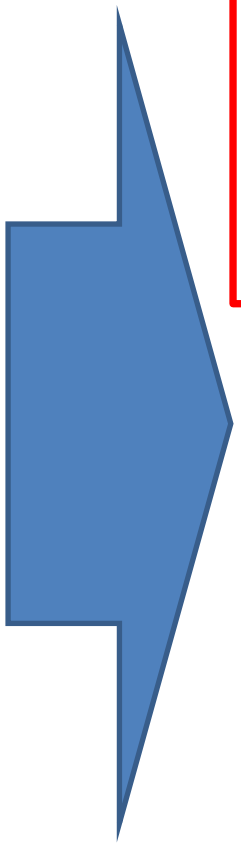
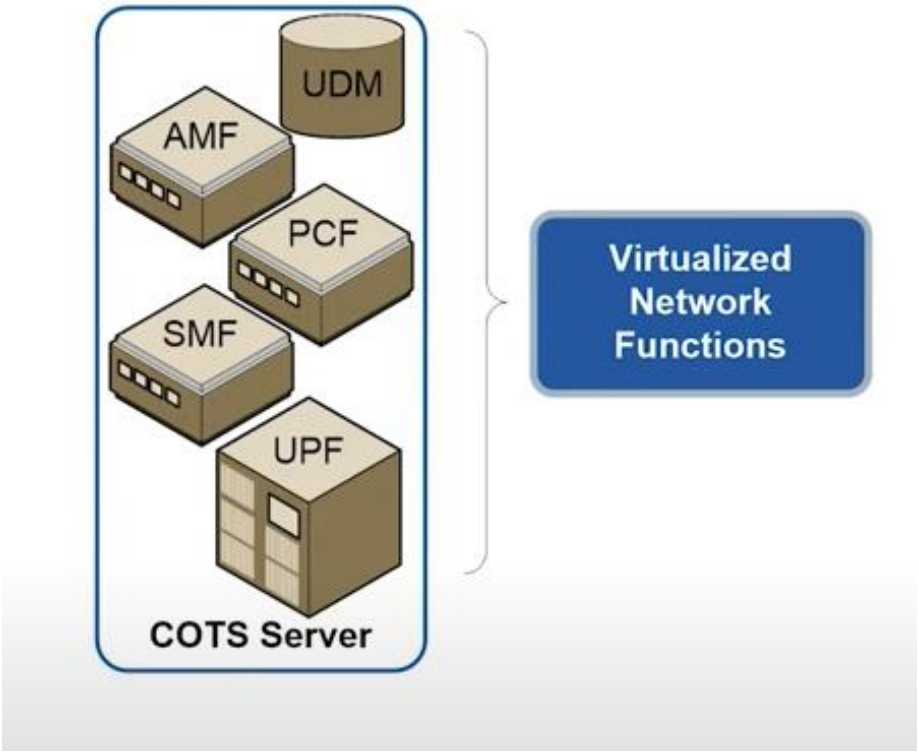

# 5G Mobile Communication System Cont.

# 5G Advancements



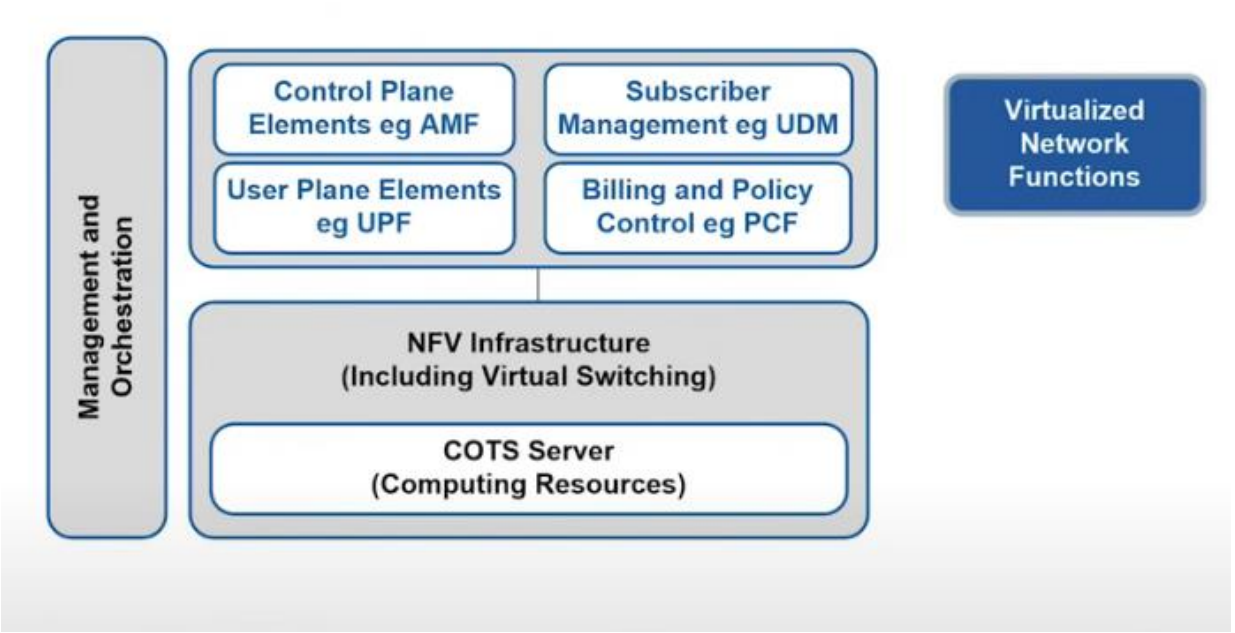
- **New Architecture**
  - Advanced core network functions / NG RAN
  - Incorporate SDN/NFV (NFV MANO)
    - Decupling of control and data plane
    - Decupling of functions from the hardware
- **Network Slicing**
  - eMBB, URLLC, mMTC | 8 subclasses pes slice type
- **New Radio (NR)**
  - RAN protocol 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)

# Network Function Virtualization



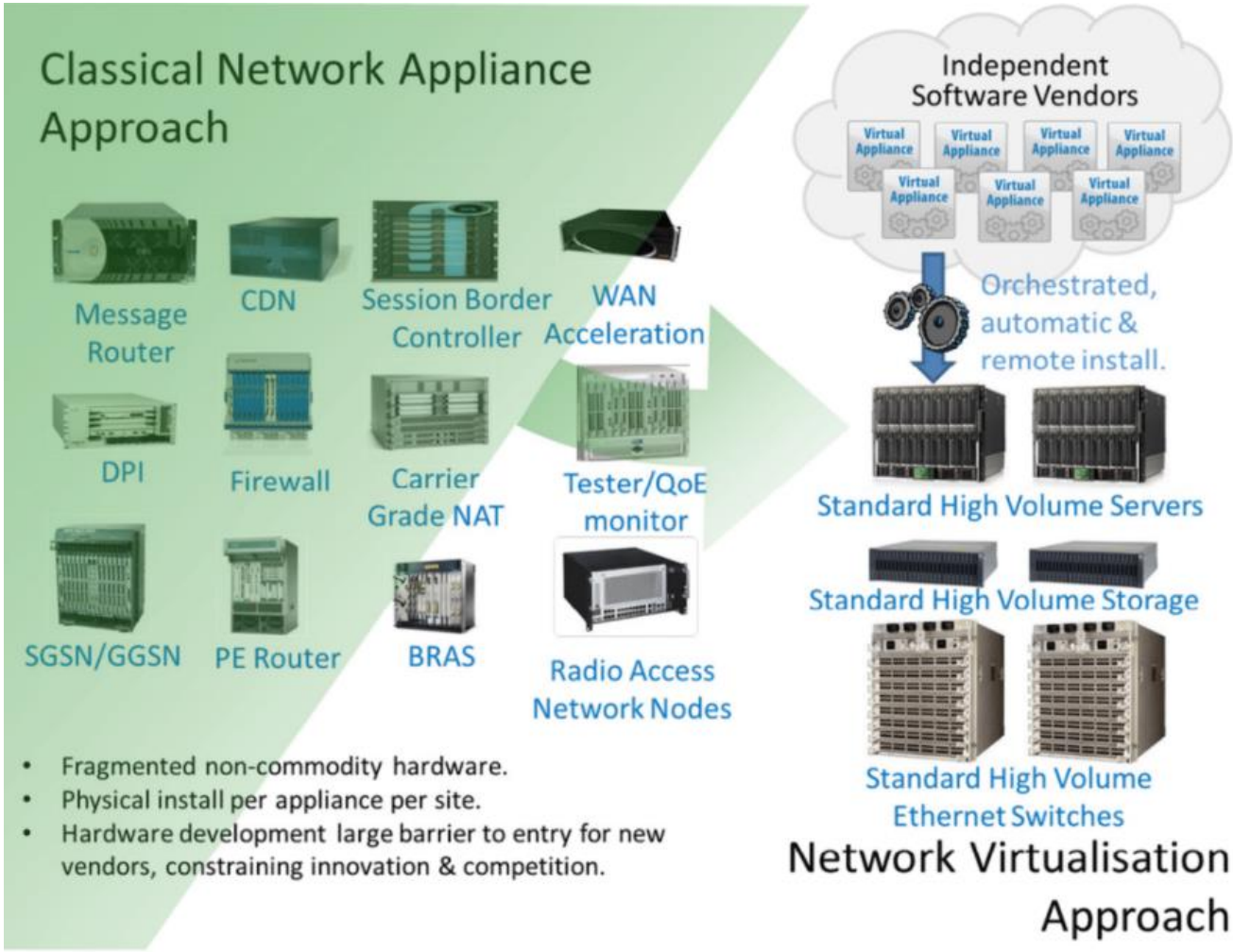

- Most of NFV nodes may be virtualized (software processes)
- Running in Commercial Off The Self (COTS) Servers

# Network Function Virtualization




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

# Network Function Virtualization




Fewer platforms

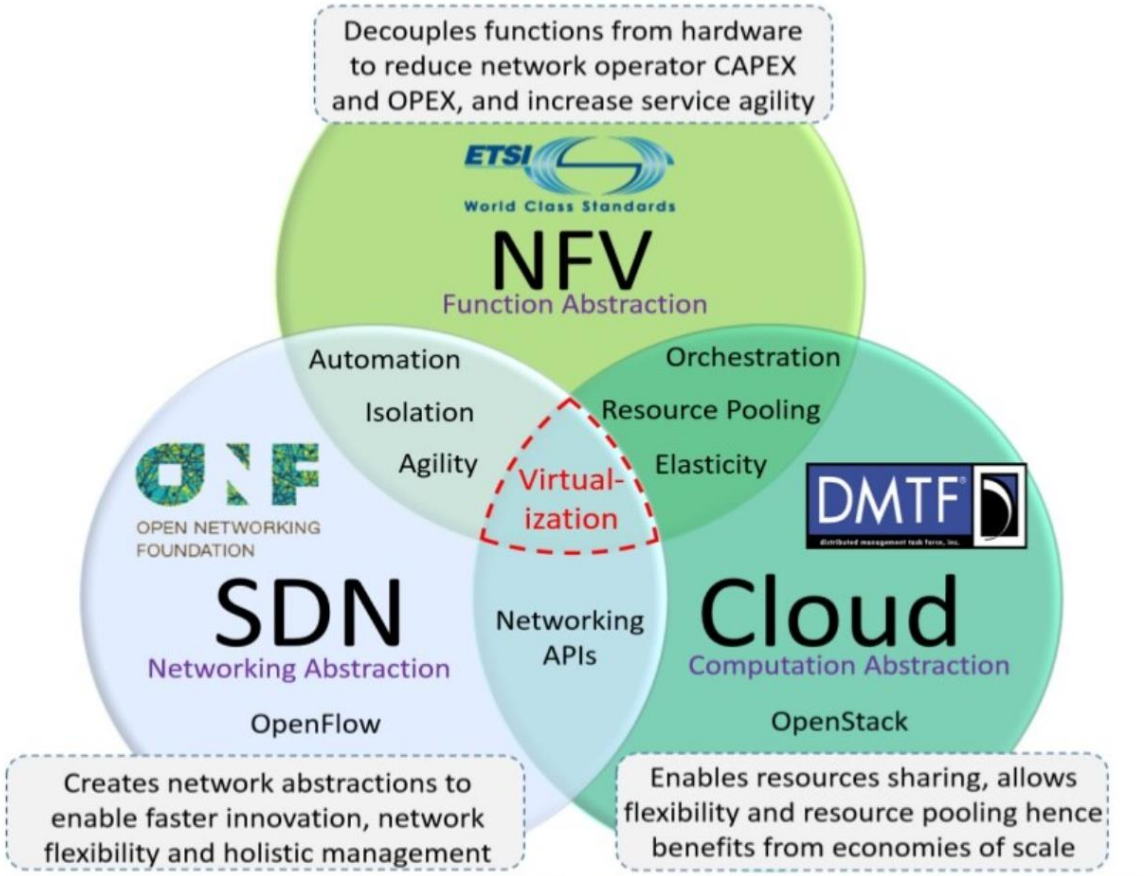
More flexibility

More efficient use of resources

Use less power

SLAs needed

# Network Function Virtualization



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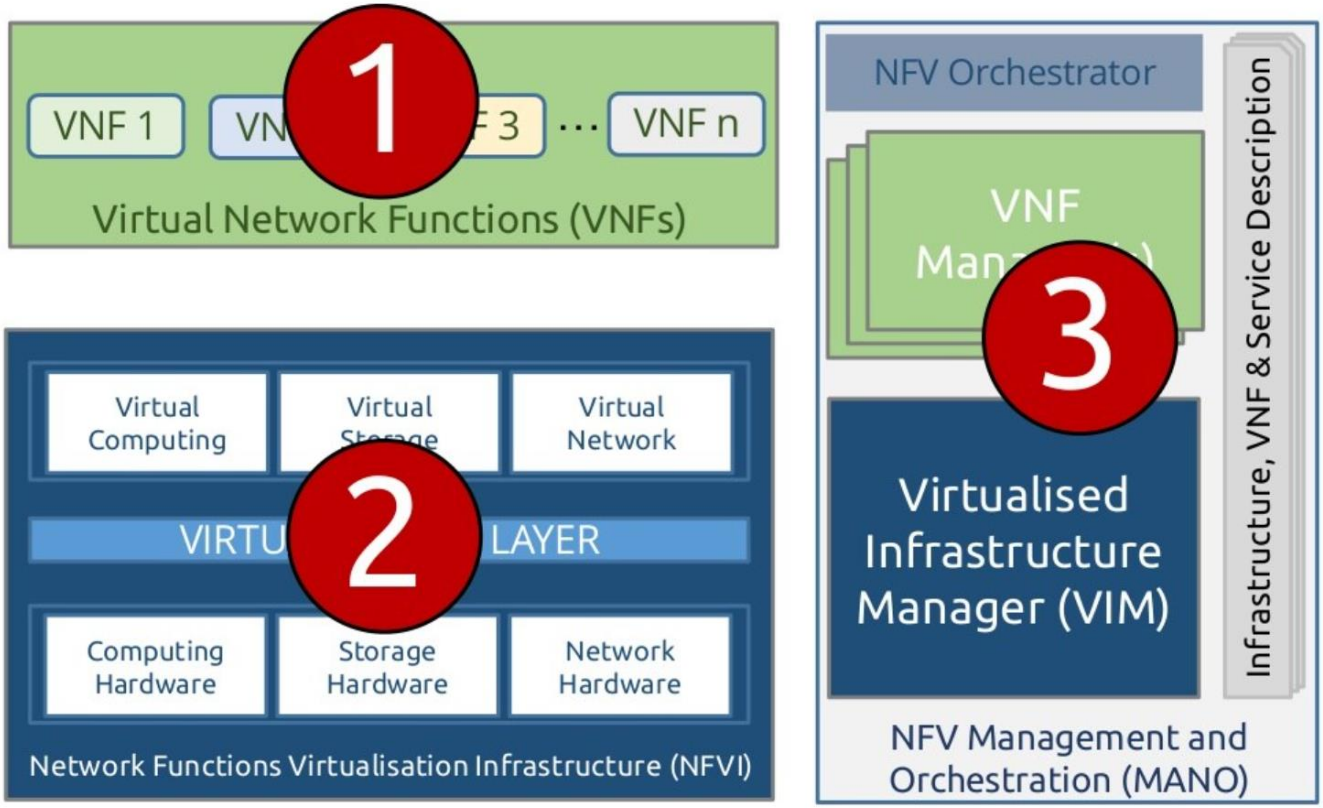

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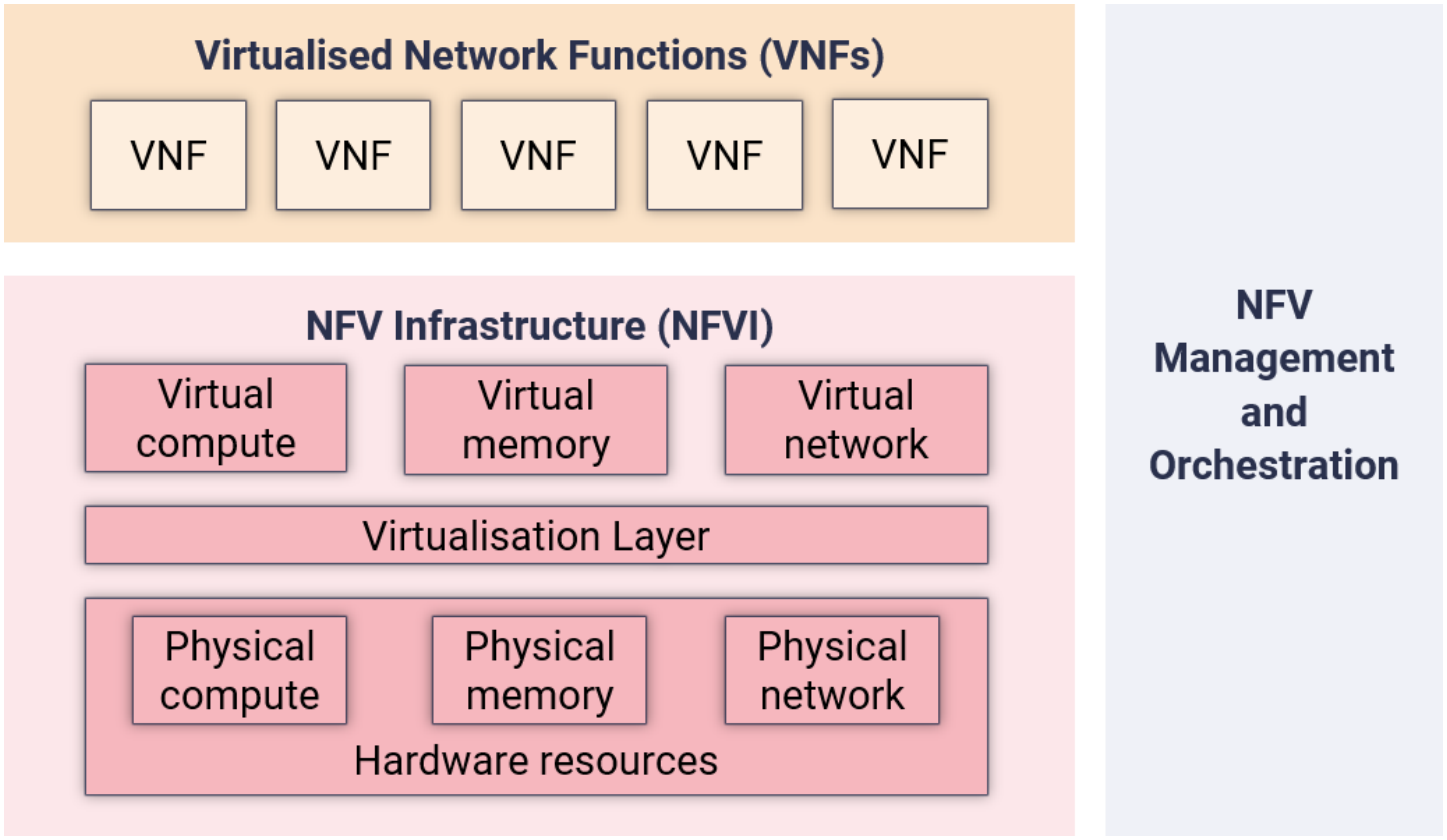

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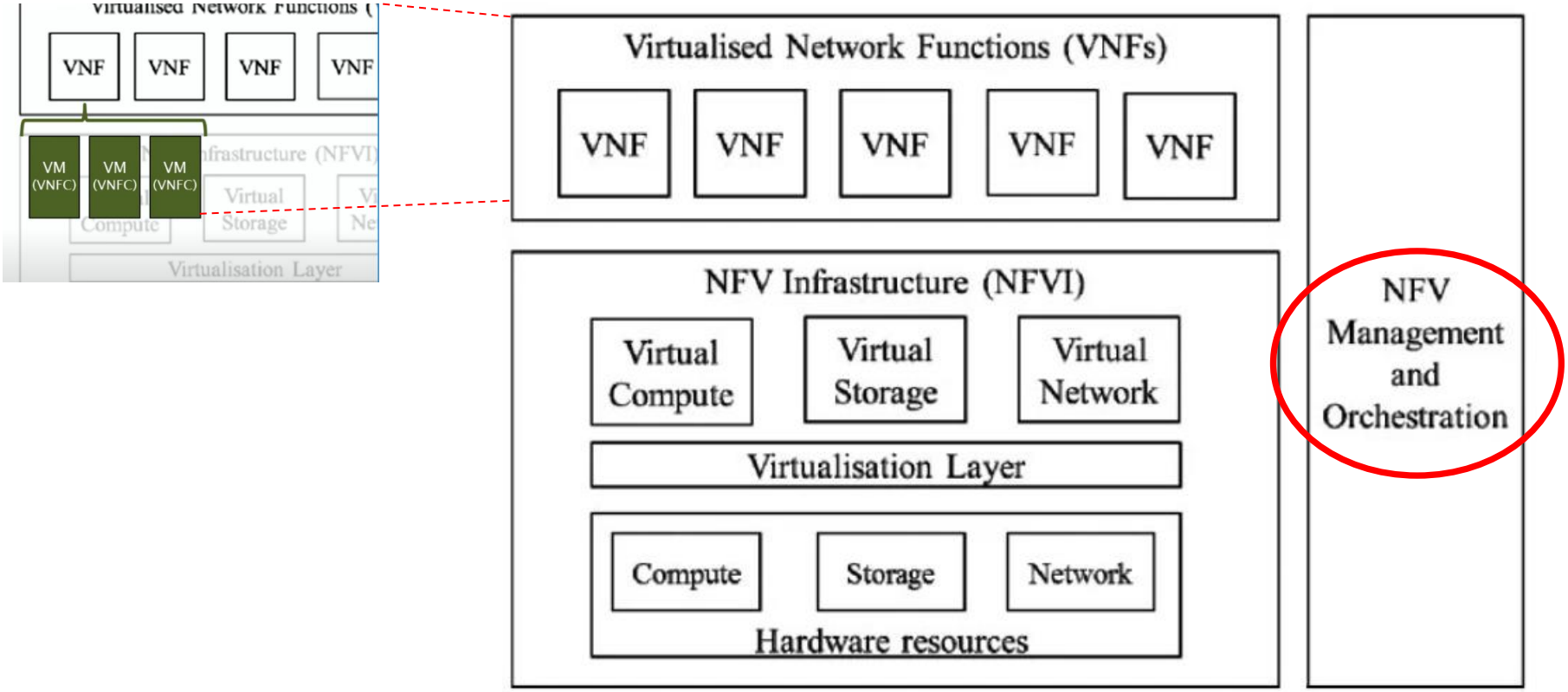


