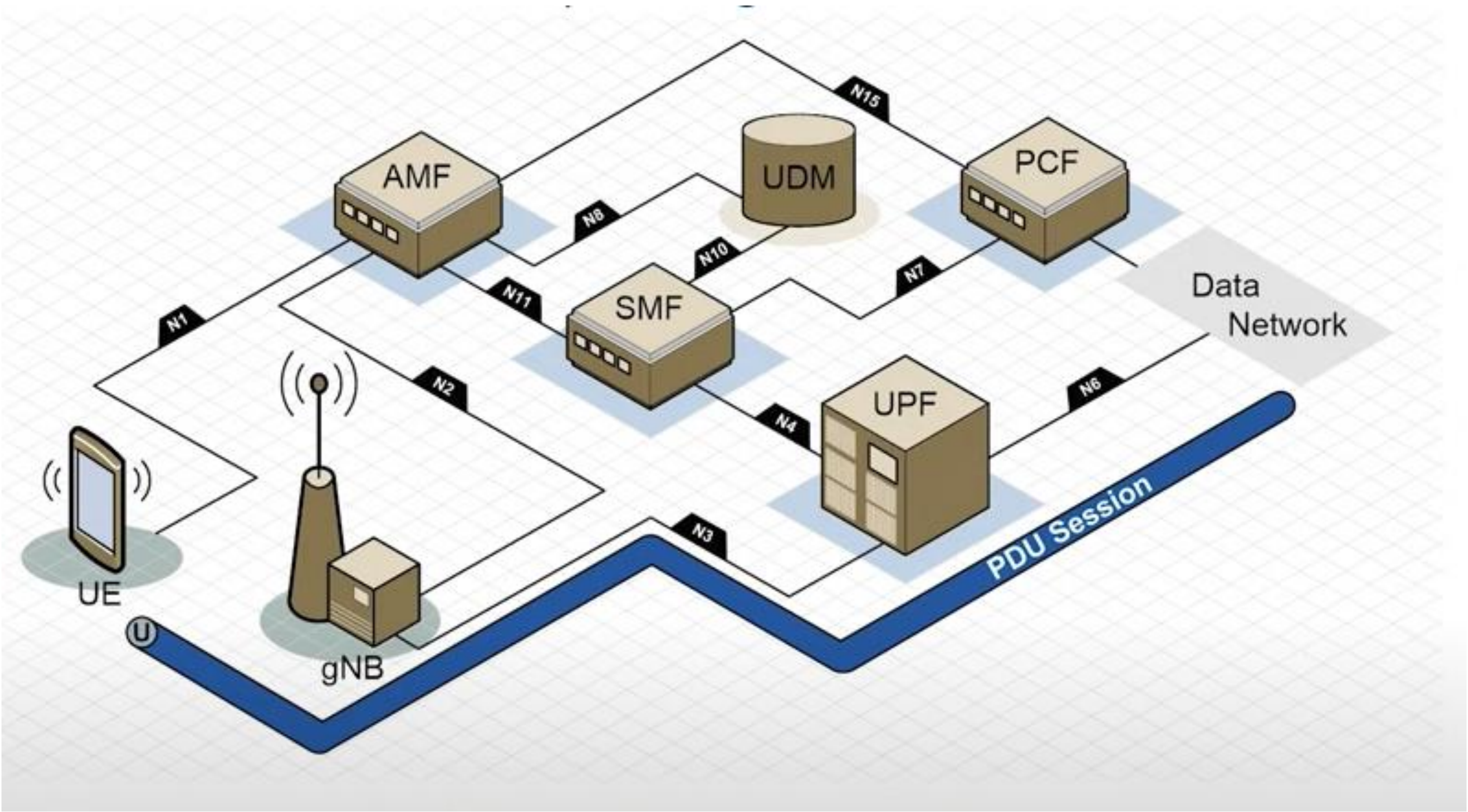
5G Mobile Communication System Cont.

5G Advancements

- **New Architecture**
  - Advanced core network functions / NG RAN
  - Incorporate SDN/NFV (NFV MANO)
    - Decupling of control and data plane
    - Decupling of functions from the hardware
- **Network Slicing**
  - eMBB, URLLC, mMTC | 8 subclasses pes slice type
- **New Radio (NR)**
  - RAN protocol stack (+SDAP)
  - New numerology for the PHY compared to LTE
- **Massive MIMO**
  - Multiple antennas and beamforming
- **Functional Split**
  - gNodeB Fronthaul Central, Distributed and Radio Units (CU, DU and RU)

General 5G architecture

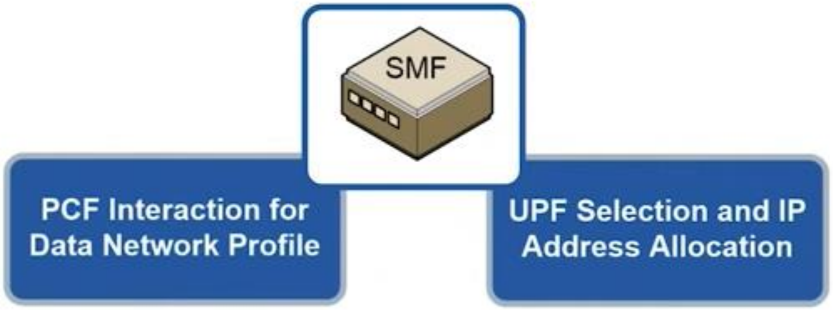


Access and Mobility-Management Function

Similar to MME in 4G
Location
Paging
Handover

Authentication
Temporary ID

Session Management Function

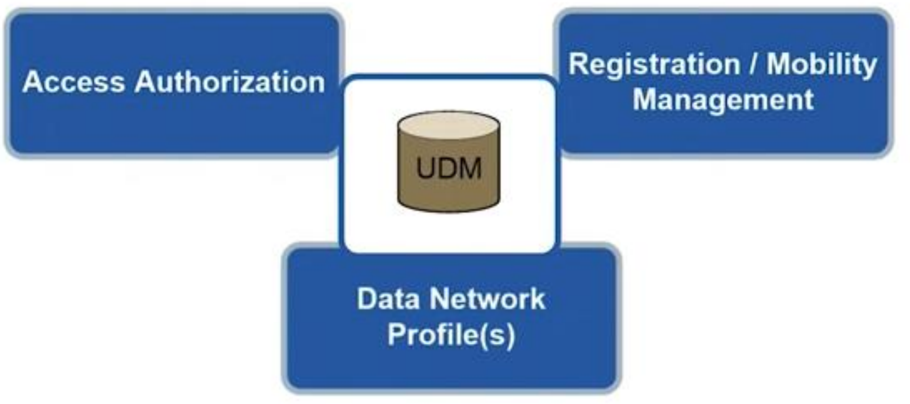


In 4G mobility and session functionality were both in one entity:
MME – In 5G this is split to AMF and SMF respectively.

Establishment, modification, termination of PDU sessions

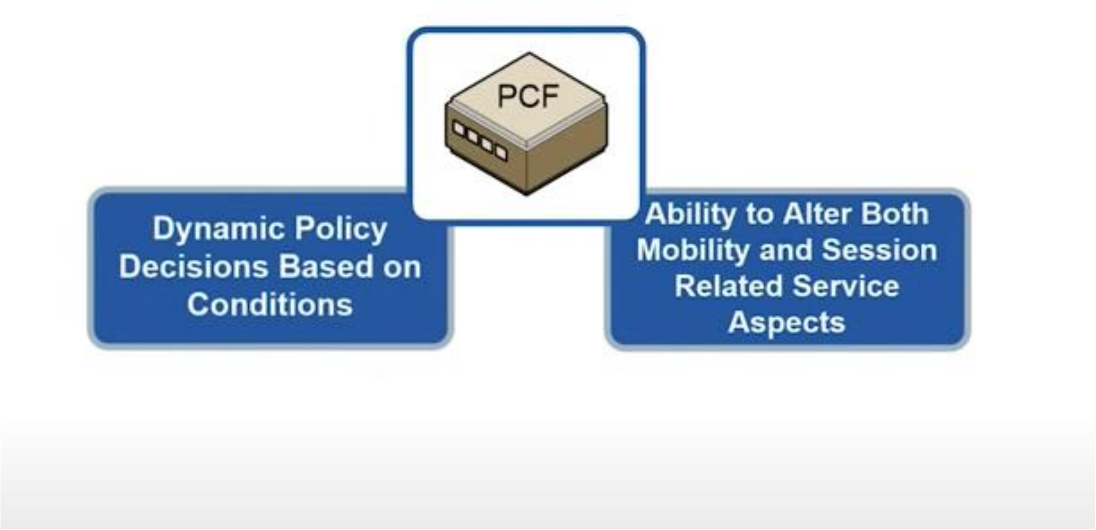
- Interact with Policy Control Function to check the user subscription status
- Interact with User Plane Function to setup the PDU session

Unified Data Management



- Central repository of subscriber information
- Access authorization
- Tracking information
- Data network profile (what the user can and cannot do)

Policy Control Function



- Knowledge of network conditions
- Real time decisions based on these conditions
- May deny or alter service if conditions do not allow
- Information from the Data Network (external) as well

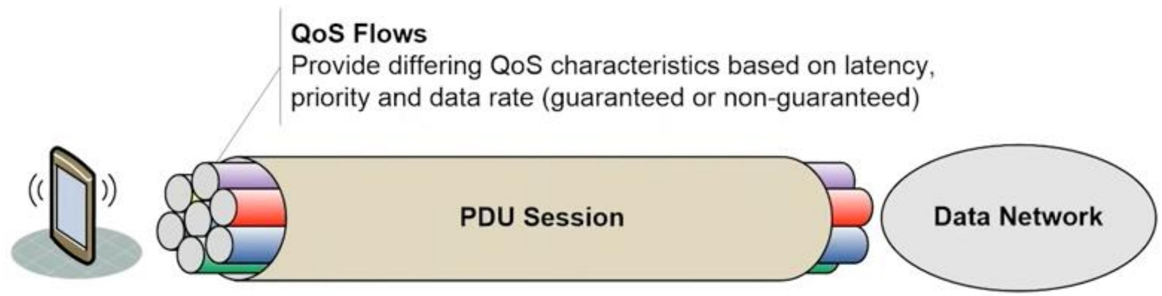
User Plane Function

Remains the same for a PDU session

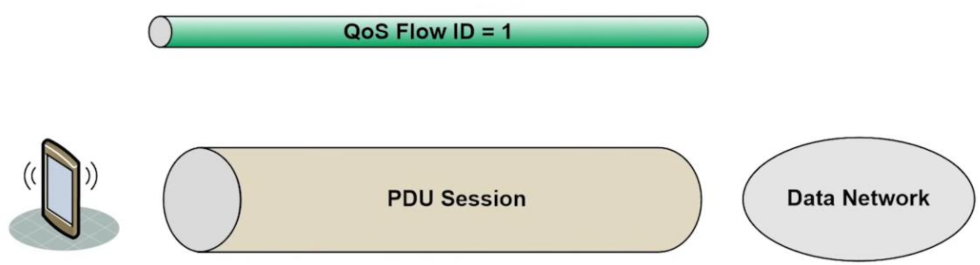
Enforces QoS and data forwarding from/to the UE to/from the data network

Data flow

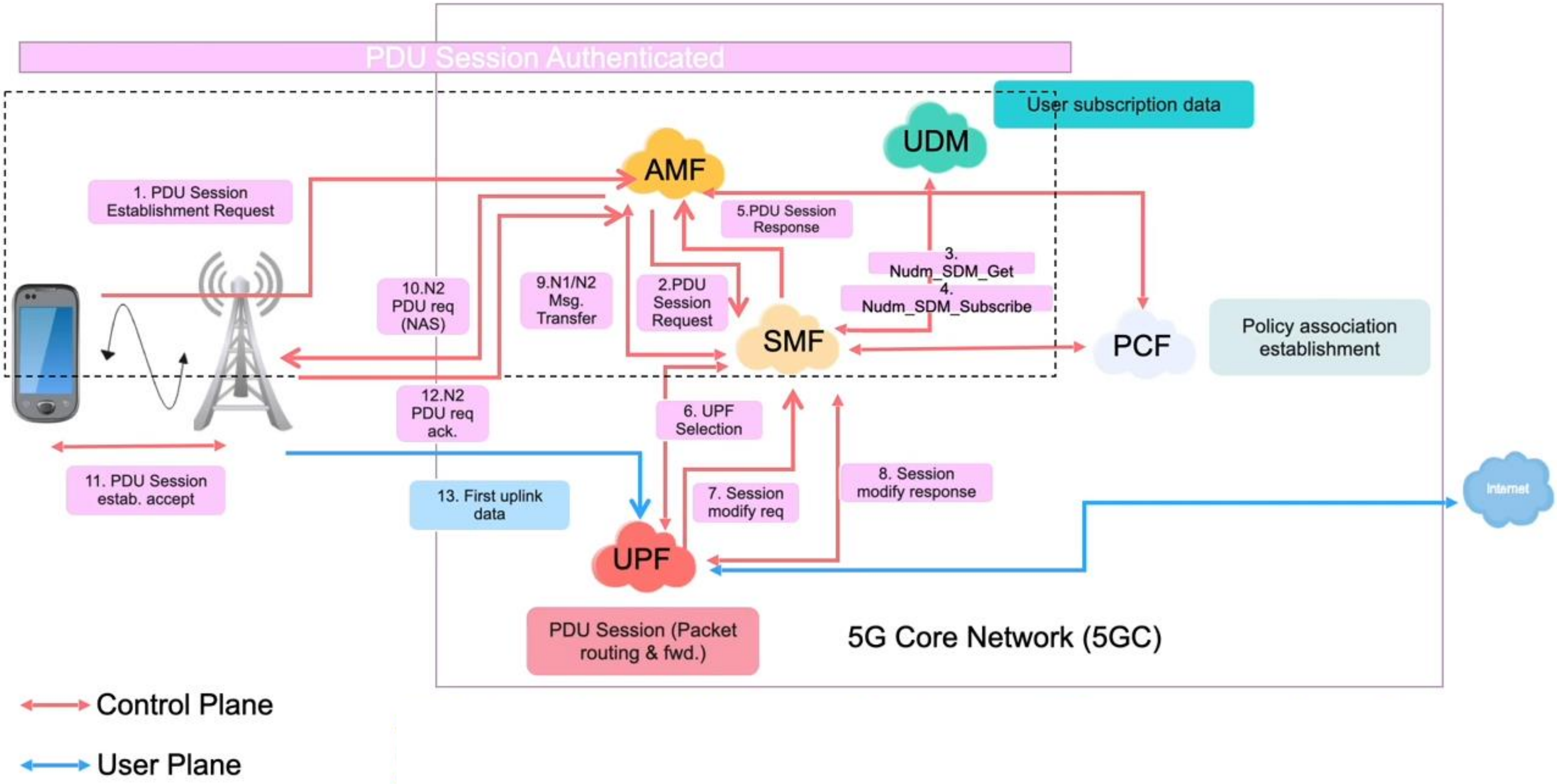
PDU Sessions and QoS Flows



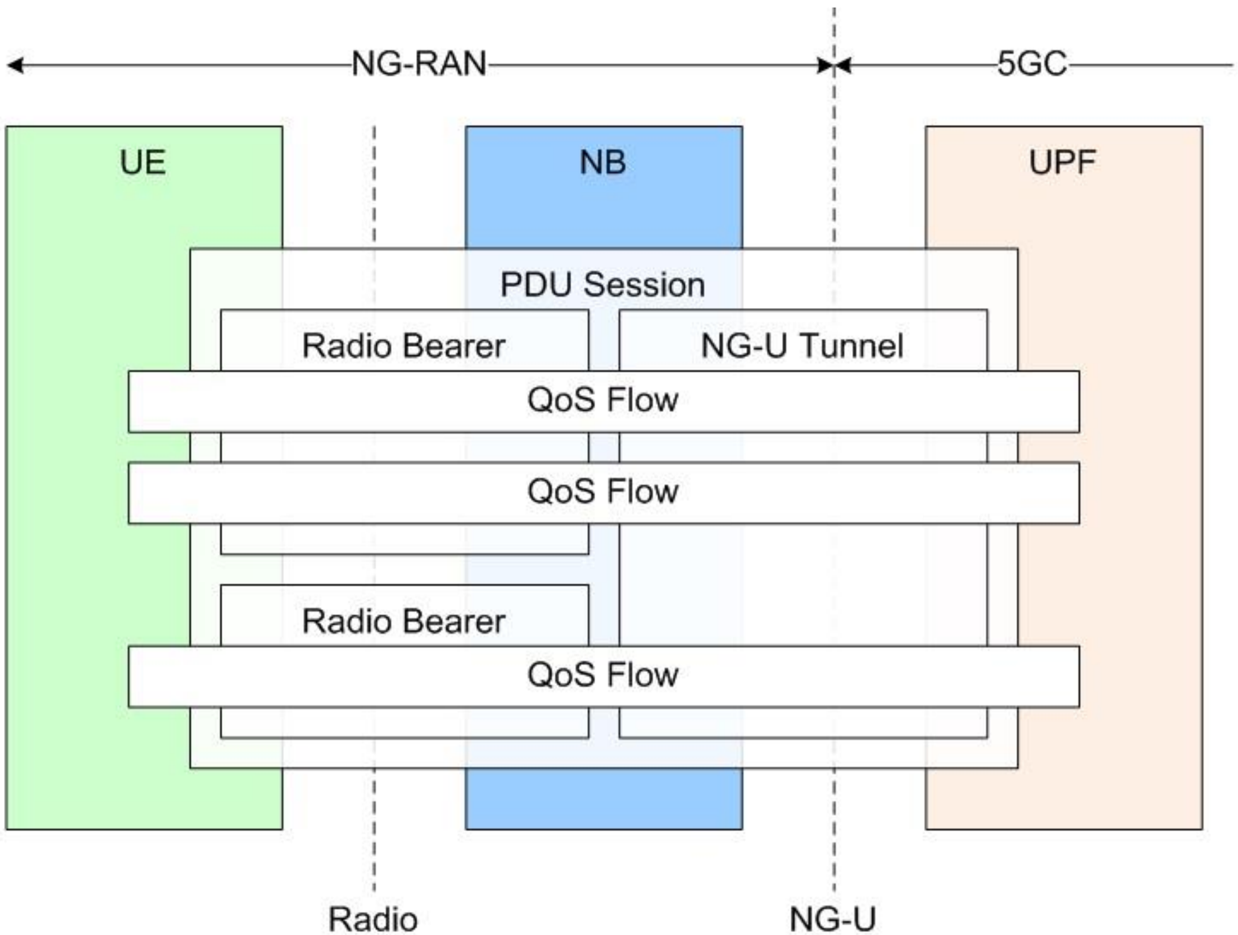
QoS Flows can be established and removed on the basis of the QoS requirements of the User Plane traffic



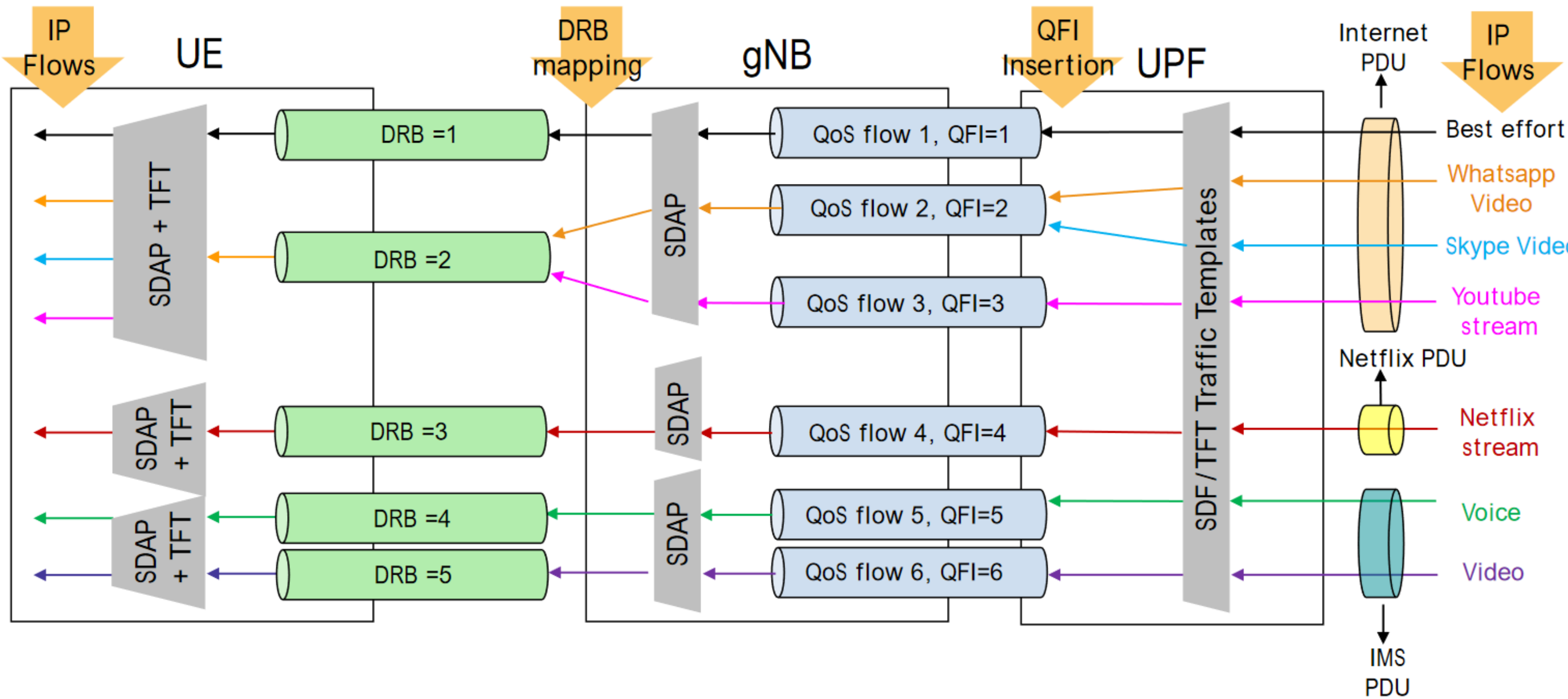
PDU Session Establishment



User Plane Function



User Plane Function

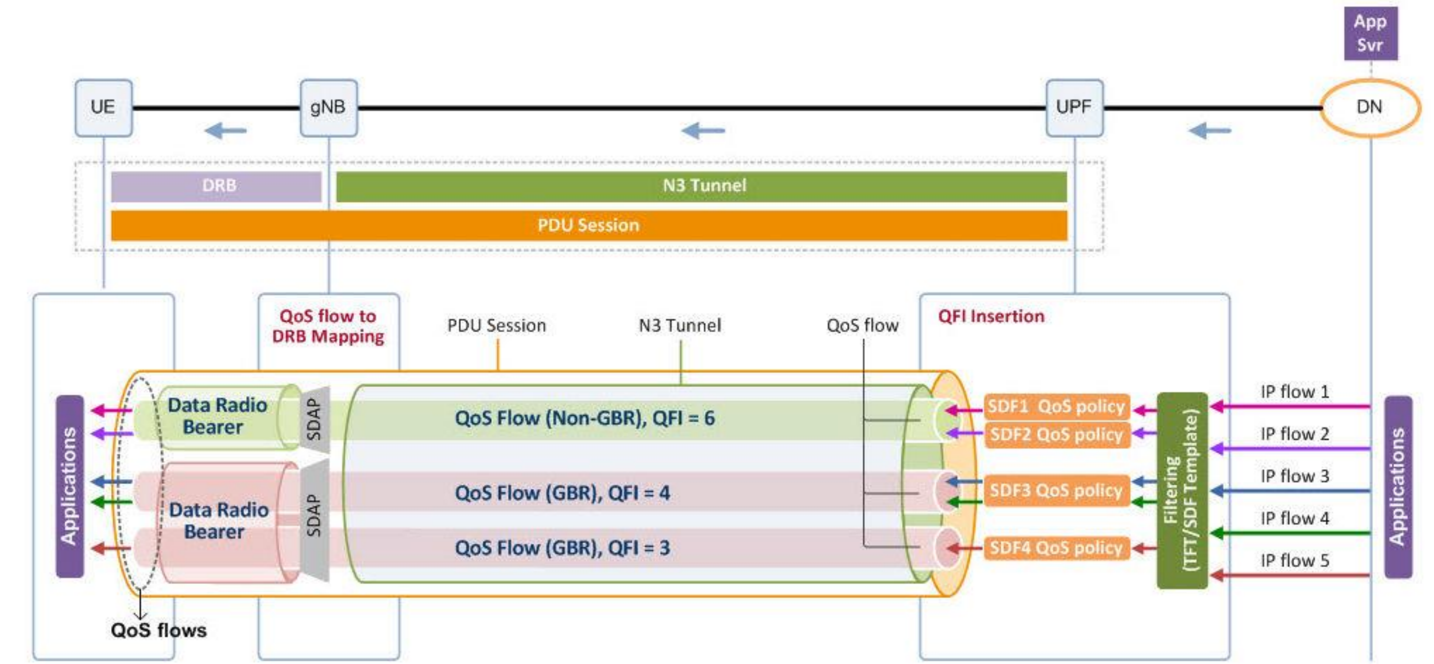


SDAP: Service Data Adaptation Protocol
SDF/TFT: Service Data Flow / Traffic Flow Template

