Session 7: 5G networks and 3GPP Release 15

ITU Asia-Pacific Centre of Excellence Training
On
"Traffic engineering and advanced wireless network planning"

17-19 October 2018,
Suva, Fiji

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Objectives

Present 5G networks architecture and main technologies (radio interface, cloud and virtualization etc.).

Agenda

I. 5G Concepts and Technologies

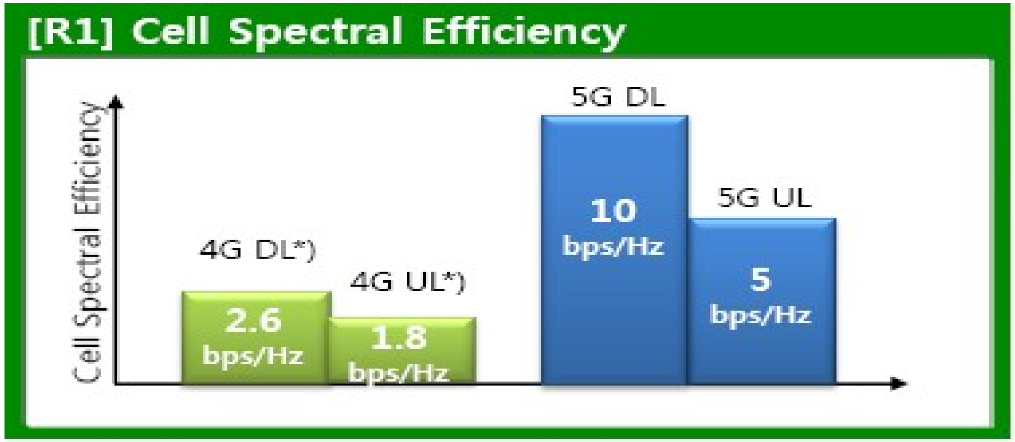
II. 5G Radio Features

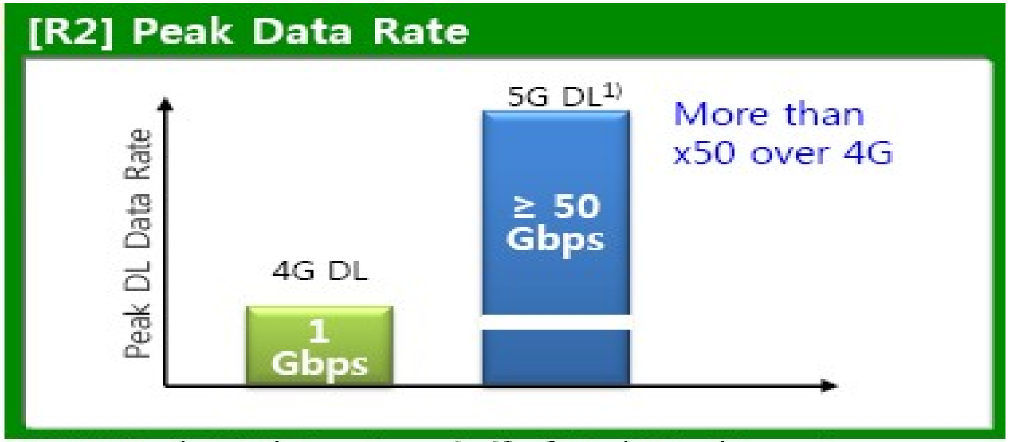
III. 3GPP Release 15

Agenda

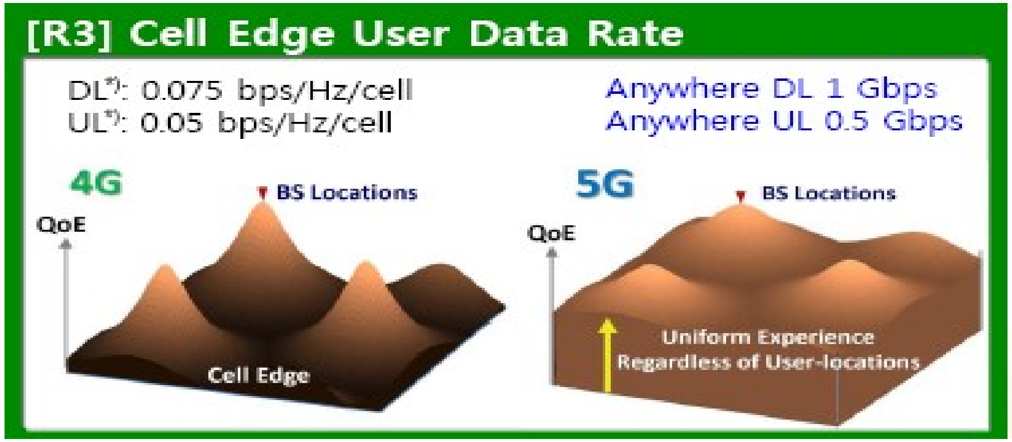
I. 5G Concepts and Technologies

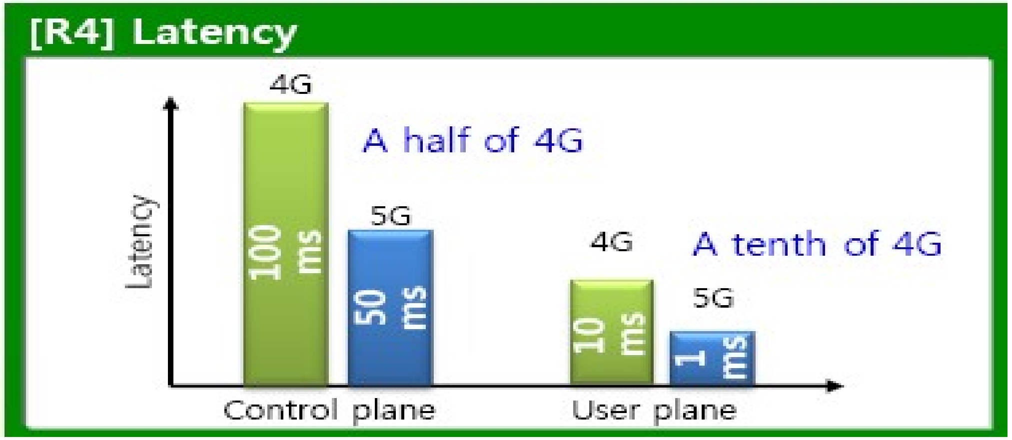
5G versus 4G (1)





1) 5G Peak UL data rate: a half of Peak DL data rate



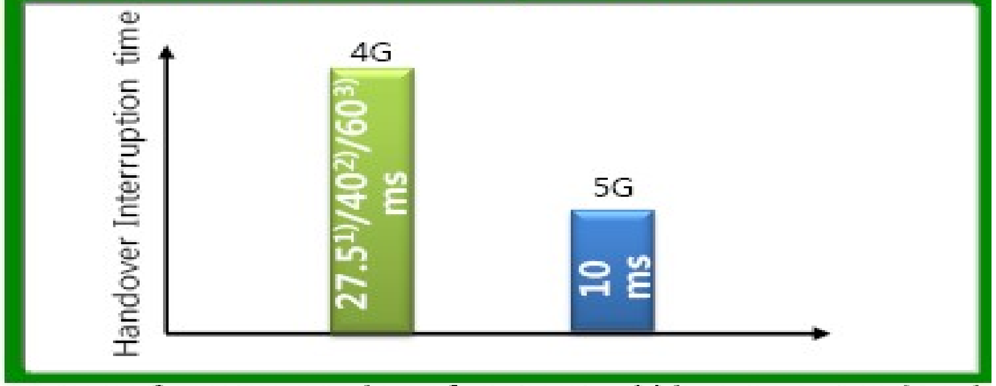


Source: 5G Forum

5G versus 4G (2)

[R5] Mobility

[R6] Handover Interruption Time



1) Intra-frequency, 2) inter-frequency within a spectrum band
3) inter-frequency between spectrum bands

[R7] Areal Capacity

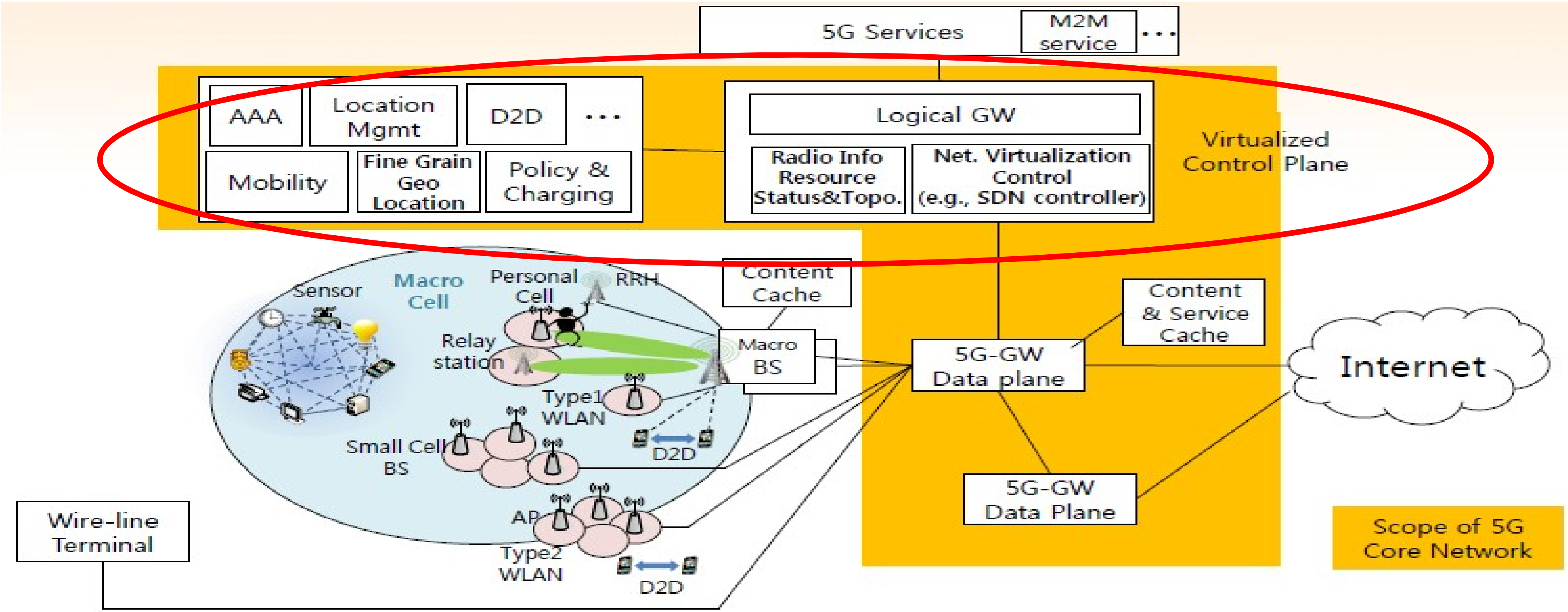
- In order to accommodate the explosive increase of future mobile data traffic, 5G RAN should be able to scale-up system capacity by adding more cells in a target area
- If necessary, a metric value in unit of bps/km^2 may be specified.

[R8] Energy Efficiency

- 5G radio access technology design should aim for higher energy efficiency against increased device/network energy consumption required on 5G wireless communications.
- If necessary, a metric value in unit of J/bit may be specified.

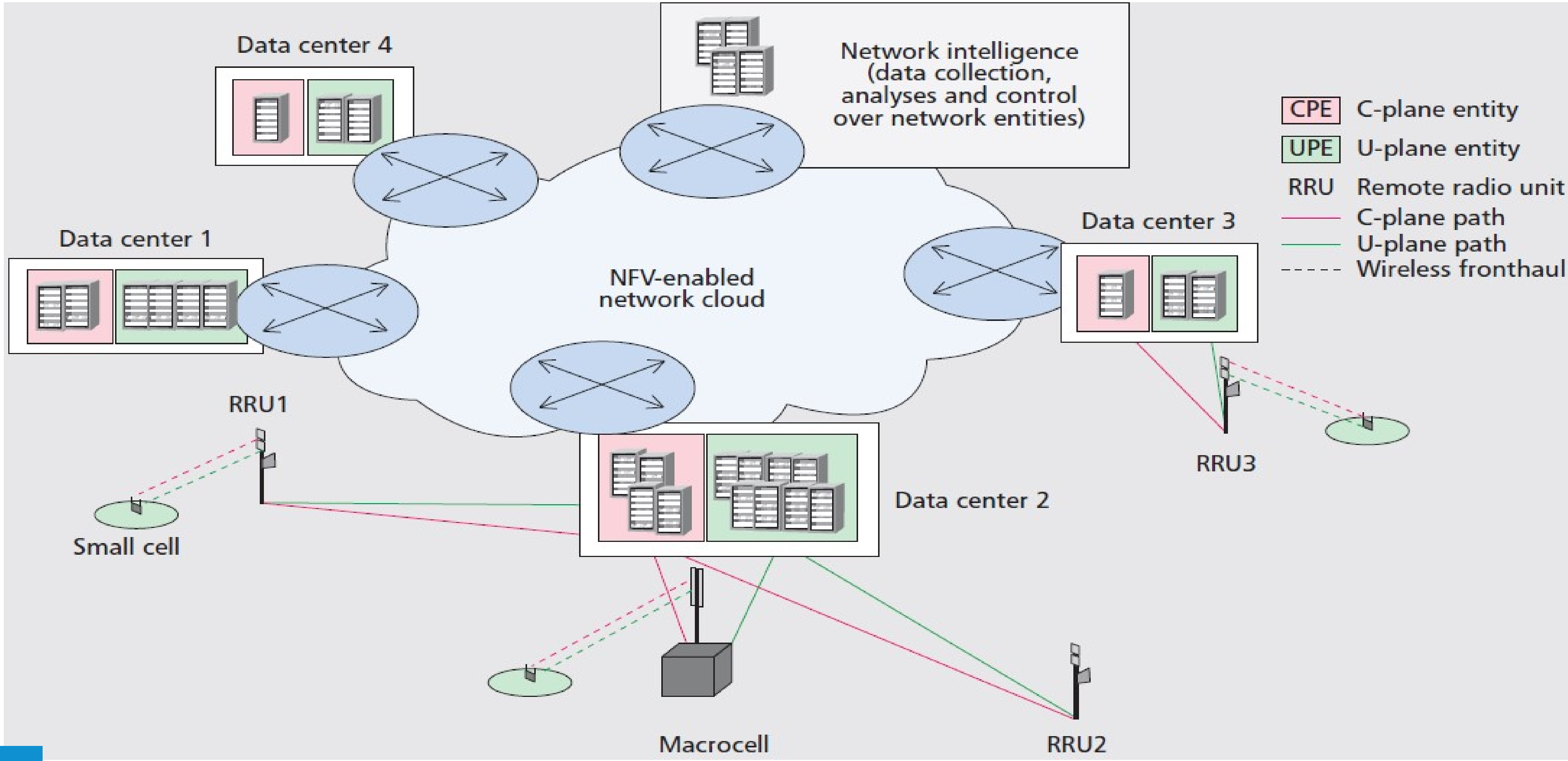
Source: 5G Forum

5G Network Architecture

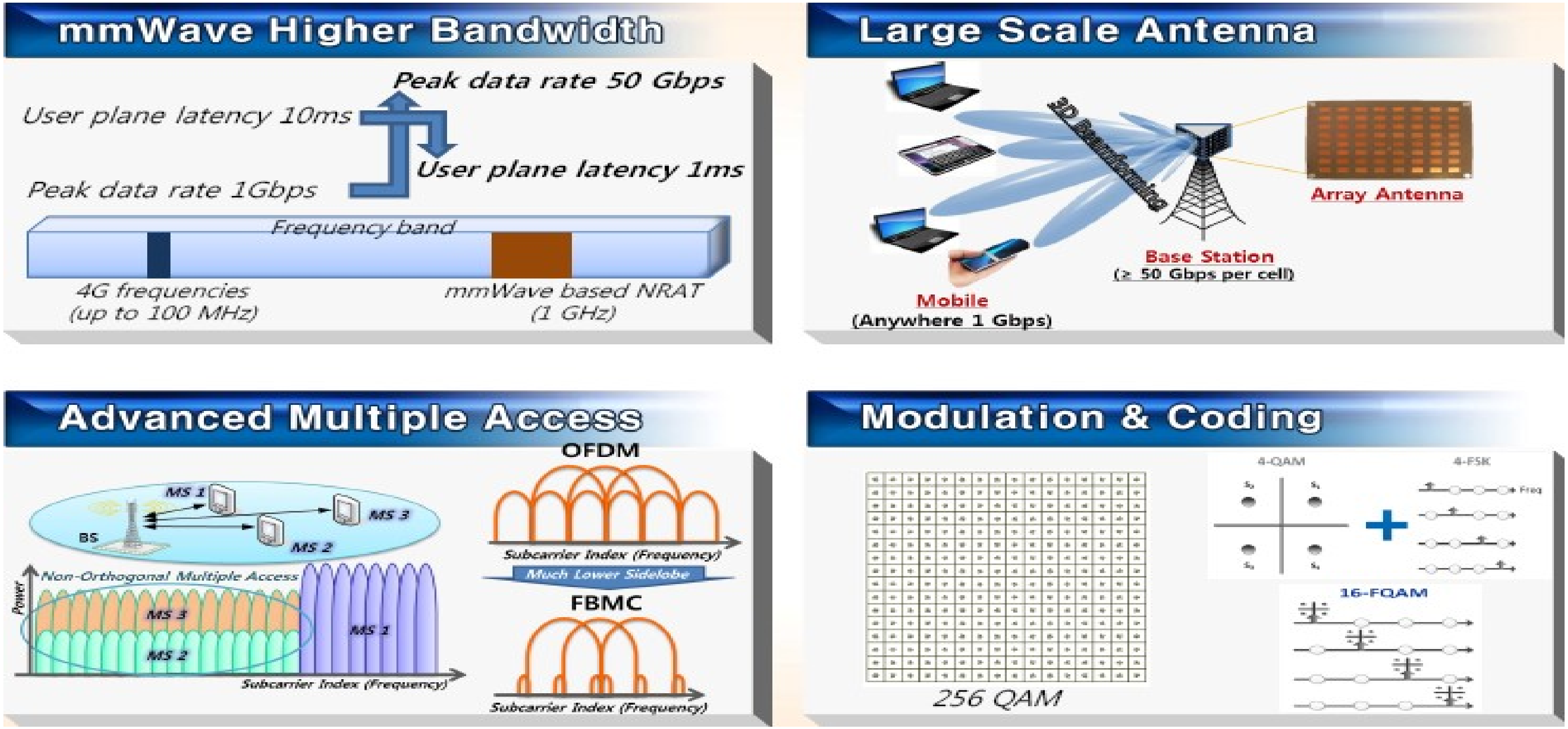


- 5G core network covers both wire-line and wireless accesses
- Control plane is separated from the data plane and implemented in a virtualized environment
- Fully distributed network architecture with single level of hierarchy
- GW to GW interface to support seamless mobility between 5G-GW
- Traffic of the same flow can be delivered over multiple RAT