# What a MANO should do

- **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

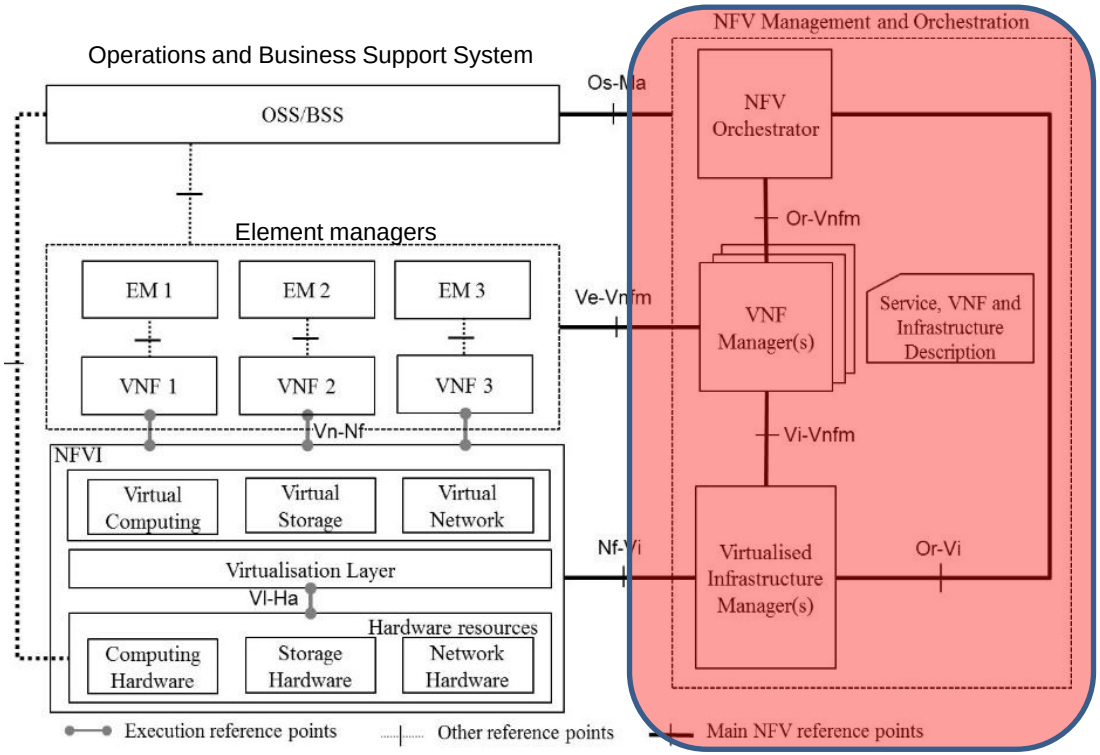
- **Initiate**
- **Scale**
- **Update/upgrade**
- **Terminate**

**VNFs**

# 5G Architecture

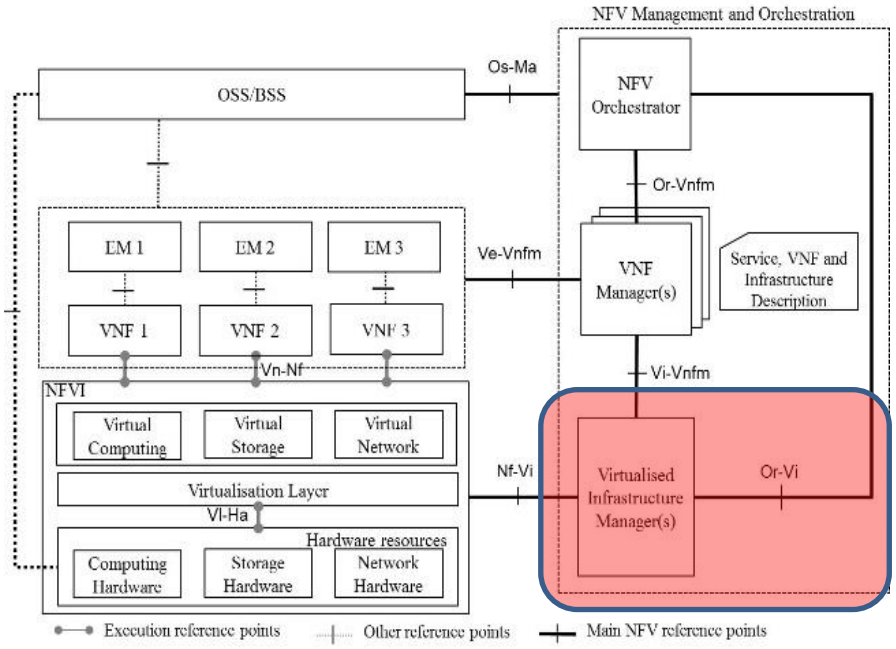
## Taking advantage of MANO

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



# 5G Architecture

## Taking advantage of MANO



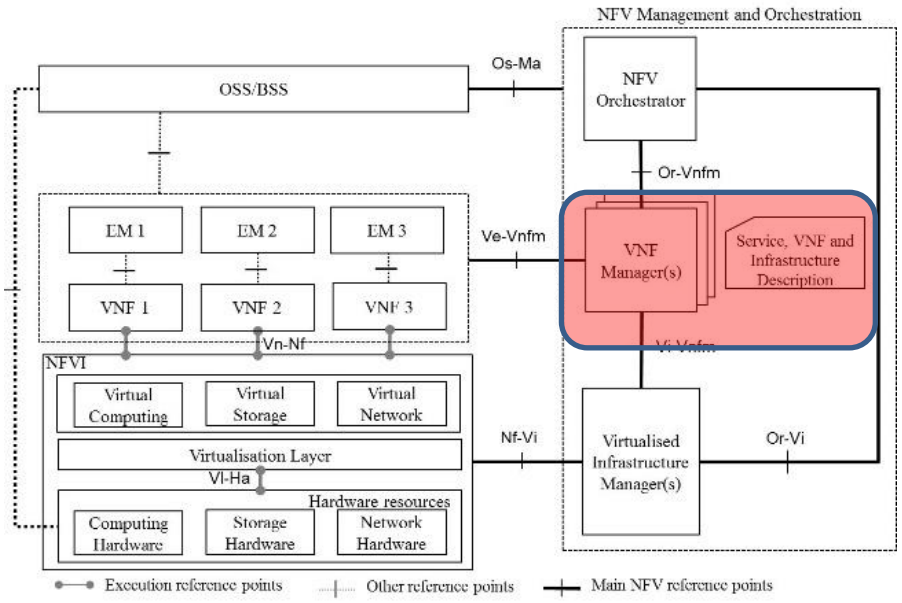

**Virtualized Infrastructure Manager (VIM)**

- 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

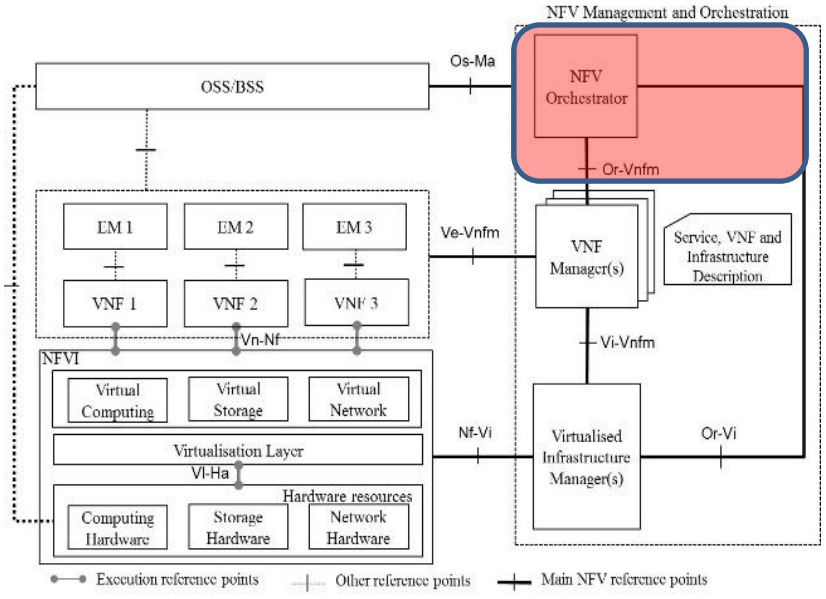



**VNF Manager (VNFM)**

- 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

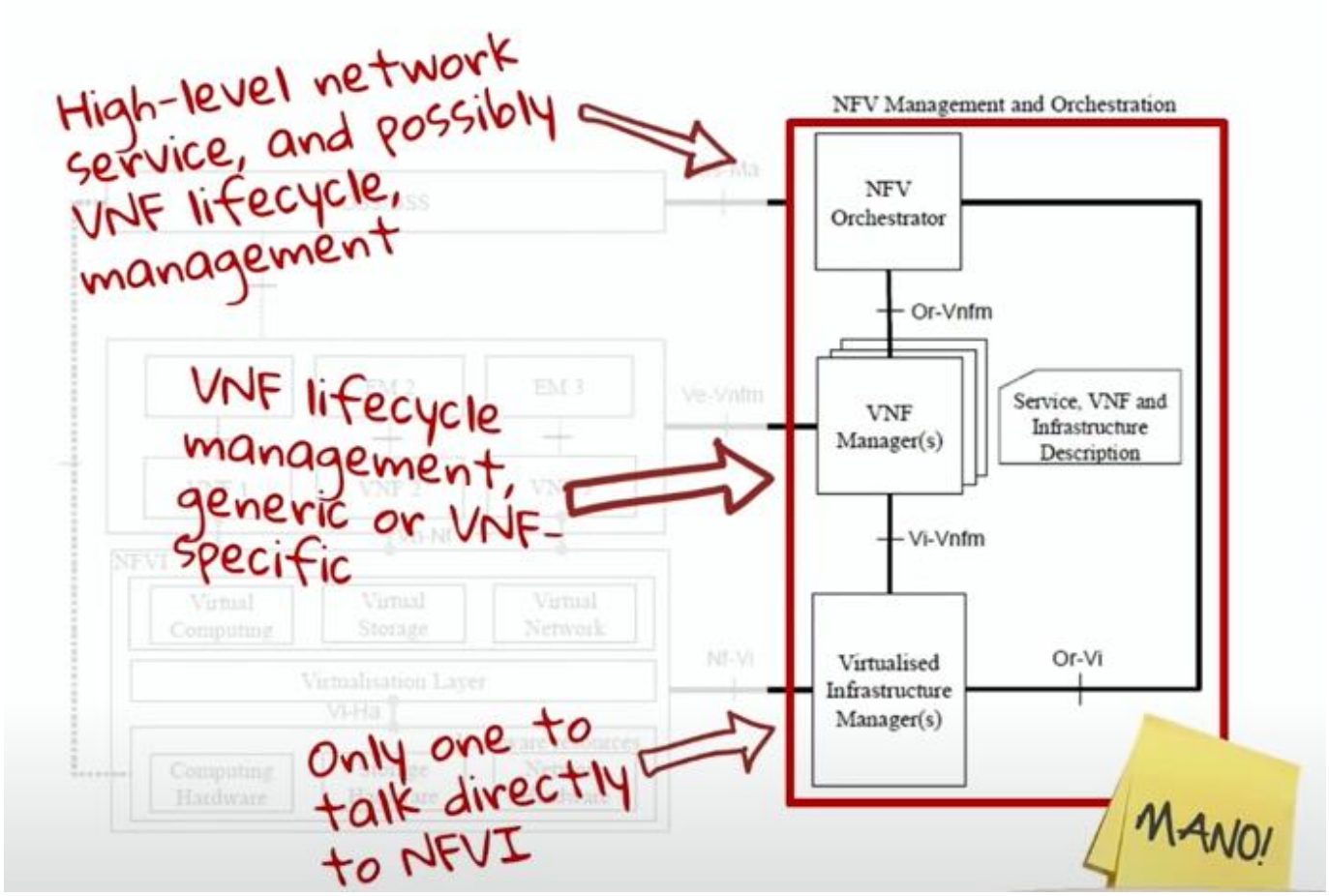
- NFVO coordinates, authorizes, releases and engages NFVI resources. This does so by engaging with the VIMs directly through their north bound APIs instead of engaging with the NFVI resources, directly.

Service Orchestration

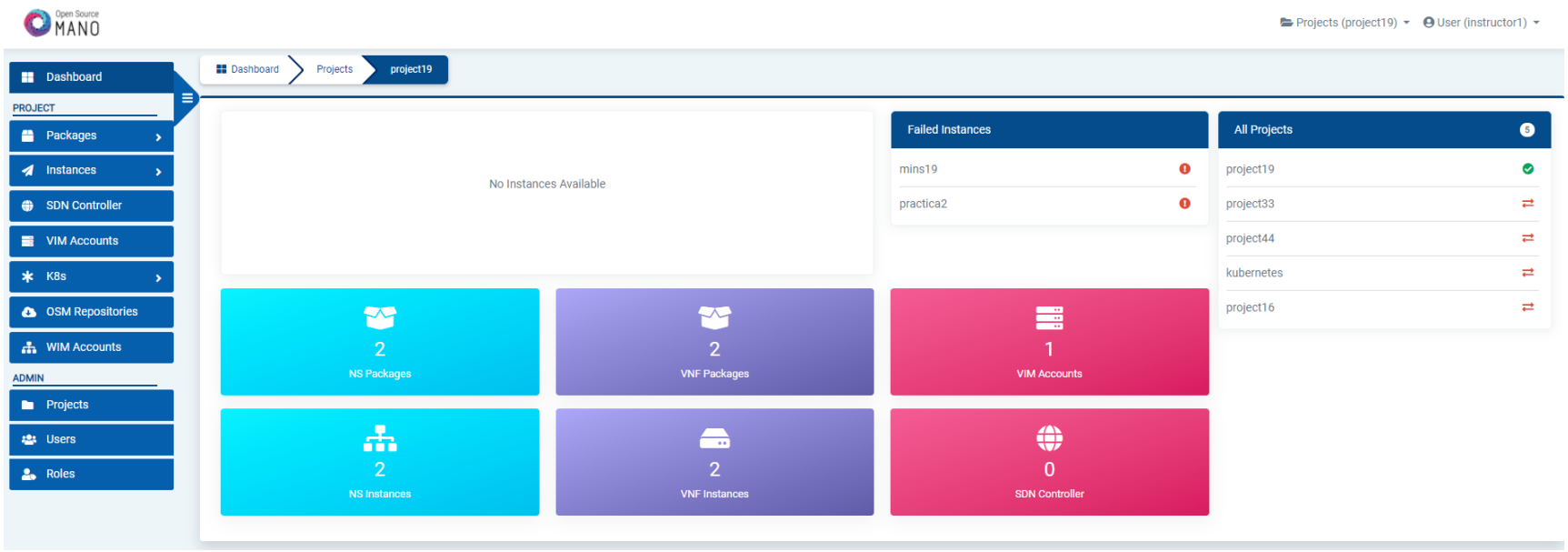
- Service Orchestration creates end to end service between different VNFs. It achieves this by coordinating with the respective VNF Managers so it does not need to talk to VNFs directly.
- Service Orchestration can instantiate VNF Managers, where applicable.
- It does the topology management of the network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