User Plane Function

5QI Value	Resource Type	Default Priority Level	Packet Delay Budget (NOTE 3)	Packet Error Rate	Default Maximum Data Burst Volume (NOTE 2)	Default Averaging Window	Example Services
1	GBR (NOTE 1)	20	100 ms (NOTE 11, NOTE 13)	10^{-2}	N/A	2000 ms	Conversational Voice
2		40	150 ms (NOTE 11, NOTE 13)	10^{-3}	N/A	2000 ms	Conversational Video (Live Streaming)
3		30	50 ms (NOTE 11, NOTE 13)	10^{-3}	N/A	2000 ms	Real Time Gaming, V2X messages (see TS 23.287 [121]). Electricity distribution – medium voltage, Process automation monitoring
•••		•••	•••	•••	•••	•••	•••
5	Non-GBR (NOTE 1)	10	100 ms NOTE 10, NOTE 13)	10^{-6}	N/A	N/A	IMS Signalling
6		60	300 ms (NOTE 10, NOTE 13)	10^{-6}	N/A	N/A	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
7		70	100 ms (NOTE 10, NOTE 13)	10^{-3}	N/A	N/A	Voice, Video (Live Streaming) Interactive Gaming
•••		•••	•••	•••	•••	•••	•••
82	Delay-critical GBR	19	10 ms (NOTE 4)	10^{-4}	255 bytes	2000 ms	Discrete Automation (see TS 22.261 [2])
83		22	10 ms (NOTE 4)	10^{-4}	1354 bytes (NOTE 3)	2000 ms	Discrete Automation (see TS 22.261 [2]); V2X messages (UE - RSU Platooning, Advanced Driving: Cooperative Lane Change with low LoA. See TS 22.186 [111], TS 23.287 [121])
84		24	30 ms (NOTE 6)	10^{-5}	1354 bytes (NOTE 3)	2000 ms	Intelligent transport systems (see TS 22.261 [2])
•••		•••	•••	•••	•••	•••	•••

User Plane Function



5QI : 5G QoS Identifier
ARP : Allocation and Retention Priority
GFBR : Guaranteed Flow Bit Rate
MFBR : Maximum Flow Bit Rate
PDB : Packet Delay Budget
PER : Packet Error Rate
QFI : QoS Flow Identifier
RQA : Reflective QoS Attribute

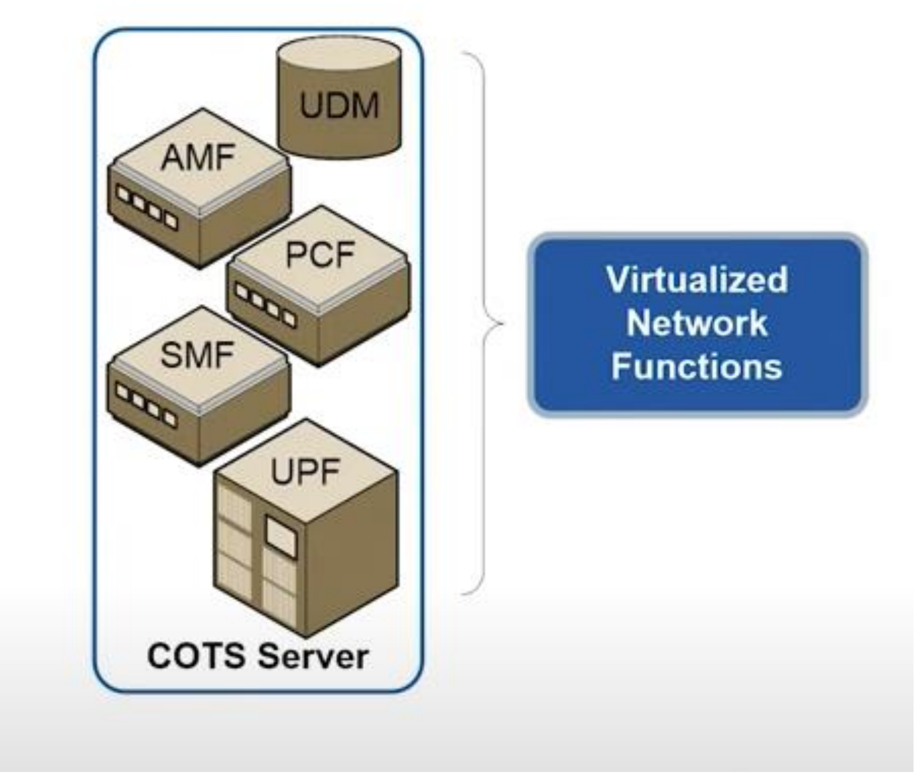
QoS Flow type		QoS Flow parameters
GBR flow	Non-GBR flow	5QI
		ARP
		RQA
		GFBR
		MFBR
		Notification Control
		Maximum Packet Loss Rate

5QI

Resource Type*
Default Priority Level
PDB
PER
Default Maximum Data Burst Volume
Default Averaging Window

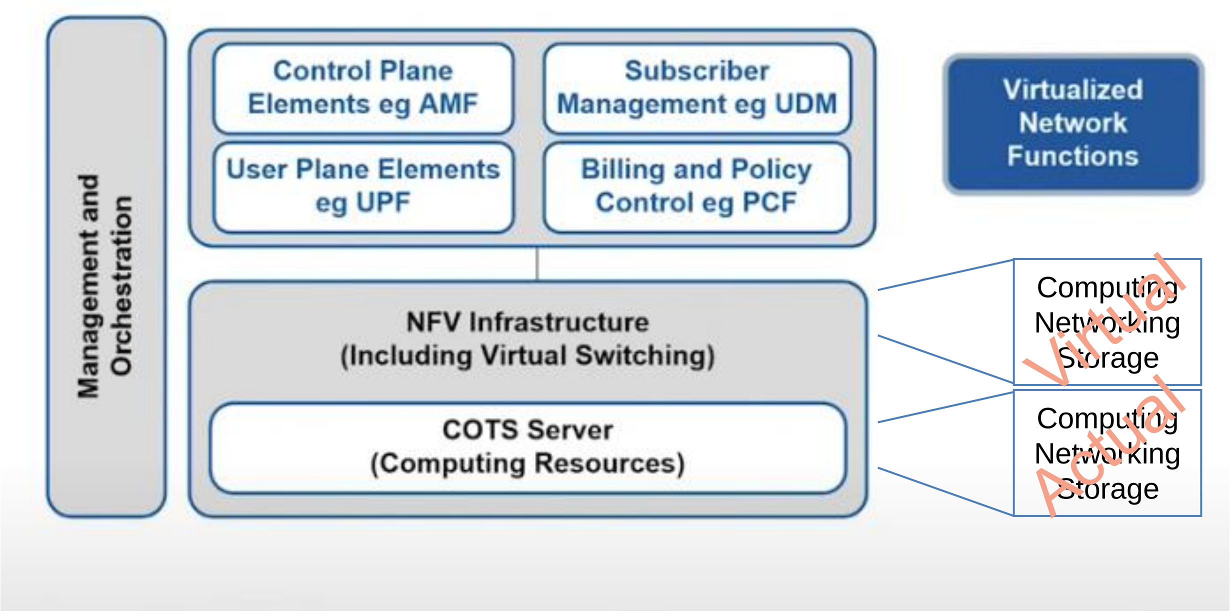
* GBR, non-GBR or delay critical GBR

Network Function Virtualization



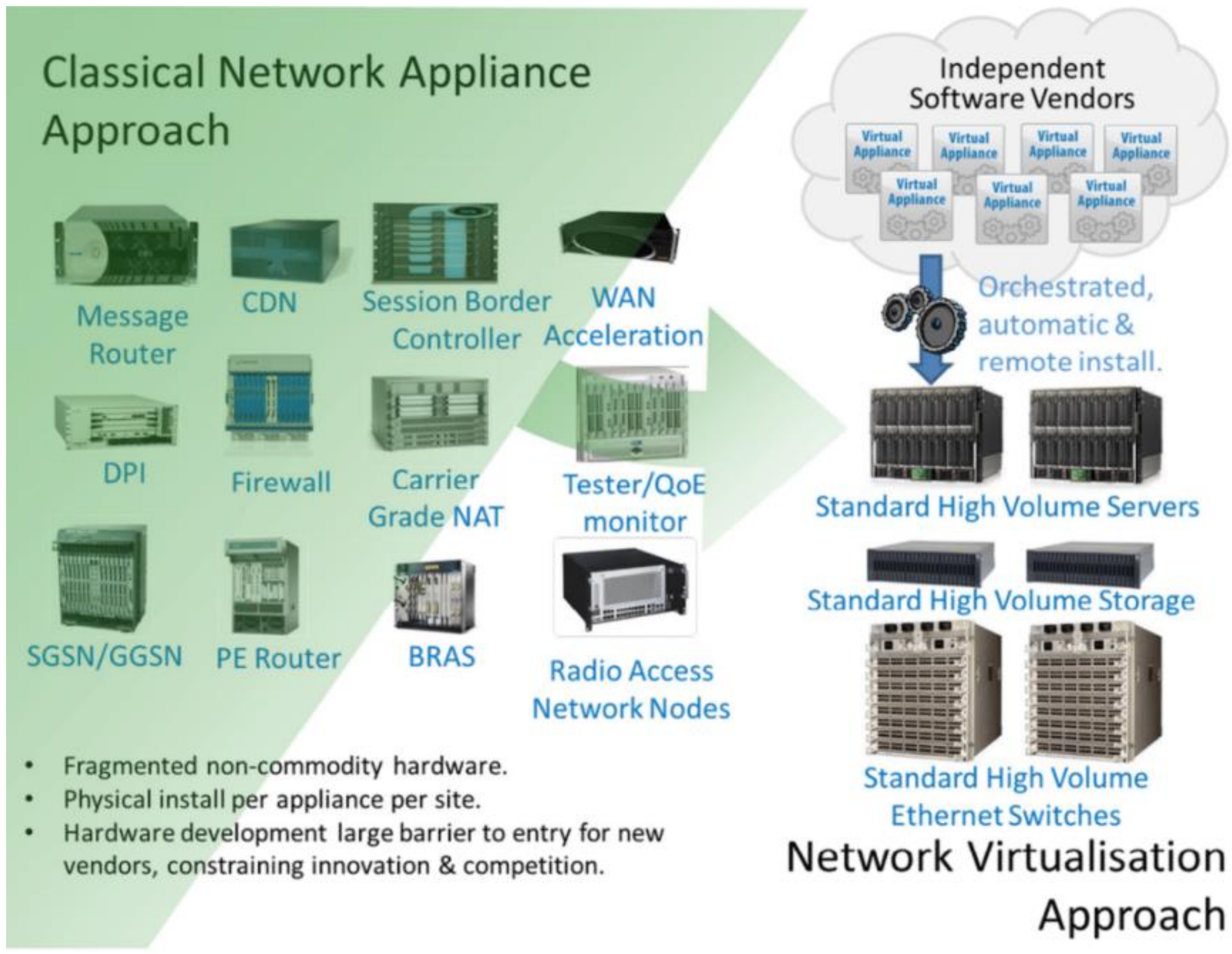
- Most of NFV nodes may be virtualized (software processes)
- Running in Commercial Off The Self (COTS) Servers

Network Function Virtualization



- Flexibility
- Scaling through software
- MANO in needed
- 5G is a series of virtualized processes
- API driven

Network Function Virtualization



Fewer platforms

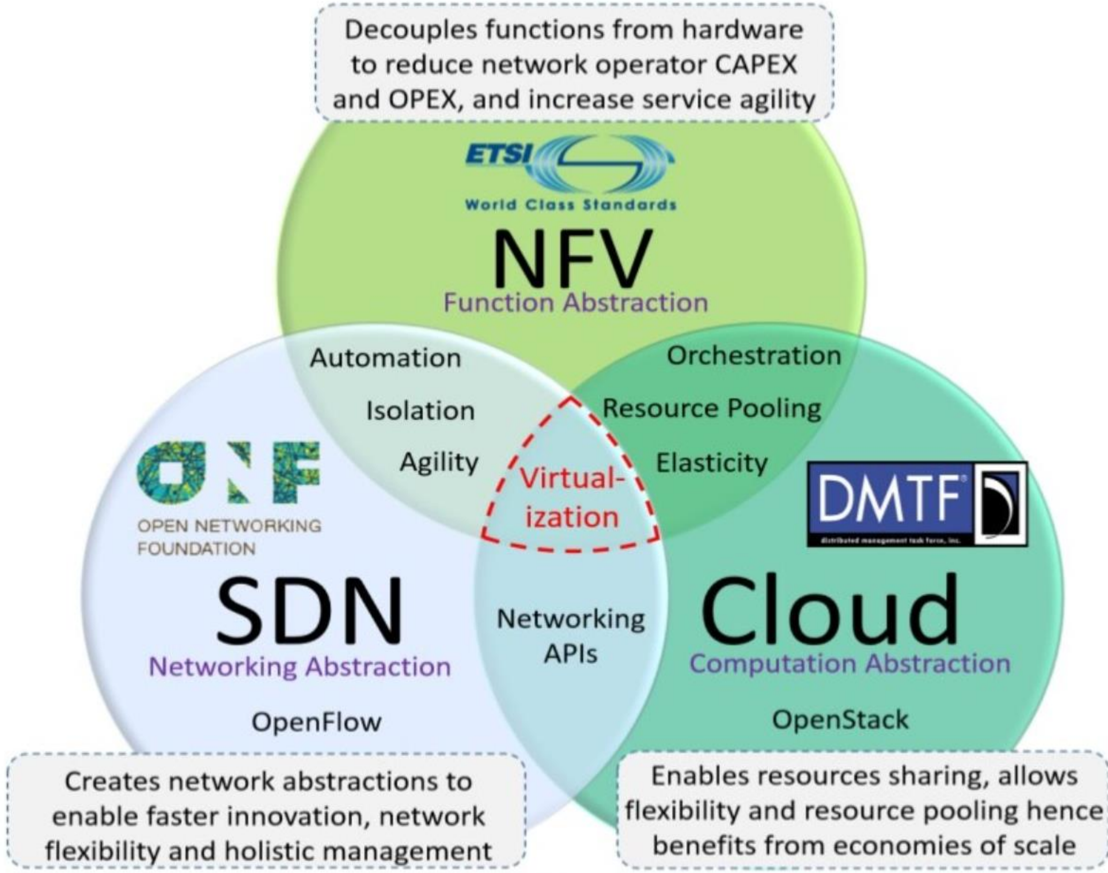
More flexibility

More efficient use of resources

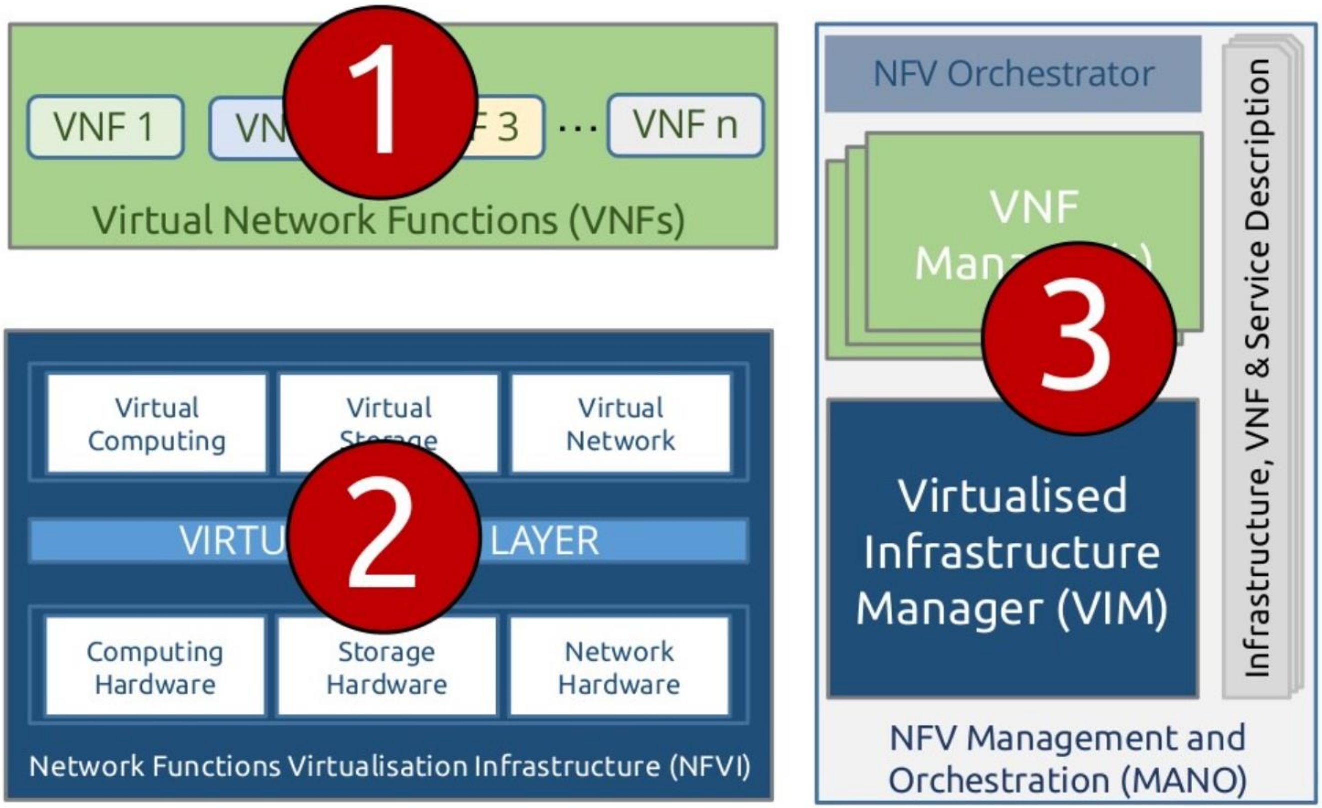
Use less power

SLAs needed

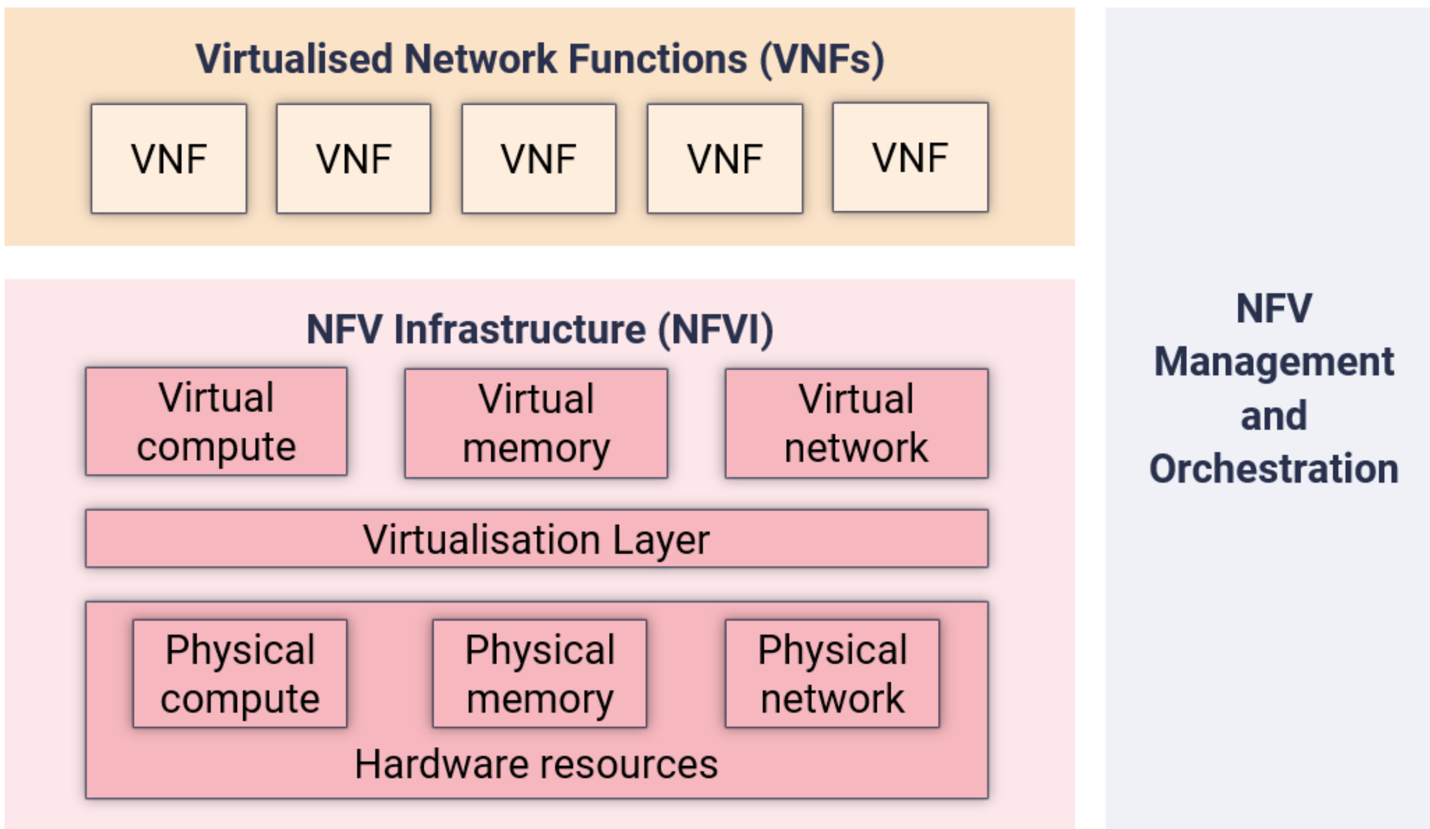
Network Function Virtualization



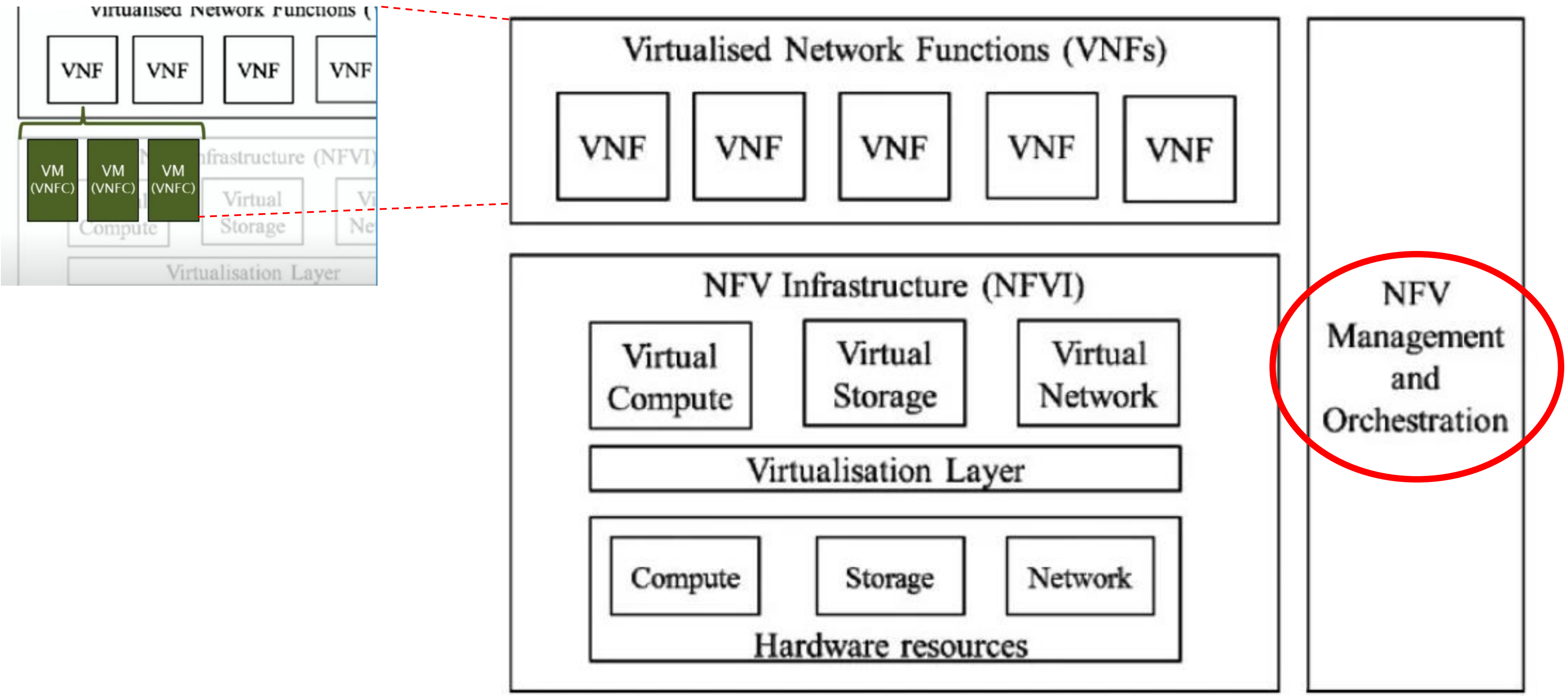
Network Function Virtualization



Network Function Virtualization



Network Function Virtualization



What a MANO should do

- **Implementable as software only (even virtualized)**
- **Distributed across NFVI**
- **Support full automation without human intervention**
- **Avoid single-point-of-failure**
- **Use standards or “de-facto” standards**
- **Support munti-ventor environment**

