5G networks and 3GPP Release 15

ITU PITA Workshop on

Mobile network planning and security

Sami TABBANE

23-25 October 2019 – Nadi, Fiji Islands

Agenda

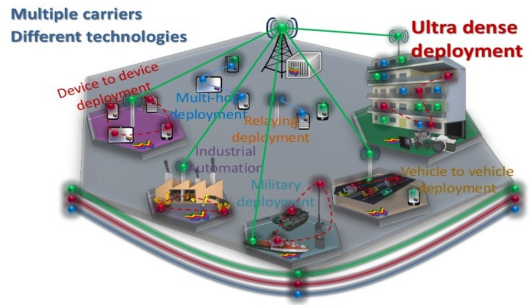
I. 5G concepts and technologies

II. 3GPP Release 15

Agenda

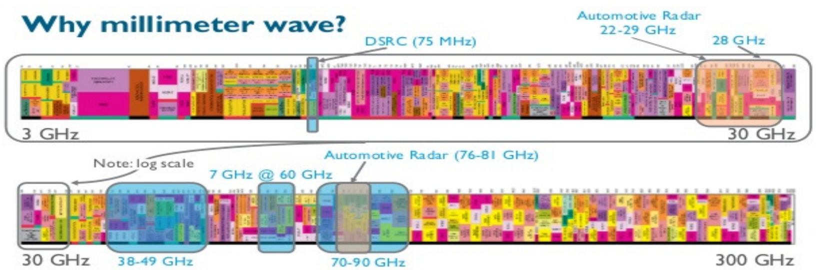
I. Concepts and Technologies

Future cellular systems technologies



- ➢**UDN** (Ultra Dense Networks)

- ➢**Massive MIMO**
- ➢**mmWave** and/or **TeraHertz** communications

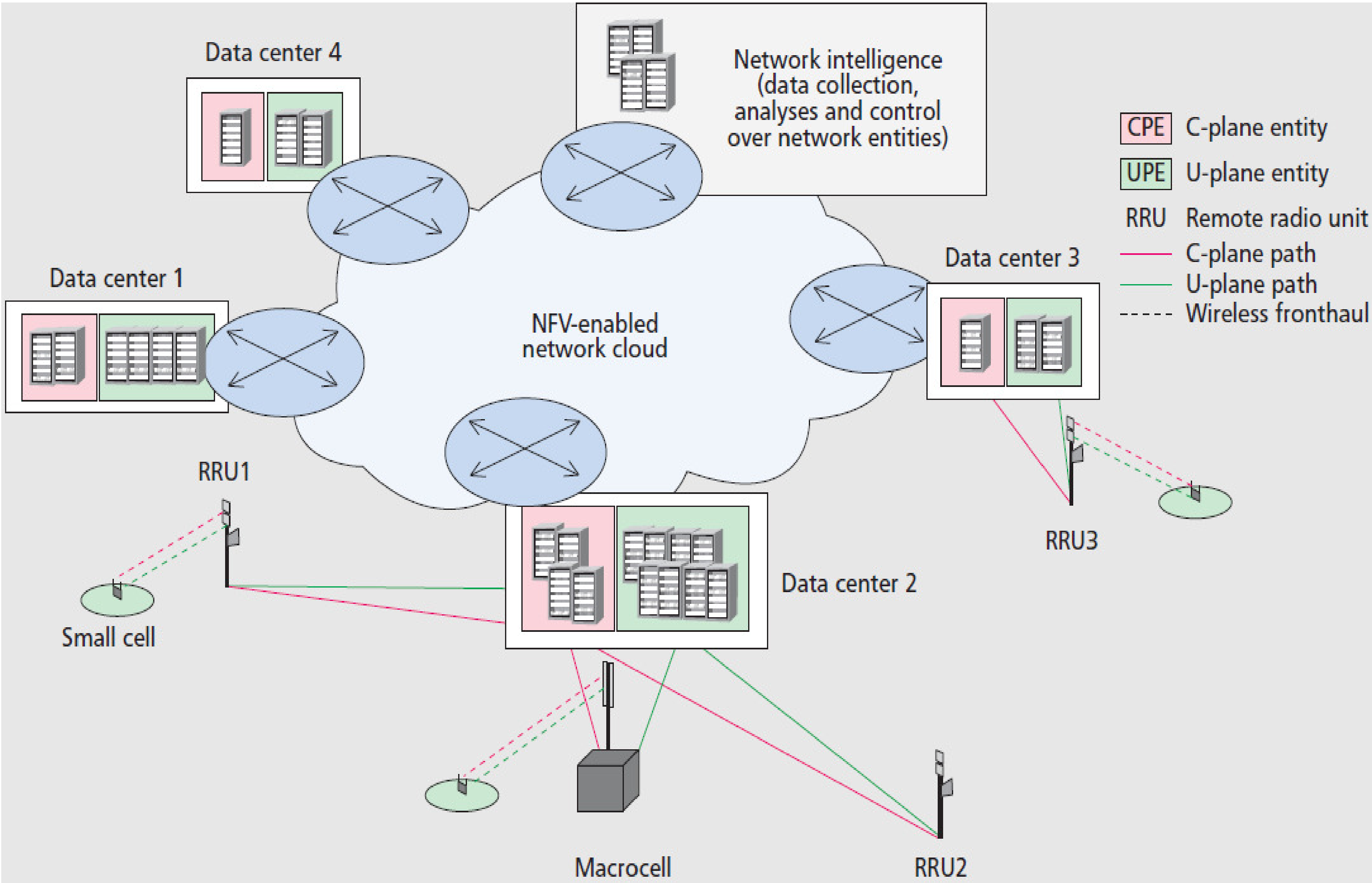


5G Mobile network architecture vision

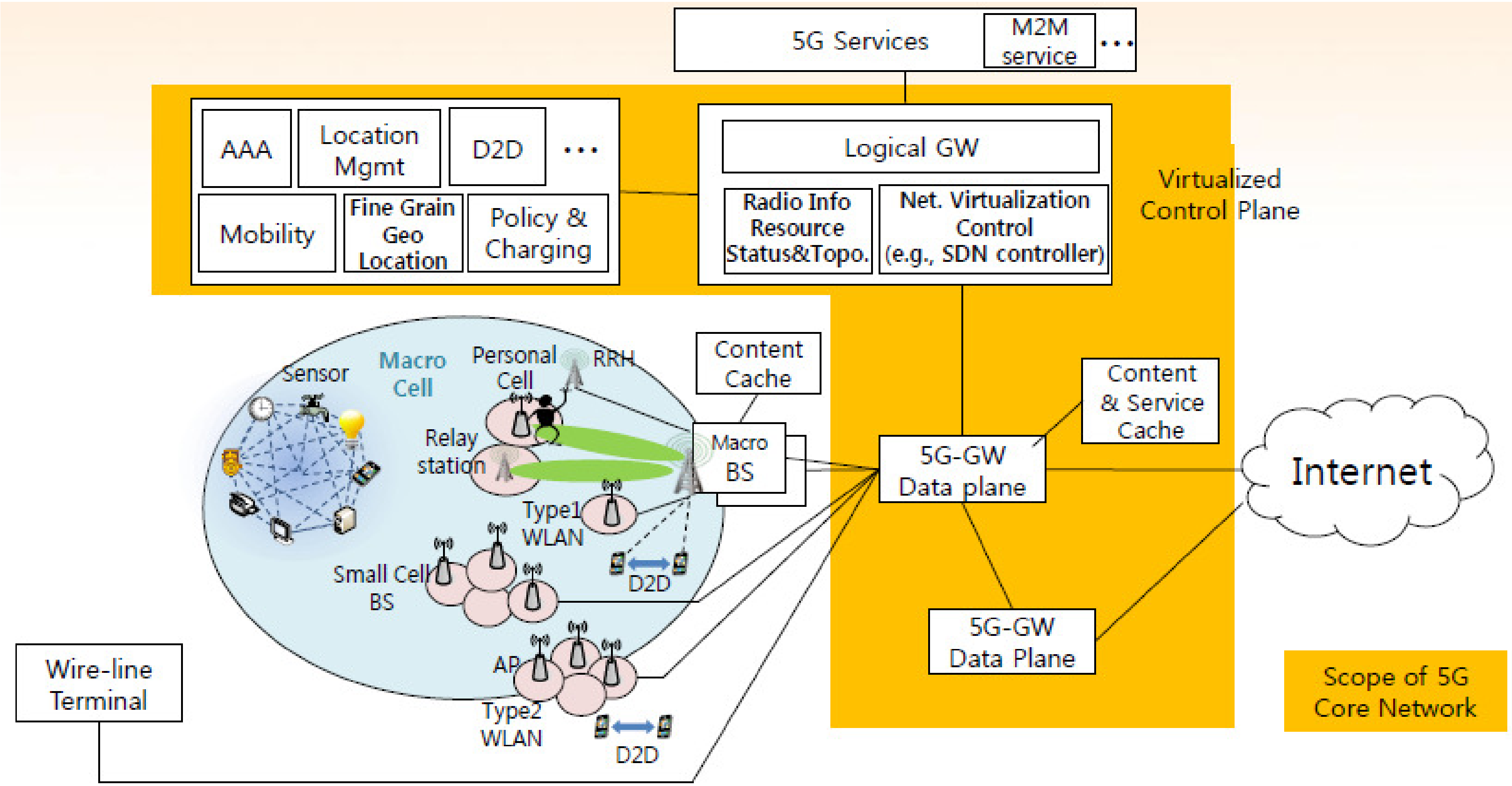
Key architecture elements are:

- **2 logical network layers**:
  - A ***radio network*** (RN) with a minimum set of L1/L2 functionalities
  - A ***network cloud*** with all higher layer functionalities
- Dynamic deployment and scaling of functions in the network cloud through SDN and NFV
- **Separate provisioning of coverage and capacity** in the RN by use of C/U-plane split architecture and different frequency bands for coverage and capacity
- **Relaying and nesting** (connecting devices with limited resources non-transparently to the network through one or more devices that have more resources) to support multiple devices, group mobility, and nomadic hotspots
- **Connectionless** and **contention-based** access with new waveforms for asynchronous access of massive numbers of MTC devices
- **Data-driven** network intelligence to optimize network resource usage and planning

5G network cloud

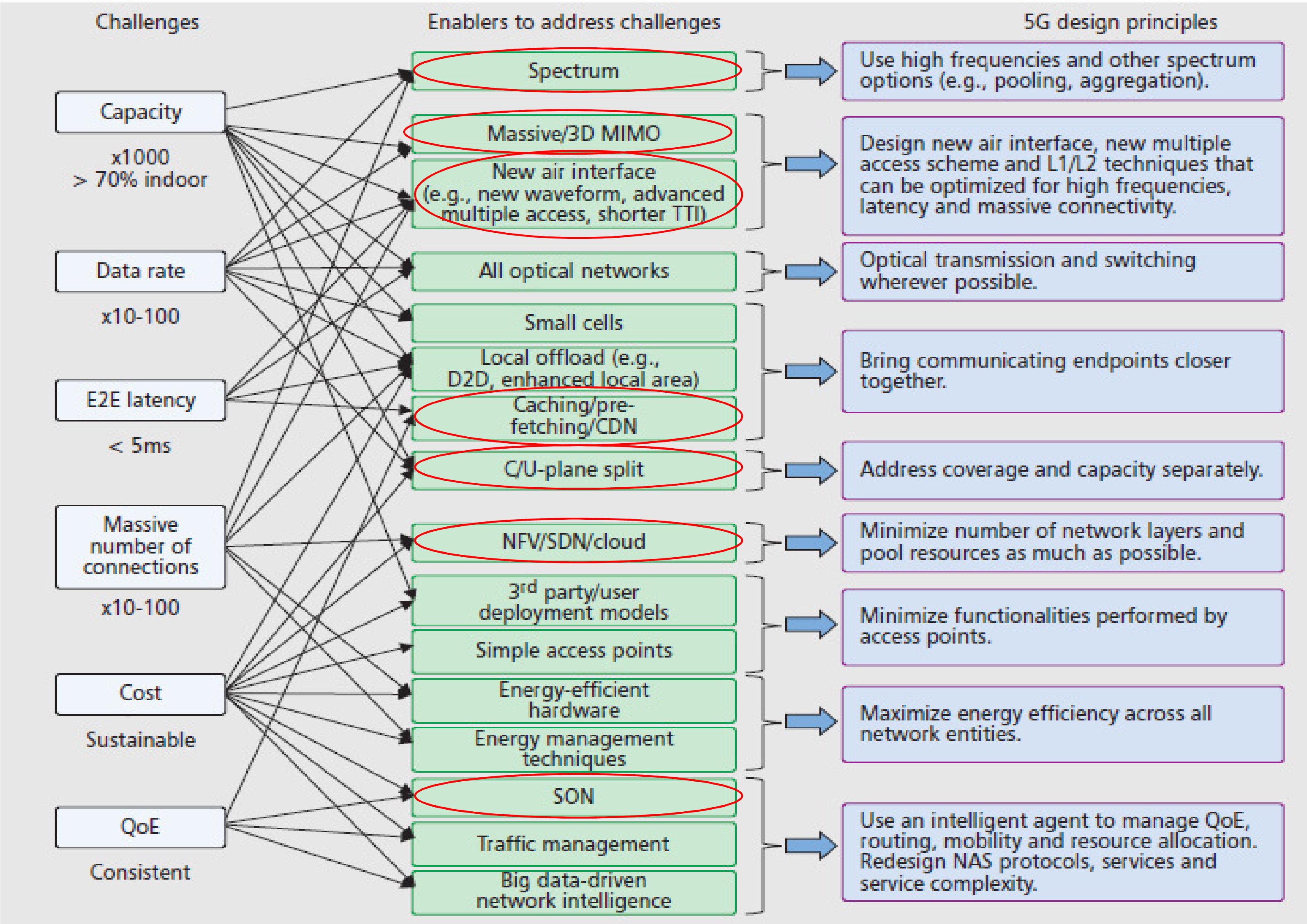


5G Network Architecture



- 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

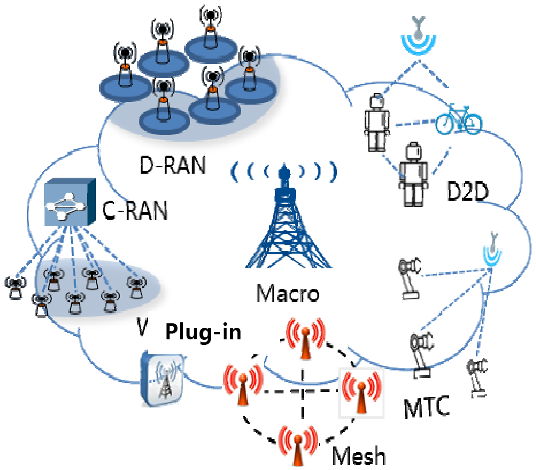
5G challenges, potential enablers, and design principles



5G Network Technology Features

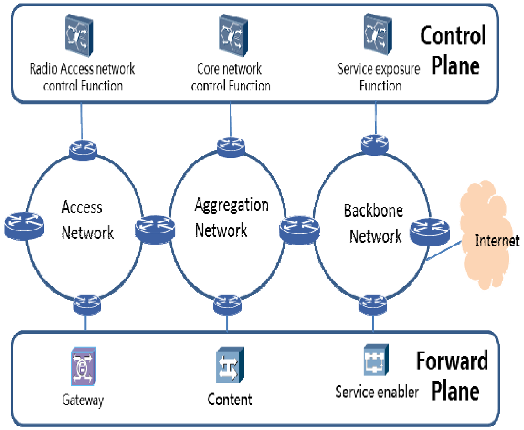
The innovative features of 5G network can be summarized as diversified RAN networking, flexible function deployment, and on-demand slicing.

Diversified RAN networking



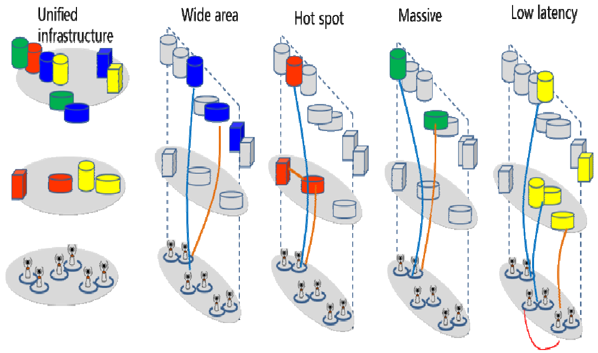
- Support diverse networking mode: **C-RAN, D-RAN, mesh, D2D, BS plug-in**
- To fit different 5G wireless scenarios
- **HetNet**

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

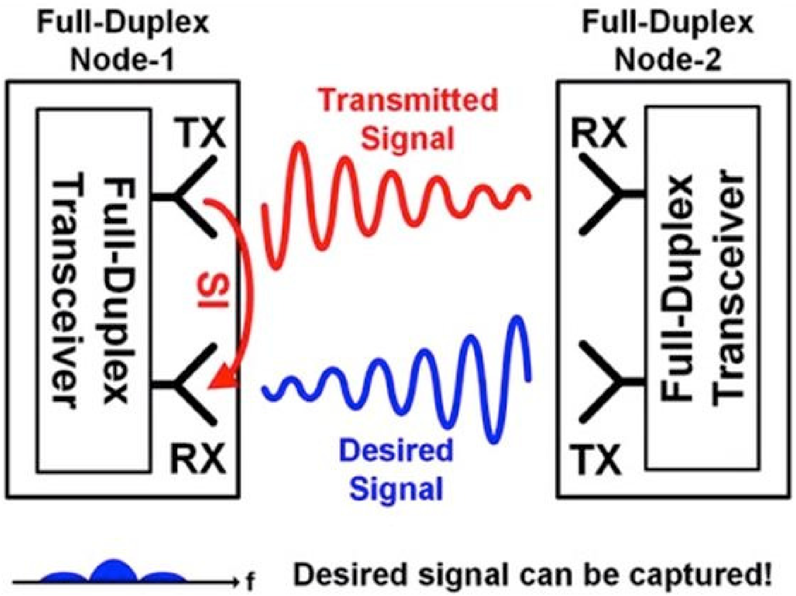
Trends driving 5G transition

- **Limitation in macrocells capacity**:
  - Flatter and more distributed networks,
  - Advanced source coding (H265),
  - Advanced RANs (HetNets),
  - Advanced RATs (new WWAN and WLANs technologies),
  - Transport technologies at the cell sites (fronthaul and backhaul) significantly improved in terms of speed and deployment flexibility.

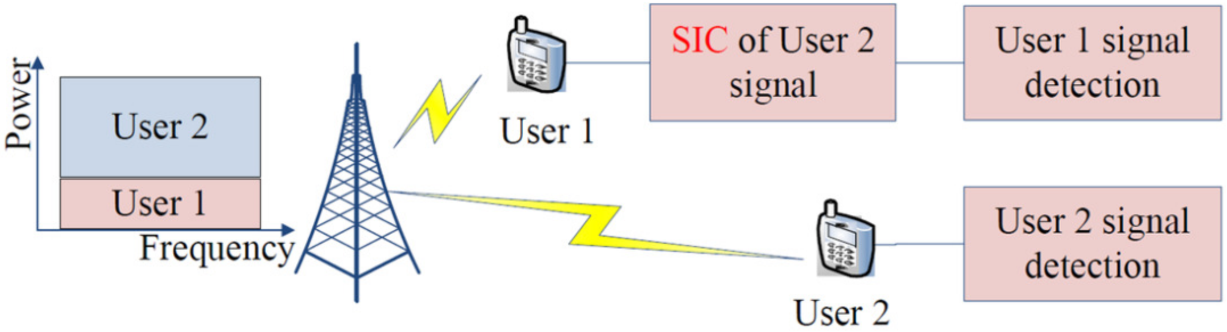
Trends driving 5G transition

- **Mobile performance metrics changes**:
  - 3G/4G network performance evaluated on “hard” metrics: ***peak data rates, coverage, spectral efficiency***,
  - 5G performance metrics centered on user’ QoE: ***ease of connectivity with nearby devices and improved energy efficiency, context-aware experience, personalized content, assistance services***.
- **User Centric, No Cell** (*UCNC): novel radio access framework evolved from the classical cell-centric access protocol to a user-centric protocol with hyper-cell abstraction.*
- **Variety of RATs and wireless devices** : many devices with multiple RATs and modes from D2D based on LTE or WiFi Direct to short-range millimeter-wave (WiGig, new BAN oriented toward wearable devices).
- **IoT with M2M**.

- Full duplex



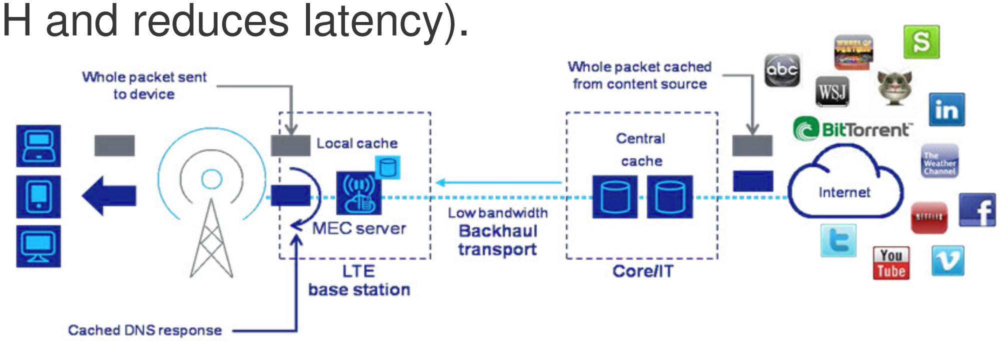
- NOMA multiplexing



- QAM256

Disruptive Technology Directions for 5G

- **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).



- A distributed caching technology can provide backhaul and transport savings and improved QoE
- Potential to reduce backhaul capacity requirements by up to 35%. Local Domain Name System (DNS) caching can reduce web page download time by 20%

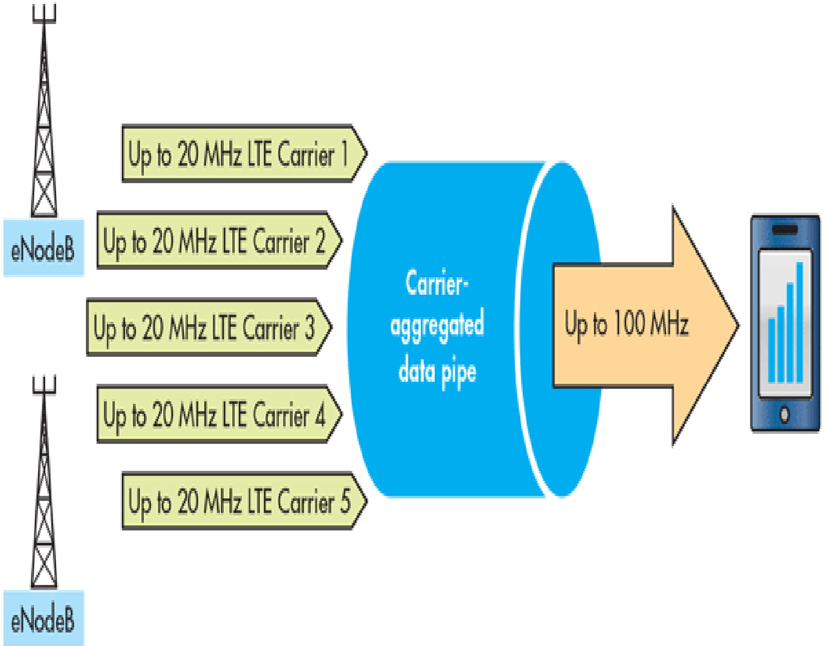
- **Optimized content delivery, Pre-caching of user generated content and Internet content** based on estimated popularity, social trends and used presence and preferences. Better utilize network pipelines based on context information.

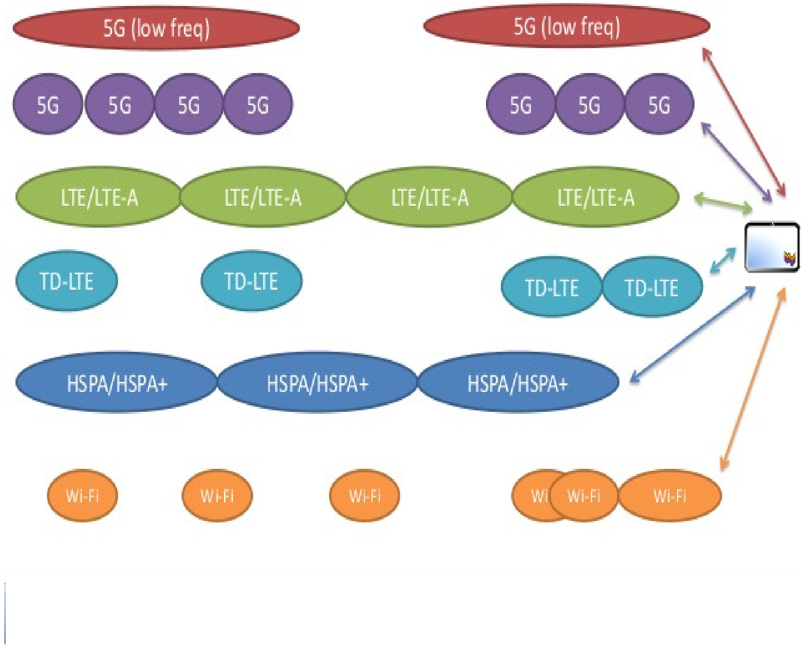
Disruptive Technology Directions for 5G

Carrier aggregation

2015: 10 MHz at Band 5 (850 MHz), 20 MHz at Band 7 (2600 MHz) and 10 MHz at Band 1 (2100 MHz)

2016: commercially used in tens of mobile networks (South Korea, Japan, …)
DL 3-CC CA deployed in some areas of South Korea.





5G RAN technologies for capacity enhancements

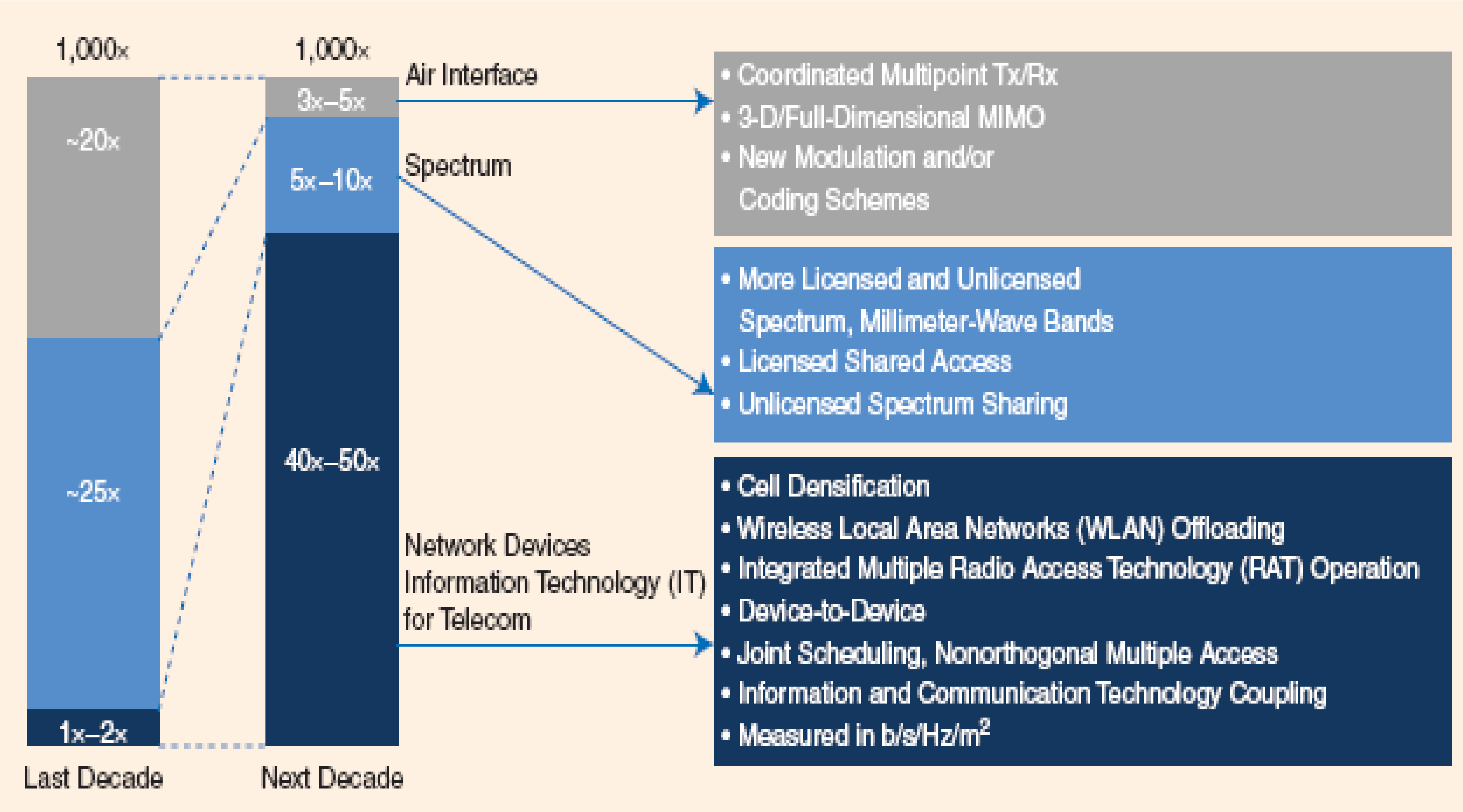
Physical Layer Features to Improve Capacity

Advanced physical layer techniques:

- **Higher-order modulation and coding schemes** (MCS), such as 256-quadrature amplitude modulation (QAM),
- **mMIMO** (64x64 tested) to include AR, VR, …
- **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).

