

Network slicing

Lecture 8,

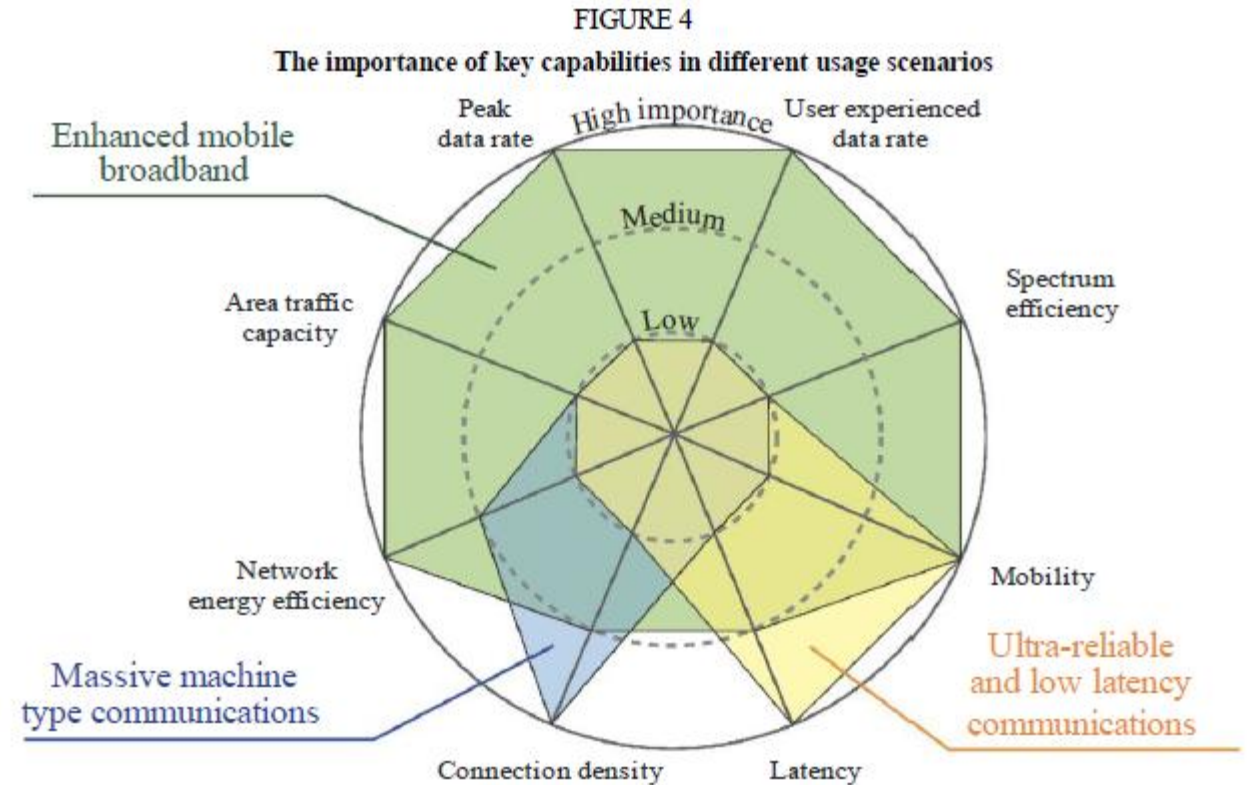
IEE2650: Cellular Communication Technologies

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23.03.2026

Requirements and capabilities (want to serve them all)

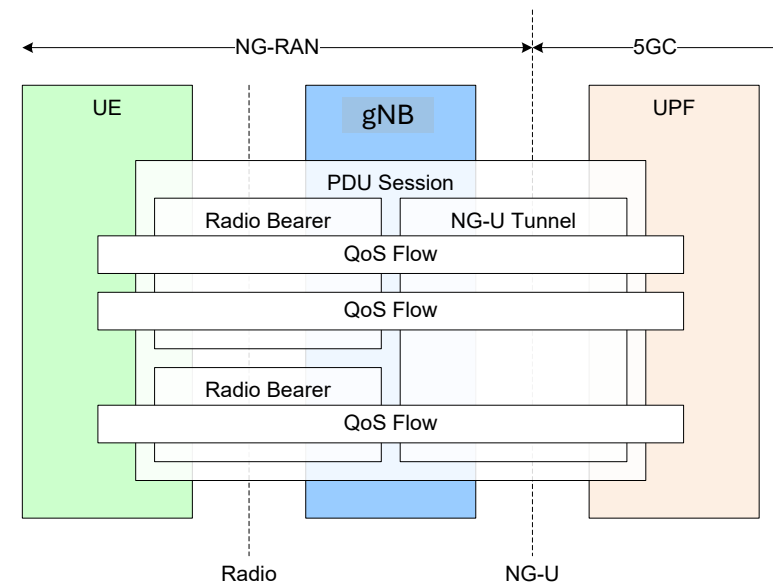
- Usage scenarios: eMBB, mMTC, URLLC
- Capabilities:
 - Peak data rate
 - UE experienced data rate
 - Latency
 - Mobility
 - Connection density
 - Energy efficiency
 - Spectrum efficiency
 - Area traffic capacity
- Other capabilities
 - Spectrum and bandwidth flexibility
 - Reliability
 - Resilience
 - Security and privacy
 - Operational lifetime



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QoS in 5G

- The types of Quality of Service (QoS) Flows are (TS 38.300):
 - Guaranteed Bit Rate, (GBR)
 - Non-GBR
 - Delay Critical GBR
- QoS profile contains QoS parameters (TS 23.501, TS 38.300):
 - 5G QoS Identifier (5QI)
 - Allocation and Retention Priority (ARP) - indicates relative importance of QoS Flow. Values 1-15, lower value means higher priority.
 - Reflective QoS Attribute (RQA) - if Reflective QoS is supported by UE and 5GC then the same QoS rules may be set to uplink user plane traffic flow that are present in downlink user plane flow.
 - Notification control - it can be requested a notification if guaranteed bit rate can not be guaranteed for a while for a QoS Flow during its lifetime.
 - Flow Bit Rate (FBR) - Guaranteed FBR or Max FBR to be provided by the network to the QoS Flow over the Averaging Time Window.
 - Aggregate Maximum Bit Rate (AMBR) - per session or per UE.
- 5QI is associated with QoS characteristics (TS 23.501, TS38.300):
 - Resource Type - GBR, Delay Critical GBR, Non-GBR
 - Priority level - lowest value means higher priority
 - Packet Delay Budget (includes CN delay)
 - Packet Error Rate (PER)
 - Averaging Window - for GBR and Delay Critical GBR
 - Maximum Data Burst Volume (MDBV) - for Delay Critical GBR