5G network cloud



5G Enabling Technologies

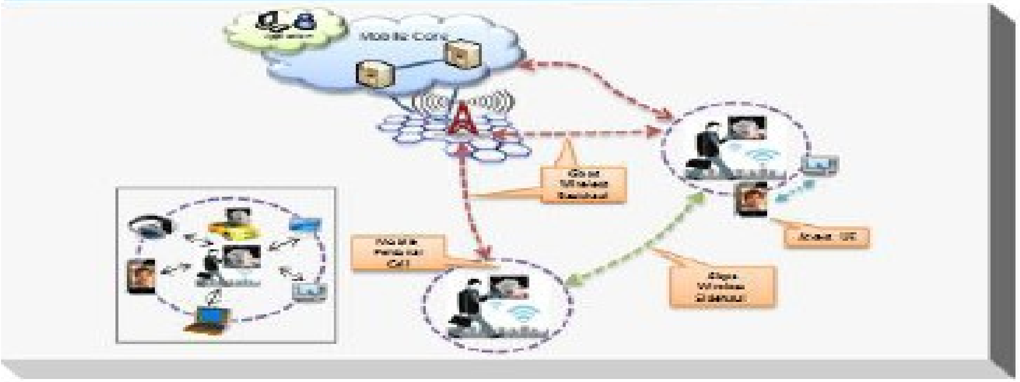


NRAT: New Radio Access Technology, **FBMC**: Filter-Bank Multi-Carrier
FQAM: Frequency, Quadrature Amplitude Modulation

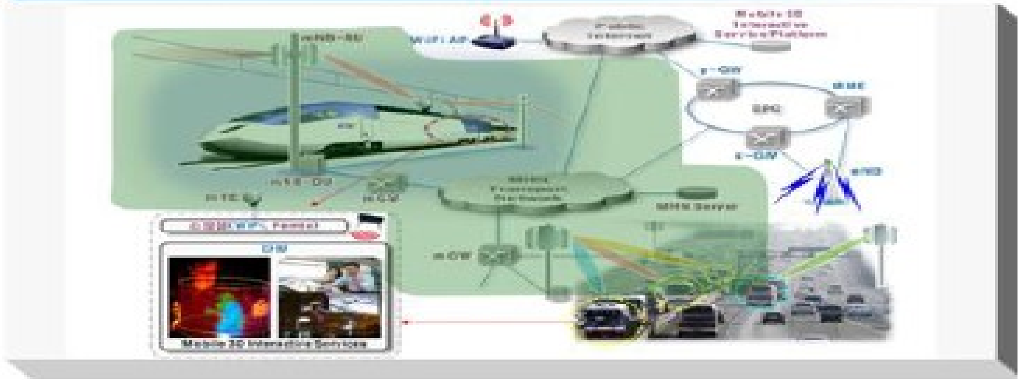
Source: 5G Forum

5G Wireless Network Requirements

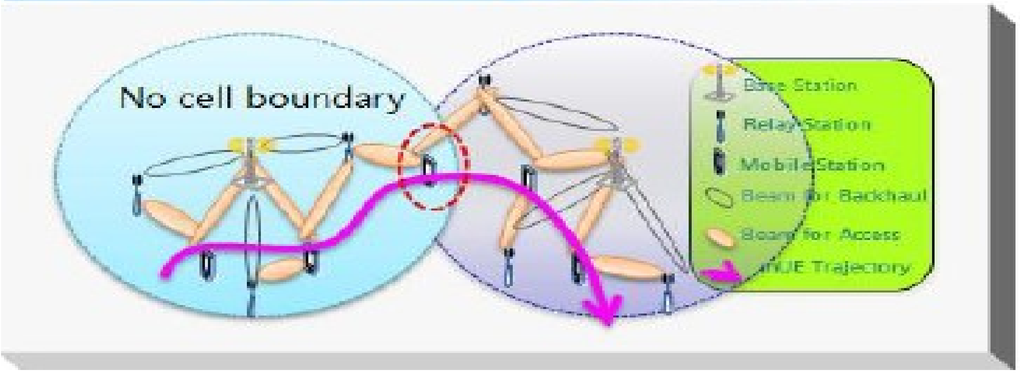
Advanced Small Cell



Moving Backhaul



Fast and Seamless Handover



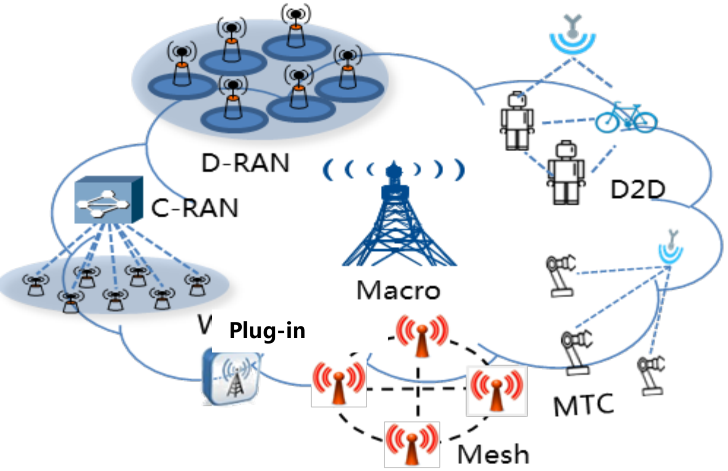
Fully Distributed Network

Source: 5G Forum

5G Network Technology Features

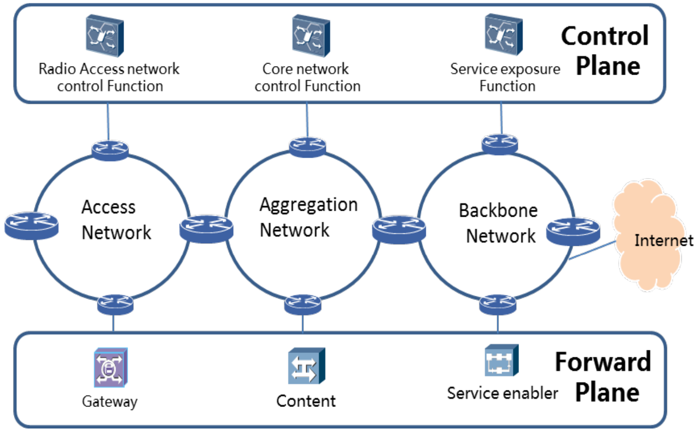
The innovative features of 5G network can be summarized as diversified RAN networking, flexible function deployment, and on-demand slicing.

Diversified RAN networking



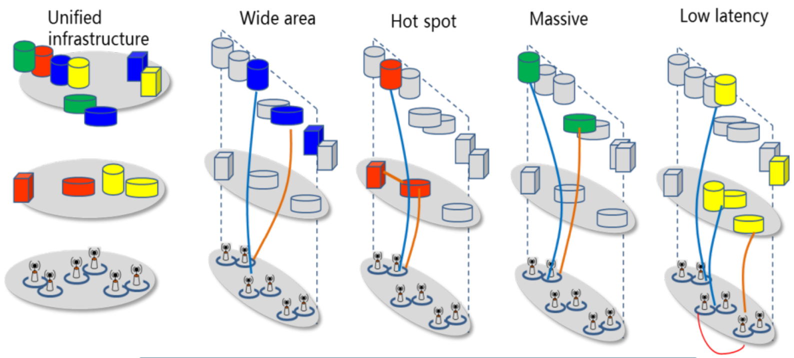
- Support diverse networking mode: C-RAN, D-RAN, mesh,D2D, BS plug-in
- To fit different 5G wireless scenarios

Flexible function deployment



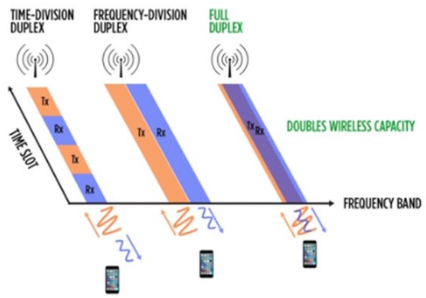
- Modularized Network function
- Network functions can be deployed flexibly based on NFV platform

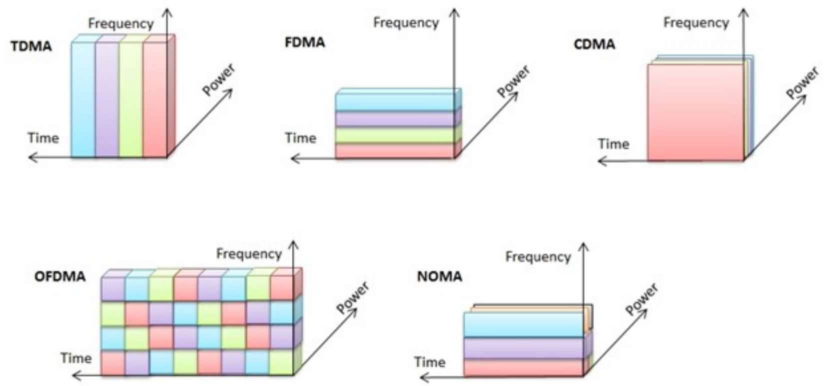
On-demand slicing



- One Logical Architecture, maps to multiple Service Slices.
- Orchestrating network resource on-demand for each slice.
- Isolated slices ensure efficiency, elasticity, security and robustness

Disruptive Technology Directions for 5G





- **Full duplex**
- **NOMA multiplexing**
- **QAM256**
- **Flexible and powerful nodes at the edge:**
  - ➢ Offload the traffic from the core network,
  - ➢ Manage data flows efficiently by dynamically adjusting network resources to insure high QoE for each application flow.
- **Mobile Edge Computing:** More content cached at the edge (reduces core network traffic at BH and reduces latency).
- **Optimized content delivery, Pre-caching of user generated content and Internet content** based on estimated popularity, social trends and used presence and preferences. Better utilize network pipelines based on context information.

Disruptive Technology Directions for 5G

- **Device-centric architectures**: Better routes information flows with different priorities and purposes toward different sets of nodes.
- **Millimeter wave (mmWave)**: mmWave technologies standardized for short-range services and niche applications (small-cell backhaul).
- **Massive MIMO**: very high number of antennas to multiplex messages for several devices on each time-frequency resource, focusing the radiated energy toward the intended directions while minimizing intra and intercell interference.
- **Smarter devices**: 2G-3G-4G cellular networks were built with complete control at the infrastructure side. 5G based on the device intelligence within different layers of the protocol stack (e.g., D2D) or **smart caching** at the mobile side.
- **Native support for M2M and D2D communication**.
- **SDN and NFV**
- **Cloud RAN**

V. 5G Radio Features

- **Multiple access** and advanced waveform technologies combined with coding and modulation algorithms
- **Interference management**
- Authorized Shared Access (**ASA**) or Licensed Shared Access (**LSA**)
- Service delivery architecture
- Mass-scale MIMO
- Single frequency **full duplex** radio technologies
- **Virtualized and cloud-based** radio access infrastructure

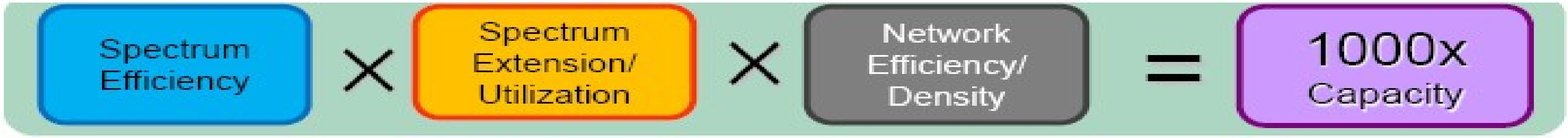
Physical Layer Features to Improve Capacity

Advanced physical layer techniques:

- Higher-order modulation and coding schemes (MCS), such as **256-quadrature amplitude modulation** (QAM),
- **mMIMO**,
- Add some intelligence at the transmitter and receiver to coordinate and **cancel potential interference at the receiver**,
- Introduce new schemes such as **non orthogonal multiple access** (NOMA),
- Filter bank multicarrier (FBMC),
- Sparse coded multiple access (SCMA),
- Advanced power control,
- **Successive interference cancelling** (SIC).

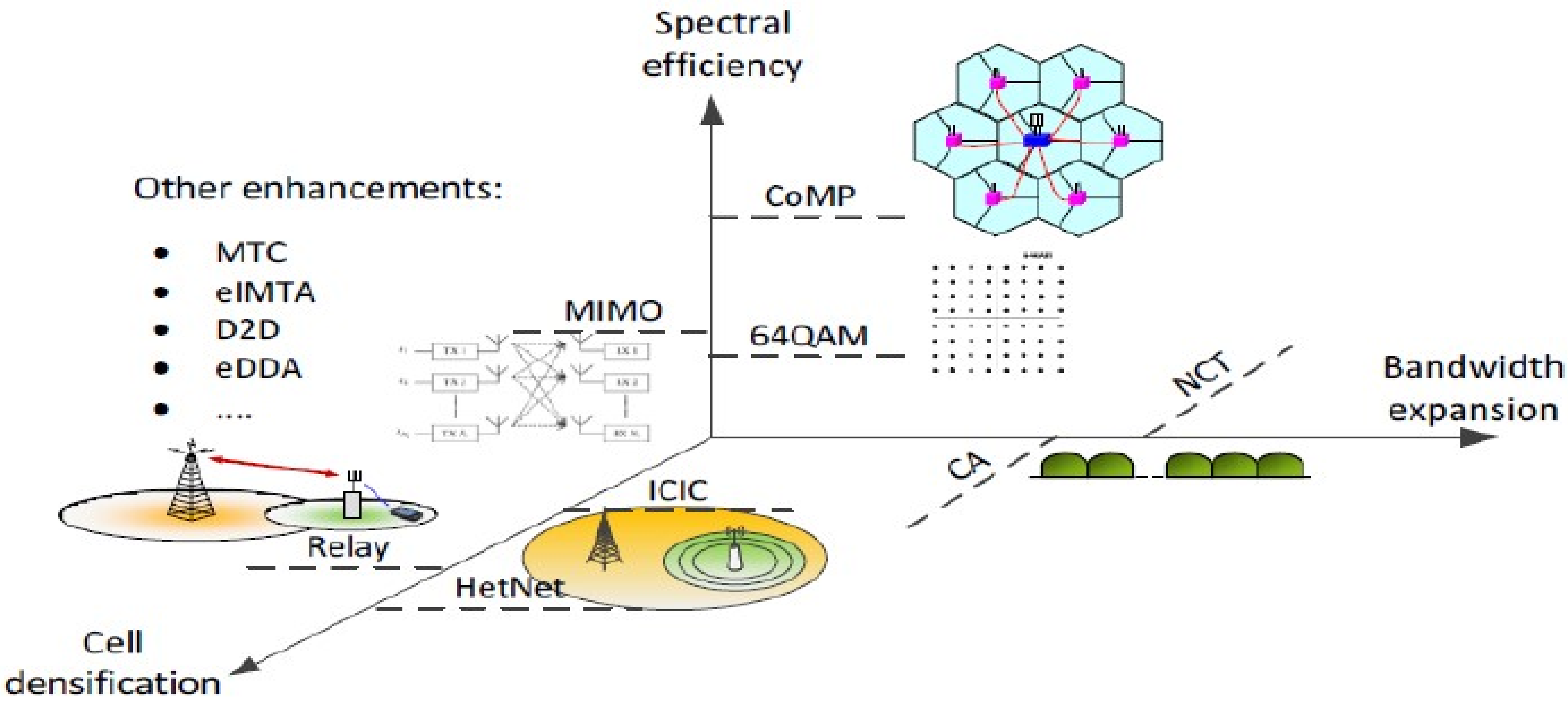
SIC + NOMA can Improve overall throughput in macrocells compared to orthogonal multiple access schemes by up to 30 percent even for high-speed terminals.