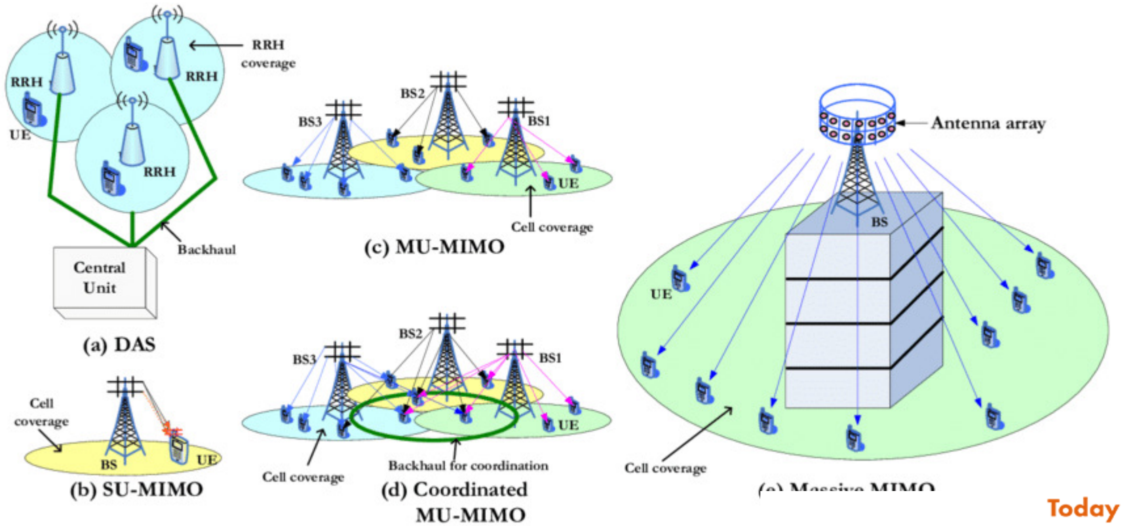
SIC + NOMA can Improve overall throughput in macrocells compared to orthogonal multiple access schemes by up to 30 percent even for high-speed terminals.

Capacity Enhancements

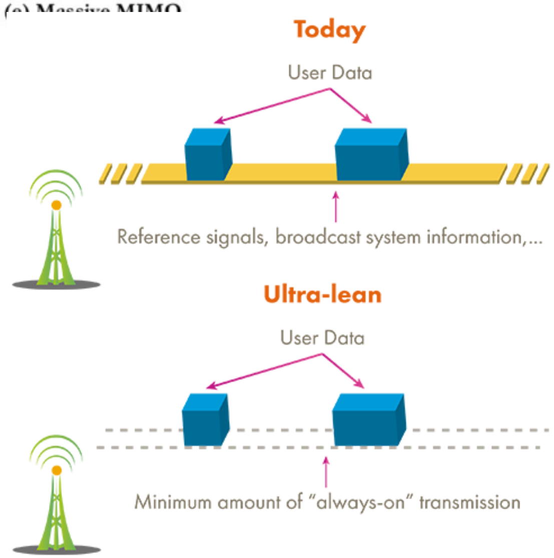


Technology components for the evolution to 5G wireless access

- **Multi-antenna transmission**

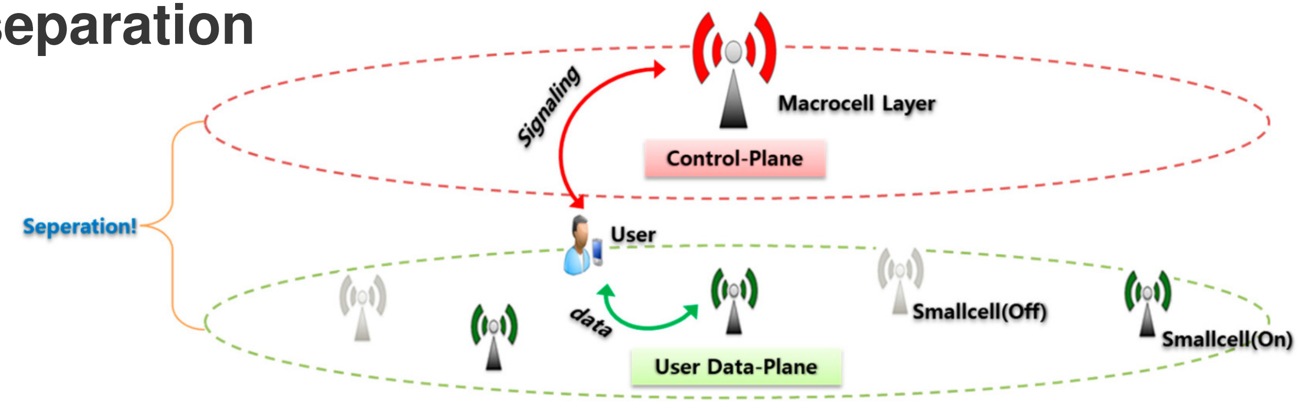


- **Ultra-lean design**: minimize transmissions not directly related to the delivery of user data (i.e., synchronization, network acquisition and channel estimation, broadcast of different types of system and control information) ⇨ ***control signals deactivated if the cell is empty***.



Technology components for the evolution to 5G wireless access

- **User/Control separation**



- **Flexible spectrum usage**: spectrum sharing between a limited set of operators, operation in unlicensed spectrum.
- **Flexible duplex**

- **Direct D2D communication**
- **Access/Backhaul integration**: wireless-access link and wireless backhaul integrated (same technology) and operate using a common spectrum pool.

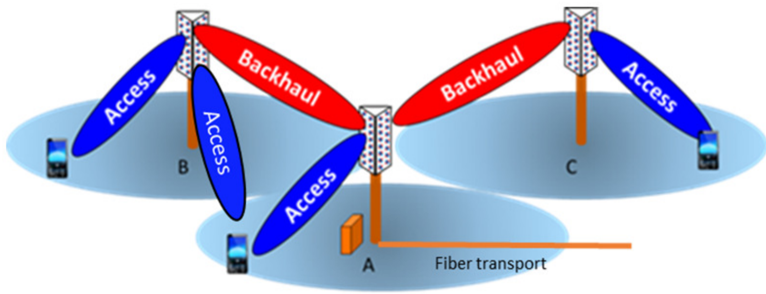
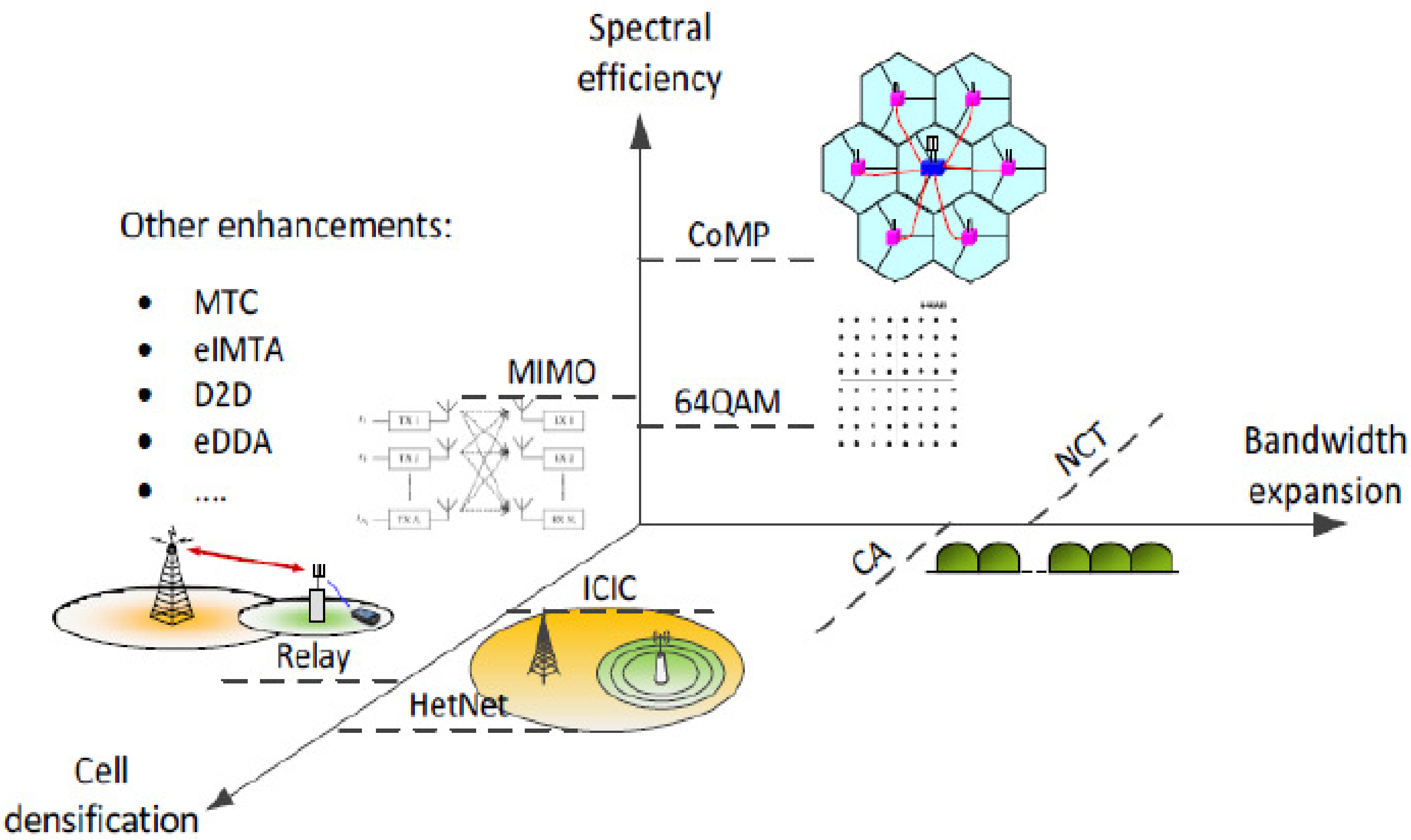


Figure 1: Integrated access and backhaul links

Via: The 3G4G Blog - blog.3g4g.co.uk

3 Dimensions for Capacity Enhancements



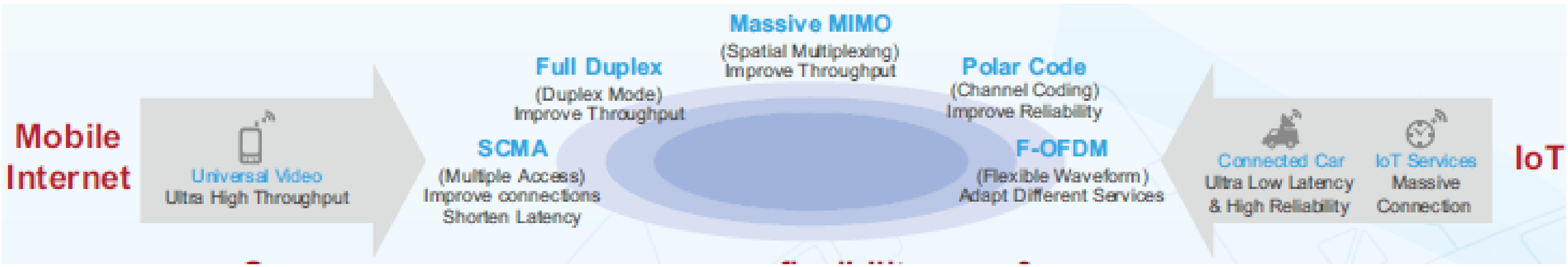
Multiple Access Techniques

Candidate multiple access techniques

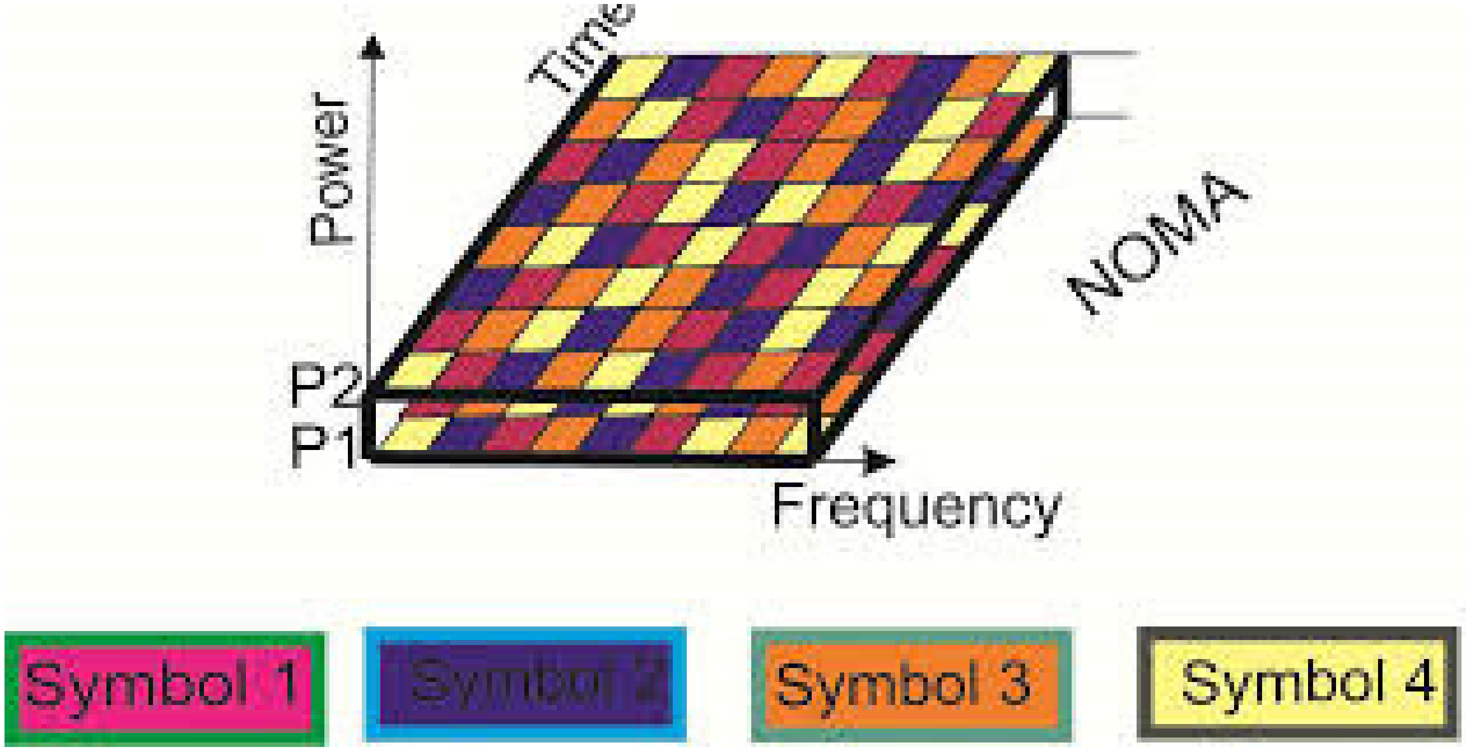
- **Filtered-OFDM** (*Filtered-Orthogonal Frequency Division Multiplexing*), allows inter-subband non-orthogonality,
- **SCMA** (*Sparse Code Multiple Access*), enables intra-subband non-orthogonality
- **UFMC** (*Universal Filtered Multi Carrier*)
- **GFDM** (*Generalized Frequency Division Multiplexing*).

With:

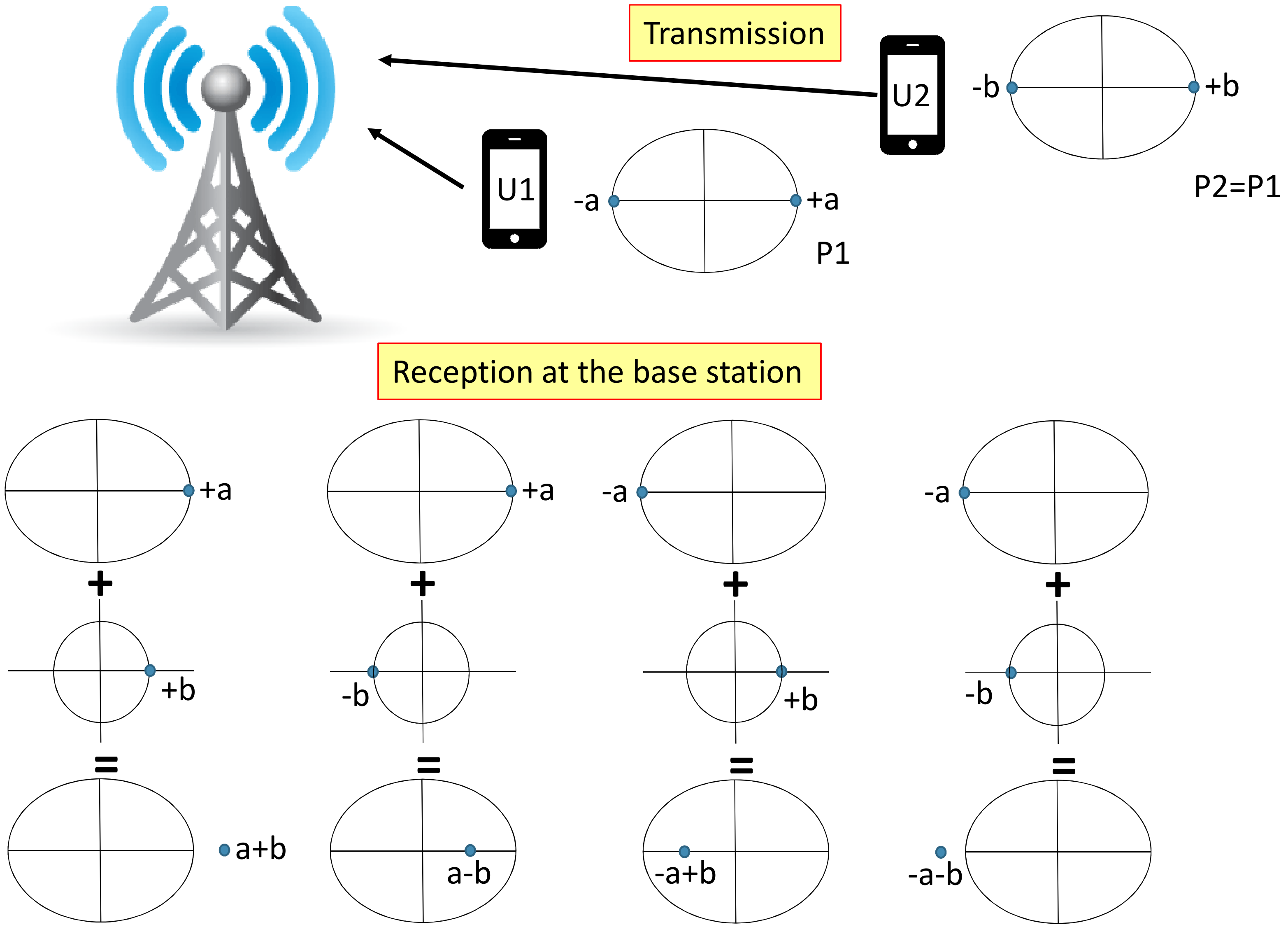
- Channel code Polar Code,
- Full-duplex mode,
- Massive MIMO technology.



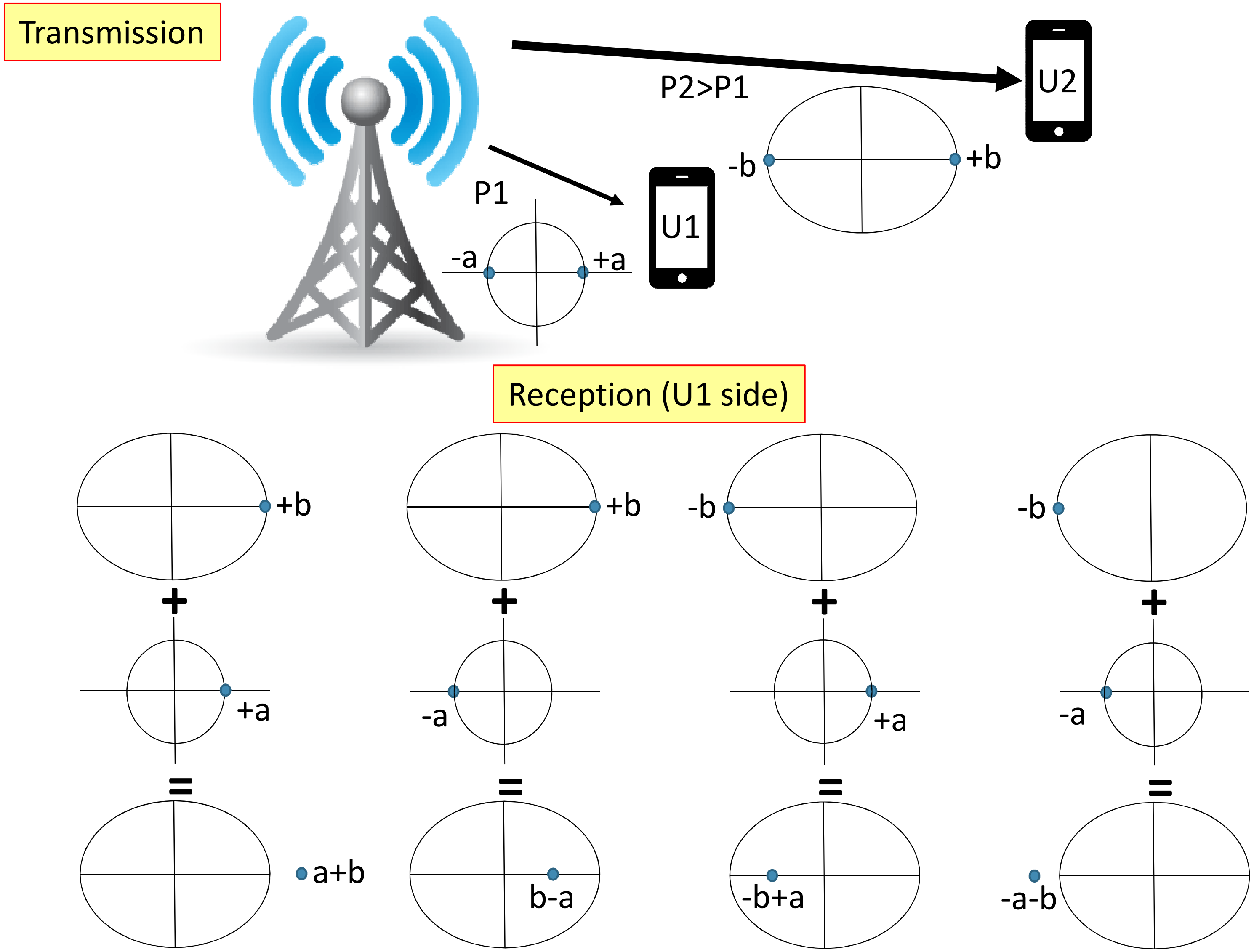
Non Orthogonal Multiple Access



Non Orthogonal Multiple Access

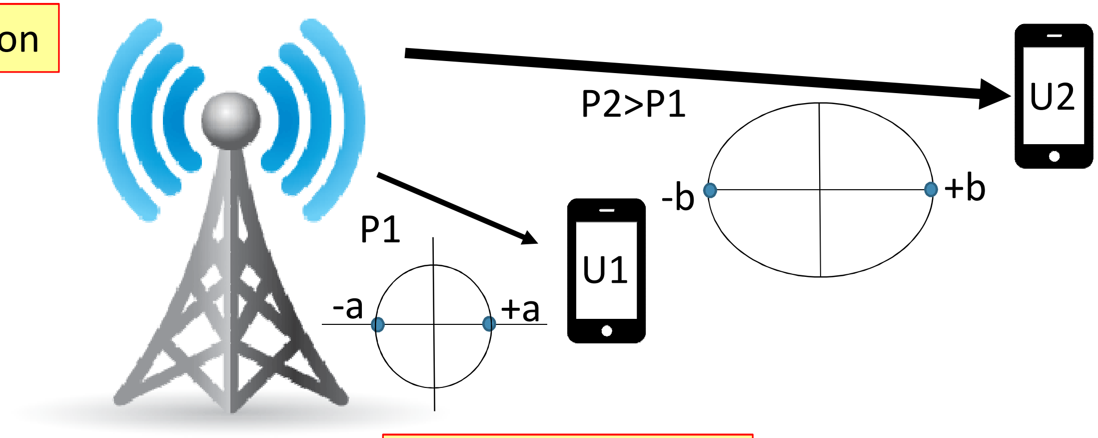


Non Orthogonal Multiple Access

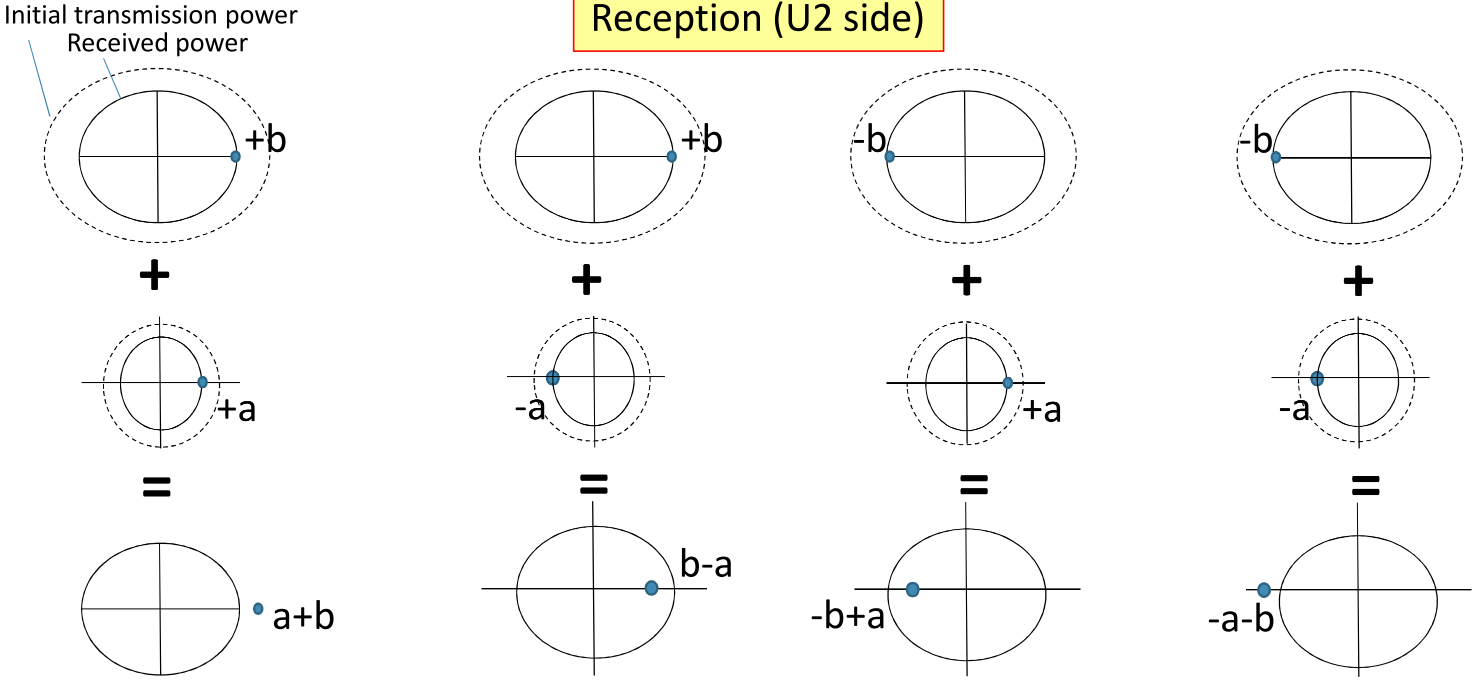


Non Orthogonal Multiple Access

Transmission



Reception (U2 side)

