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5G Core Network

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5G Core Network

Services :

- eMBB
- CC & URLLC
- mIOT
- Flexible network operations

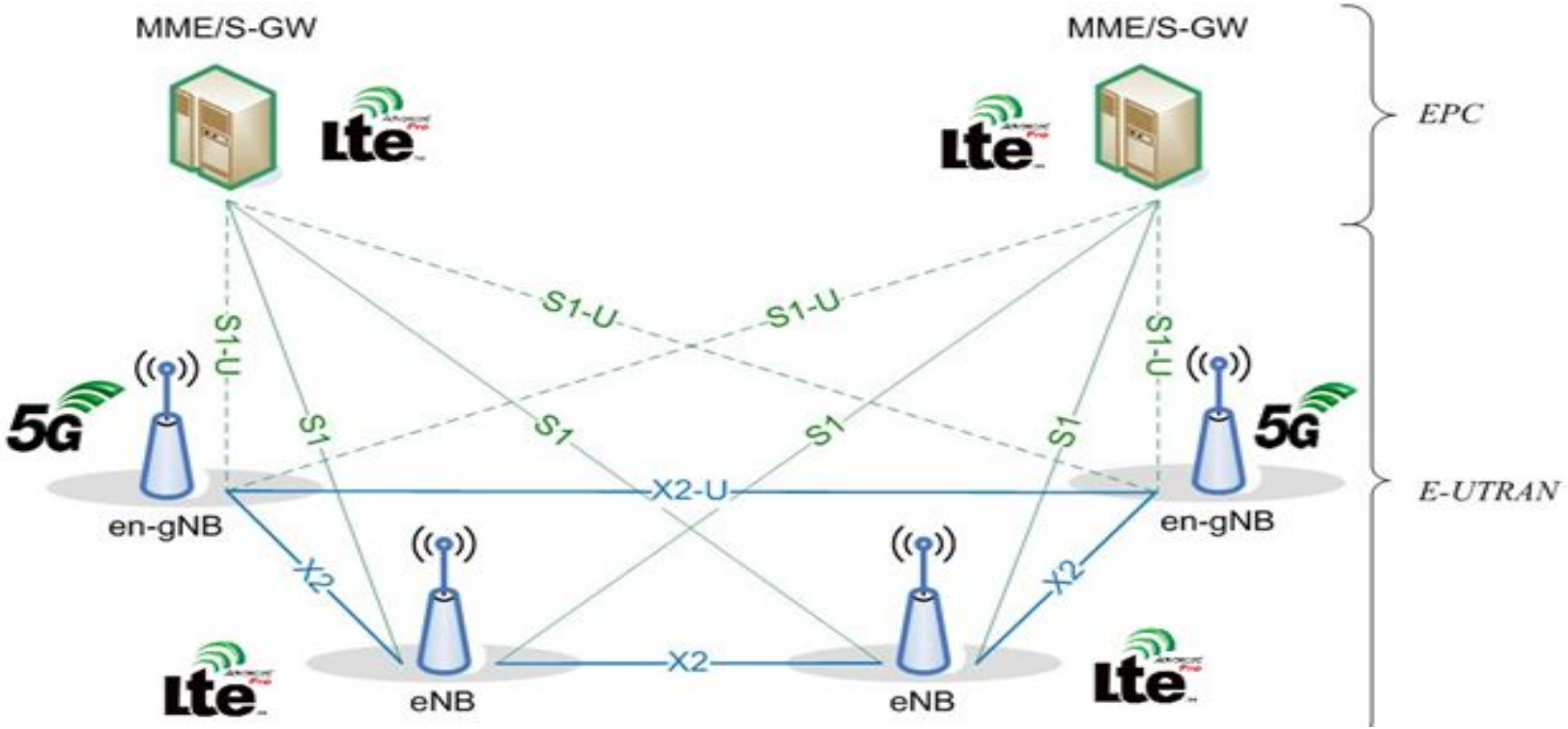
The 5G system overall architecture

Deployment options for 5G

NSA :

- In this architecture, where the 5G RAN , also called New Radio is used in conjunction with existing LTE & EPC infrastructure CN.
- In this configuration , only the 4G services are supported , but enjoying the capacities offered by the 5G radio.