Quarantee SLA

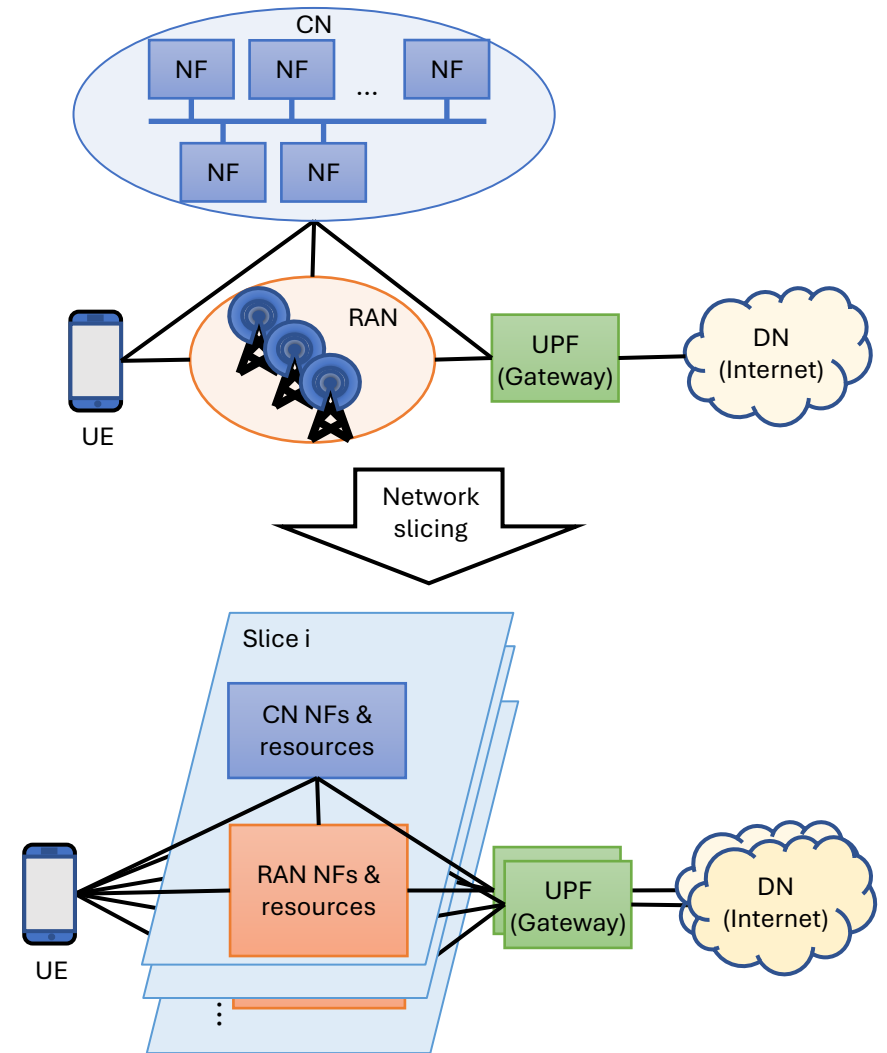
- Unsliced network provides best-effort QoS
- Slices must provide guaranteed QoS according to SLA
- How to guarantee SLA if insufficient resources
 - Optimization
 - Trade-offs

Network slicing

- Network slicing enables to build multiple logical networks on top of physical infrastructure
- Network services are implemented as network functions (NF)
- Virtualization → VNF can run on general-purpose hardware with sufficient computing, storage and networking resources
- Slicing benefits are resource allocation efficiency and better SLA satisfaction

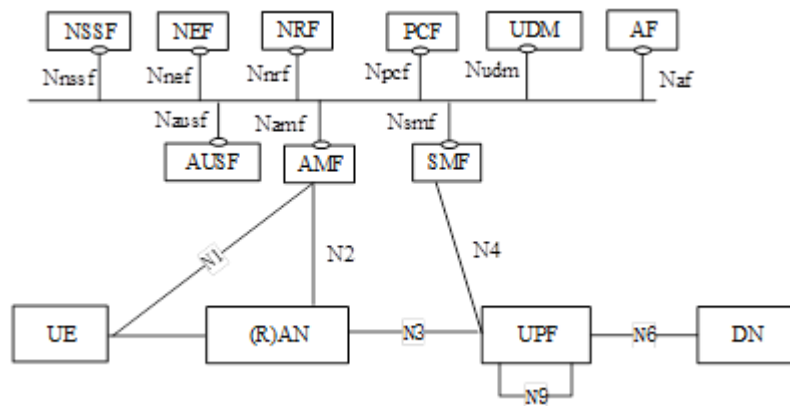
CN – core network

RAN – radio access network

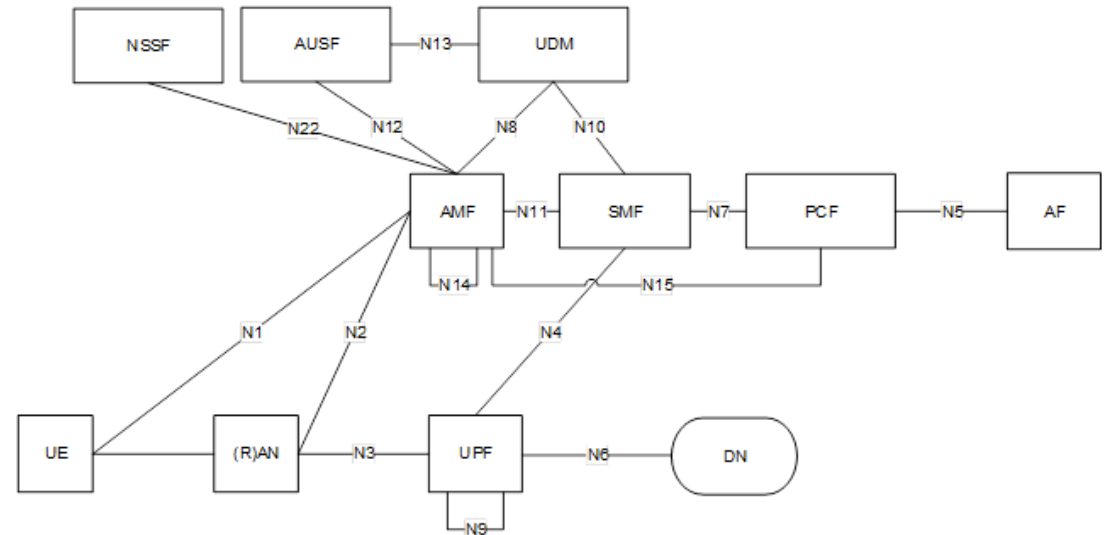


5GS architecture

Service Based Architecture

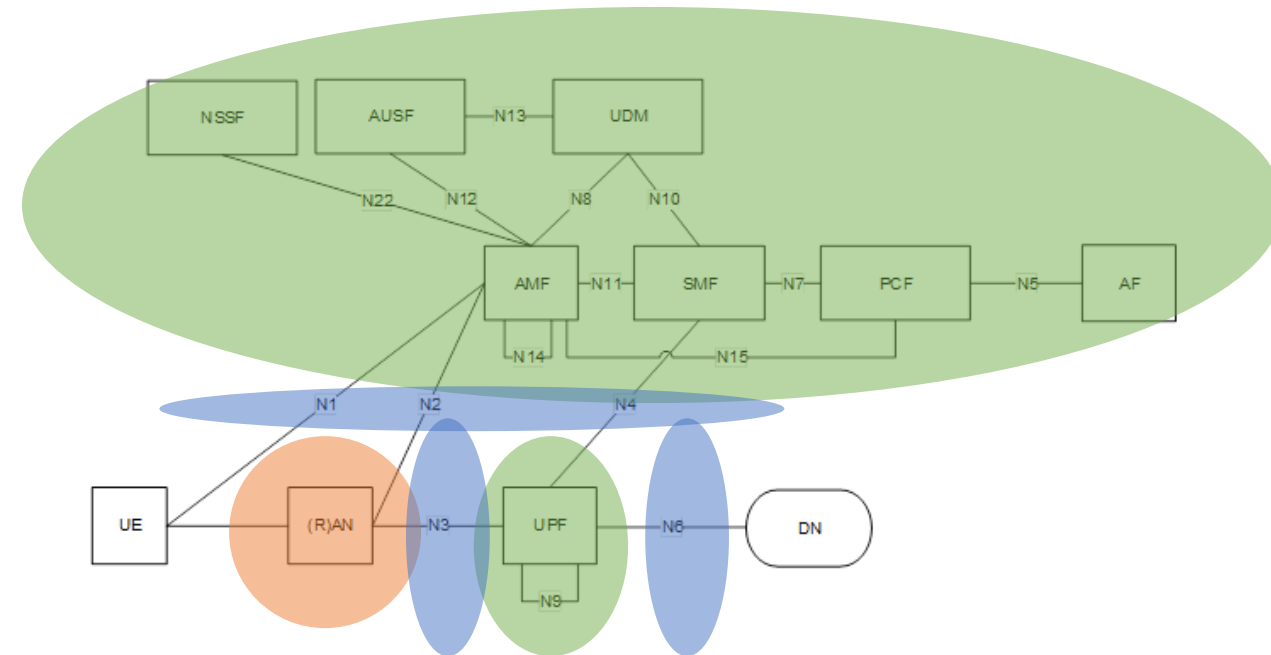


With reference points



5G system (5GS)

- Core network (CN)
- Radio access network (RAN)
- Transport network (TN) connects CN and RAN.
 - Usually, a SDN is used for TN.
- End-to-end (E2E) slice: slice has allocated resources from both subnetworks CN and RAN