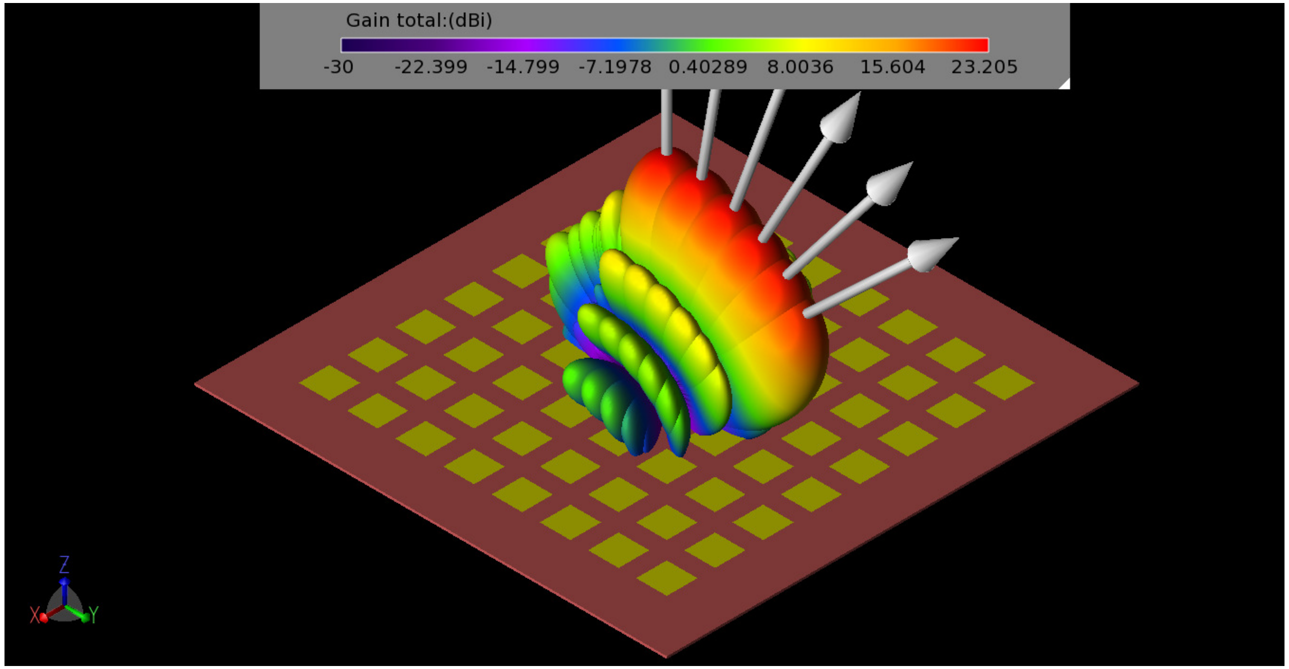


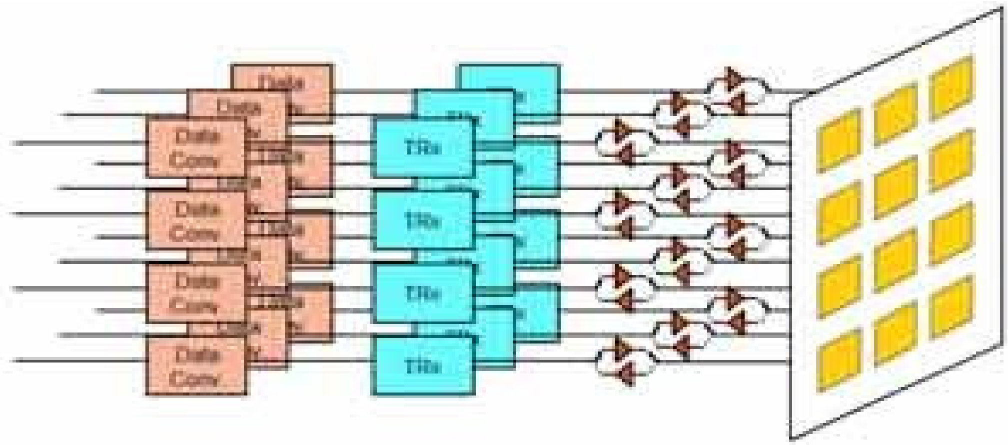
OFDM drawbacks

- OFDM draw too much power in 5G devices and BSs.
- A 5G BS is expected to consume 3 times as much power as a 4G BS.
- Any receiver needs to be able to take a lot of energy at once, and any transmitter needs to be able to put out a lot of energy at once. This cause OFDM's high PAPR and make the method less energy efficient than other encoding schemes.
- If operators want to update their equipment to provide NOMA, this will require additional costs especially for the BSs.
- BSs would need SW updates to handle NOMA and may require more advanced receivers, more processing power or other HW upgrades.

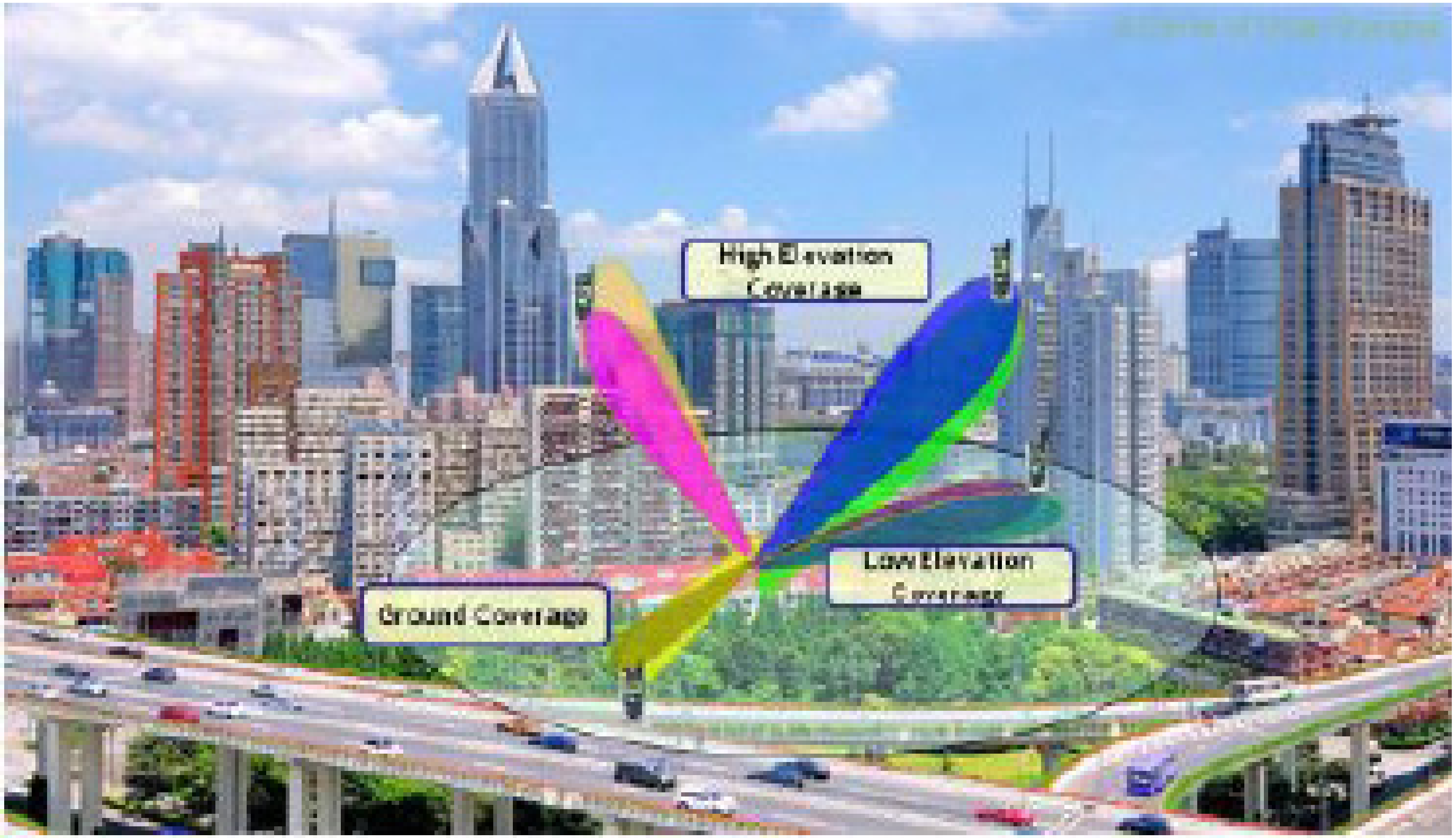
3D beamforming and cell concept change

Beamforming and Array Antennas

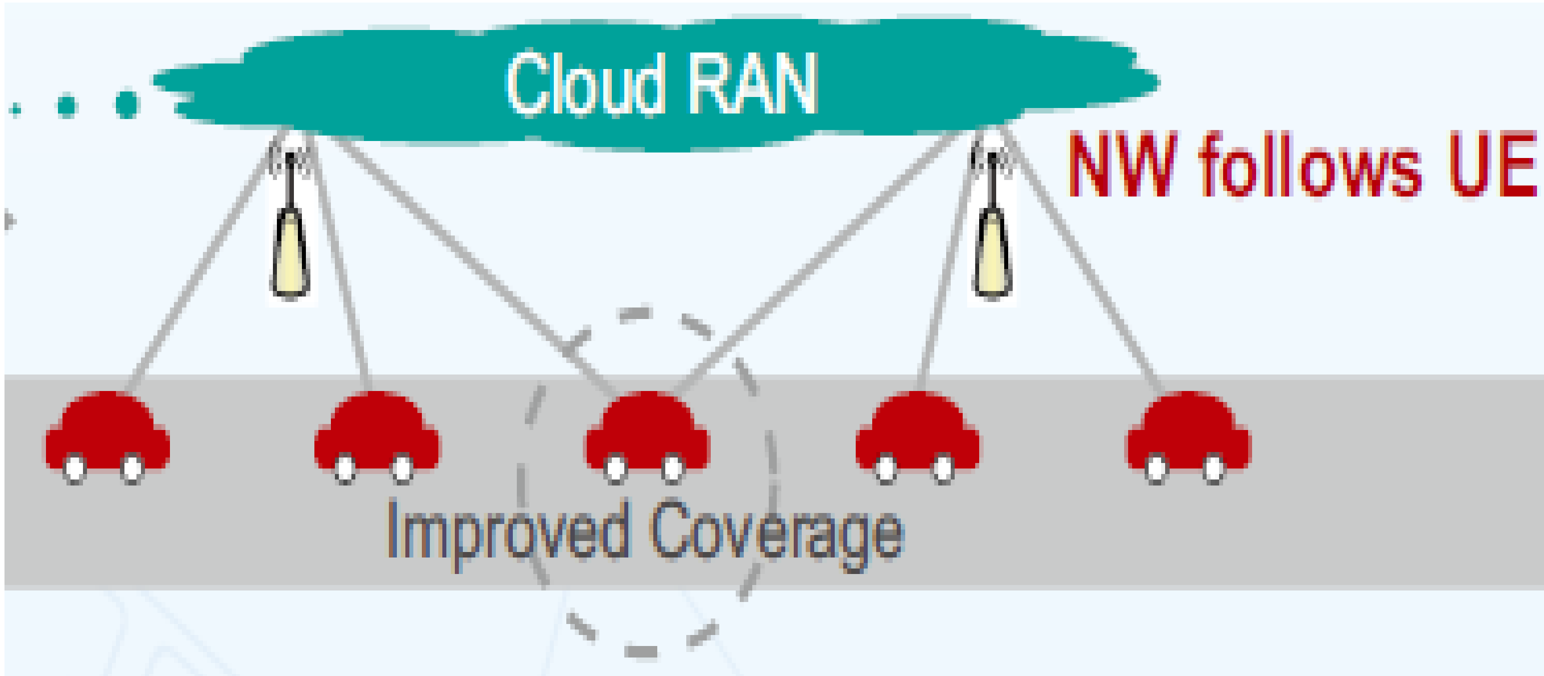




3D Beamforming



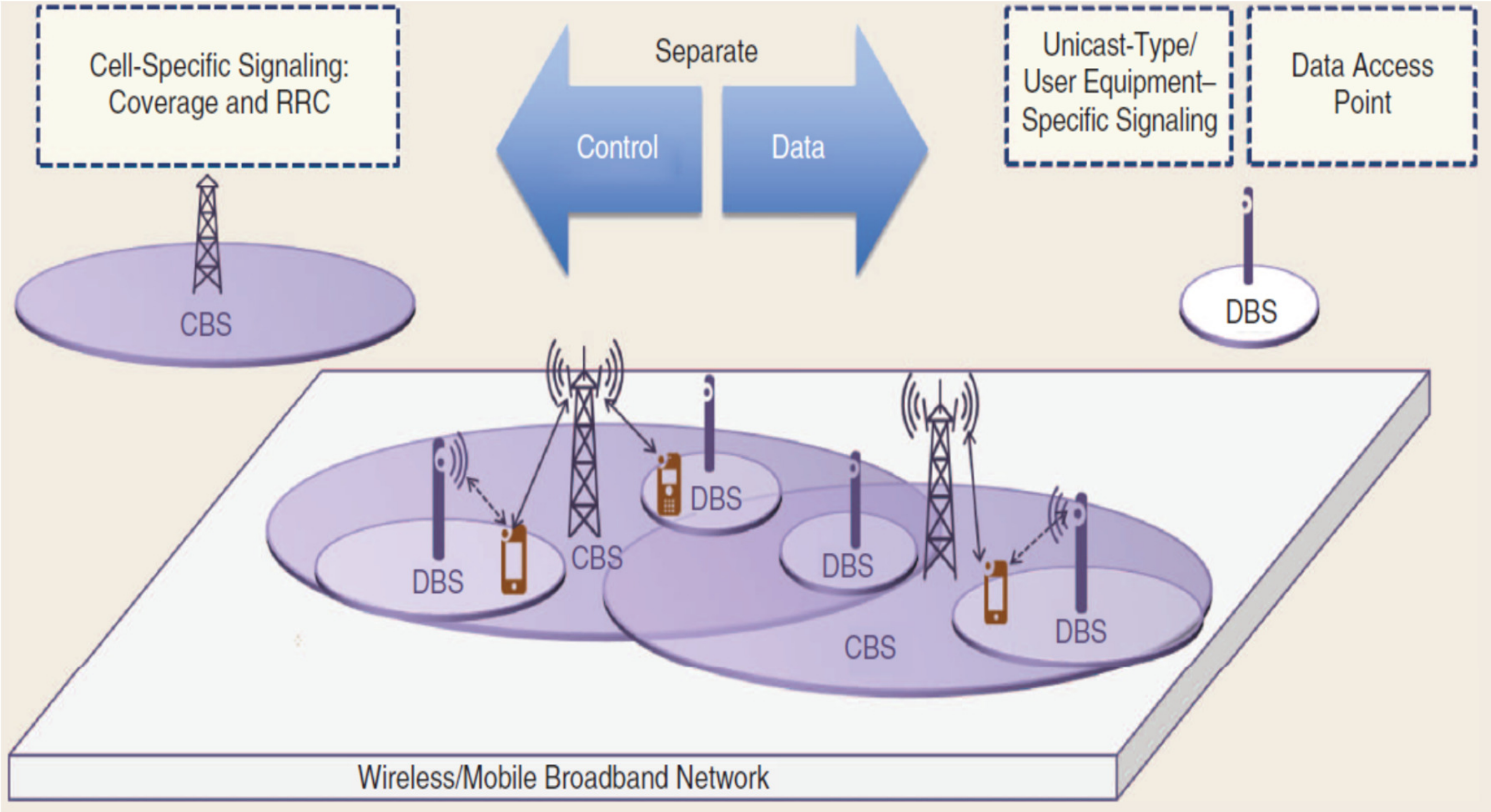
Moving cell concept



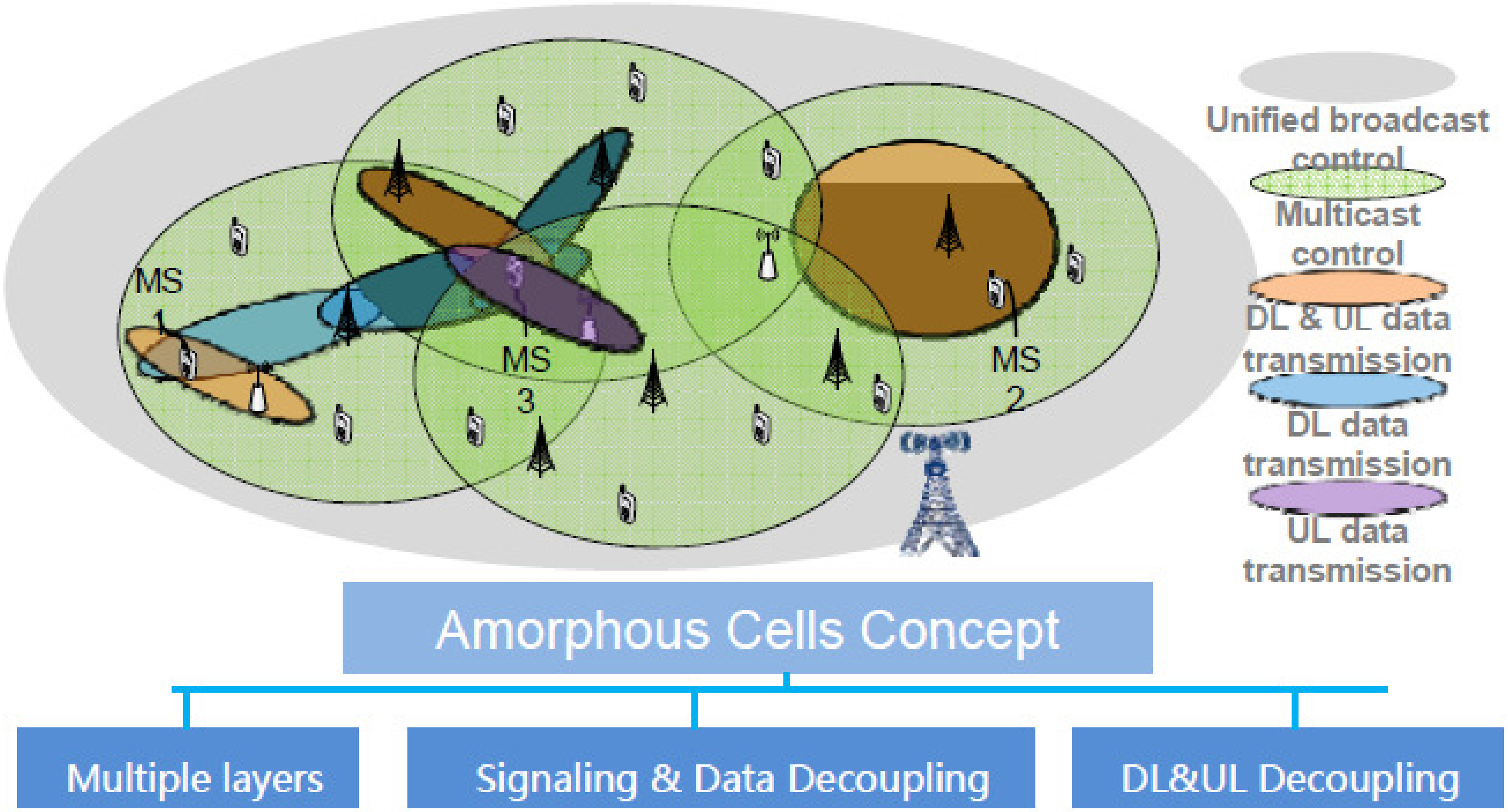
UP and CP separation

Control–data separation architecture (CDSA)

- Has a built-in feature to support the network-driven sleep mode methods with a **lower delay**, **lower on/off oscillations**, a **higher energy efficiency**, and a **higher QoS**.

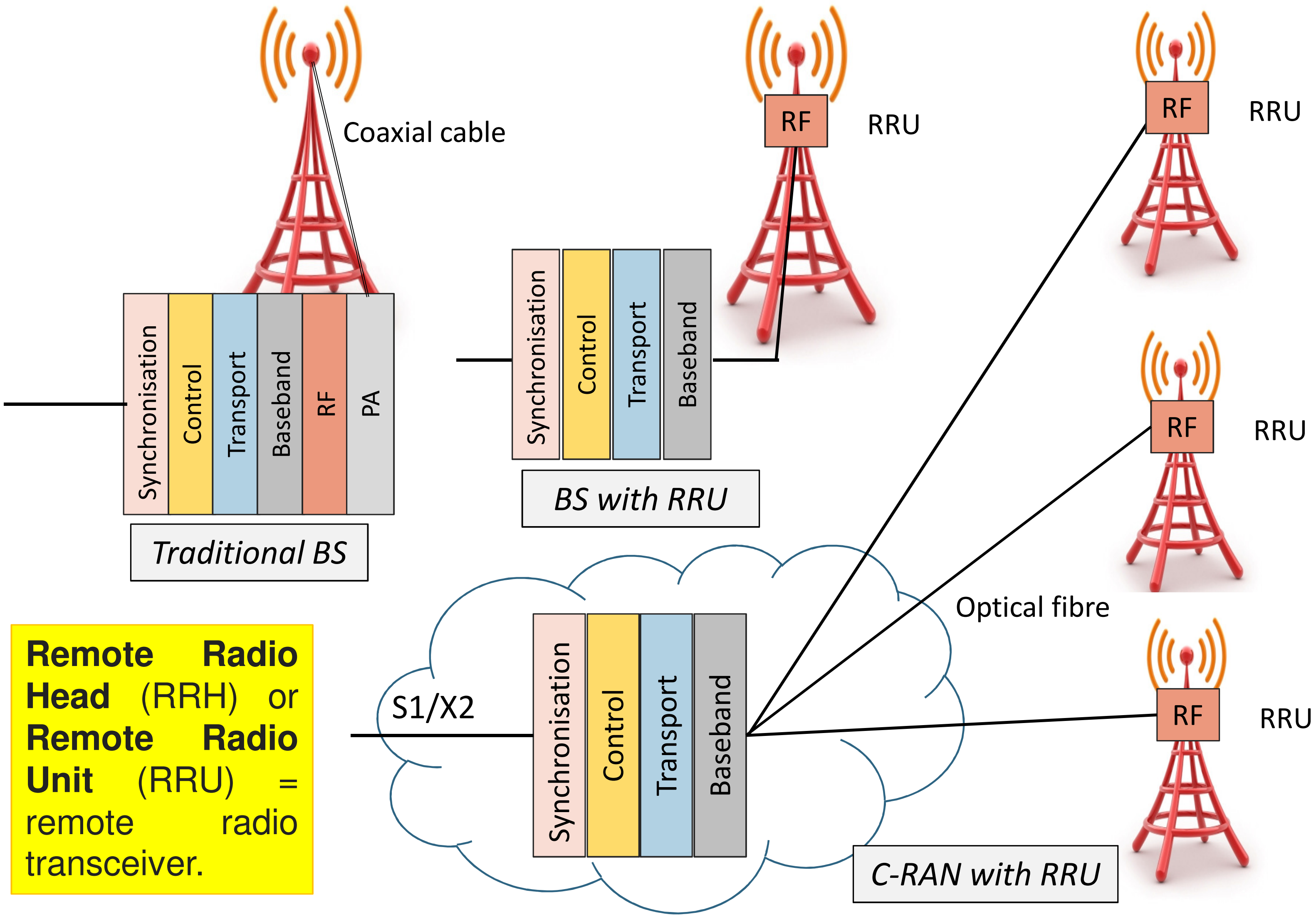


Cell concept changes



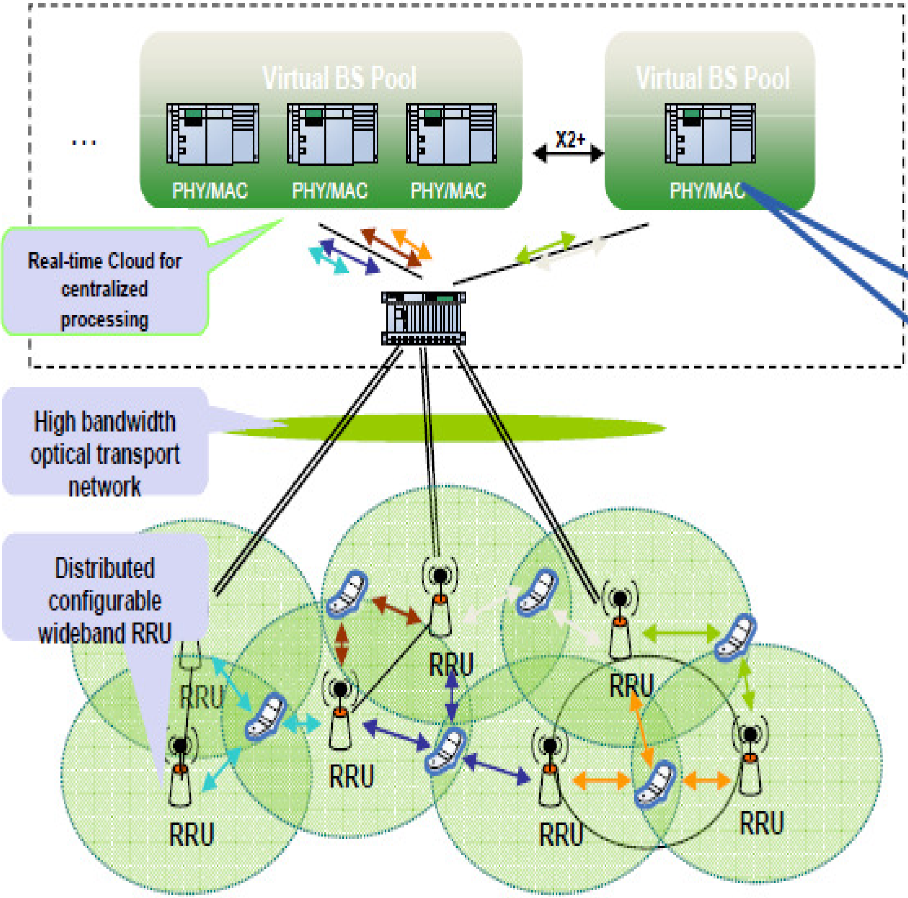
Cloud RAN

BS architecture evolution

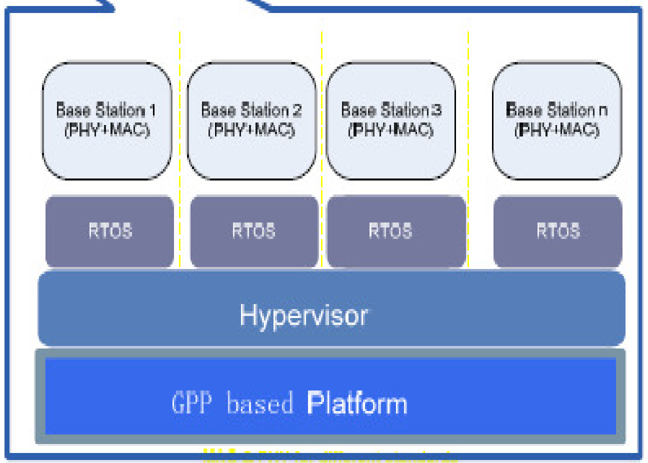


Remote Radio Head (RRH) or **Remote Radio Unit** (RRU) = remote radio transceiver.

C-RAN



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

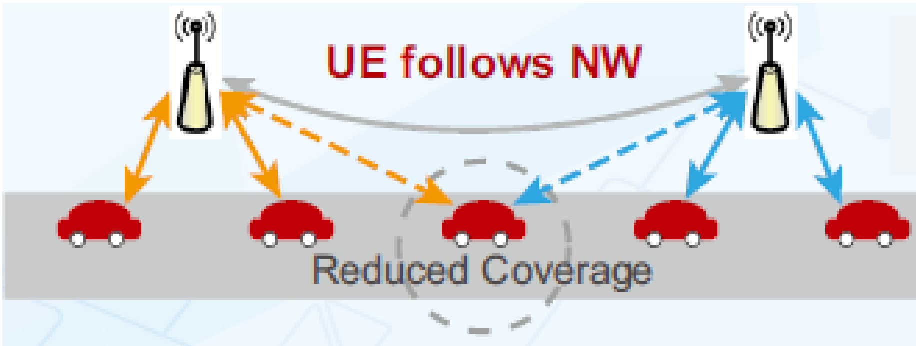


BS virtualization

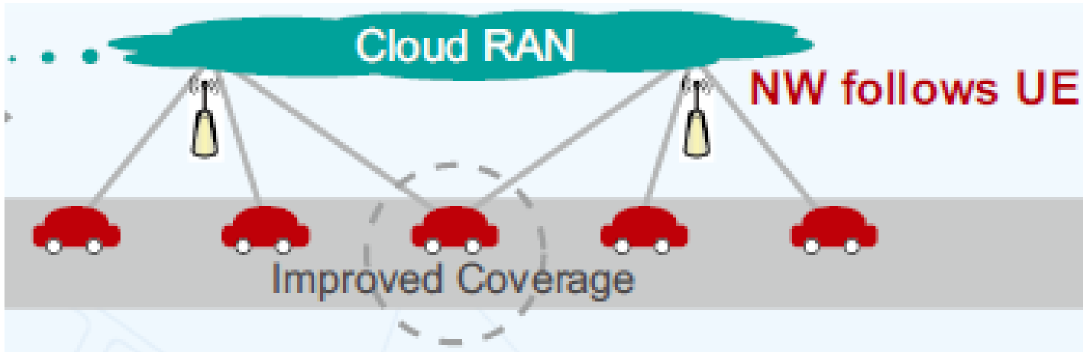
C-RAN allows significant savings in OPEX and CAPEX.
Ex. China Telecom: 53% savings in OPEX and 30% in CAPEX.