The NSA architecture :



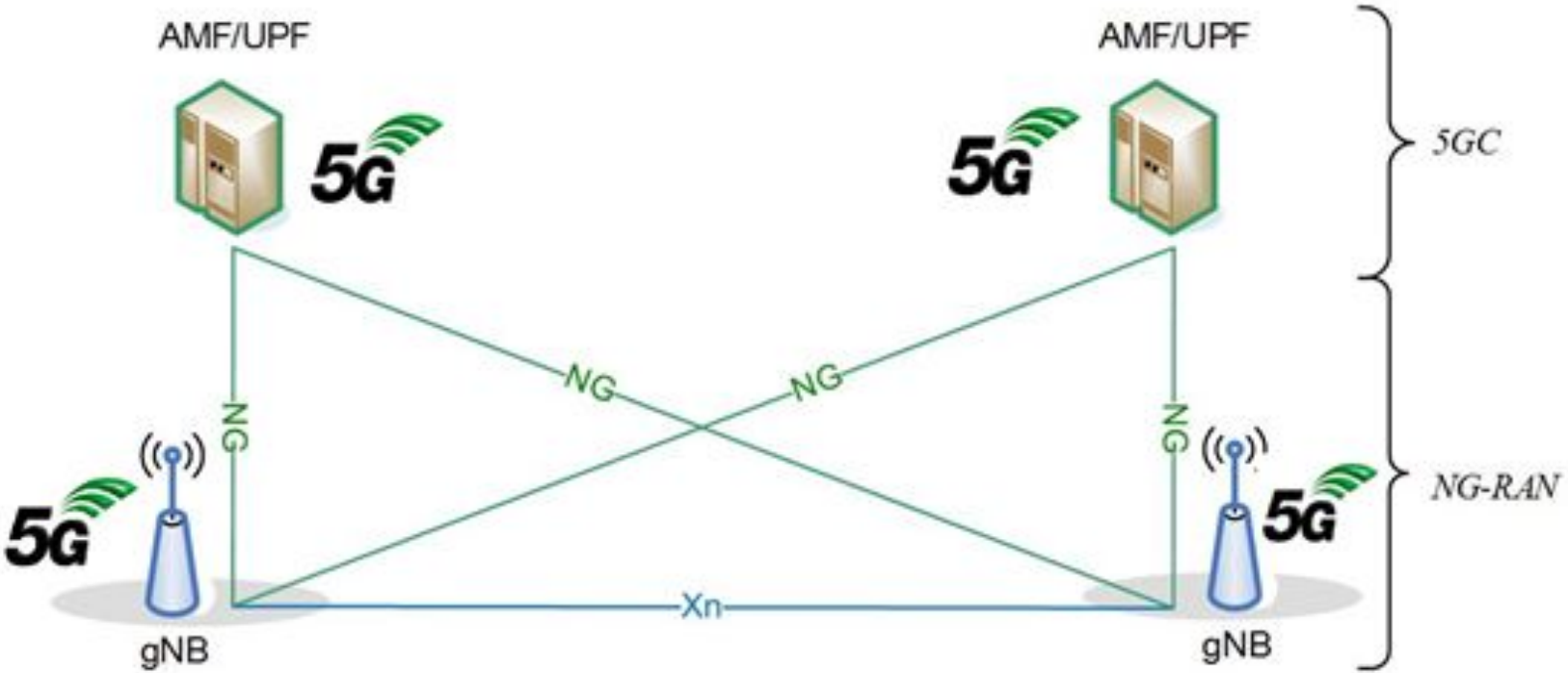
The NSA Architecture :

- In this architecture, the NR base station (logical node “en-gNB”) connects to the LTE base station (logical node “eNB”) via the X2 interface.
- E-UTRAN for NSA architecture connects to the EPC network using S1 interface.
- Dual connectivity between eNB (as master node) and en-gNB (as secondary node) is called EN-DC.

The SA Architecture :

- In the SA Architecture, the NR base station (logical node “gNB”) connects each other via the Xn interface.
- The NG-RAN for SA architecture connects to the 5GC network using the NG interface.