# 5G Architecture

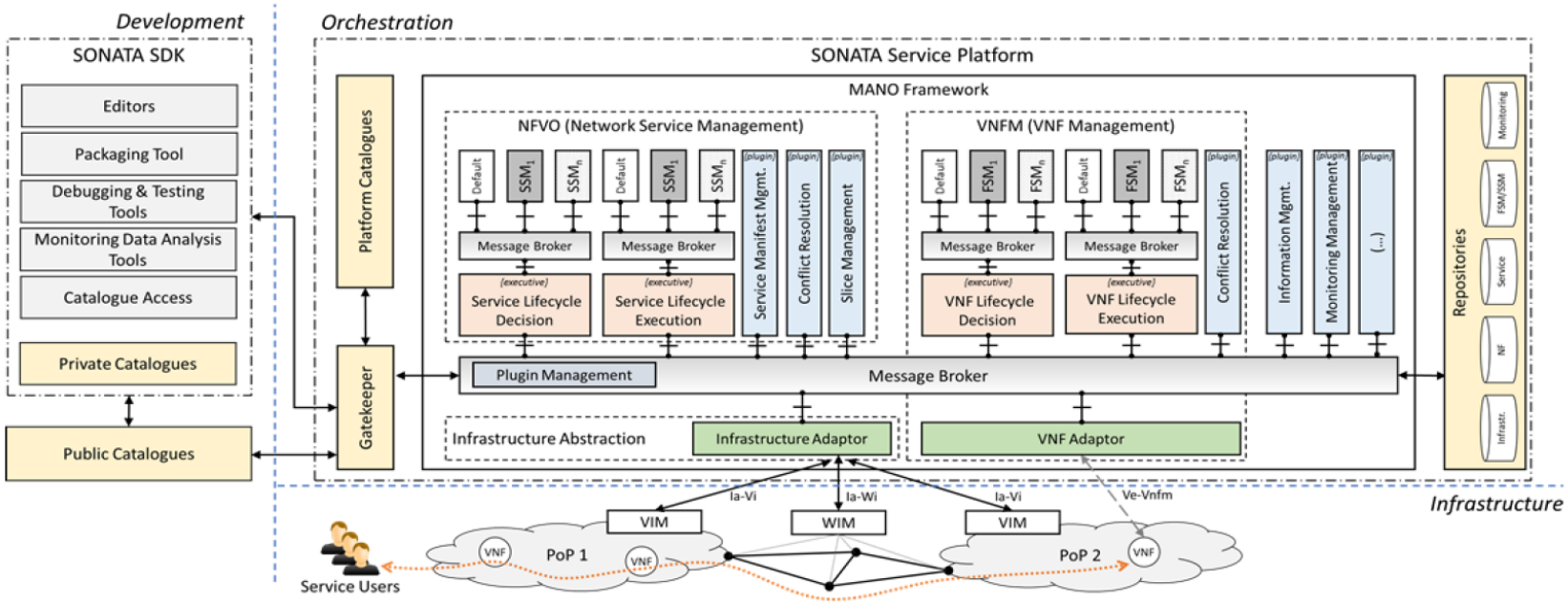
Taking advantage of MANO



# Example: Open Source MANO



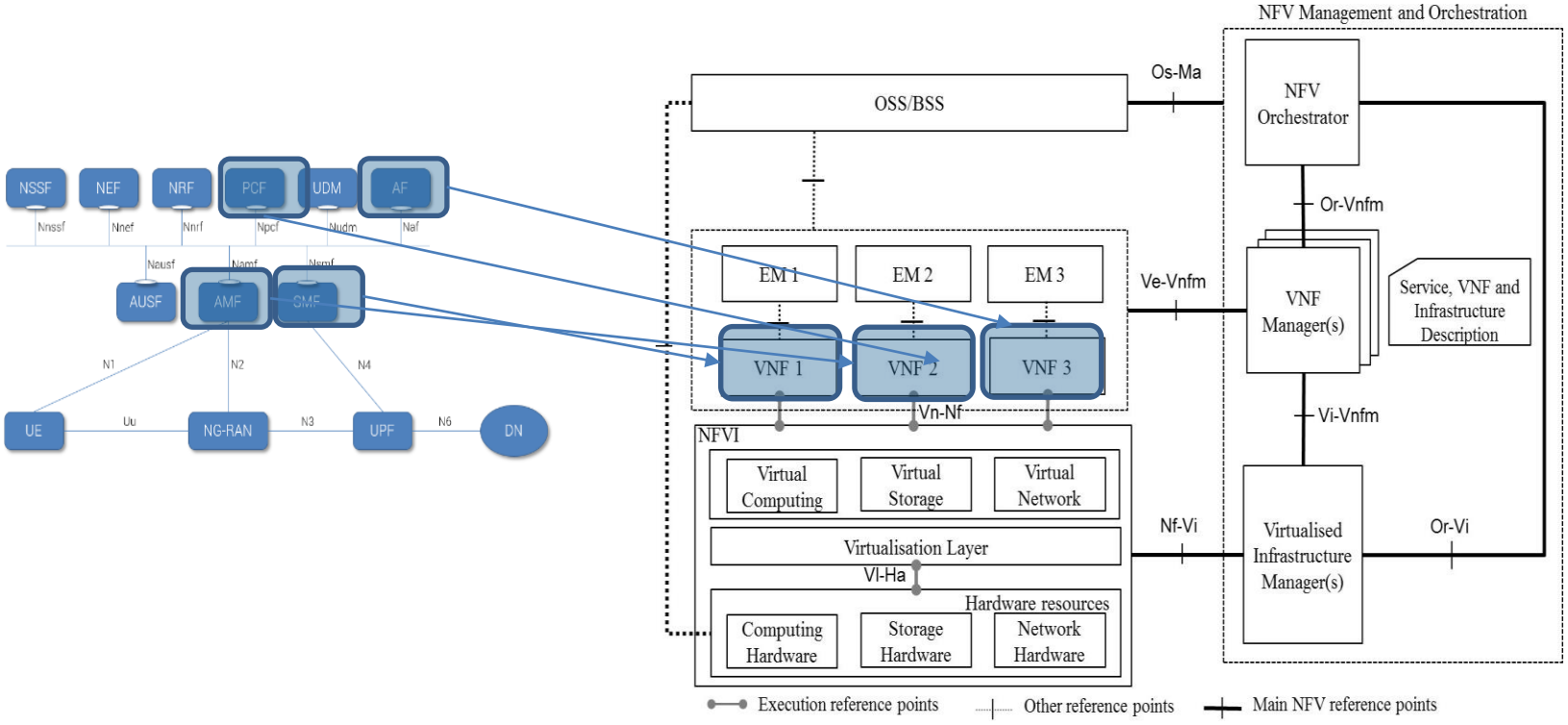
# Example: SONATA Platform



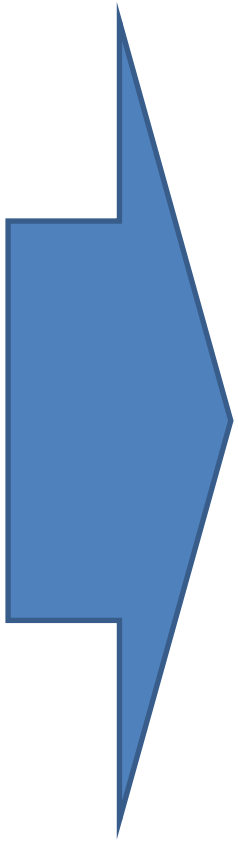
# 5G Architecture

## 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



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    - Decupling of functions from the hardware
- **Network Slicing**
  - eMBB, URLLC, mMTC | 8 subclasses pes slice type
- **New Radio (NR)**
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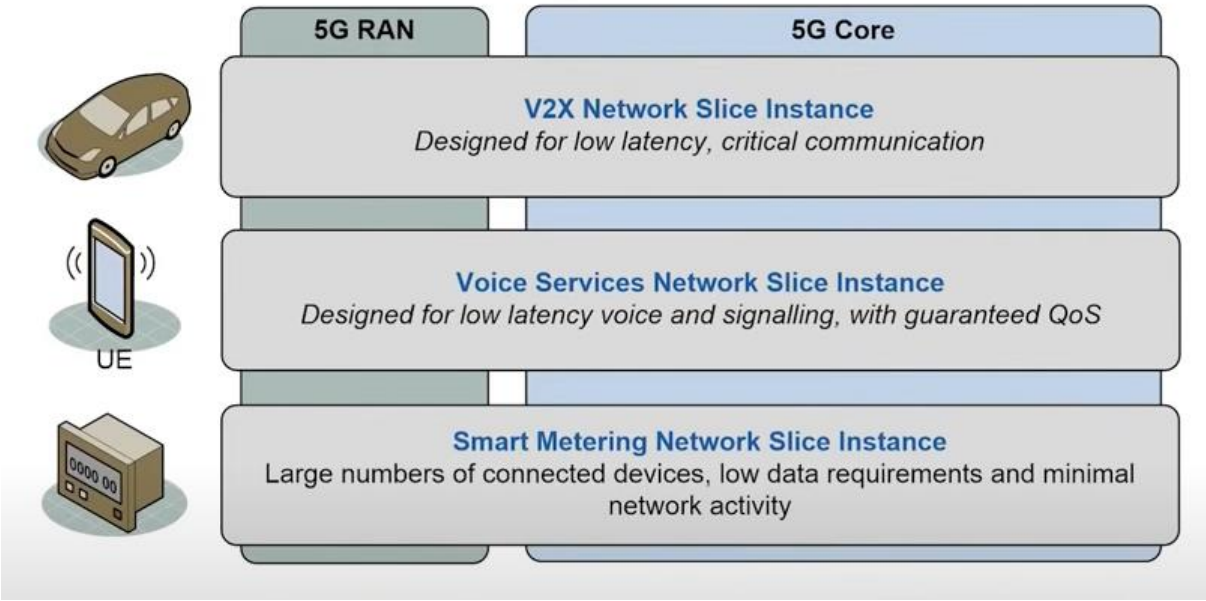
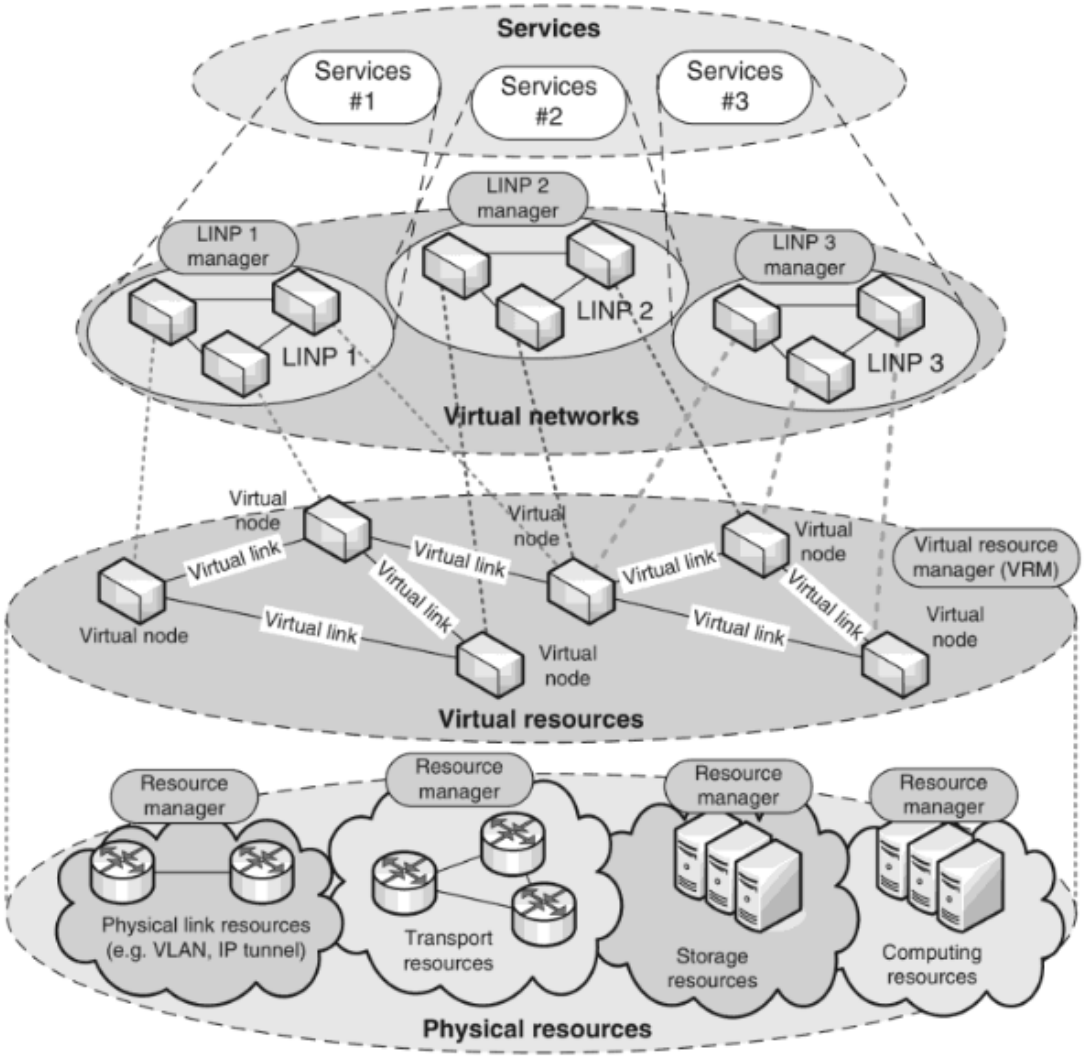
# Network Slicing

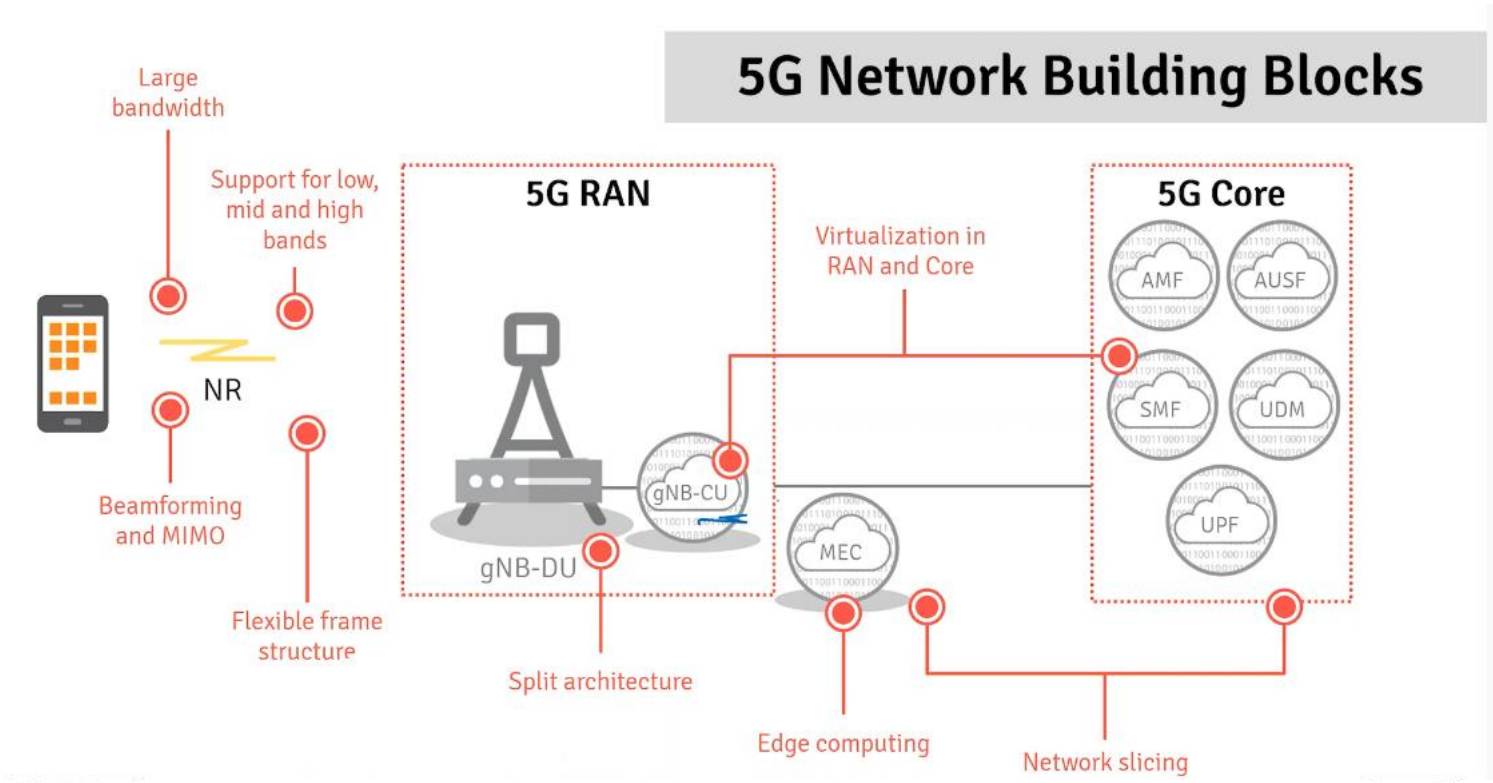
- "the capability to "slice" network resources and functions and to offer isolated end-to-end network services over shared physical infrastructures"



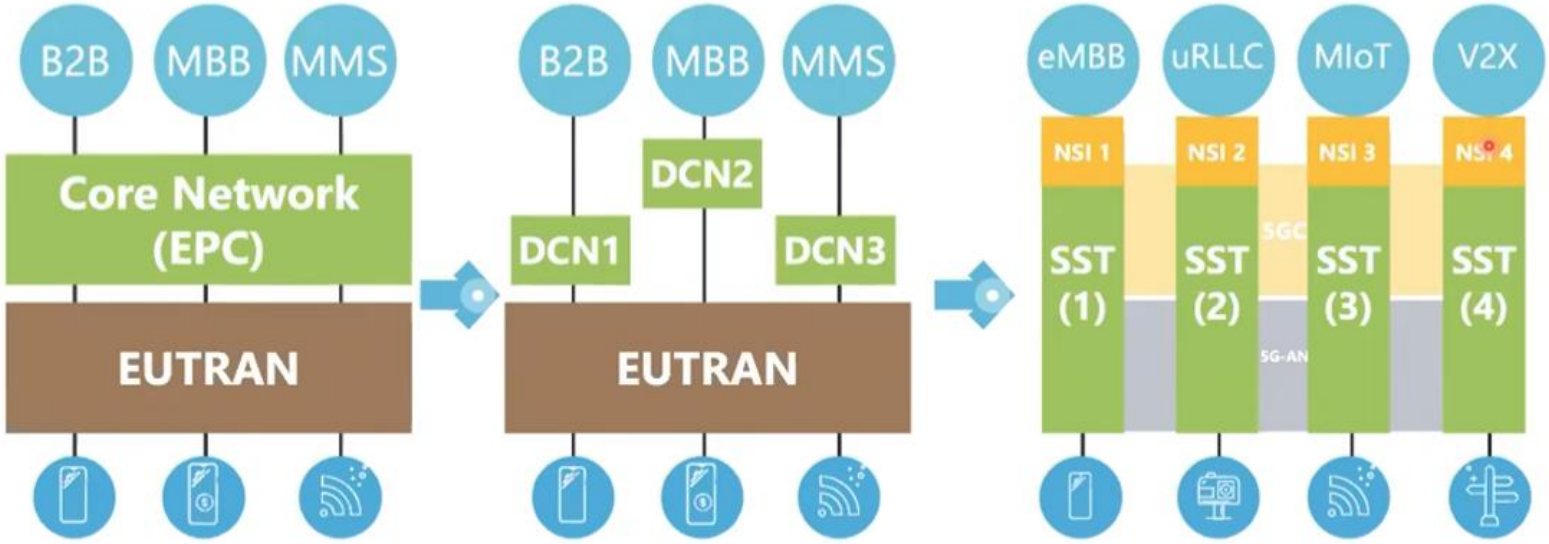

The ability to create logical networks on top of the same physical infrastructure




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


5G Network Building Blocks
Large bandwidth
Support for low, mid and high bands
NR
Beamforming and MIMO
Flexible frame structure
5G RAN
gNB-CU
gNB-DU
Split architecture
Virtualization in RAN and Core
MEC
Edge computing
5G Core
AMF
AUSF
SMF
UDM
UPF
Network slicing

# Network Slicing Evolution




**Services**

Multiple Services (APNs) sharing one MBB Network
**Pre 3GPP R13**

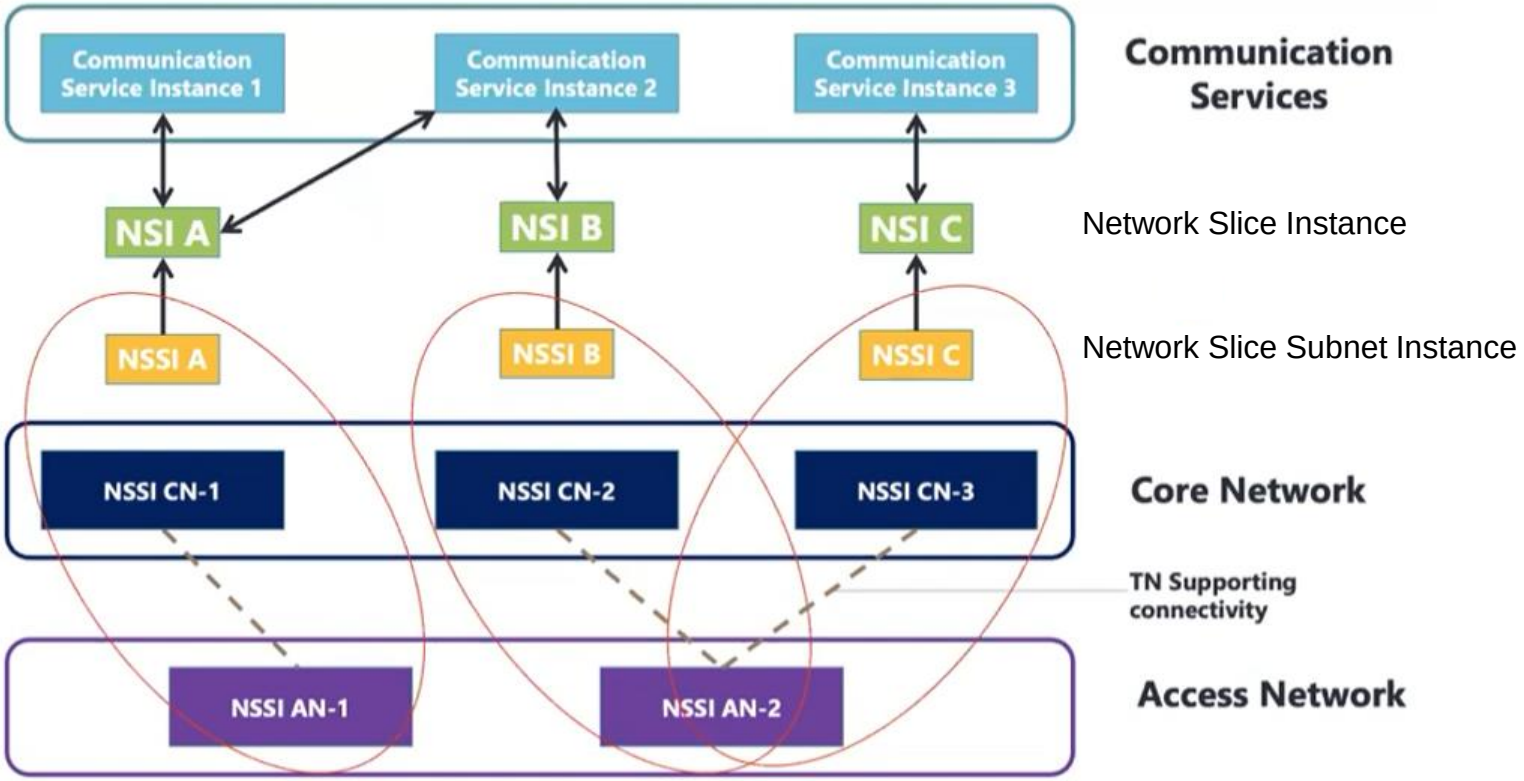
**Dedicated Core Networks**

4G Framework for Dedicated Core Selection based on UE Usage Type
**3GPP R13/R14**