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.



RAN Slicing

Slicing objectives

- Slicing is introduced in **5G networks**
- Applied to **softwarized networks** (SDN/NFV/Clouds)
- Solves similar problems to MEC
- Enables deployment of **different** (QoS), multiple **large scale networks** with low OPEX and short TTM
- Gives the slice tenant **rich management capabilities**

Benefits of slicing

- **Shared infrastructure** but many networks with different features of:
  - ***Data plane*** (QoS, caching, encryption)
  - ***Customized Control Plane*** properties
  - ***Cross ISO stack operations*** (network well integrated with services)
  - ***Dynamic placement of functions*** (cf. follow-the-crowd approach)
- **Automated operations via orchestration**
  - Includes ***dynamic placement of functions*** on the edge
- **Ownership**
  - Slice owner may have ***control over its network slice***
- **Network slice on demand** (cf. every day early in the morning)
  - The infrastructure is ready
  - Slice templates (Blueprints) are reusable
  - On-demand slices can be created by the end users

Slice definition

A slice = a collection of *logical network functions* that supports the communication service requirements of particular use case(s)

- Initial purpose: **core network partitioning**,
- **RAN** needs also specific functionalities to support multiple slices or partitioning of resources for different network slices

Definitions

Network Function (NF): Network Function refers to ***processing functions*** in a network.

Service Instance: run-time construct of an ***end-user or a business service*** realized within or by a Network Slice

Network Slice Instance: ***set of run-time NFs, and resources*** to run these NFs, forming a complete instantiated ***logical network*** to meet certain network characteristics (e.g., ultra-low-latency, ultra-reliability , value-added services for enterprises, etc.) required by the Service Instance(s).

- The resources comprise ***physical and logical resources***.
- A Network Slice Instance may be composed of Sub-network Instances. The Network Slice Instance is defined by a *Network Slice Blueprint*.

Network Slice Blueprint: description of the structure, configuration and the plans/work flows for how to instantiate and control the Network Slice Instance. Enables the instantiation of a Network Slice, which provides certain network characteristics (e.g. ULL, …). A Network Slice Blueprint refers to ***required physical and logical resources*** and/or to Sub-network Blueprint(s).

Sub-network Instance: A Sub-network Instance is a run-time construct and comprises of a set of NFs and the resources for these NFs.

- The Sub-network Instance is defined by a Sub-network Blueprint.
- A Sub-network Instance may be shared by two or more Network Slices.

Physical resource: A physical asset for ***computation, storage or transport*** including radio access

Logical Resource: ***Partition of a physical resource***, or ***grouping of multiple physical resources*** dedicated to a NF or shared between a set of NFs.

Slicing concept details

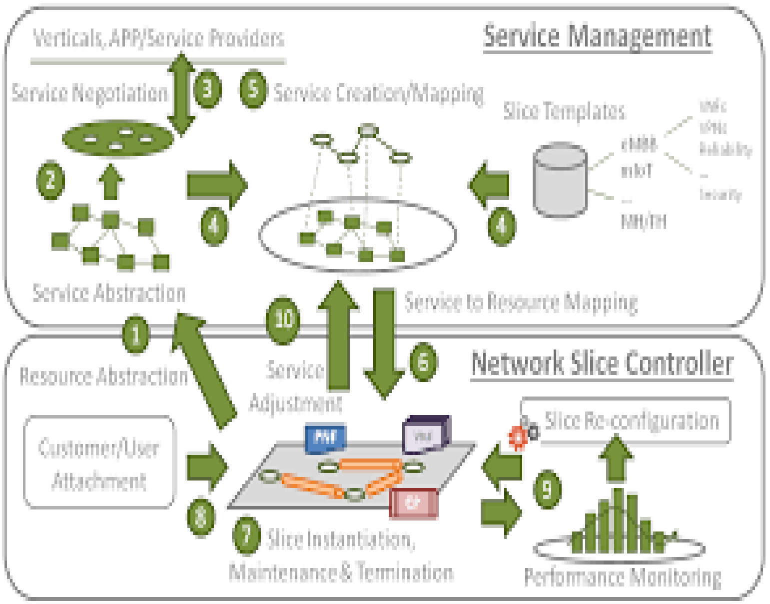
Services can be provided by the network operator or by 3rd parties.

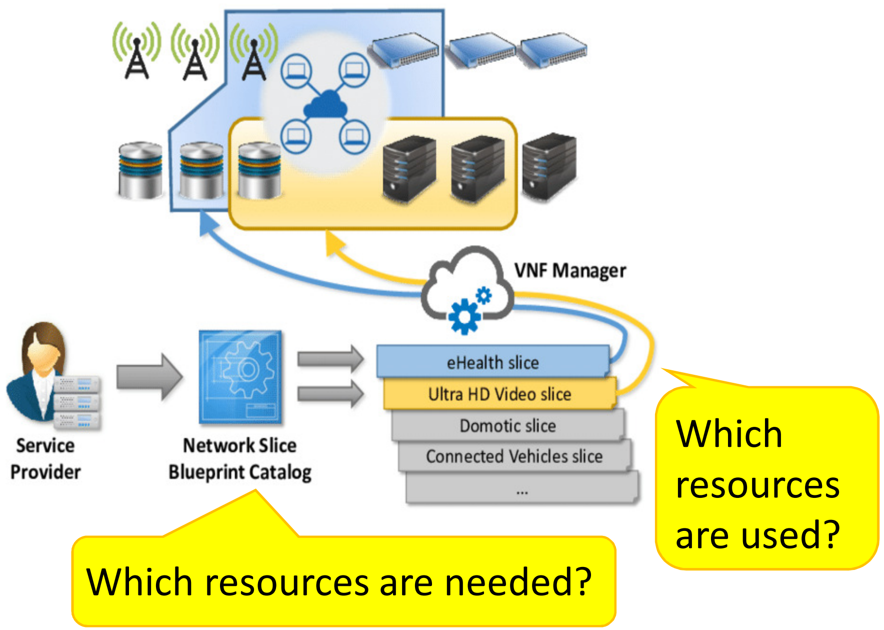
The network slicing concept = 3 layers:

Service Instance Layer
Represents the services which are to be supported. A Service Instance can either represent an *operator service* or a *3rd party provided* service
Network Slice Instance Layer
A network operator uses a **Network Slice Blueprint** to create a **Network Slice Instance**. A ***Network Slice Blueprint*** that provides the network characteristics required by a Service Instance. A **Network Slice Instance** provides the *network characteristics* which are required by a **Service Instance**
Resource layer
➢***Physical Resource***: computation, storage or transport ➢***Logical Resource***: partition of a physical resource, or grouping of multiple physical resources dedicated to a Network Function

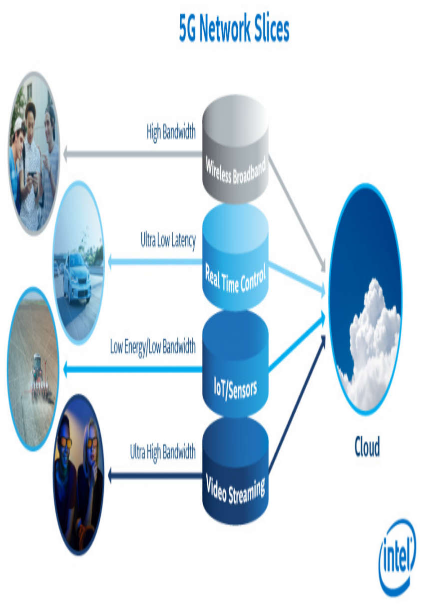
Network Slice Instances

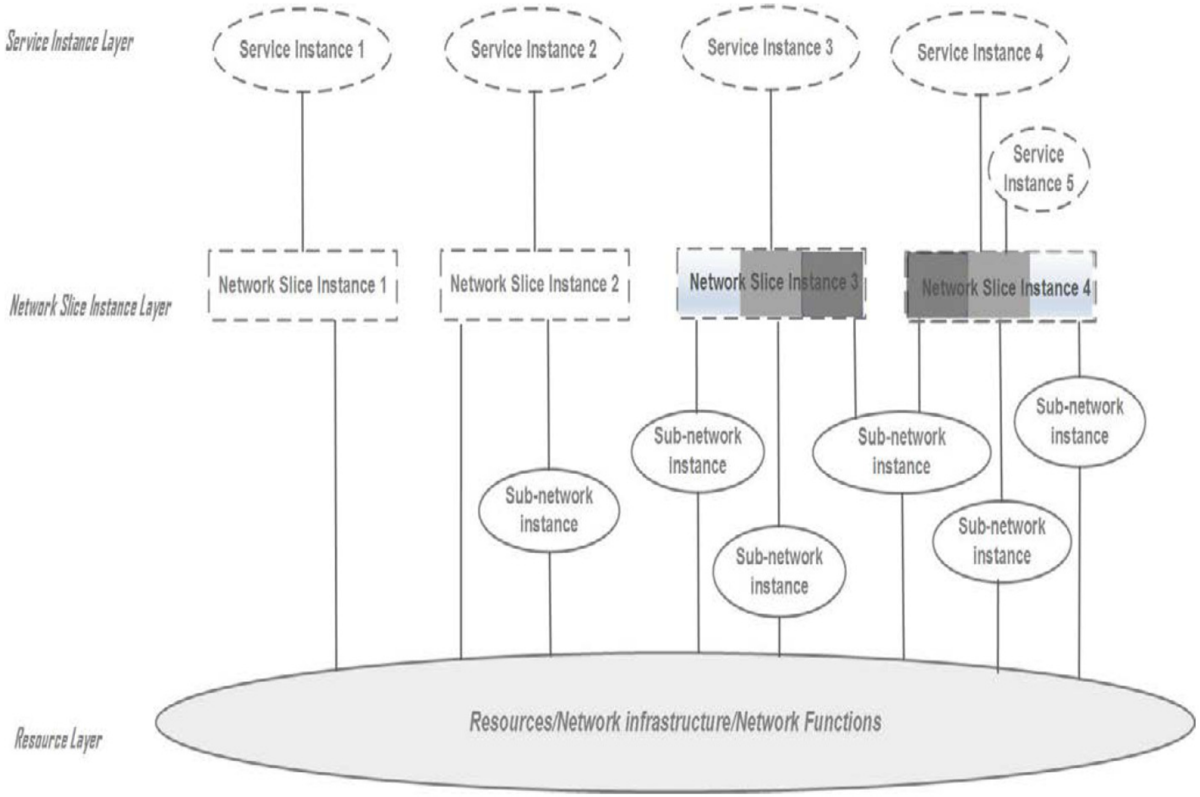
- The **Network Slice Instance** may be composed by zero, one or more *Sub-network Instances*, which may be shared by another *Network Slice Instance*. Similarly, the **Sub-network Blueprint** is used to create a *Sub-network Instance* to form a set of *Network Functions*, which run on the ***physical/logical resources***.





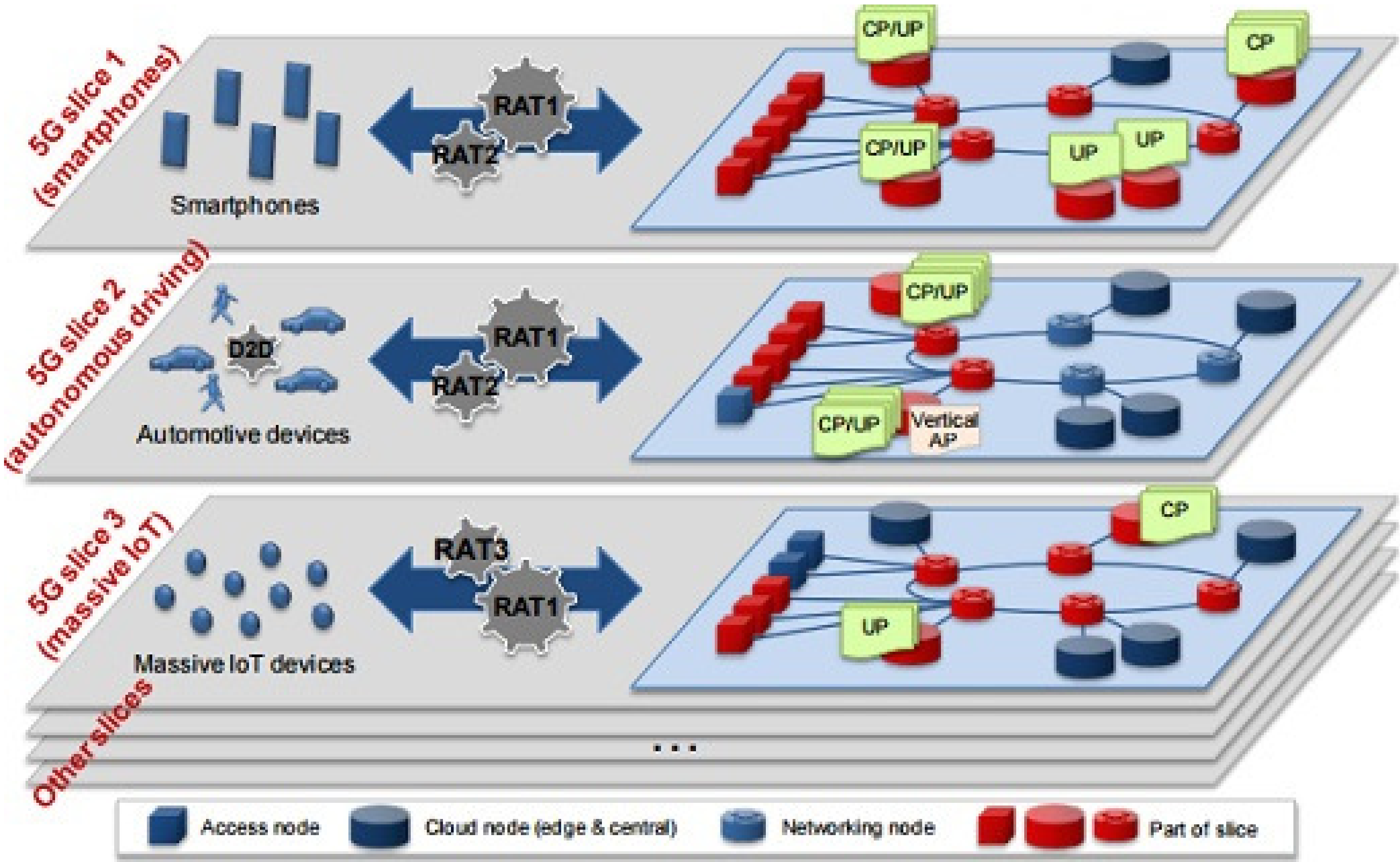
Network slicing conceptual outline





Examples of a network slice instance: Enhanced MBB, M2M, Enterprise and Industry etc.

Resources slicing principle in 5G



The 3 main ways of wireless access virtualization

- **Flow Oriented** (Management, Scheduling, Service differentiation of different data flows from different slices)

  Traffic slicing

- **Protocol Oriented** (Isolate, customize, and manage the multiple wireless protocol instances on the same radio hardware)

  System slicing

- **Spectrum Oriented** (RF bands and Raw spectrum are sliced which decouples the RF front end from the protocol, allowing multiple front ends to be used by a single node, or for a single RF front end to be used by multiple virtual wireless nodes)

  Frequency slicing

Agenda

II. 3GPP Release 15

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).

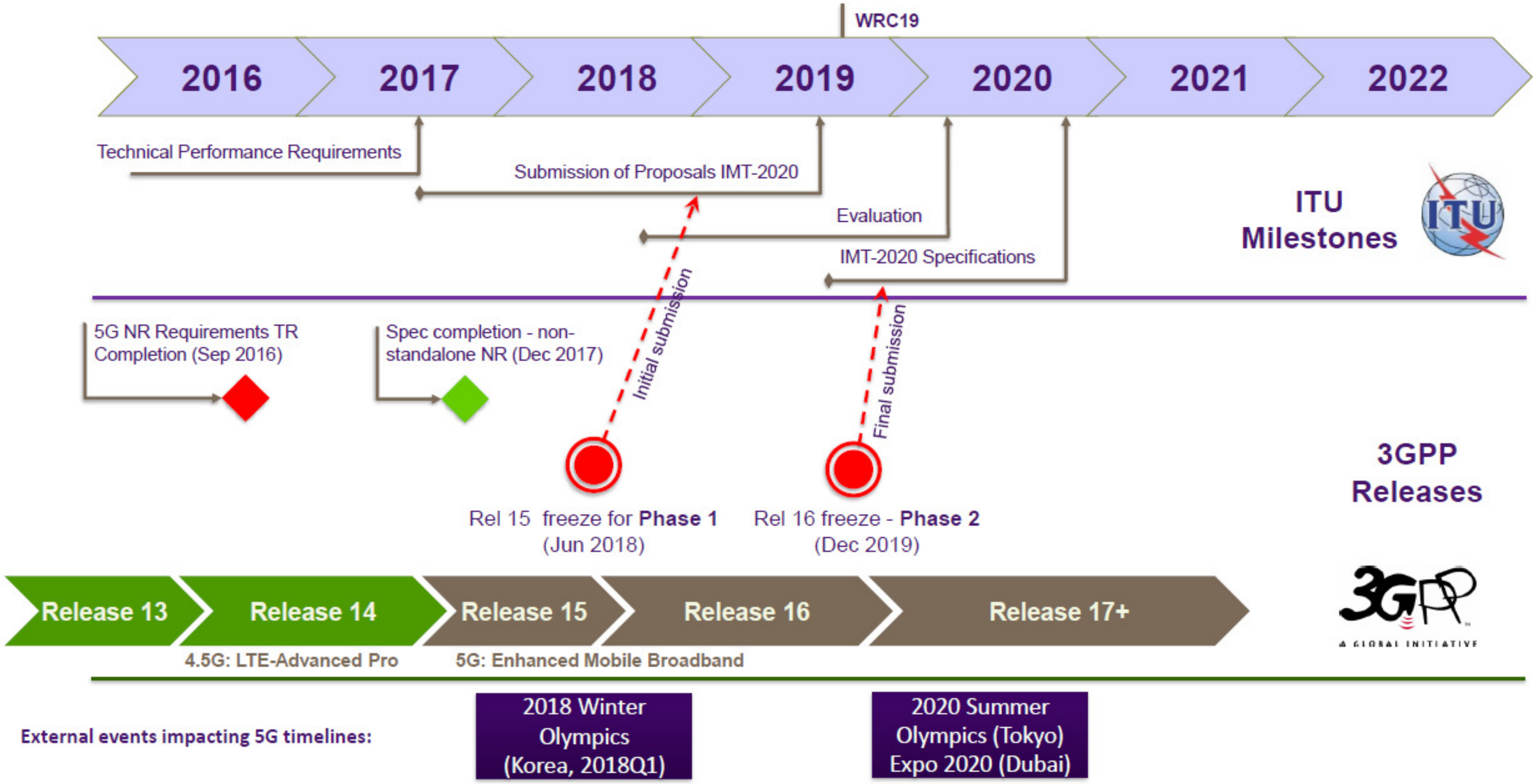
➢ **Massive Machine-Type Communications** (mMTC): infrequent, massive, and small packet transmissions for **mMTC** (with 10 s latency).

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 Timelines: ITU-R and 3GPP



5G Phase 1 (Release 15)

- Operates in any frequency band, including **low, mid, and high bands**.
- Support both **LTE** and **5G NR**, including dual connectivity with which devices have simultaneous connections to LTE and NR.
- A system architecture for user services with **different access systems**, such as **WLAN**.
- **5 Gbps peak DL** throughput in initial releases, **increasing to 50 Gbps** in subsequent versions.
- **OFDMA** in DL 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 (TDD could be dominant: 30X FDD).
- Numerologies of **2N X 15 kHz** for subcarrier spacing up to **120 kHz or 240 kHz.** This scalable OFDM approach supports both narrow radio channels (for example, 1 MHz), or wide ones (up to 400 MHz per component carrier). 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 1 (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.
- **Scalable transmission time intervals** with ***short time intervals for low latency*** and ***longer time intervals for higher spectral efficiency***.
- Dynamic **co-existence with LTE** in the same radio channels.
- Network **slicing**

5G Phase 2 (Release 16)

- **URLLC**.
- Unlicensed spectrum operation **below 7 GHz**, likely based on current LTE approaches such as LAA.
- **Integrated access and backhaul**.
- NR-based **C-V2X**.
- 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*.
- **Non-orthogonal multiple access**.

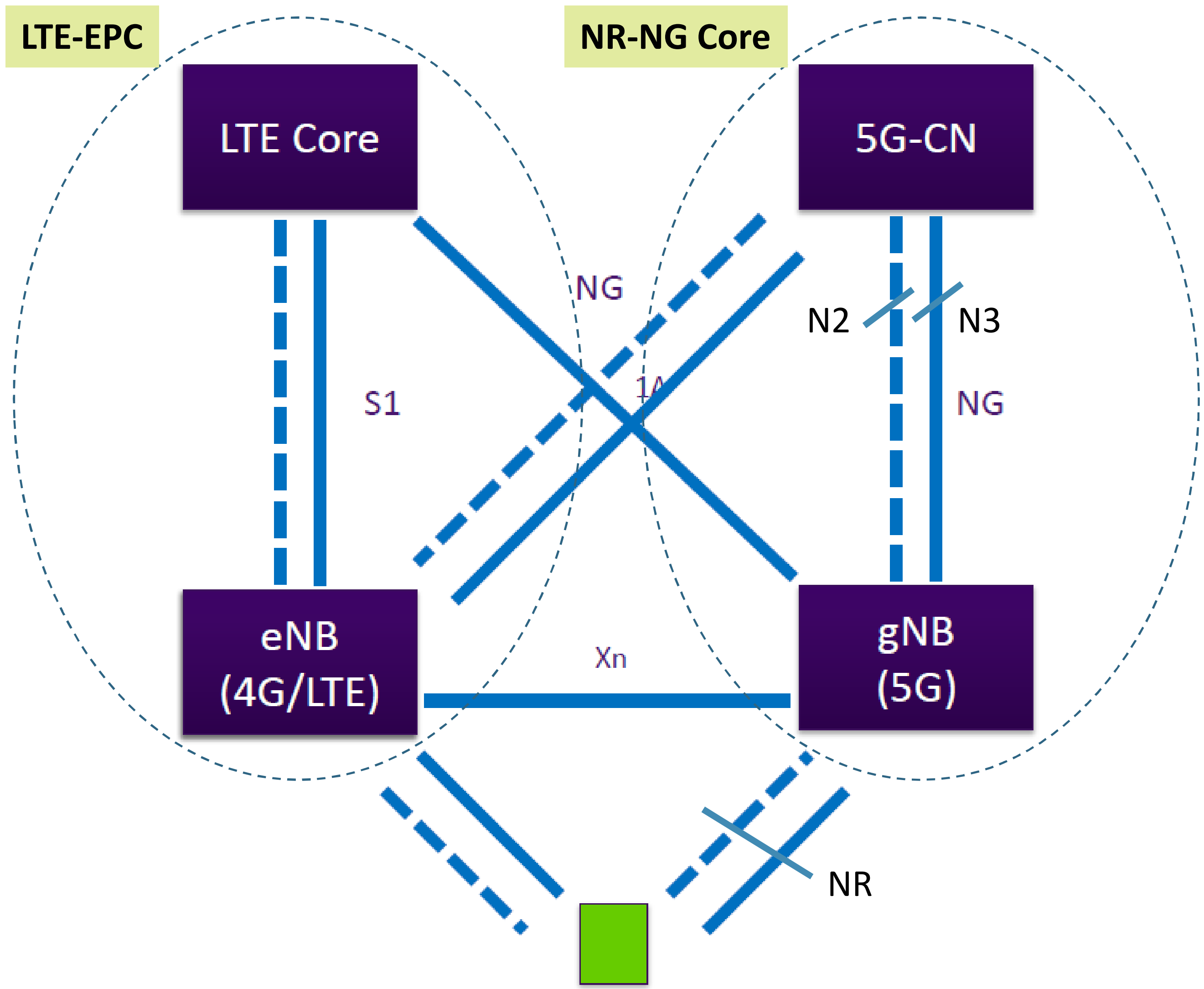
Agenda

a. Architecture and Protocols

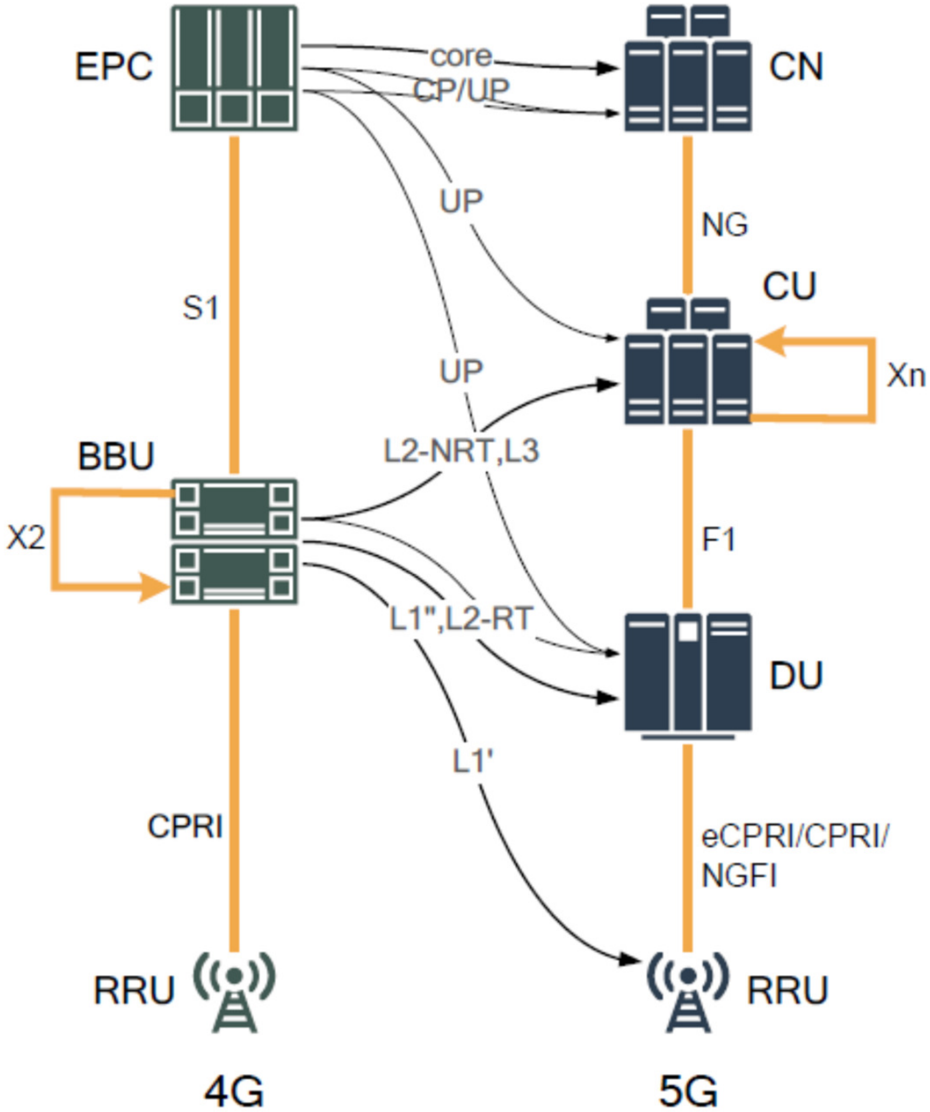
Main architecture changes

- Network **slicing**
- **CUPS** (Control and User Plane Separation) for flexible placement of UPF (central, closer to the RAN, etc.)
- **SBA** (Service Based Architecture)
- Flexible Non-3GPP access **interworking**