What a MANO actually does

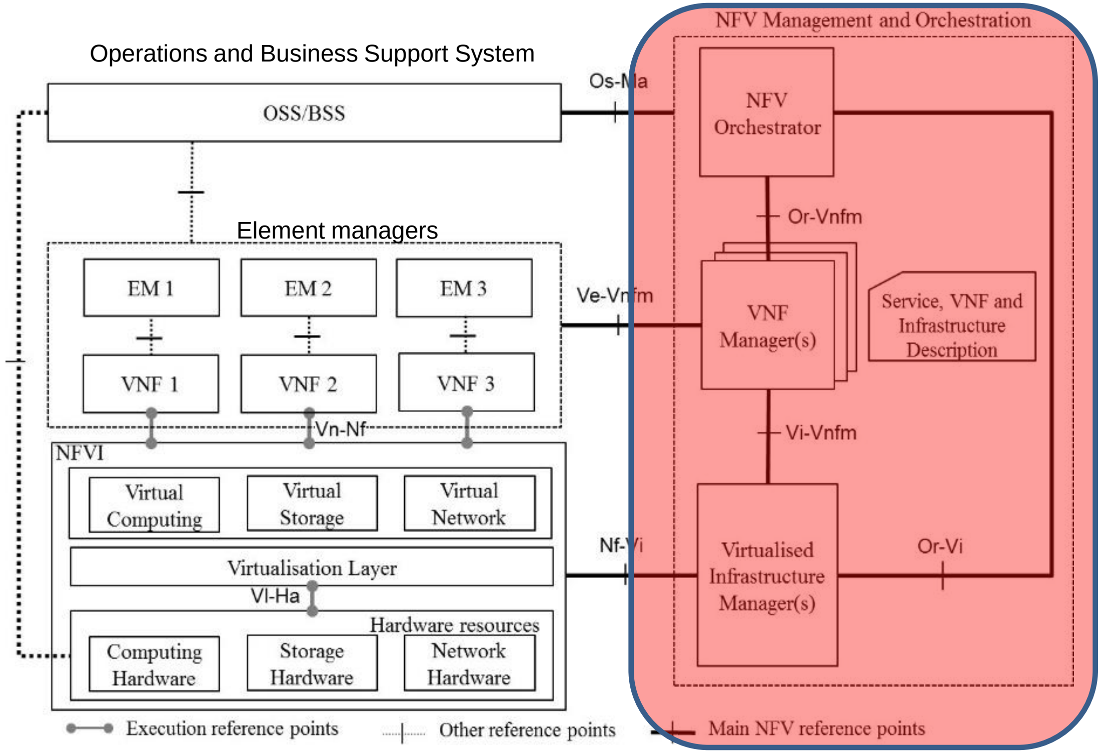
- **Initiate**
- **Scale**
- **Update/upgrade**
- **Terminate**

} **VNFs**

5G Architecture

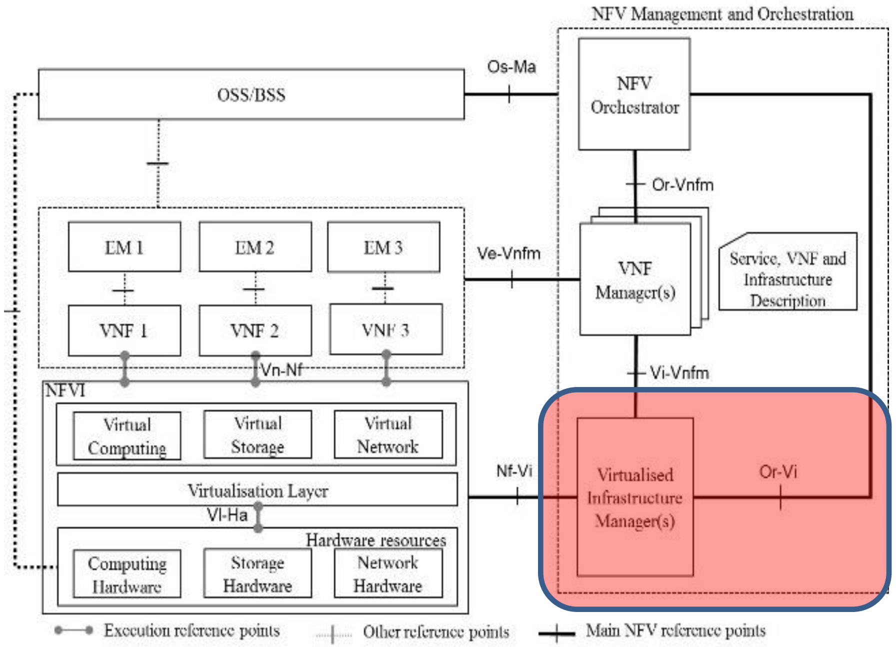
Taking advantage of MANO

- **VNFs ETSI Management and orchestration(MANO)**
  - Virtualized Infrastructure Manager (VIM)
  - VNF Manager (VNFM)
  - NFV Orchestrator (VNFO)



5G Architecture

Taking advantage of MANO



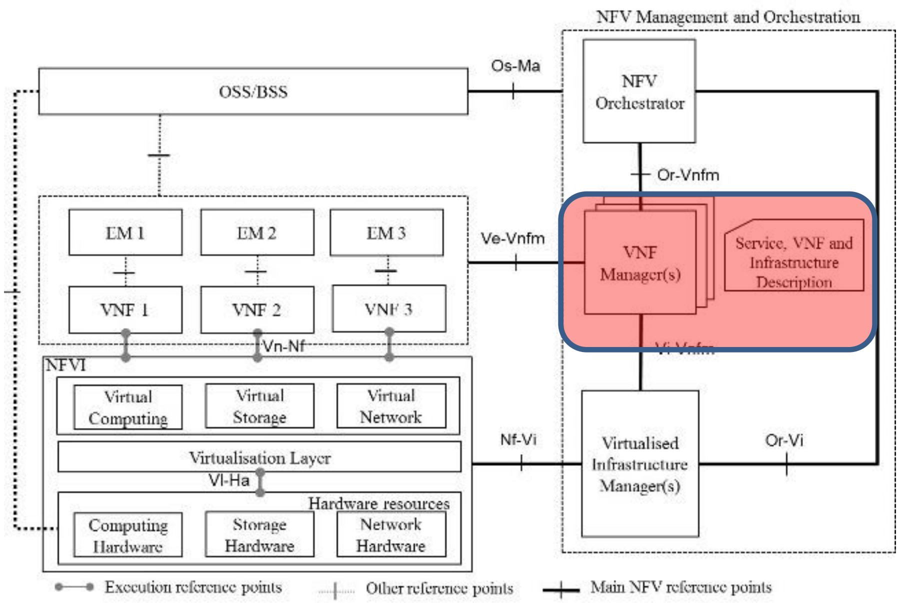
Virtualized Infrastructure Manager (VIM)

- Manages life cycle of virtual resources in an NFVI domain.
- That is, it creates, maintains and tears down virtual machines (VMs) from physical resources in an NFVI domain.
- Keeps inventory of virtual machines (VMs) associated with physical resources.
- Performance and fault management of hardware, software and virtual resources.
- Keeps north bound APIs and thus exposes physical and virtual resources to other management systems.

Reservations and current usage of physical resources

5G Architecture

Taking advantage of MANO

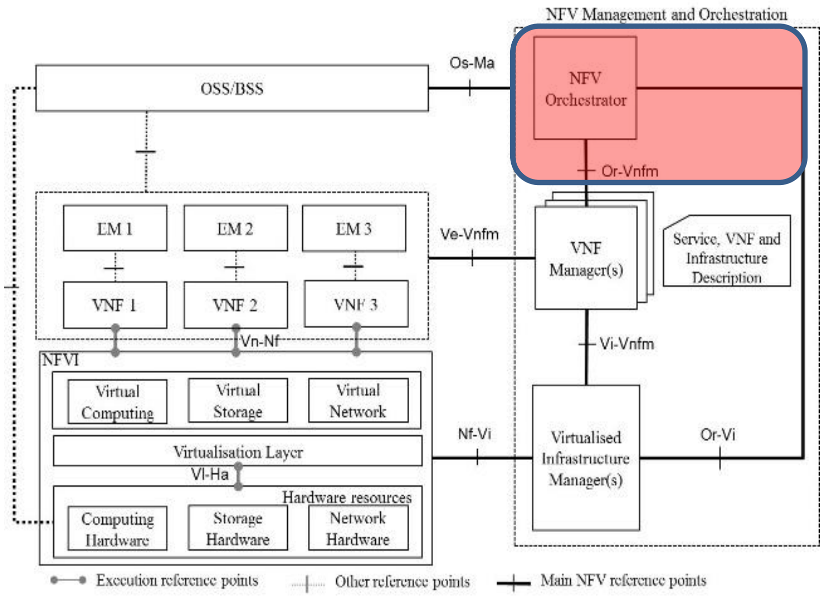


VNF Manager (VNFM)

- VNFM manages life cycle of VNFs. That is it creates, maintains and terminates VNF instances which are installed on the Virtual Machines (VMs) which the VIM creates and manages)
- It is responsible for the FCAPS of VNFs (i.e. Fault, Configuration, Accounting, Performance and Security Management of VNFs).
- It scales up/scales down VNFs which results in scaling up and scaling down of CPU usage, storage and/or network.

5G Architecture

Taking advantage of MANO



NFV Orchestrator (NFVO)

Resource Orchestration

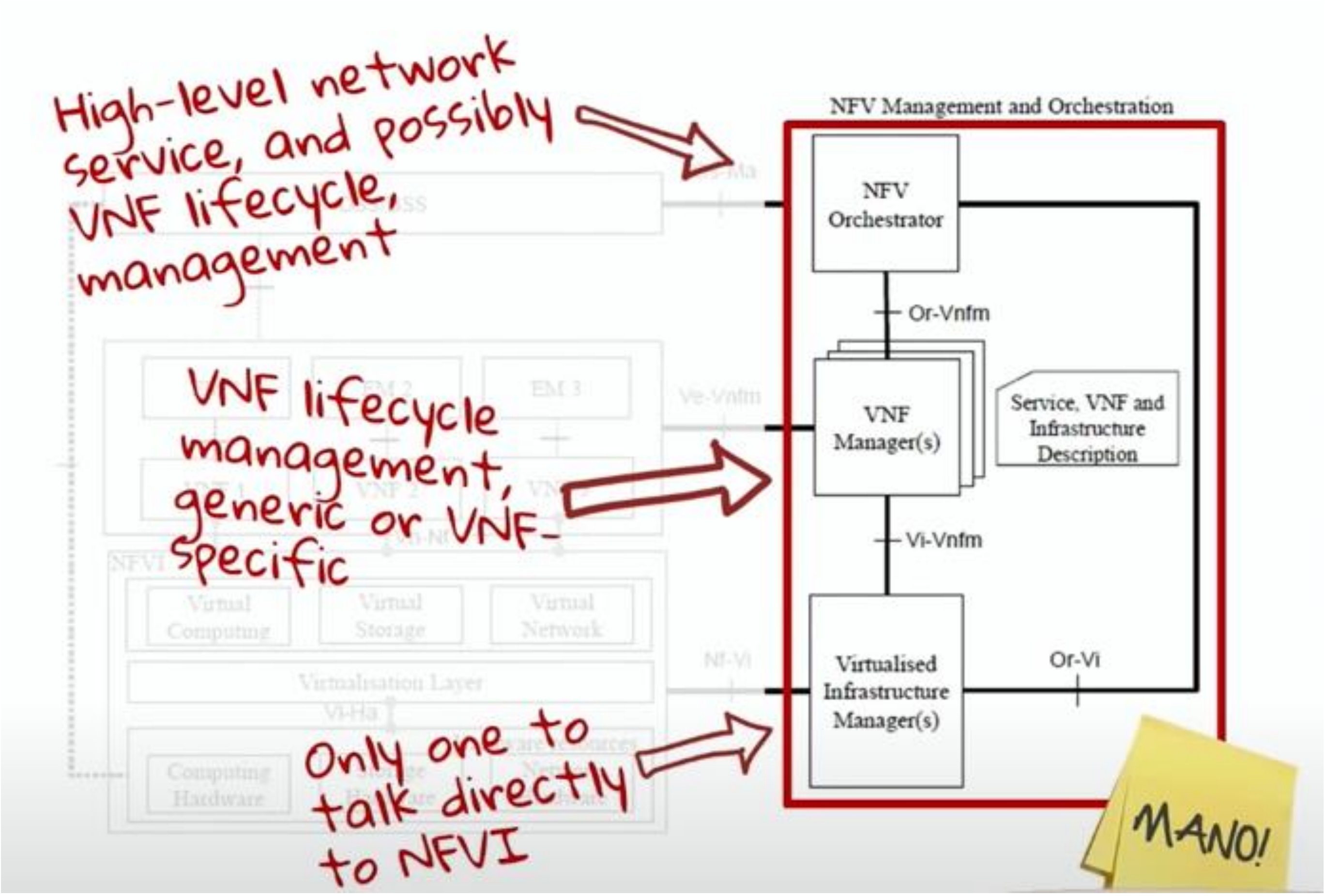
- NFVO coordinates, authorizes, releases and engages NFVI resources. This does so by engaging with the VIMs directly through their north bound APIs instead of engaging with the NFVI resources, directly.

Service Orchestration

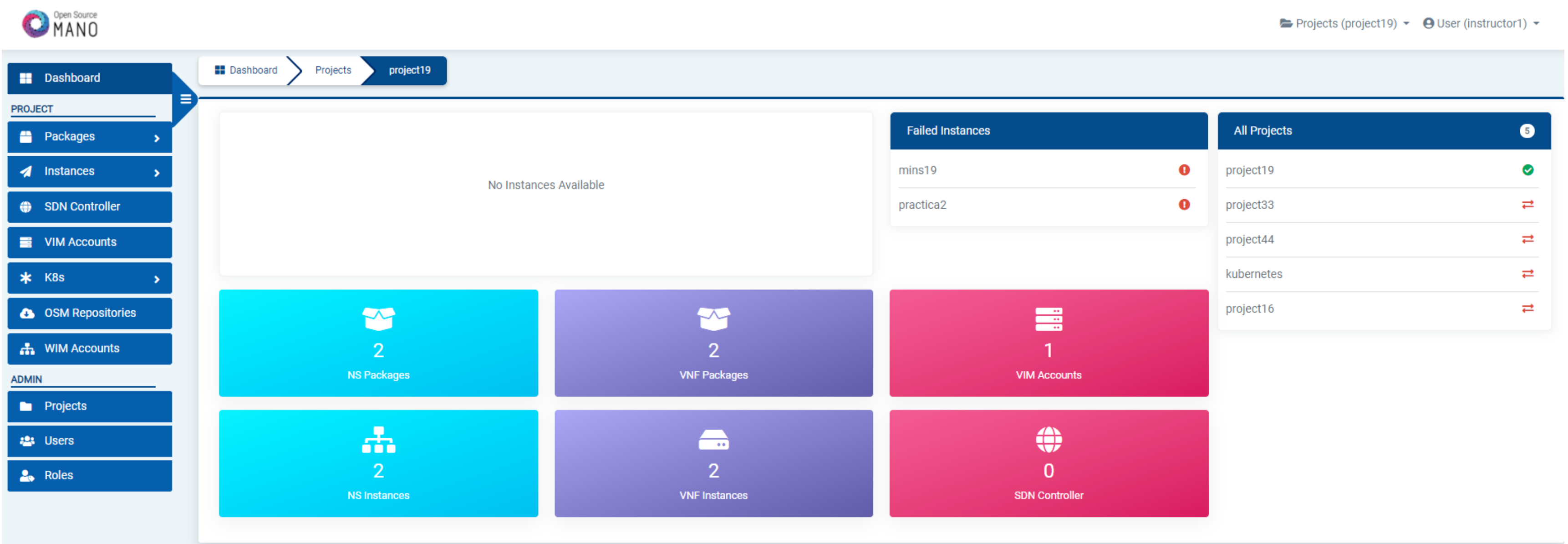
- Service Orchestration creates end to end service between different VNFs. It achieves this by coordinating with the respective VNF Managers so it does not need to talk to VNFs directly.
- Service Orchestration can instantiate VNF Managers, where applicable.
- It does the topology management of the network services instances (also called VNF Forwarding Graphs).

5G Architecture

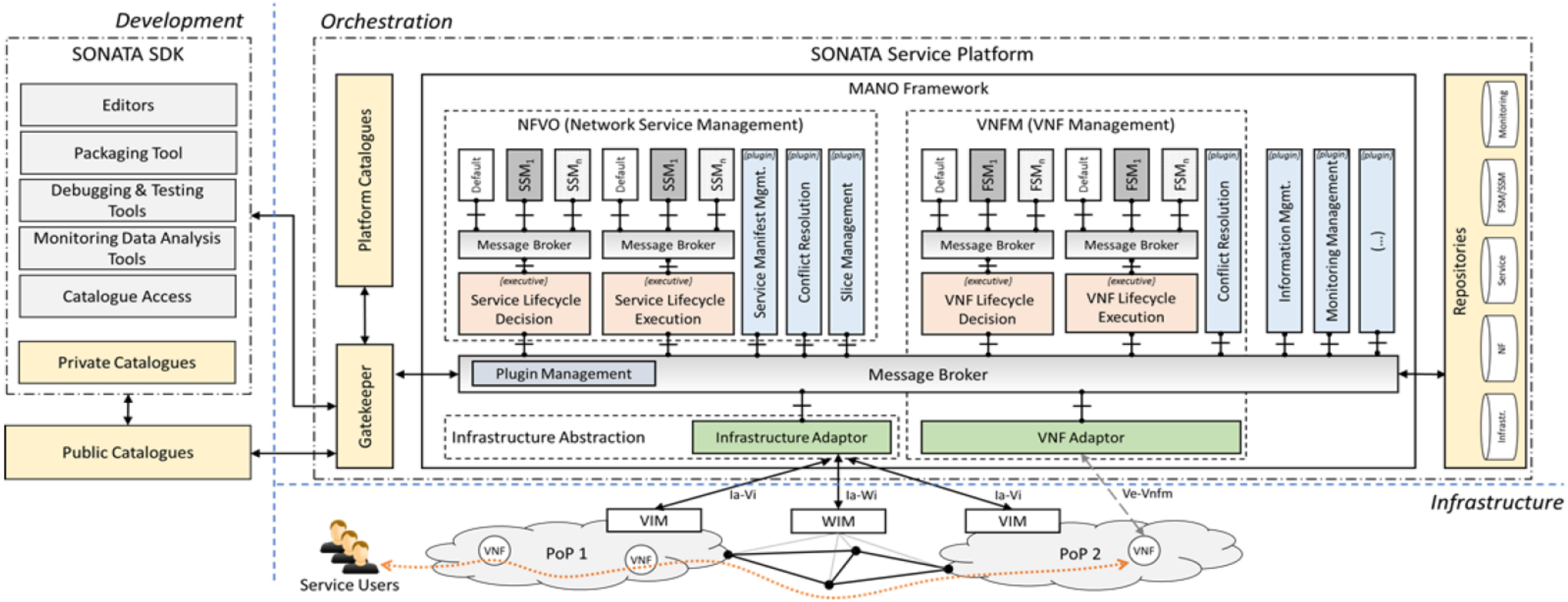
Taking advantage of MANO



Example: Open Source MANO



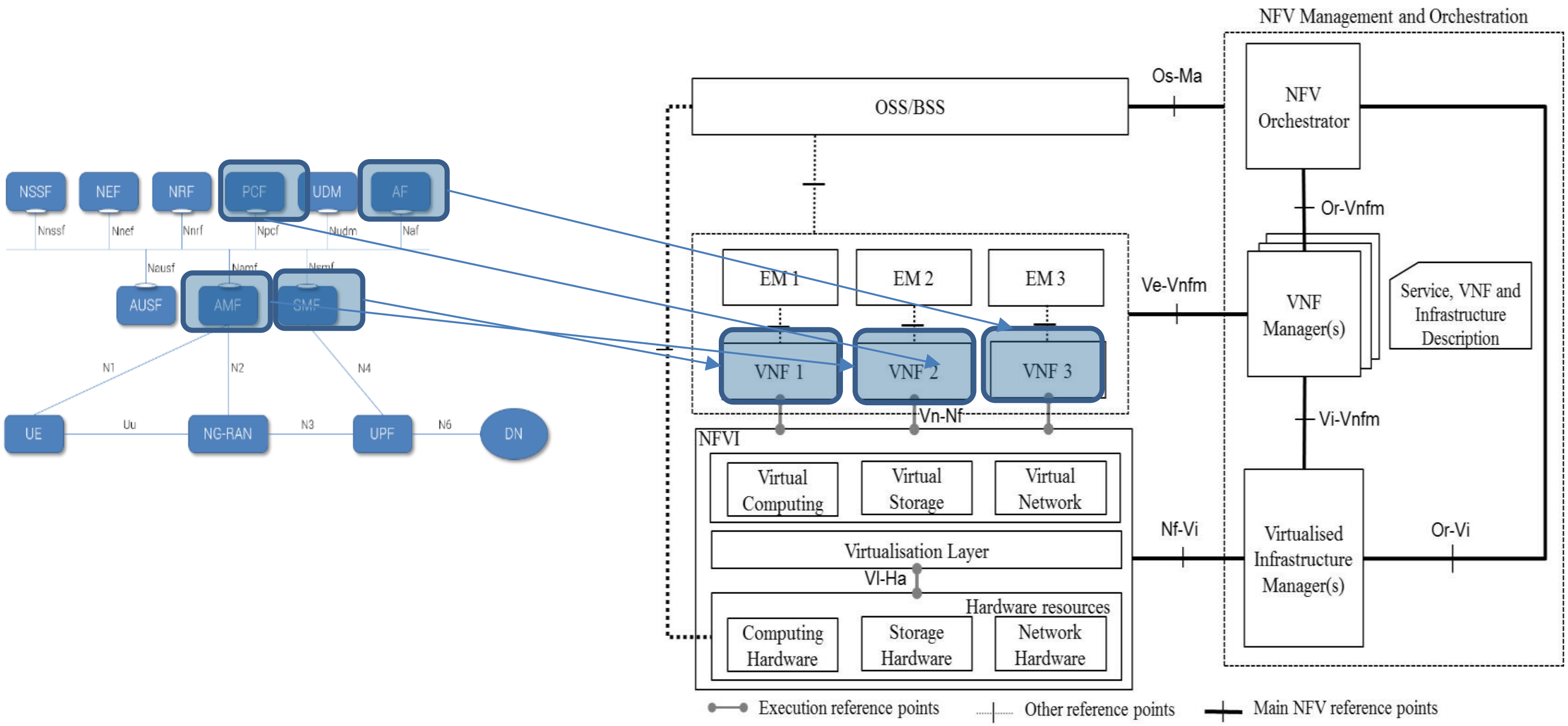
Example: SONATA Platform



5G Architecture

In-lab 5G realization

- The 5G architecture allows for the full usage of the MANO architecture
  - 5G Functions can be realized in VNFs (all?)
  - The MANO toolset can be used to manage the VNFs
    - Set a virtual 5G network
    - Control the reuses of the network