3 Dimensions for Capacity Enhancements

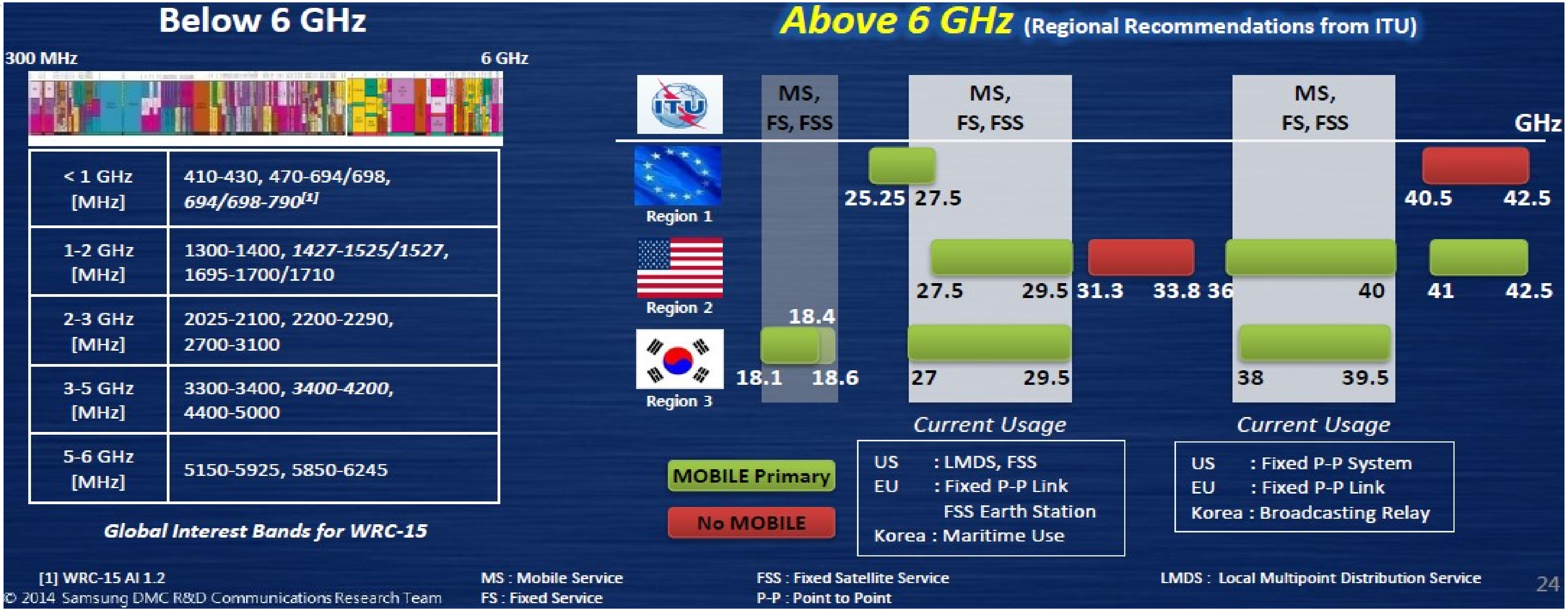


Dimensions	Feasible technologies
Spectrum efficiency	• Interference management and traffic adaptation (IMTA) • Multiple antennas (MIMO) / Massive MIMO / Smart antenna
Spectrum extension	• New Carrier Type (NCT) • Carrier aggregation (CA) • TV white space • Visible Light Communication (VLC) • Cognitive Radio (CR)
Network configuration & optimization	• Small cell deployment (relay / backhaul) • Efficient machine type communication (MTC) • Direct communication (D2D) • Self-organizing network (SON) • Heterogeneous network (HetNet) • Software-defined network (SDN)

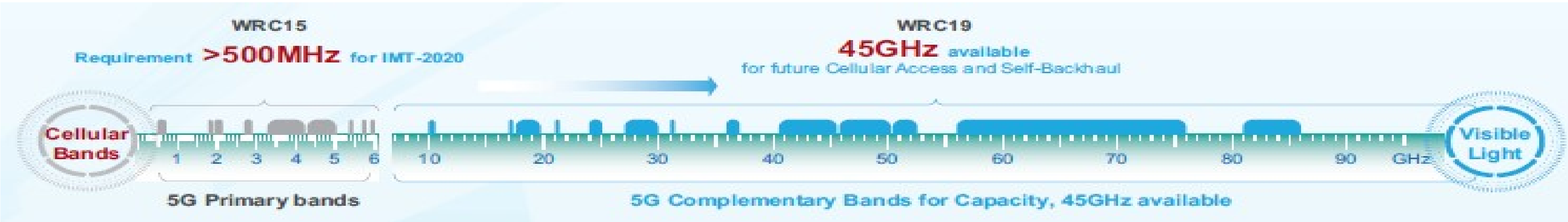
3 Dimensions for Capacity Enhancements



Identified frequency bands



< 1 GHz [MHz]	410-430, 470-694/698, *694/698-790*[1]
1-2 GHz [MHz]	1300-1400, *1427-1525/1527*, 1695-1700/1710
2-3 GHz [MHz]	2025-2100, 2200-2290, 2700-3100
3-5 GHz [MHz]	3300-3400, *3400-4200*, 4400-5000
5-6 GHz [MHz]	5150-5925, 5850-6245

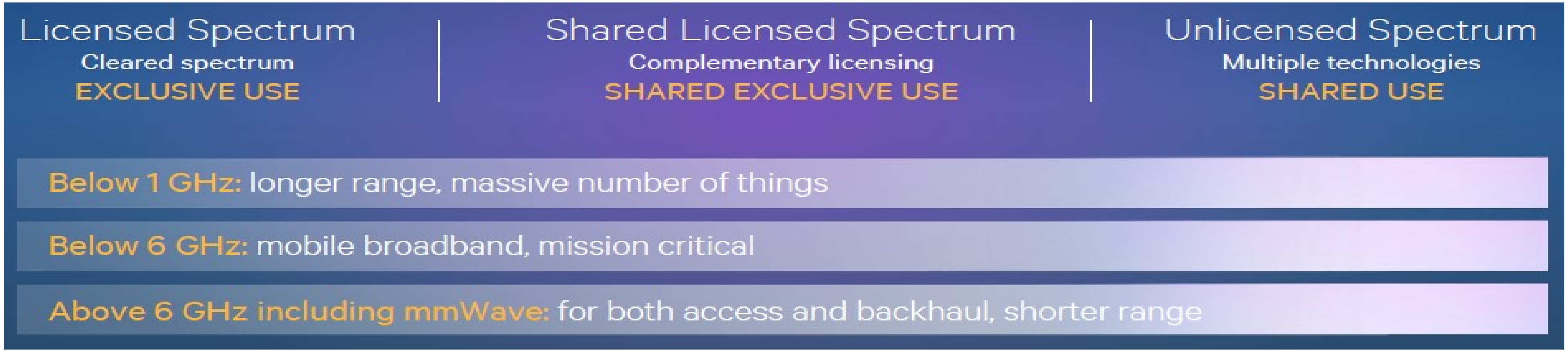


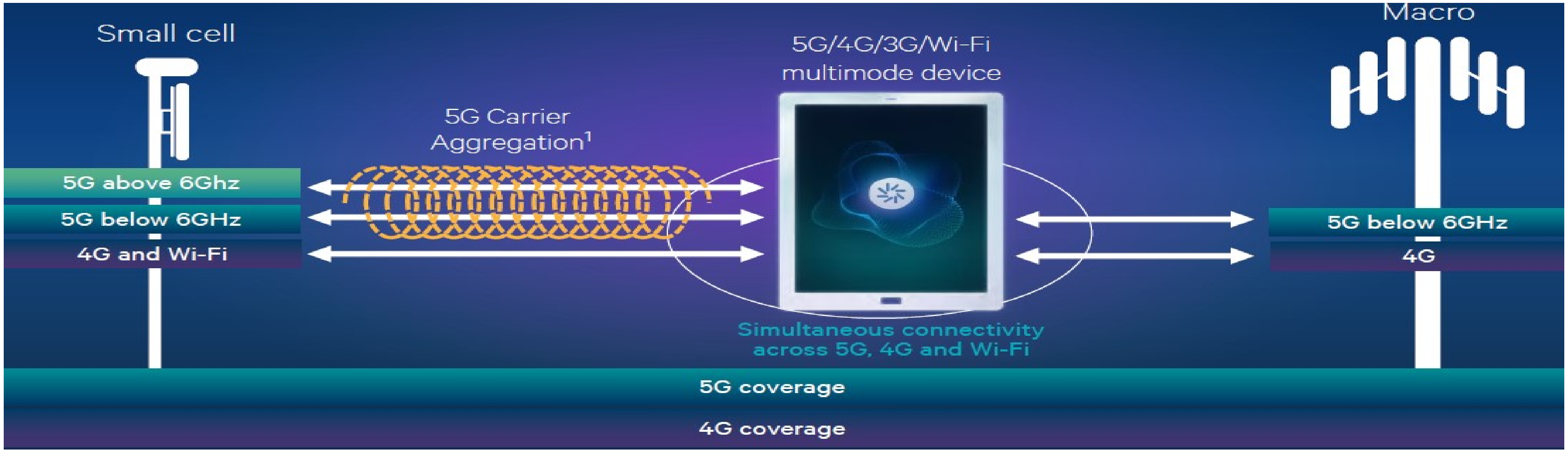
- **3.5 GHz** (16% of total number of trials)
- **26/28 GHz** (19% of total number of trials)

System configuration for LTE-A and 5G systems from 6-100 GHz

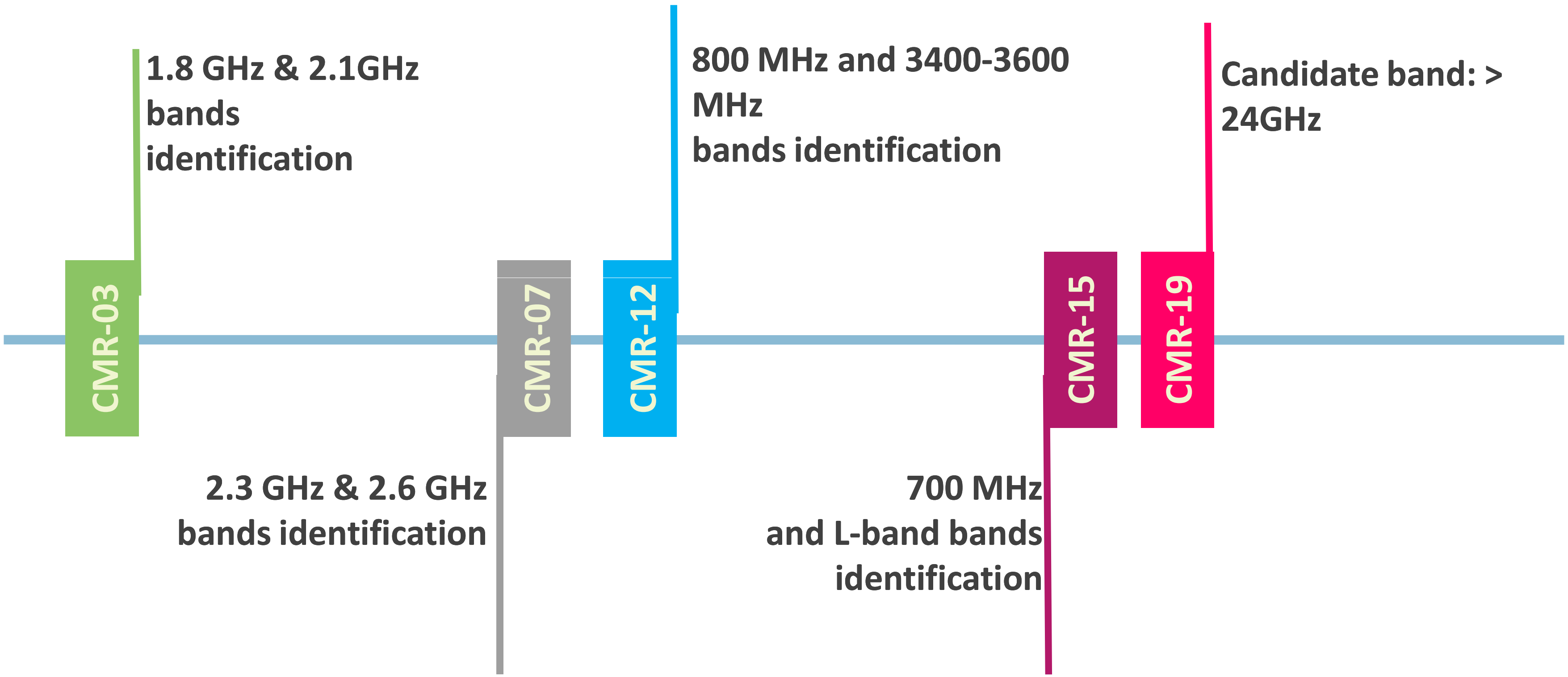
Parameter	LTE-Advanced	cmWave	mmWave
Frequency band	≤6 GHz	6-30 GHz	30-100 GHz
Carrier bandwidth	100 & 200 MHz	500 MHz	2 GHz
Modulation order	64 QAM	256 QAM	64 QAM
MIMO combination	8x8	8x8	2x2
SU-MIMO rank	8	8	2
MU-MIMO rank	2	2	2
Antenna configuration	10x1 AAS 8 antenna ports MIMO (macro)	Omni directional 4 antenna ports	4x4 AAS 4 sectors 2 antenna ports