5G Architecture Evolution

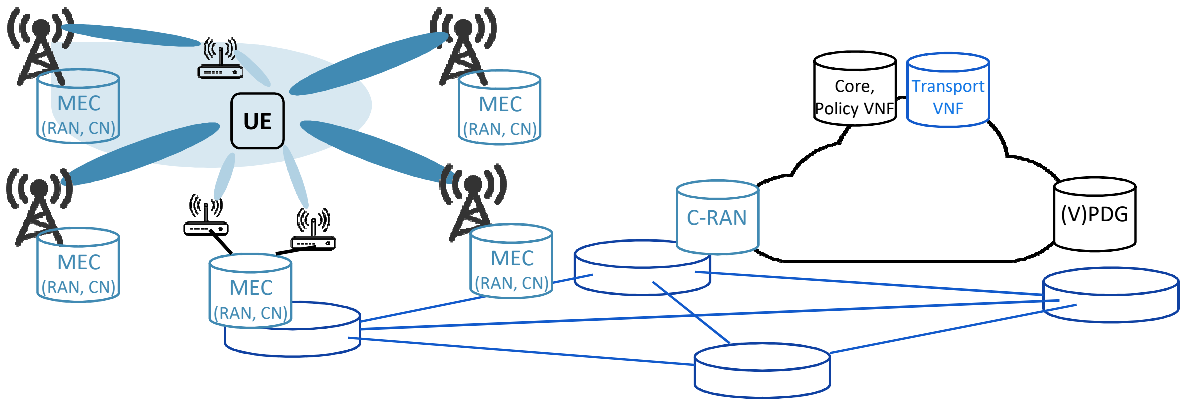


4G to 5G Network Entities Evolution



CU: Centralized Unit
DU: Distributed Unit

Softwarisation of the network



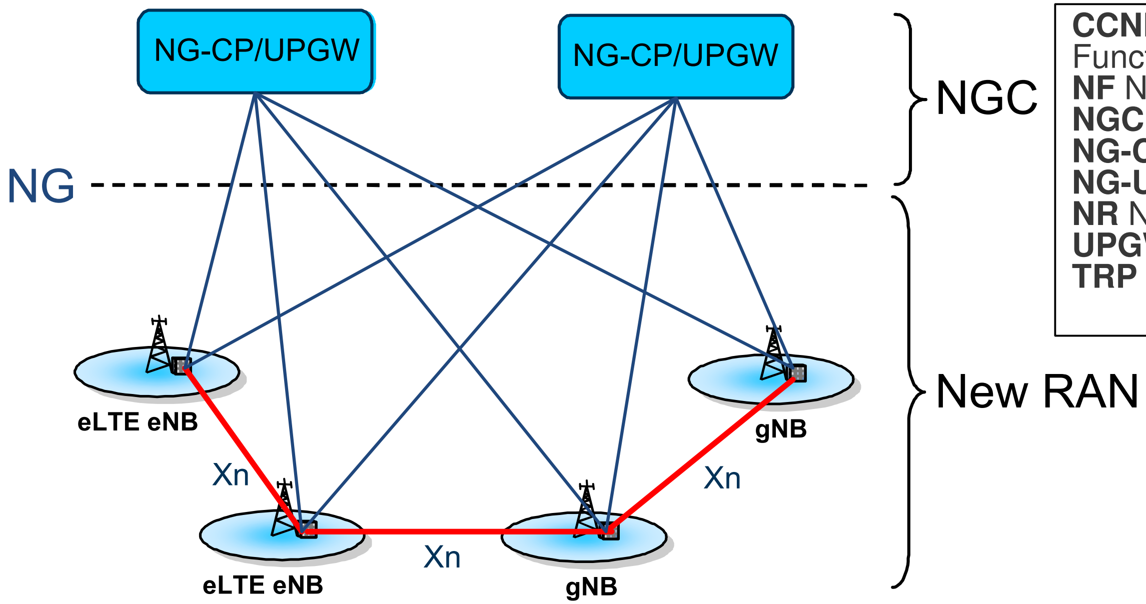
C-RAN – removal of functionality from cell sites to consolidation point in the network

NFV and SDN – enabling flexibility in where functions are deployed and scaled

MEC – pushing Core Network functions and content ingress to cell sites

CP/UP split – decoupling of user plane traffic from control plane functions (**CUPS**: *Control and User Plane Separation*)

New RAN architecture



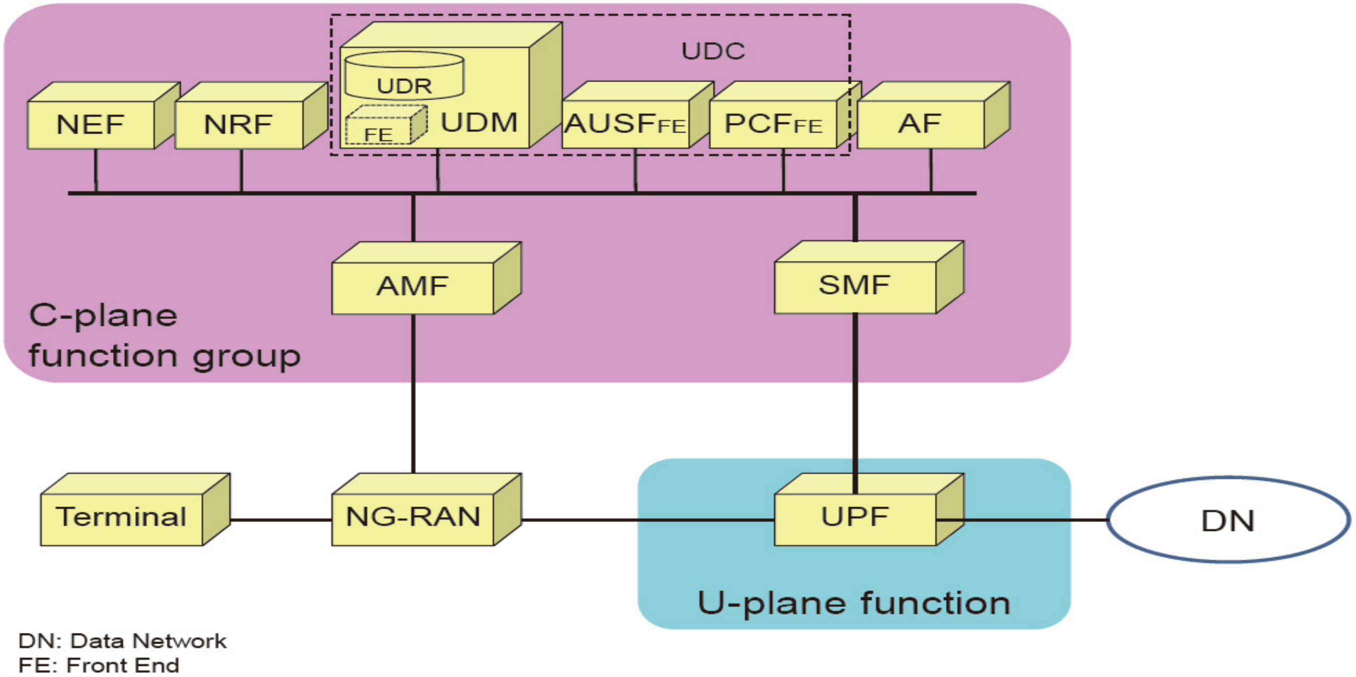
CCNF Common Control Network Function
NF Network Function
NGC Next Generation Core
NG-C NG Control Plane interface
NG-U NG User Plane interface
NR New Radio
UPGW User Plane Gateway
TRP Transmission Reception Point

Network Function: A Network Function is a ***logical node within a network infrastructure*** that has well-defined external interfaces and well-defined functional behaviour.

- **Connections** among NFs are made via a uniform interface called a **service-based interface**
- Individual NF consists of *smaller unit functions* called **NF services**
- An NF service in a certain NF can directly access an NF service in another NF without passing through another node
- Protocols for the service-based interface: **HTTP** and **JSON**

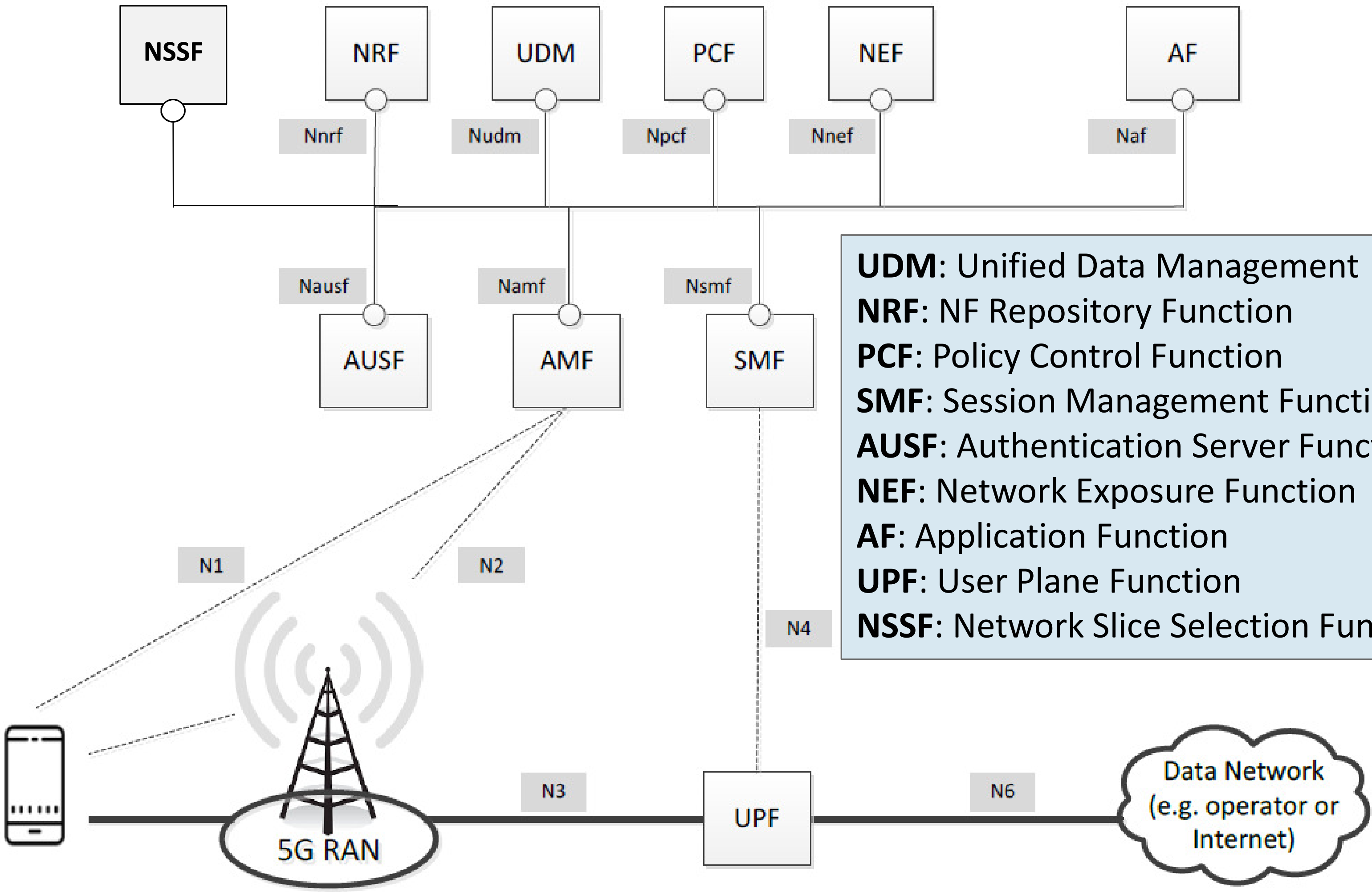
Architecture principles

U-plane function (User Plane Function, UPF) is separated from the C-Plane function group



- Terminal-related management is performed at one location and the traffic is handled on multiple slices
- These functions are reallocated in AMF and SMF: MM can be performed in a centralized manner and session management can be located in each network slice (/4G where the MME performs SM in addition to MM which is inconvenient

Service Based Architecture Network

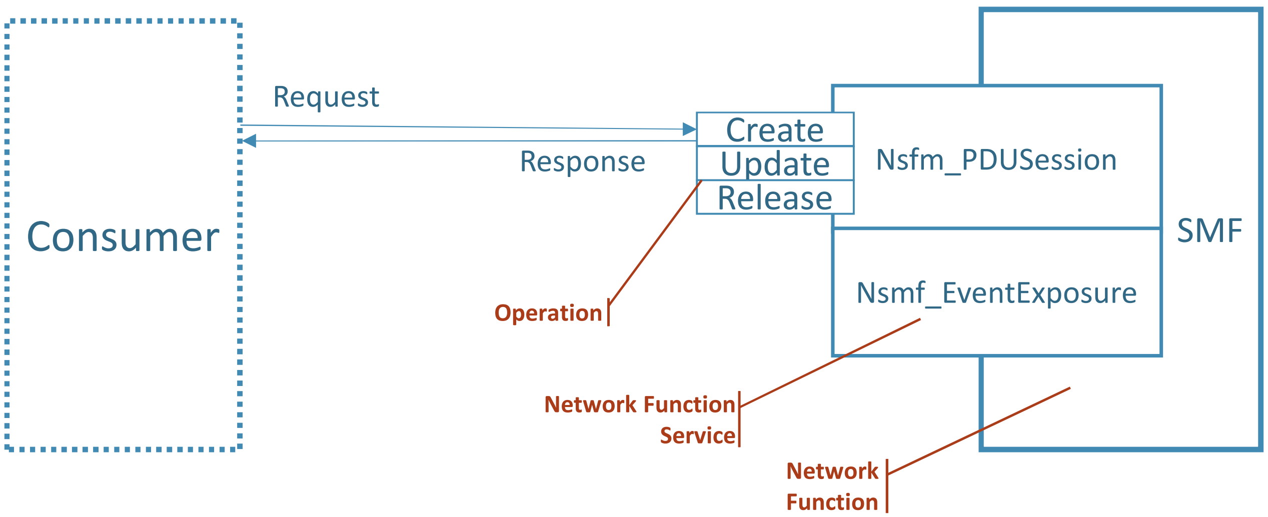


UDM: Unified Data Management
NRF: NF Repository Function
PCF: Policy Control Function
SMF: Session Management Function
AUSF: Authentication Server Function
NEF: Network Exposure Function
AF: Application Function
UPF: User Plane Function
NSSF: Network Slice Selection Function

All interactions are abstracted as: Request-Response, Subscription-Notify
System procedures are described as a sequence of NF service invocations

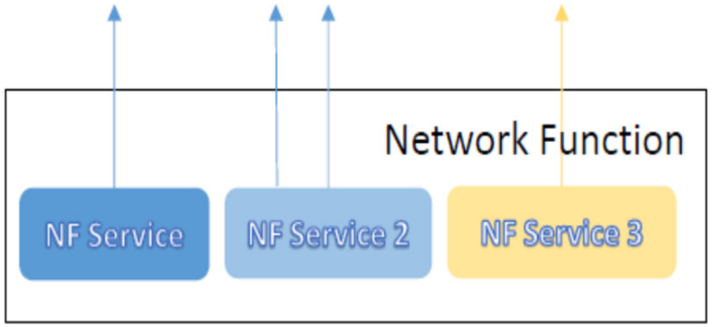
Network functions

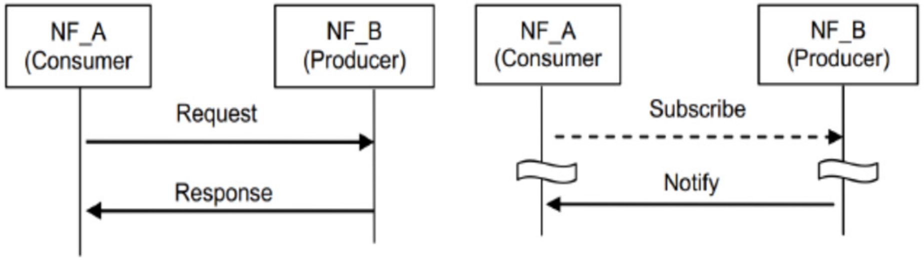
- Each entity in the architecture = ***Network Function***
- Entities of the *Service Based Architecture*
  - Each of the interfaces to the Network Functions is a Service Based Interface (e.g. Nsmf)
  - Each NF supports one or more Network Function Services exposed via its *Service Based Interface*
  - Each *Network Function Service* supports one or more *Operations*
- Operations can be invoked by other entities (Consumers)
- Defines procedures (interactions between NFs) as services : registration, connection establishment, location update, detach, etc.



Service Based architecture concept

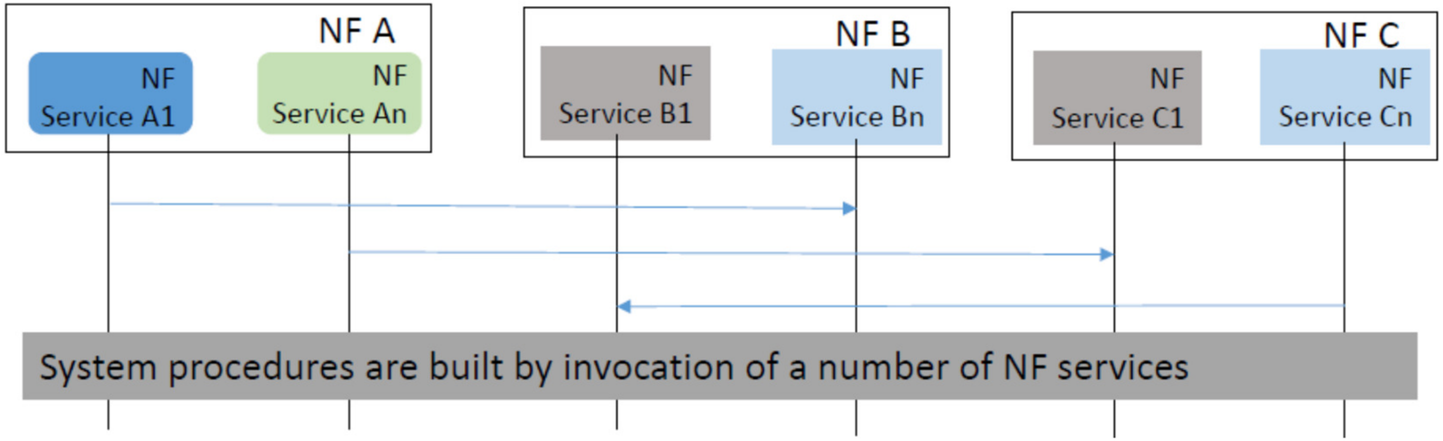
5G Service-Based Architecture is defined with "**Network function service**" + "**Service-based interface**"



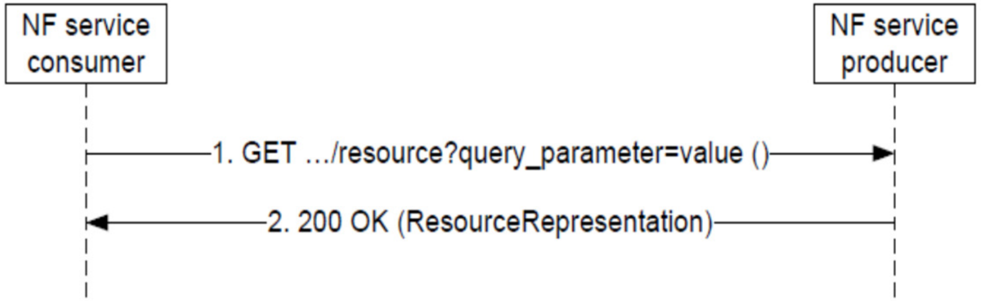


An NF service is one type of capability exposed by an NF (**NF Service Producer**) to other NF (**NF Service Consumer**)

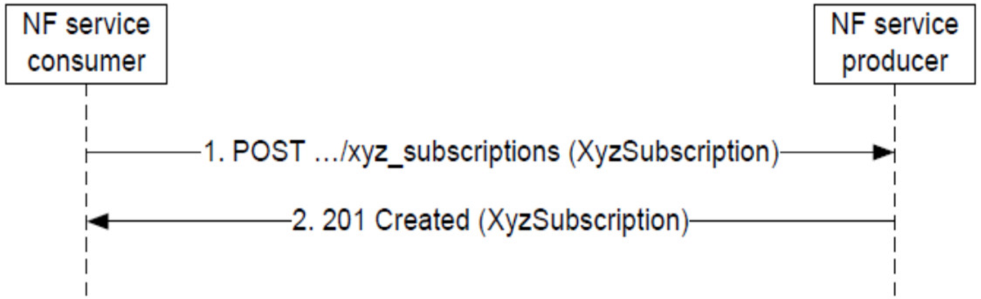
Two types of primitive operations: "**Request & Response**" and "**Subscribe-Notify**"



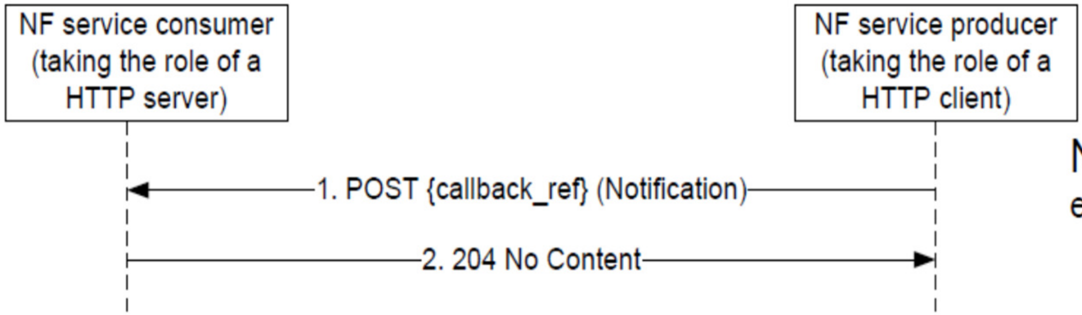
Examples of API operations



Query (Resource)
e.g. UE's Authentication Data @UDF

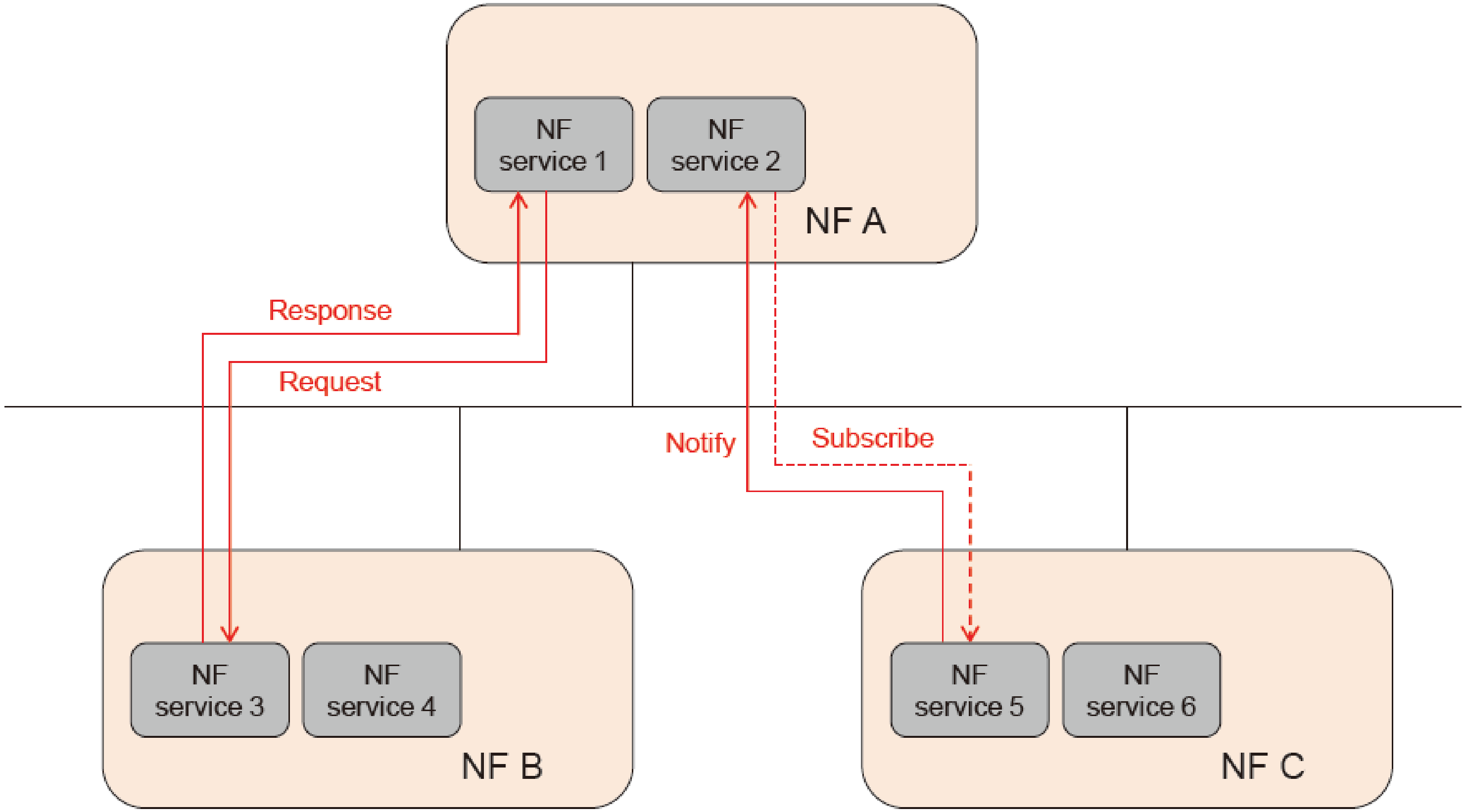


Subscription
e.g. to UE's mobility events @AMF

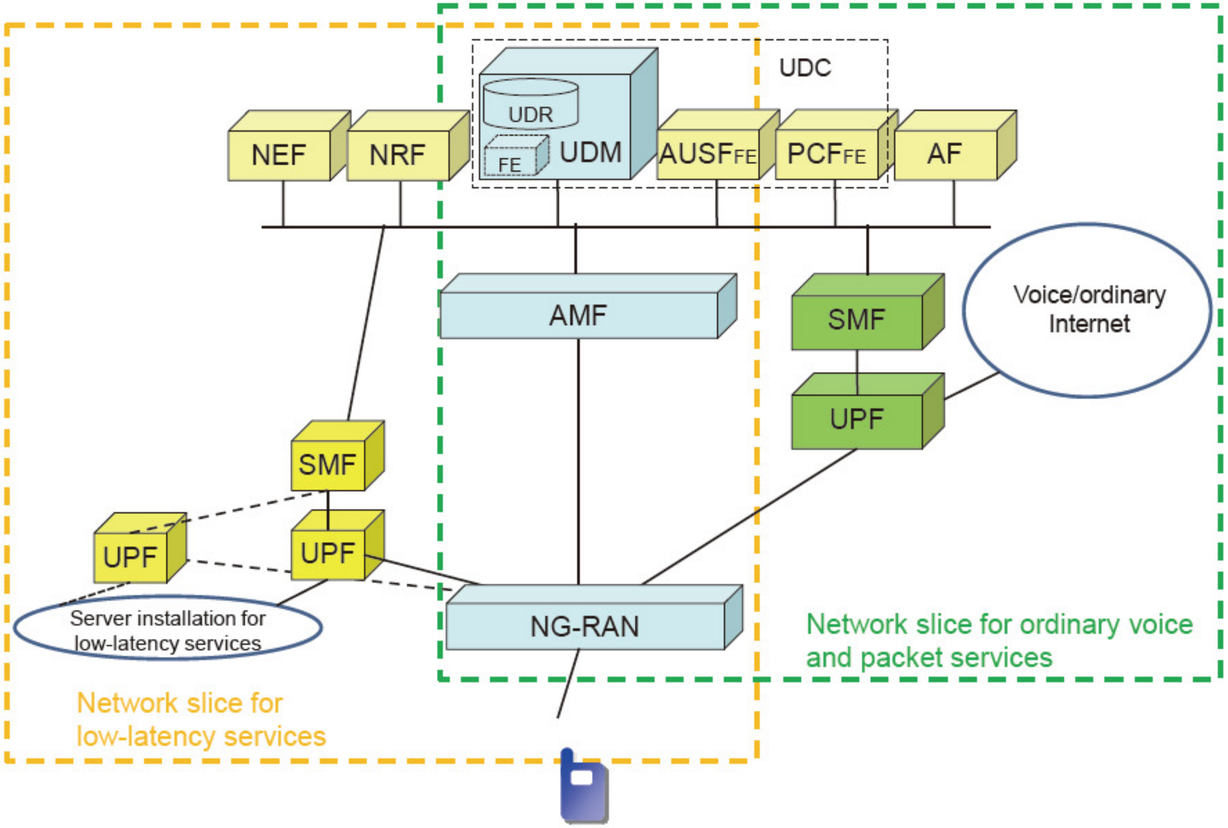


Notification
e.g. about UE mobility events

NF services interactions



Simultaneous connection to session-related nodes



- Each set of SMF/UPF belongs to a different network slice
- NG-RAN and functions like AMF are shared

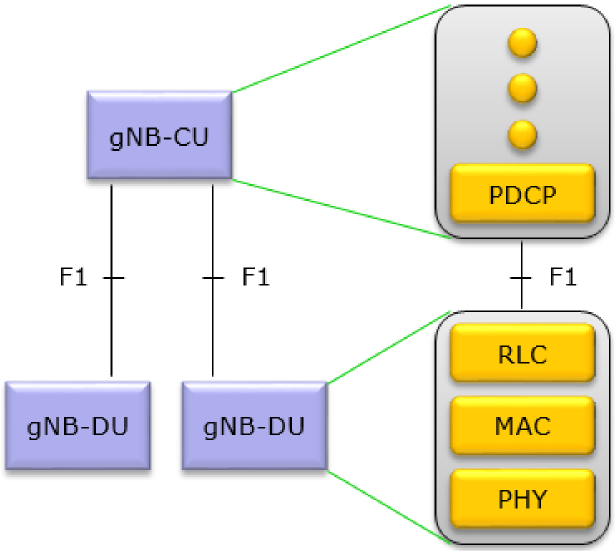
- The network slice for low-latency communication (LLC) services places the UPF at a location geographically near radio access
- Multiple SMFs are not needed but for LLC it is better to separate SMFs to avoid effects such as congestion

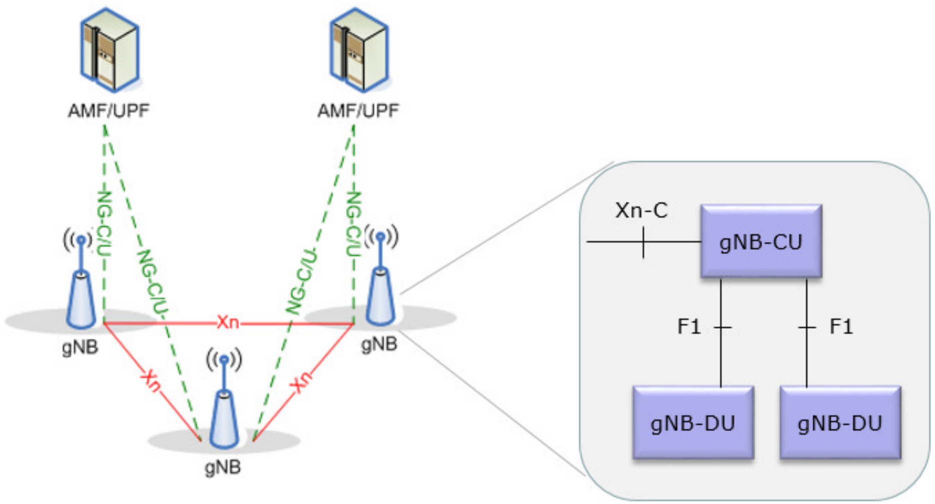
gNB and ng-eNB functions

- **RRM functions**: RB Control, Radio AC, Connection Mobility Control, Scheduling;
- IP **header compression**, **encryption** and **integrity** protection of data;
- **Selection of an AMF** at UE attachment when no routing to an AMF can be determined from the information provided by the UE;
- **Routing** of **User Plane data** towards **UPF(s)**;
- **Routing** of **Control Plane** information towards **AMF**;
- **Connection setup and release**;
- Scheduling and transmission of: **paging messages** and **system broadcast information** (AMF or O&M);
- **Measurement and measurement reporting** configuration;
- **Transport level packet marking** in the uplink;
- **Session Management**;
- **Support of Network Slicing**;
- **QoS Flow management** and mapping to data radio bearers;
- Support of UEs in RRC_INACTIVE state;
- Distribution function for NAS messages;
- Radio access network sharing;
- Dual Connectivity;
- Tight interworking between NR and E-UTRA.