The SA Architecture ：

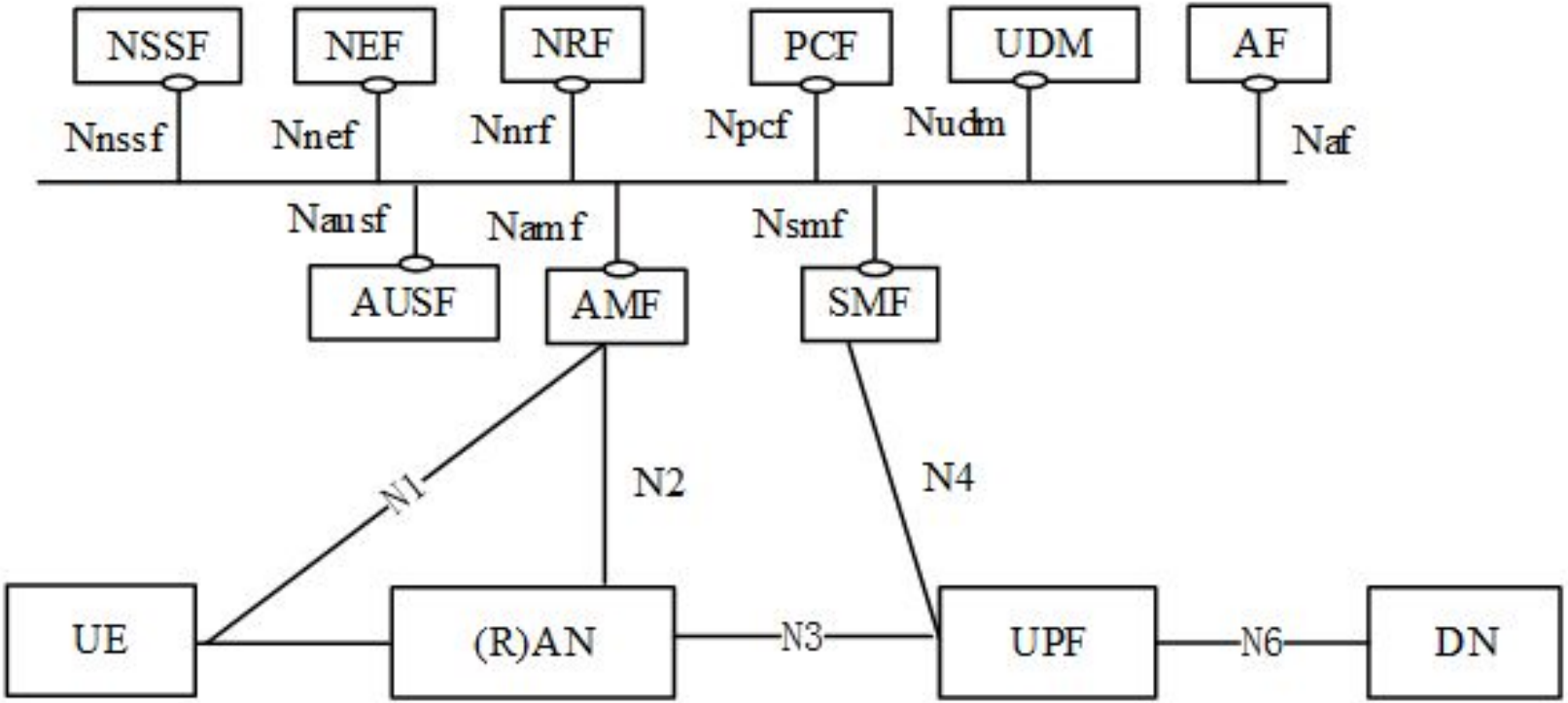


The 5G core network

Overview of 5GC architecture :

- In the SA deployment, 5GS is composed of UE, 5G access network and 5GC.
- The 5GC uses a Service based Architecture framework.
- SBA approach offers modularity and reusability.

5G system Architecture :



5G system architecture composition :

- UE
- (R) AN
- UPF
- AF
- DN
- Other NFs

Support of virtualized deployment :

- The SBA approach enables a virtualized deployment.
- A NF instance can be deployed as : fully distributed , fully redundant , stateless and fully scalable.