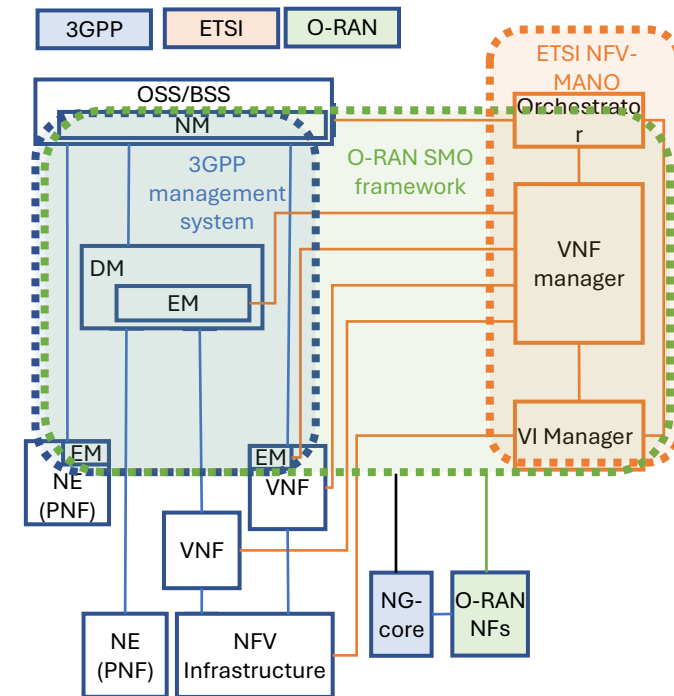


Software defined

- Software defined network (SDN)
 - Separate control plane and data plane
 - Protocol example OpenFlow, used to configure network devices (switches, routers)
- Software defined radio (SDR)
 - General-purpose hardware
 - Software generates signals to send and receives specific to the technology
- Control plane and user plane separation (CUPS) – in LTE and 5G

SDO approaches to infrastructure

- 3GPP
- ETSI
- O-RAN



Service provider – service customer relationships

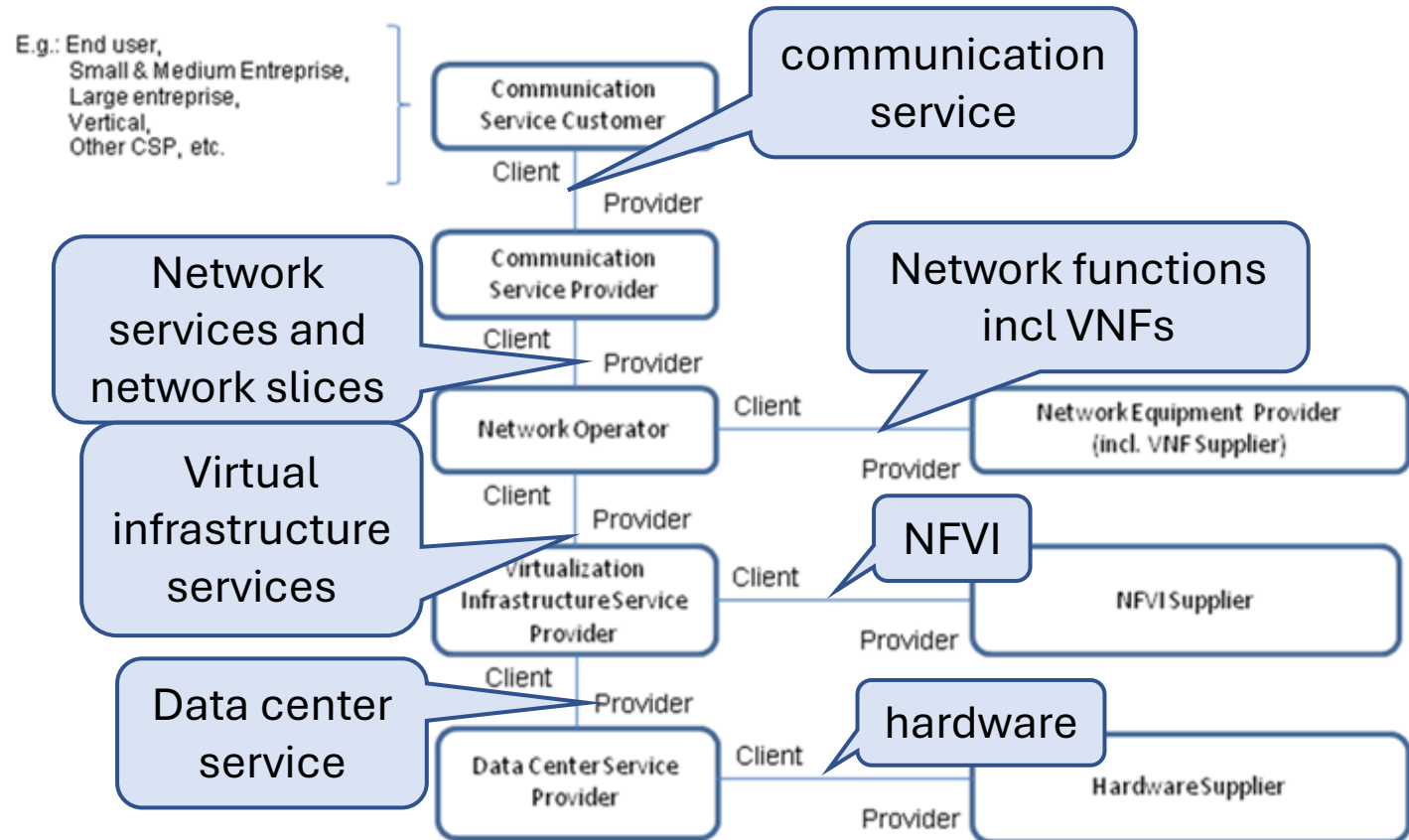
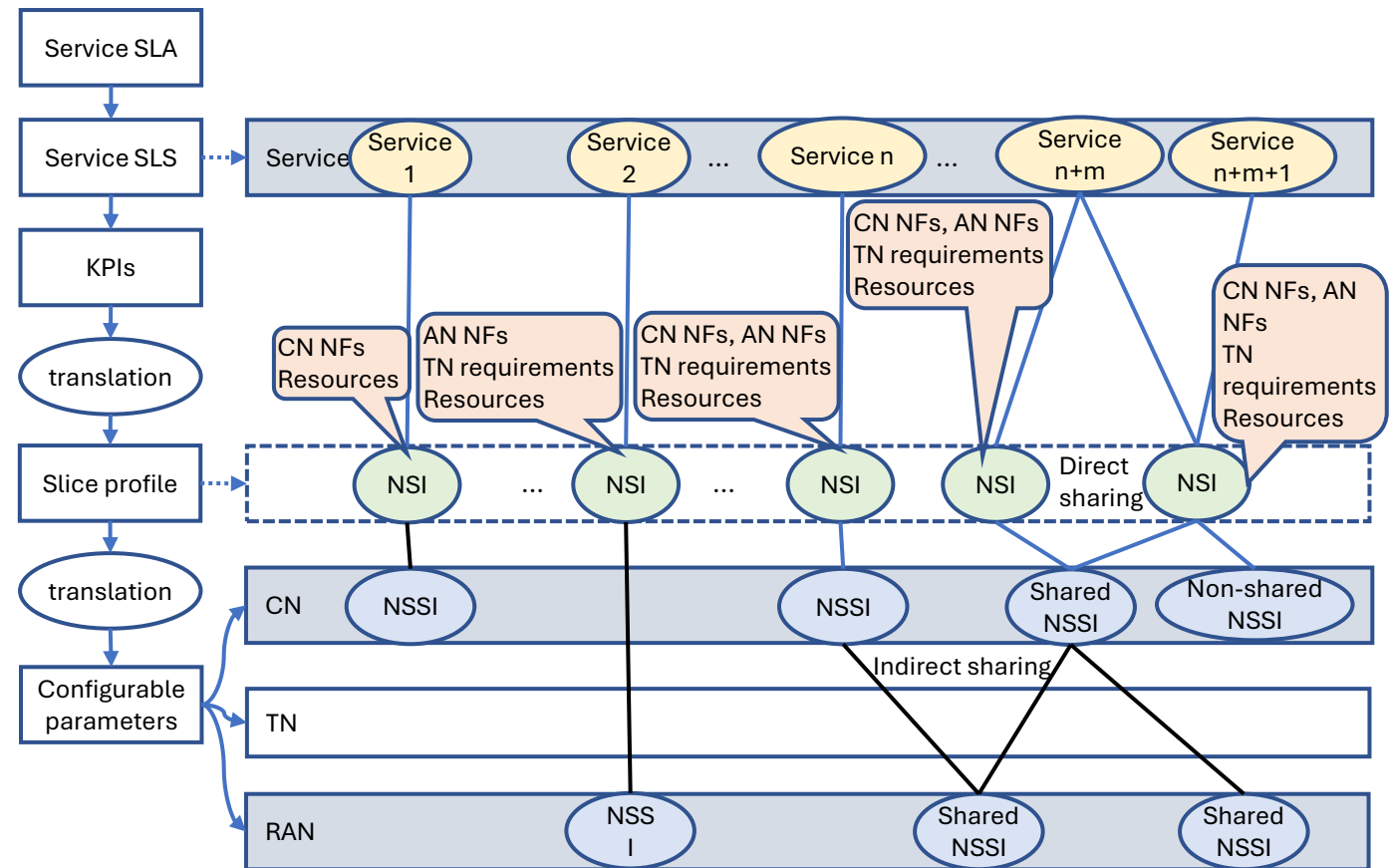