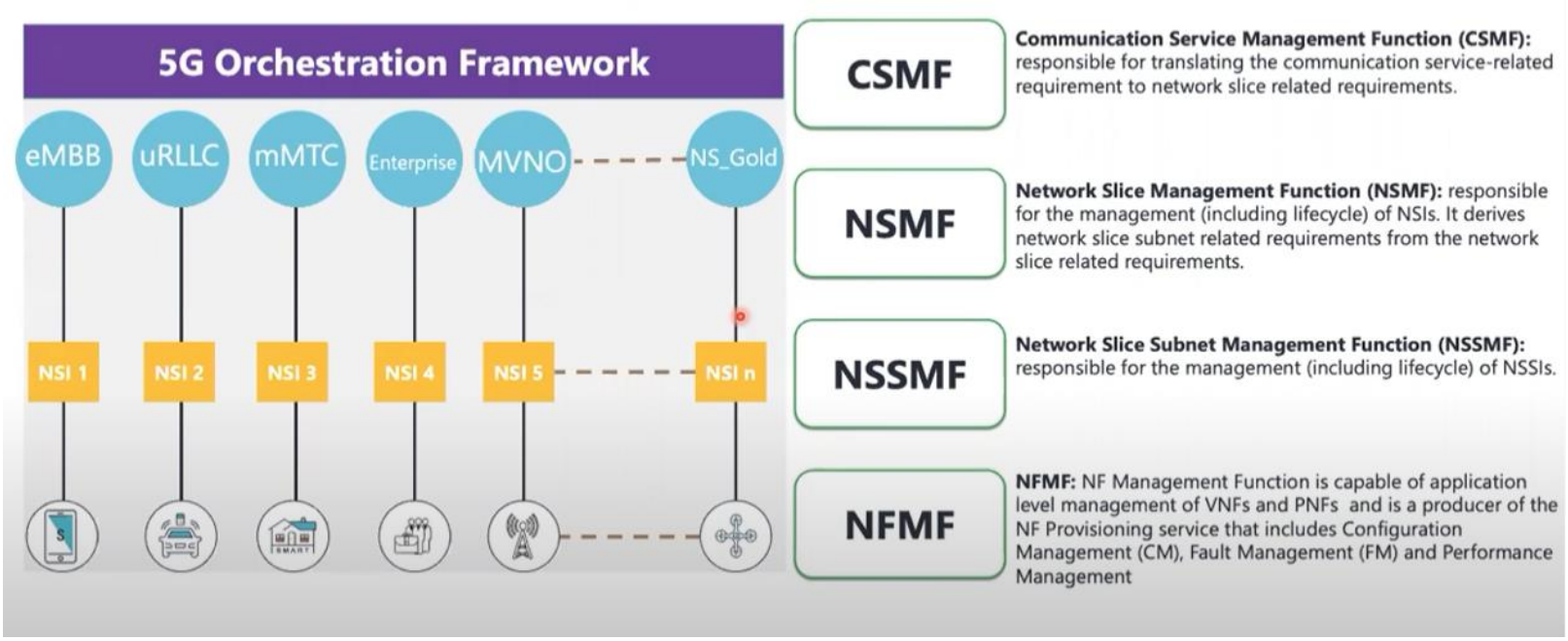
**5G Network Slicing**

5G Framework for Network Slicing based on Slice/Service Type (SST)
**3GPP R15**

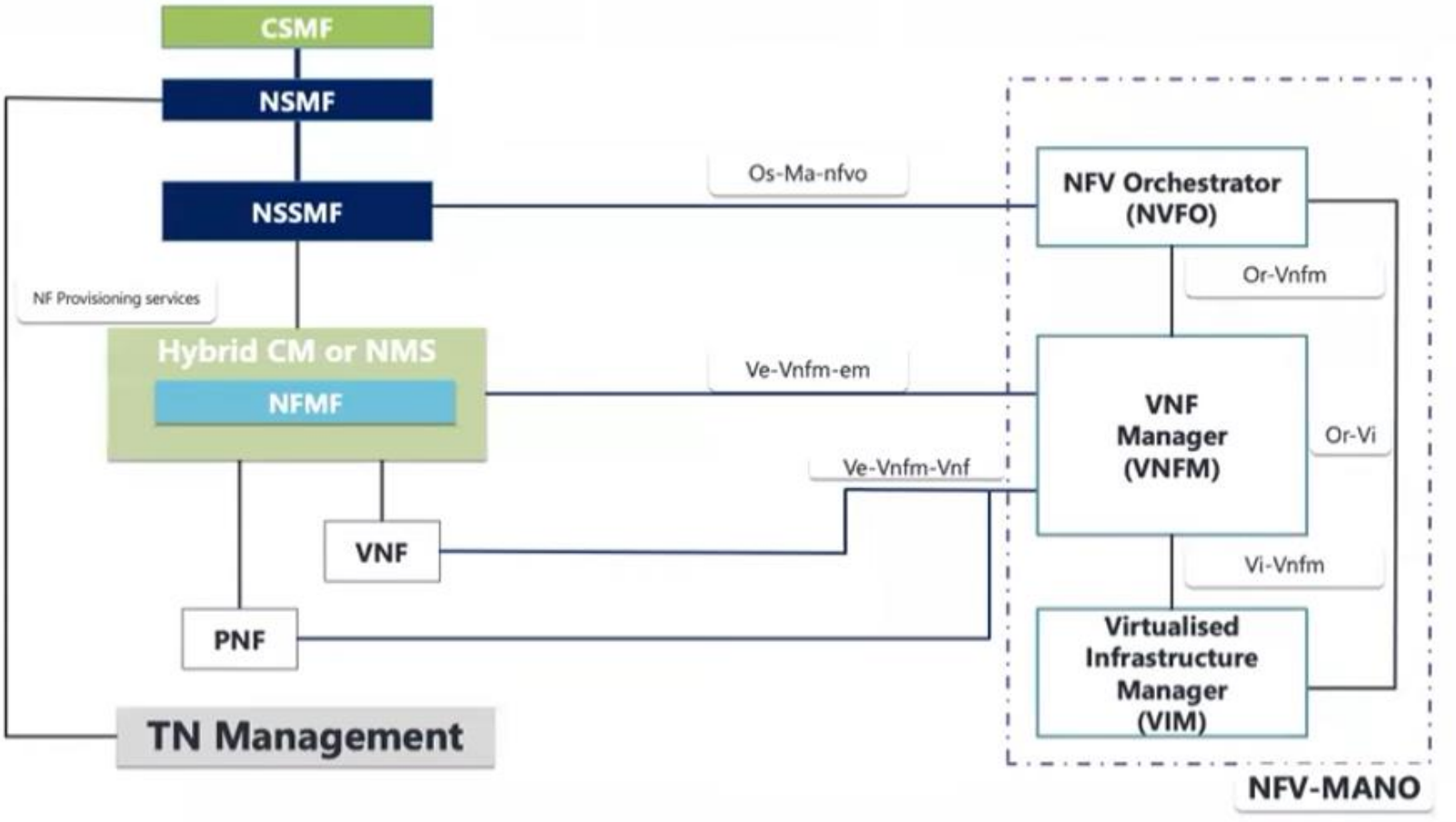
# Network Slicing Evolution



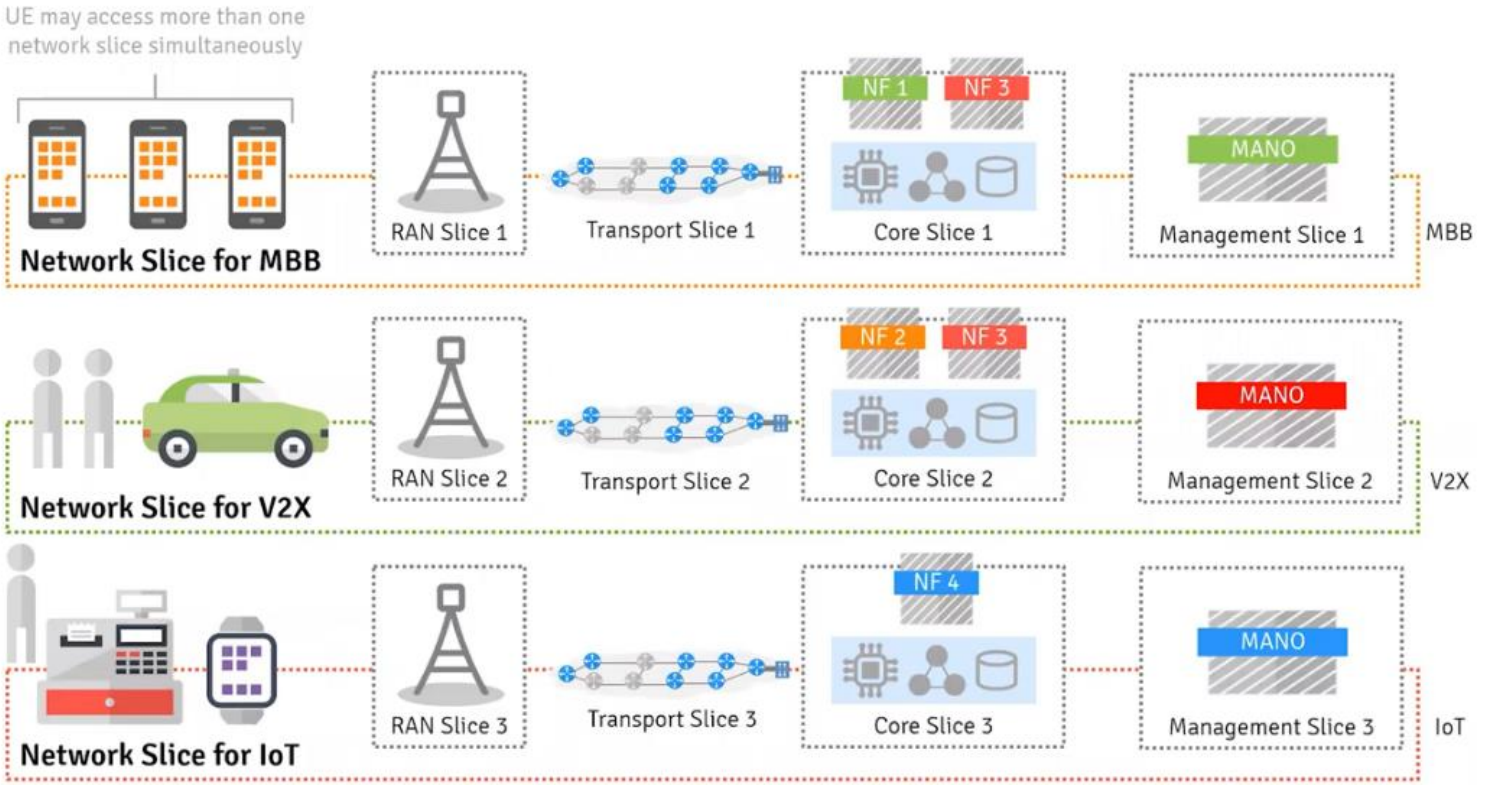
# Network Slicing Management



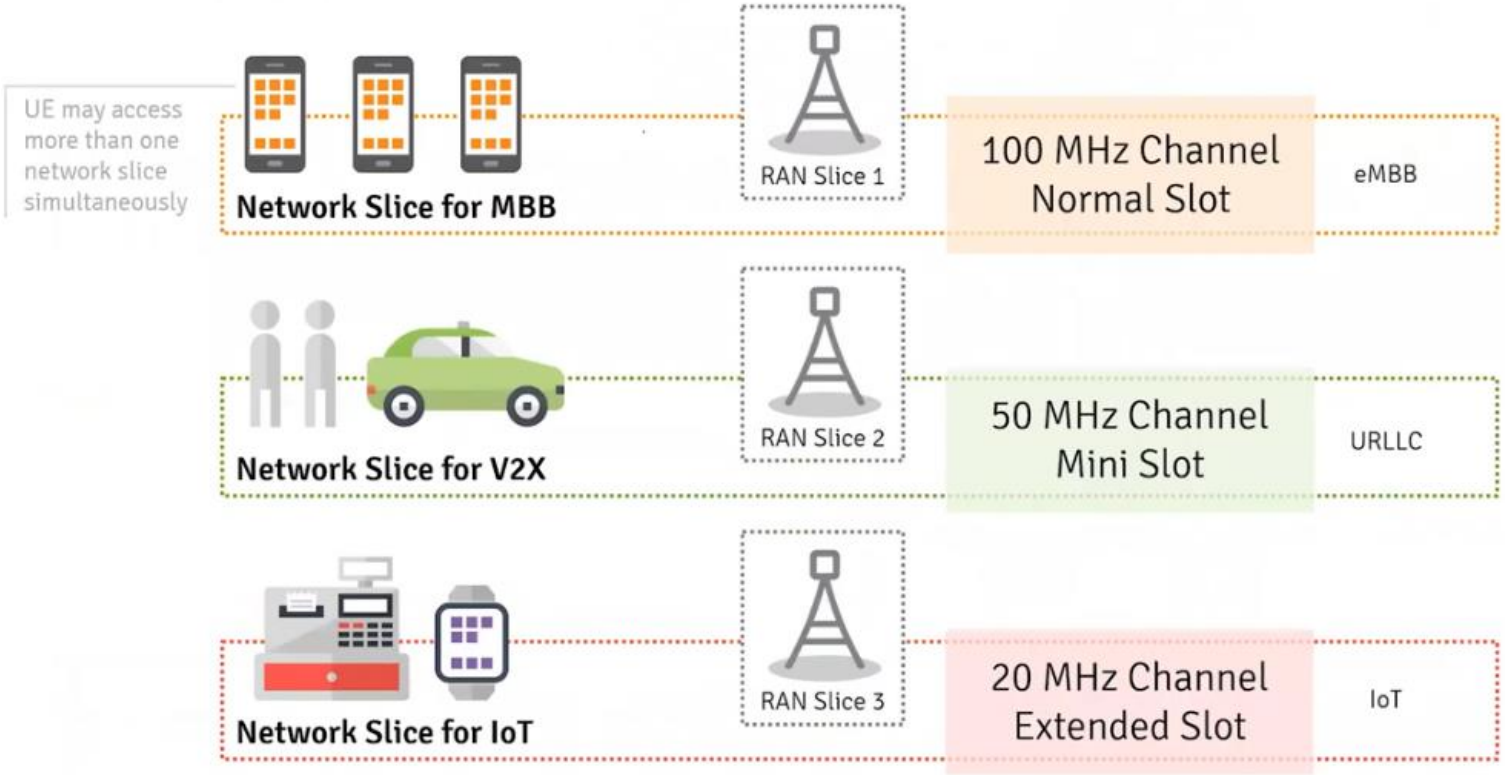
# A NFV application



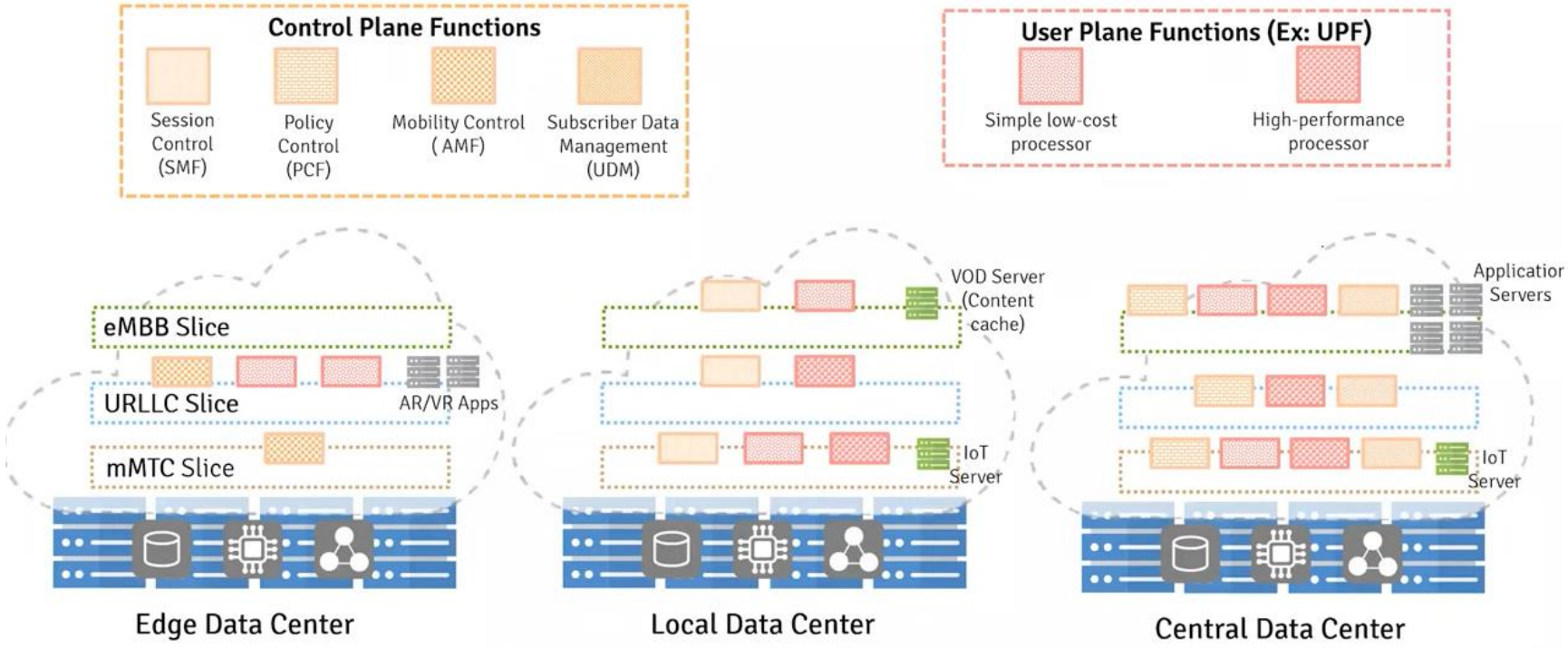
# Independent Virtual Networks



# RAN Slicing

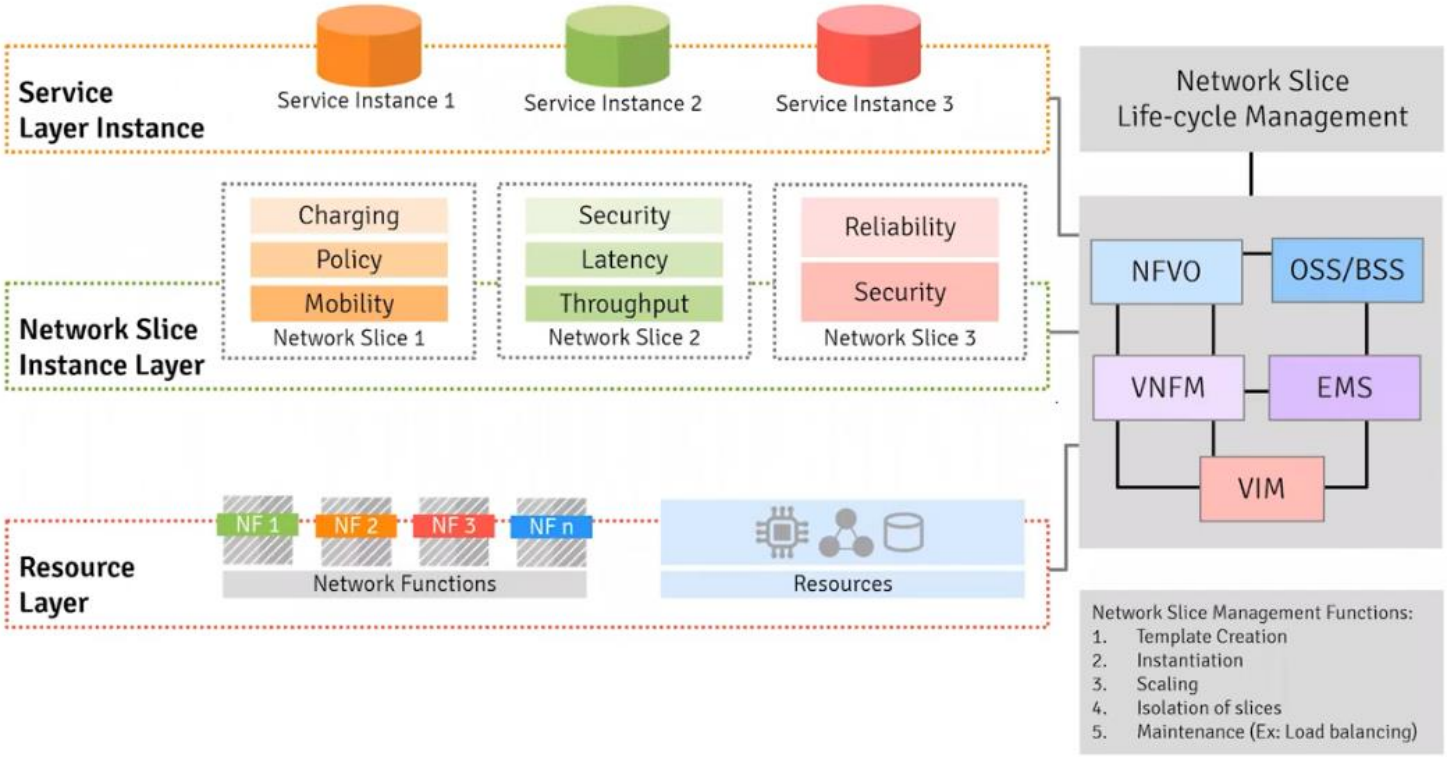

UE may access more than one network slice simultaneously
Network Slice for MBB
RAN Slice 1
100 MHz Channel
Normal Slot
eMBB
Network Slice for V2X
RAN Slice 2
50 MHz Channel
Mini Slot
URLLC
Network Slice for IoT
RAN Slice 3
20 MHz Channel
Extended Slot
IoT

# Core Network Slicing

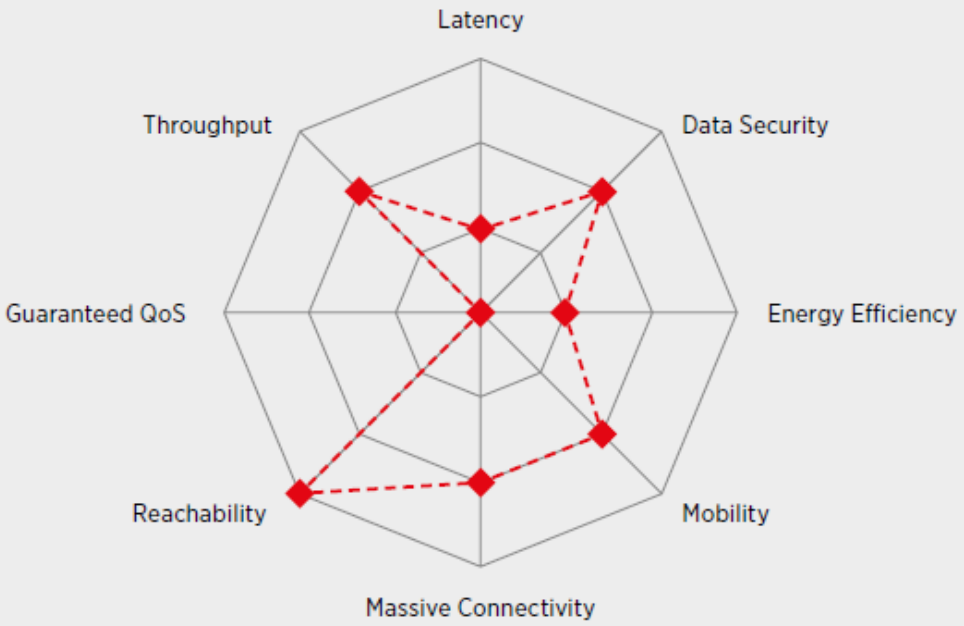


# Transport Slicing

# MANO


Service Layer Instance
Service Instance 1
Service Instance 2
Service Instance 3
Network Slice Instance Layer
Charging
Policy
Mobility
Network Slice 1
Security
Latency
Throughput
Network Slice 2
Reliability
Security
Network Slice 3
Resource Layer
NF 1
NF 2
NF 3
NF n
Network Functions
Resources
Network Slice Life-cycle Management
NFVO
OSS/BSS
VNFM
EMS
VIM
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**

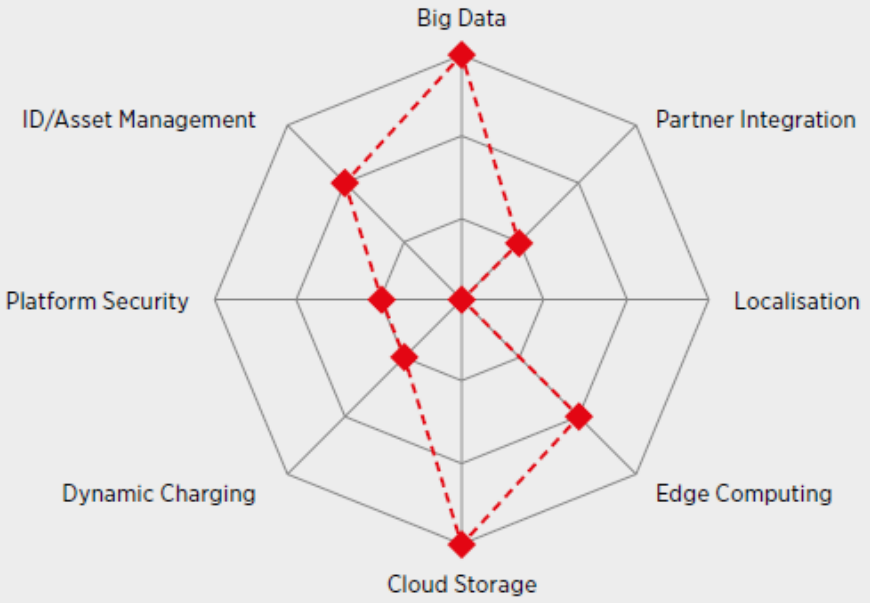
- Latency
- Data Security
- Energy Efficiency
- Mobility
- Massive Connectivity
- Reachability
- Guaranteed QoS
- Throughput