5G Advancements

- **New Architecture**
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  - Incorporate SDN/NFV (NFV MANO)
    - Decupling of control and data plane
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- **Network Slicing**
  - eMBB, URLLC, mMTC | 8 subclasses pes slice type
- **New Radio (NR)**
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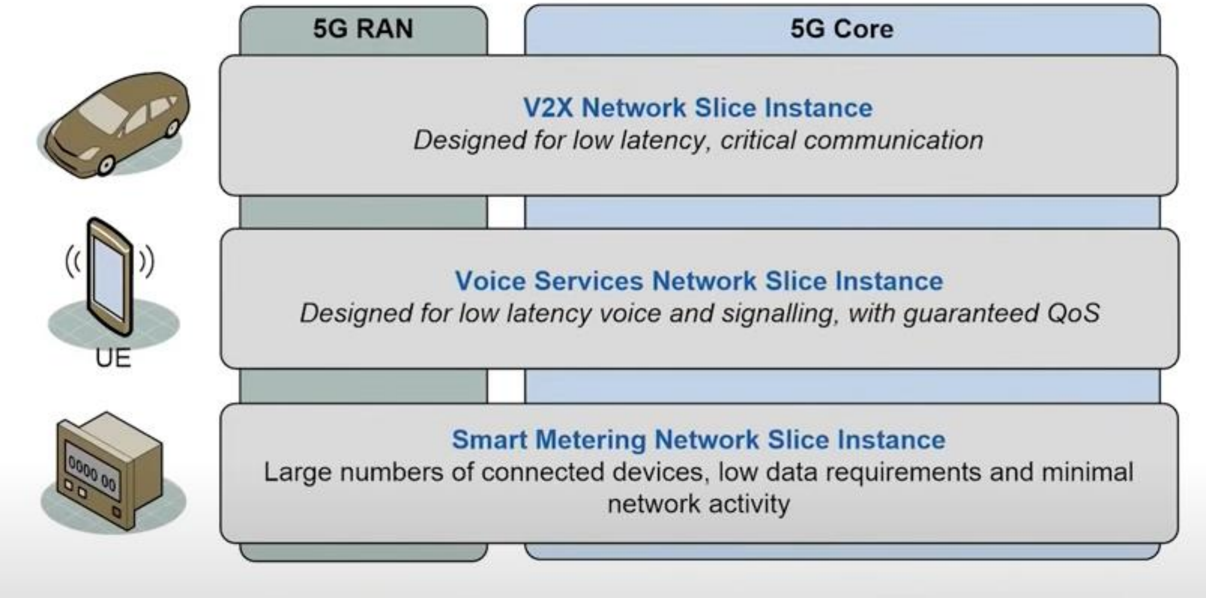
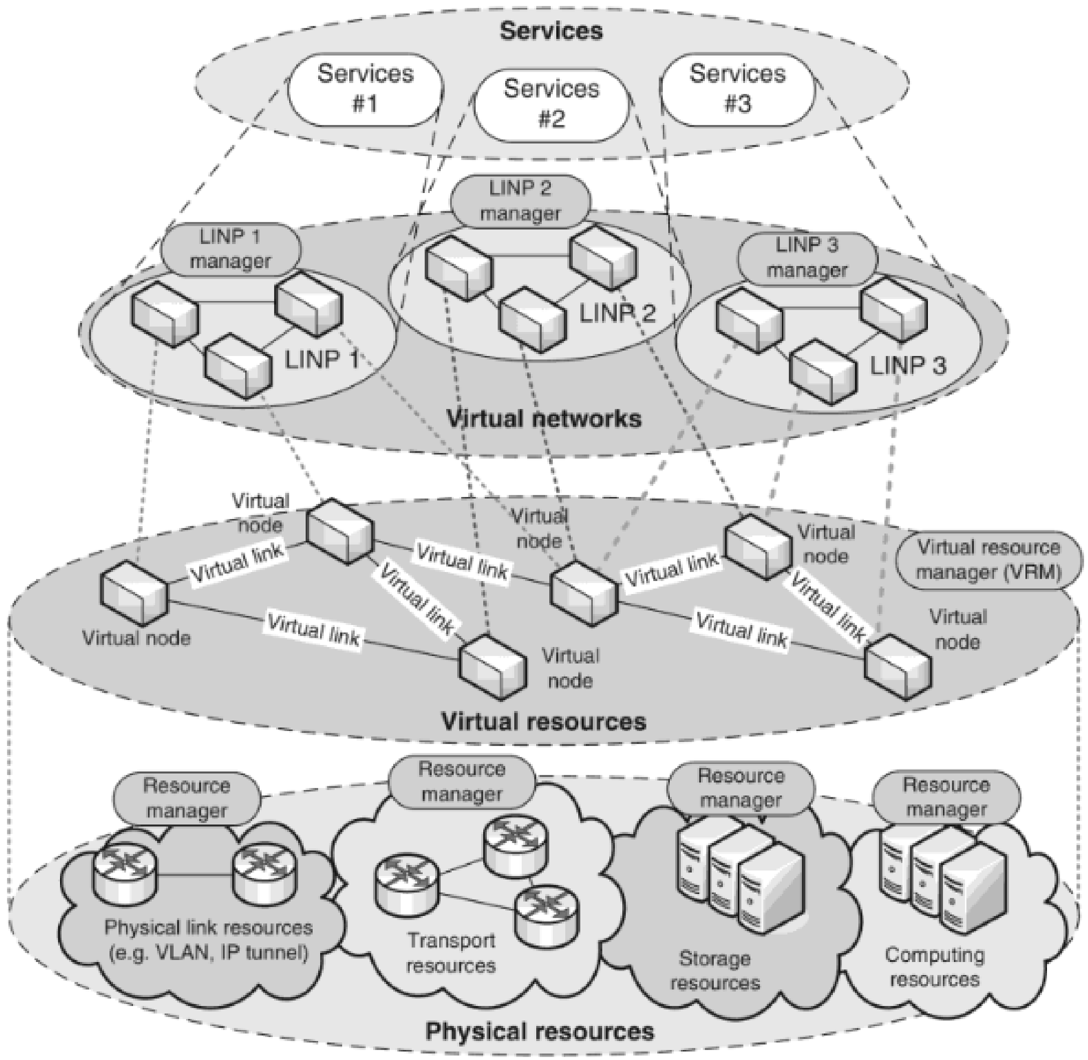
Network Slicing

- “the capability to “slice” network resources and functions and to offer isolated end-to-end network services over shared physical infrastructures”

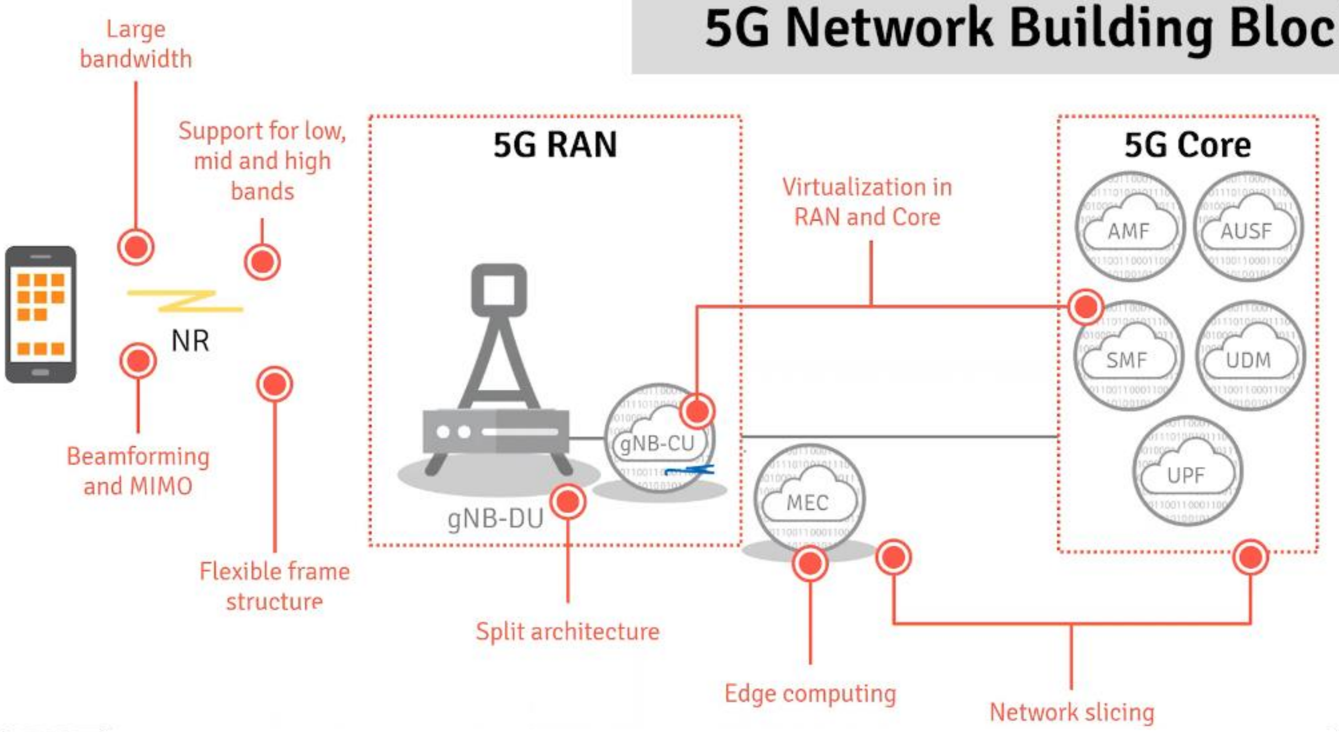


The ability to create logical networks on top of the same physical infrastructure

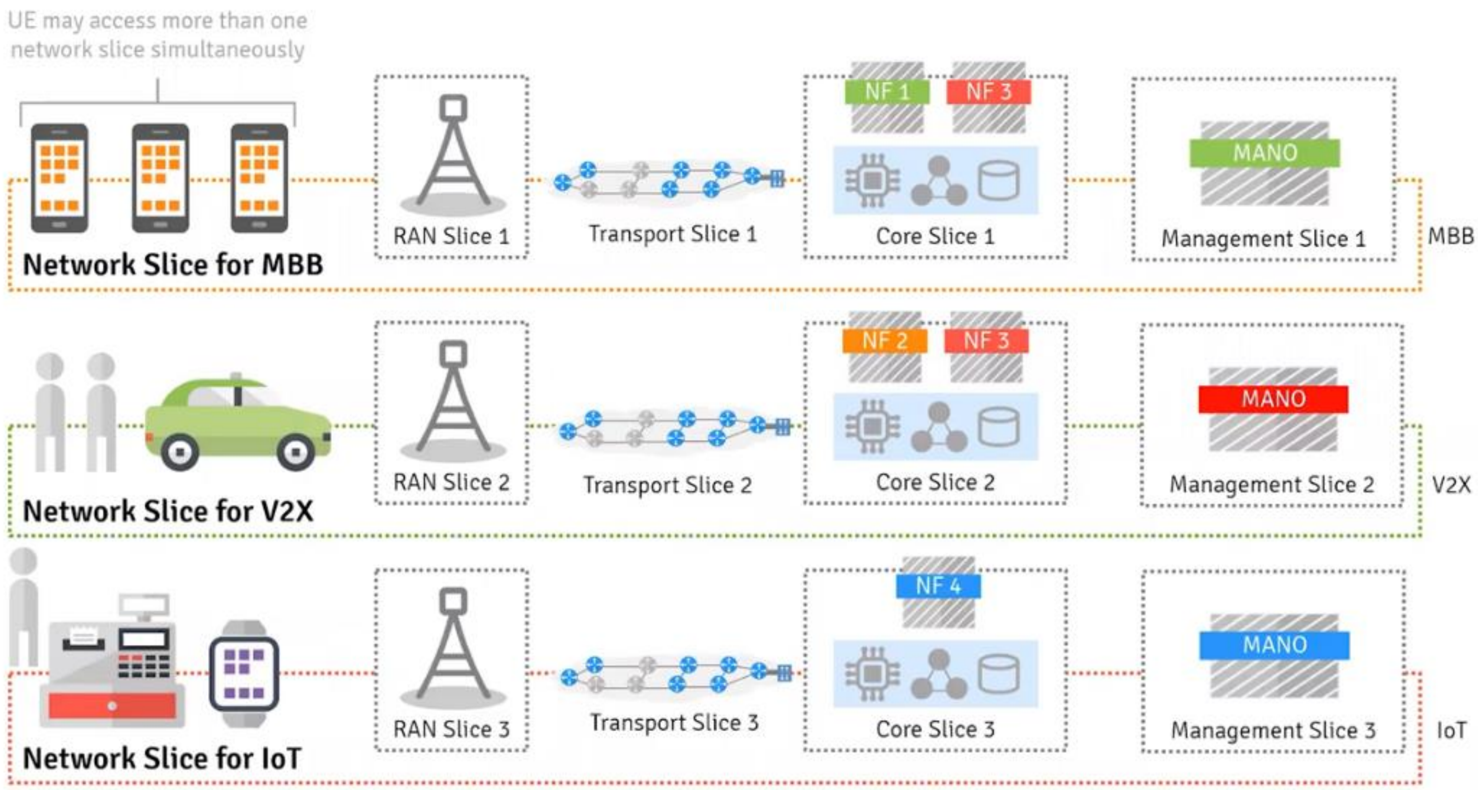


LINP – Logically isolated network partitions
VLAN – Virtual local area network

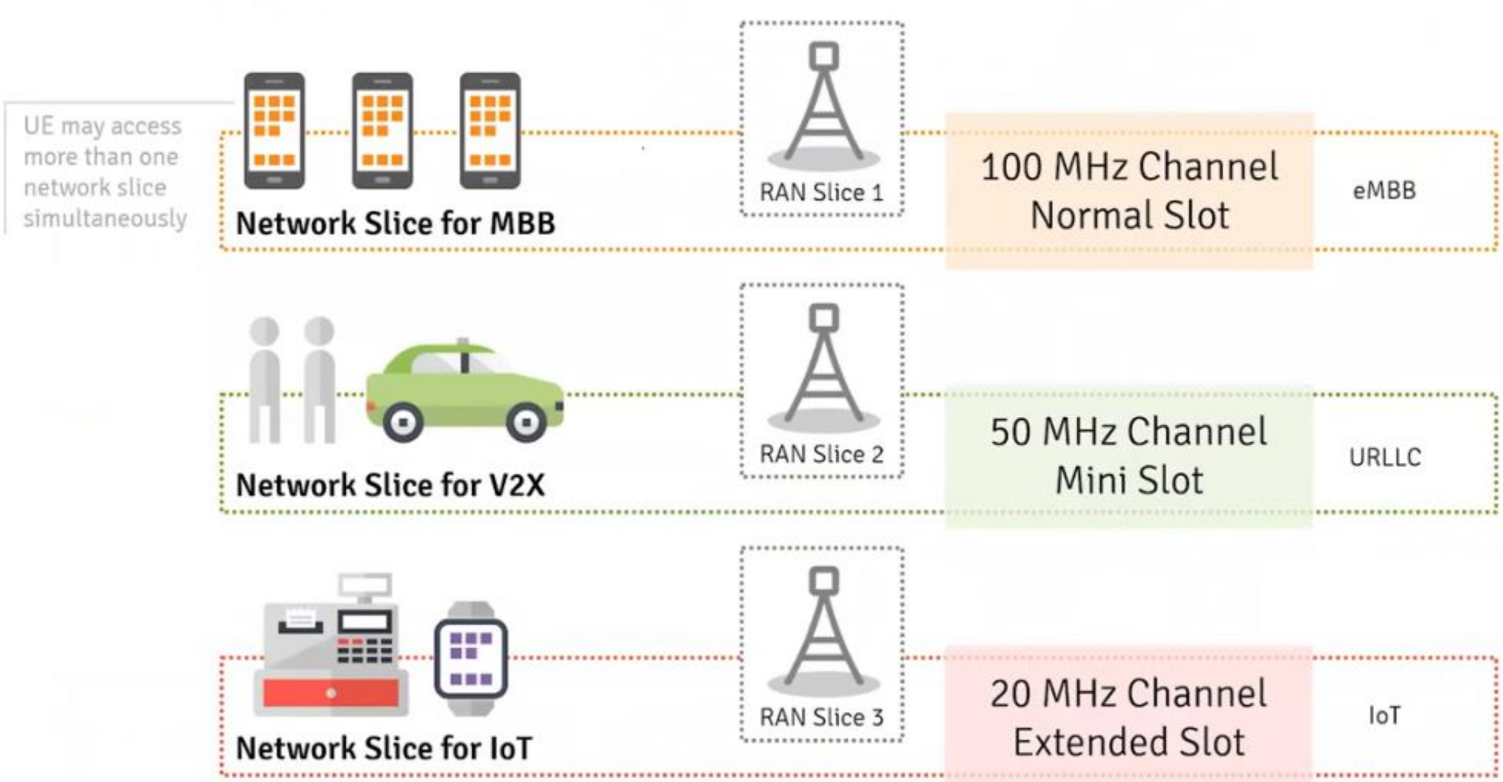
5G Network Building Blocks



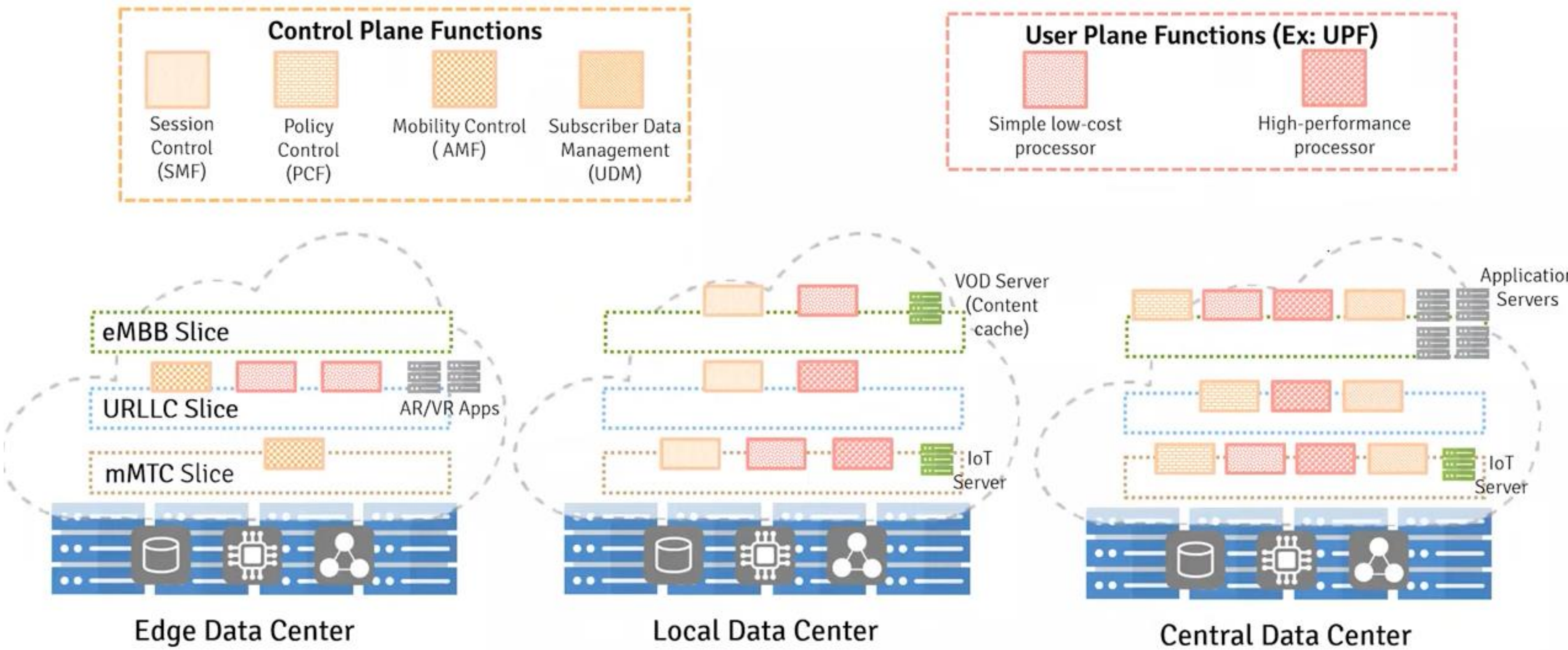
Independent Virtual Networks



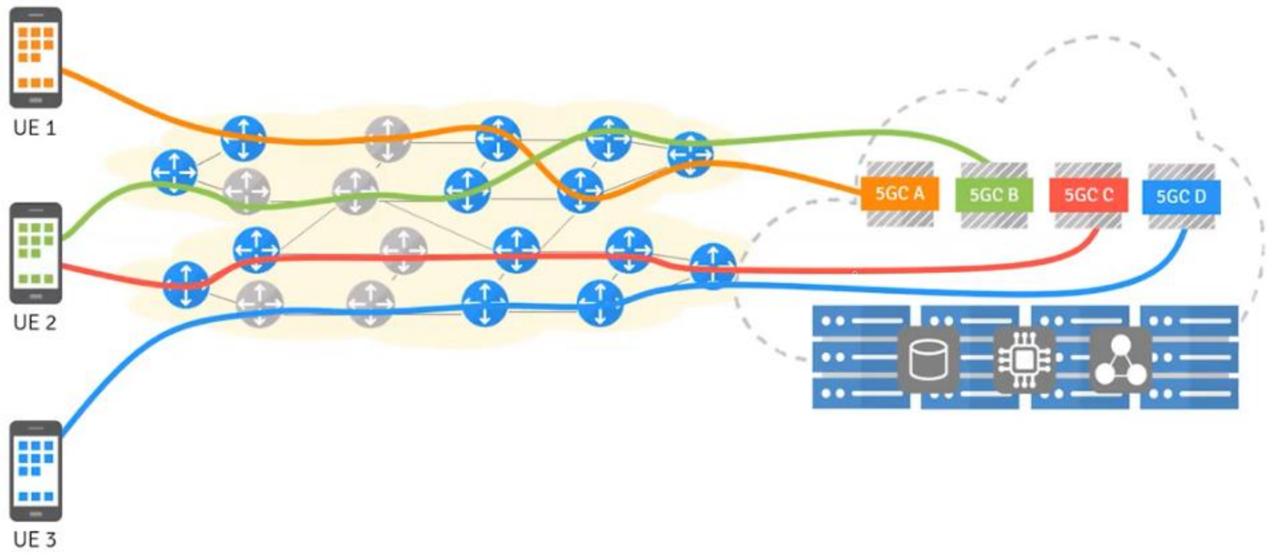
RAN Slicing


UE may access more than one network slice simultaneously
Network Slice for MBB
RAN Slice 1
100 MHz Channel Normal Slot
eMBB
Network Slice for V2X
RAN Slice 2
50 MHz Channel Mini Slot
URLLC
Network Slice for IoT
RAN Slice 3
20 MHz Channel Extended Slot
IoT