Figure 4.8.1: High-level model of roles

Slice profile

- defining a slice from service level agreement (SLA)
- Service level specification (SLS) is derived that contains a set of service level requirements
- Key performance indicators (KPI) can be formulated and translated to a slice profile
 - KPIs are measurable indicators of performance and quality of service (QoS) that is specified by the requirements.
- Network slice contains network slice subnets in CN and RAN domain, called core and RAN network slice subnets (NSS) respectively.
 - Network slice subnet may be shared or non-shared.
 - Shared network slice subnet may be shared by many network slice subnets directly or indirectly (via other shared network slice subnets)
- Network slice subnet instance (NSSI)



Network slice identifier

- The information about all slices is called Network Slice Selection Assistance Information (NSSAI) that consists of up to 8 S-NSSAI-s, i.e., slice identifiers.
- Single Network Slice Selection Assistance Information (S-NSSAI) and it consists of two fields (3GPP TS 23.501, 3GPP TS 38.300):
 - mandatory Slice/Service Type (SST), field length is 8 bits (256 different values)
 - optional Slice Descriptor (SD), field length is 24 bits (16777216 different values). If SD does not exist, then SD has a value of FFFFFFFF (TS 23.003).
- The standardized SST values are defined in 3GPP TS 23.501 and support roaming:
 - SST=1 enhanced Mobile Broadband, eMBB
 - SST=2 massive Internet of Things, MIoT (to serve mMTC vertical)
 - SST=3 Ultra Reliable Low Latency Communication, URLLC
 - SST=4 Vehicle to everything, V2X (added in Rel-16)
 - SST=5 High-Performance Machine-type Communications (HMTC) (added in Rel-17)
- If non-standard S-NSSAI is used, then this S-NSSAI is used only on the Public Land Mobile Network (PLMN) to which it is associated.

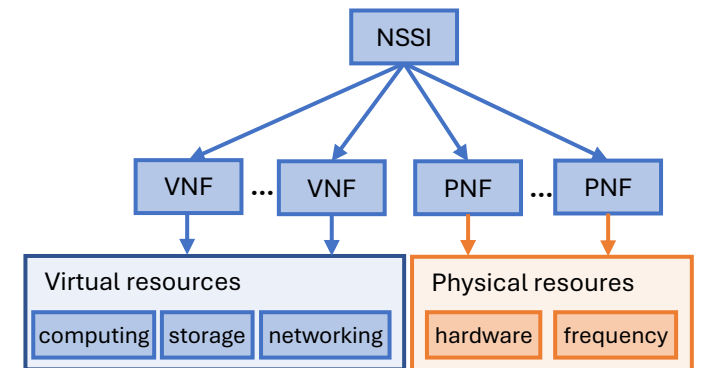
3GPP. TS 23.501 - System architecture for the 5G System (5GS); Stage 2. 2020. URL: <https://www.3gpp.org/DynaReport/23501.htm>.

3GPP. "TS 38.300 NR; NR and NG-RAN Overall Description; Stage 2". (2021). URL: <https://www.3gpp.org/DynaReport/38300.htm>

3GPP. TS 23.003. Numbering, addressing and identification.2021. URL: <https://www.3gpp.org/DynaReport/23003.htm> .

Resources

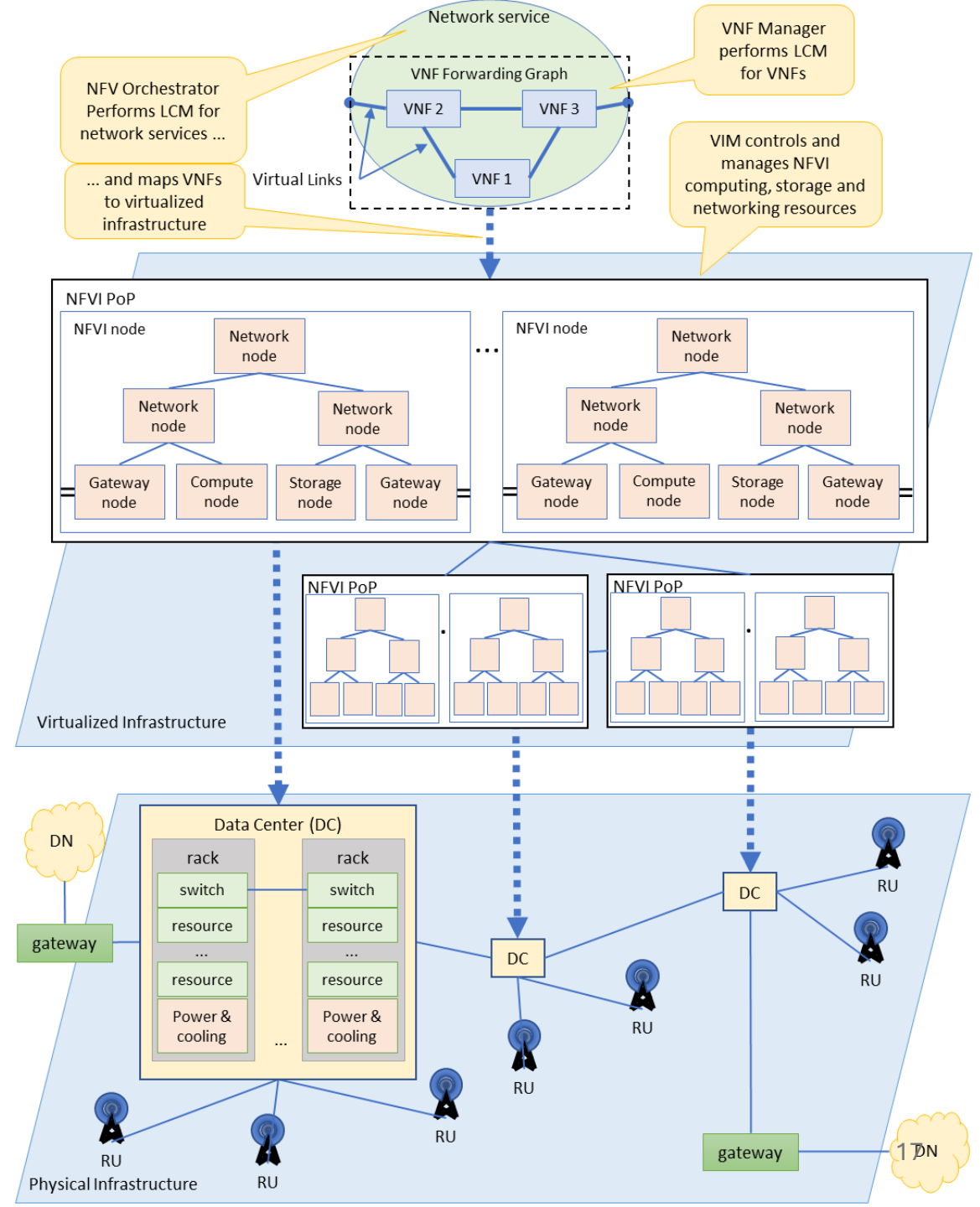
- Network slice is not a slice of the network but slice of the resources
- Isolation
 - No interference