Unified 5G design across spectrum types and bands





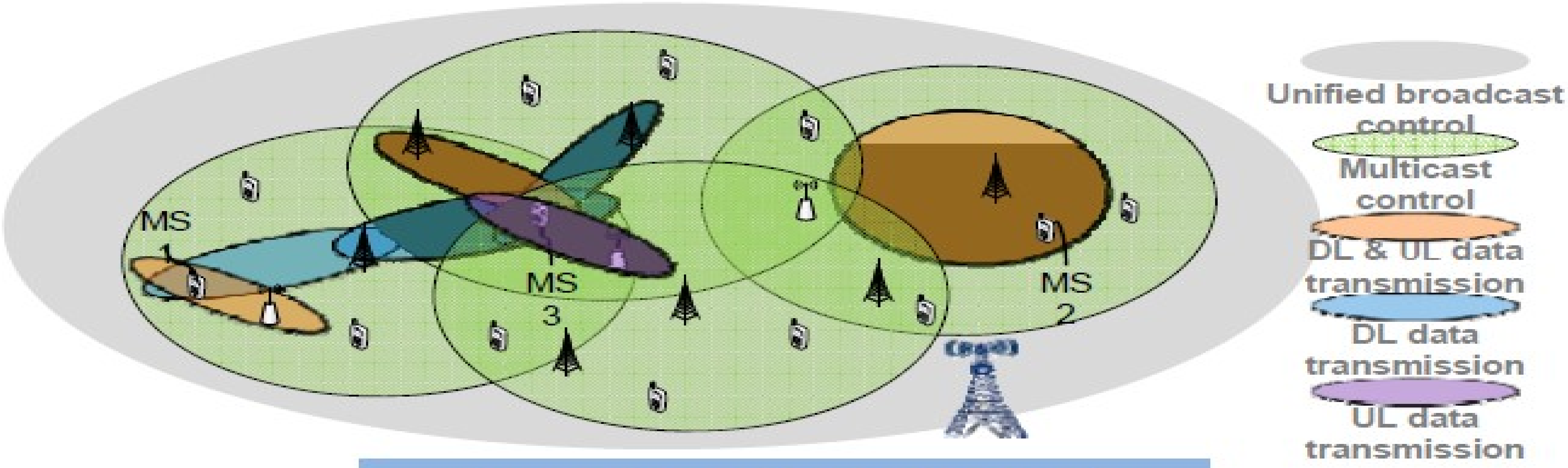
IMT Spectrum – Deadlines



3D beamforming and cell concept change

3D Beamforming

Cell concept changes

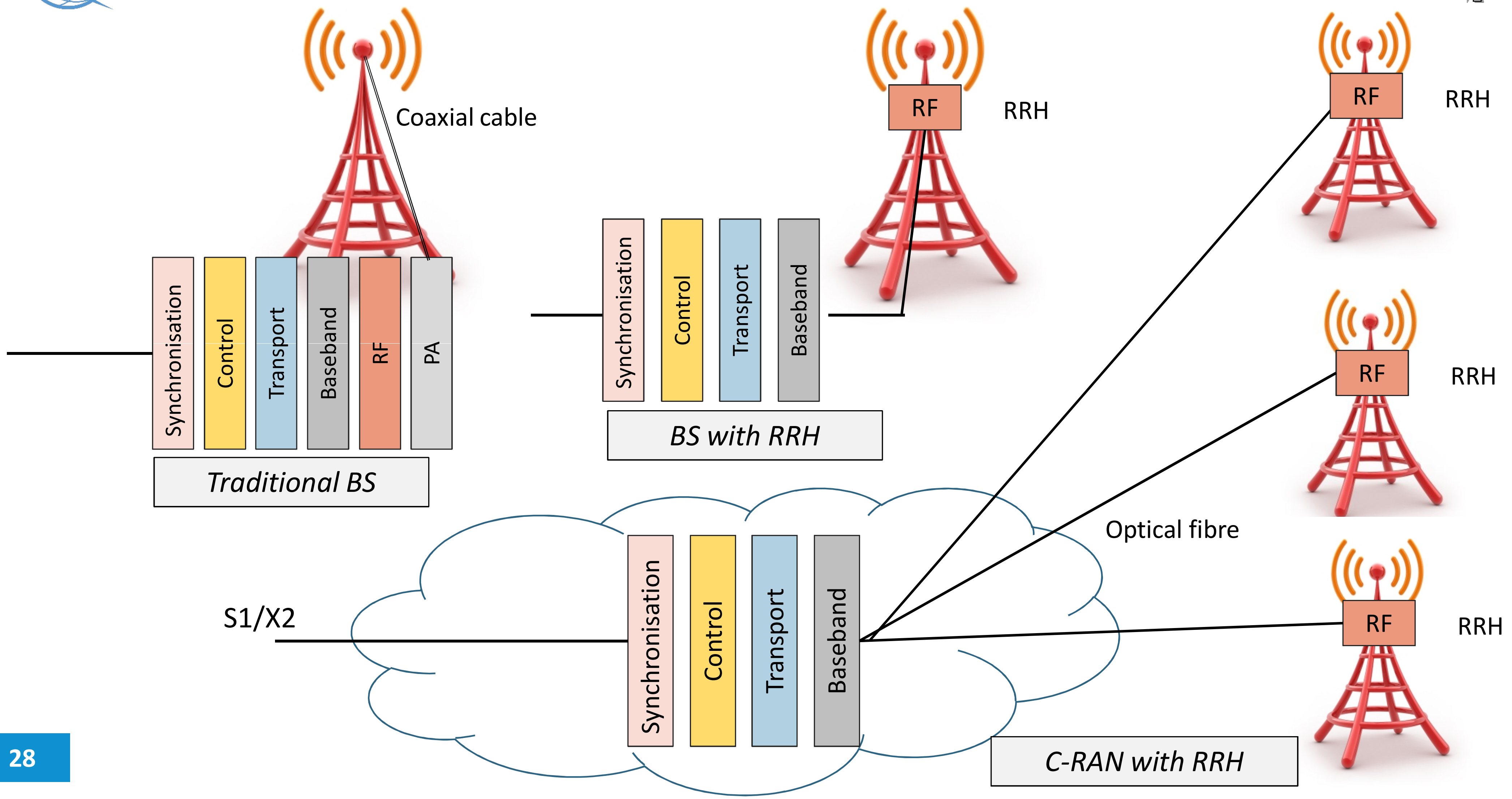


Amorphous Cells Concept

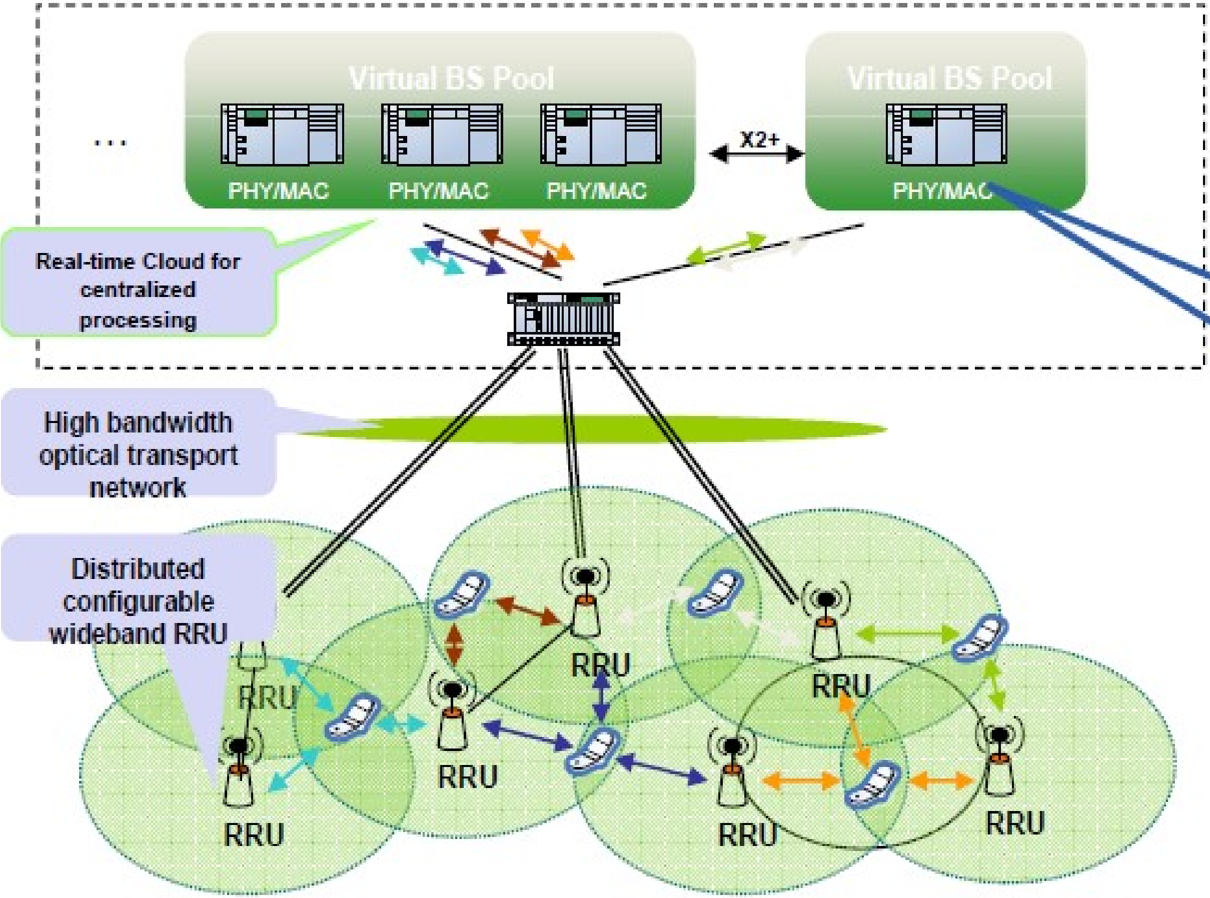
- Multiple layers
- Signaling & Data Decoupling
- DL&UL Decoupling

Cloud RAN

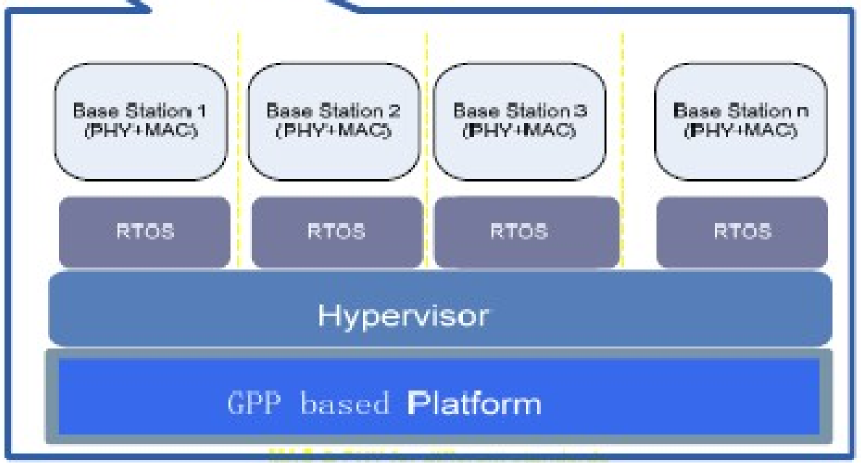
BS architecture evolution



C-RAN



- Common platform, software based solution
- Live (soft) computation resource transition
- Inherent cooperation



BS virtualization

C-RAN allows significant savings in OPEX and CAPEX.
Ex. China Telecom: 53% savings in OPEX and 30% in CAPEX.

C-RAN

C-RAN = Separation of the radio elements (**RRH**) of the BS from the elements processing the BB signal (**BBU**).

BBUs: main RAB intelligence aggregated and **centralized** in a single location of **virtualized** into the cloud (BBU pools) in the operator controlled premises.

➪***Simpler radio equipment*** at the network edge, ***easier operation*** and ***cheaper maintenance***.

➪RRHs ***deployment cost decreases*** considerably (installation footprint is much smaller).

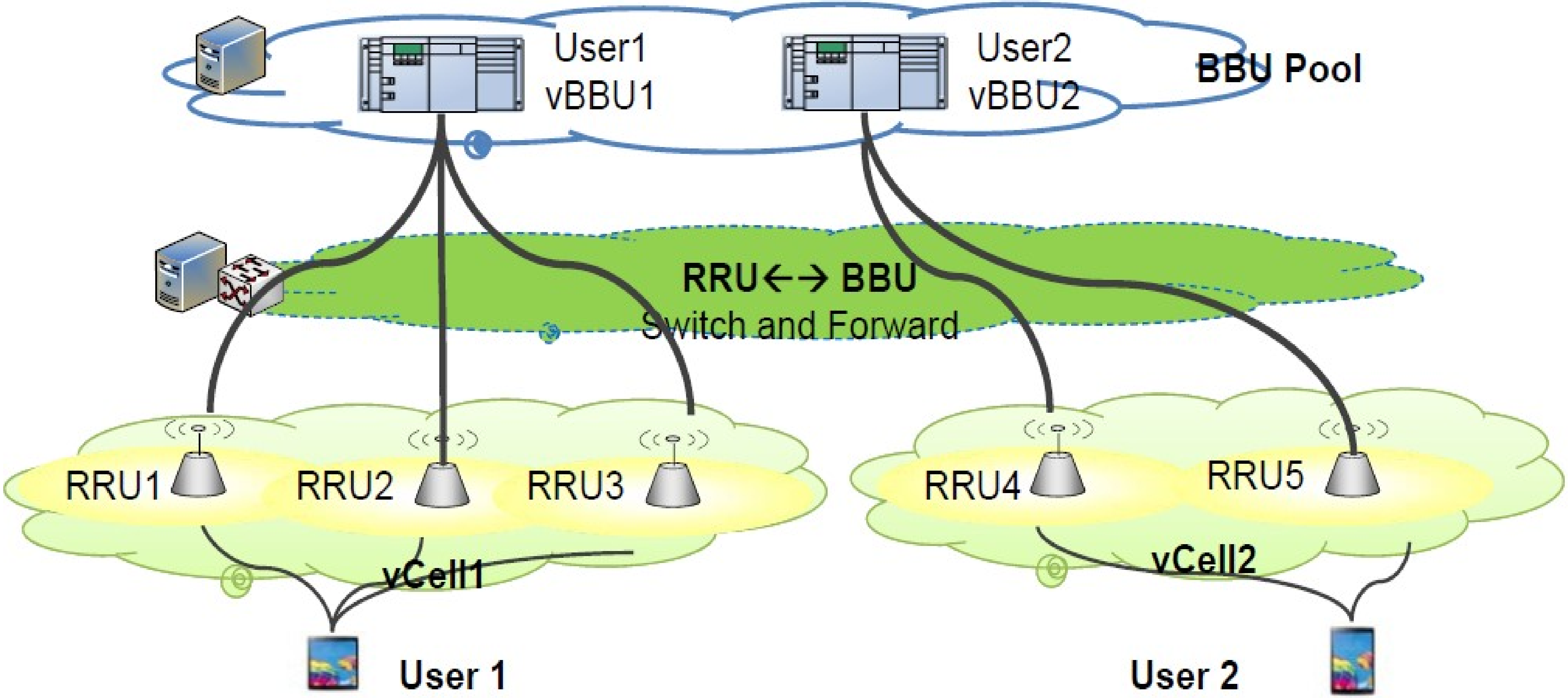
➪***No refrigeration*** and ***no costly on-site construction*** for RRHs.

➪BBUs ***shared*** and ***turned off*** when necessary reducing the cost of maintaining the network with *low loads*.

➪C-RAN enables the use of ***cooperative radio techniques***, CoMP, allowing interference reduction between different radio transmissions. Enables denser RRH deployments as interference among BSs is better mitigated.

C-RAN **challenges**: BBU and RRH must be connected through a high-speed, low-latency and accurately synchronized network (the fronthaul).

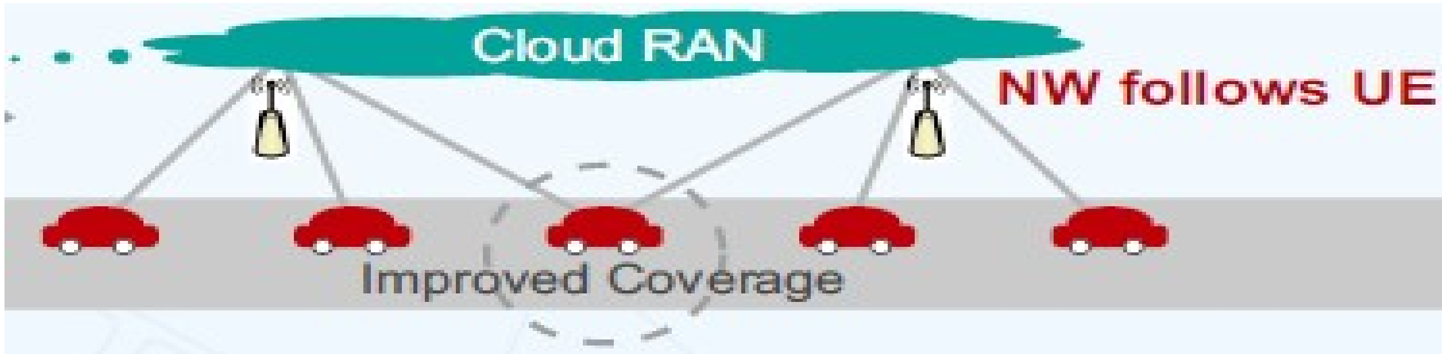
User-centric cells



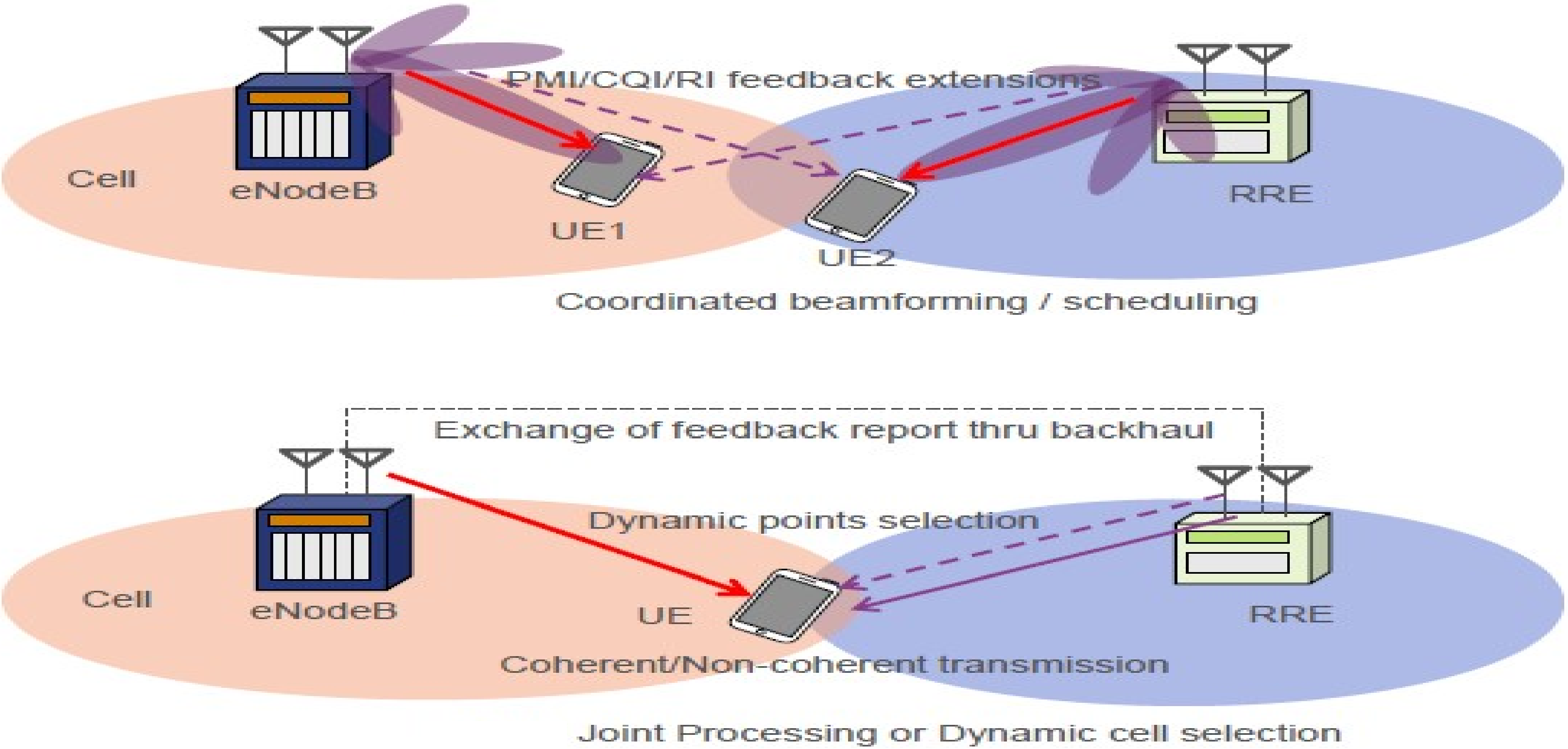
Elimination of cell boundaries

- *Classical networks*: devices associate with a cell.

- *5G = virtualized device centric network*: access point(s) associated with the device. The cell **moves** with and always surrounds the device.



Enhanced ComP mechanism



VII. Architecture Features

5G Network Technology Architecture

Driven by requirements and new IT technologies, 5G network can be re-constructed into three-planes based architecture.