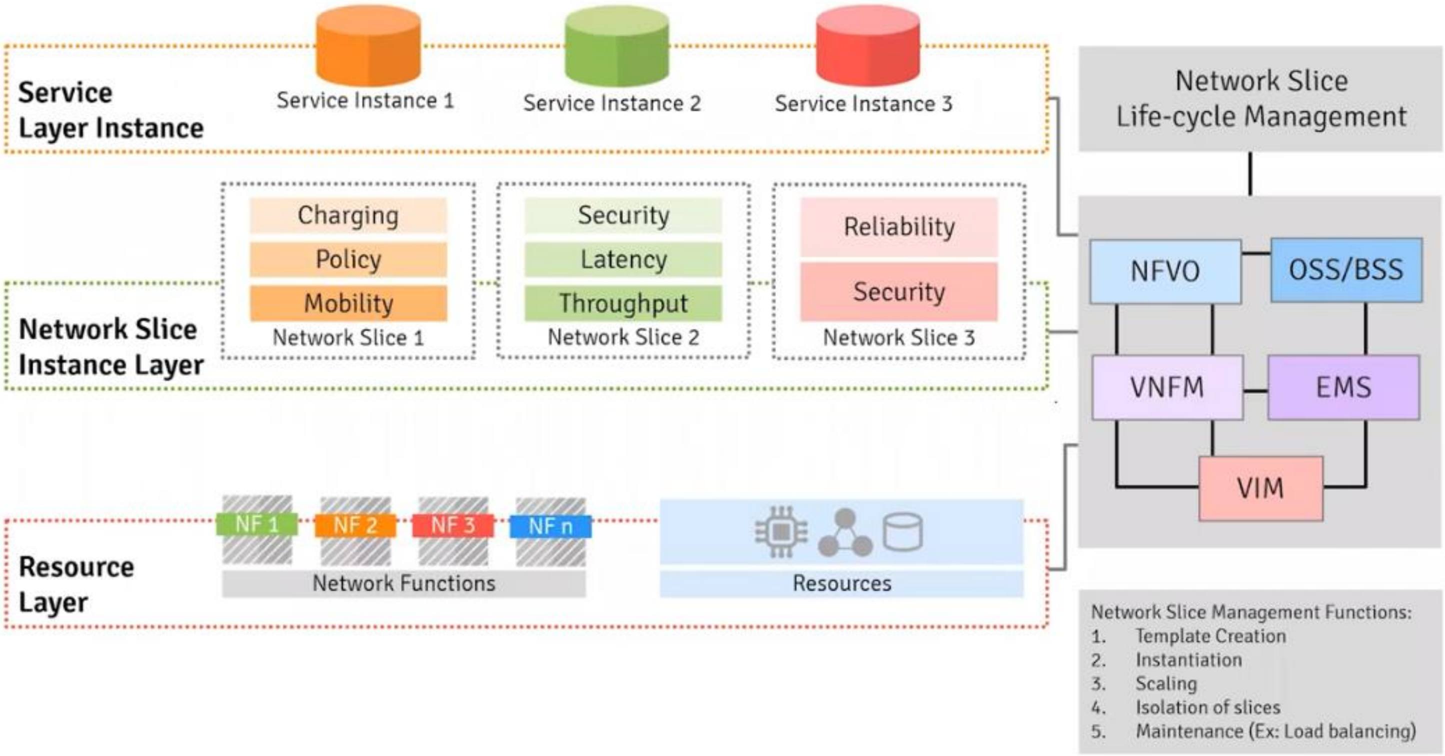
Core Network Slicing



Transport Slicing

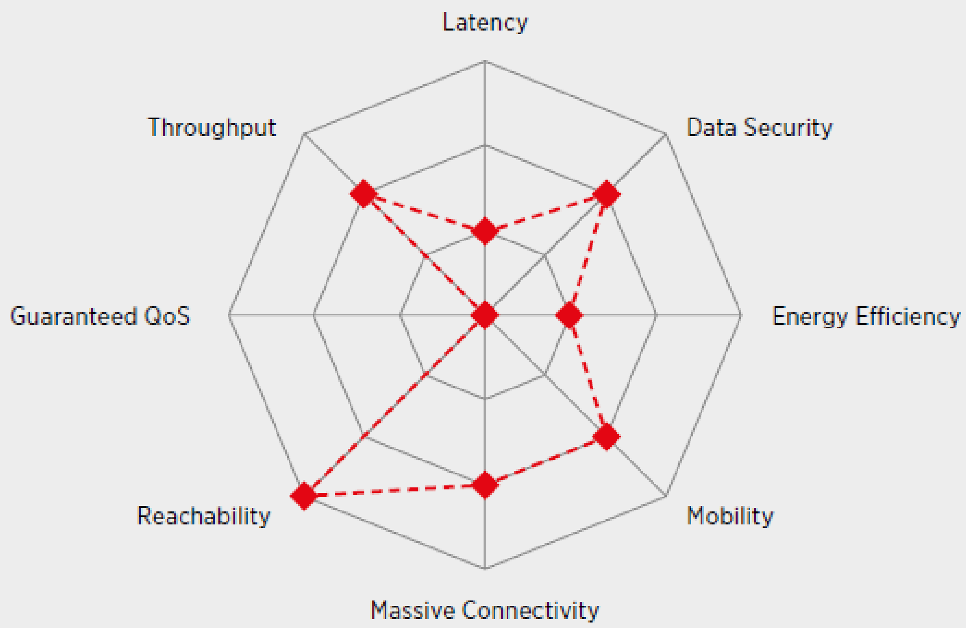


MANO



Service Layer Instance
Service Instance 1
Service Instance 2
Service Instance 3
Network Slice Life-cycle Management
Charging
Policy
Mobility
Network Slice 1
Security
Latency
Throughput
Network Slice 2
Reliability
Security
Network Slice 3
Network Slice Instance Layer
NFVO
OSS/BSS
VNFM
EMS
VIM
NF 1
NF 2
NF 3
NF n
Network Functions
Resources
Resource Layer
Network Slice Management Functions:
1. Template Creation
2. Instantiation
3. Scaling
4. Isolation of slices
5. Maintenance (Ex: Load balancing)

Network Slicing Customization



Network Capability

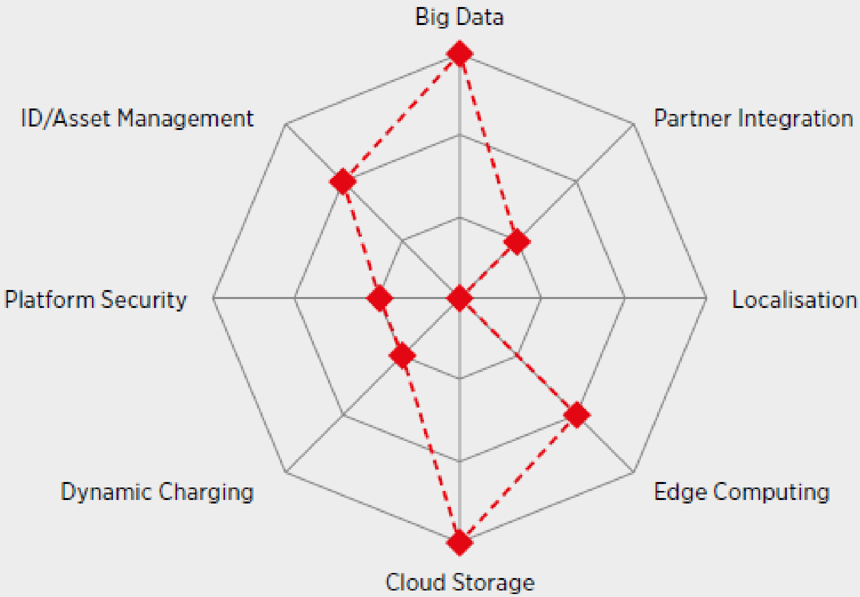
- Latency
- Data Security
- Energy Efficiency
- Mobility
- Massive Connectivity
- Reachability
- Guaranteed QoS
- Throughput

*GSMA Introduction to Network Slicing

Network Slicing Customization

Network Services

- Big Data
- Partner Integration
- Localisation
- Edge Computing
- Cloud Storage
- Dynamic Charging
- Platform Security
- ID Management



*GSMA Introduction to Network Slicing

Network Slicing Challenges

– Resource management/sharing among slices
– Isolation among network slices
– Life-cycle management of the network slices
– Security Aspects
– Slicing in wireless part (virtualization of RAN functions)

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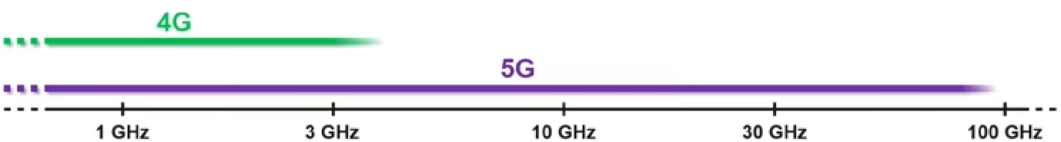
5G New Radio Spectrum Range

Spectrum for 5G/NR

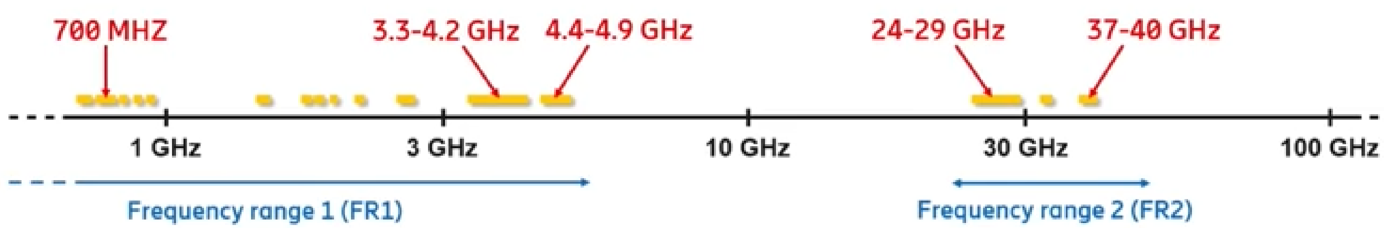
Extension to higher frequencies including millimeter-wave spectrum



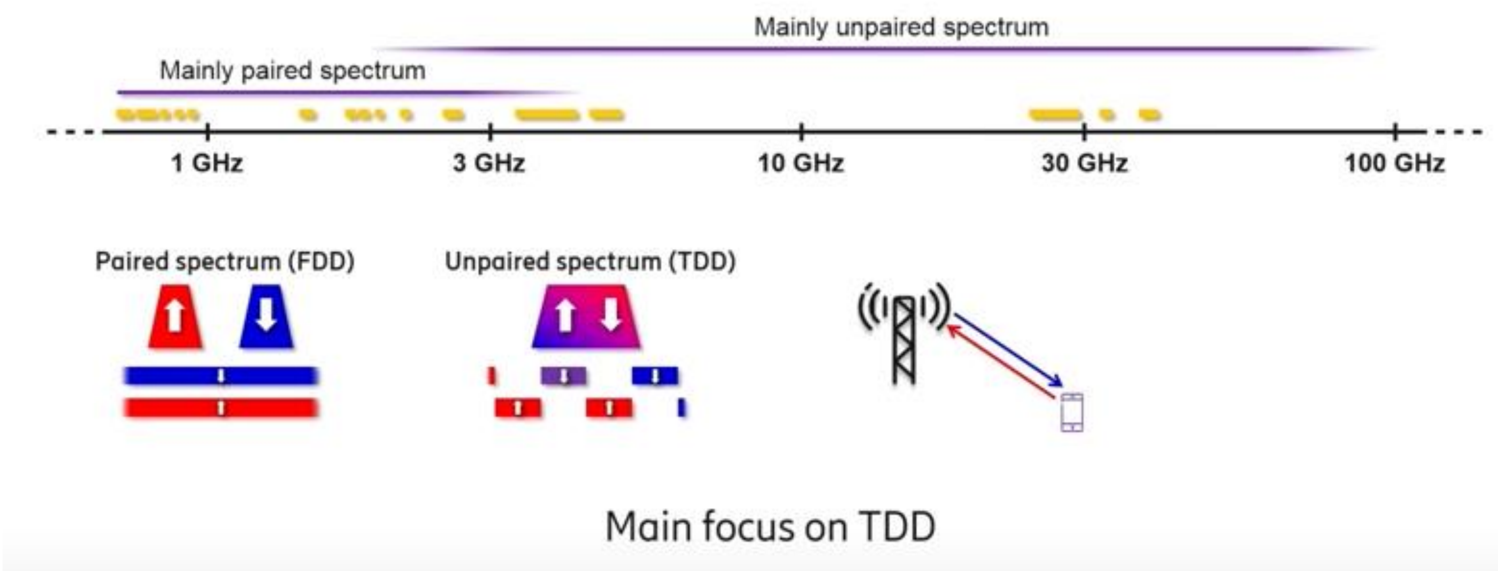
— Lower frequencies for wide-area coverage

— Higher frequencies for very high traffic capacity and very high data rates in dense deployments

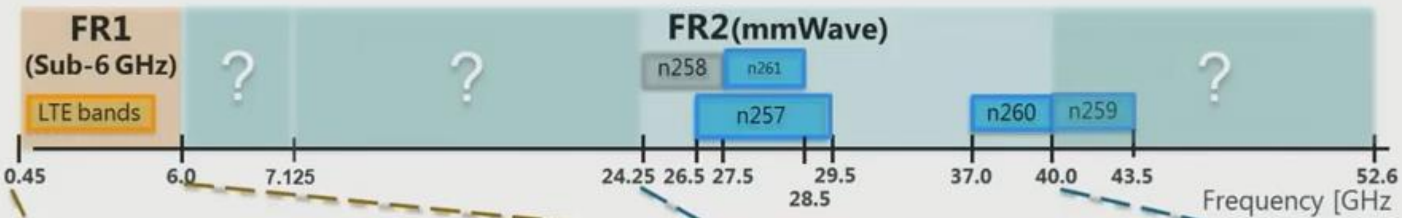
Spectrum for 5G/NR
Specified frequency bands



5G New Radio Duplexing



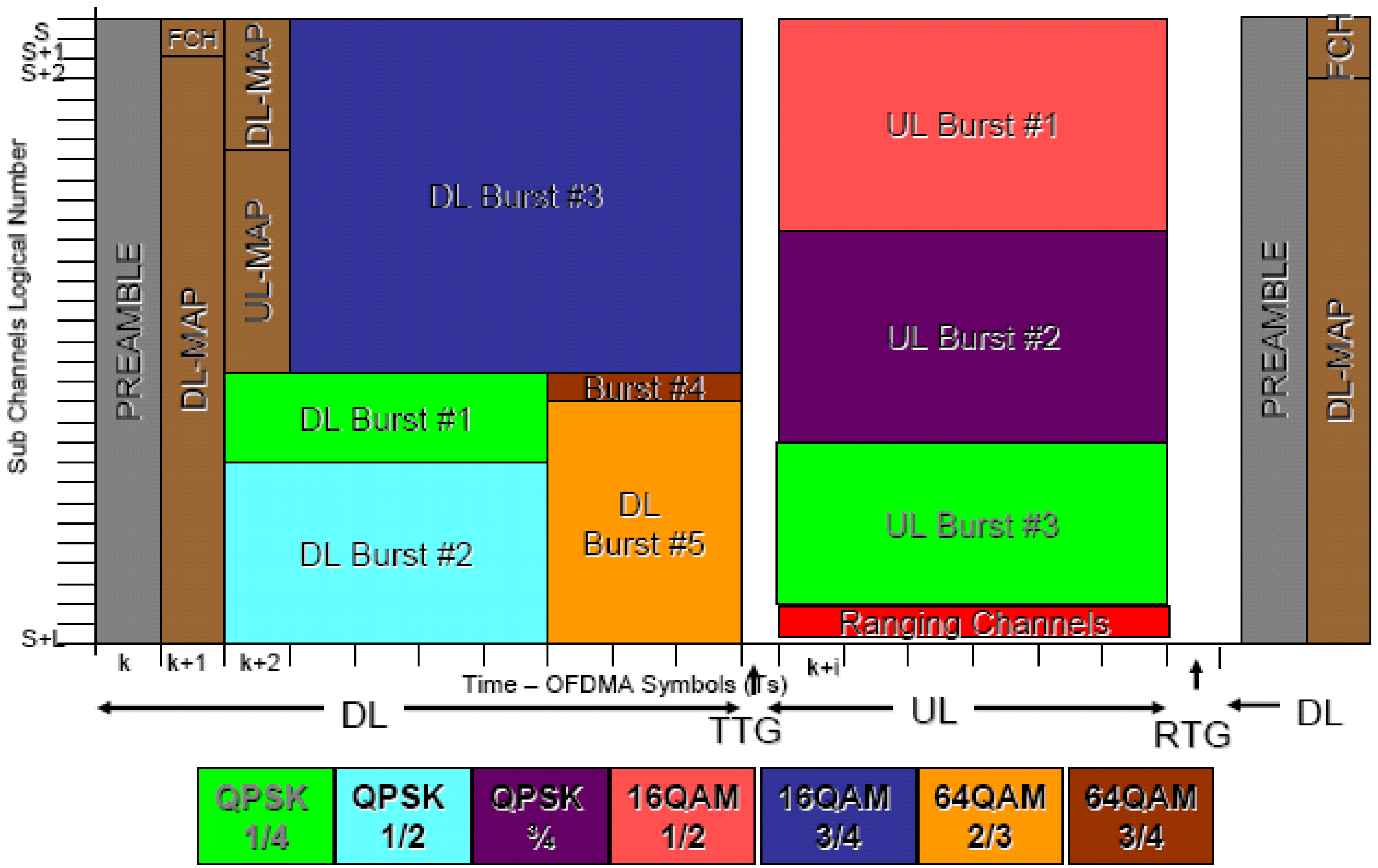
5G New Radio Duplexing



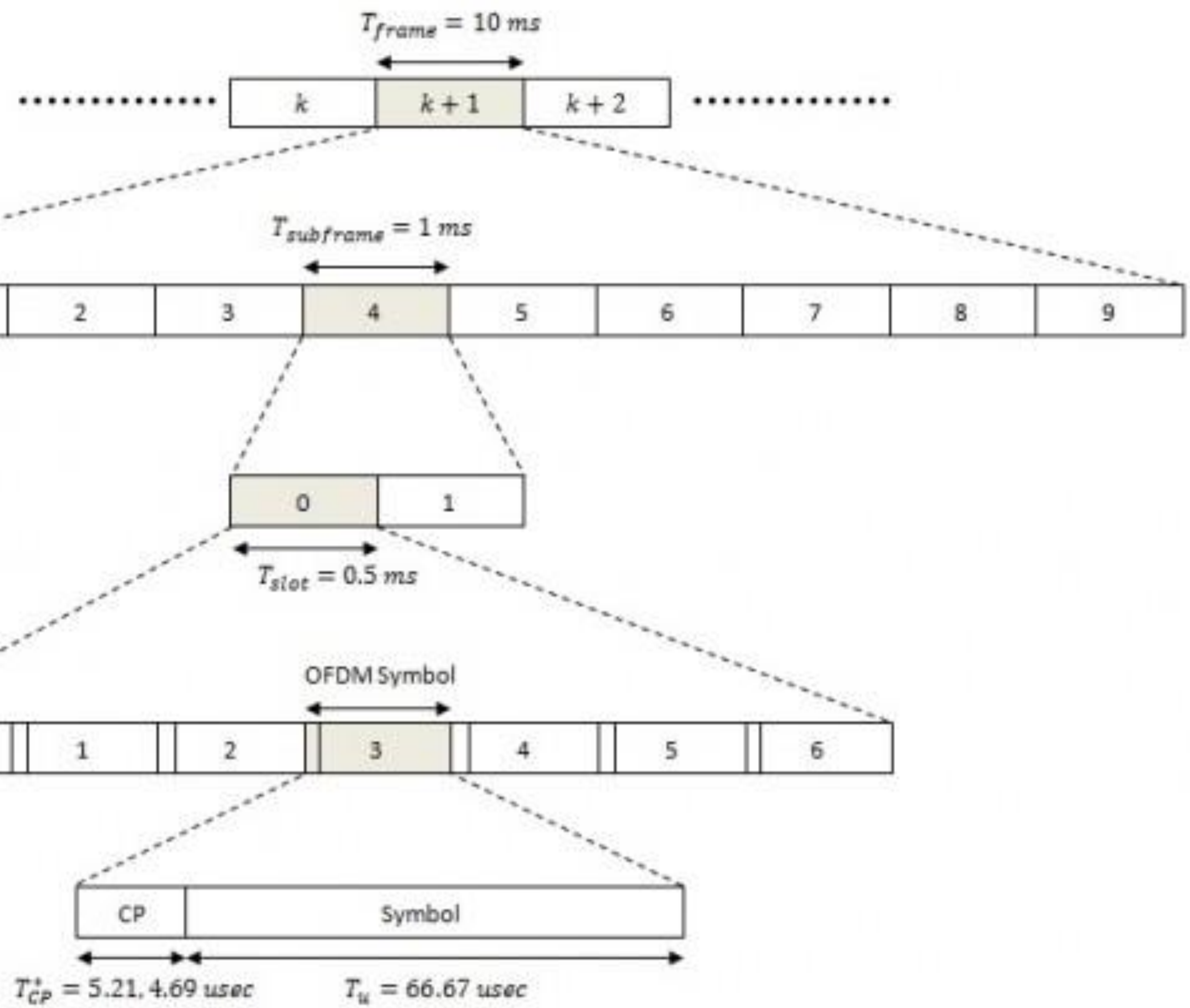
	Band number	UL	DL
FDD	n1	1920 – 1980 MHz	2110 – 2170 MHz
FDD	n2	1850 – 1910 MHz	1930 – 1990 MHz
FDD	n3	1710 – 1785 MHz	1805 – 1880 MHz
FDD	n5	824 – 849 MHz	869 – 894MHz
FDD	n7	2500 – 2570 MHz	2620 – 2690 MHz
FDD	n8	880 – 915 MHz	925 – 960 MHz
FDD	n20	832 – 862 MHz	791– 821MHz
FDD	n28	703 – 748 MHz	758 – 803 MHz
TDD	n38	2570 – 2620 MHz	2570 – 2620 MHz
TDD	n41	2496 – 2690 MHz	2496 – 2690 MHz
TDD	n50	1432 – 1517 MHz	1432 – 1517 MHz
TDD	n51	1427 – 1432 MHz	1427 – 1432 MHz
FDD	n66	1710 – 1780 MHz	2110 – 2200 MHz
FDD	n70	1695 – 1710 MHz	1995– 2020 MHz
FDD	n71	663 – 698 MHz	617 – 652 MHz
FDD	n74	1427 –1470 MHz	1475 – 1518 MHz
SDL	n75	N/A	1432 – 1517 MHz
SDL	n76	N/A	1427 – 1432 MHz
TDD	n77	3.3 – 4.2 GHz	3.3 – 4.2 GHz
TDD	n78	3.3 – 3.8 GHz	3.3 – 3.8 GHz
TDD	n79	4.4 – 5.0 GHz	4.4 – 5.0 GHz
SUL	n80	1710 – 1785 MHz	N/A
SUL	n81	880 – 915 MHz	N/A
SUL	n82	832 – 862 MHz	N/A
SUL	n83	703 – 748 MHz	N/A
SUL	n84	1920 – 1980 MHz	N/A
SUL	n85	2496 – 2690 MHz	N/A

Band number	UL	DL	
n257	26.5 –29.5 GHz	26.5 –29.5 GHz	TDD
n258	24.25 – 27.5 GHz	24.25 – 27.5 GHz	TDD
n259	40.5 – 43.5 GHz	40.5 – 43.5 GHz	TDD
n260	37–40 GHz	37–40 GHz	TDD
n261	27.5 – 28.35 GHz	27.5 – 28.35 GHz	TDD

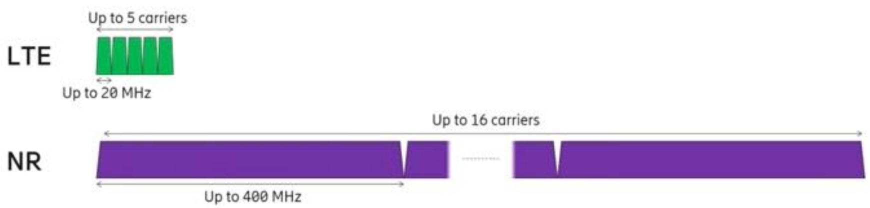
Comparison with 4G



Generic Frame Structure



5G New Radio Carriers

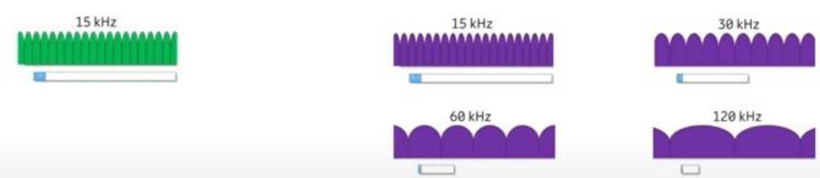


LTE
- Per carrier bandwidth up to 20 MHz
  - Minimum carrier bandwidth: 1.25 MHz
- Carrier aggregation up to 5 carriers
  ⇨ Maximum bandwidth: 100 MHz

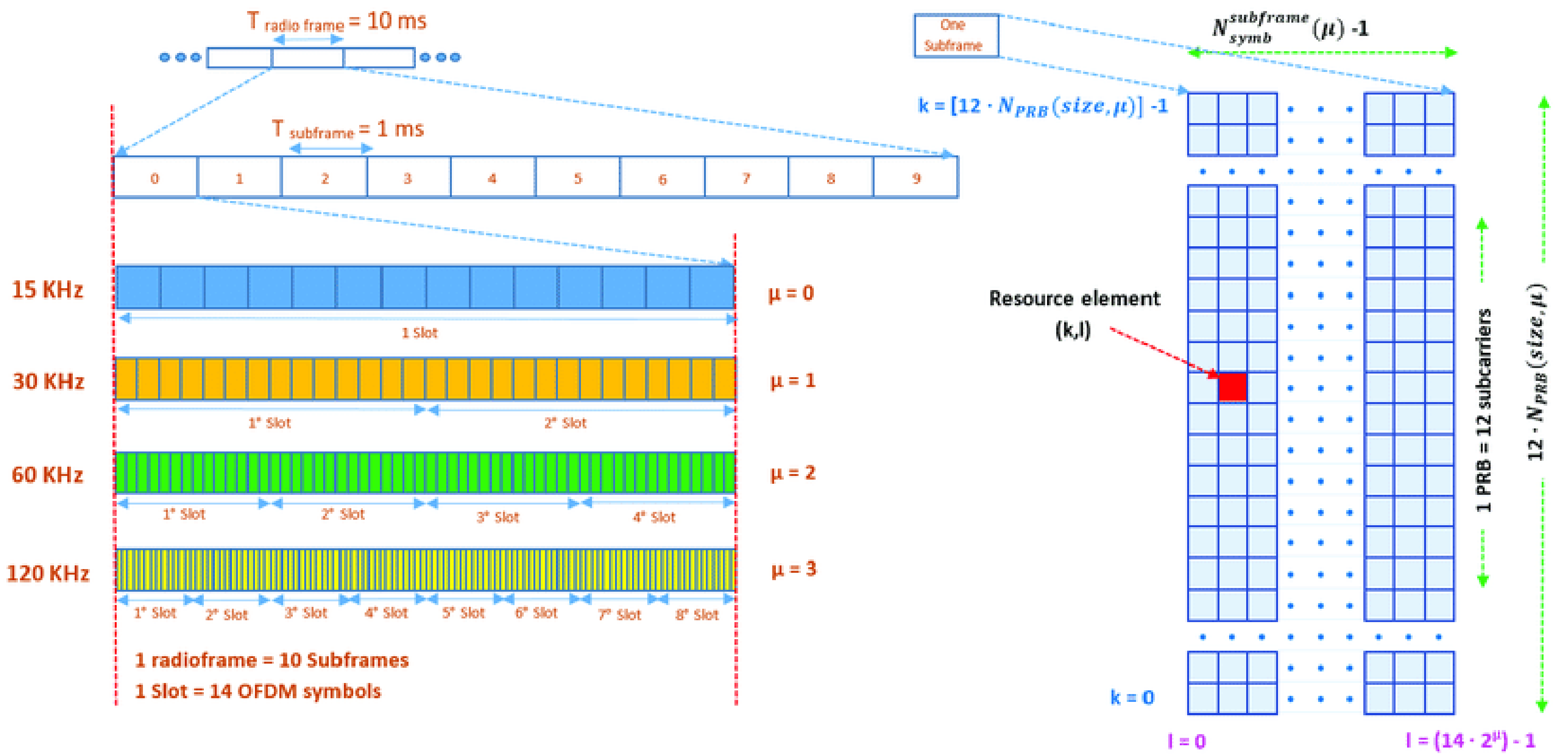
NR
- Per-carrier bandwidth up to 400 MHz
  - Minimum carrier bandwidth: 5 MHz
- Carrier aggregation up to 16 carriers
  ⇨ Maximum bandwidth: 6.4 GHz (!)

