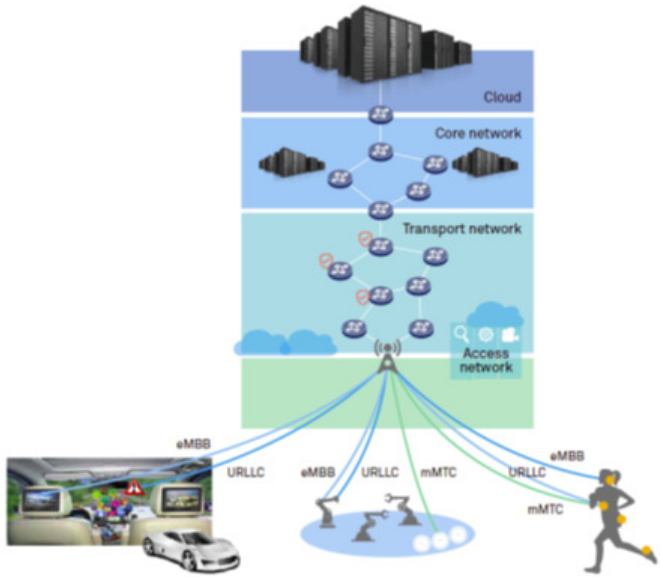




Network Slicing

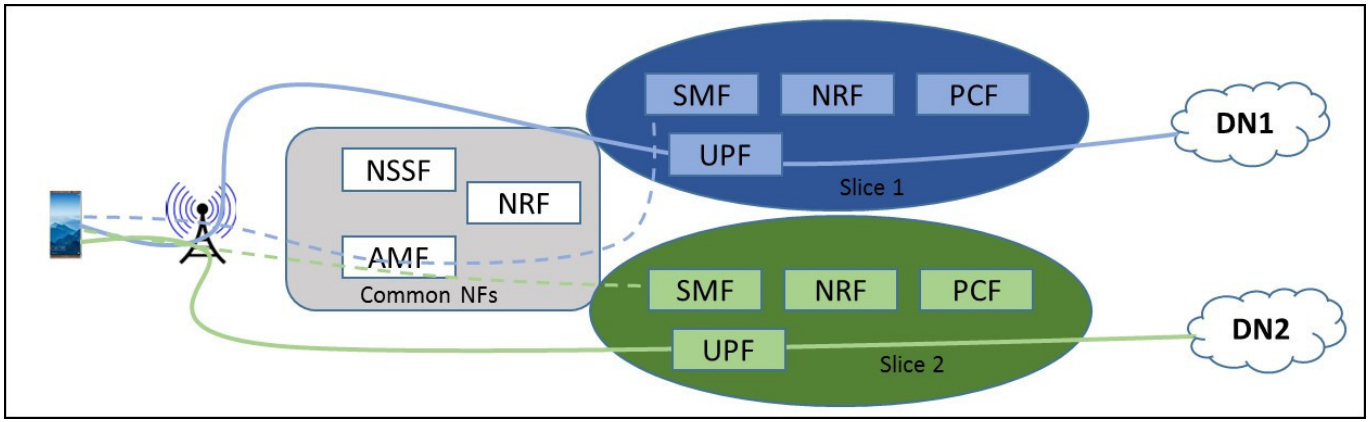
What is a Network Slice?

- A logical end-to-end network
  - dynamically created,
  - meets differentiated SLA requirements,
  - managed independently,
  - isolated from other services,



What is a Network Slice?

- Within a PLMN, a network slice includes:
  - The Core Network Control Plane.
  - User Plane Network Functions.
  - RAN
- Each slice also require
  - Compute resources, storage resources, and networking resources.