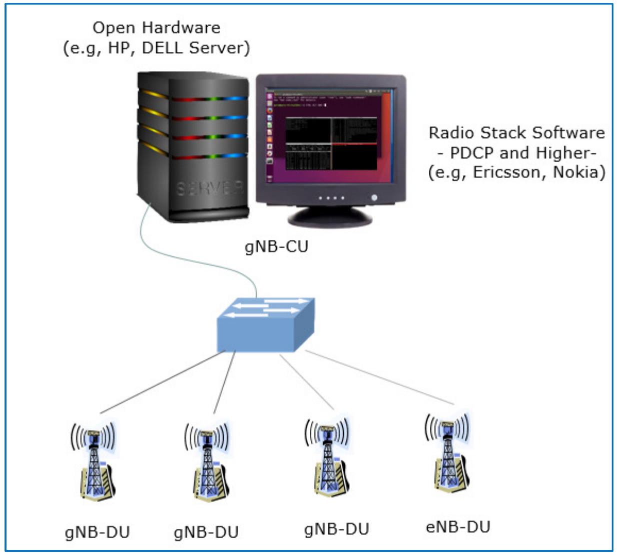
gNB Architecture

The gNB internal structure is split into two parts called **CU** (*Central Unit*) and **DU** (*Distributed Unit*)
It helps to virtualize the network functionalities: Virtualization means *flexibility* and *cost reduction*





CU : Central Unit
DU : Distributed Unit



Core network functions

Core Access and Mobility Management Function (AMF)

- Termination point for RAN CP interfaces (N2)
- ***UE Authentication & Access Security***.
- ***Mobility Management*** (Reachability, Idle/Active Mode mobility state handling)
- ***Registration Area*** management;
- Access Authorization including check of roaming rights;
- Session Management Function (SMF) selection
- ***NAS signaling*** including ***NAS Ciphering and Integrity protection***, termination of MM NAS and forwarding of SM NAS (N1).
- AMF obtains information related to MM from UDM.
- May include the ***Network Slice Selection Function*** (NSSF)
- Attach procedure without session management adopted in CIoT implemented in EPC is defined also in 5GCN (registration management procedure)
- User Plane (UP) selection and termination of N4 interface (*AMF has part of the MME and PGW functionality from EPC*)

Data Network (DN)

- Services offered: Operator services, Internet access, 3rd party services

Authentication Server Function (AUSF)

- Contains mainly the ***EAP authentication*** server functionality
- Storage for ***Keys*** (*part of HSS from EPC*)
- Obtains authentication vectors from UDM and achieves UE authentication.

NF Repository Function (NRF)

- Provides profiles of *Network Function* (NF) instances and their supported services within the network
- Service discovery function, maintains NF profile and available NF instances. (*not present in EPC world*)

NRF offers to other NFs the following services:

- *Nnrf_NFManagement*
- *Nnrf_NFDiscovery*
- *OAuth2 Authorization*

Core network functions

Network Exposure Function (NEF)

- Provides ***security*** for services or AF accessing 5G Core nodes
- Seen as a ***proxy***, or ***API aggregation point***, or translator into the Core Network
- Secure provision of information from external application to 3GPP network, translation of internal/external information (*not present in EPC world*)
- *NF profile of NF instance* : NF instance ID, NF type, PLMN ID, Network Slice related Identifier(s) e.g. S-NSSAI, NSI ID, FQDN or IP address of NF, NF capacity information, NF Specific Service authorization information, Names of supported services, Endpoint information of instance(s) of each supported service, Identification of stored data/information
- *Secure provision of information from external application to 3GPP network*: The NEF may authenticate and authorize and assist in throttling the AF.

NEF

- *Translation of internal-external information*: It translates between information exchanged with the AF and information exchanged with the internal network function. NEF handles masking of network and user sensitive information to external AF's according to the network policy.

Services supported by the NEF:

- *Nnef_EventExposure service*
- *Nnef_Trigger service*
- *Nnef_BDTPNegotiation service*
- *Nnef_ParameterProvision service*
- *Nnef_PFDmanagement service*
- *Nnef_TrafficInfluence service*

Core network functions

Policy Control Function (PCF)

- Expected to have similarities with the existing policy framework (4G PCRF)
- Updates to include the addition of 5G standardized mobility based policies (*part of the PCRF functionality from EPC*)

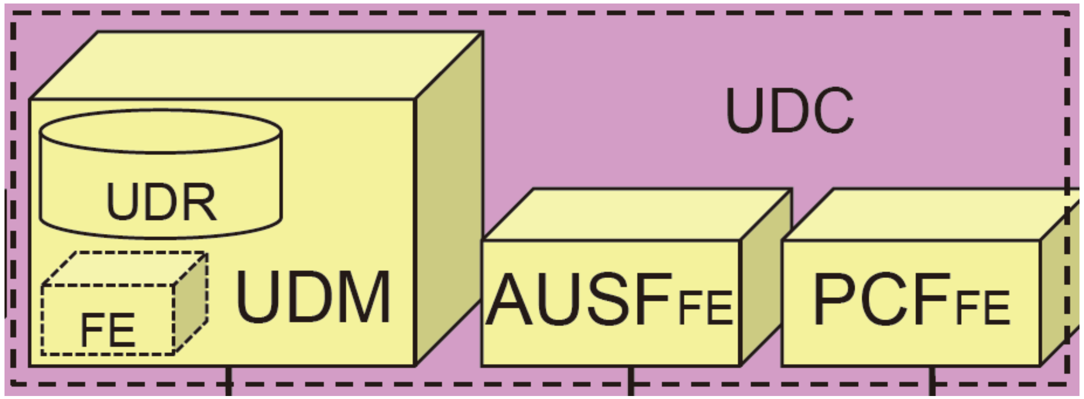
Session Management Function (SMF)

- DHCP functions
- Termination of NAS signaling related to session management
- Sending QoS/policy N2 information to the Access Network (AN) via AMF
- Idle/Active aware
- **Session** Management information obtained from UDM
- DL data notification
- Selection and control of **UP function**
- Control part of **policy enforcement** and QoS.
- ***UE IP address allocation & management***
- Policy and Offline/Online ***charging*** interface termination
- ***Policy enforcement*** control part
- ***Lawful intercept*** (CP and interface to LI System)

Core network functions

Unified Data Management (UDM)

- Similar functionality as the ***HSS*** in Release 14 EPC



User Data Convergence (UDC) concept: separates user information storage and management from the front end

- **User Data Repository** (UDR): storing and managing subscriber information processing and network policies
- The front-end section: **Authentication Server Function** (AUSF) for authentication processing and **Policy Control Function** (PCF).

Core network functions

User Plane Function (UPF)

- Allows for numerous configurations which essential for latency reduction
- Anchor point for Intra-/Inter-RAT mobility
- ***Packet routing and forwarding***
- QoS handling for User Plane
- ***Packet inspection and PCC rule enforcement***
- Lawful intercept (UP Collection)
- Roaming interface (UP)
- May integrate the FW and Network Address Translation (NAT) functions
- Traffic counting and reporting (UPF includes SGW and PGW functionalities)

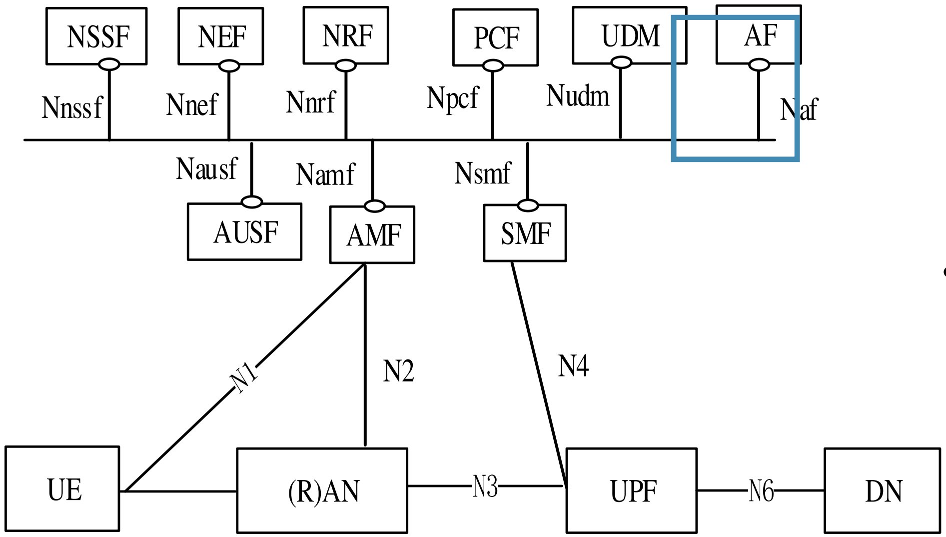
Application Functions (AF)

- Services considered to be trusted by the operator
- Can access Network Functions directly or via the NEF
- AF can use the PCF interface PCF for requesting a given QoS applied to an IP data flow (e.g., VoIP).
- Un-trusted or third-party AFs would access the Network Functions through the NEF (*same as AF in EPC*)

Network Slice Selection Functions (NSSF)

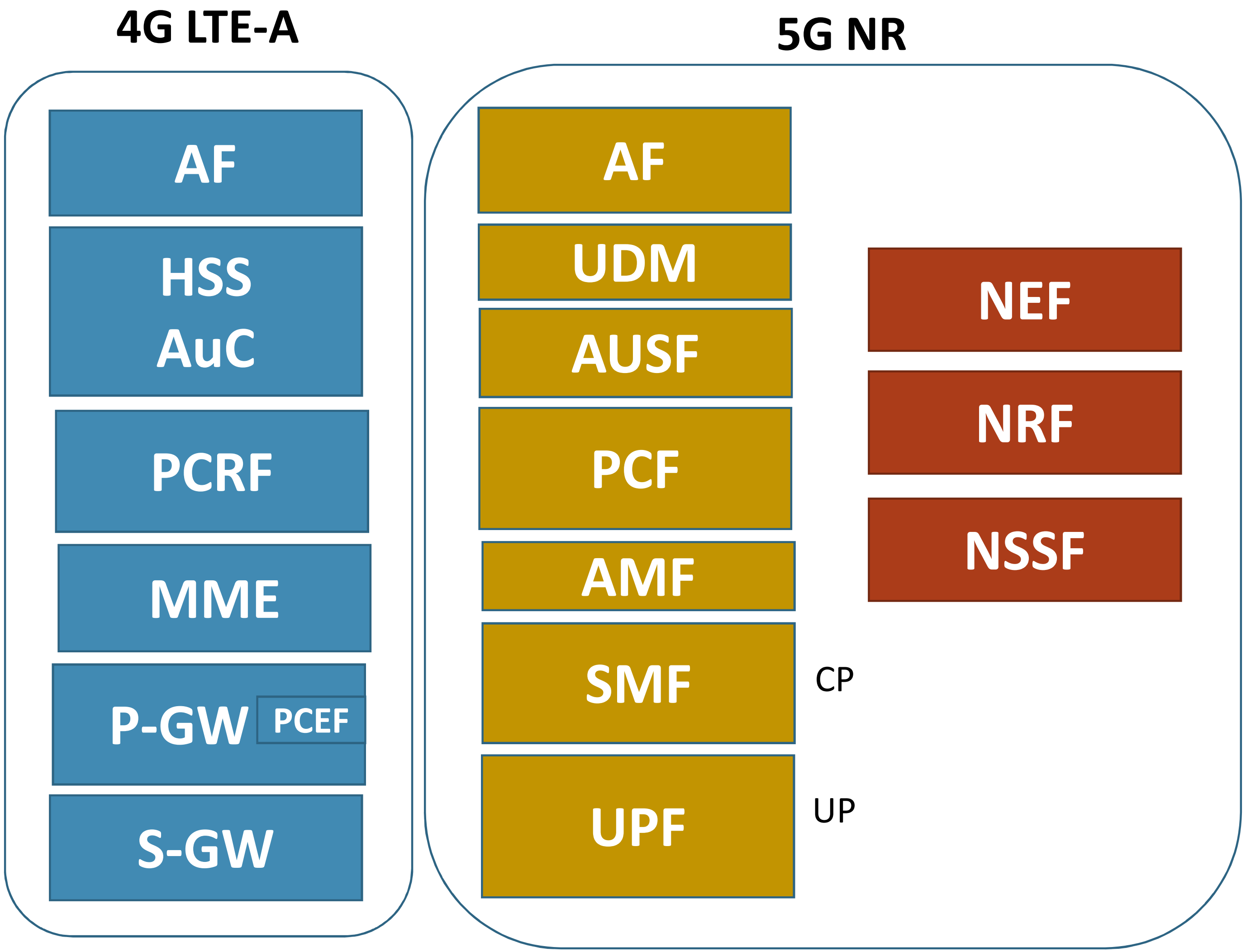
- Selecting of the Network Slice instances to a UE, determining the allowed NSSAI,
- Determining the AMF set to be used to serve the UE *(not present in EPC world)*

Application Function

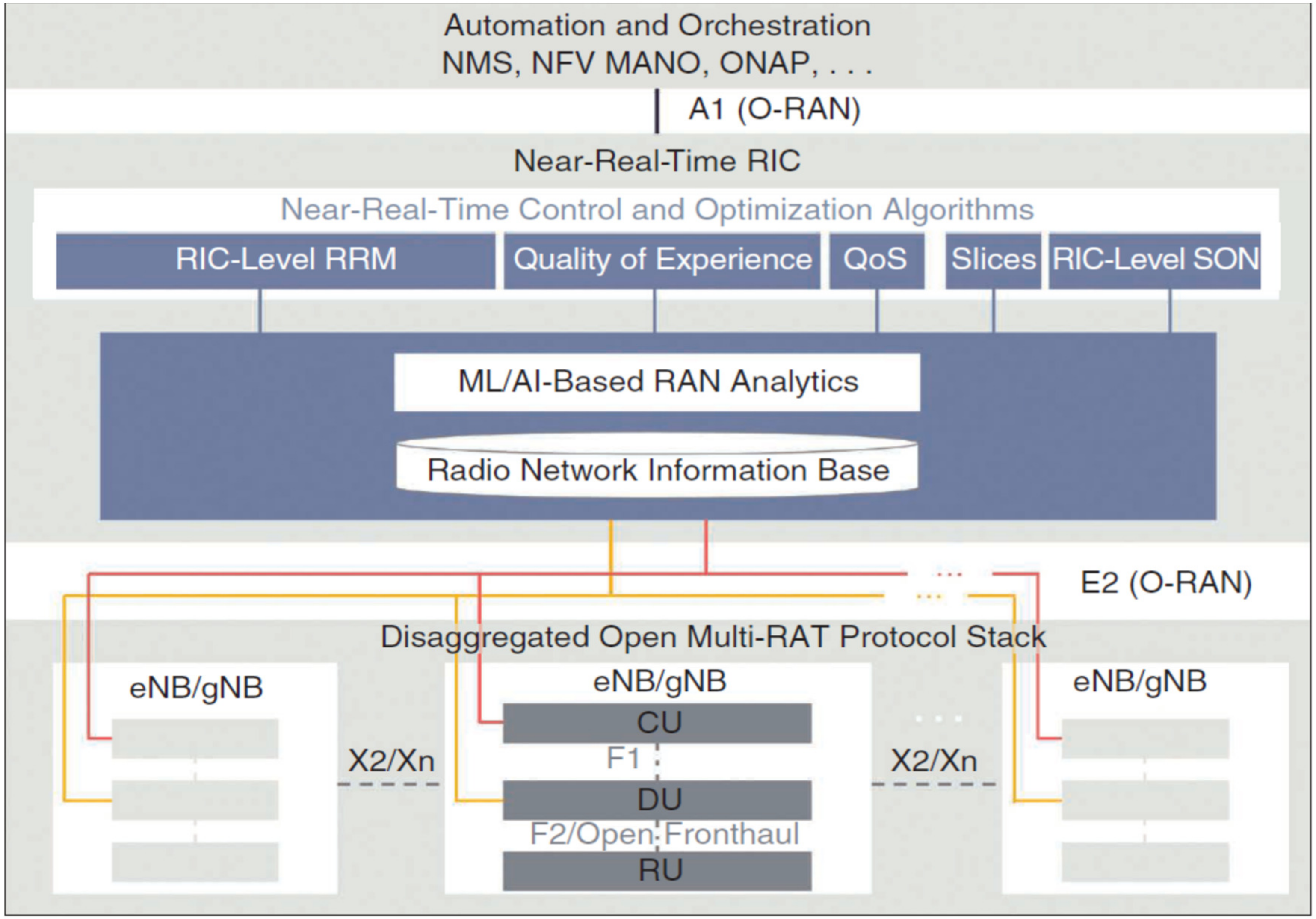


- The Application Function (AF) can be a mutually authenticated third party.
  - Could be a specific 3rd party with a direct http2 interface or a interworking gateway exposing alternative API's to external applications.
- Enables applications to directly control Policy (reserve network resource, enforce SLAs), create network Slices, learn device capabilities and adapt service accordingly, invoke other VNF's within the network…
- Can also subscribe to events and have direct understanding of how the network behaves in relation to the service delivered.

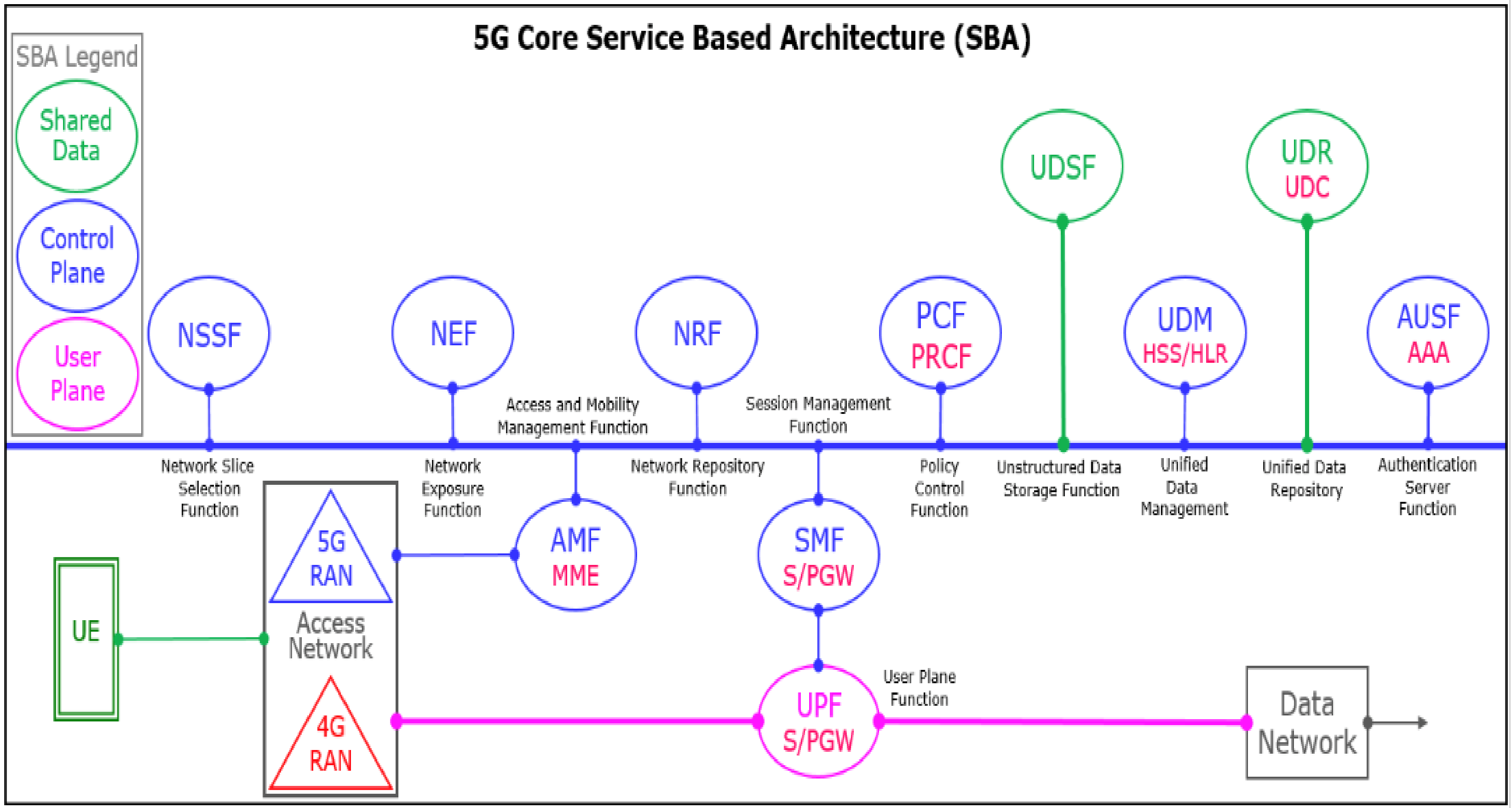
4G/5G Core Network Features Evolution



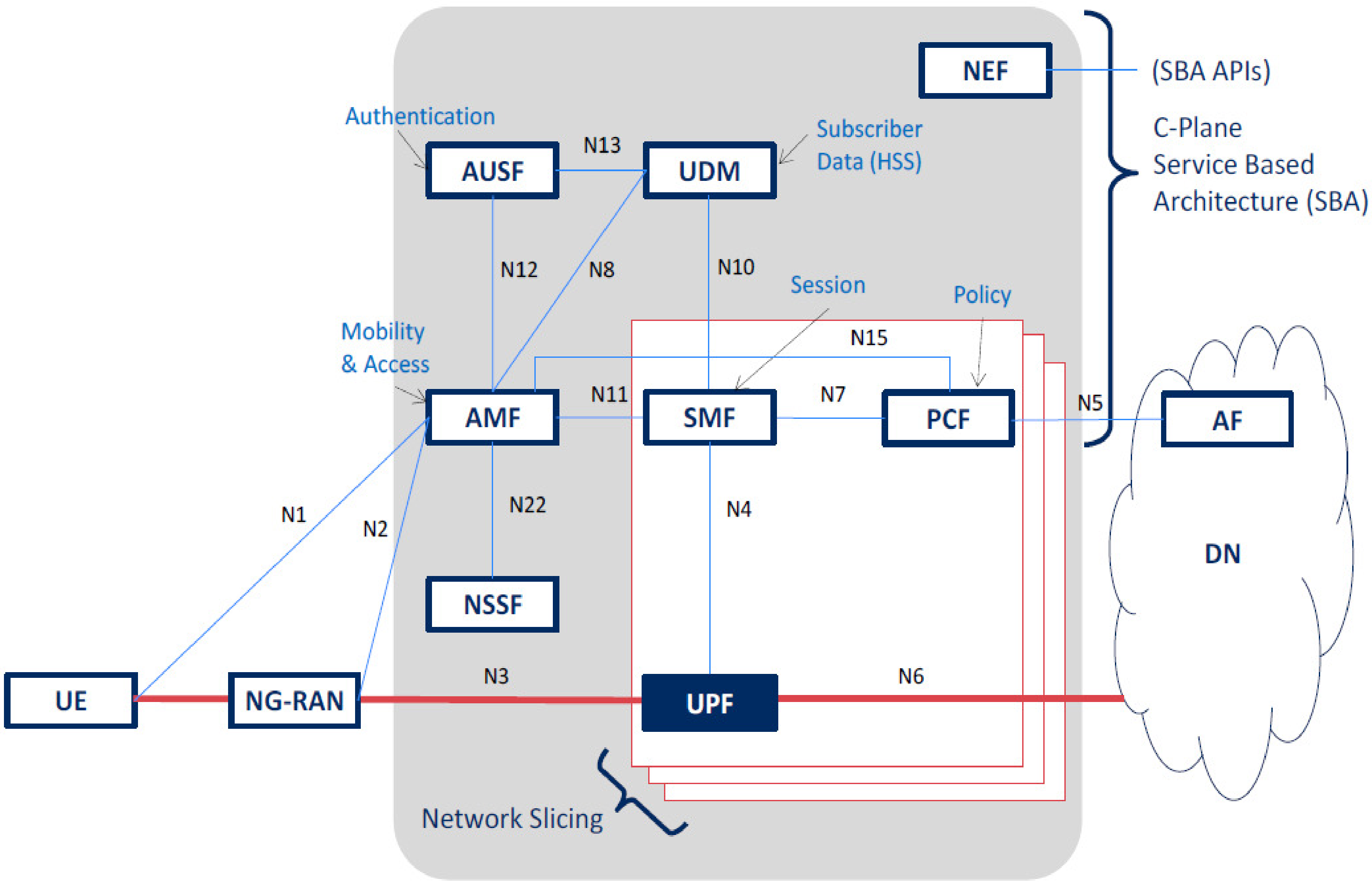
The Open RAN network management architecture