LTE
- Downlink: Conventional OFDM
- Uplink: DFT-precoded OFDM
- A single numerology with 15 kHz sub-carrier spacing

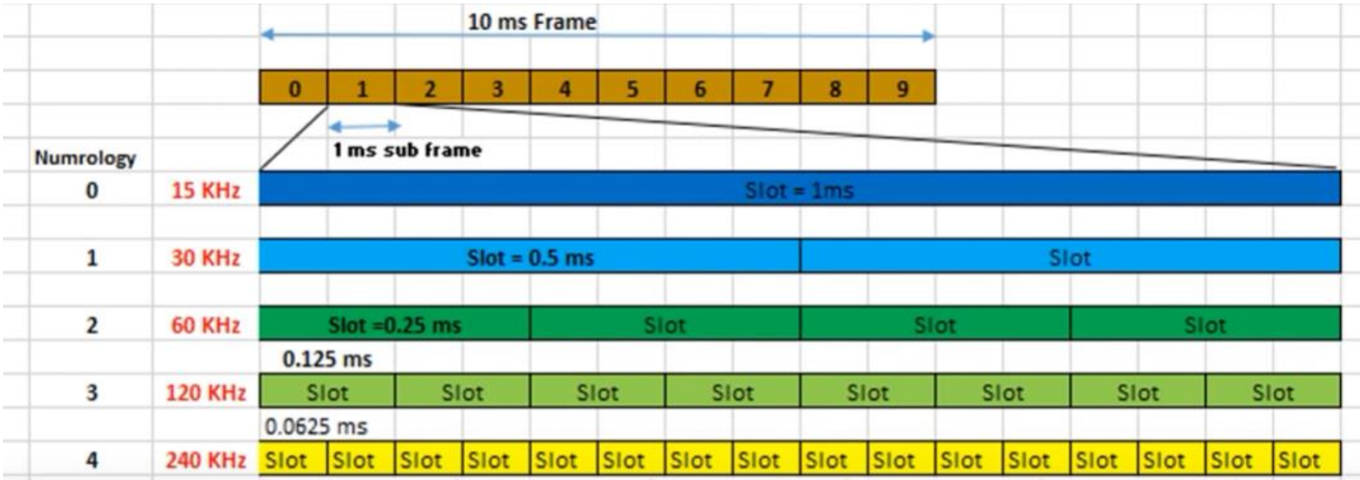
NR
- Downlink: Conventional OFDM
- Uplink: Conventional OFDM or DFT-precoded OFDM
- Flexible/scalable numerology
  - 15 kHz, 30 kHz, 60 kHz, 120 kHz
  - Correspondingly scaled symbol length



5G New Radio Numerology

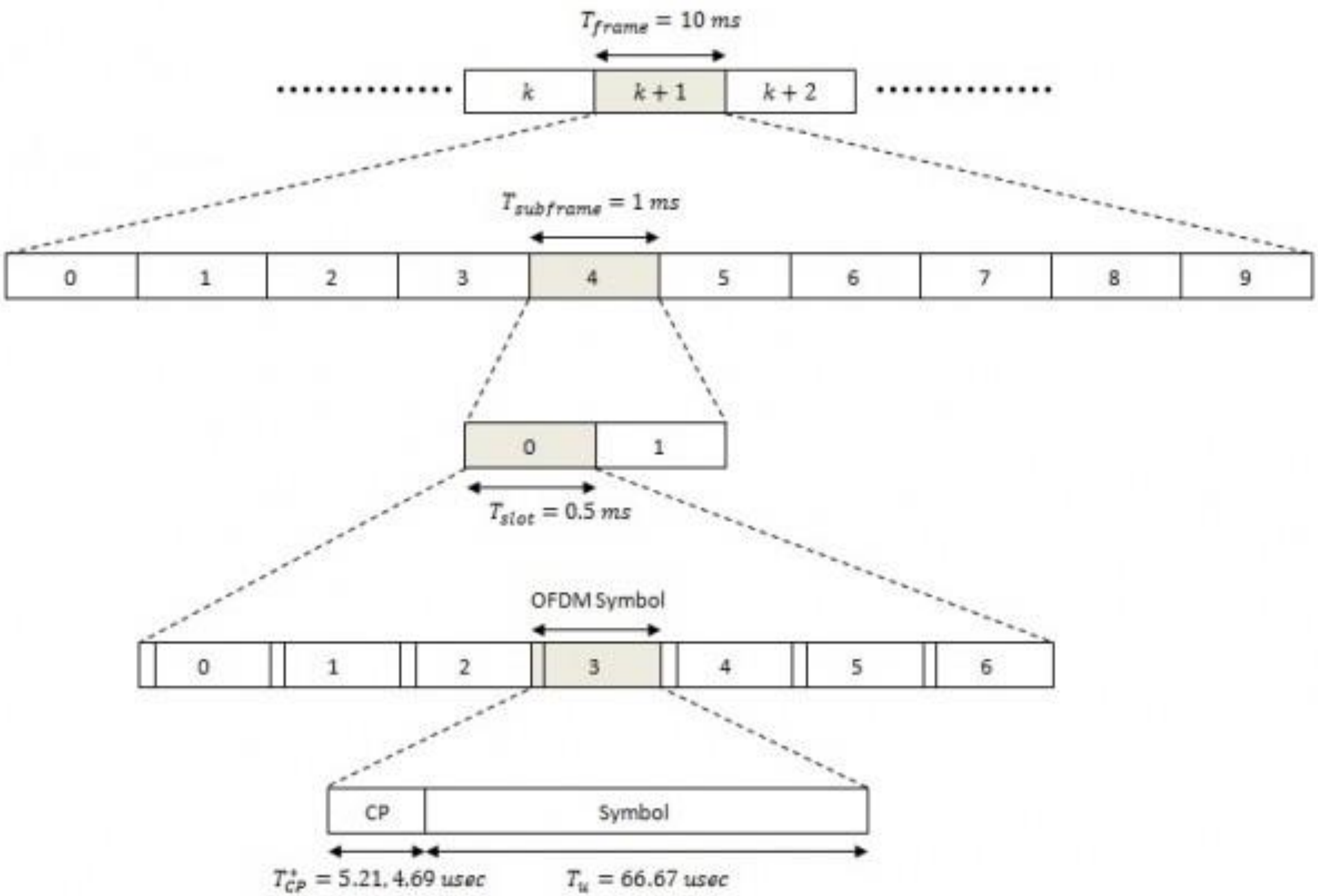


5G New Radio Numerology

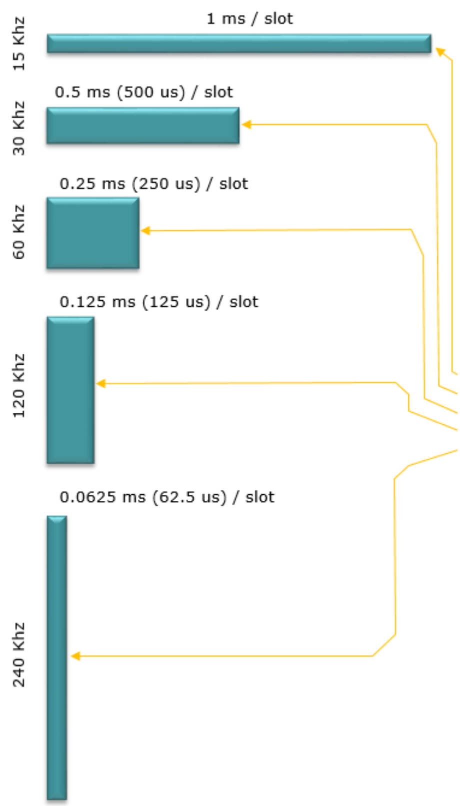


Numrology	Sub Carrier Spacing (KHz)	Slot Duration (ms)	No.of Slots in one 1ms Sub Frame	No. of Symbols in 1 ms Sub Frame
0	15	1	1	14
1	30	0.5	2	28
2	60	0.25	4	56
3	120	0.125	8	112
4	240	0.0625	16	224

Generic LTE Frame Structure



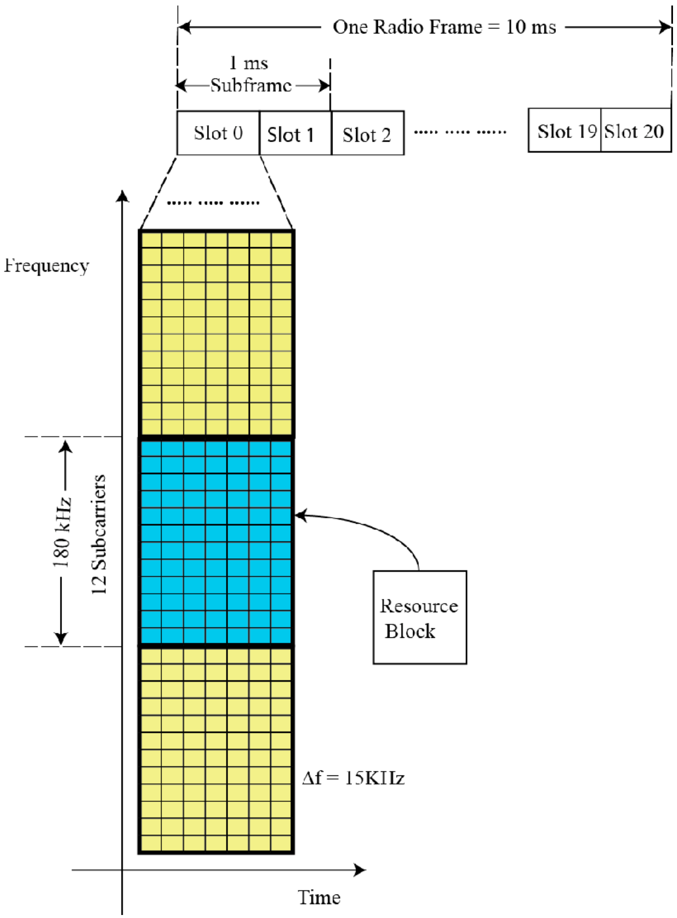
5G New Radio Numerology

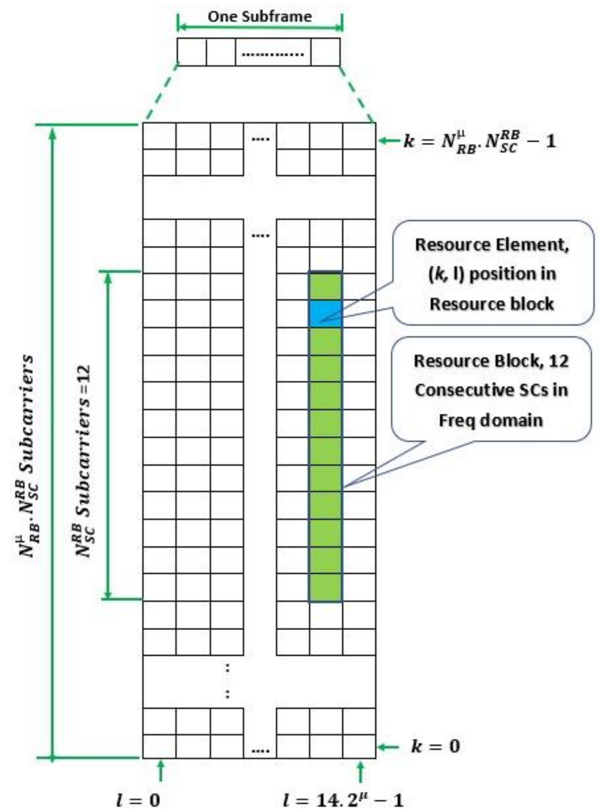


< 38.211 – Table 4.3.2-1 >

μ	N_{symb}^{slot}	$N_{slot}^{frame,\mu}$	$N_{slot}^{subframe,\mu}$
0	14	10	1
1	14	20	2
2	14	40	4
3	14	80	8
4	14	160	16

4G vs 5G Resource Block

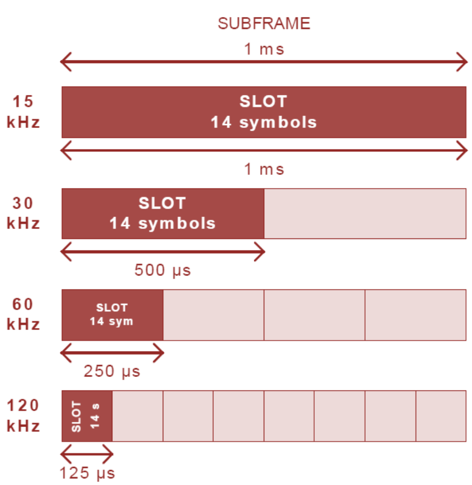




5G New Radio (Protocol Stack – Layer 1)

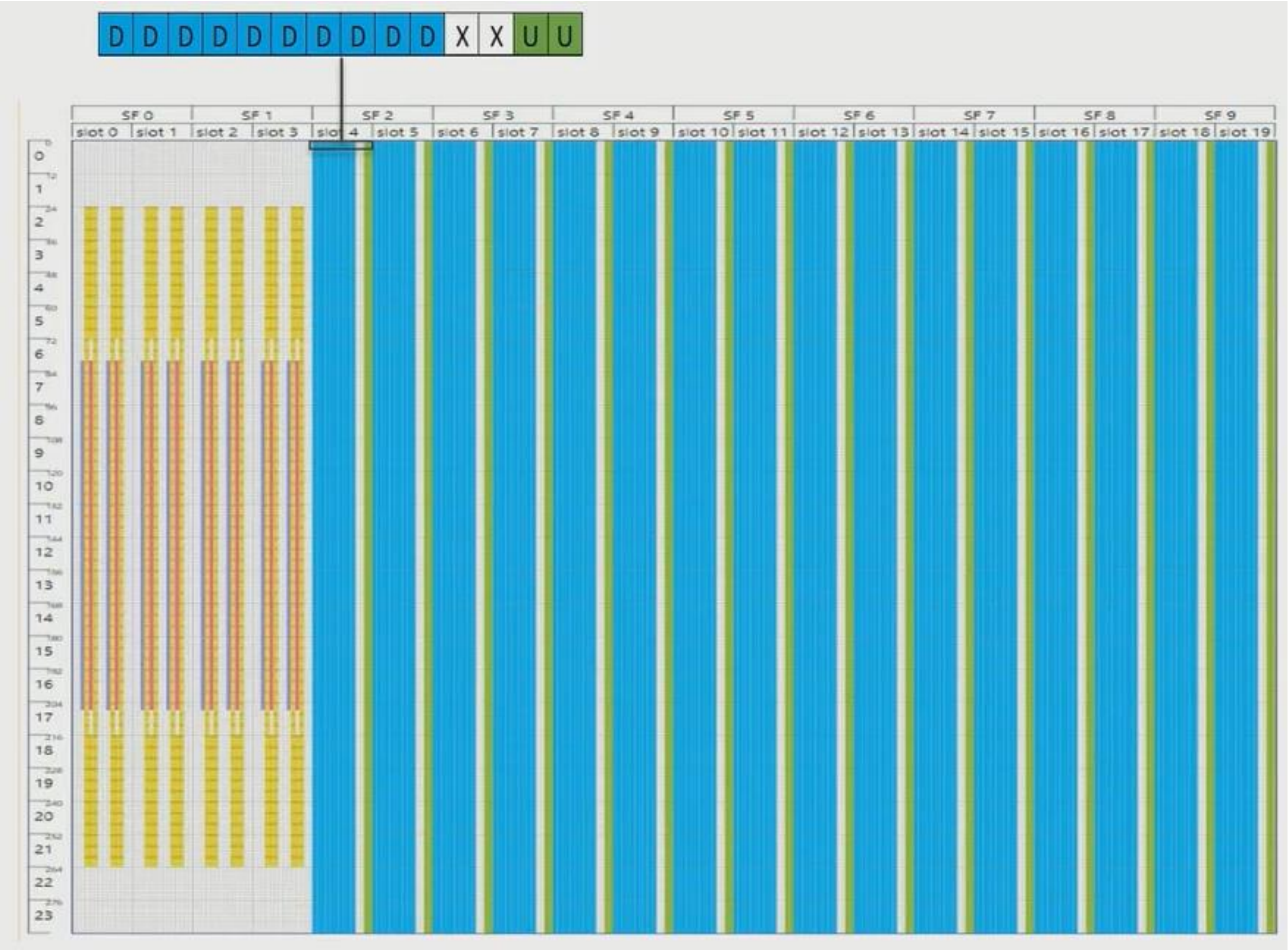
PHY Layer Functions

- Flexible numerology
    - various structures for the subframe (time domain) and subcarriers grouping (frequency-domain))
- Flexible slot format (mixed DL UL)



Subcarrier Spacing (µ)	Number of OFDM Symbols per Slot (N_{symb}^{slot})	Number of Slots per Subframe ($N_{slot}^{subframe,\mu}$)	Number of Slots per Frame ($N_{slot}^{frame,\mu}$)
0 *15 kHz*	14 *1 ms*	1 *1 slot x 1 ms = 1 ms*	10 *10 ms*
1 *30 kHz*	14 *500 µs*	2 *2 slots x 500 µs = 1 ms*	20 *10 ms*
2 *60 kHz (normal CP)*	14 *250 µs*	4 *4 slots x 250 µs = 1 ms*	40 *10 ms*
2 *60 kHz (extended CP)*	12 *250 µs*	4 *4 slots x 250 µs = 1 ms*	40 *10 ms*
3 *120 kHz*	14 *125 µs*	8 *8 slots x 125 µs = 1 ms*	80 *10 ms*
4 *240 kHz*	14 *62.5 µs*	16 *16 slots x 62.5 µs = 1 ms*	160 *10 ms*
5 *480 kHz*	14 *31.25 µs*	32 *32 slots x 31.25 µs = 1 ms*	320 *10 ms*

5G New Radio Frame Structure



5G New Radio Slot Formats

<38.213 v15.7 -Table 11.1.1-1: Slot formats for normal cyclic prefix>
D : Downlink, U : Uplink, F : Flexible

	Symbol Number in a slot													
Format	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	D	D	D	D	D	D	D	D	D	D	D	D	D	D
1	U	U	U	U	U	U	U	U	U	U	U	U	U	U
2	F	F	F	F	F	F	F	F	F	F	F	F	F	F
3	D	D	D	D	D	D	D	D	D	D	D	D	D	F
4	D	D	D	D	D	D	D	D	D	D	D	D	F	F
5	D	D	D	D	D	D	D	D	D	D	D	F	F	F
6	D	D	D	D	D	D	D	D	D	D	F	F	F	F
7	D	D	D	D	D	D	D	D	D	F	F	F	F	F
8	F	F	F	F	F	F	F	F	F	F	F	F	F	U
9	F	F	F	F	F	F	F	F	F	F	F	F	U	U
10	F	U	U	U	U	U	U	U	U	U	U	U	U	U
11	F	F	U	U	U	U	U	U	U	U	U	U	U	U
12	F	F	F	U	U	U	U	U	U	U	U	U	U	U
13	F	F	F	F	U	U	U	U	U	U	U	U	U	U
14	F	F	F	F	F	U	U	U	U	U	U	U	U	U
15	F	F	F	F	F	F	U	U	U	U	U	U	U	U
16	D	F	F	F	F	F	F	F	F	F	F	F	F	F
17	D	D	F	F	F	F	F	F	F	F	F	F	F	F
18	D	D	D	F	F	F	F	F	F	F	F	F	F	F
19	D	F	F	F	F	F	F	F	F	F	F	F	F	U
20	D	D	F	F	F	F	F	F	F	F	F	F	F	U
21	D	D	D	F	F	F	F	F	F	F	F	F	F	U
22	D	F	F	F	F	F	F	F	F	F	F	F	U	U
23	D	D	F	F	F	F	F	F	F	F	F	F	U	U
24	D	D	D	F	F	F	F	F	F	F	F	F	U	U
25	D	F	F	F	F	F	F	F	F	F	F	U	U	U
26	D	D	F	F	F	F	F	F	F	F	F	U	U	U

Slot Format Examples

DL-heavy transmission with UL part																											
Slot (e.g, slot format 28)														Slot(e.g, slot format 28)													
D	D	D	D	D	D	D	D	D	D	D	D	F	U	D	D	D	D	D	D	D	D	D	D	D	D	F	U

UL-heavy transmission with DL Control																											
Slot(e.g, slot format 34)														Slot(e.g, slot format 34)													
D	F	U	U	U	U	U	U	U	U	U	U	U	U	D	F	U	U	U	U	U	U	U	U	U	U	U	U