Virtualization

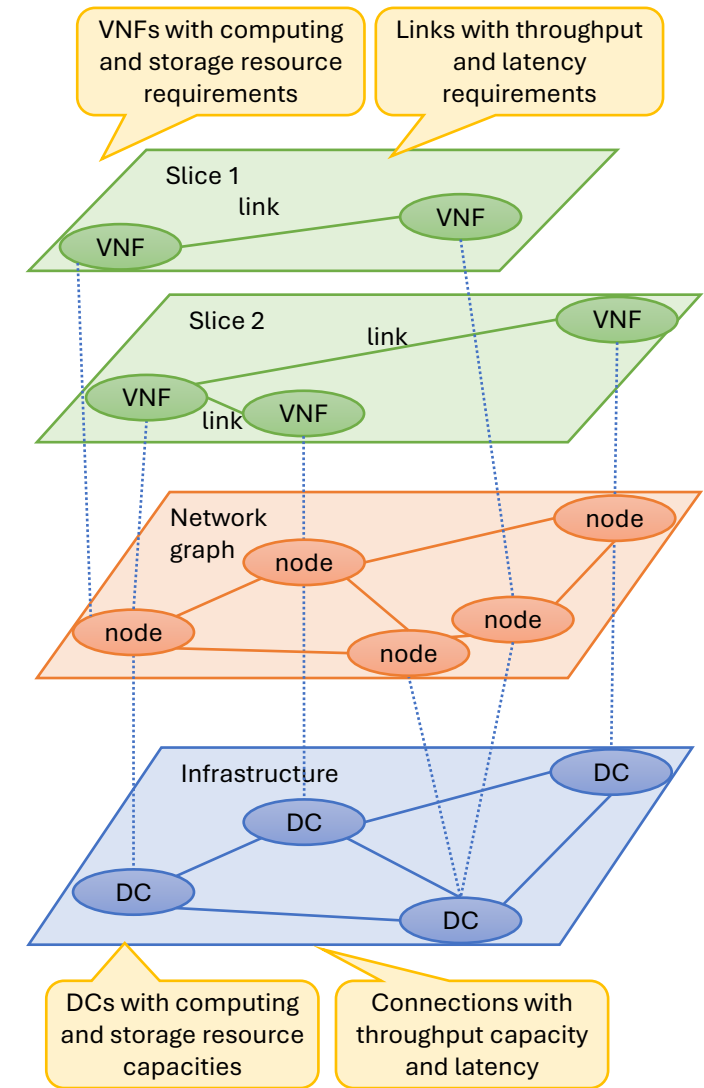
- The network service is realized using network functions.
 - VNFs and PNFs, VNF Forwarding Graphs and Virtual Links.
- The VNF runs on Network Function Virtualization Infrastructure (NFVI) node
- Several NFVI nodes are physically located in NFVI-PoP that contains physical racks for NFVI node constituents.
- Data Centers (DC) are located in different geographical locations.

ETSI. GS NFV-MAN 001 V1.1.1. Network Functions Virtualisation (NFV); Management and Orchestration. Tech. rep. 2014. URL: https://portal.etsi.org/webapp/workprogram/Report_WorkItem.asp?WKI_ID=41954 .

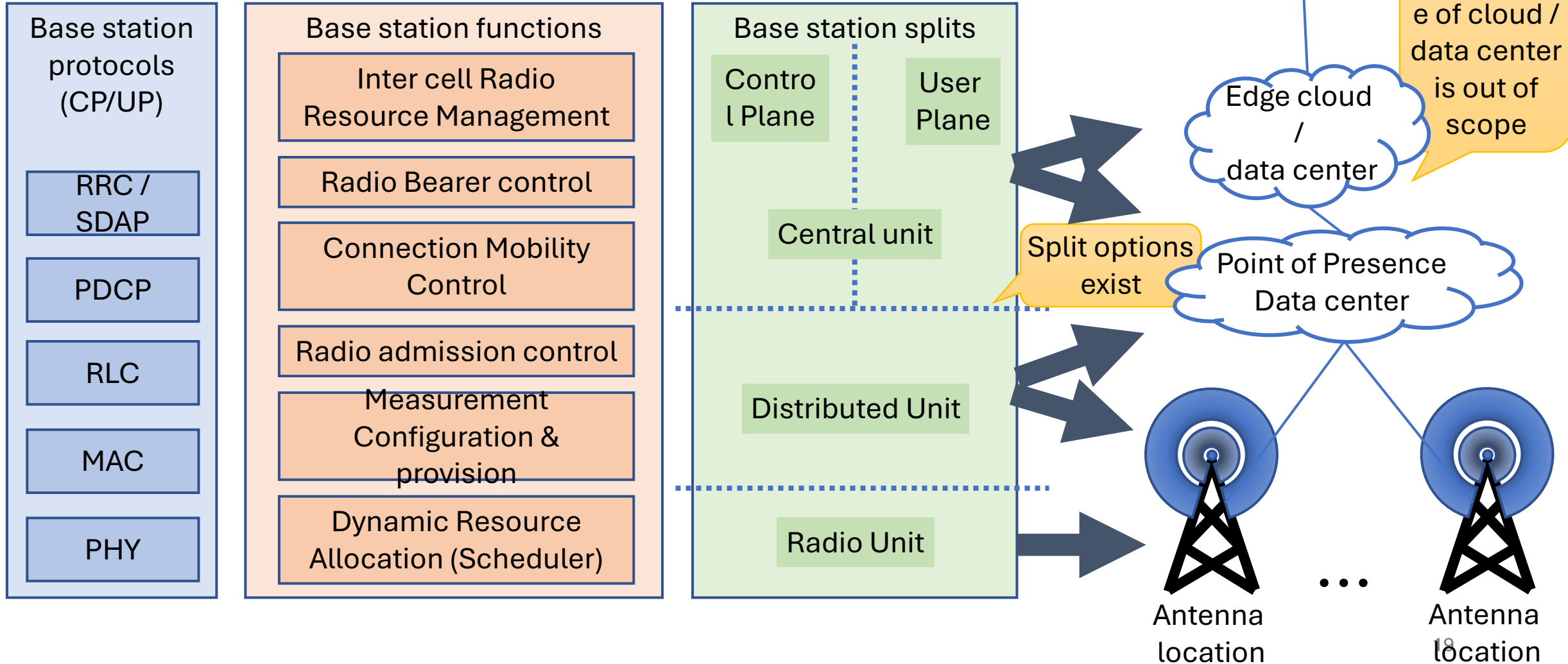


VNF placement

- mapping of VNFs to nodes and to physical infrastructure
- VNFs in network slice formulate the service function chain (SFC) that can be represented as graph with nodes as VNFs and links as connections between VNFs
- physical infrastructure consists of connected DC-s with resources
- VNF Orchestrator deals with finding optimal placement for VNFs in the NFV Infrastructure.