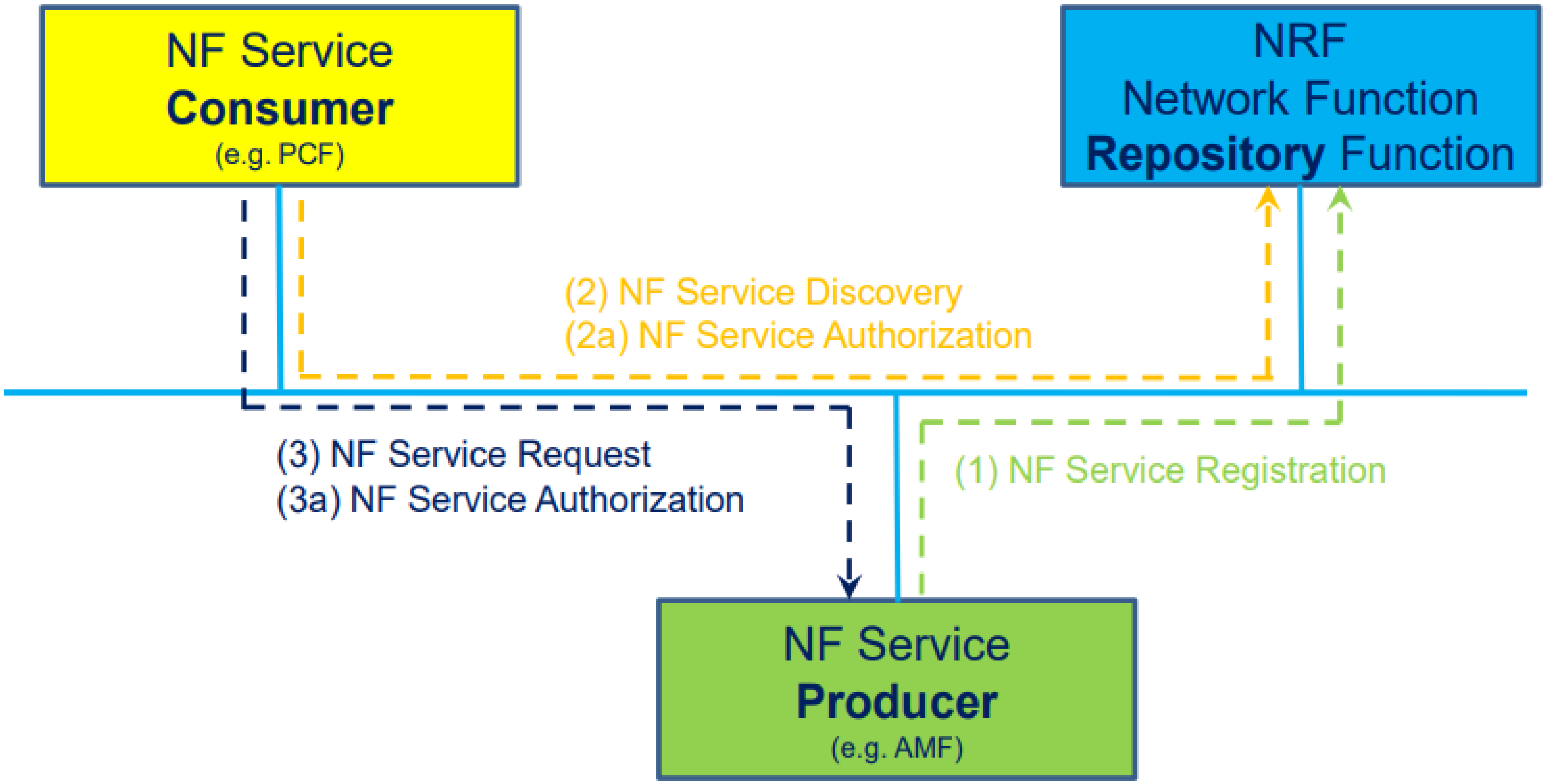
4G and 5G network functions and entities



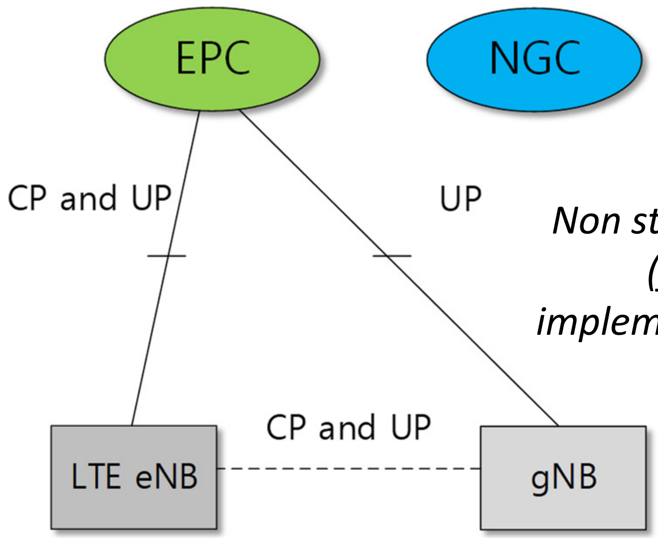
5G Functions Synthesis



Network Repository Function service registration and discovery

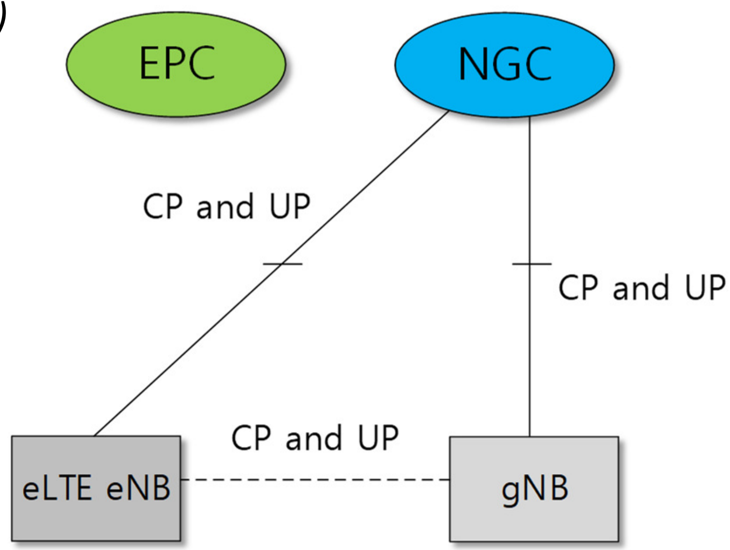


Standalone vs Non-Standalone



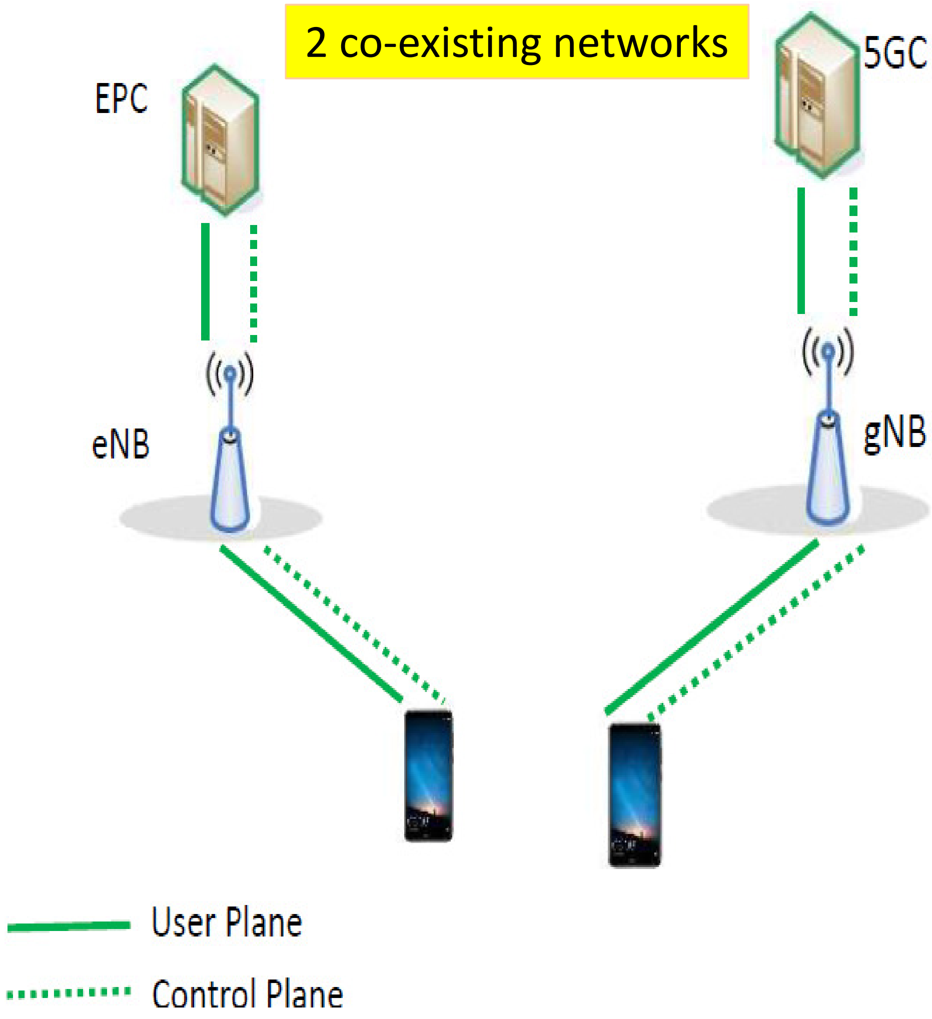
E-UTRA and NR connected to the EPC

Non standalone (first implementations)



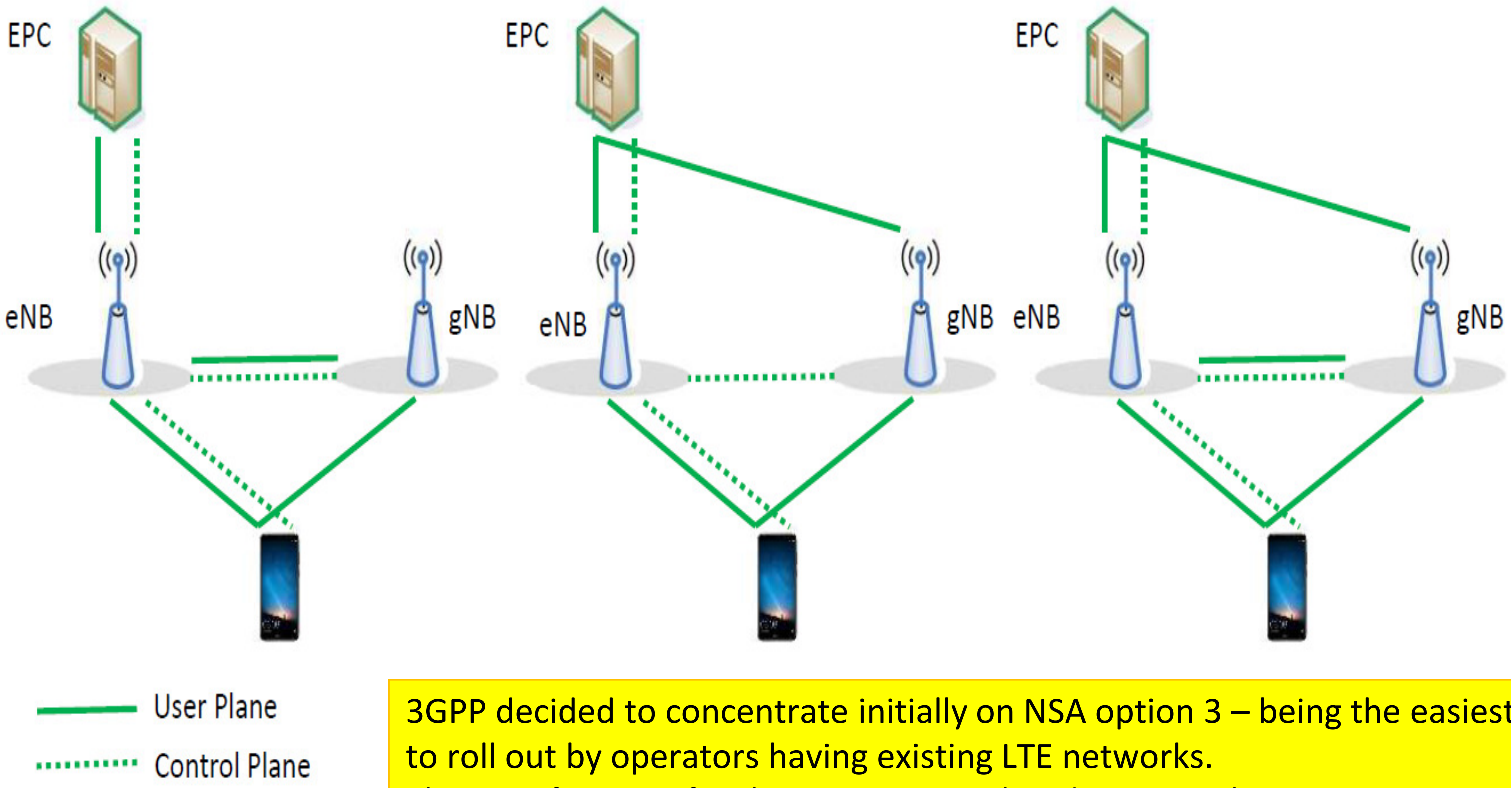
E-UTRA and NR connected to the NGC

5G Architecture – Option 1/2



5G Architecture – Option 3/3a/3x

Core network = 4G – RAN = 4G and 5G with eNB being the **Master Node**

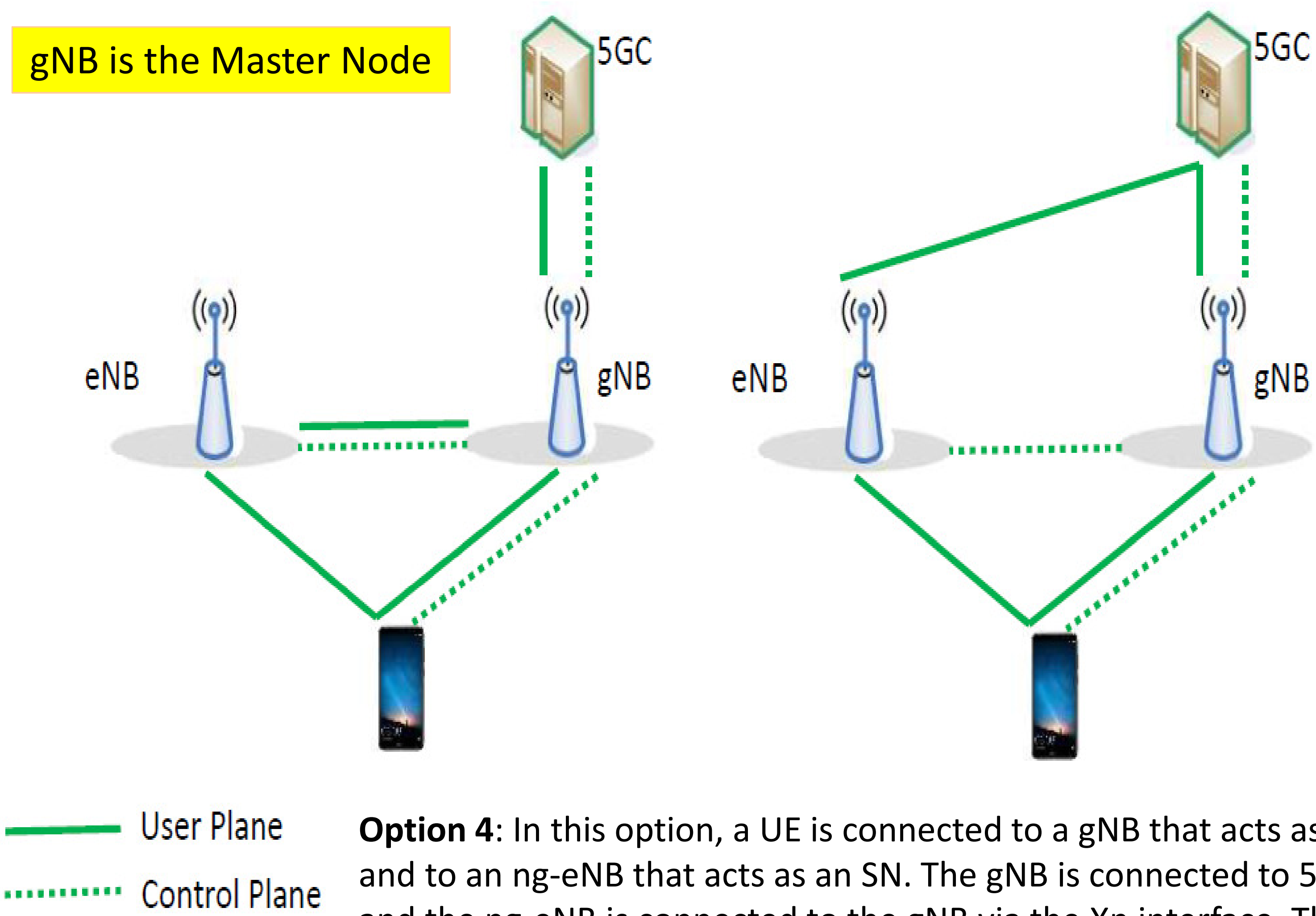


3GPP decided to concentrate initially on NSA option 3 – being the easiest to roll out by operators having existing LTE networks.
The specifications for these were completed in December 2017.

Option 3 or EN-DC (LTE-NR Dual Connectivity): a UE is connected to an eNB that acts as a **MN** and to an en-gNB that acts as a **SN**. The eNB is connected to the EPC via the S1 interface and to the en-gNB via the X2 interface. The en-gNB may also be connected to the EPC via the S1-U interface and to other en-gNBs via the X2-U interface. The en-gNB may send UP to the EPC either directly or via the eNB.

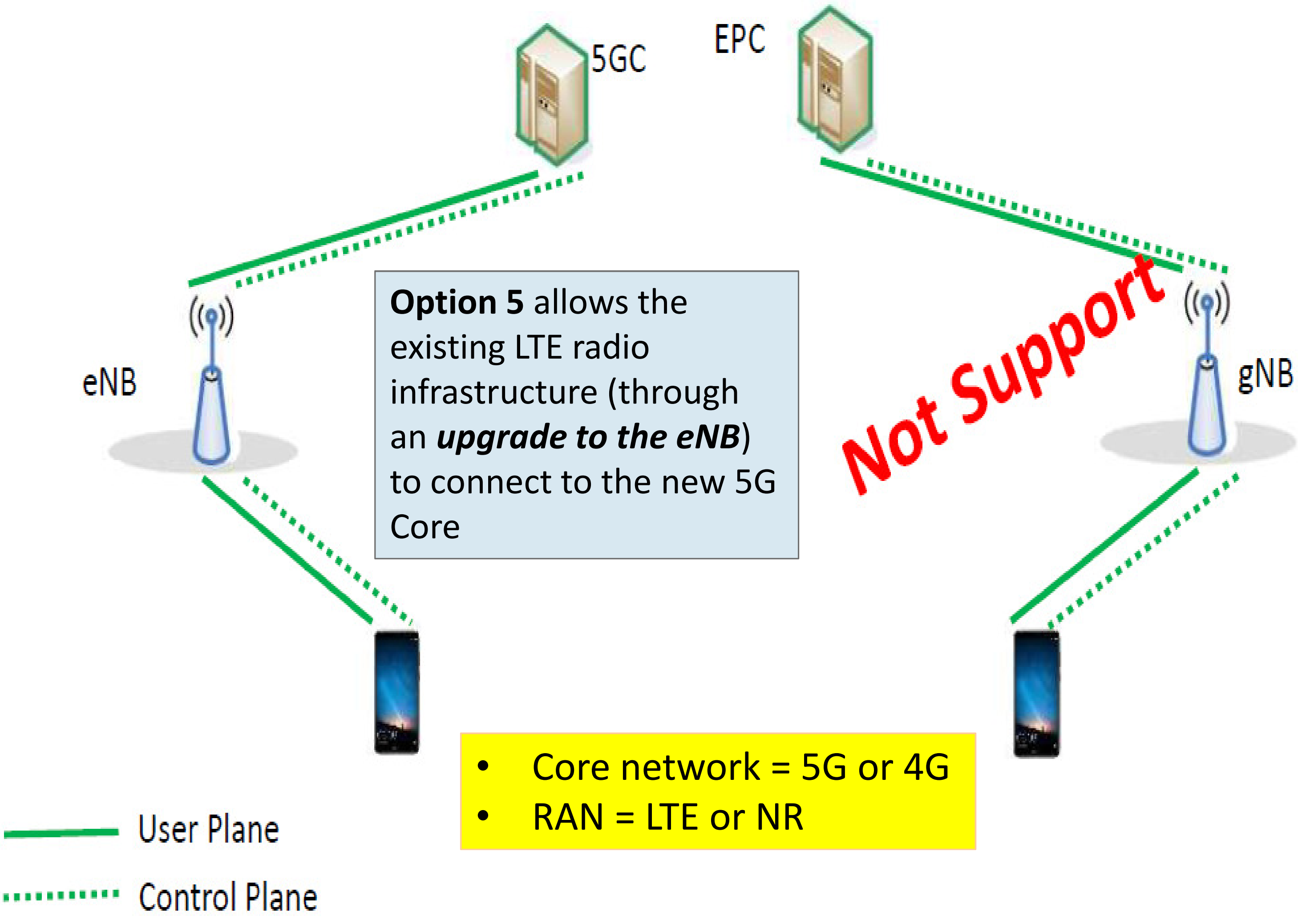
5G Architecture – Option 4/4a

gNB is the Master Node



Option 4: In this option, a UE is connected to a gNB that acts as a MN and to an ng-eNB that acts as an SN. The gNB is connected to 5GC and the ng-eNB is connected to the gNB via the Xn interface. The ng-eNB may send UP to the 5G Core either directly or via the gNB.

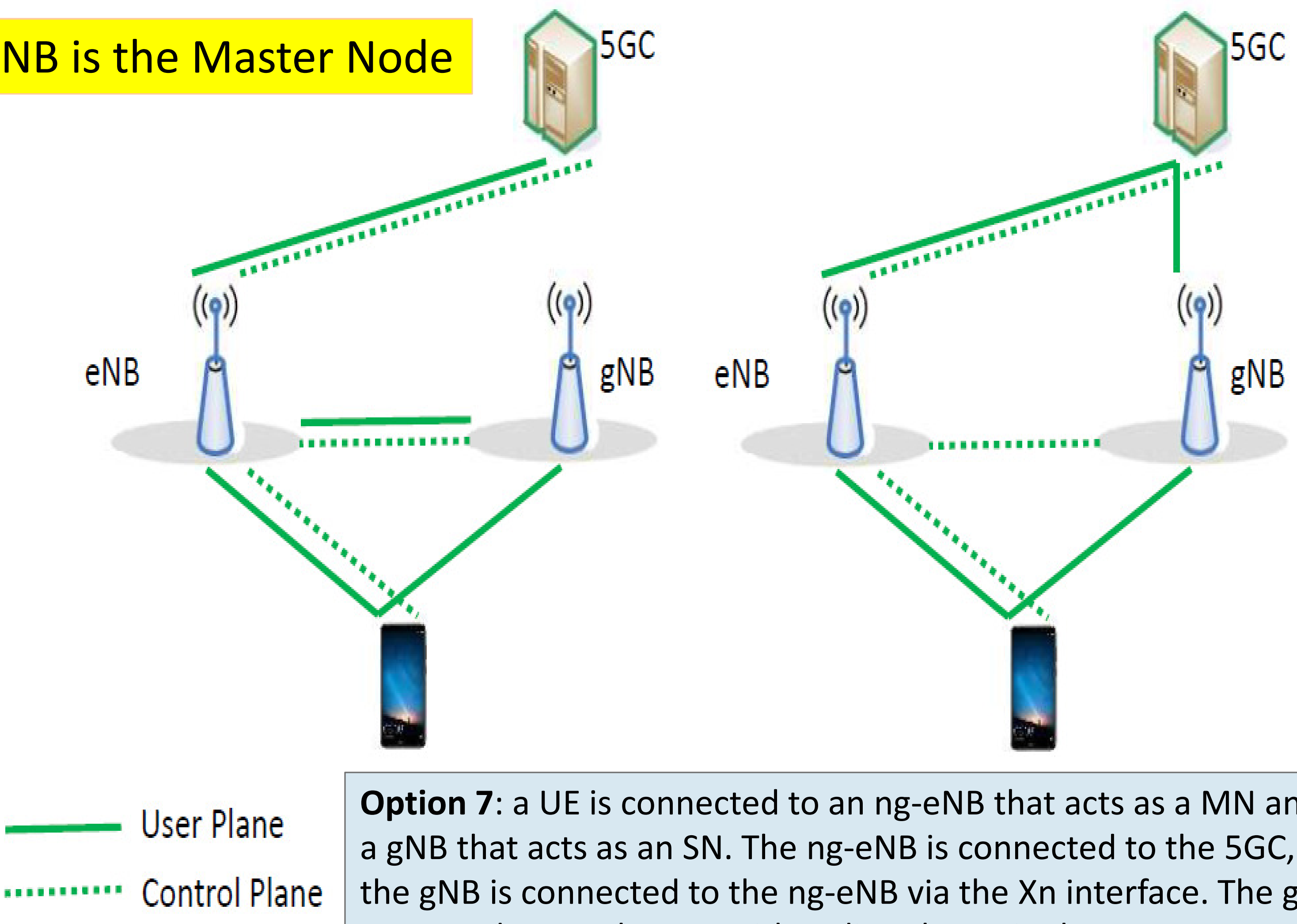
5G Architecture – Option 5/6



- Core network = 5G or 4G
- RAN = LTE or NR

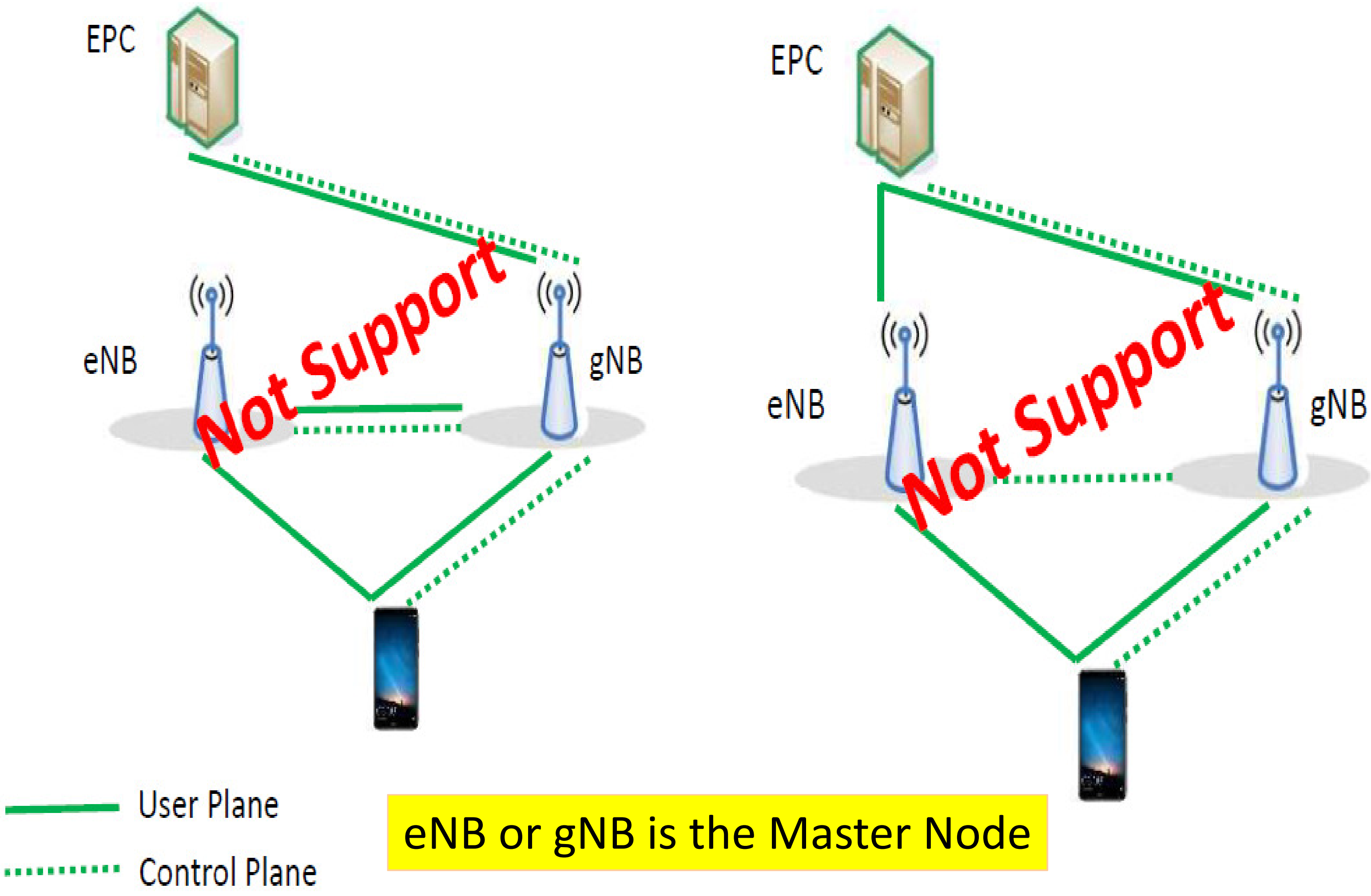
5G Architecture – Option 7/7a

eNB is the Master Node



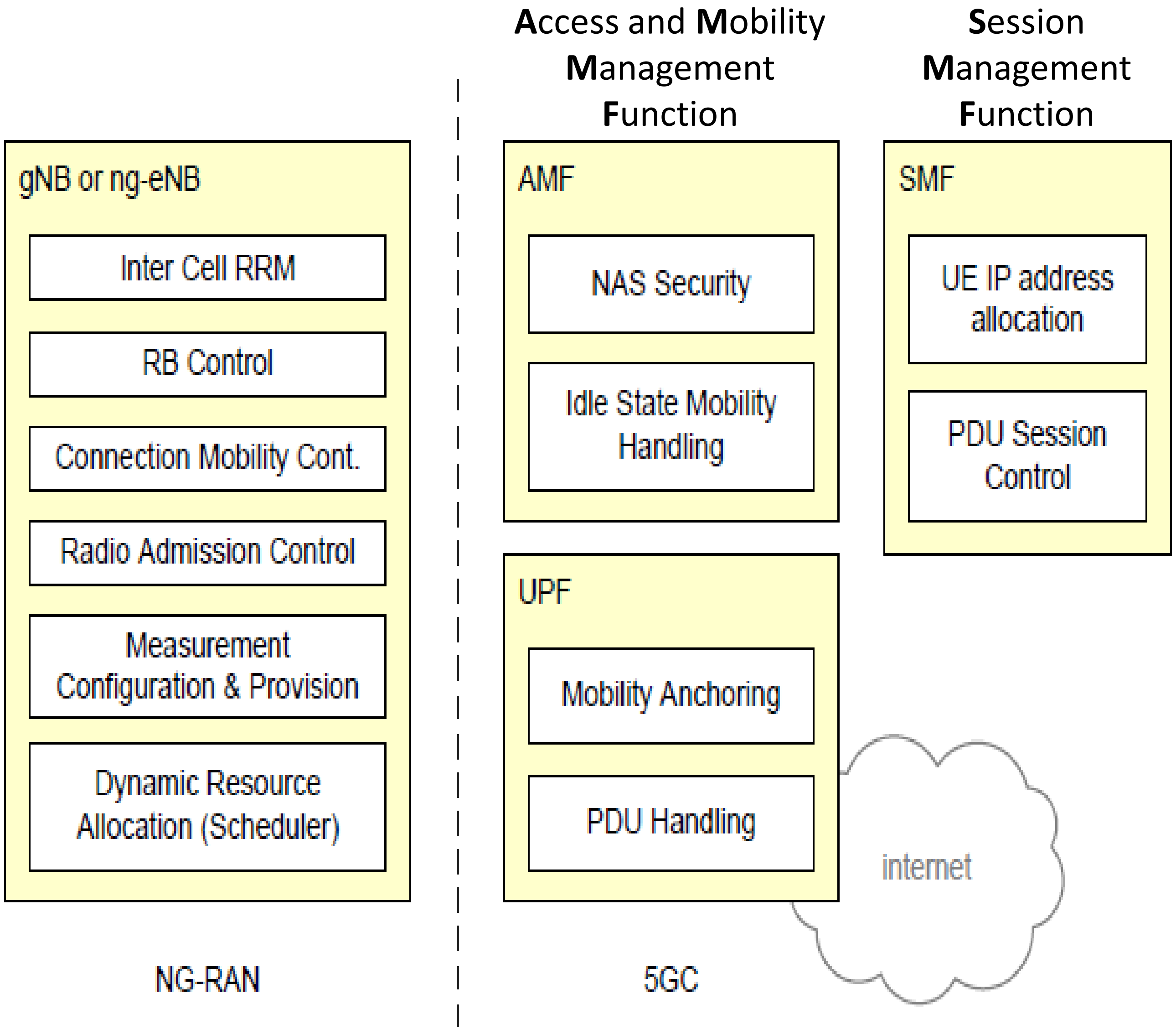
Option 7: a UE is connected to an ng-eNB that acts as a MN and to a gNB that acts as an SN. The ng-eNB is connected to the 5GC, and the gNB is connected to the ng-eNB via the Xn interface. The gNB may send UP to the 5GC either directly or via the ng-eNB.