*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

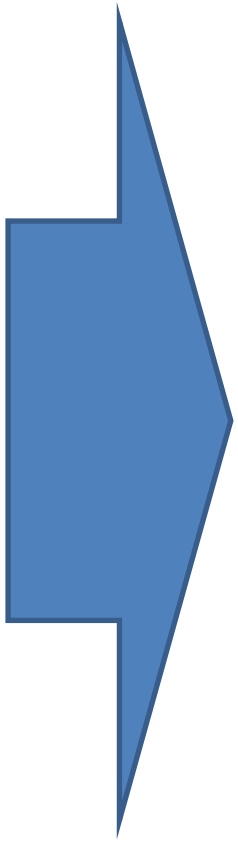



*GSMA Introduction to Network Slicing

# 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)

# 5G Advancements



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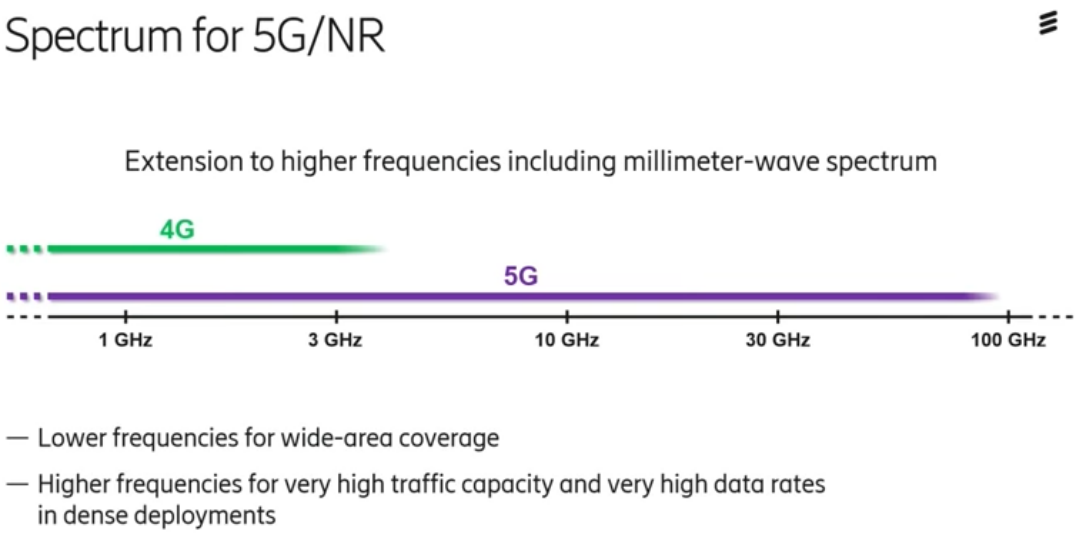
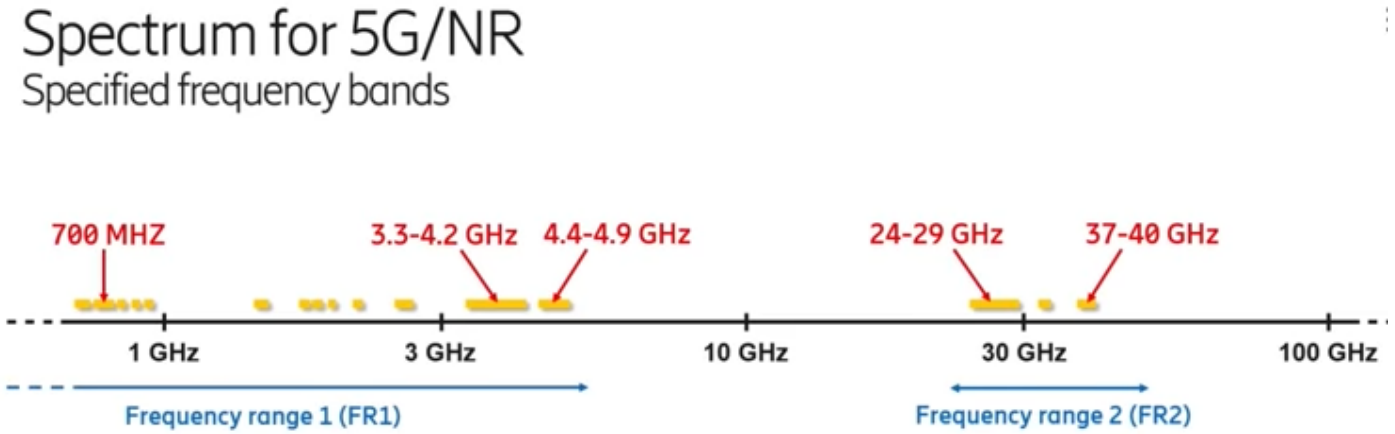
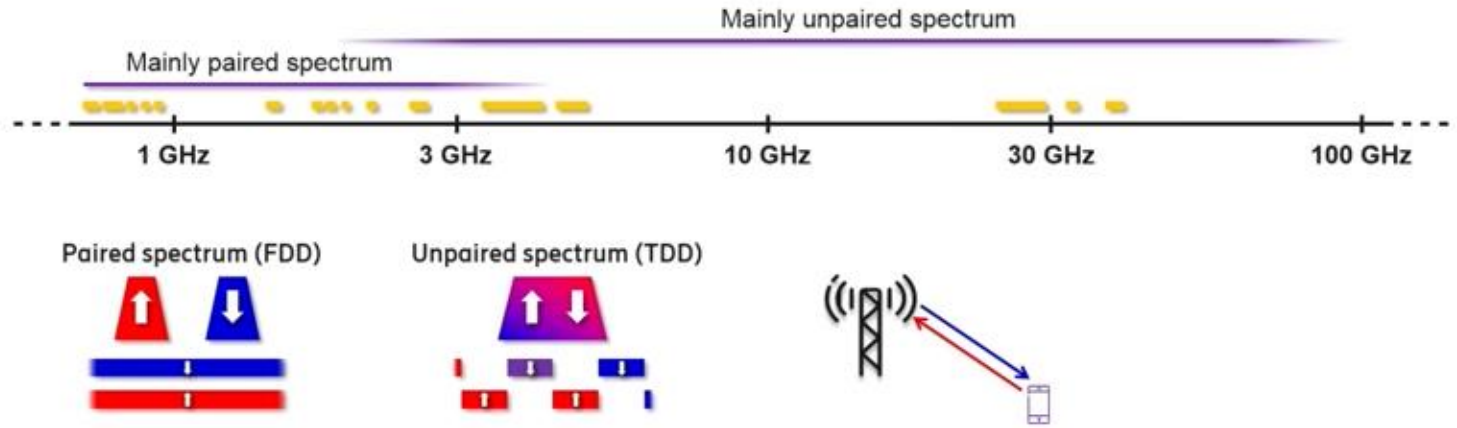
# 5G New Radio Spectrum Range



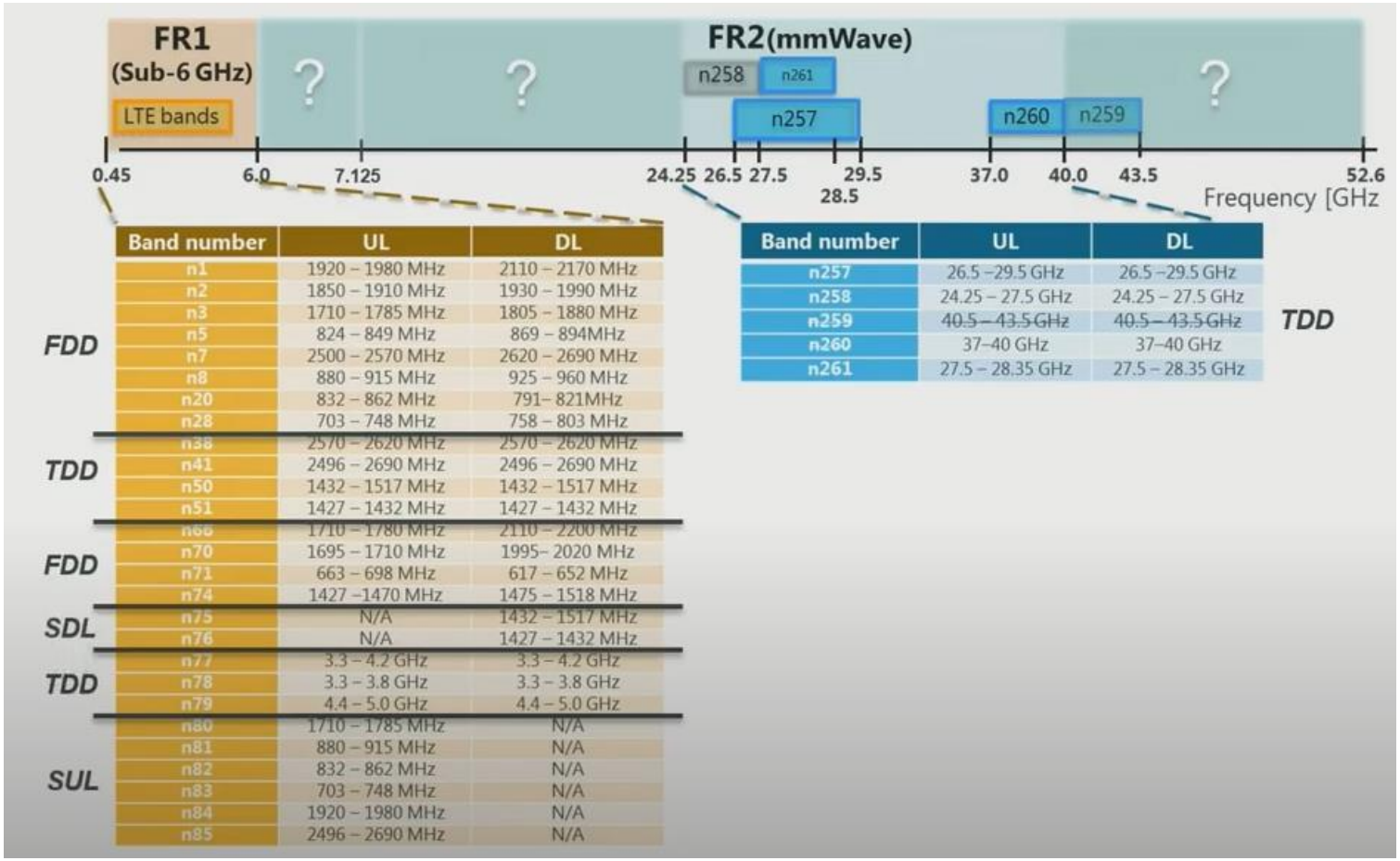



# 5G New Radio Duplexing




Main focus on TDD

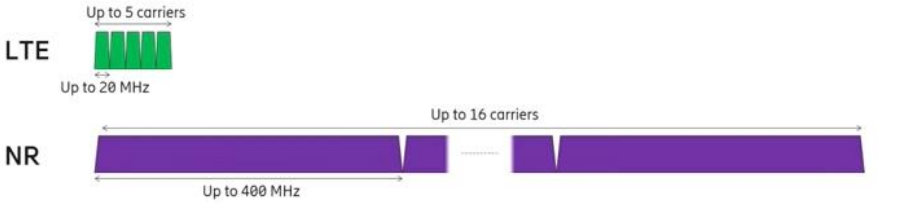
# 5G New Radio Duplexing




| | Band number | UL | DL |
|---|---|---|---|
| FDD | n1 | 1920 – 1980 MHz | 2110 – 2170 MHz |
| | n2 | 1850 – 1910 MHz | 1930 – 1990 MHz |
| | n3 | 1710 – 1785 MHz | 1805 – 1880 MHz |
| | n5 | 824 – 849 MHz | 869 – 894MHz |
| | n7 | 2500 – 2570 MHz | 2620 – 2690 MHz |
| | n8 | 880 – 915 MHz | 925 – 960 MHz |
| | n20 | 832 – 862 MHz | 791– 821MHz |
| | n28 | 703 – 748 MHz | 758 – 803 MHz |
| TDD | n38 | 2570 – 2620 MHz | 2570 – 2620 MHz |
| | n41 | 2496 – 2690 MHz | 2496 – 2690 MHz |
| | n50 | 1432 – 1517 MHz | 1432 – 1517 MHz |
| | n51 | 1427 – 1432 MHz | 1427 – 1432 MHz |
| FDD | n66 | 1710 – 1780 MHz | 2110 – 2200 MHz |
| | n70 | 1695 – 1710 MHz | 1995– 2020 MHz |
| | n71 | 663 – 698 MHz | 617 – 652 MHz |
| | n74 | 1427 –1470 MHz | 1475 – 1518 MHz |
| SDL | n75 | N/A | 1432 – 1517 MHz |
| | n76 | N/A | 1427 – 1432 MHz |
| TDD | n77 | 3.3 – 4.2 GHz | 3.3 – 4.2 GHz |
| | n78 | 3.3 – 3.8 GHz | 3.3 – 3.8 GHz |
| | n79 | 4.4 – 5.0 GHz | 4.4 – 5.0 GHz |
| SUL | n80 | 1710 – 1785 MHz | N/A |
| | n81 | 880 – 915 MHz | N/A |
| | n82 | 832 – 862 MHz | N/A |
| | n83 | 703 – 748 MHz | N/A |
| | n84 | 1920 – 1980 MHz | N/A |
| | 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 | |
| n259 | 40.5 – 43.5 GHz | 40.5 – 43.5 GHz | |
| n260 | 37–40 GHz | 37–40 GHz | |
| n261 | 27.5 – 28.35 GHz | 27.5 – 28.35 GHz | |

# 5G New Radio Carriers

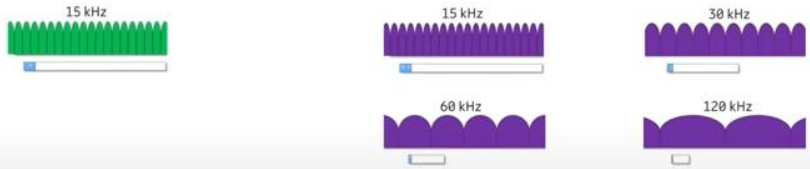



**LTE**
- Per carrier bandwidth up to 20 MHz
  - Minimum carrier bandwidth: 1.25 MHz
- Carrier aggregation up to 5 carriers
  - ⇨ Maximum bandwidth: 100 MHz

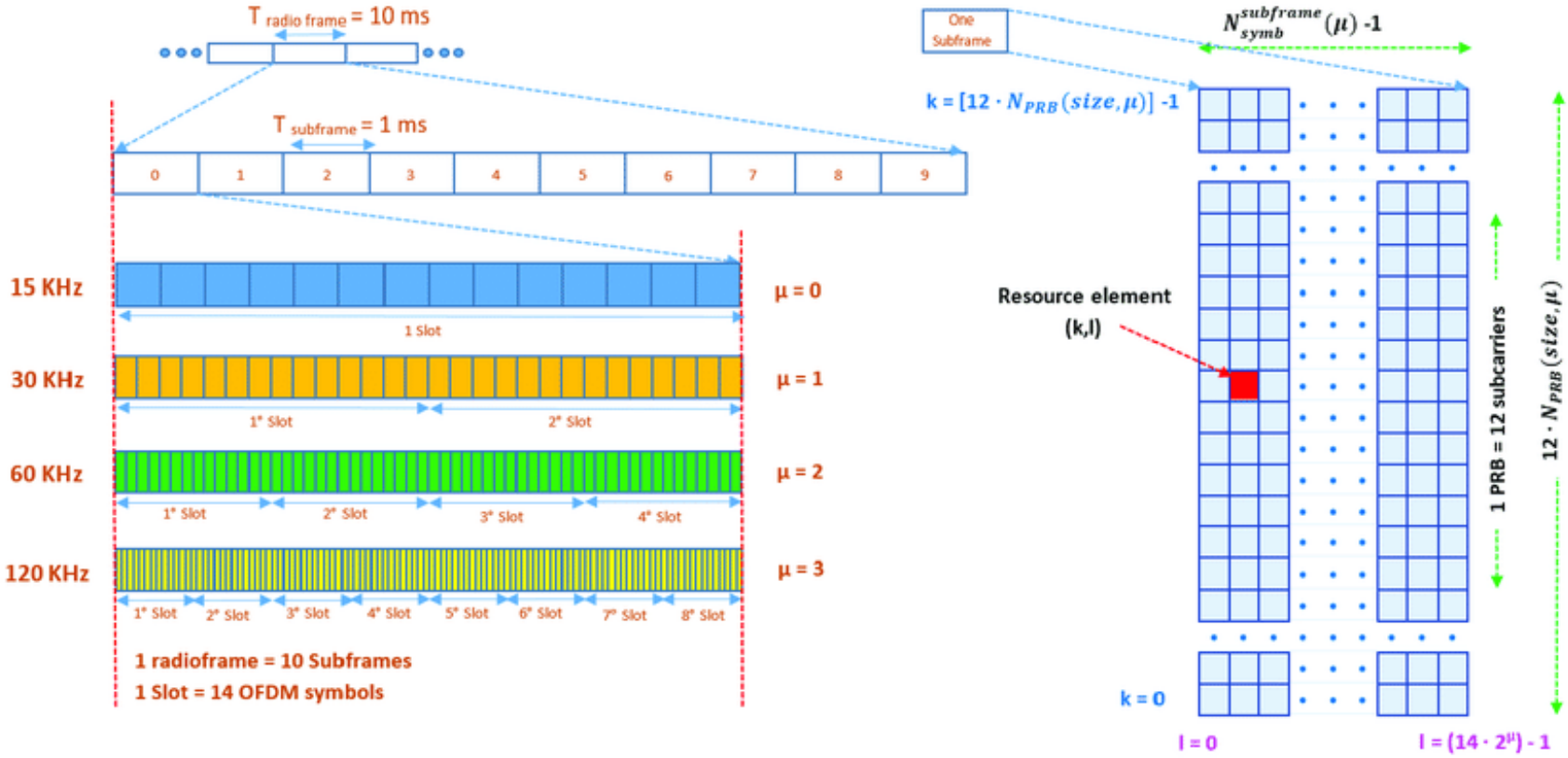
**NR**
- Per-carrier bandwidth up to 400 MHz
  - Minimum carrier bandwidth: 5 MHz
- Carrier aggregation up to 16 carriers
  - ⇨ Maximum bandwidth: 6.4 GHz (!)

**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



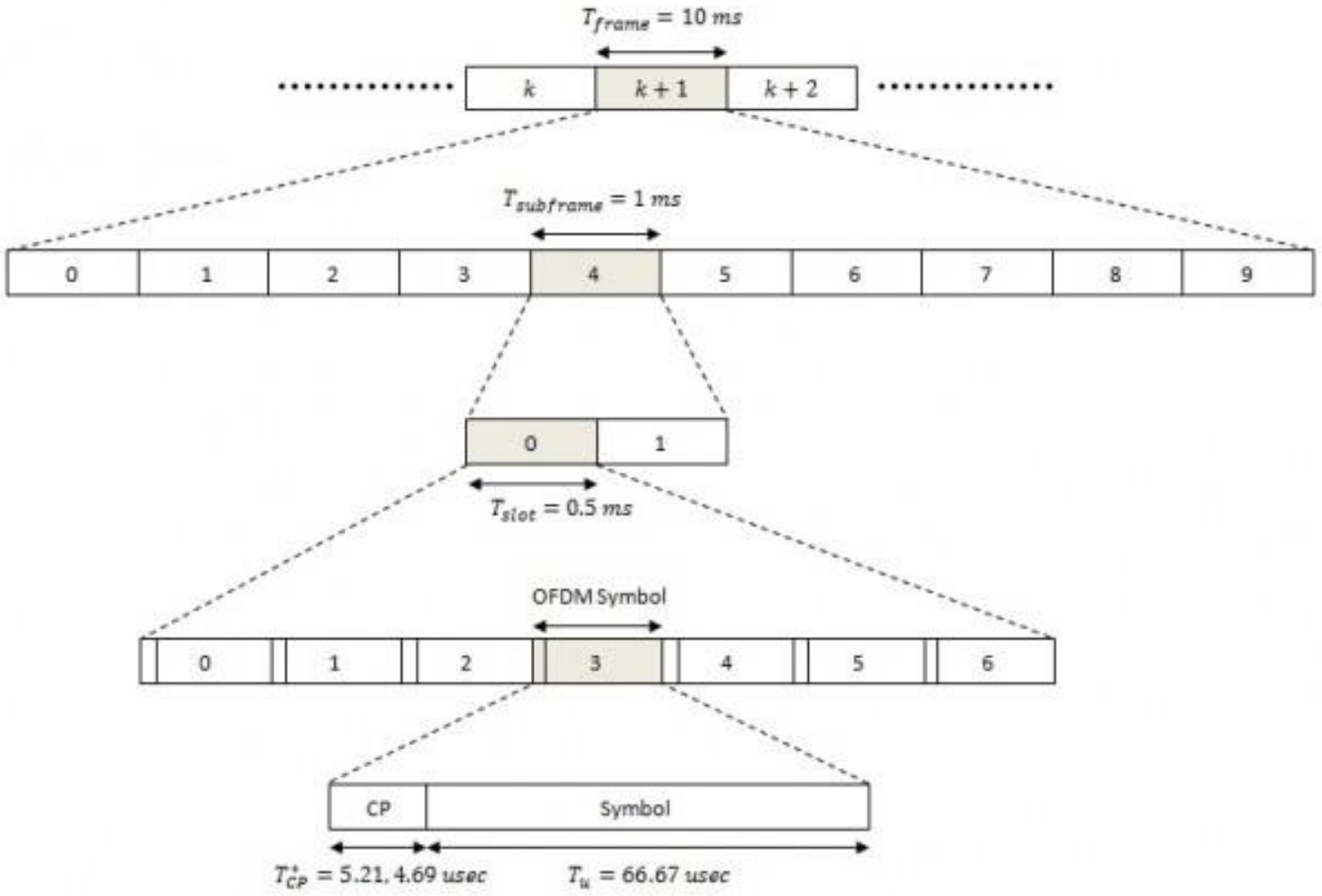
# 5G New Radio Numerology



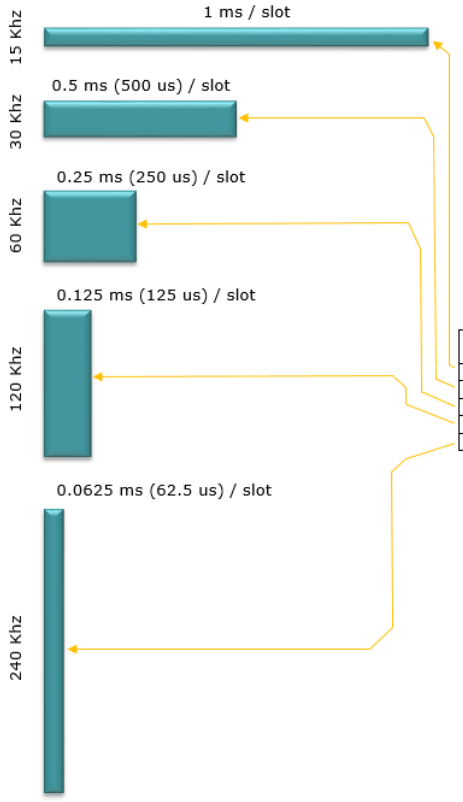
# 5G New Radio Numerology


| 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



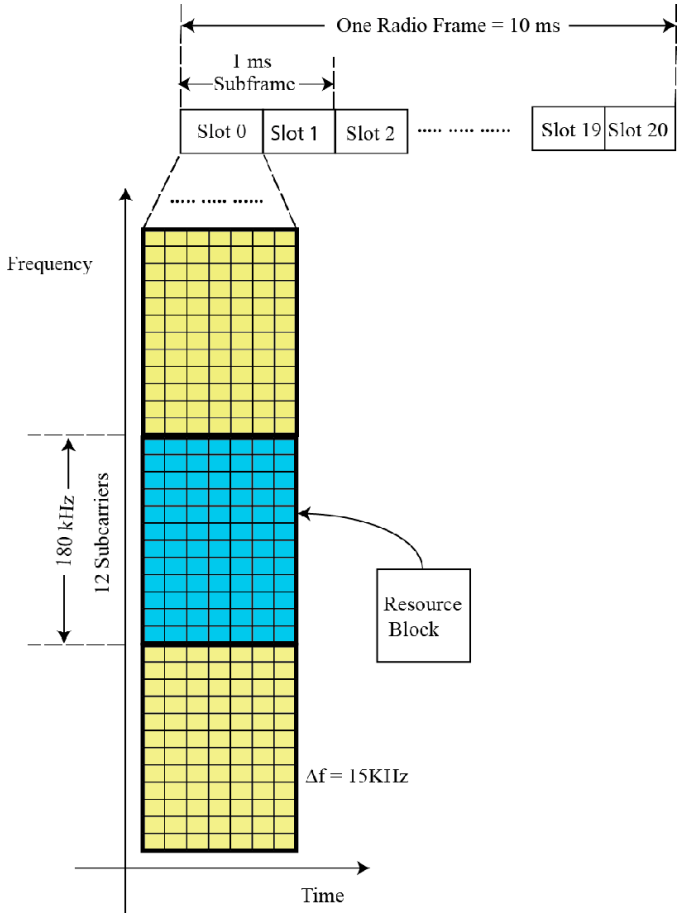
# 5G New Radio Numerology

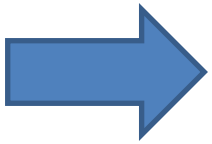


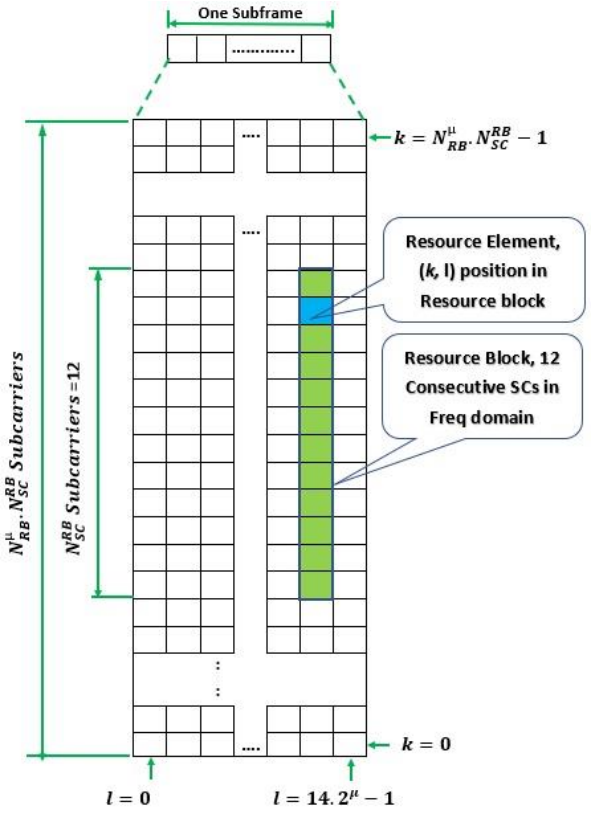

< 38.211 – Table 4.3.2-1 >

| $\mu$ | $N^{slot}_{symb}$ | $N^{frame,\mu}_{slot}$ | $N^{subframe,\mu}_{slot}$ |
|---|---|---|---|
| 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