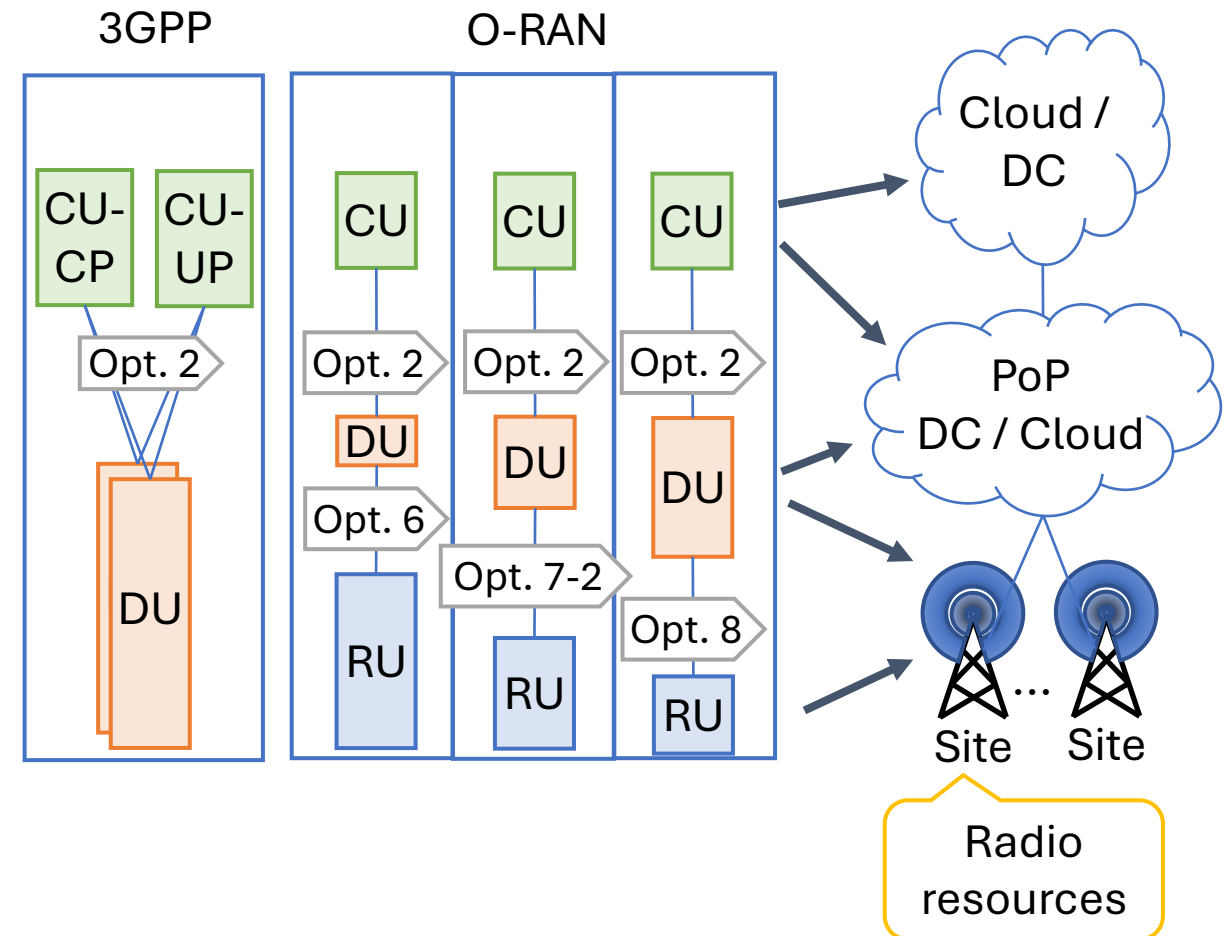


5G NR BS



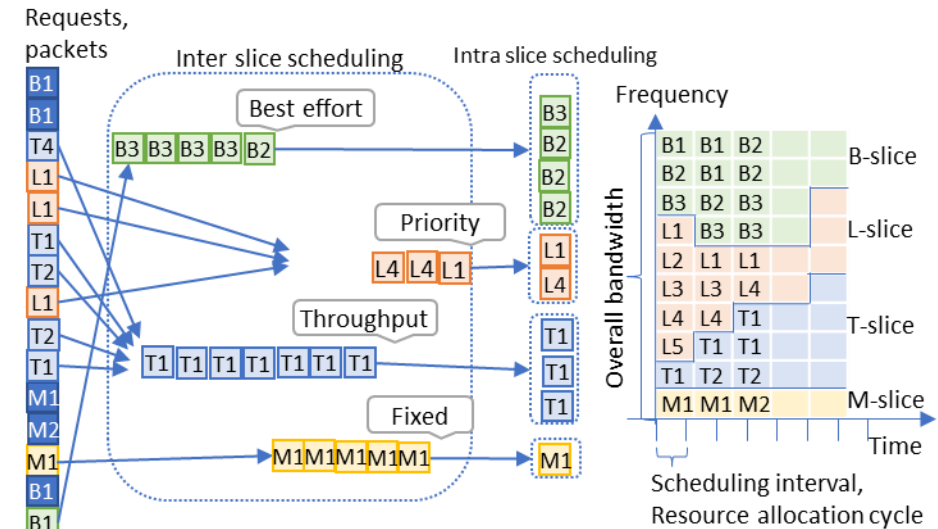
Integrated vs disintegrated RAN

- Monolith gNB disaggregated and split
- VNFs use computing, storage and networking resources
- PNFs (antennas, RU) use radio resources
- Resource allocation is the most relevant research topic



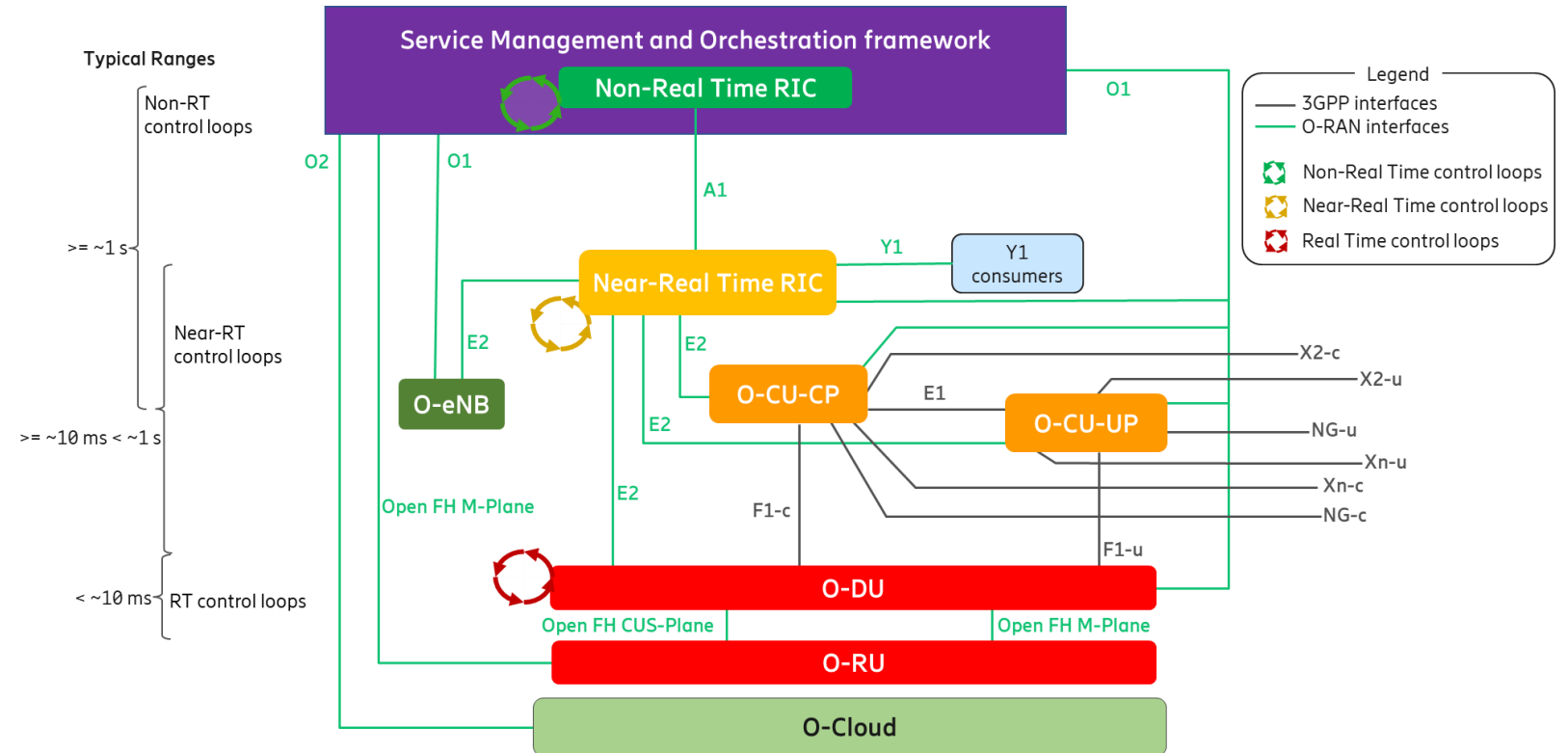
Radio resource allocation, i.e. scheduling