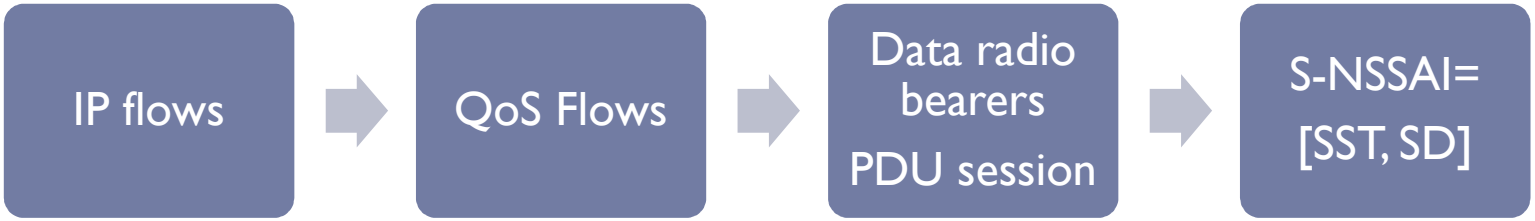


Network Slice Selection Assistance Information

- Network slice instance is the set of functions providing a service.
- Identification of a Network Slice is done via the Single Network Slice Selection Assistance Information (S-NSSAI).
- The NSSAI (Network Slice Selection Assistance Information) is a collection of S-NSSAIs.
- The S-NSSAI **signaled by the UE to the network**, assists the network in **selecting a particular Network Slice** instance.
- 3GPP allows **up to eight (8)** S-NSSAIs in the NSSAI.
- This means **a single UE** may be served by **at most eight Network Slices** at a time.

Network Slice Selection Assistance Information

- S-NSSAI is composed of
  - Slice/Service type (SST): the expected Network Slice behaviour in terms of features and services;
  - Slice Differentiator (SD): optional information that complements the Slice/Service type(s) to differentiate amongst multiple Network Slices of the same Slice/Service type.



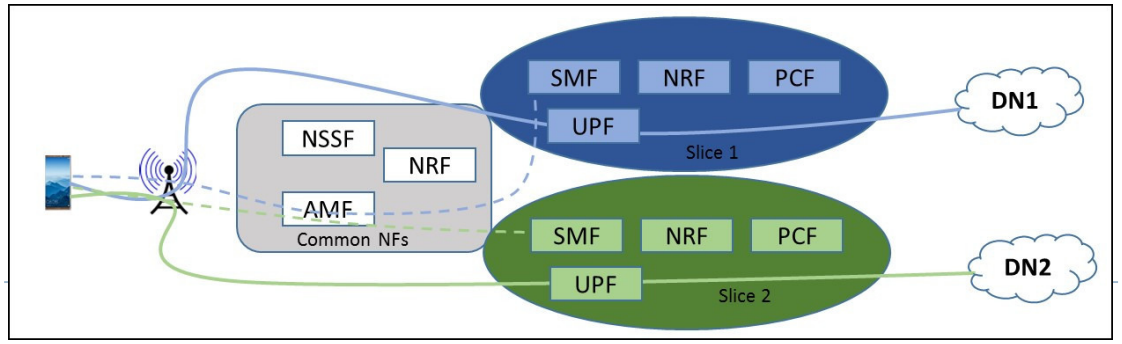
Network Slice Selection Assistance Information

- An S-NSSAI can have standard values (TS 23.501)
  - such S-NSSAI is only comprised of an SST with a standardised SST value
- Non-standard values
  - such S-NSSAI is comprised of either both an SST and an SD
  - or only an SST without a standardised SST value and no SD.

Slice/Service type	SST value	Characteristics.
eMBB	1	Slice suitable for the handling of 5G enhanced Mobile Broadband.
URLLC	2	Slice suitable for the handling of ultra- reliable low latency communications.
MIoT	3	Slice suitable for the handling of massive IoT.