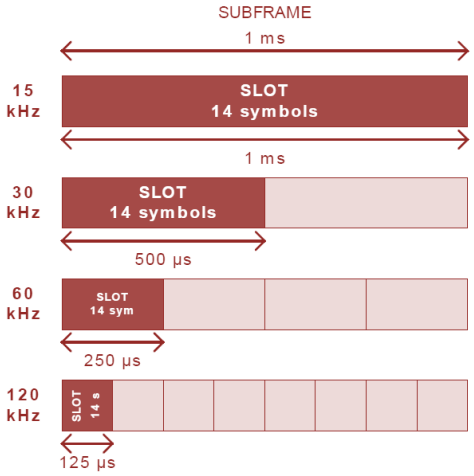





# 5G New Radio (Protocol Stack – Layer 1)

**PHY Layer Functions**

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



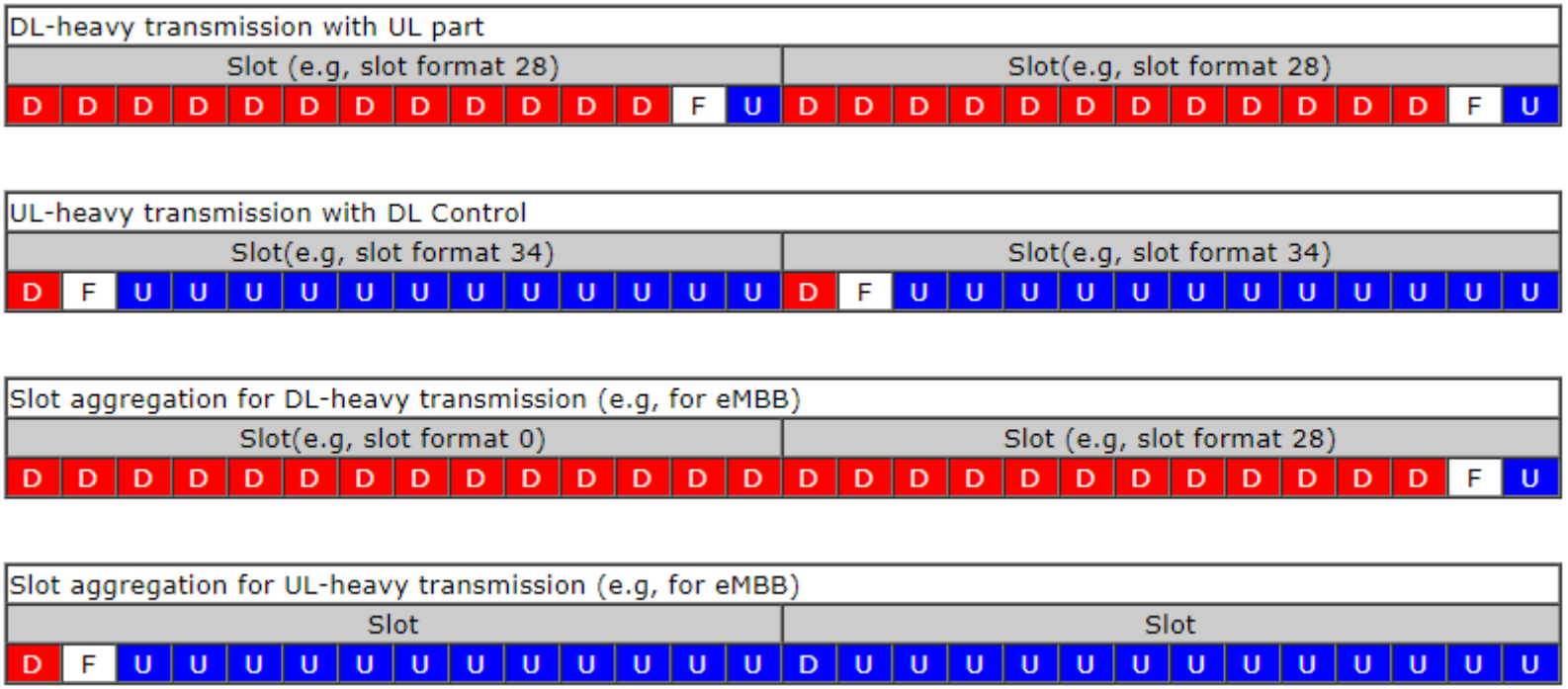

| Subcarrier Spacing (μ) | Number of OFDM Symbols per Slot ($N_{symb}^{slot}$) | Number of Slots per Subframe ($N_{slot}^{subframe,\mu}$) | Number of Slots per Frame ($N_{slot}^{frame,\mu}$) |
|---|---|---|---|
| **0**<br>*15 kHz* | 14<br>*1 ms* | 1<br>*1 slot x 1 ms = 1 ms* | 10<br>*10 ms* |
| **1**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

# 5G New Radio Slot Formats

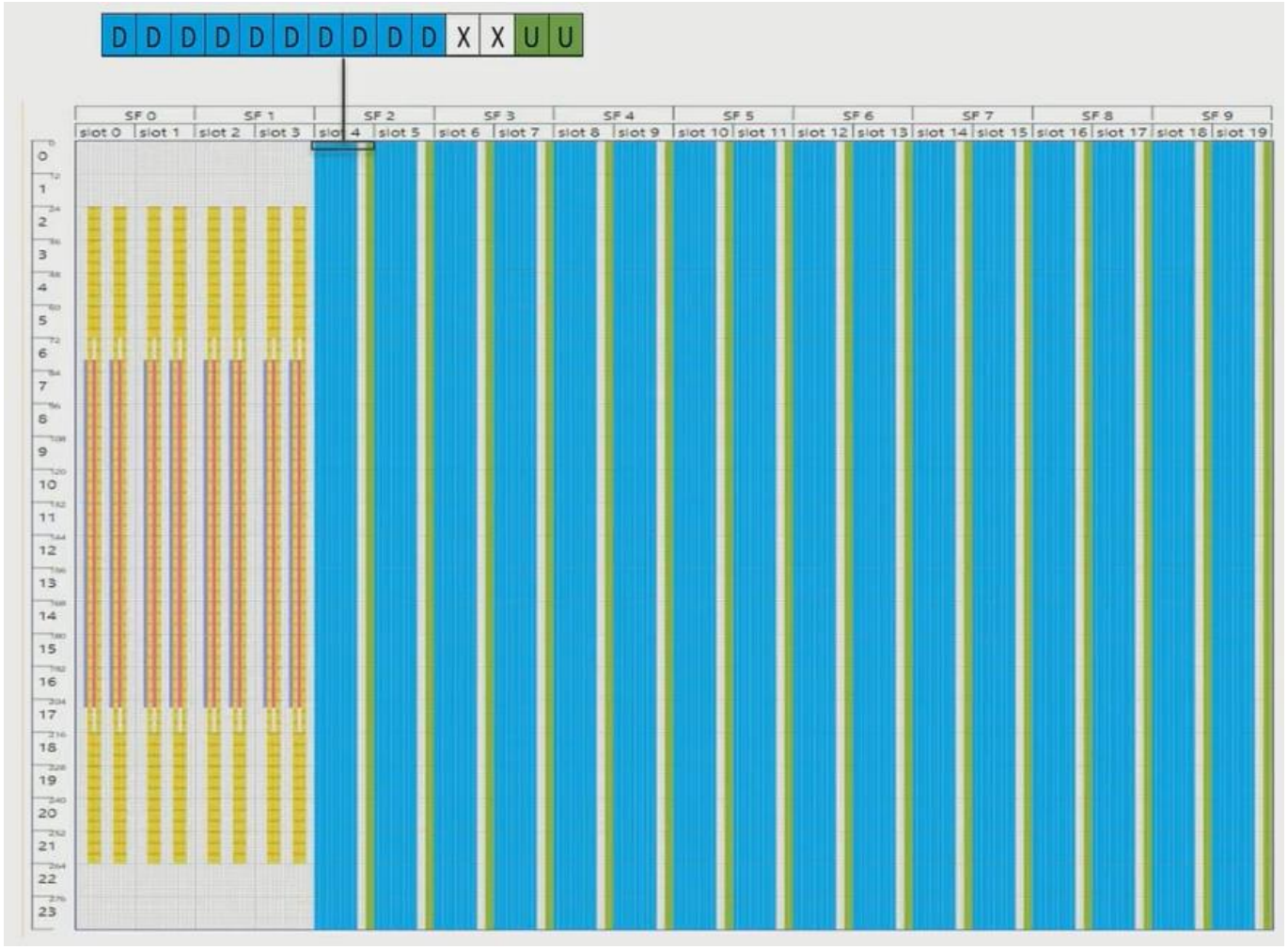
<38.213 v15.7 -Table 11.1.1-1: Slot formats for normal cyclic prefix>
D : Downlink, U : Uplink, F : Flexible

| | 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 |

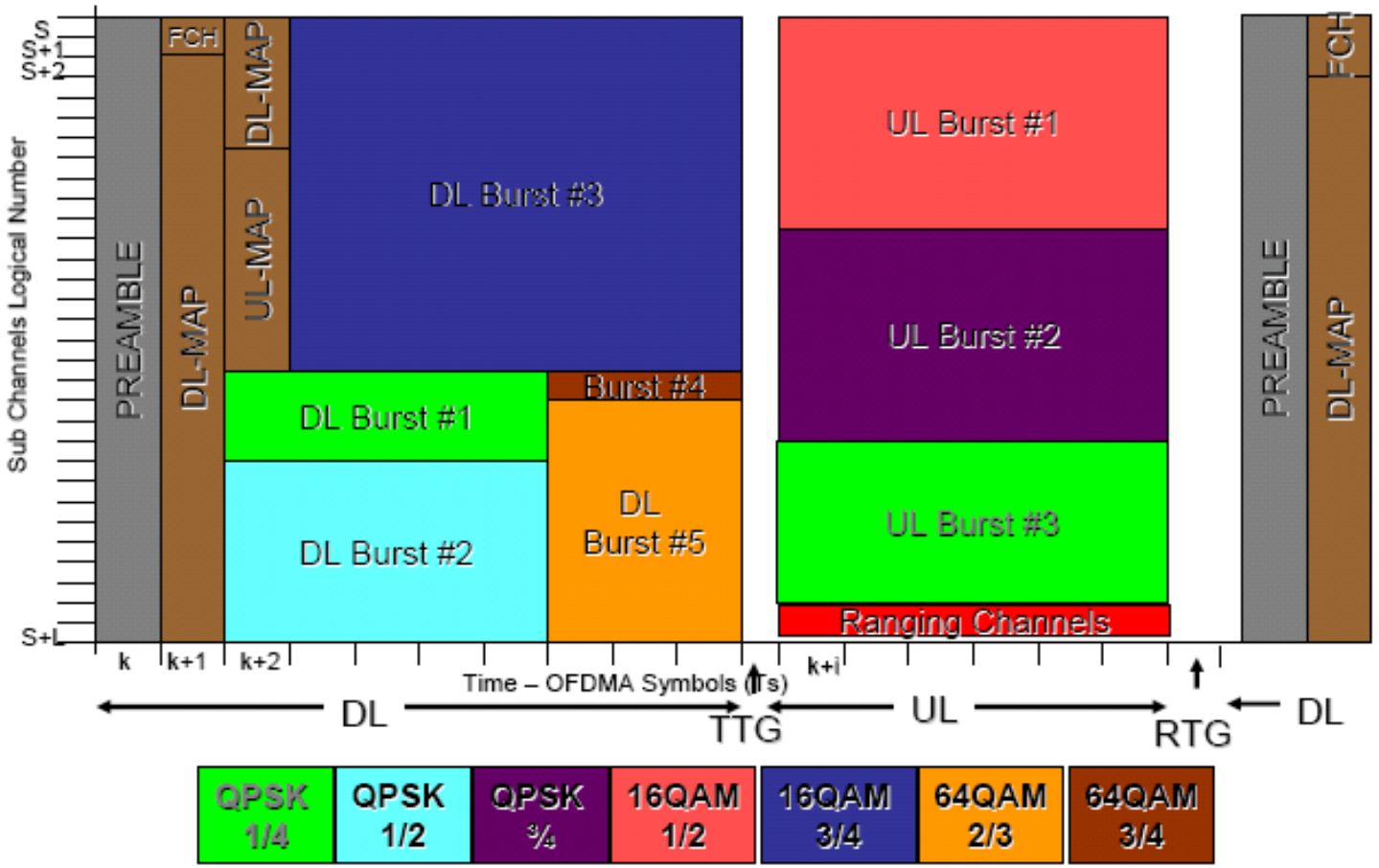
# Slot Format Examples



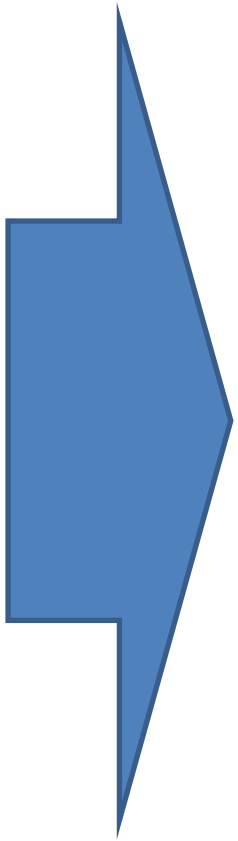
# 5G New Radio Frame Structure



# Comparison with 4G

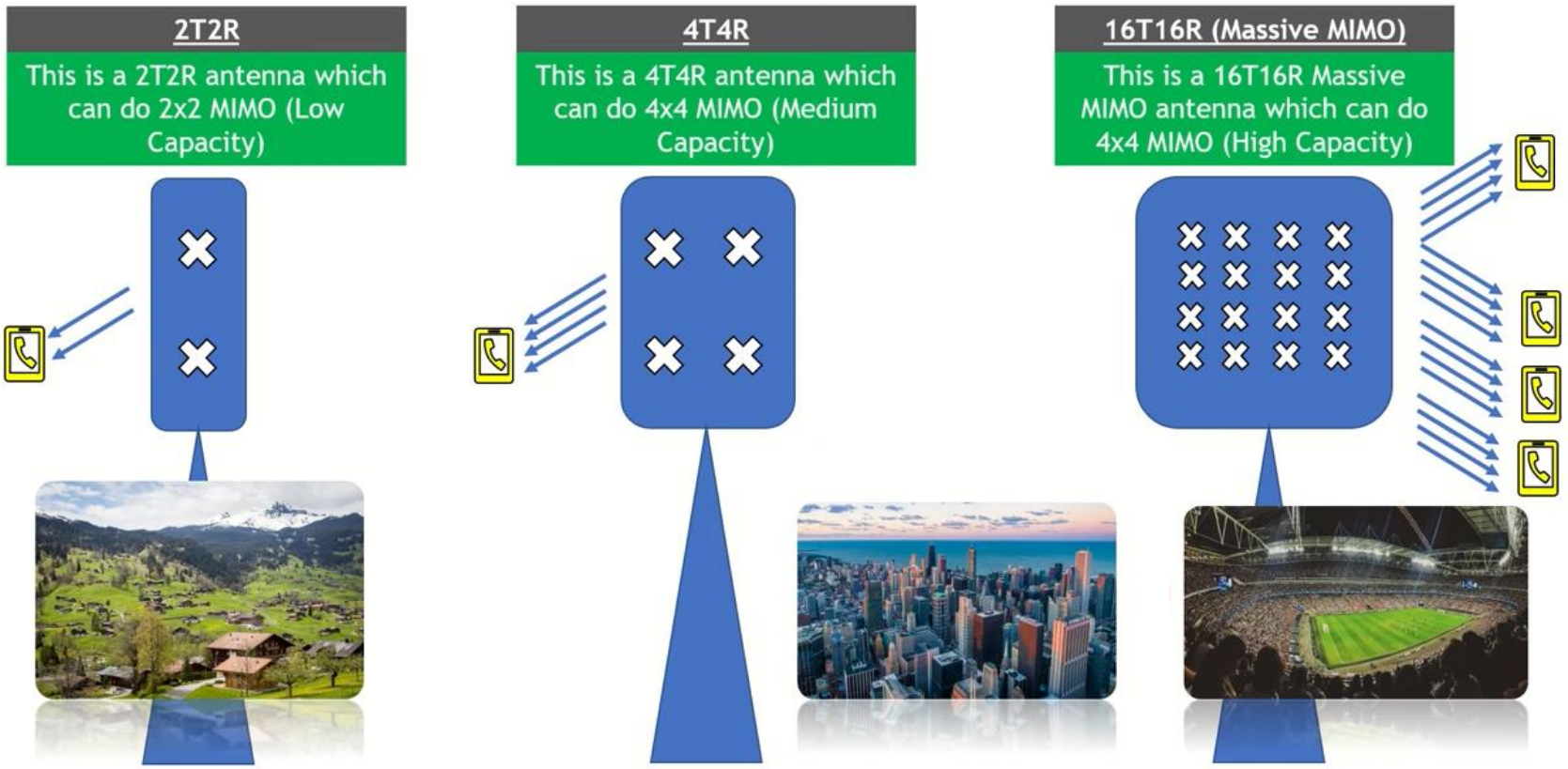


# 5G Advancements



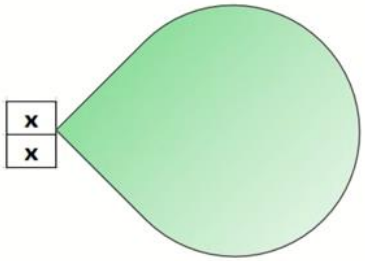
- **New Architecture**
  - Advanced core network functions / NG RAN
  - Incorporate SDN/NFV (NFV MANO)
    - Decupling of control and data plane
    - Decupling of functions from the hardware
- **Network Slicing**
  - eMBB, URLLC, mMTC | 8 subclasses pes slice type
- **New Radio (NR)**
  - RAN protocol 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



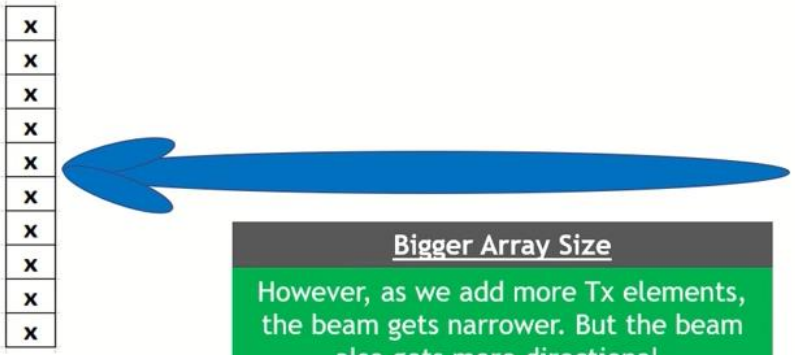
# Massive MIMO

## Beam-Forming Mechanism



**Smaller Array Size**

A smaller number of Tx elements can generate beams with bigger beamwidth. So they are good in cases where we want to cover wide spaces with minimum cost

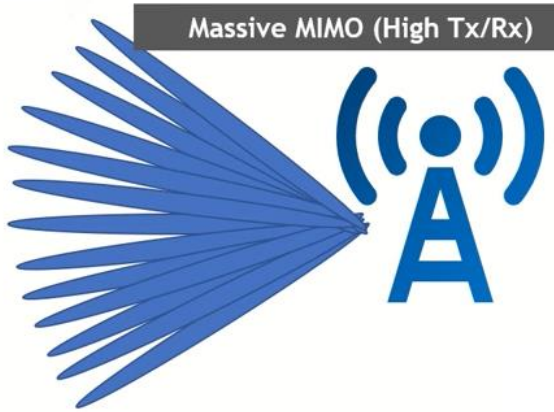


**Bigger Array Size**

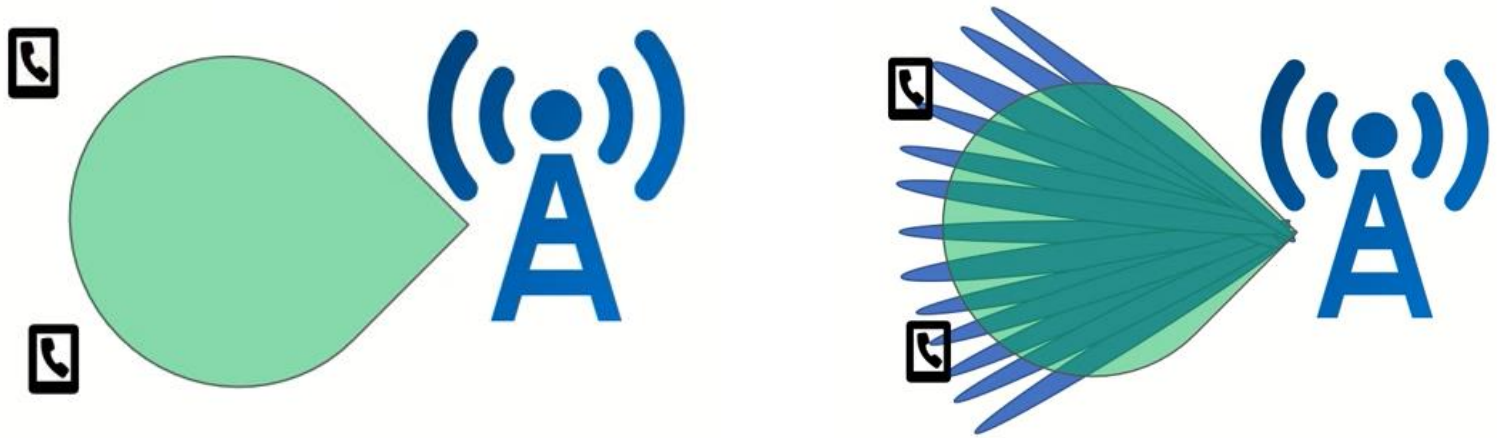
However, as we add more Tx elements, the beam gets narrower. But the beam also gets more directional.