Requirements driven

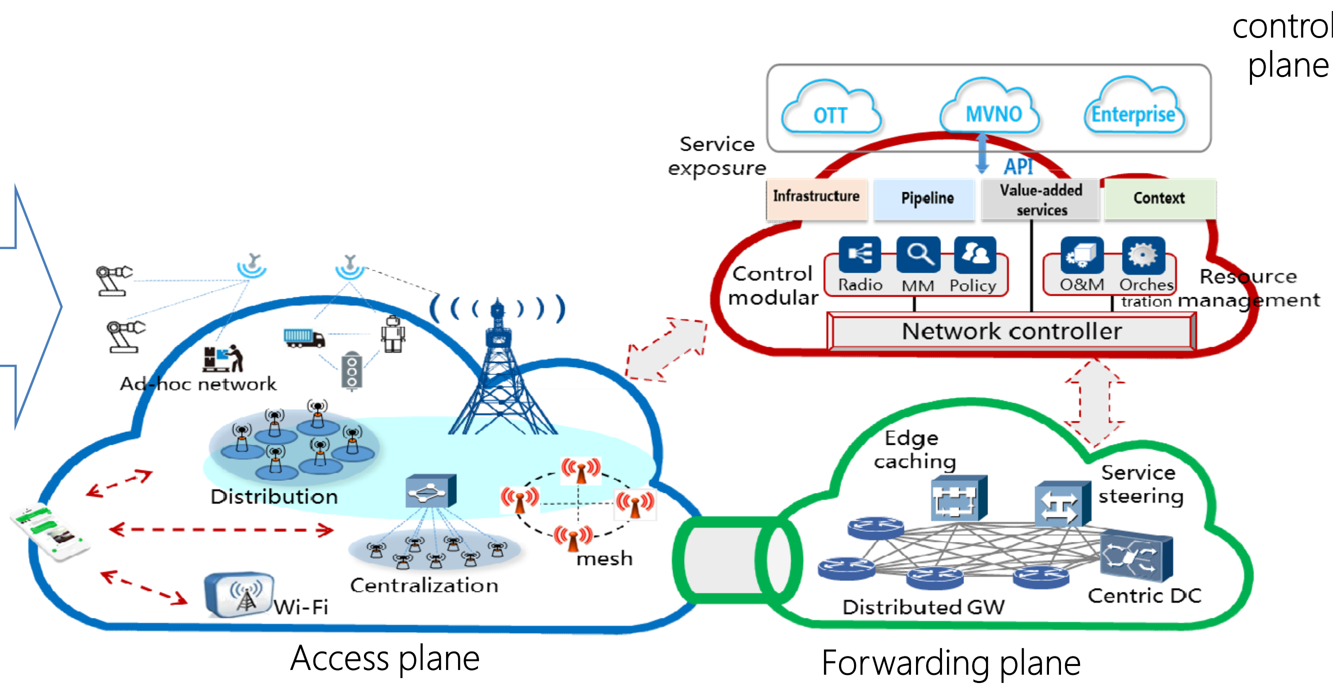
- 5G scenarios and KPI
- Operation enhancement
- Smooth evolution consideration

Technologies driven

NFV
separation of software and hardware，provide flexible infrastructure platform

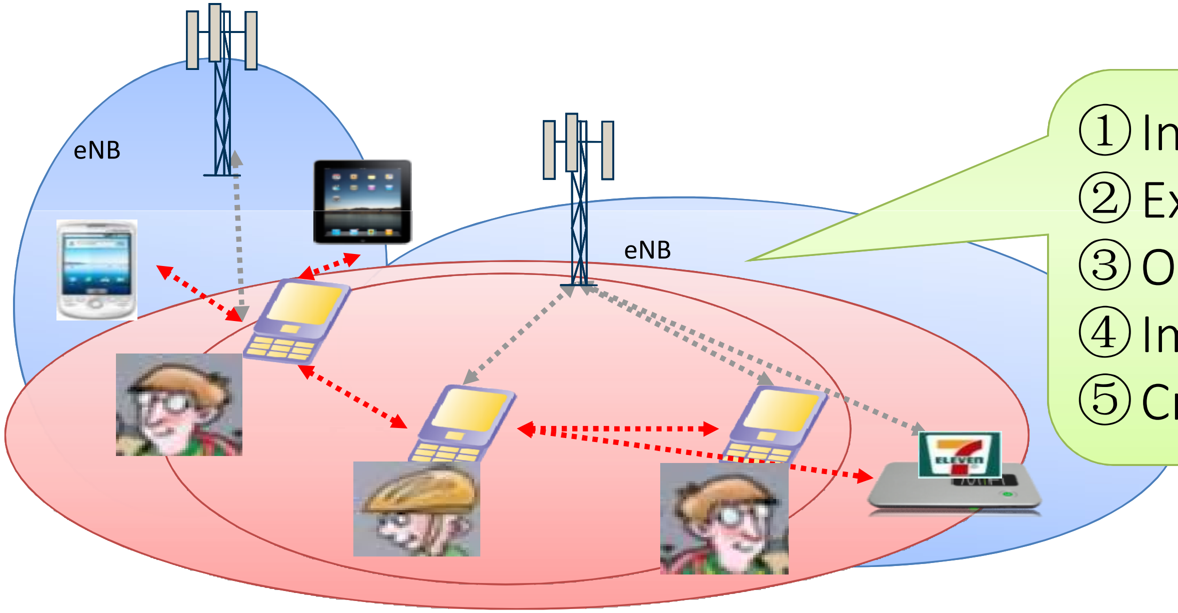
SDN
separation of control function and forwarding function ，impact on architecture design

Three-planes based 5G network architecture



Device-to-Device (D2D) Communications

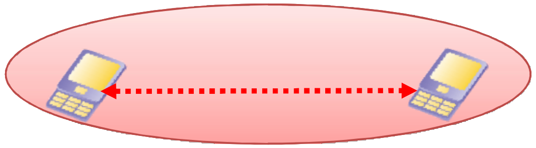
Enable devices to communicate directly without an infrastructure of access points or base stations.

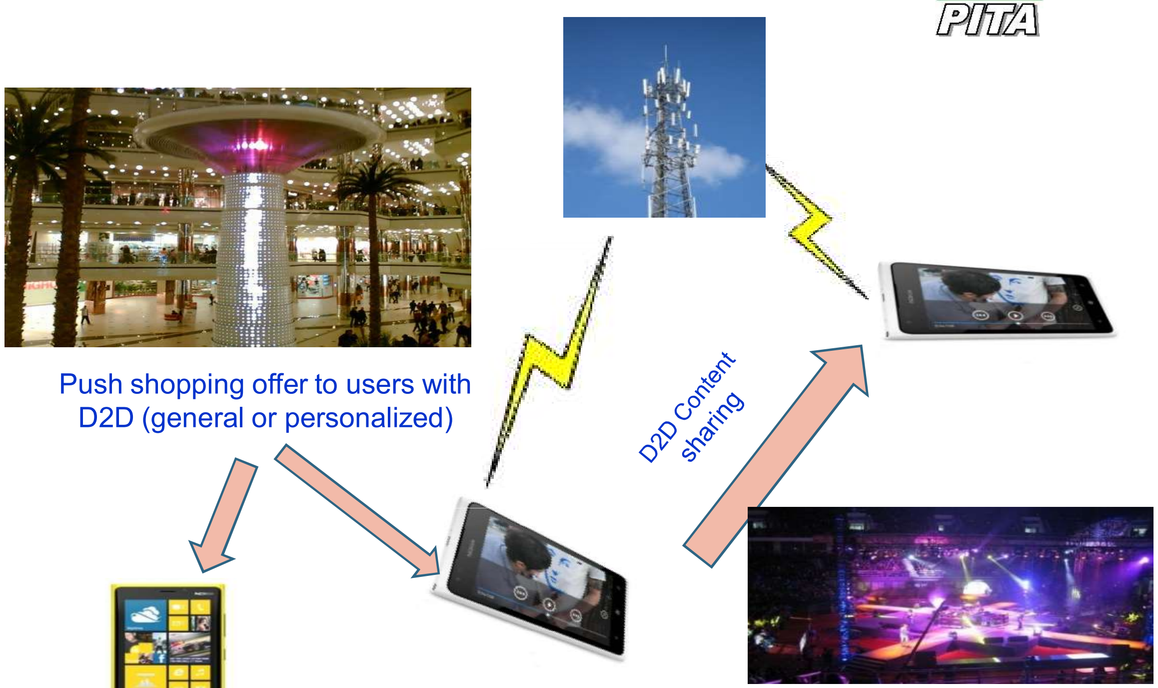


① Increase network capacity
② Extend coverage
③ Offload data
④ Improve energy efficiency
⑤ Create new applications

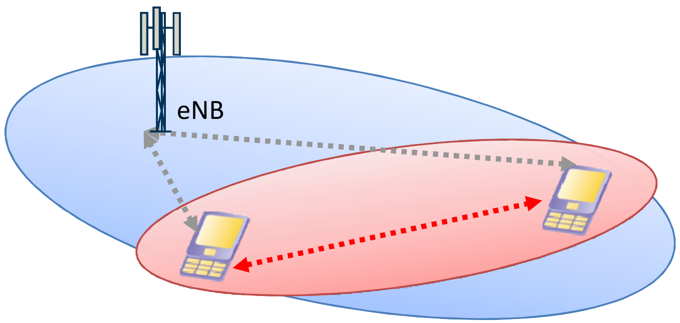
Device-to-Device Communications

- **Peer-to-peer Communications**

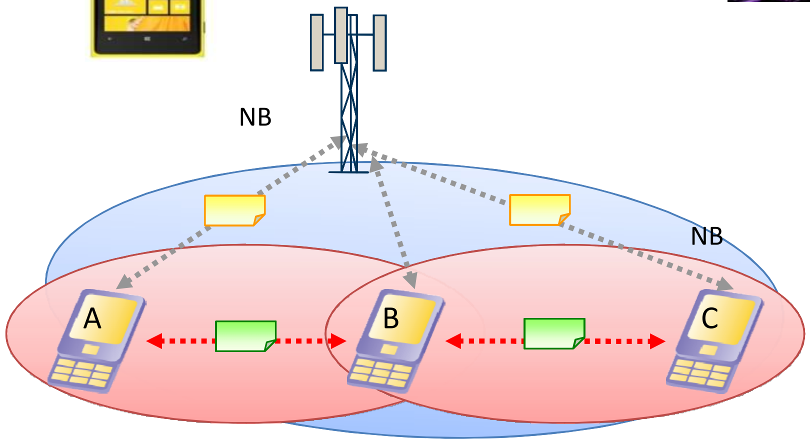




- **Cooperative Communications**
  - Cooperative Mobile as Relay
  - Cooperative Diversity



- **Wireless Network Coding**



Network slicing

Allows differentiated treatment depending on each customer requirements. Mobile Network Operators (MNO) can consider customers as belonging to different tenant types with each having different service requirements that govern in terms of what slice types each tenant is eligible to use based on SLA and subscriptions

RAN awareness of slices: supports a differentiated handling of traffic for different pre-configured network slices.

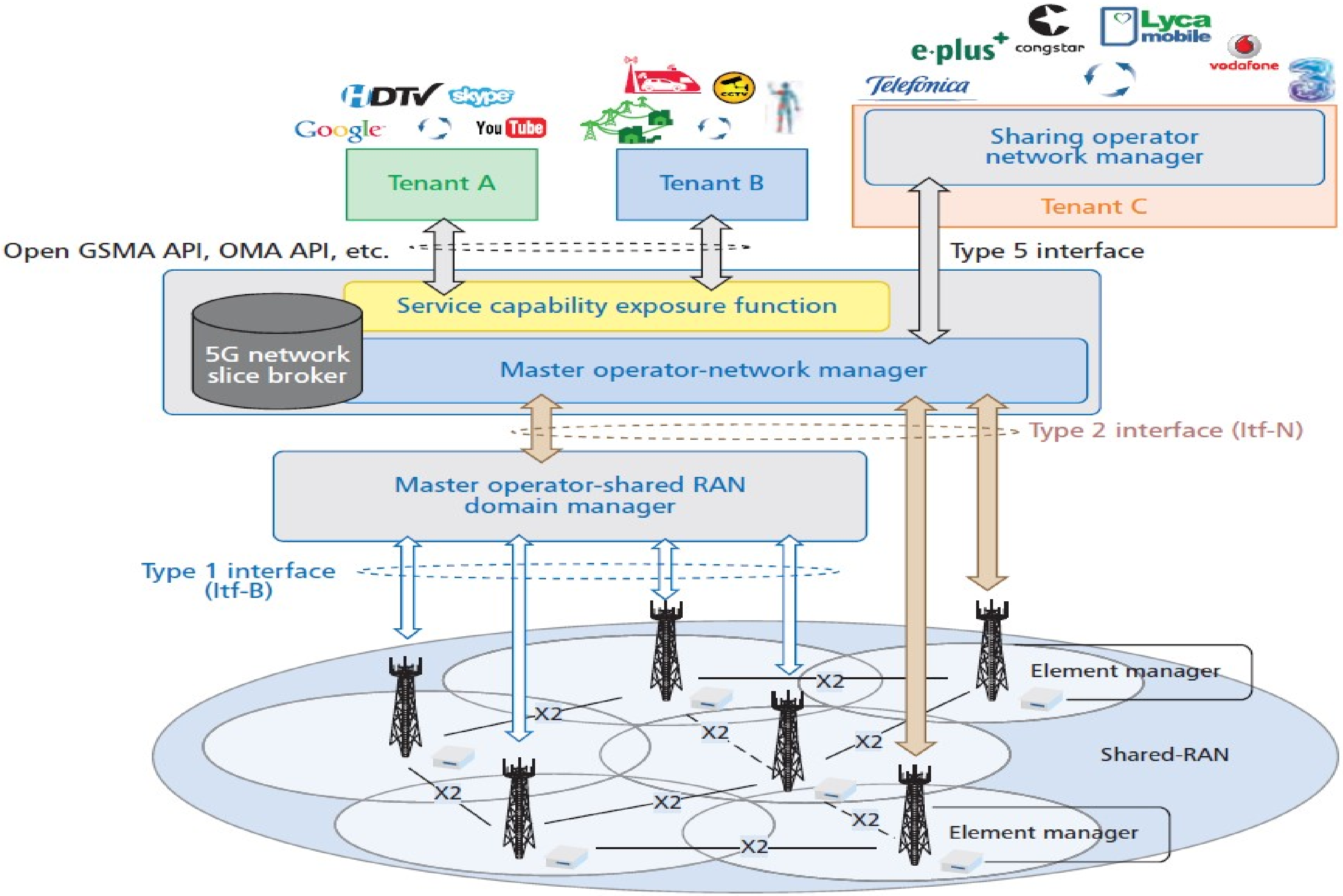
Selection of RAN part of the network slice: RAN shall support the selection of the RAN part of the network slice, by one or more slice ID(s) provided by the UE or the CN which unambiguously identifies one or more of the pre-configured network slices in the PLMN.

Resource management between slices: a single RAN node can support multiple slices. The RAN can apply the best RRM policy for the SLA in place to each supported slice.

Support of QoS

Resource isolation between slices: May be achieved by means of RRM policies and protection mechanisms to avoid that shortage of shared resources in one slice breaks the SLA for another slice. It is possible to fully dedicate RAN resources to a certain slice.

5G Network Slice Broker

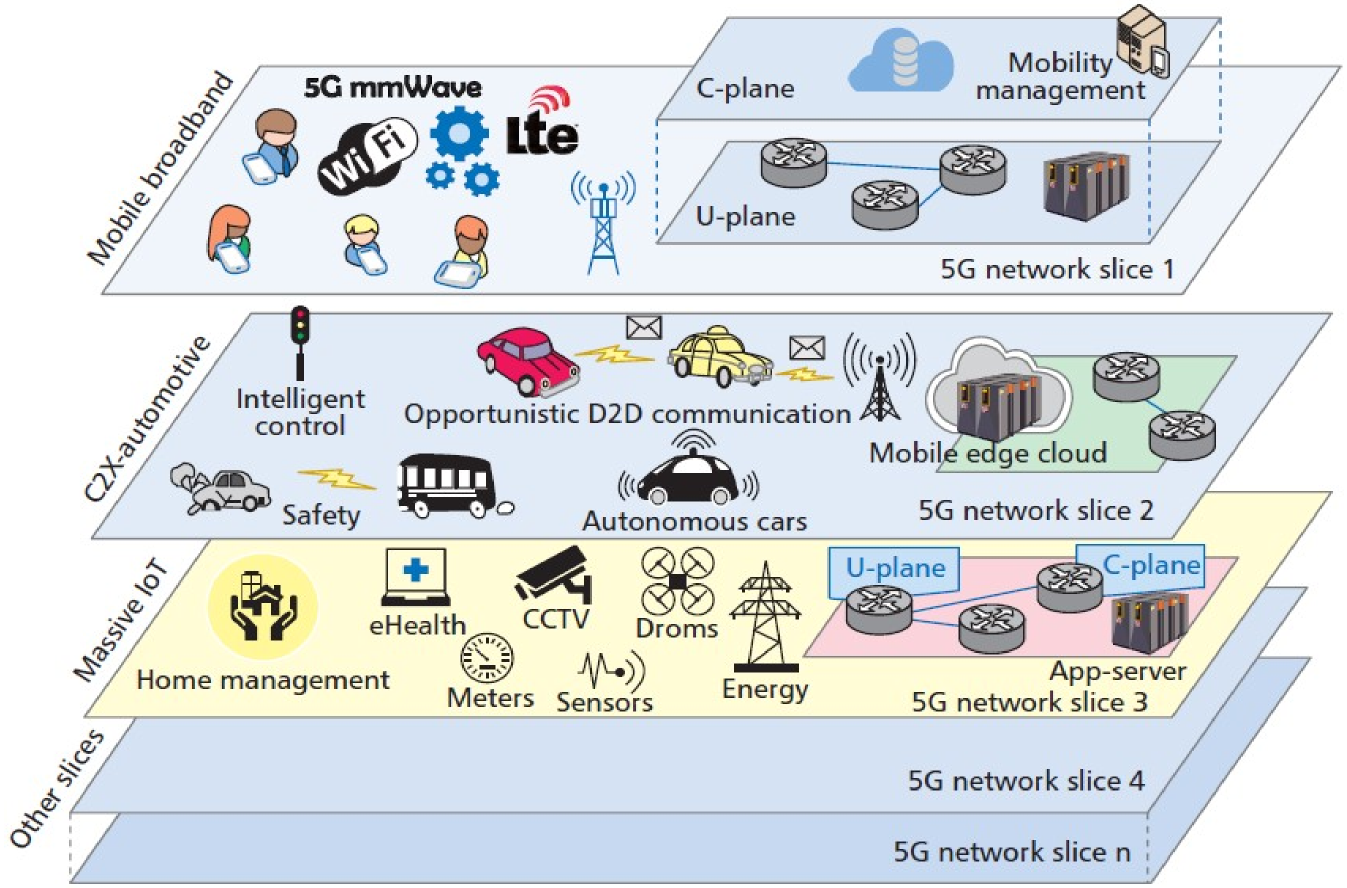


Management architecture (*Release 14*)

5G network slices structure

In composing and allocating network slicing:

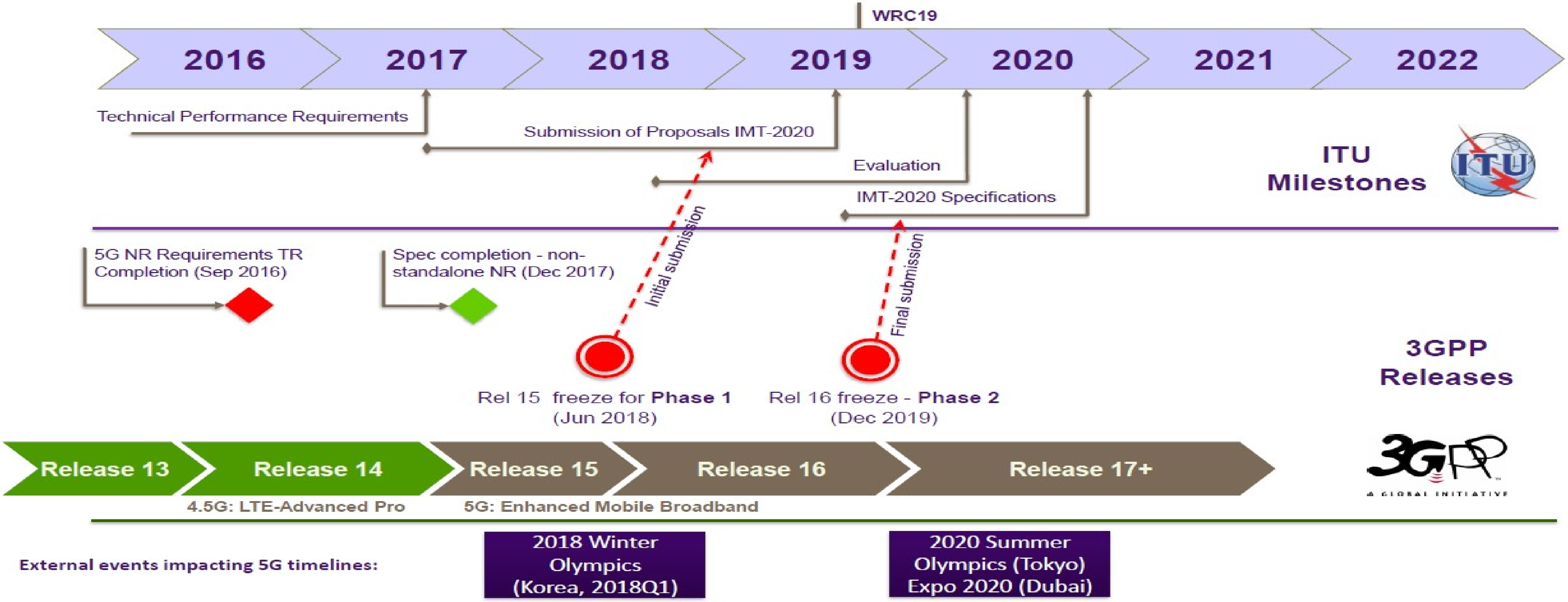
- **Software defined control and separation of control/data plane**: Network programming via SDN APPs
- **Network function virtualization**: (De)compose/allocate VNFs
- **Flexible service chaining and service provision**
- **Edge cloud services closer to the user**
- **QoS provision policy**
- **Selection of RAT / fix access**



Agenda

IV. 3GPP Release 15

5G Timelines: ITU-R and 3GPP



5G New Radio (NR) specifications in Release 15

- Scope:

➢ **Standalone** (full control plane and data plane functions are provided in NR) and **Non-Standalone NR** (control plane functions of LTE and LTE-A are utilized as an anchor for NR) Operations

➢ **Spectrum Below and Above 6 GHz**

➢ **Enhanced Mobile Broadband** (eMBB: supports high capacity and high mobility (up to 500 km/h) radio access (with 4 ms user plane latency)

➢ **Ultra-Reliable and Low Latency Communications** (URLCC): provides urgent and reliable data exchange (with 0.5 ms user plane latency).

➢ **Massive Machine-Type Communications** (mMTC): infrequent, massive, and small packet transmissions for **mMTC** (with 10 s latency).

Preliminary 5G (NR) KPIs

Item	Value
Peak data rate	20 Gbps for downlink, 10 Gbps for uplink
Peak spectral efficiency	30bps/Hz for downlink and 15bps/Hz for uplink
Bandwidth	Up to 1 GHz (DL+UL). Pending ITU-R
Control plane latency	10ms
User plane latency	URLLC: 0.5ms for DL and 0.5ms for UL, eMBB: 4ms for DL and 4ms for UL
Latency for infrequent small packets	No worse than 10 ms
Mobility interruption time	0ms
Inter-system mobility	At least with LTE/LTE evolution (other systems TDB)
Reliability	99.999% for URLLC and eV2X
Coverage	UL link budget will provide at least the same MCL as LTE
UE battery life for mMTC	>10 years requirement, 15 years desirable
Cell/Cell edge spectral efficiency	3x spectral efficiency of IMT-Advanced
Connection density	1000000 device/km2 in urban environment
Mobility	500 km/h

3GPP TR 38.913 (Draft 2016-09)

5G 3GPP terminology

- **eLTE eNB:** The eLTE eNB is the evolution of eNB that supports connectivity to EPC and NGC.
- **gNB:** A node which supports the NR as well as connectivity to NGC.
- **New RAN:** A Radio Access Network which supports either NR or E-UTRA or both, interfacing with the NGC.
- **New Radio:** A new radio access technology .
- **Network Slice:** A Network Slice is a network created by the operator customized to provide an optimized solution for a specific market scenario.
- **Network Function:** A Network Function is a logical node within a network infrastructure that has well-defined external interfaces and well-defined functional behaviour.
- **NG-C:** A control plane interface used on the NG2 reference points between New RAN and NGC.
- **NG-U:** A user plane interface used on the NG3 reference points between New RAN and NGC.
- **Non-standalone NR**: A deployment configuration where the gNB requires an LTE eNB as anchor for control plane connectivity to EPC, or an eLTE eNB as anchor for control plane connectivity to NGC.
- **Non-standalone E-UTRA**: A deployment configuration where the eLTE eNB requires a gNB as anchor for control plane connectivity to NGC.
- **User Plane Gateway**: Termination point of the NG-U interface.

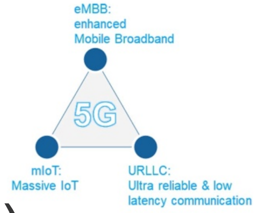
5G Phase One (Release 15)

- Ability to operate in **any frequency band**, including low, mid, and high bands.
- Network can support both LTE and 5G NR, including **dual connectivity** with which devices have simultaneous connections to LTE and NR.
- A system architecture that enables user services with **different access systems**, such as WLAN.
- 5 Gbps peak downlink throughput in initial releases, increasing to **50 Gbps** in subsequent versions.
- **OFDMA in downlink and uplink**, with optional Single Carrier Frequency Division Multiple Access (SC-FDMA) for uplink. Radio approach for URLLC to be defined in Release 16, but Release 15 will provide physical layer frame structure and numerology support.
- **Massive MIMO** and **beamforming**. Data, control and broadcast channels are all beamformed.
- Ability to support either **FDD** or **TDD** modes for 5G radio bands.
- Numerologies of **2N X 15 kHz** for subcarrier spacing up to **120 kHz or 240 kHz**. Phase 1 likely to support a maximum of **400 MHz bandwidth with 240 kHz subcarrier spacing**.
- Carrier aggregation for up to **16 NR carriers**.
- Aggregation up to approximately **1 GHz of bandwidth**.

5G Phase One (Release 15)

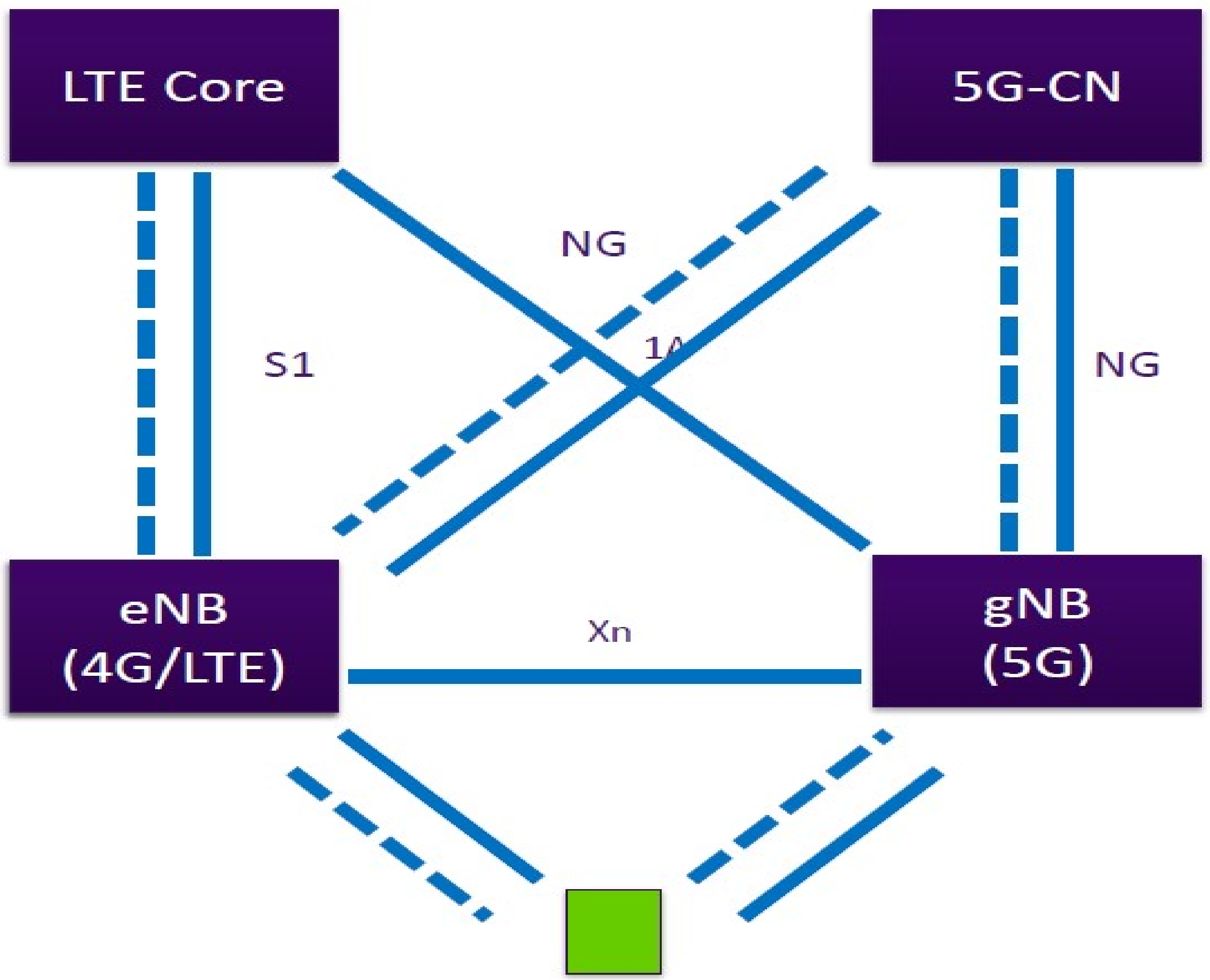
- Error correction through **low-density parity codes** (LDPC) for data transmission, which are computationally more efficient than LTE turbo codes at higher data rates. Control channels use **polar codes**.
- Standards-based **cloud RAN** support that specifies a split between the PDCP and Radio Link Control (RLC) protocol layers.
- Self-contained integrated subframes (slots) that combine scheduling, data, and acknowledgement. Benefits include fast and flexible TDD switching, lower latency, and efficient massive MIMO.
- Future-proofing by providing a flexible radio framework that has forward compatibility to support future, currently unknown services, such as URLLC to be specified in Release 16 and unlicensed/shared spectrum.
- **Scalable transmission time intervals** with short time intervals for low latency and longer time intervals for higher spectral efficiency.
- QoS support using a new model.
- **Dynamic co-existence with LTE** in the same radio channels.
- **Network slicing**

5G Phase Two (Release 16)

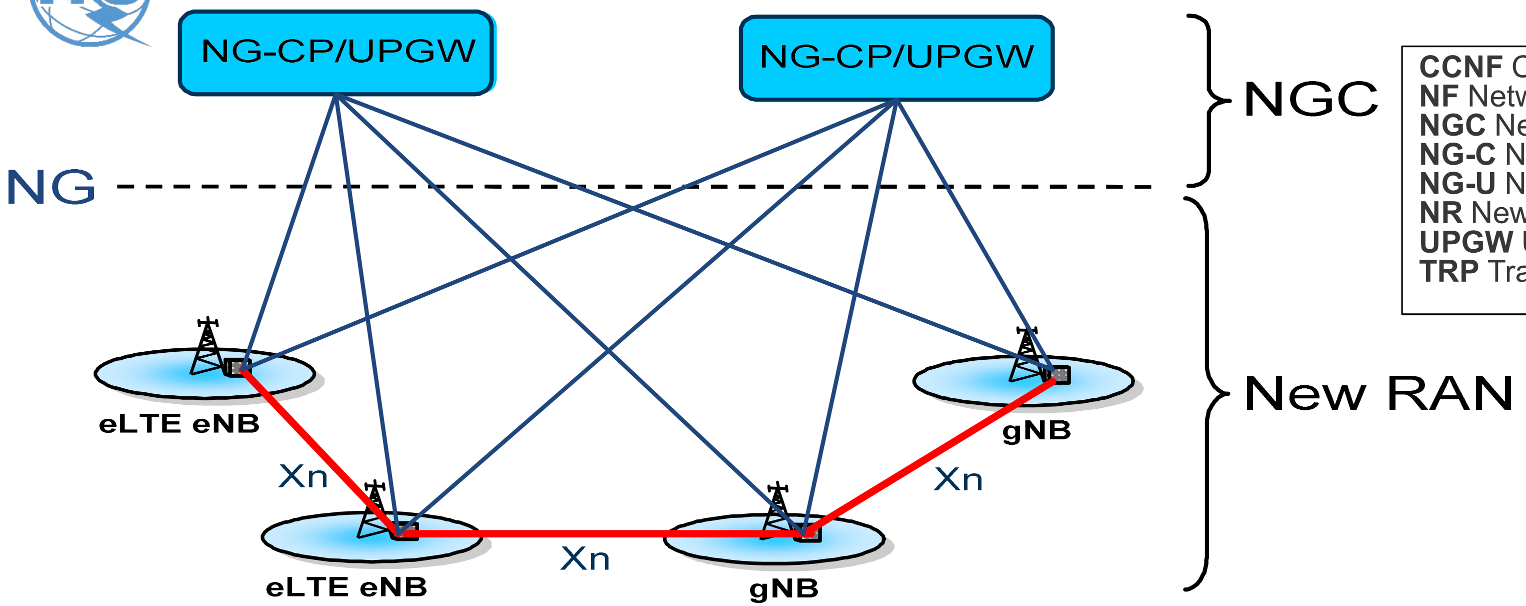


- **URLLC** (Ultra Reliable Low Latency Communications).
- **Unlicensed spectrum** operation below 7 GHz, likely based on current LTE approaches such as LAA.
- **Integrated access and backhaul**.
- NR-based **C-V2X**.
- Positioning for both commercial and regulatory uses.
- NR for non-terrestrial networks, including **satellites**.
- Support for radio bands above **52.6 GHz**.
- **Dual-carrier, carrier-aggregation,** and **mobility** enhancements.
- UE **power consumption reduction**.

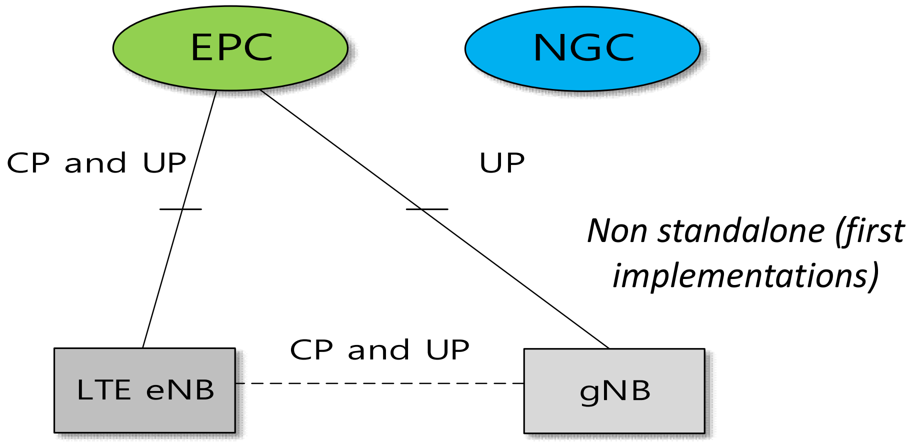
5G Architecture Evolution



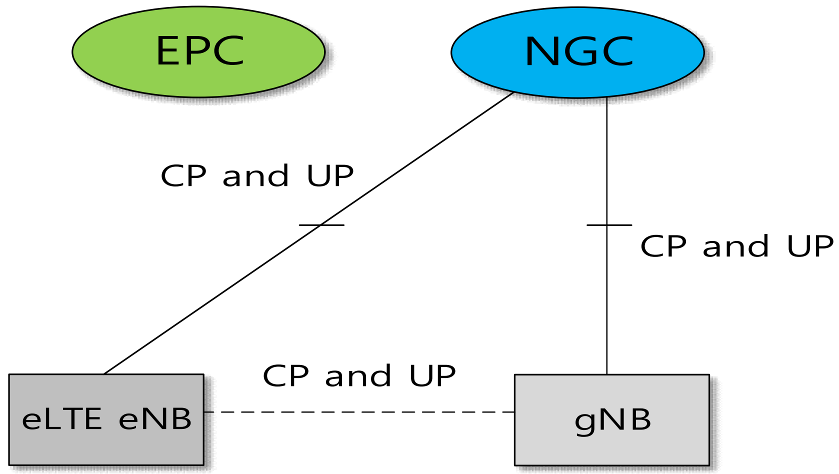
New RAN architecture



CCNF Common Control Network Function
NF Network Function
NGC Next Generation Core
NG-C NG Control Plane interface
NG-U NG User Plane interface
NR New Radio
UPGW User Plane Gateway
TRP Transmission Reception Point