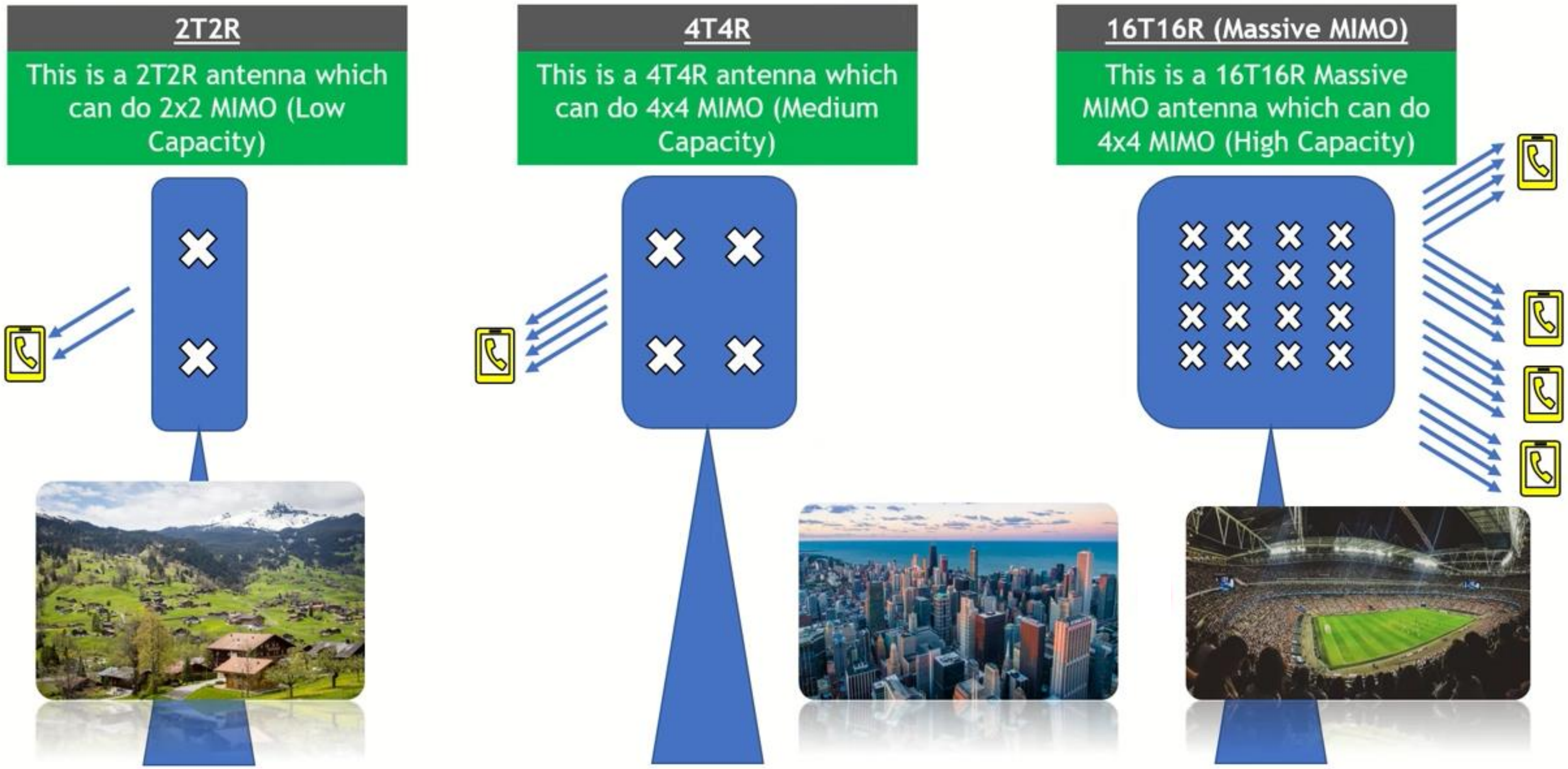
Slot aggregation for DL-heavy transmission (e.g, for eMBB)																											
Slot(e.g, slot format 0)														Slot (e.g, slot format 28)													
D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	F	U

Slot aggregation for UL-heavy transmission (e.g, for eMBB)																											
Slot														Slot													
D	F	U	U	U	U	U	U	U	U	U	U	U	U	D	U	U	U	U	U	U	U	U	U	U	U	U	U

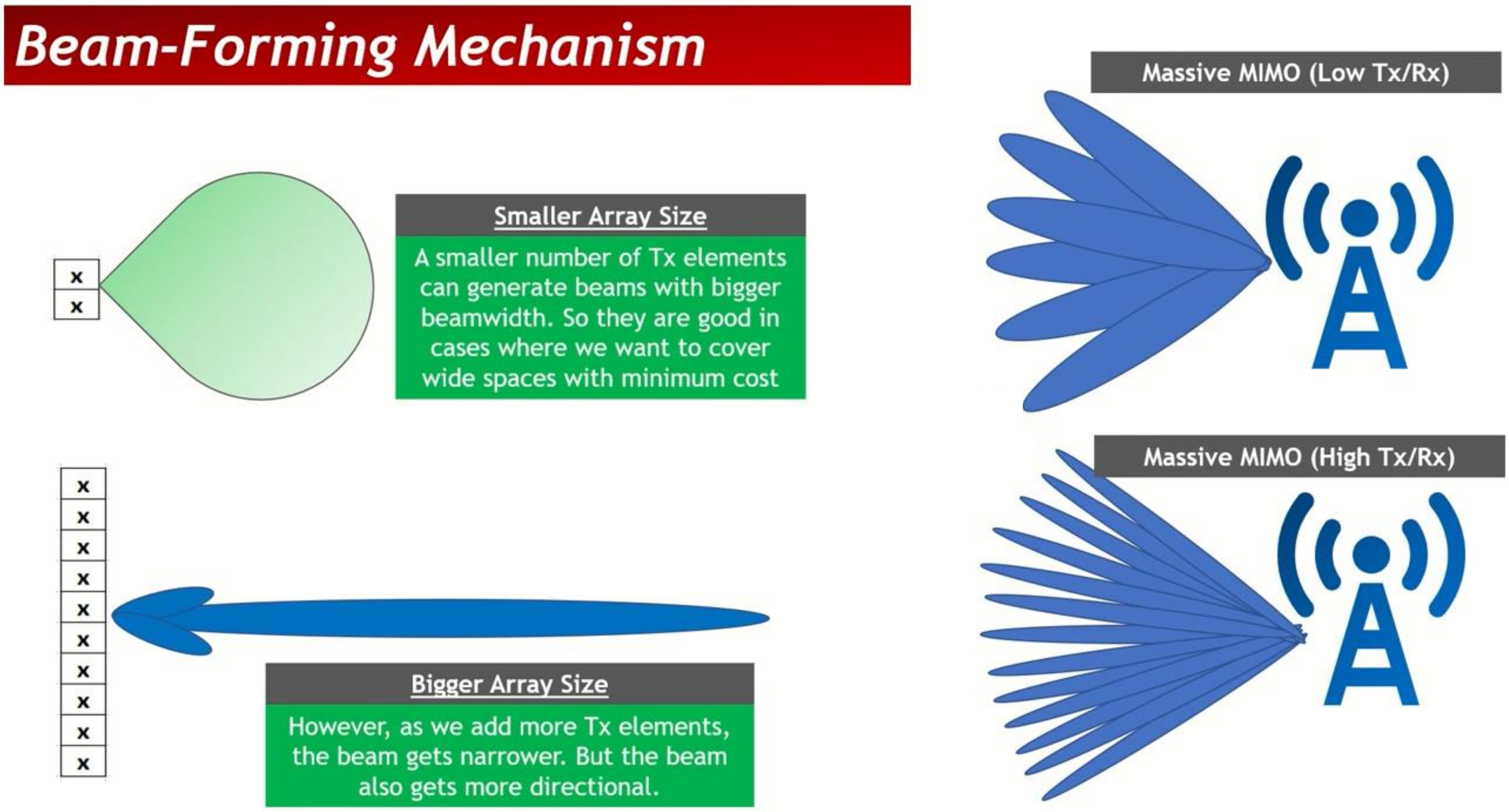
5G Advancements

- **New Architecture**
  - Advanced core network functions / NG RAN
  - Incorporate SDN/NFV (NFV MANO)
    - Decupling of control and data plane
    - Decupling of functions from the hardware
- **Network Slicing**
  - eMBB, URLLC, mMTC | 8 subclasses pes slice type
- **New Radio (NR)**
  - RAN protocol stack (+SDAP)
  - New numerology for the PHY compared to LTE
- **Massive MIMO**
  - Multiple antennas and beamforming
- **Functional Split**
  - gNodeB Fronthaul Central, Distributed and Radio Units (CU, DU and RU)

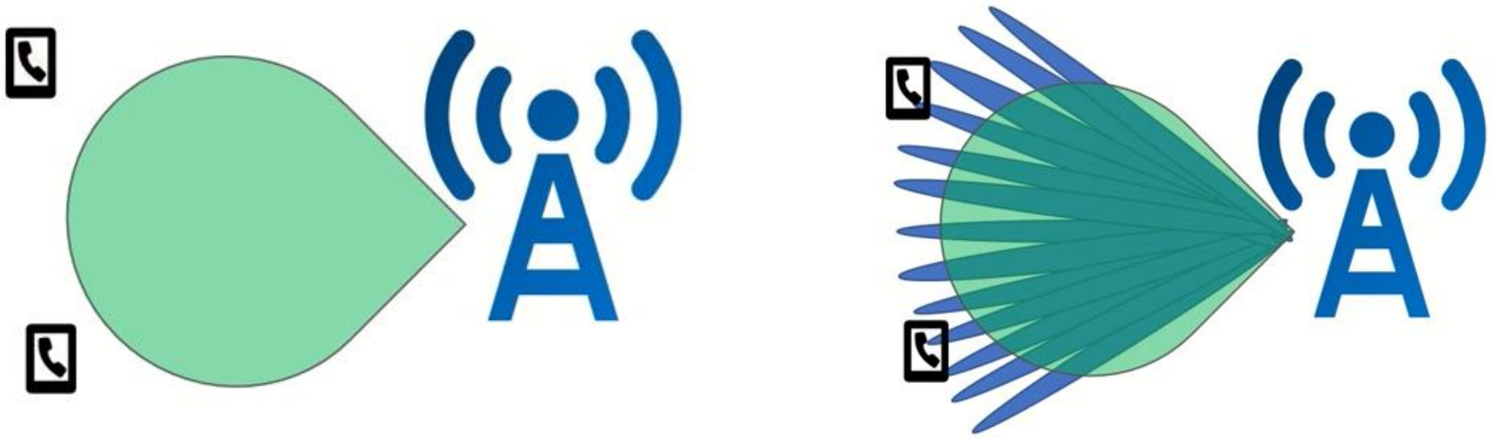
Massive MIMO



Massive MIMO

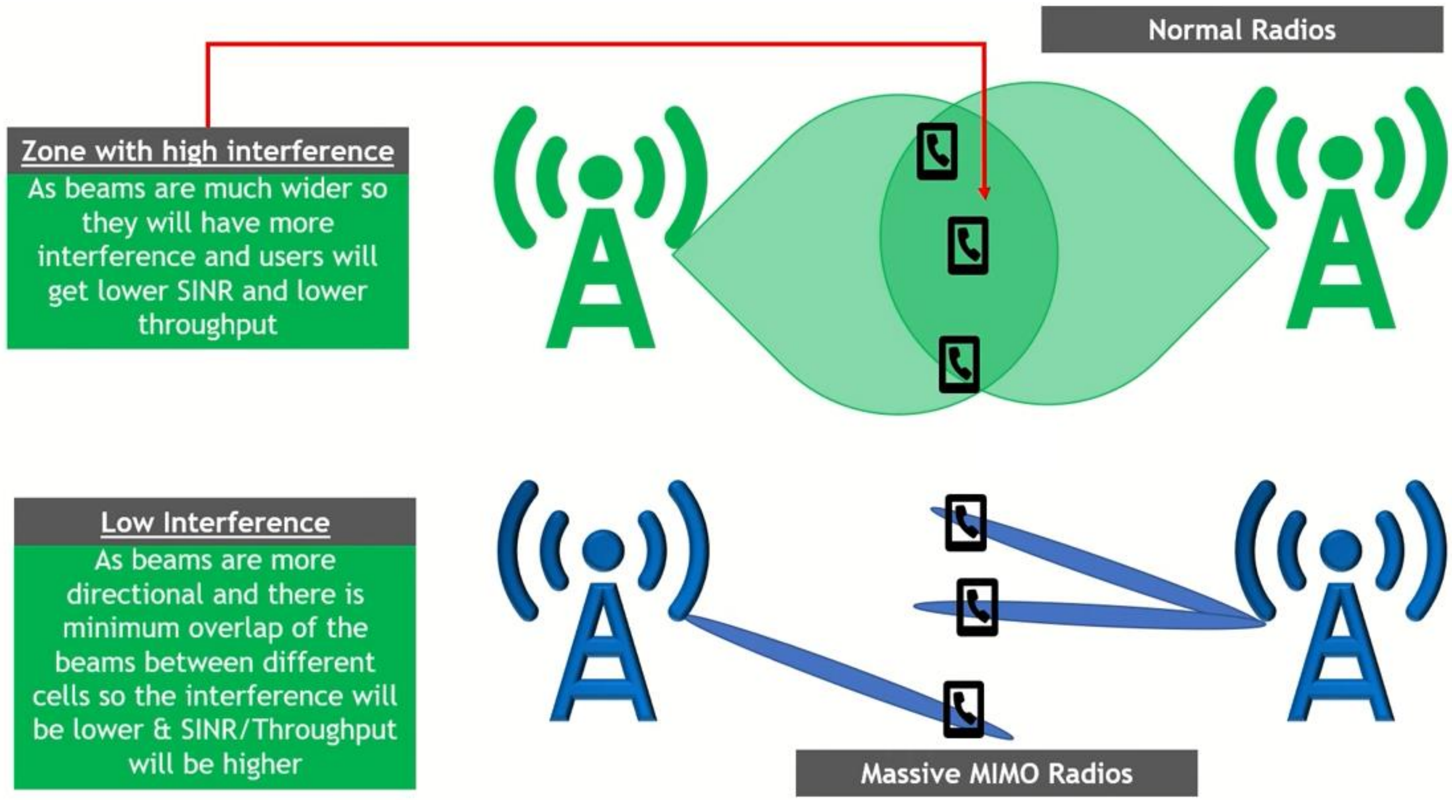


Massive MIMO



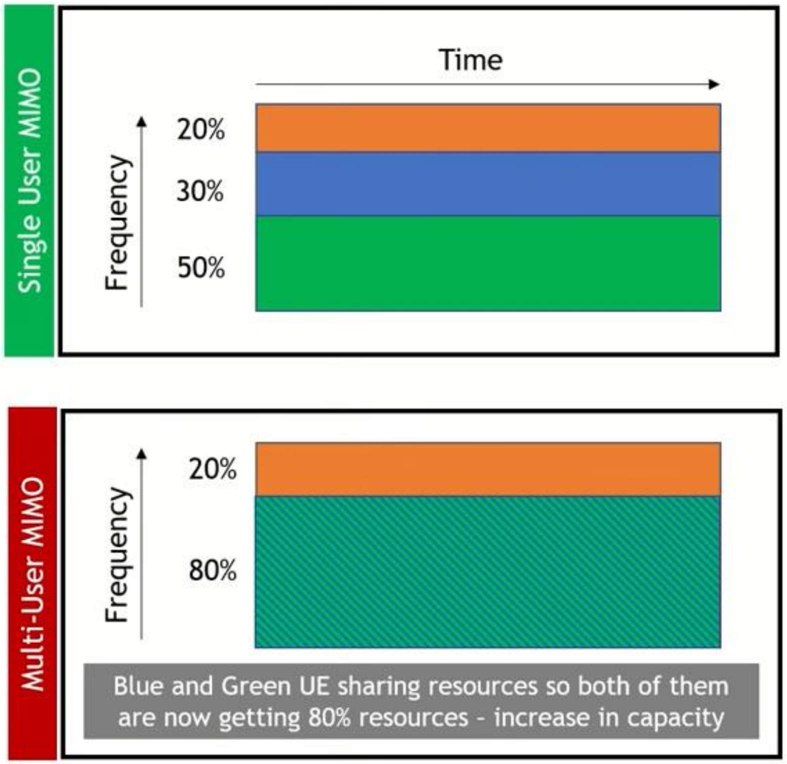
Increase coverage and capacity

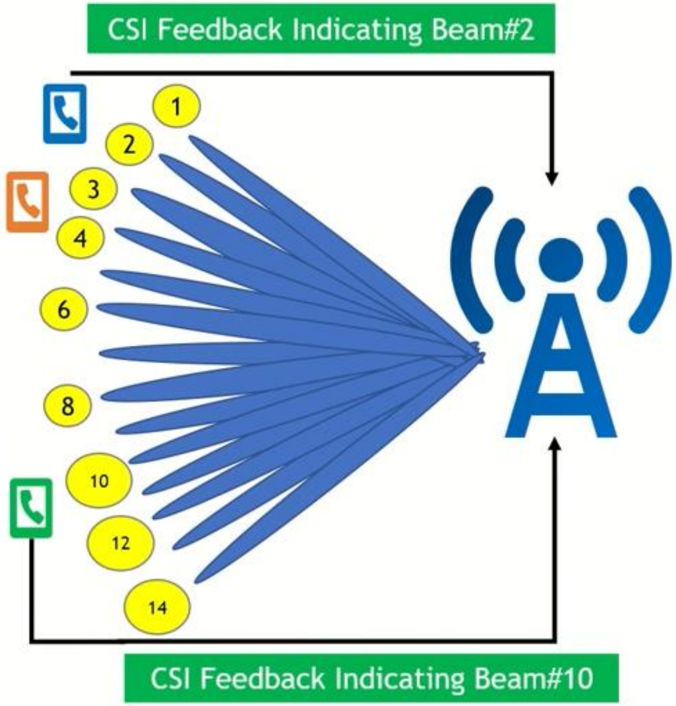
Massive MIMO



Less interference

Massive MIMO



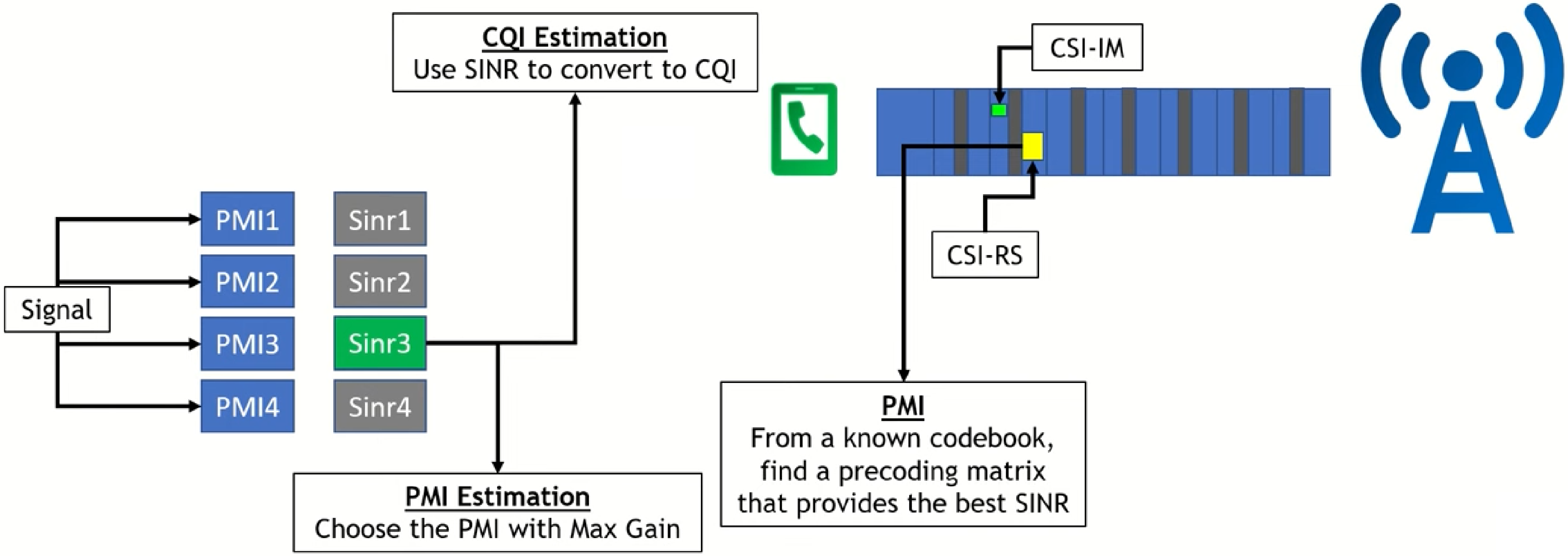


Why not sharing frequency also for Orange UE?

Massive MIMO

CSI Feedback

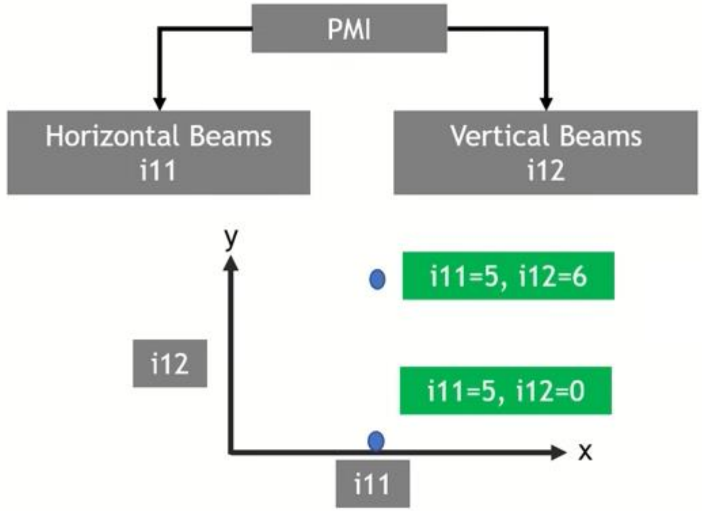
CSI Feedback has three parts
- Rank Indicator (RI)
- Channel Quality Indicator (CQI)
- Precoding Matrix Information (PMI)

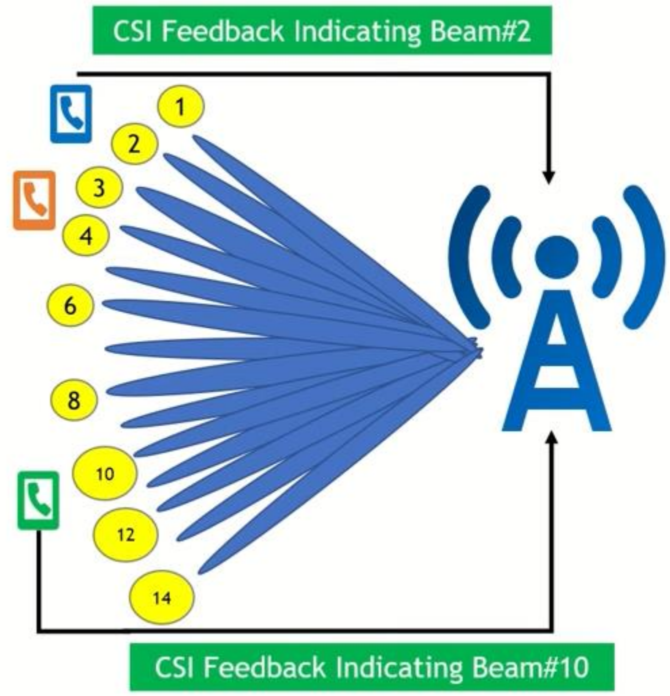


Massive MIMO

How To Choose The Beam

- The UE needs to tell the 5G cell about the best beam
- This can be done by using CSI feedback
- The CSI Feedback carries PMI information which has two important components - i11 and i12
- The i11 is used to tell about beams in azimuth direction while i12 is used to tell about beams in vertical direction