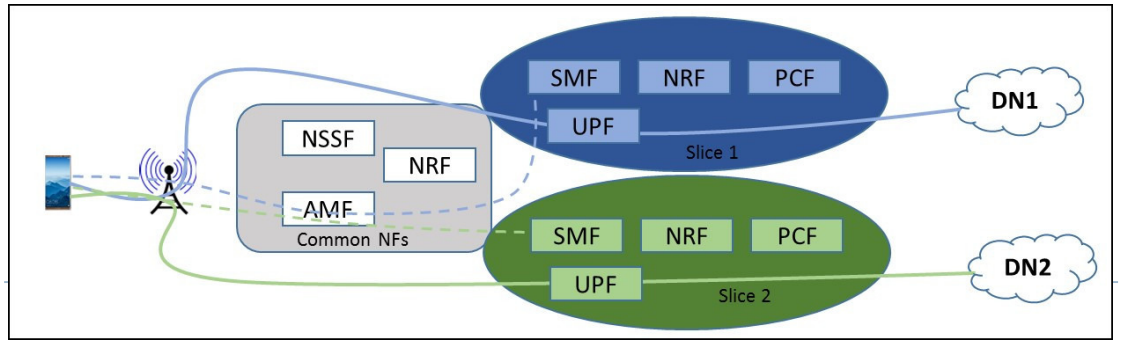
Network Slice Selection

- A network slice instance can be associated with one or more S-NSSAIs.
- Multiple network Slice instances associated with the same S-NSSAI may be deployed in the same or in different Tracking Areas.
- AMF instance serving the UE may logically belong to more than one network slice instance associated with an S-NSSAI.
- One of these Network Slice instances, as a result of the Network Slice instance selection serves a UE that is allowed to use this S-NSSAI.



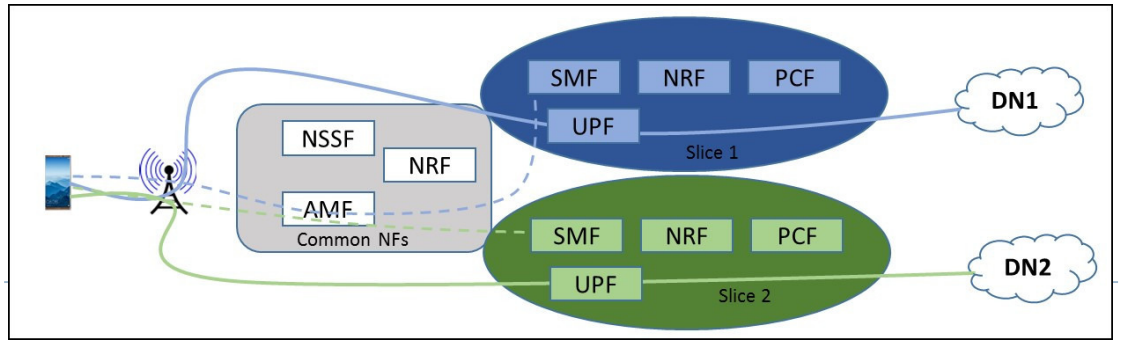
Network Slice Selection

- The Access and Mobility Management Function (**AMF**) instance that is serving the UE **may be shared** between slices.
- Other network functions, such as the Session Management Function (SMF) or the User Plan Function (UPF), may be specific to each Network Slice.
- The Network Slice **instance selection** for a UE is normally triggered as part of the **registration procedure** by the **first AMF** that receives the registration request from the UE.
- This could result in **a change of AMF** if needed. This is done the help of network function repository (NFR).



Network Slice Selection

- AMF may query the UDM to retrieve UE subscription information
- The AMF retrieves the slices that are allowed by the user subscription and interacts with the **Network Slice Selection Function (NSSF)** to select the appropriate Network Slice **instance**.
  - e.g., based on Allowed S-NSSAIs, PLMN ID, etc.
- The Network Repository Function (NRF) is used by AMF for the discovery of the required Network Functions using the selected Network Slice instance.



Network Slice Selection

- The establishment of a PDU session within the selected instances NSSAI is triggered when the AMF receives a Session Management message from UE.
- The AMF discovers candidate Session Management Functions (SMF) using multiple parameters including the S-NSSAI provided in the UE request and selects the appropriate SMF.
- The selection of the User Plane Function (UPF) is performed by the SMF and uses the S-NSSAI.
- The S-NSSAI associated with a PDU Session is provided to the AN, and to the policy and charging entities, to apply slice specific policies.
- During the UE operation, network may decide to change the NSI of the UE.