E-UTRA and NR connected to the EPC

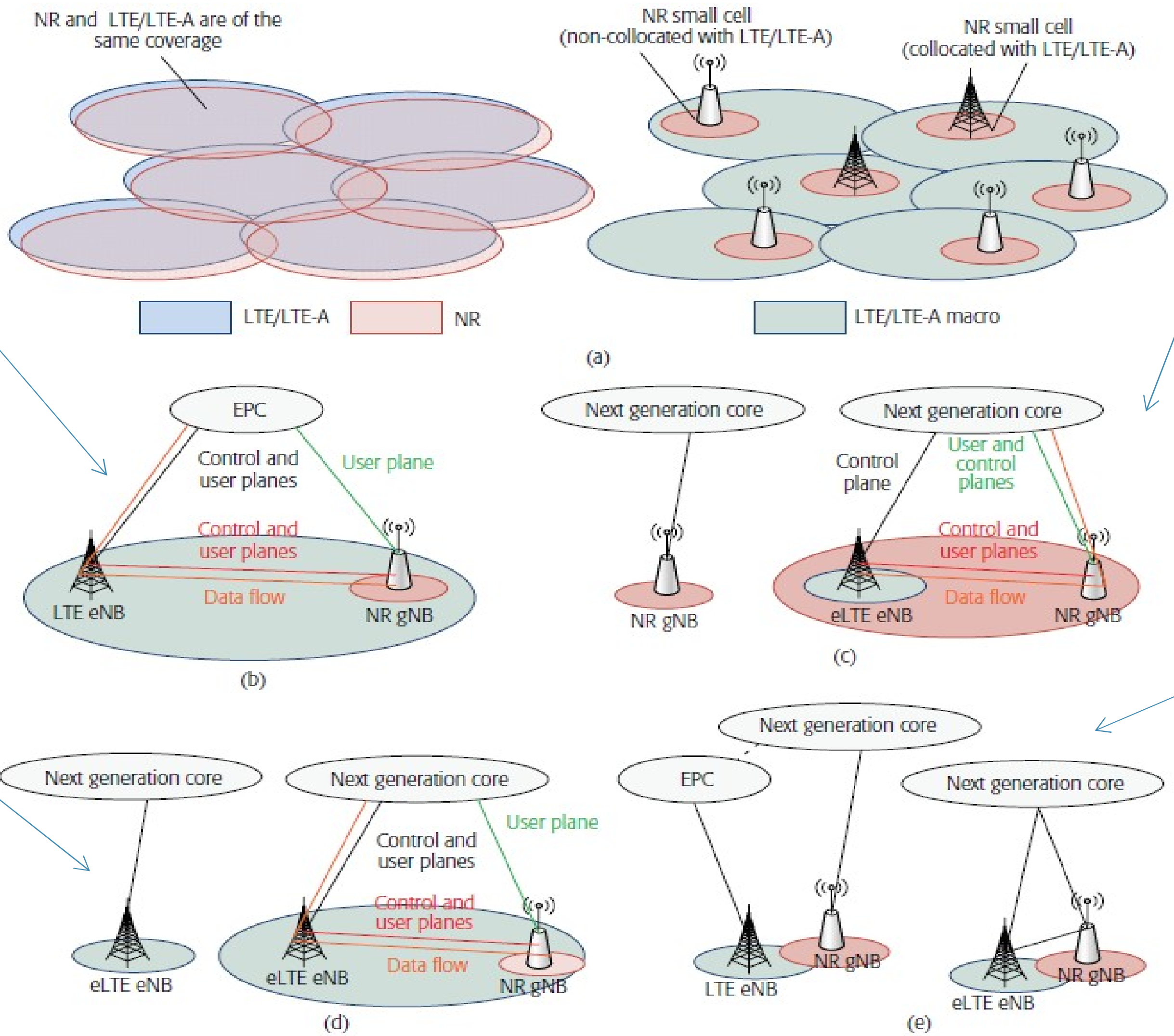


E-UTRA and NR connected to the NGC

Deployment scenarios of NR

LTE/LTE-A eNB Is a Master Node: An LTE/LTE-A eNB offers an anchor carrier (control and user planes), and an NR gNB offers a booster carrier. Data flow aggregates across an eNB and a gNB via the EPC

eLTE eNB Is a Master Node: A standalone eLTE eNB offers wireless services (control and user planes) via the NG core, or a collocated NR gNB is able to provide booster carriers

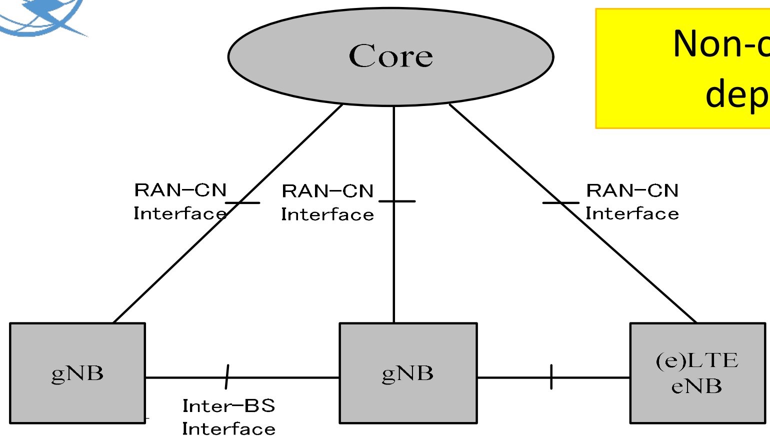


NR gNB Is a Master Node: A standalone NR gNB offers wireless services (control and user planes) via the NG core. A collocated enhanced LTE (eLTE) eNB is able to additionally provide booster carriers for dual connections

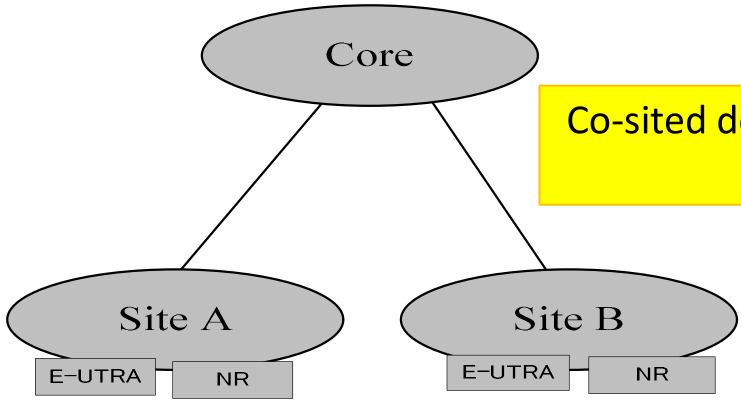
Inter-RAT HO between (e)LTE/LTE-A eNB and NR gNB: An LTE/LTE-A eNB connects to the EPC, and an NR gNB connects to the NG core to support HO between eNB and gNB. An eLTE eNB can also connect to the NG core, and HO between eNB and gNB can be fully managed through the NG core

Different architecture options

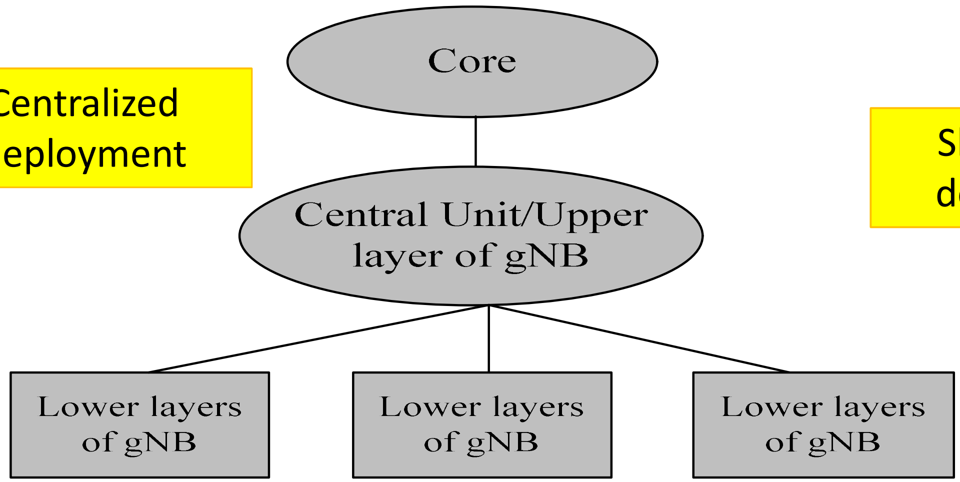
Non-centralised deployment



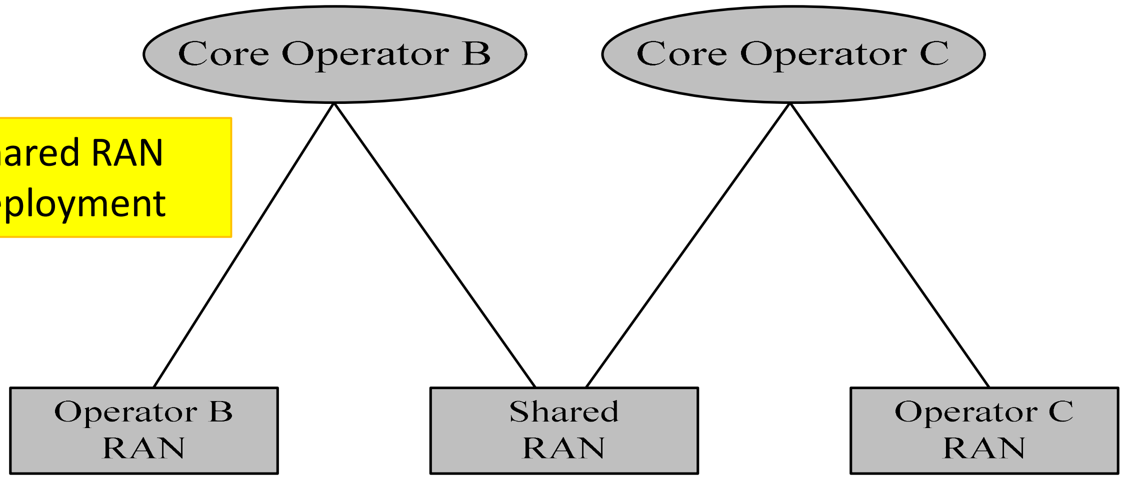
Co-sited deployment with E-UTRA



Centralized deployment

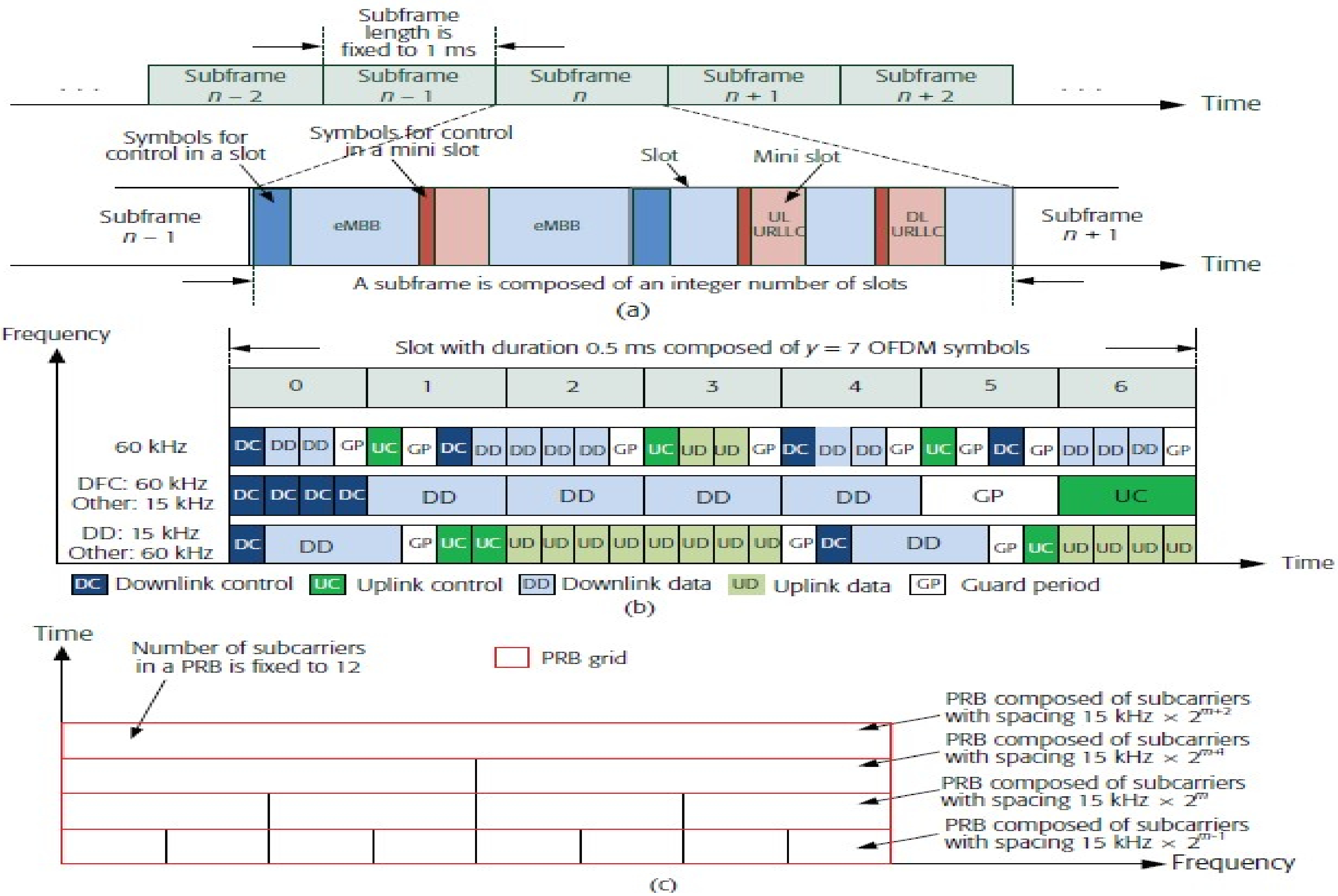


Shared RAN deployment



CCNF Common Control Network Function – **NF** Network Function – **NGC** Next Generation Core
NG-C NG Control Plane interface - **NG-U** NG User Plane interface – **NR** New Radio
UPGW User Plane Gateway – **TRP** Transmission Reception Point

Frame structure of NR



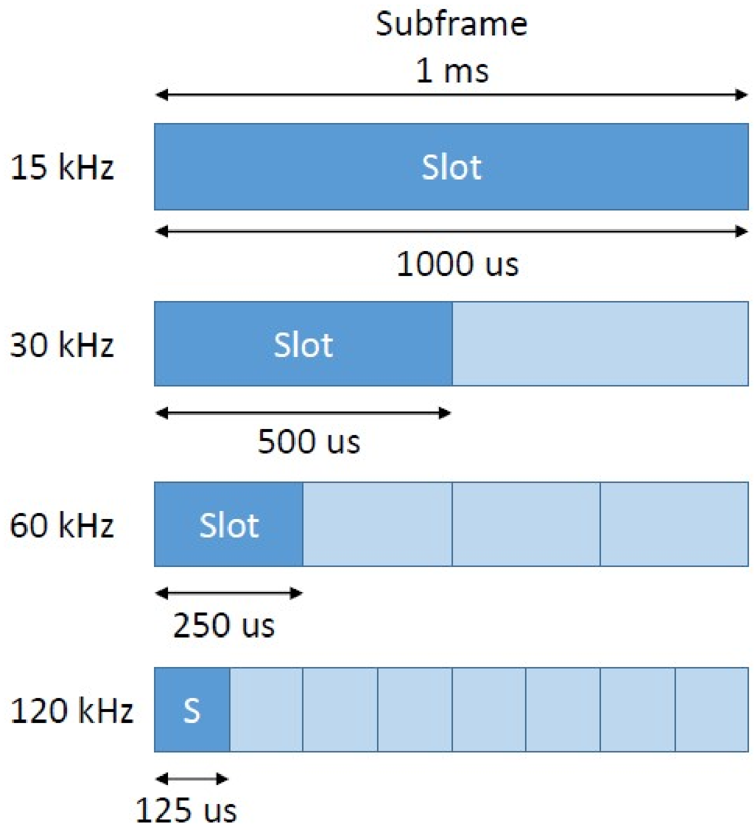
Numerology - SCS

- Scalable subcarrier spacing
- *Δf = 2μ × 15 kHz*
- SCS for PSS, SSS and PBCH
- Sub 6 GHz: 15 or 30 kHz
- 24~52.6 GHz: 120 or 240 kHz
- SCS for NR
- Below 1 GHz: 15/30 kHz
- UE Mandatory: 15k, 30k
- 1~6 GHz: 15/30/60 KHz
- UE Mandatory: 15k, 30k
- UE Optional: 60k
- 24~52.6 GHz: 60/120 kHz, 240 kHz (only for SS)
- UE Mandatory: 60k, 120k

μ	$\Delta f = 2^{\mu} \cdot 15\,[\text{kHz}]$	Cyclic prefix	Supported for data	Supported for synch
0	15	Normal	Yes	Yes
1	30	Normal	Yes	Yes
2	60	Normal, Extended	Yes	No
3	120	Normal	Yes	Yes
4	240	Normal	No	Yes

Frame Structure – Slot

- Frame: 10 ms
- Subframe: 1 ms
- Slot
  - For all SCS with NCP: 14 symbols
  - For 60kHz SCS with ECP: 12 symbols
  - Duration time: $1/2^{\mu}$
- Mini-Slot
  - a minimum scheduling unit with 7, 4 or 2 OFDM symbols