**Massive MIMO (Low Tx/Rx)**

**Massive MIMO (High Tx/Rx)**

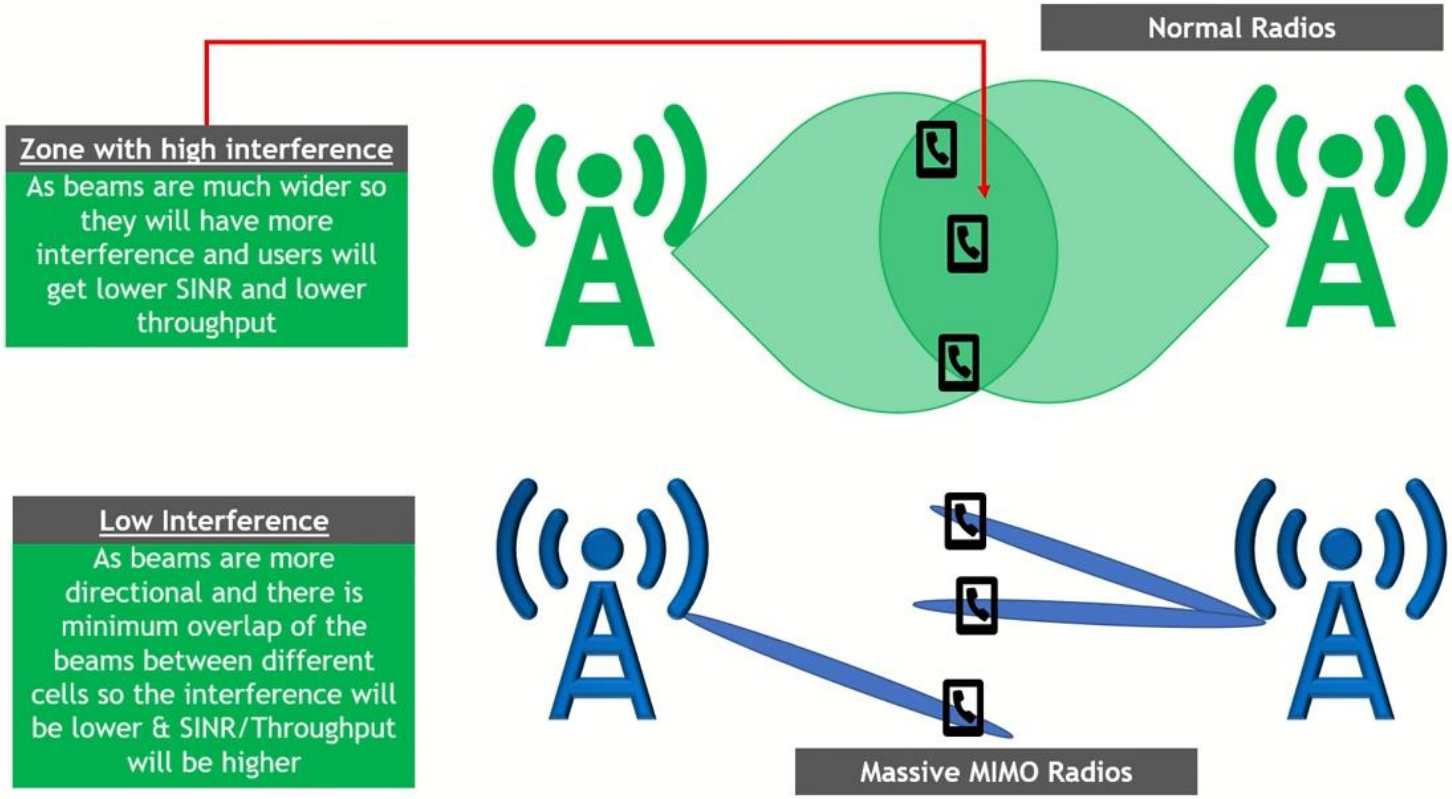


# Massive MIMO



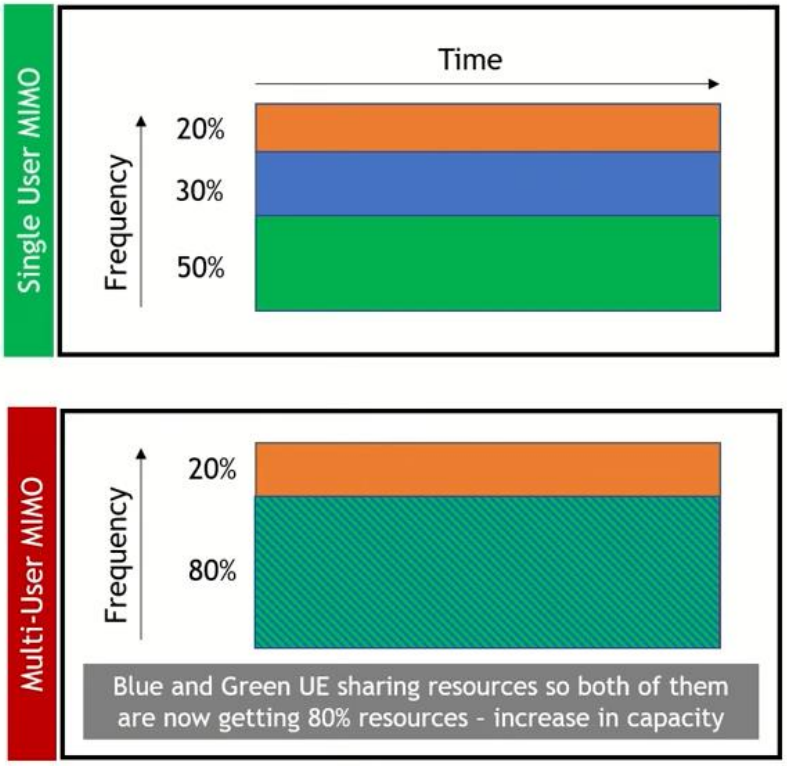
Increase coverage and capacity

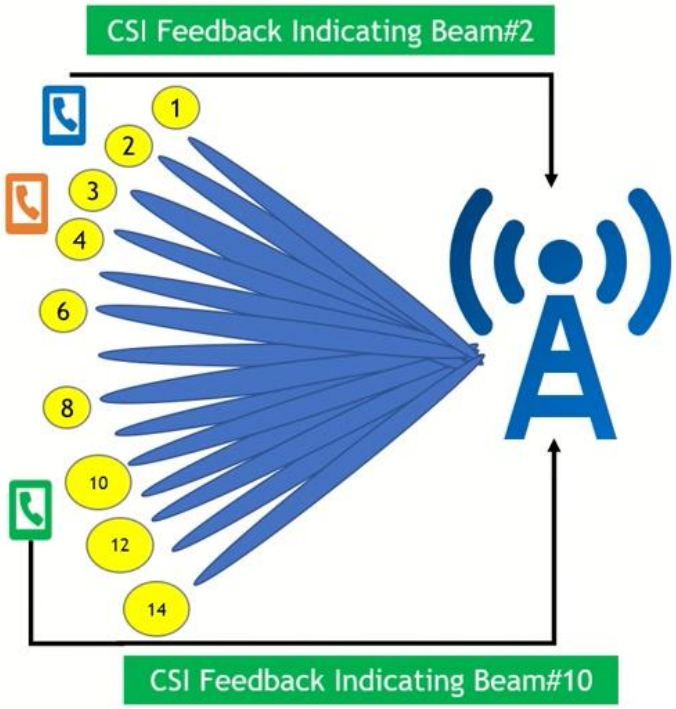
# Massive MIMO




Less interference

# Massive MIMO



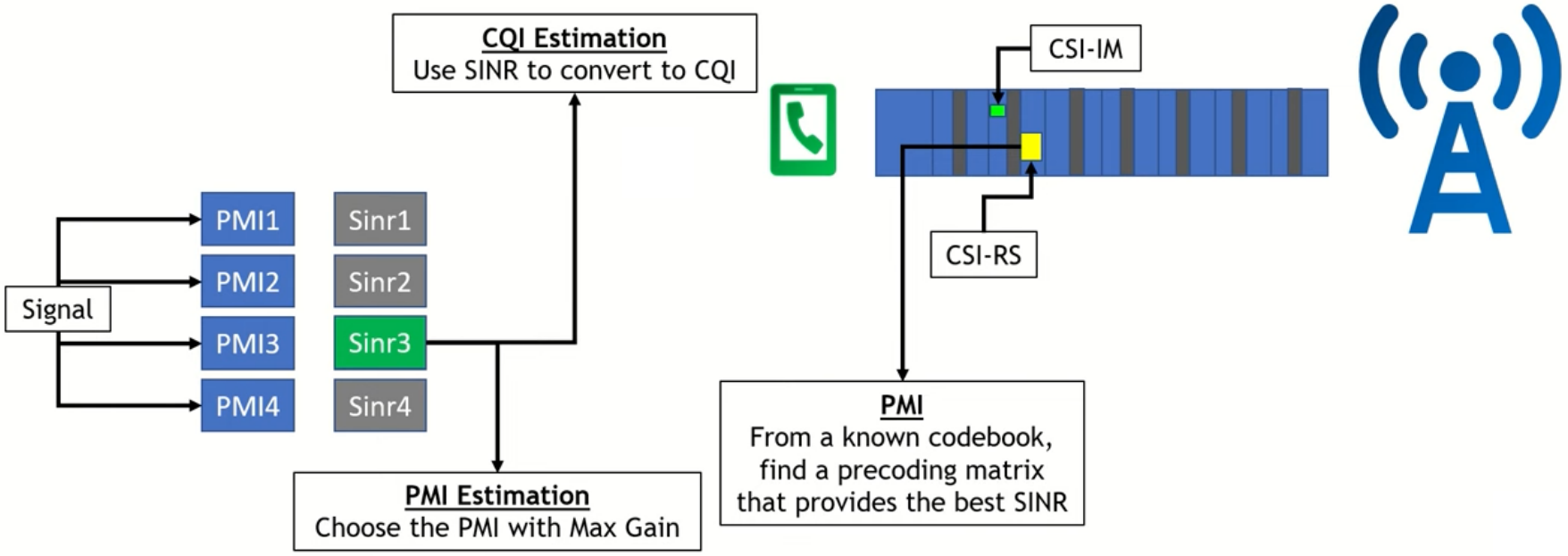




Why not sharing frequency also for Orange UE?

# Massive MIMO

## CSI Feedback

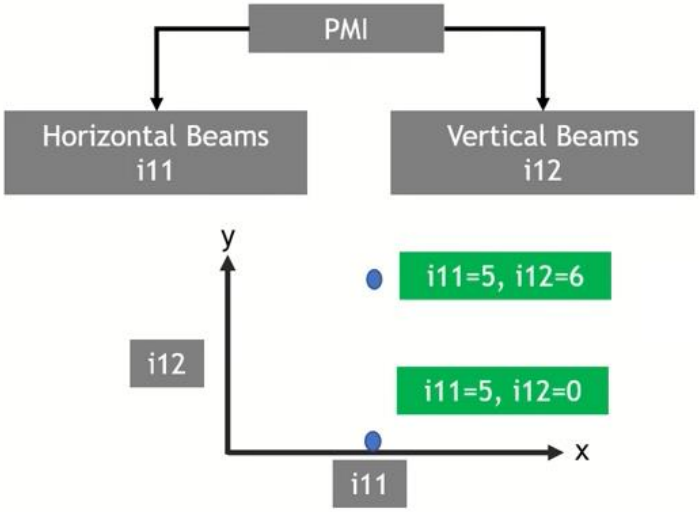
CSI Feedback has three parts
- Rank Indicator (RI)
- Channel Quality Indicator (CQI)
- Precoding Matrix Information (PMI)

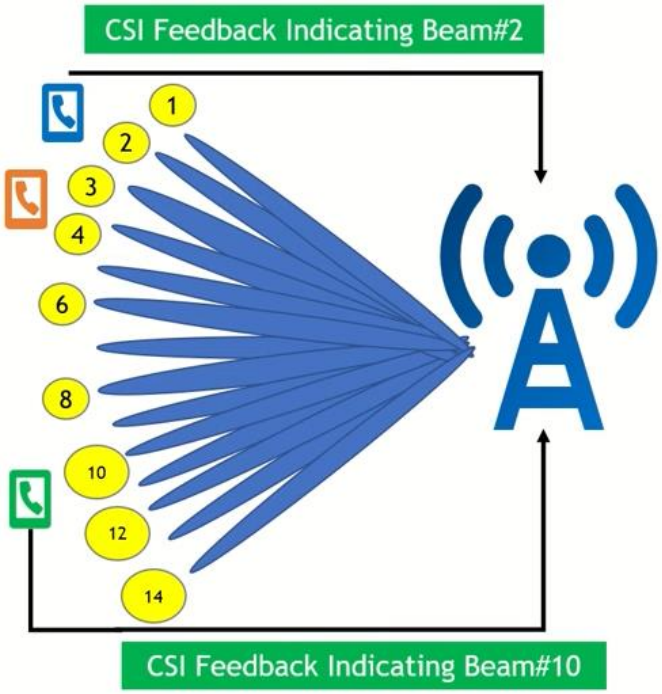


# Massive MIMO

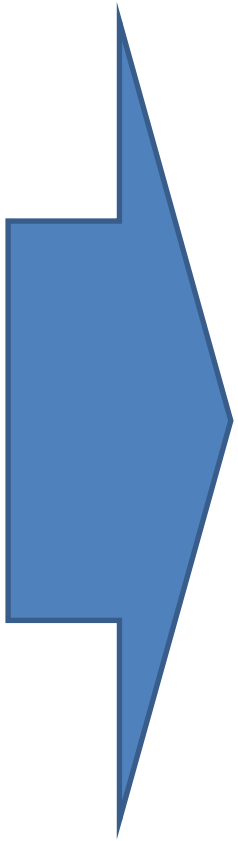
## How To Choose The Beam

- 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



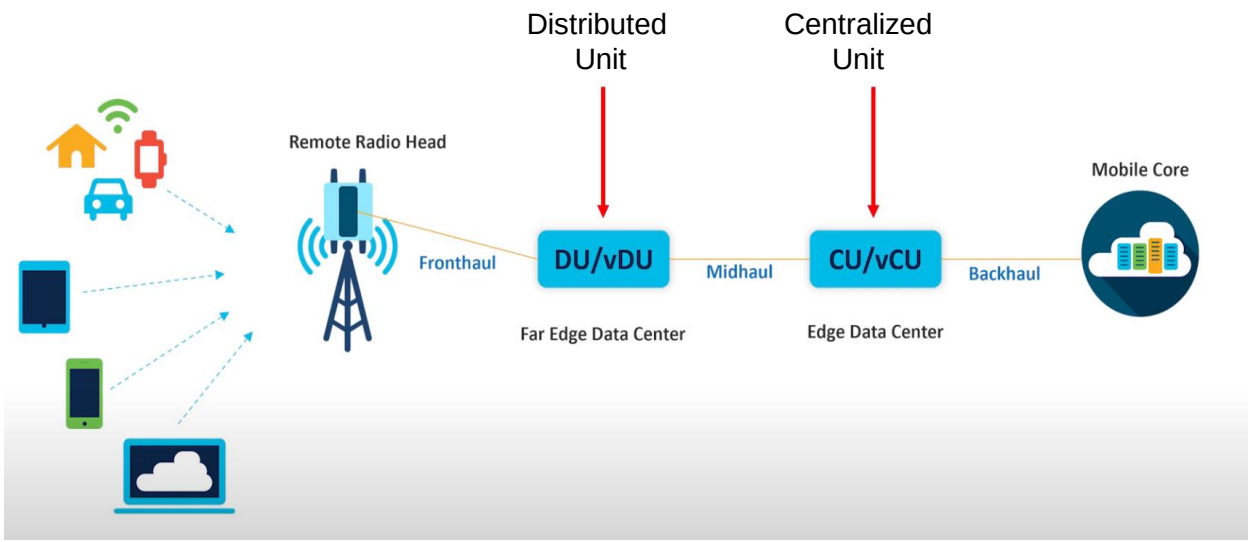
# 5G Advancements



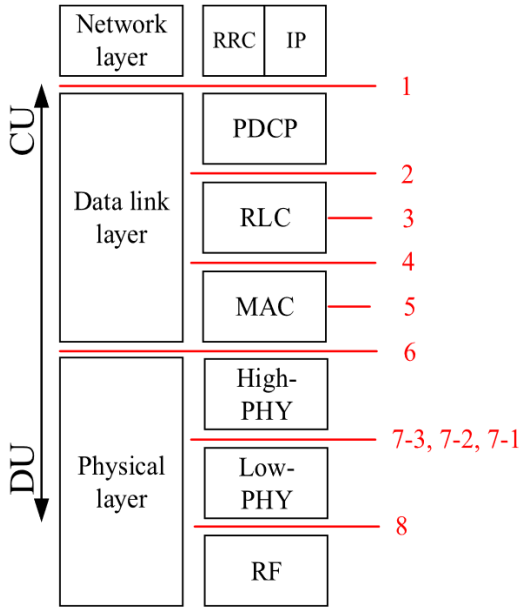
- **New Architecture**
  - Advanced core network functions / NG RAN
  - Incorporate SDN/NFV (NFV MANO)
    - Decupling of control and data plane
    - Decupling of functions from the hardware
- **Network Slicing**
  - eMBB, URLLC, mMTC | 8 subclasses pes slice type
- **New Radio (NR)**
  - RAN protocol 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)

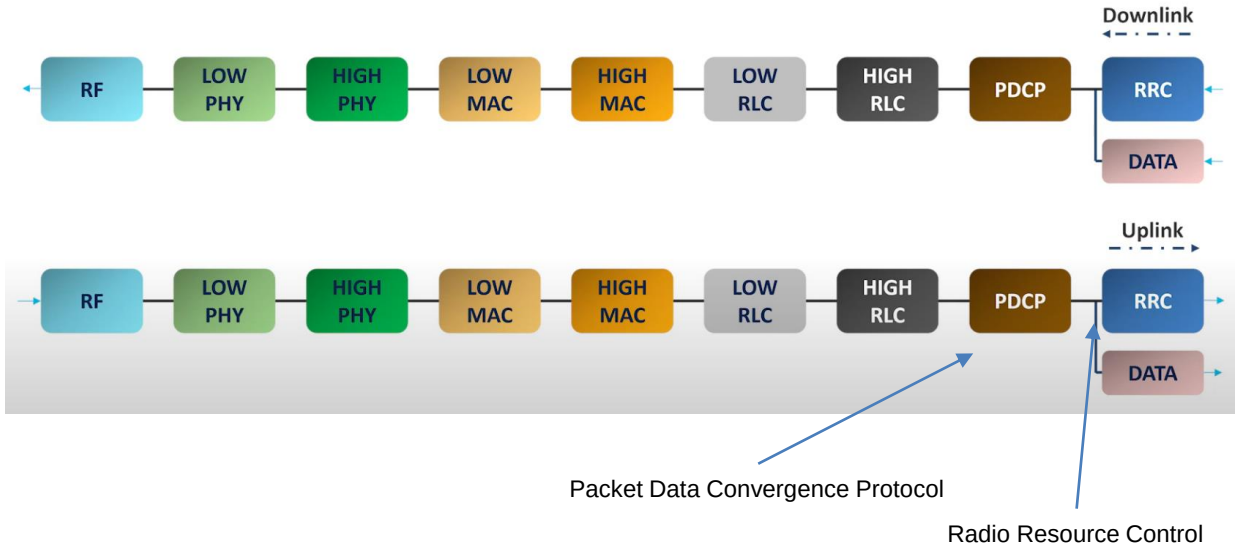
# Functional Split

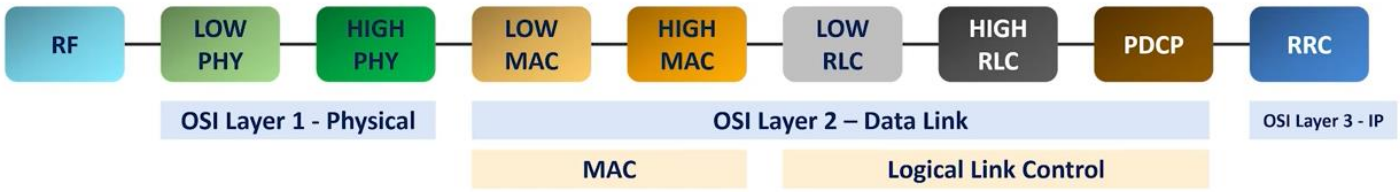
- Introduction of the Backhaul and Fronthaul network
- The main challenge refers to the RAN layer where the split is performed