5G Architecture – Option 8/8a



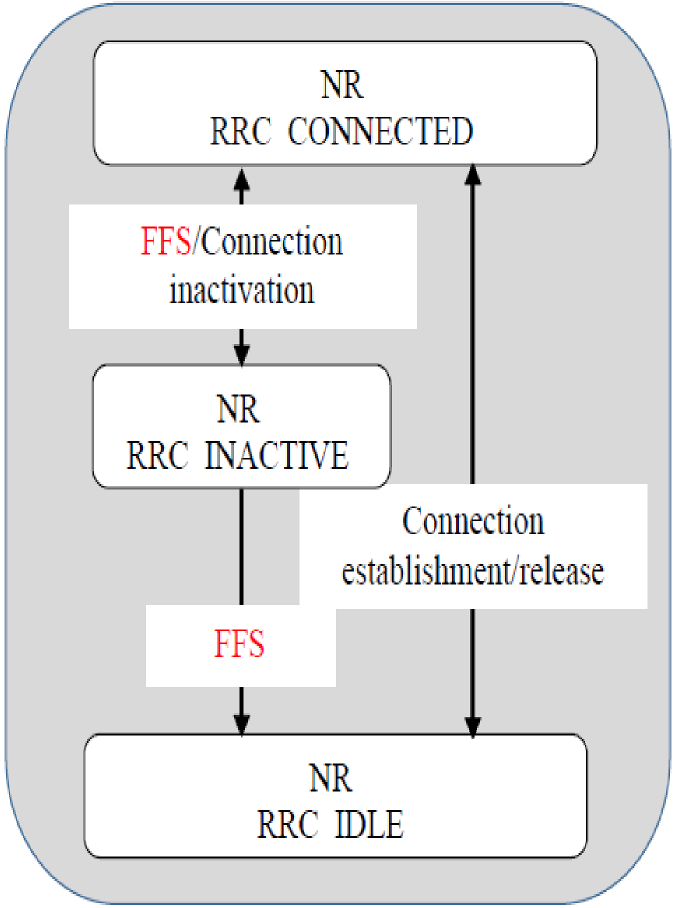
eNB or gNB is the Master Node

Protocols architecture

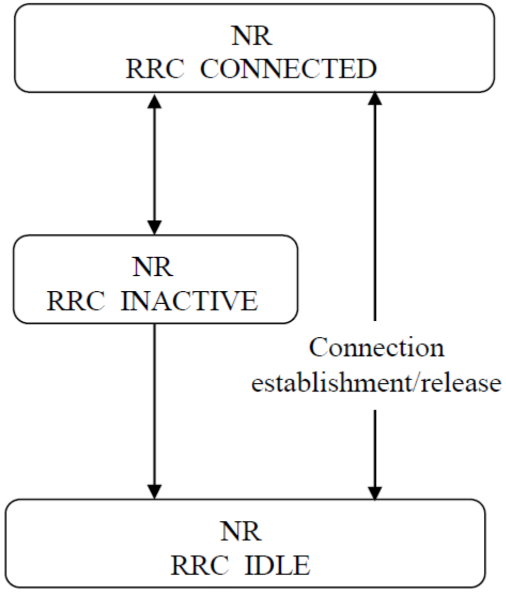


NR UE RRC States

- RRC_IDLE and RRC_CONNECTED, ***same as LTE***
- **RRC_INACTIVE**
  - ➢ Motivation: *Signaling/Latency reduction*
  - ➢ Characteristics: *Cell re-selection mobility*
- The UE AS context is stored in at least one gNB and the UE
- Paging is initiated by NR RAN
- RAN-based ***notification area*** is managed by NR RAN



UE state machine and state transitions in NR



New RRC state: **RRC INACTIVE** (same as UMTS CELL_PCH). Intended to reduce signaling for always-on UEs.
Main characteristics:

- Cell reselection mobility
- Established CN-RAN connection for both CP and UP
- The UE AS context is stored at the UE and in gNB
- Performs RAN-based ***notification area*** updates periodically and when moving outside the configured RAN-based ***notification area***

LTE States

UE status	Off	Attaching	Idle/ Registered	Connecting to EPC	Active
EMM	Deregistered		Registered		
ECM	Idle				Connected
RRC	Idle	Connected	Idle	Connected	
Mobility control	-	UE based	UE based	NW based	

5G States

UE status	Off	Attaching	Connected/ Inactive	Connected/ Active
MM*	Deregistered		Registered	
CM*	-	Connected		
RRC*	-	Connected	Inactive	Connected
Mobility control	-	UE based	UE based, NW assisted	NW based

EPS Mobility Management (EMM)
EPS Connection Management (ECM)
Evolved Packet System (EPS)
Evolved Packet Core (EPC)

RRC States

RRC_IDLE

- A UE **specific DRX** may be configured by upper layers;
- **UE controlled mobility** based on network configuration;
- The UE:
  - **Monitors a Paging channel** for CN paging using 5G-S-TMSI;
  - Performs **neighboring cell measurements and cell (re-)selection**;
  - Acquires **system information** and **can send SI request** (if configured).

RRC_INACTIVE

- A UE **specific DRX** may be configured by upper layers or by RRC layer;
- **UE controlled mobility** based on network configuration;
- The UE stores the **AS context**;
- A RAN-based **notification area** is configured by RRC layer;
- The UE:
  - **Monitors a Paging channel for** CN paging using 5G-S-TMSI and RAN paging using I-RNTI;
  - Performs **neighboring cell measurements and cell (re-)selection**;
  - Performs **RAN-based notification area updates** periodically and when moving outside the configured RAN-based **notification area**;
  - Acquires **system information** and can send SI request (if configured).

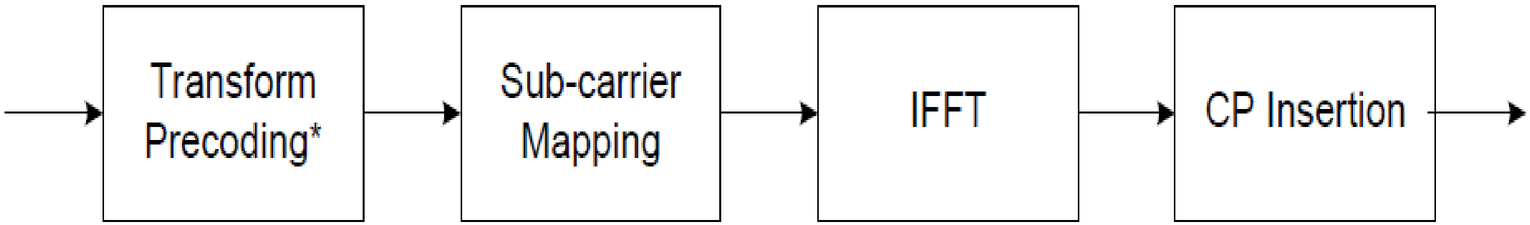
RRC_CONNECTED

- The UE **stores the AS context**;
- **Transfer of unicast data to/from UE**;
- The UE may be configured with a **specific DRX**;
- For UEs **supporting CA**, use of one or more Scells (Secondary Cells), aggregated with the PSCell (Primary Scell), for increased bandwidth;
- For UEs **supporting DC**, use of one SCG (Secondary Cell Group), aggregated with the MCG (Master Cell Group), for increased bandwidth;
- **Network controlled mobility** within NR and to/from E-UTRA;
- The UE:
    - **Monitors a Paging channel**, if configured;
    - **Monitors control channels** associated with the shared data channel to determine if data is scheduled for it;
    - **Provides channel quality** and **feedback** information;
    - **Performs neighboring cell measurements and measurement reporting**;
    - **Acquires system information**.

b. Air Interface

Waveform and MA

- Waveform for up to **52.6GHz eMBB** and **URLLC**
- ***DL Waveform***: **CP(Cyclic Prefix)-OFDM** (QPSK to 256QAM)
- ***UL Waveform***: **CP-OFDM** or **DFT-s-(discrete Fourier transform** (**DFT**) **spread) OFDM** (π/2 BPSK to 256QAM)
- **CP-OFDM** targeted at *high throughput* scenarios
- **DFT-s-OFDM** targeted at *power limited* scenarios
- **Non-Orthogonal Multiple Access** (NOMA) ***not supported in Rel-15***



*Optionally present in UL, not present in DL

4G versus 5G radio interfaces

Item	LTE	NR
Subcarrier spacing	Unicast + MBMS • 15 KHz MBMS dedicated carrier • {7.5 kHz, 1.25 kHz}	Below 6 GHz • {15 KHz, 30 kHz, 60 kHz} Beyond 6 GHz • {60 kHz, 120 kHz, 240 kHz (*1)}
Minimum/Maximum channel bandwidth	1.4 MHz / 20 MHz	Below 6 GHz • 5 MHz / 100 MHz Beyond 6 GHz • 50 MHz / 400 MHz
Maximum number of carrier aggregation	Up to 32 CC	Up to 16 CC
Frame structure	• 1 radio frame = 10 ms • 1 subframe= 1ms • 1 slot = 0.5 ms • Slot format: pre-defined in the specification	• 1 radio frame = 10 ms • 1 subframe= 1ms • 1 slot = {1 ms, 0.5 ms, 0.25 ms, 0.125 ms} depending on subcarrier spacing • Slot format: semi-statically and dynamically configurable
Channel coding	• Turbo coding (Data) • TBCC (Control)	• LDPC (Data) • Polar (Control)
Multiplexing scheme	• Downlink: OFDM • Uplink: DFT-S-OFDM	• Downlink: OFDM • Uplink: {OFDM, DFT-S-OFDM}
MIMO	• 8 antenna ports for SU-MIMO • 2 antenna ports for MU-MIMO	• 8 antenna ports for SU-MIMO • 16 antenna ports for MU-MIMO
HARQ	• TB based transmission & retransmission	• TB based transmission & retransmission • Code block group based transmission & retransmission
Carrier frequency	• 450 MHz ~ 3.8 GHz • Unlicensed band (5GHz)	• 600 MHz ~ 40 GHz

Numerology - SCS

Scalable subcarrier spacing

Frequency Band	< 1 GHz	6 GHz	24 to 52.6 GHz
UE SCS (Sub-Carrier Spacing)	15/30 kHz	15/30/60 kHz	60/120/240 kHz

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

Shorter TTI for low latency constraints

Feature: Shorter TTI (LTE) = minislot (NR)

Allows scheduling and transmission with a granularity finer than a 1 ms transmission slot length. Allows subdivision of the transmission slot into up to 6 short TTIs.

Waiting times for th next TTI, the TTI length and round-trip times for potential retransmissions are significantly reduced.

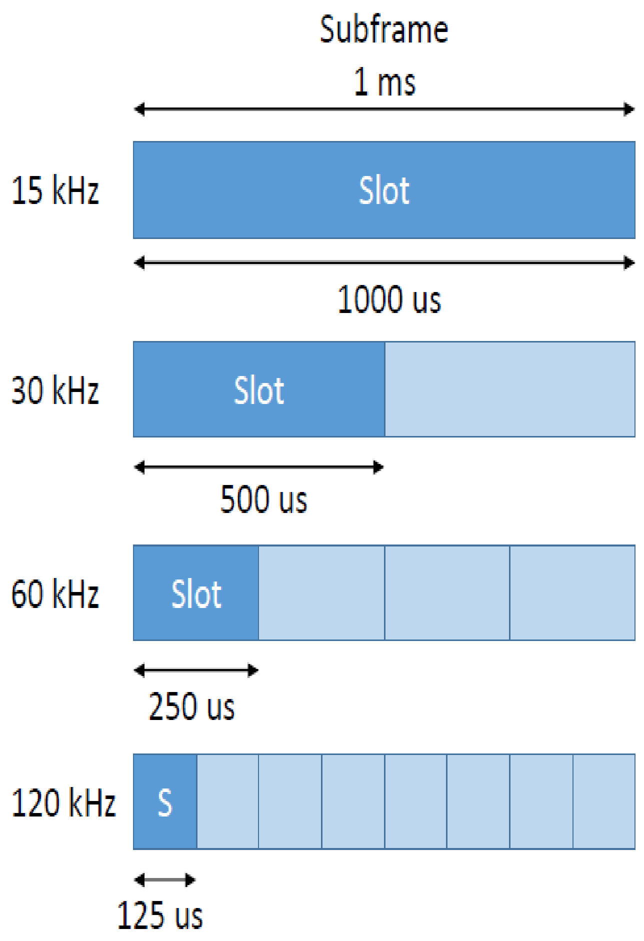
Flexible OFDM numerology (subcarrier spacing SCS) = another potential for latency reduction: higher SCSs (15-240 kHz) translate to shorter slot lengths (1-0.0625 ms).

Resource pre-allocation with configured scheduling: long-lasting periodic UL grant to the UE before potential UL transmissions occur.

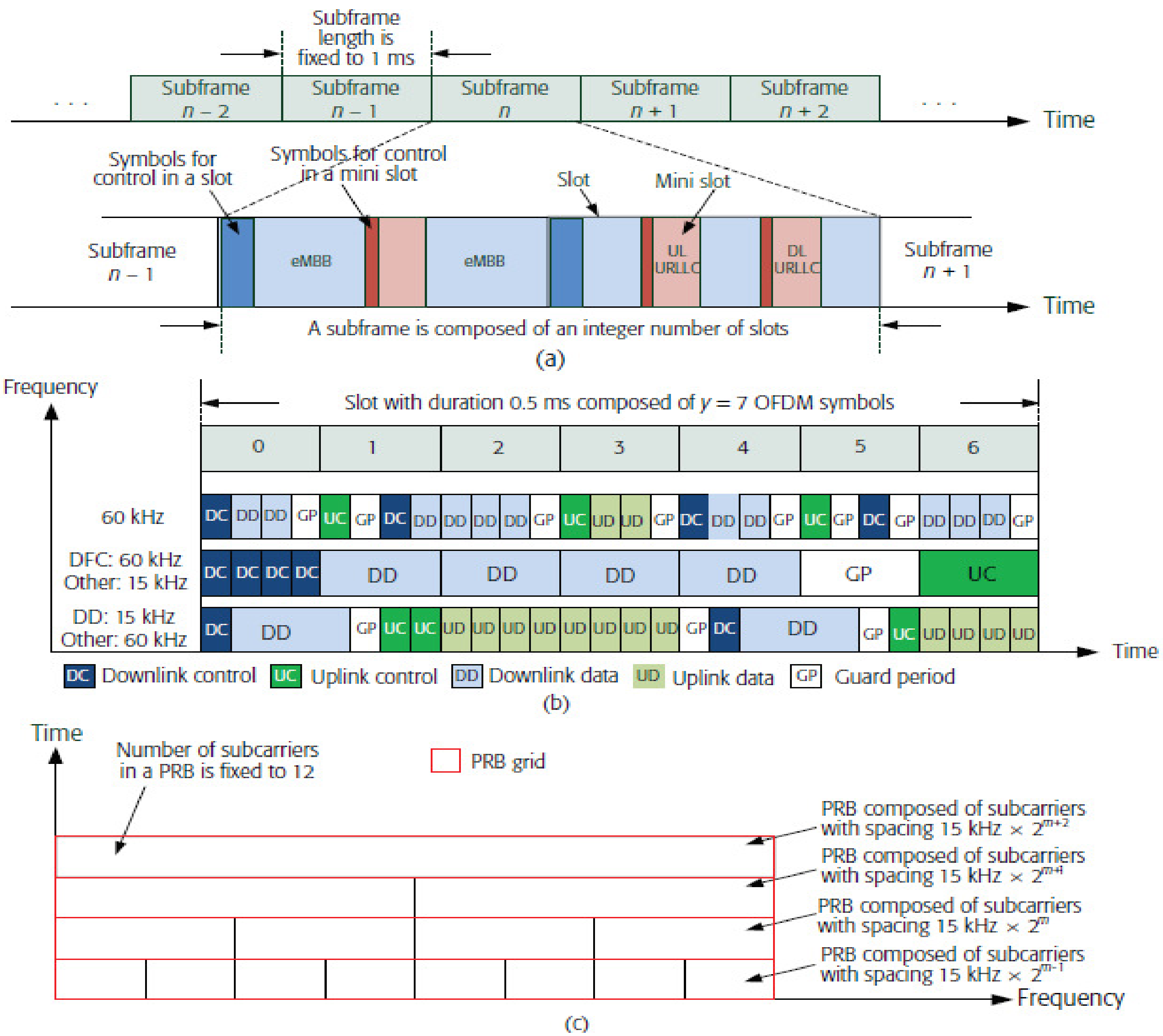
MC: users simultaneously connected via multiple wireless links. For URLLC, it is most desirable to transmit information over independent channels in a single time slot.

Frame Structure – Slot

- Frame = 10 ms
- Subframe = 1 ms
- Mini slot: a minimum scheduling unit with 7, 4 or 2 OFDMA symbols
- Slot:
  - For all SCS with NCP (Normal CP): 14 symbols
  - For 60 kHz SCS with ECP (Extended CP): 13 symbols
  - Duration time = $1/2^{\mu}$

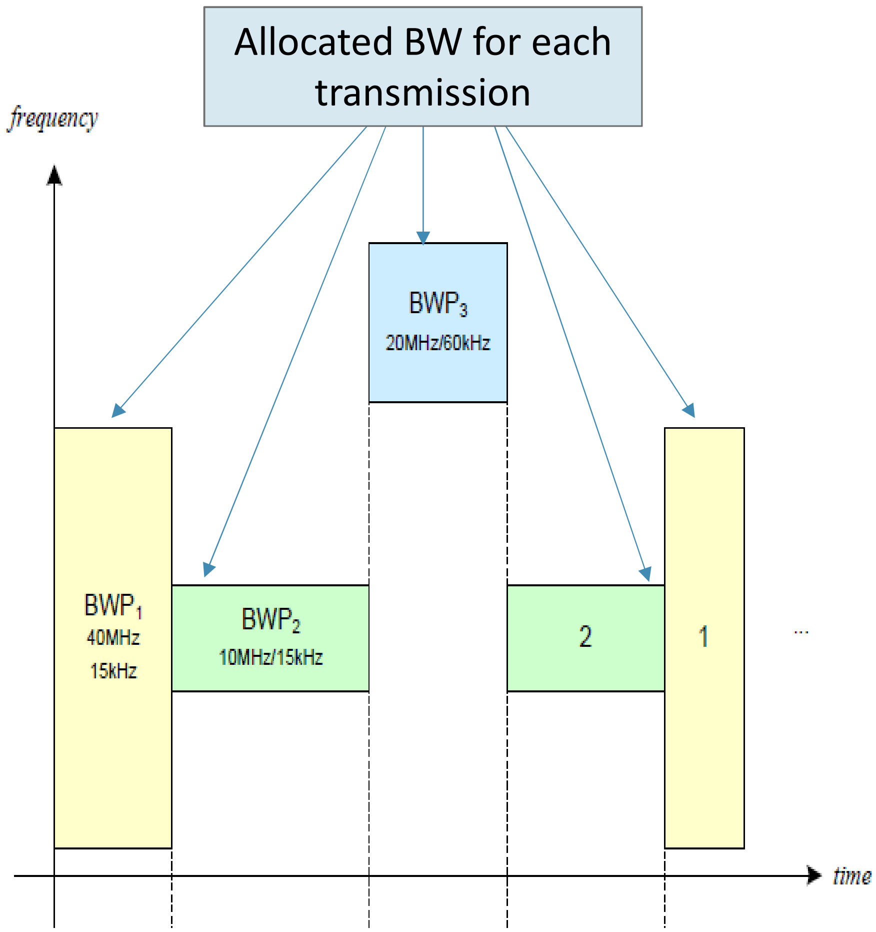


Frame structure of NR



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



Numerology – CBW & FFT Size

Frequency Range	FR1 < 6 GHz	FR2 24 to 52.6 GHz
CBW	100 MHz	400 MHz

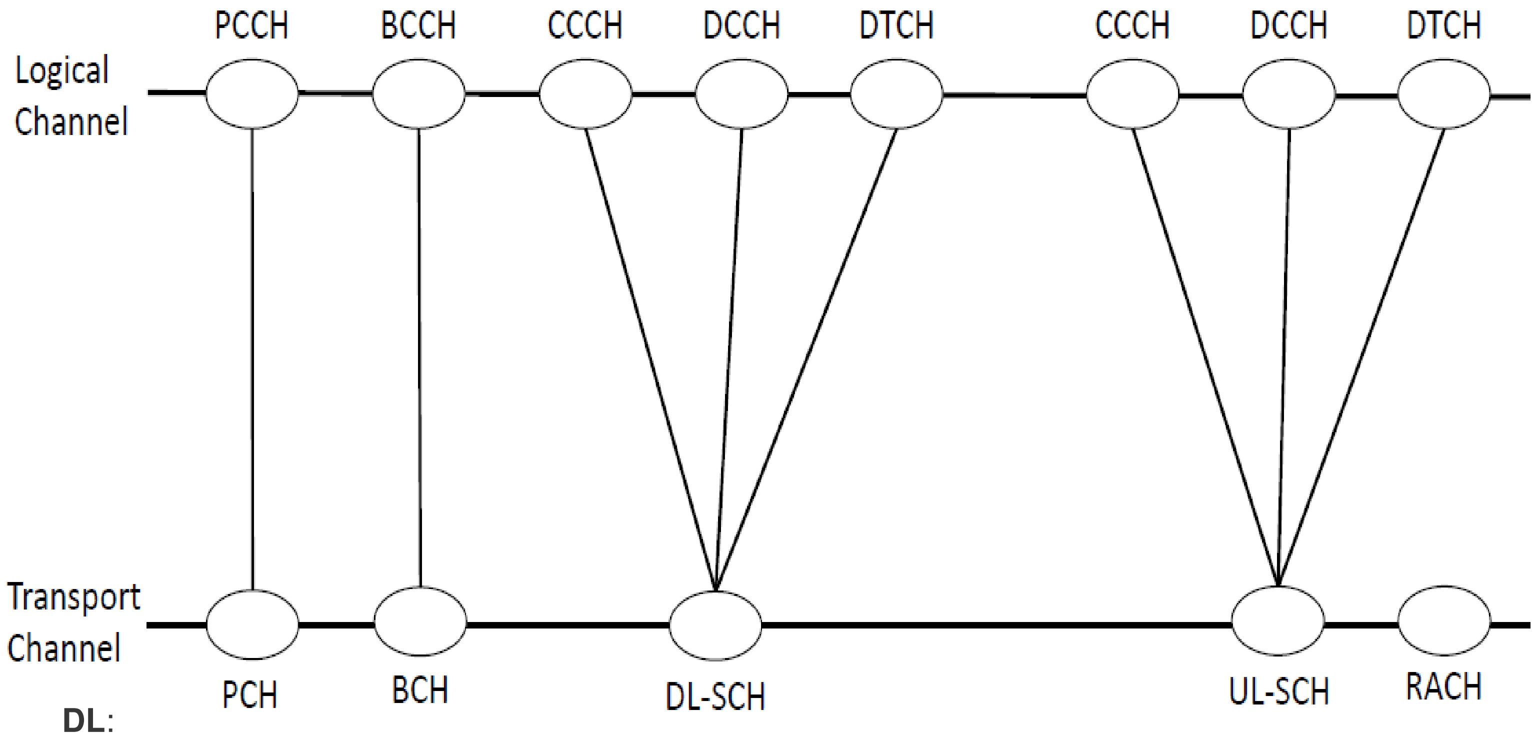
Frequency range	SCS (kHz)	Min CHBW (MHz)	Max RB	Max CHBW (MHz)
FR1	15	5	270	50
	30	5	273	100
	60	10	135	100
FR2	60	50	264	200
	120	50	264	400

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

c. Channels

Channel mapping



DL:

- **PDSCH** (Physical DL Shared Channel)
- **PDCCH** (Physical DL Control Channel)
- **PBCH** (Physical Broadcast Channel)
- **PSS** (Primary Synchronization Signal)
- **SSS** (Secondary Synchronization Signal)
- **CSI-RS** (Channel State Information Reference Signal)
- **DM-RS** (Demodulation Reference Signal)
- **PT-RS** (Phase-tracking Reference Signal)

Uplink:

- **PUSCH** (Physical Uplink Shared Channel)
- **PUCCH** (Physical Uplink Control Channel)
- **PRACH** (Physical Random Access Channel)
- **SRS** (Sounding Reference Signal)
- **DM-RS** (Demodulation Reference Signal)
- **PT-RS** (Phase-tracking Reference Signal)

Signaling radio bearers

SRBs are used only for the transmission of RRC and NAS messages.

- **SRB0**: for ***RRC messages*** using the ***CCCH*** logical channel;
- **SRB1**: for ***RRC messages*** (which may include a piggybacked NAS message) as well as for NAS messages prior to the establishment of SRB2, all using ***DCCH*** logical channel;
- **SRB2**: for ***NAS messages***, all using ***DCCH*** logical channel. SRB2 has a lower-priority than SRB1 and is always configured by the network after security activation;
- **SRB3**: for ***specific RRC messages*** when UE is in ***EN-DC*** (*Evolved UTRAN-Dual Carrier*), all using DCCH logical channel.

Thank You