- Levels of scheduling with slicing - inter-slice, intra-slice and both inter- and intra-slice schedulers.
- Domains of scheduling - time domain, frequency domain, both.
- Length of scheduling interval or bandwidth allocation cycle
- Satisfy different SLAs
- Multi-step RB schedulers
- Scope - the resources to be scheduled can be located on single or on multiple cells/BSs.
- Input to scheduler
- Transmit power management
- Optimization goal



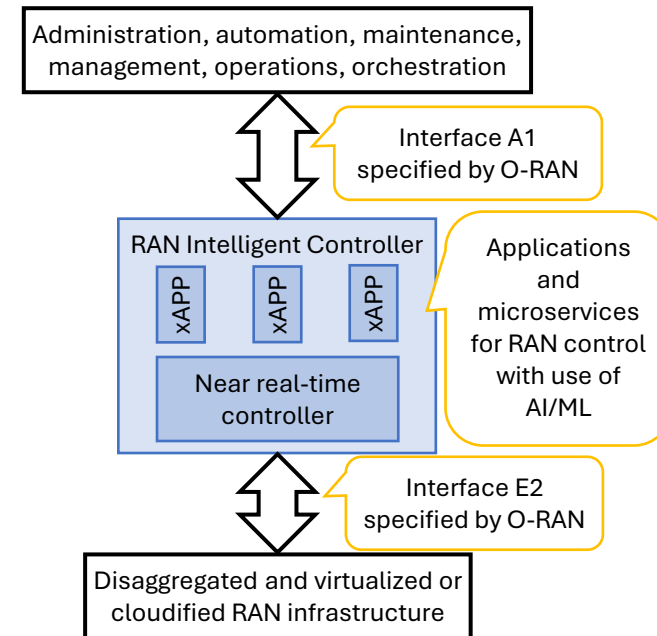
O-RAN architecture

- Open interfaces



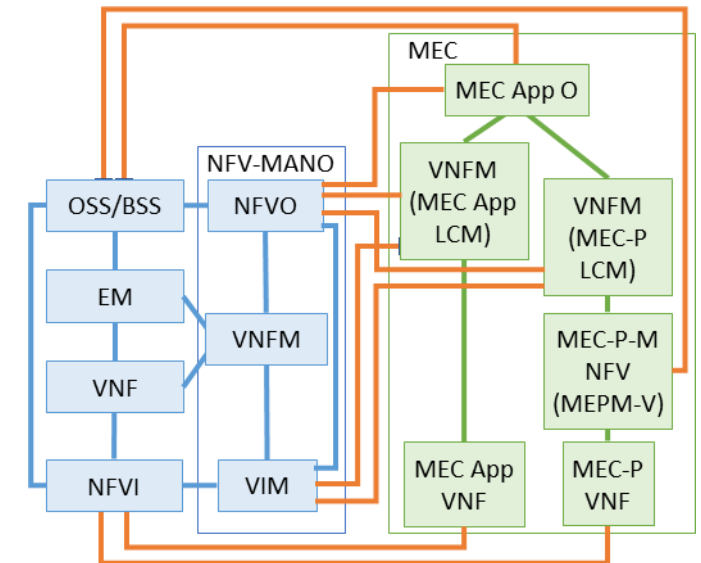
O-RAN approach to RAN control

- RAN intelligent controller (RIC)
 - For near-real-time (delay 10 ms to 1 s) RAN control
- The xApps are applications and microservices operate near-real-time control loop with the possibility to use trained AI/ML models.



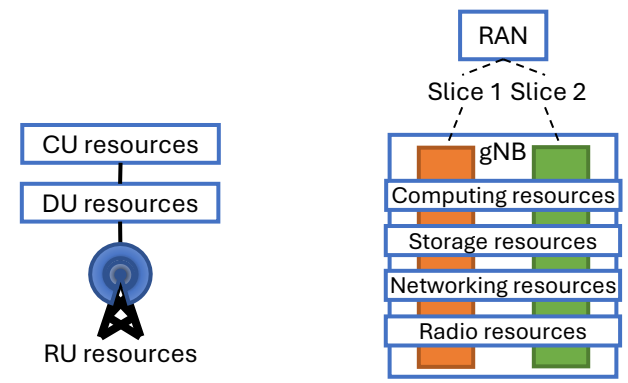
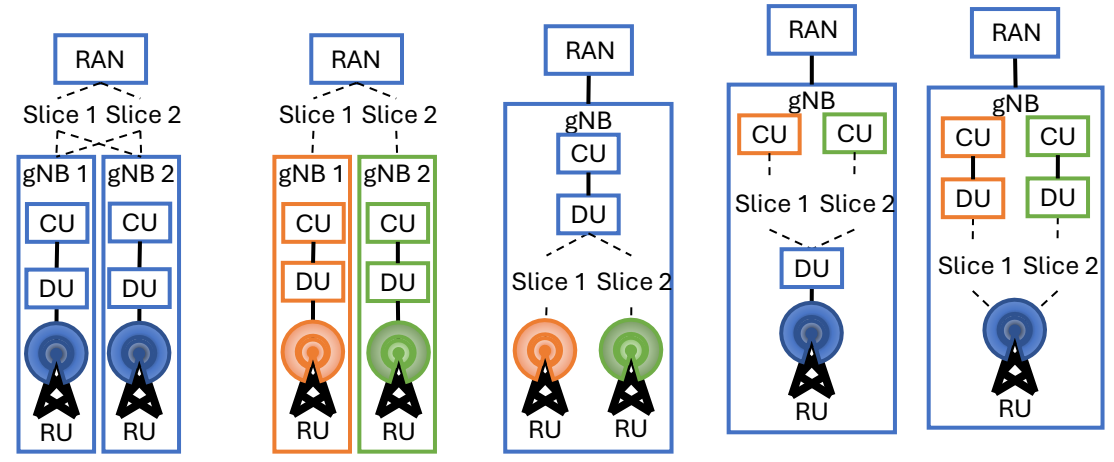
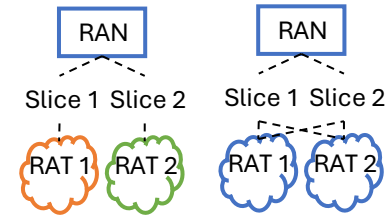
Infrastructure for edge computing

- Multiaccess edge computing (MEC) platform
 - Outside of 5GS
 - Similar NFV architecture
 - Connected to NFV-MANO



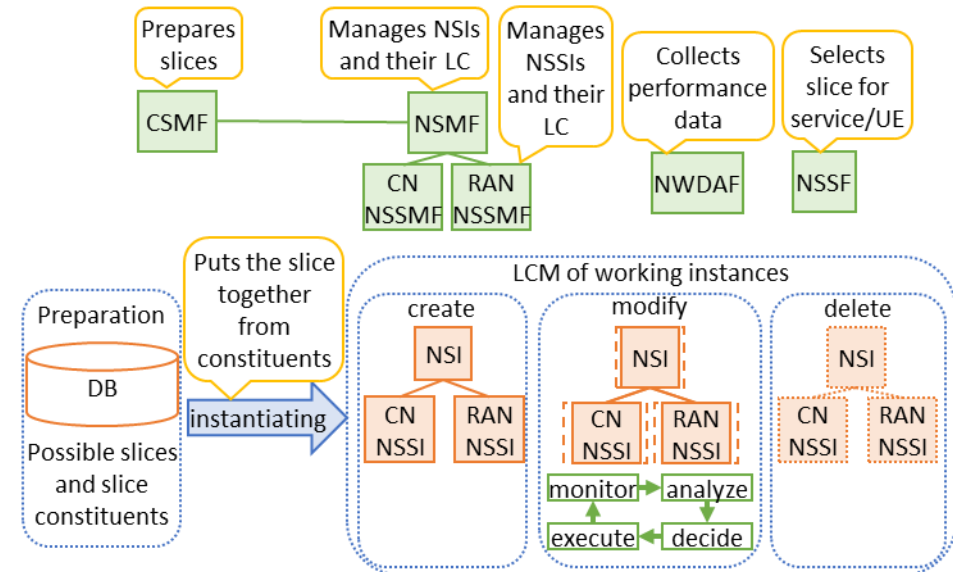
RAN slicing options

- RAT based slicing
- RAN node based slicing
- Resource based slicing.