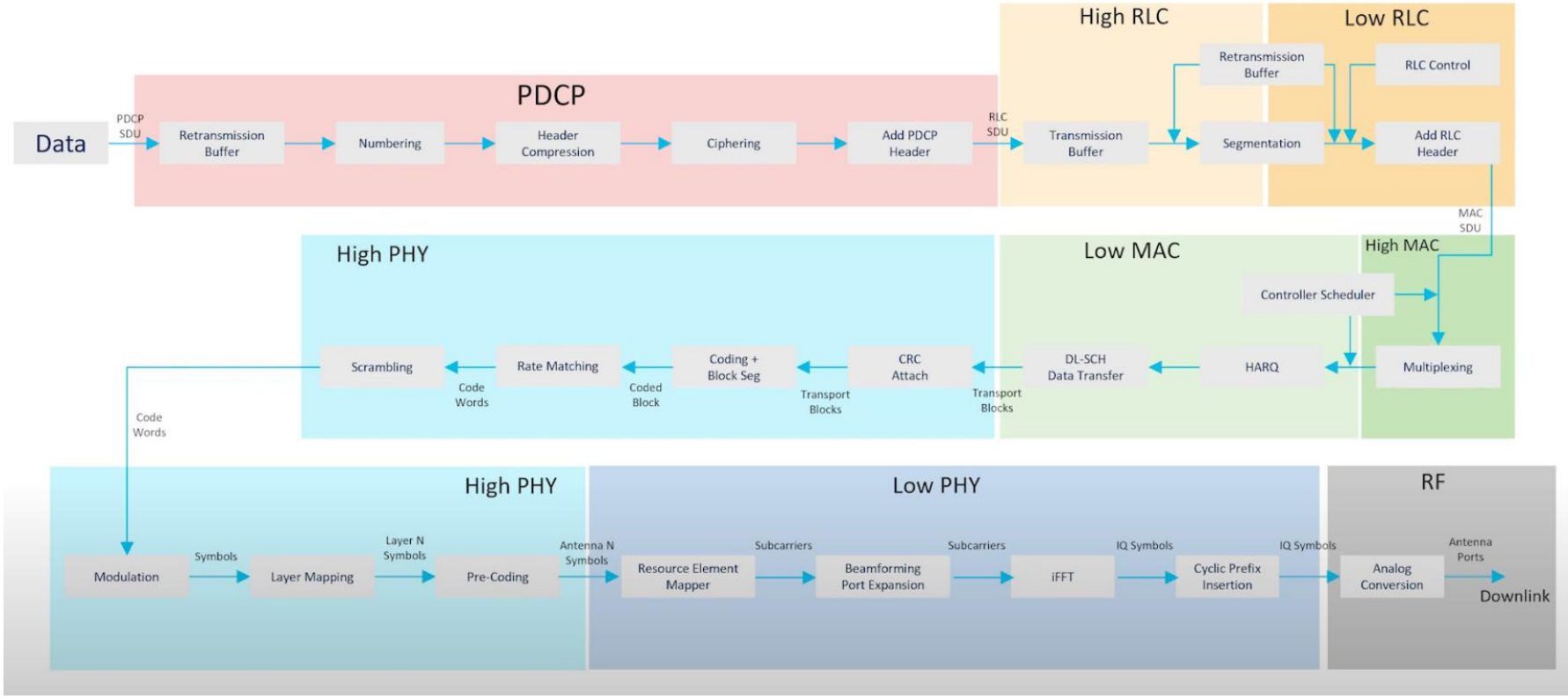
# Functional Split



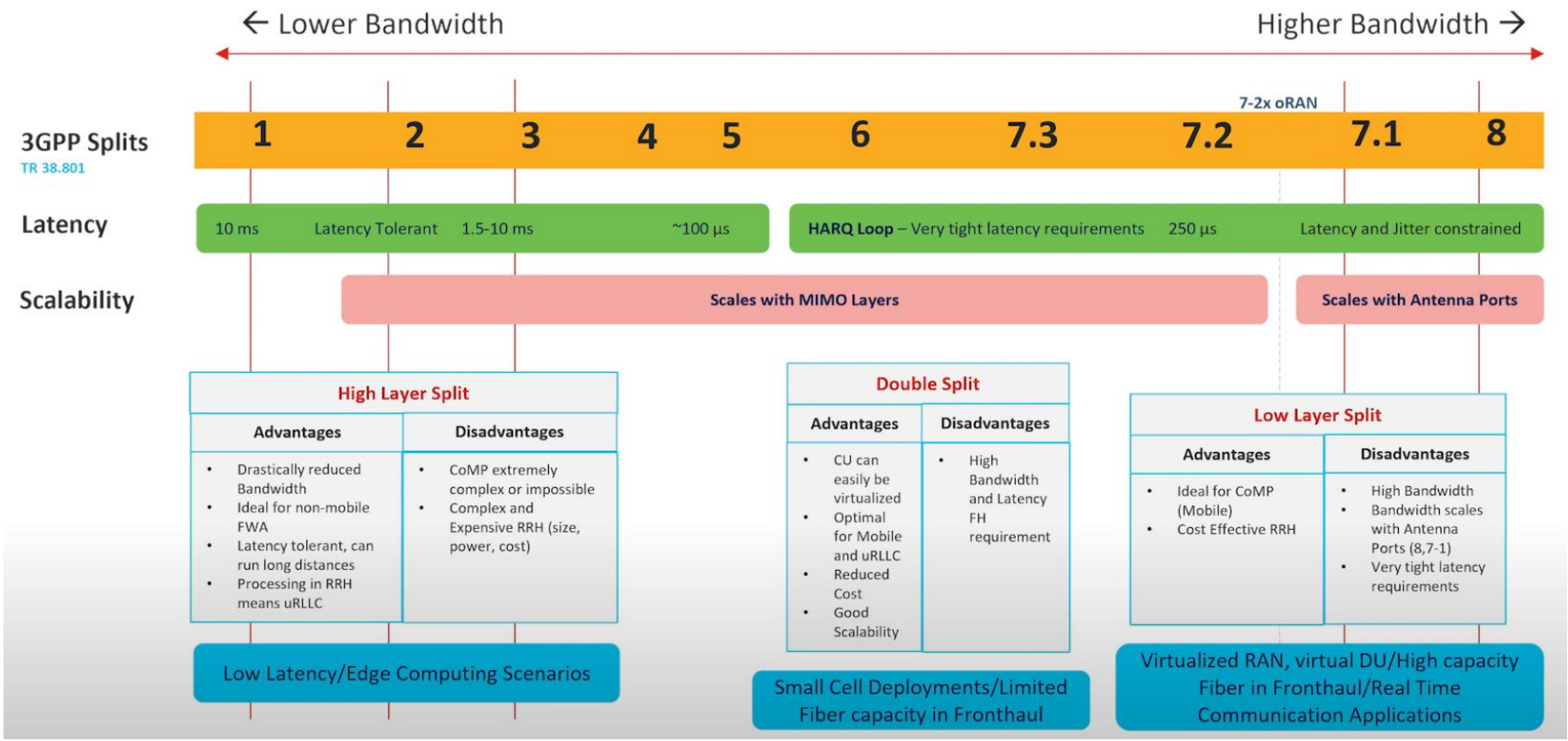



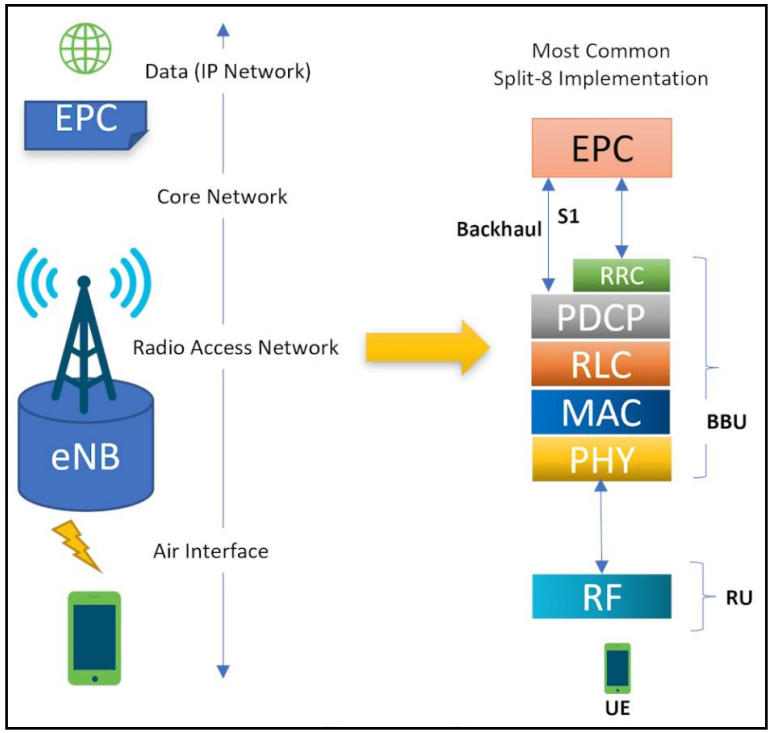



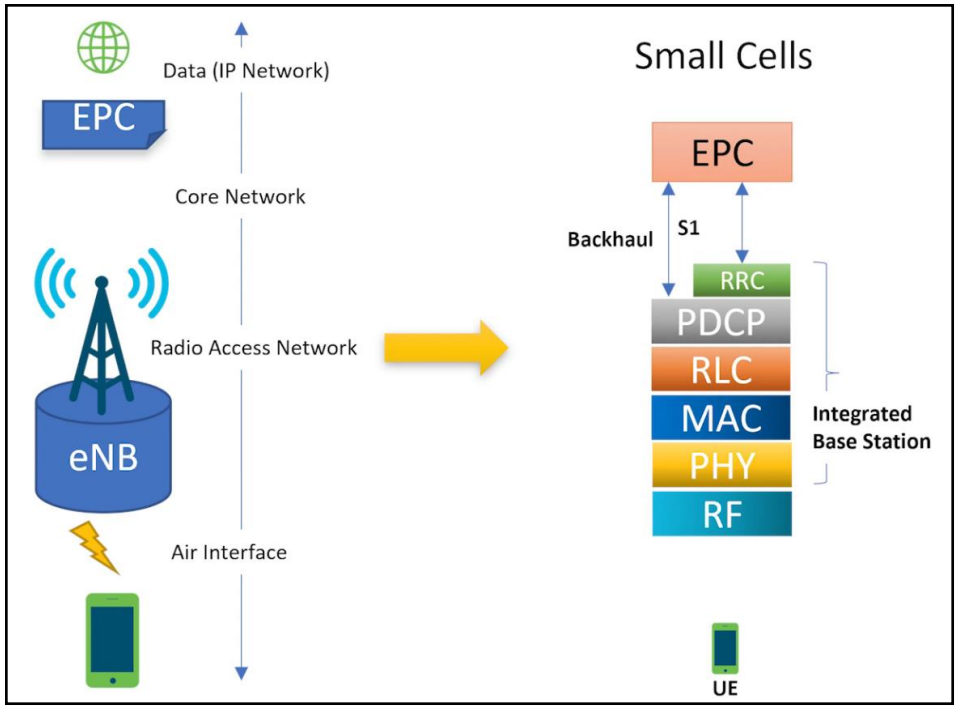
# Functional Split

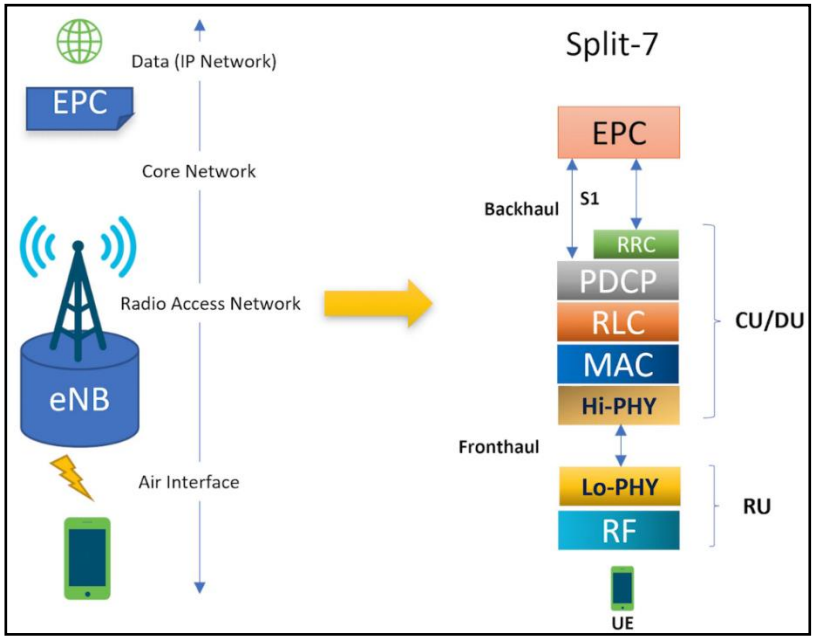


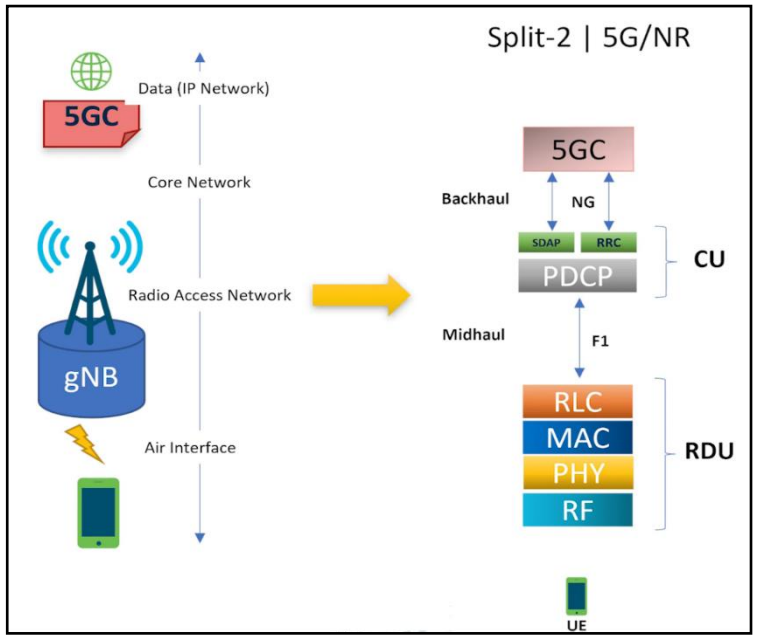
# Functional Split



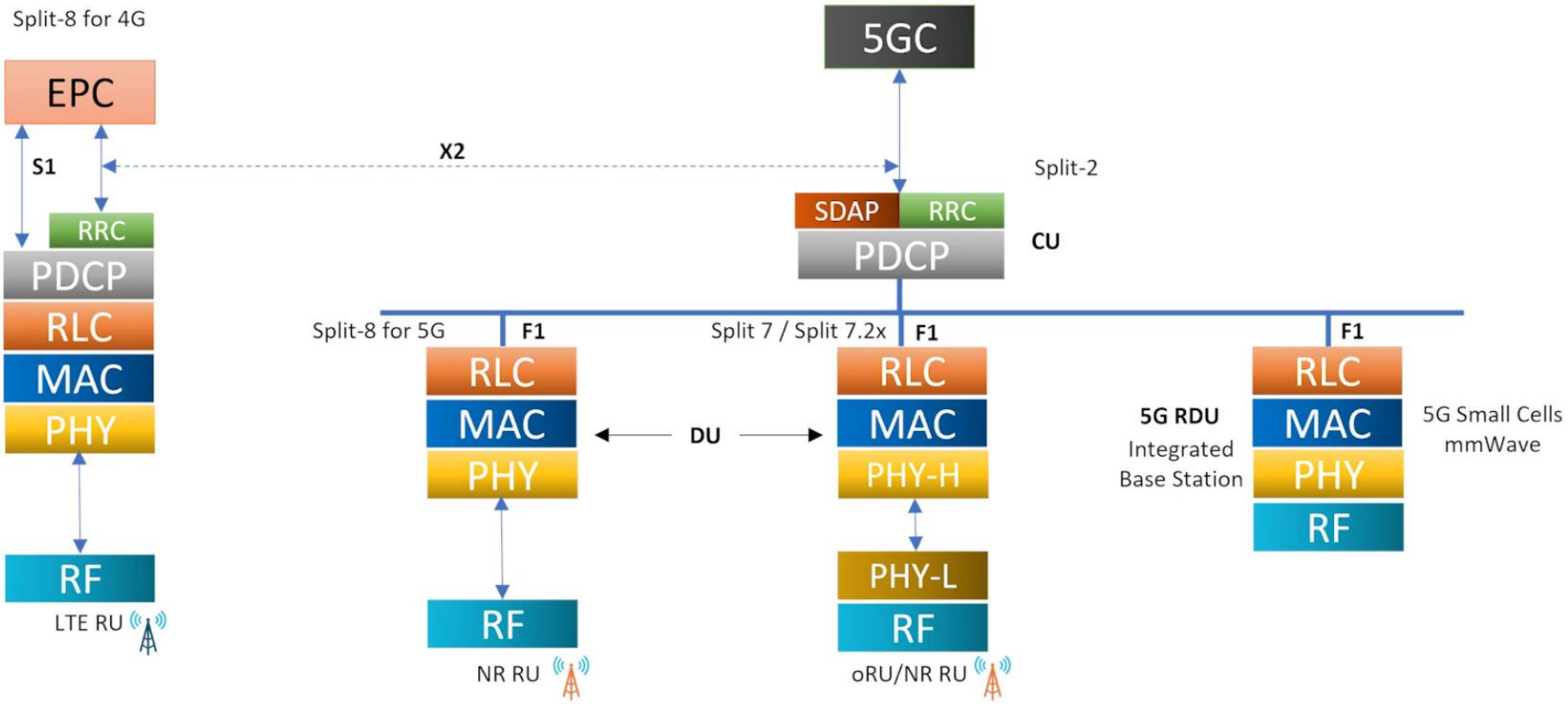

Data (IP Network)
EPC
Core Network
Radio Access Network
eNB
Air Interface
Most Common
Split-8 Implementation
EPC
Backhaul
S1
RRC
PDCP
RLC
MAC
PHY
BBU
RF
RU
UE


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

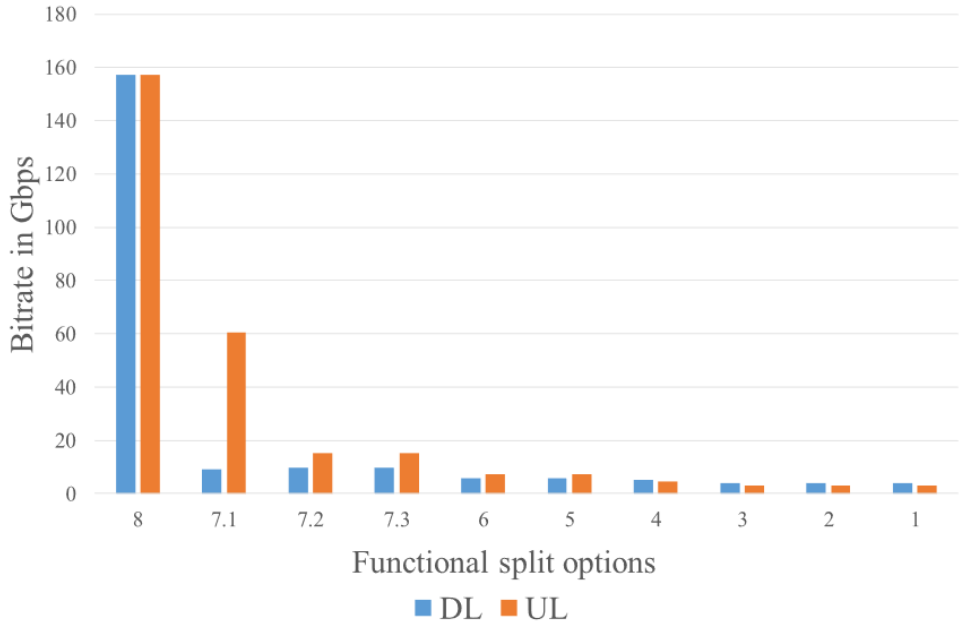

Data (IP Network)
EPC
Core Network
Radio Access Network
eNB
Air Interface
Split-7
EPC
Backhaul
S1
RRC
PDCP
RLC
MAC
Hi-PHY
CU/DU
Fronthaul
Lo-PHY
RF
RU
UE


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

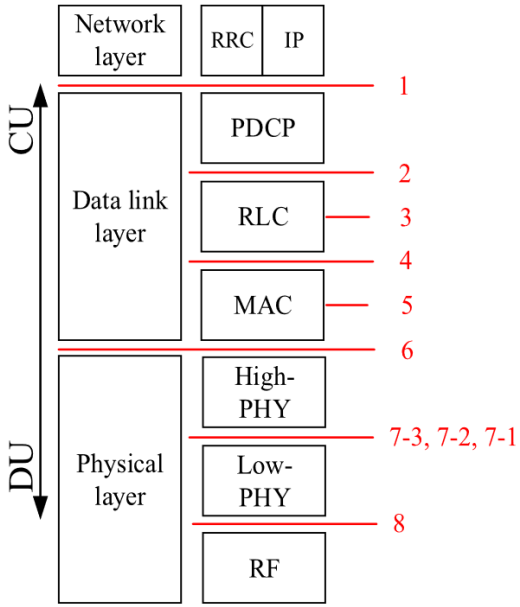
# Functional Split



# Functional Split




M. Agiwal, A. Roy, and N. Saxena, "Next generation 5G wirelessnetworks: A comprehensive survey,"IEEE Commun. Surveys Tuts.,vol. 18, no. 3, pp. 1617–1655, 3rd Quart., 2016.



# Παράδειγμα θεμάτων εξέτασης

**Θέμα 1ο**

Συγκρίνετε τα συστήματα 802.11 (WiFi) και LTE σε σχέση με την παροχή Ποιότητας Υπηρεσίας.

**Θέμα 2ο**

Ποιο (μόνο ένα) θεωρείτε το πιο σημαντικό νέο τεχνολογικό χαρακτηριστικό των δικτύων 5G σε σχέση με τα δίκτυα 4G; Αιτιολογήστε την απάντησή σας (να είστε συγκεκριμένοι).

**Θέμα 3ο**

Μια υπηρεσία πολύ αυστηρών απαιτήσεων καθυστέρησης πρέπει να στηθεί πάνω από δίκτυο 5G (π.χ. εγχείρηση εξ αποστάσεως). Εξηγήστε ποια μέρη του δικτύου (τόσο στο δίκτυο κορμού όσο και πρόσβασης) εμπλέκονται και πως, ώστε να προσφερθεί η συγκεκριμένη υπηρεσία.