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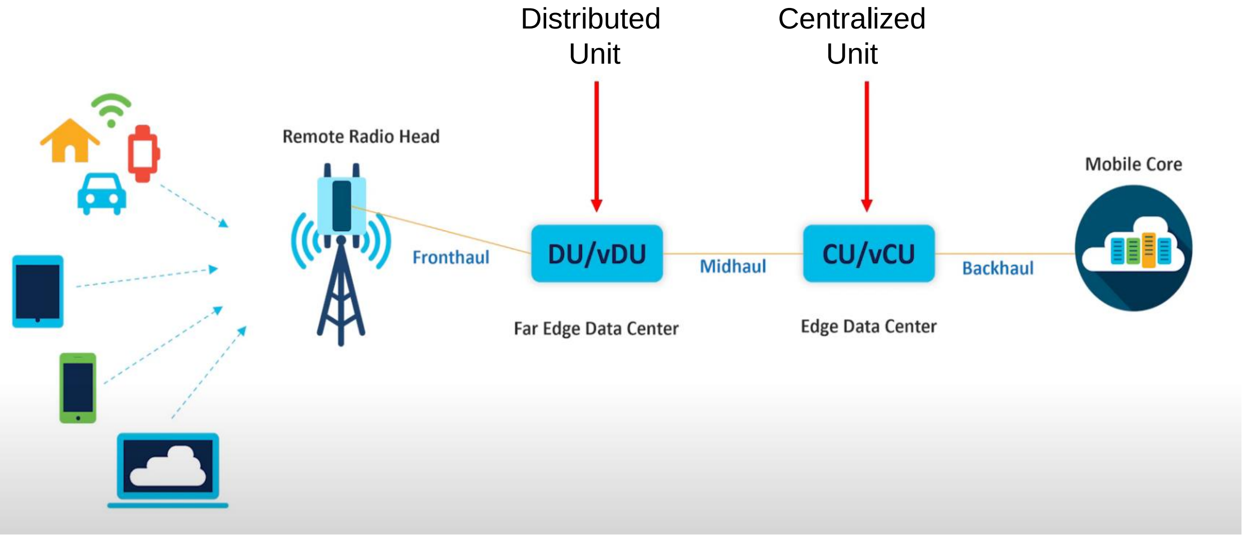
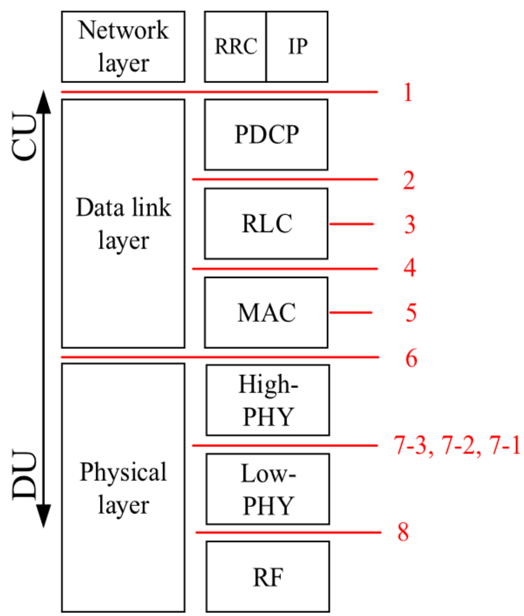
  - New numerology for the PHY compared to LTE
- **Massive MIMO**
  - Multiple antennas and beamforming
- **Functional Split**
  - gNodeB Fronthaul Central, Distributed and Radio Units (CU, DU and RU)

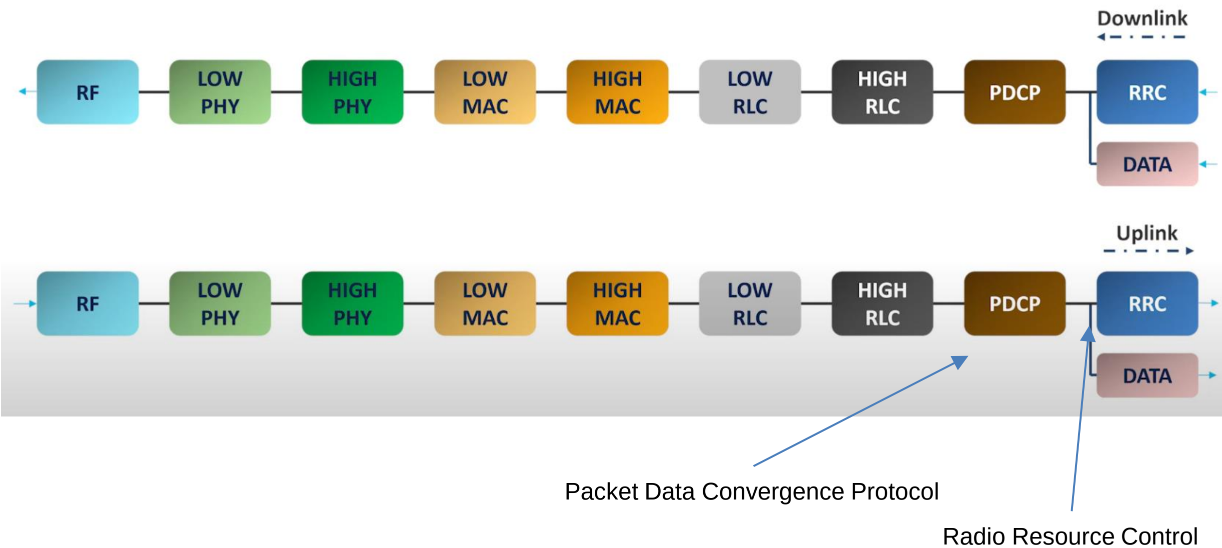
Functional Split

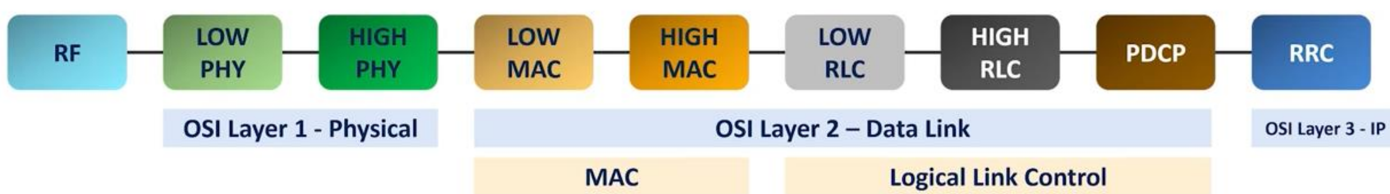
- Introduction of the Backhaul and Fronthaul network
- The main challenge refers to the RAN layer where the split is performed



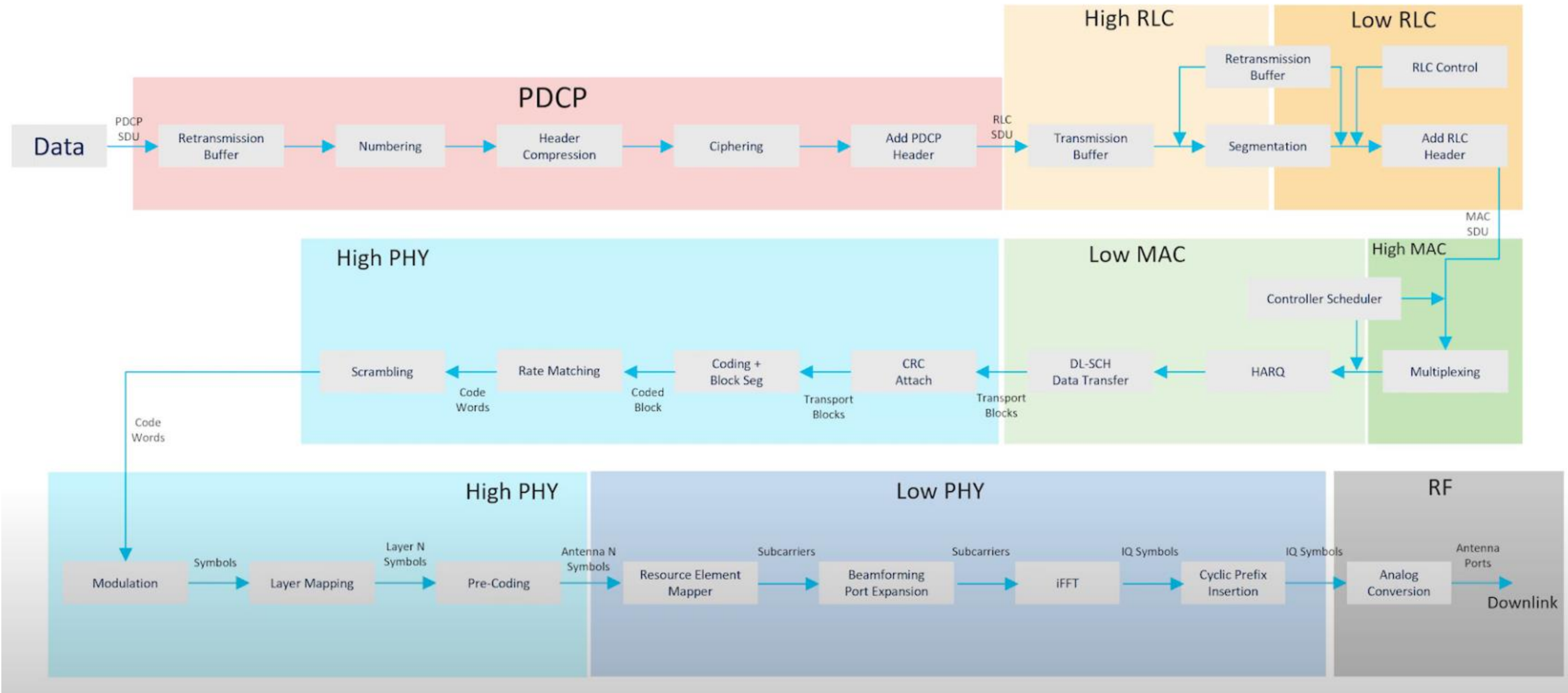
Functional Split



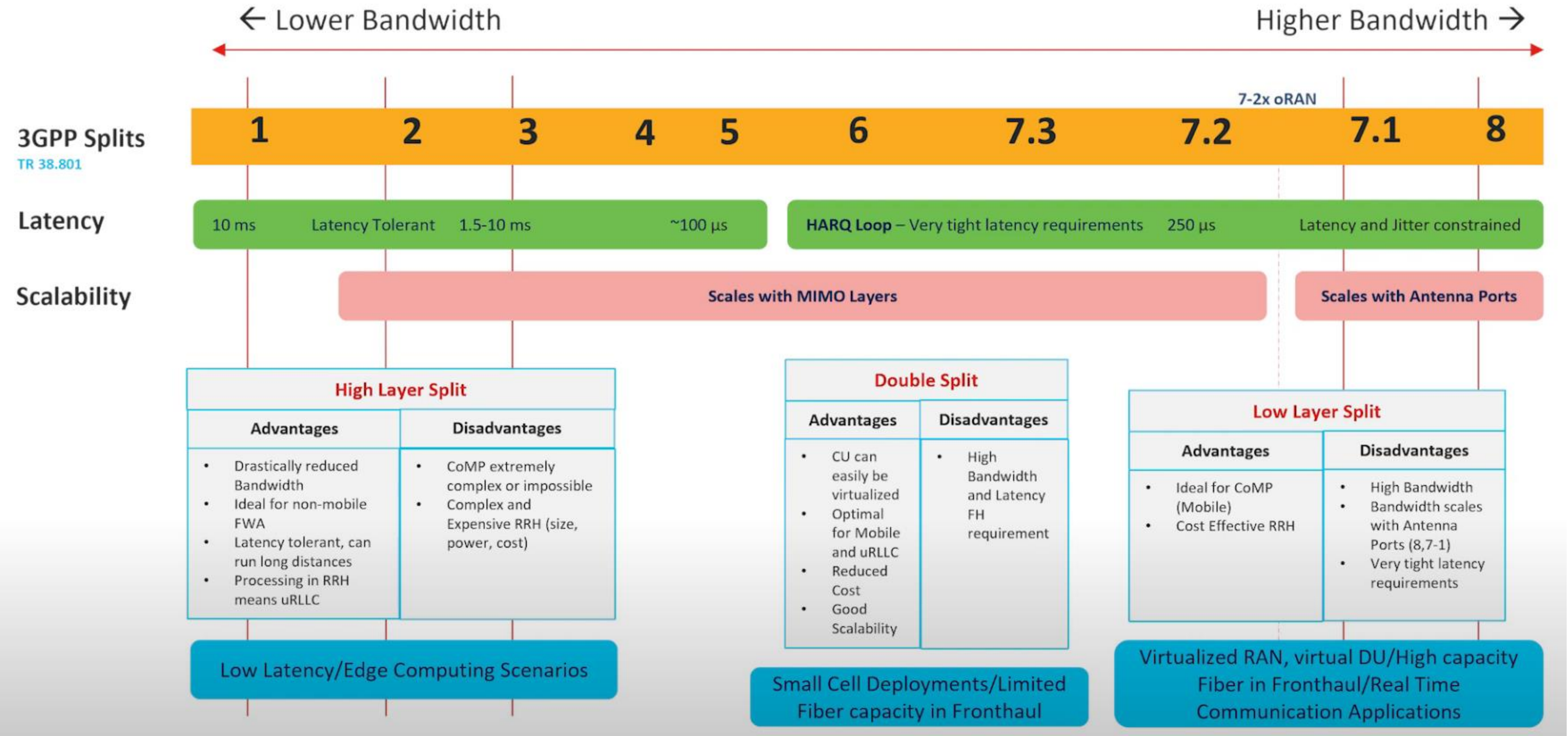


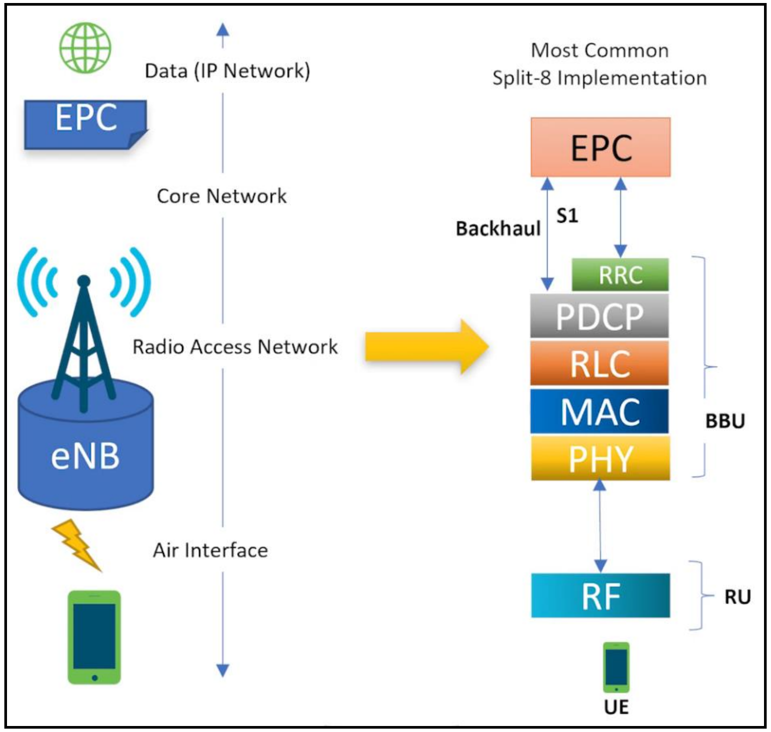


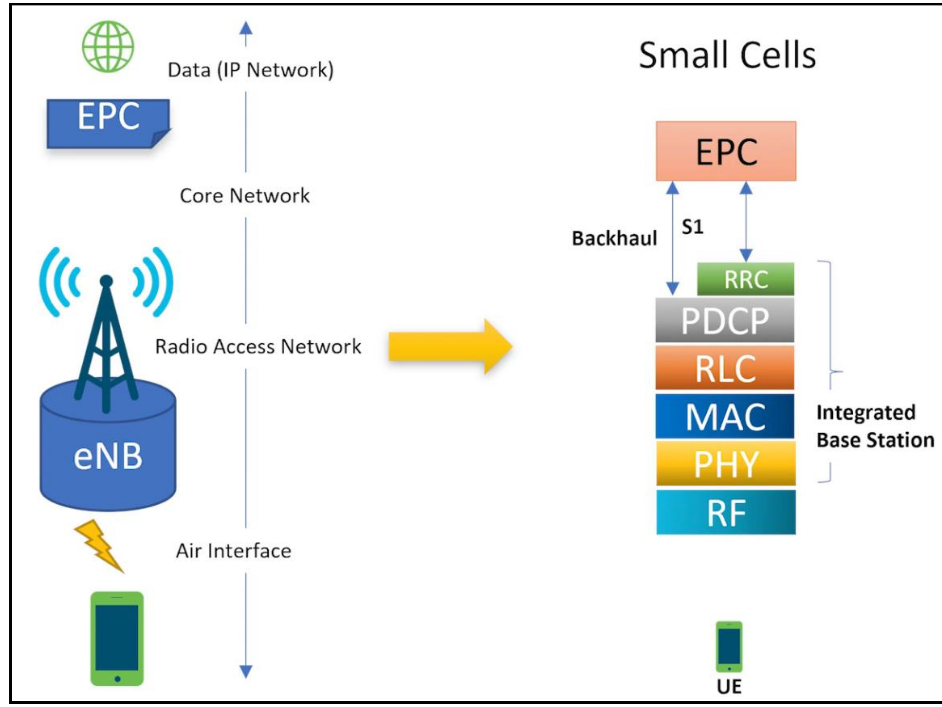
Functional Split

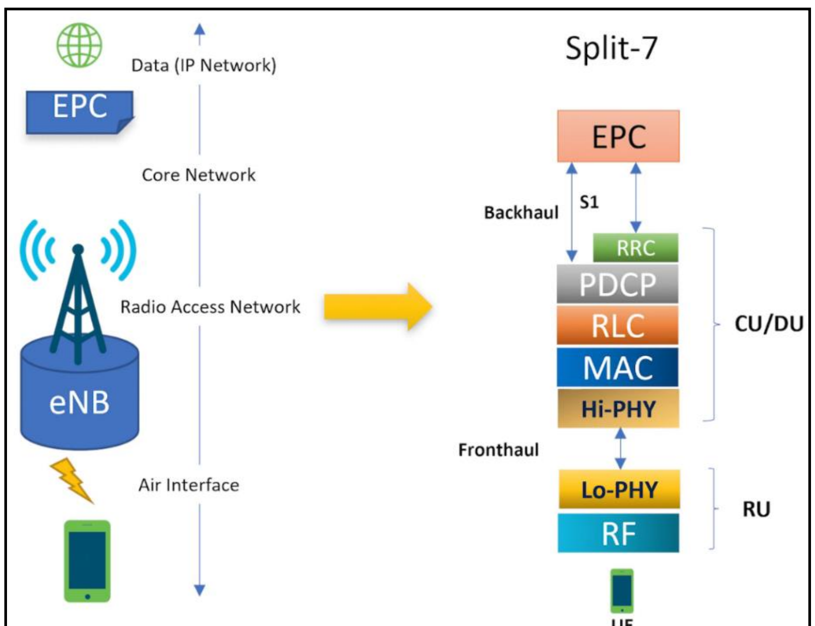


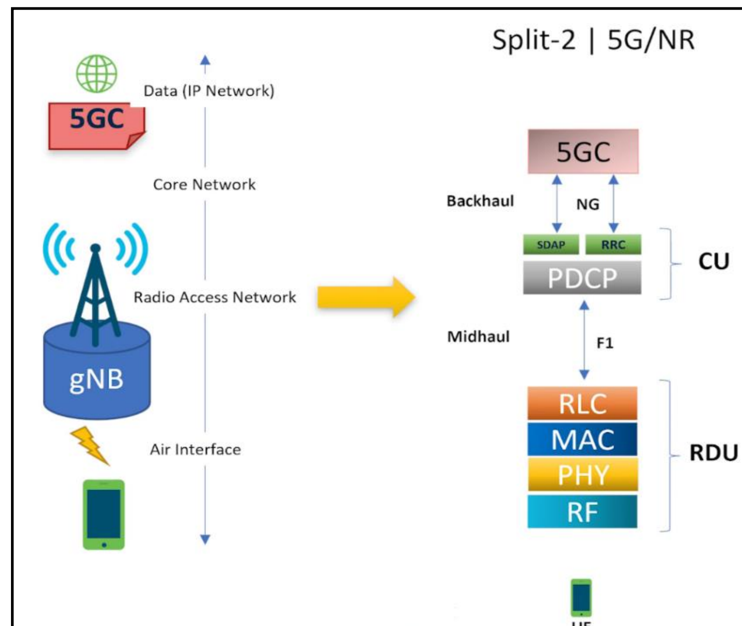
Functional Split



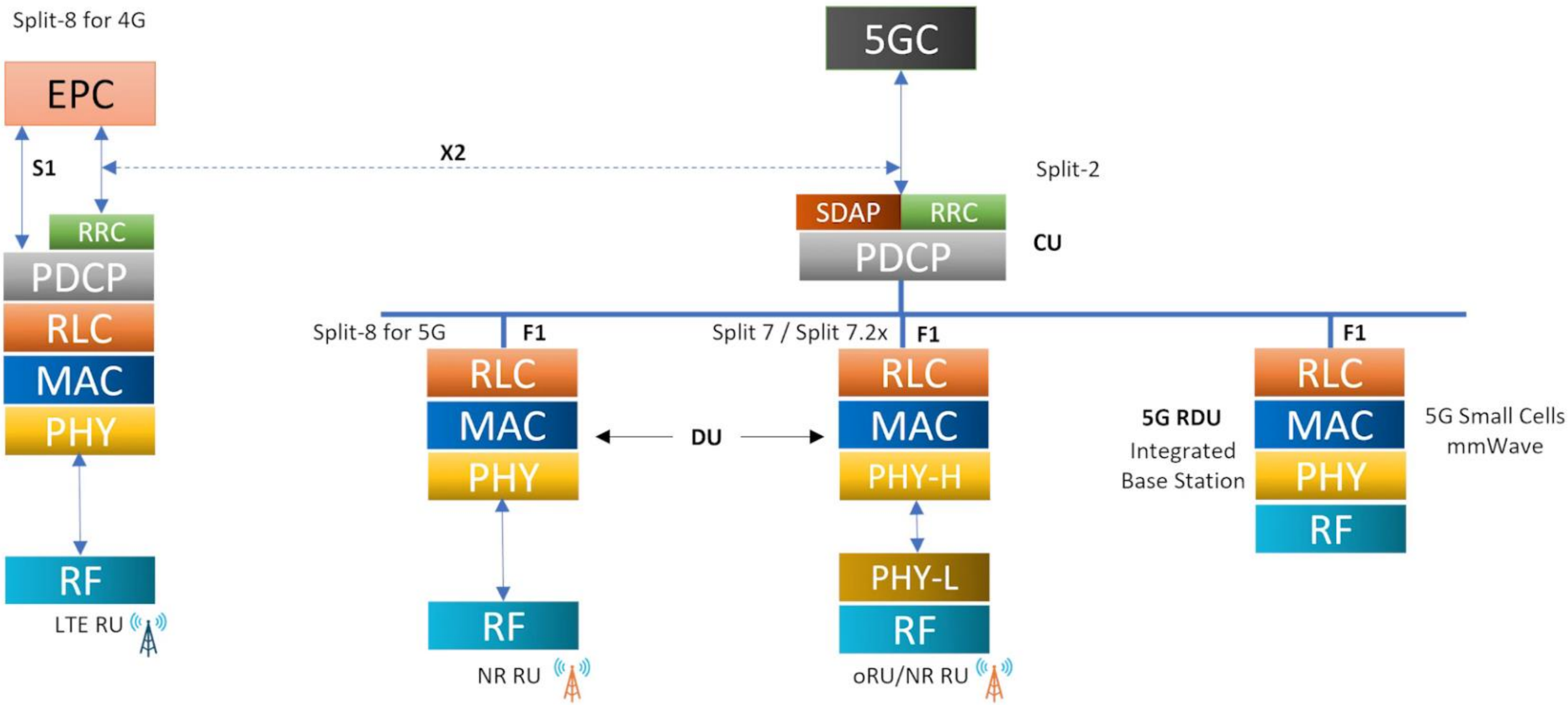

Most Common
Split-8 Implementation
Data (IP Network)
EPC
Core Network
Radio Access Network
eNB
Air Interface
EPC
Backhaul
S1
RRC
PDCP
RLC
MAC
PHY
BBU
RF
RU
UE


Small Cells
Data (IP Network)
EPC
Core Network
Radio Access Network
eNB
Air Interface
EPC
Backhaul
S1
RRC
PDCP
RLC
MAC
PHY
RF
Integrated
Base Station
UE


Split-7
Data (IP Network)
EPC
Core Network
Radio Access Network
eNB
Air Interface
EPC
Backhaul
S1
RRC
PDCP
RLC
MAC
Hi-PHY
CU/DU
Fronthaul
Lo-PHY
RF
RU
UE


Split-2 | 5G/NR
Data (IP Network)
5GC
Core Network
Radio Access Network
gNB
Air Interface
5GC
Backhaul
NG
SDAP
RRC
PDCP
CU
Midhaul
F1
RLC
MAC
PHY
RF
RDU
UE

Functional Split



Functional Split