Slice life cycle management

- Life cycle
- Management using closed control loop (CCL)

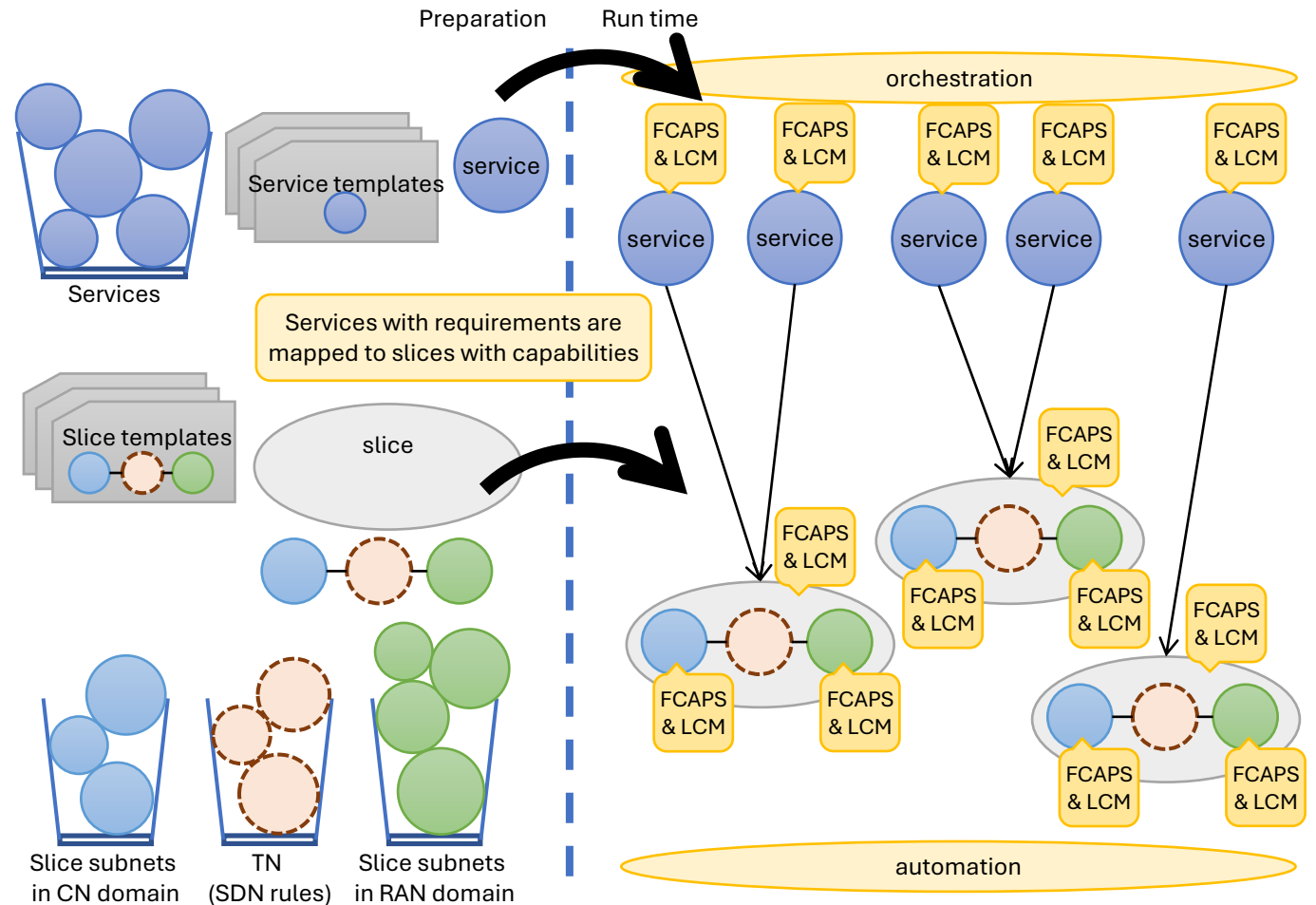


3GPP. TS 28.530 - Management and orchestration;
Concepts, use cases and requirements. 2020.

URL: <https://www.3gpp.org/DynaReport/28530.htm>

Manage slices automatically

- Building blocks
- Role of AI/ML:
 - Decide
 - Predict



3GPP 3rd Generation Partnership Project	CU Central Unit	MAC Medium Access Control	NSSMF Network Slice Subnet Management Function	identifier
5GC 5th generation core network	CUPS control and user plane separation	MANO Management and Orchestration	OAI OpenAirInterface software platform to emulate 4G/5G networks	SDK Software Development Kit
5GS 5G System	DC data center	MBR Minimum Bit Rate	OFDM Orthogonal Frequency Division Multiplexing	SDR Software Defined Radio
5QI 5G QoS Identifier	DL downlink - from RAN to UE	MCPTT mission critical push to talk	OSS operations support system	SD-RAN Software defined RAN
AAA Authentication, Authorization, and Accounting	DN Data Network	MCS Modulation and Coding Scheme	PDU Protocol Data Unit (generally a data packet with protocol header)	SINR signal-to-interference-plus-noise ratio
AI Artificial Intelligence	DNN Deep Neural Network	MEC Multi-access Edge Computing	PLMN Public Land Mobile Network	SLA Service Level Agreement
AMF Access and Mobility Management Function	DQL Deep Q Learning	MIoT Massive Internet of Things	PM Performance Management	SLS Service Level Specification
AN Access Network	DQN Deep Q Network	ML Machine Learning	PNF Physical Network Function – the NF that runs on specific hardware	SNPN Stand-alone Non Public Network
API Application Programming Interface	DRL Deep Reinforcement Learning	mMTC massive Machine Type Communication	PoC Proof of Concept	SST Slice/Service Type – mandatory part of slice identifier
ARP Allocation and Retention Priority	DU Distributed Unit	MVNO Mobile Virtual Network Operator	PoP Point of Presence	TBS Transport Block Size
AUSF Authentication Server Function BDA Big Data Analytics	eNB e Node B - a 4th generation RAN base station	NBI Northbound Interface (to communicate with higher level component)	PS Public Safety	TN Transport Network
BE Best Effort	ETSI European Telecommunications Standards Institute	NF Network Function	QoS Quality of Service	TTI Transmission Time Interval
BS Base Station	FCAPS Fault, Configuration, Accounting, Performance, Security Management	NFV Network Function Virtualization	RAN Radio Access Network	UE User Equipment - mobile user device
BSS Susiness Support System	GBR Guaranteed Bit Rate	NFVI Network Function Virtualization Infrastructure	RAT Radio Access Technology	UDM User Data Management
BWP Bandwidth Part	gNB g Node B - a 5th generation RAN base station	NFVO Network Function VirtualizationOrchestrator	RLC Radio Link Control	UL uplink - from UE to RAN
CBR Constant Bit Rate	GSMA Global System for Mobile communication Association	NGRAN Next Generation Radio Access Network - same as NR	RQA Reflective	UP User Plane
CN Core Network	IoT Internet of Things	NR New Radio - evolution from LTE (4G RAN) to 5G	QoS Attribute	UPF User Plane Function
COTS Commercial Off-The Shelf	IQ data In-phase and Quadrature data (complex signal representation)	NSI Network Slice Instance	RRM Radio Resource Management	URLLC Ultra Reliable Low Latency Communication
CP Control Plane	KPI Key Performance Indicator	NSM Network Slice Manager	RU Radio Unit	V2X Vehicle to everything
CPU Central Processing Unit	LCM Lifecycle Management	NSMF Network Slice Management Function	SBA Service Based Architecture	VIM Virtual Infrastructure Manager
CQI Channel Quality Indicator	LSTM Long Short-Term Memory	NSSAI Network Slice Selection Assistance Information	SBI Southbound Interface (to communicate with lower level component)	VNE Virtual Network Embedding (mapping virtual resources to physical hardware)
CRAN Cloud RAN	LTE Long Term Evolution - 4G mobile cellular network	NSSI Network Slice Subnet Instance	SCS Subcarrier Spacing	VNF Virtual Network Function - the NF that runs on general purpose hardware
CSMF Communication Service Management Function			SD Slice Descriptor - optional part of slice	VNFM Virtual Network Function Manager