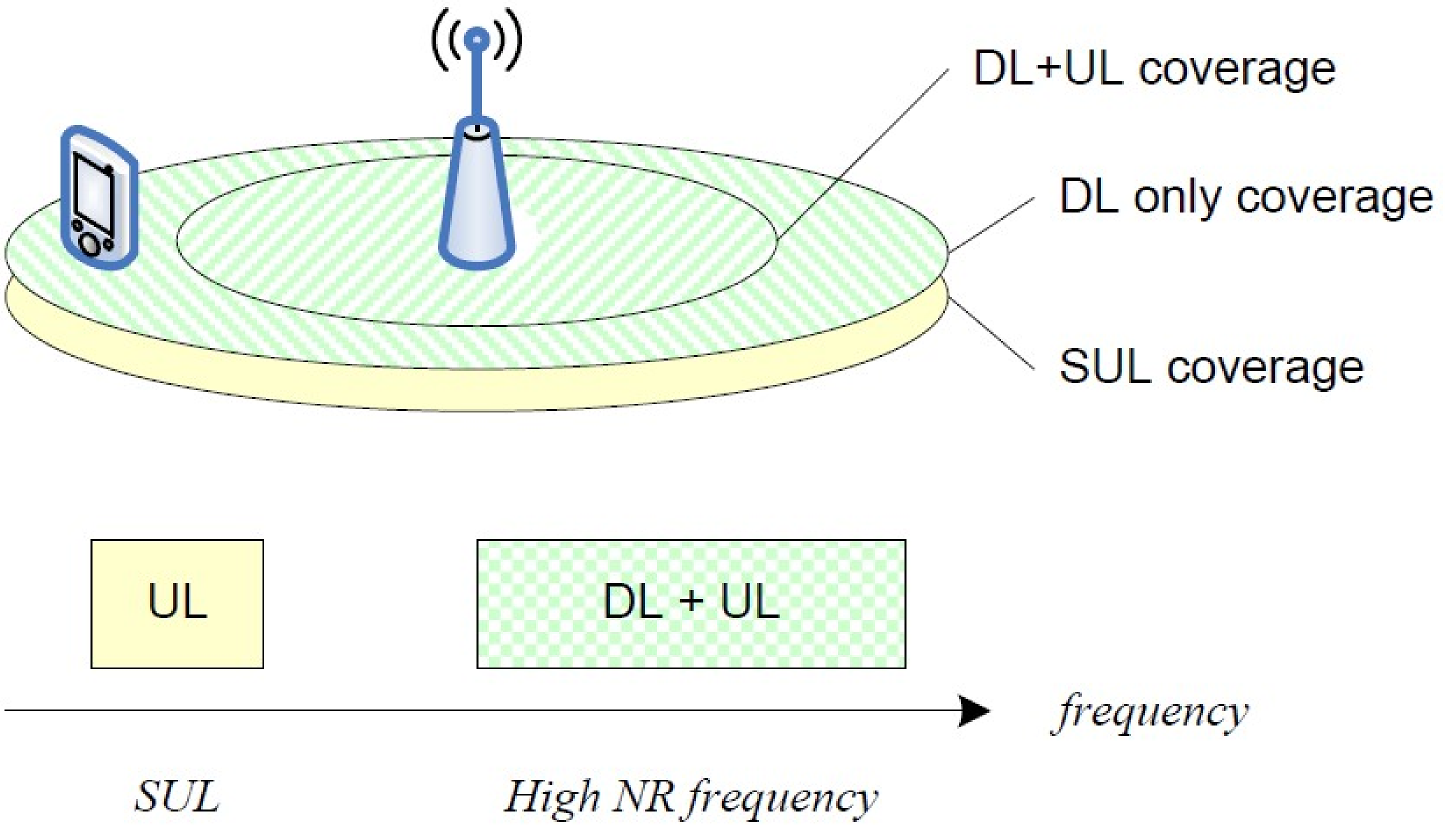


Numerology – CBW & FFT Size

- Numerology – CBW & FFT Size
- Channel Bandwidth
- Frequency Range 1 (FR1) Sub 6 GHz: 100 MHz
- Frequency Range 2 (FR2) 24~52.6 GHz: 400 MHz
- UE can support different maximum channel bandwidth in DL and UL (agreed for data channel)
- For single numerology, maximum number of subcarriers per NR carrier is 3300 in Rel-15, i.e. 275 RB
- Resource block
- A resource block is defined as 12 consecutive subcarriers in the frequency domain

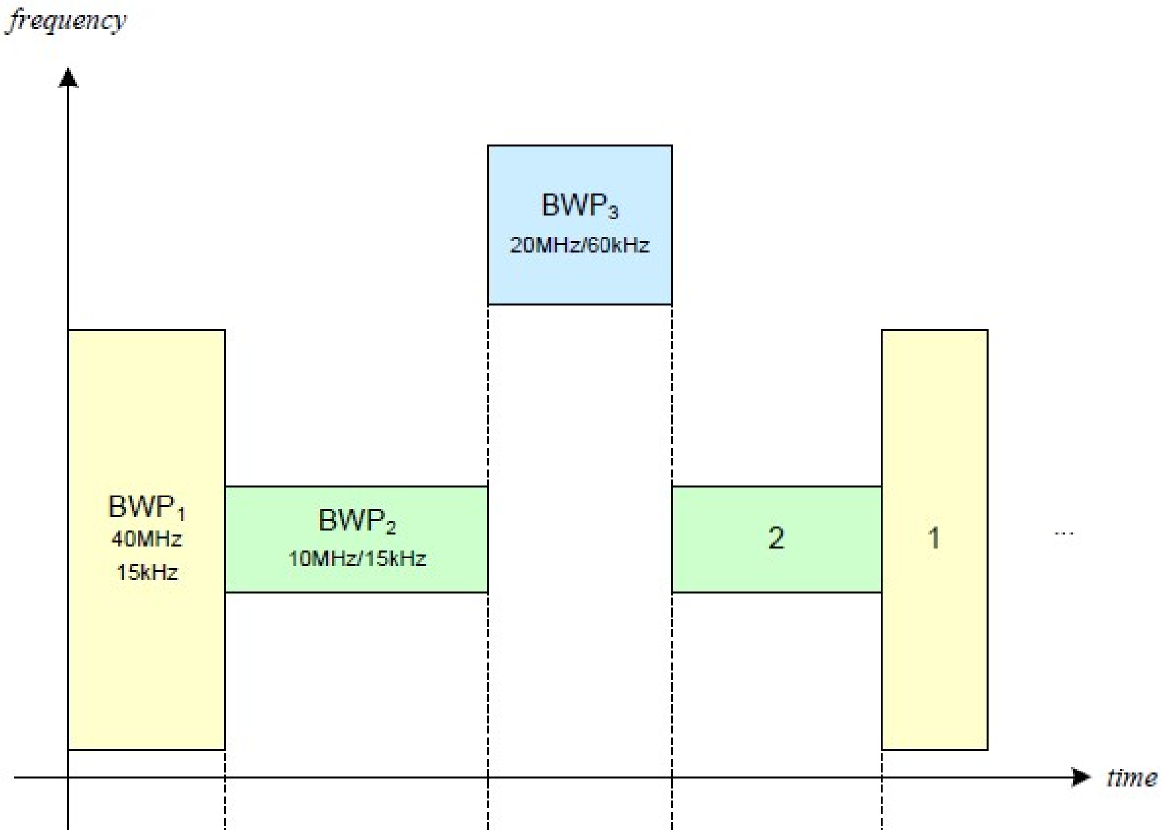
Frequency range	SCS (kHz)	Min CHBW (MHz)	Max RB	Max CHBW (MHz)
FR1	15	5	270	50
	30	5	273	100
	60	10	135	100
FR2	60	50	264	200
	120	50	264	400

Deployment scenarios - SUL

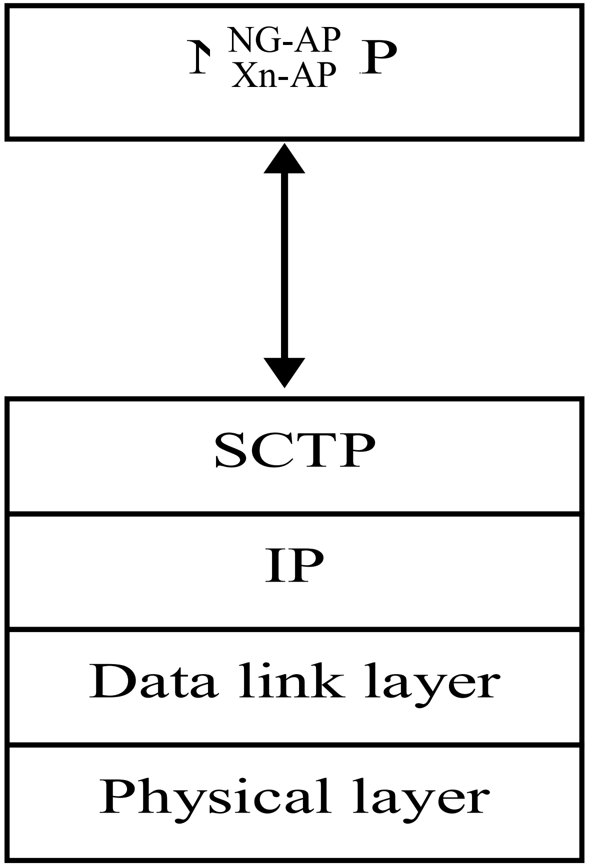


Bandwidth Part (BWP)

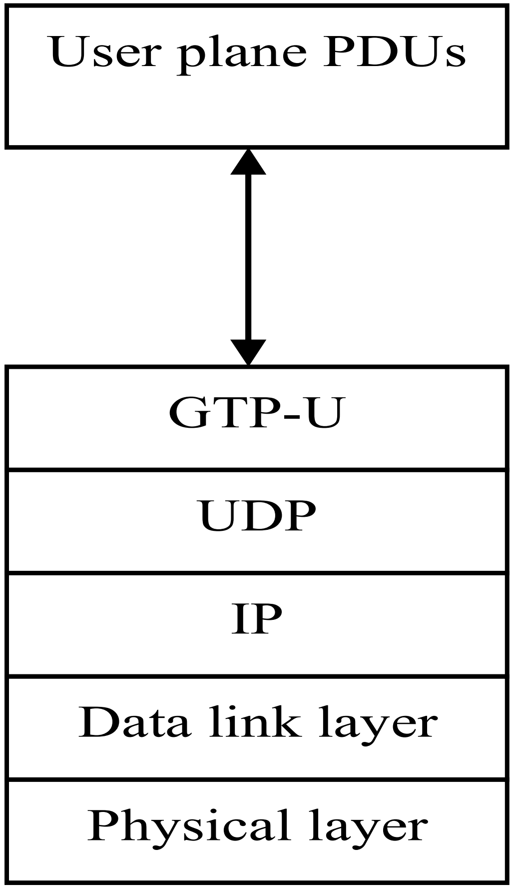
- UE BW can be less than the total BW of the cell and can be adjusted
- Allows to save power during low activity periods
- Increase scheduling flexibility
- Allow different QoS



Protocols layers for NG and Xn interfaces

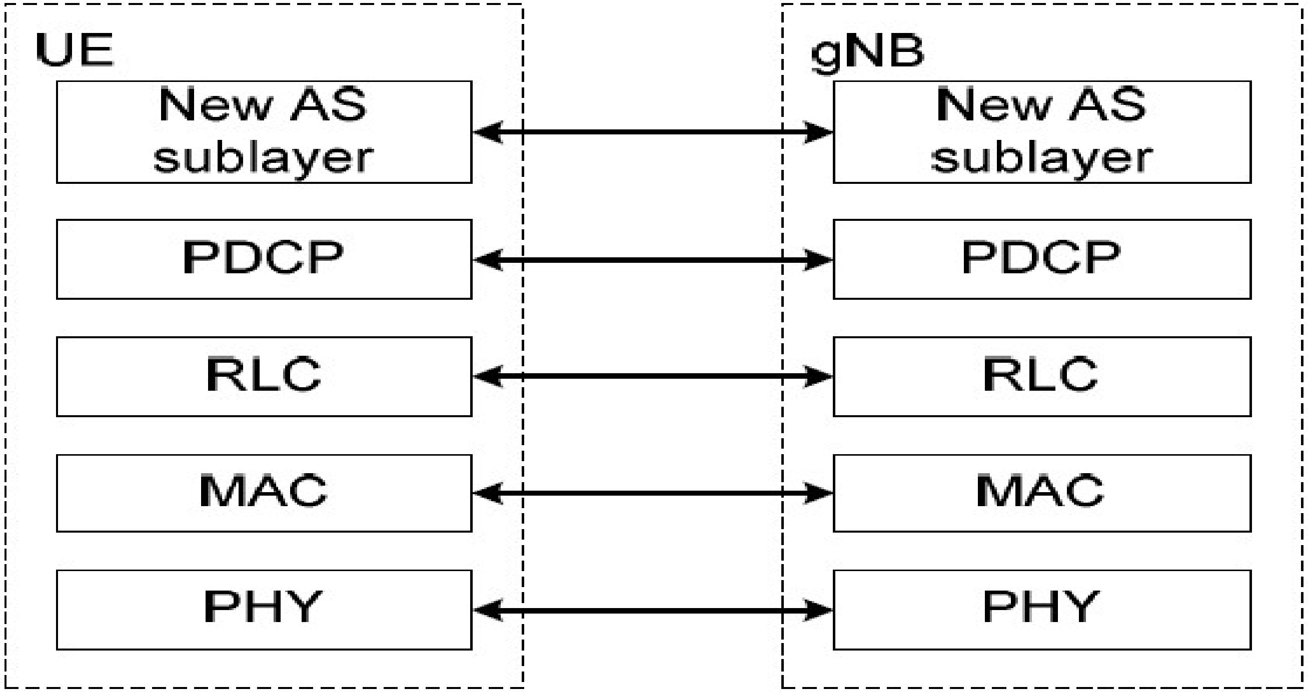


NG / Xn Interface Control Plane



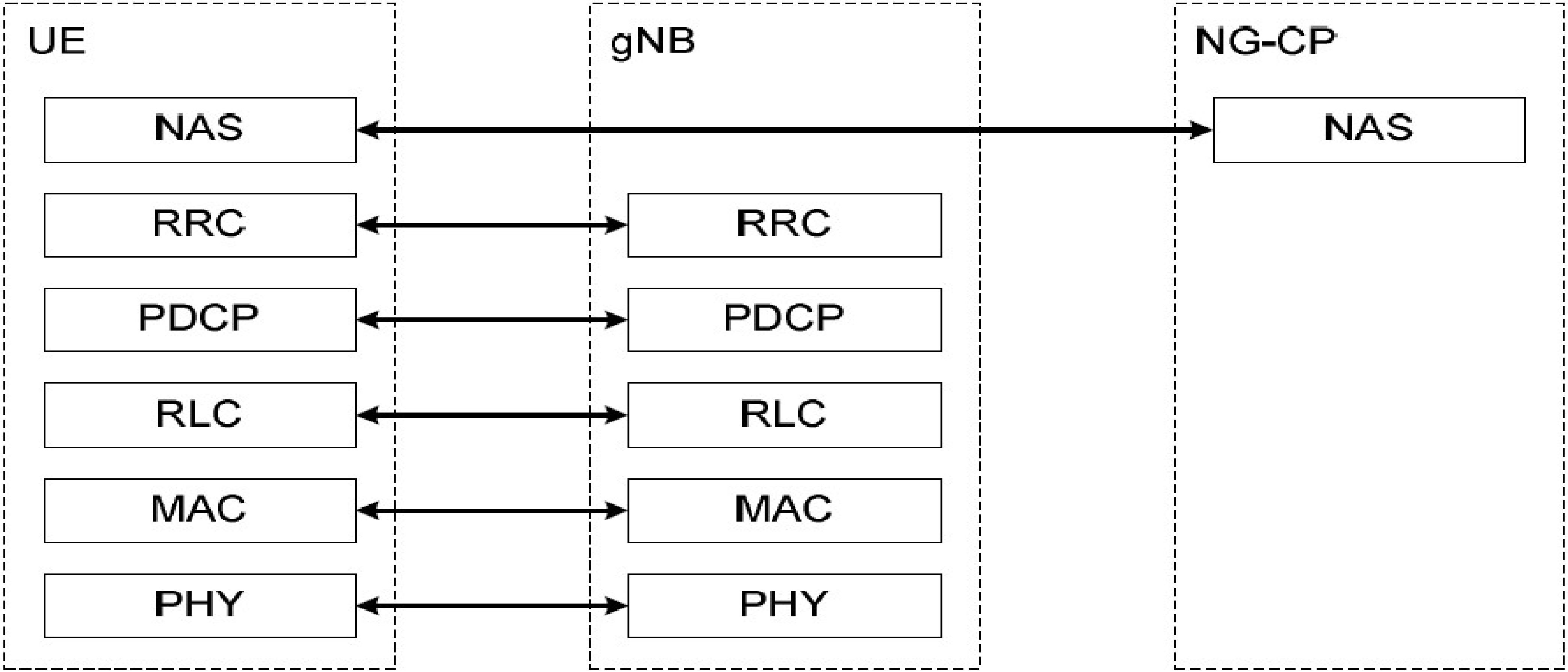
NG-U / Xn protocol structure

User plane protocol stack



Protocol	Legacy U-plane functions
PDCP	IP header compression and encryption of user data (security) In-order delivery to upper layer and duplicate detection Packet-level retransmissions across links (upon connection re-establishment)
RLC	Concatenation Segmentation and reassembly In-order delivery to upper layer and duplicate detection Byte-level retransmissions (AM only)
MAC	Priority handling between logical channels Concatenation, (De)multiplexing of MAC SDUs and padding

Control plane protocol stack



ETSI TR 138 912 V14.0.0 (2017-05)

Examples of maximum required bitrate on a transmission link for one possible PHY/RF based RAN architecture split

Number of Antenna Ports	Frequency System Bandwidth			
	10 MHz	20 MHz	200 MHz	1GHz
2	1Gbps	2Gbps	20Gbps	100Gbps
8	4Gbps	8Gbps	80Gbps	400Gbps
64	32Gbps	64Gbps	640Gbps	3200Gbps
256	128Gbps	256Gbps	2560Gbps	12800Gbps

Thank You