Basic Network Functions

Network Functions for the entire network :

- NRF
- NEF
- UDM
- NSSF

NF’s to handle UE’s mobility & Activities :

- AMF
- SMF

Specifications of the 5GC architecture

Local hosting of services & edge computing :

- 5G supports “ service hosting environment “ which is a service platform located inside of an operator’s network as to offer Hosted services closer to the end user to meet specific requirement like low latency , low bandwidth pressure.
- Various PDU session types are supported including IPv4, IPv6, IPv4v6, ethernet and unstructured.

Local hosting of services & edge computing ：

- The system provides SSC mode 1.
- The system also introduces new models such as SSC mode 3 .
- Local hosting of services is provided in particular through the Edge computing capability.

To enable this：

- The 5GCN selects a UPF close to the UE and executes the traffic steering from the UPF to the local data network via N6 interface.

Network Slicing

Network slicing :

- A network slice is a set of elements of the network specialized in the provisioning of certain types of services.
- End -to-end network slicing is a major characteristics of 5G system.
- The characteristics of each slice are defined in terms of QoS, bit rate, latency etc.

Network slicing types :

- Type 1 : dedicated to support eMBB
- Type 2 : dedicated to support URLLC
- Type 3 : dedicated to support MIoT

NSSF enables the selection of appropriate slices.

Unified Access control

Unified access control :

- Different criteria for access control are associated with access identities and access categories.
- A unified access control allows for categorizing each UE access attempt into one access category.
- There are mobility management congestion control, the DNN based congestion control and network slice based congestion control.

Converged architecture for non-3GPP :

- Interoperability among the various access technologies is imperative.
- For optimization and resource efficiency, the 5G system can select the most appropriate 3GPP and non-3GPP access technology for a service, potentially allowing multiple access technologies to be used simultaneously for one or more services active on a UE.

Policy framework & QoS support

Policy framework & QoS support :

- A policy framework is supported for Session, Access and mobility control , QoS and charging enforcement, as well as policy provisioning in the UE.
- URSP is used by the UE to determine if a detected can be associated with an established PDU session.

Policy framework & QoS support :

- ANDSP is used by the UE for selecting non-3GPP accesses.
- URSP and ANDSP are delivered from the Policy control function (PCF) to the UE through signalling.
- As for QoS, the system defines a flow-based QoS framework , with two basic modes : with or without QoS dedicated signalling.

Network capability exposure :

- The 3GPP SEES and eFMSS features allow the operator to expose network capabilities e.g QoS policy to 3rd party ISPs/ICPs.

Support of other specific services :

- SMS
- IMS and its services
- In 5GS phase 1, location services are optional and restricted to regulatory (emergency) services.
- MOCN
- PWS
- MPS
- MCS
- PS Data off

Main protocols of the 5G Core network

Services provided by 5G NFs :

- The transport layer protocol is TCP
- Transport layer security protection is supported with TLS
- Application layer protocol is HTTP/2
- The serialization protocol is JSON
  The openAPI 3.0.0 is adopted as the interface definition language.

Service based interface protocol stack :

Application
HTTP/2
TLS
TCP
IP
L2

Protocols :

To reduce the coupling between clients and servers, the RESTful framework is applied for the APIs design as follows :

- The REST-style service operations implement the L2 of the Richardson maturity model.
- Level 3 (HATEOAS) of the Richardson maturity model is optional.

Protocols :

- The SBI's also support procedures for overload control and message prioritisation.
- PFCP is used over the N4 interface for the separation of CP and UP in the 5GC.
- GTPv2 is used over the N26 interface for mobility between EPC and 5GC.

Functional split between radio and core

The gNB functions :

- Functions for radio resource management
- IP header compression
- Routing of user plane data towards UPFs
- Routing of control plane information towards AMF
- Connection setup and release
- Scheduling and transmission of paging messages
- Scheduling and transmission of system broadcast information (originated from AMF & O&M)
- Measurement and measurement reporting configuration for mobility & scheduling

The AMF functions :

- The NAS signalling termination
- The NAS signalling security
- The AS security control
- Registration area management
- Support of intra-system and inter-system mobility
- Access authentication
- SMF selection

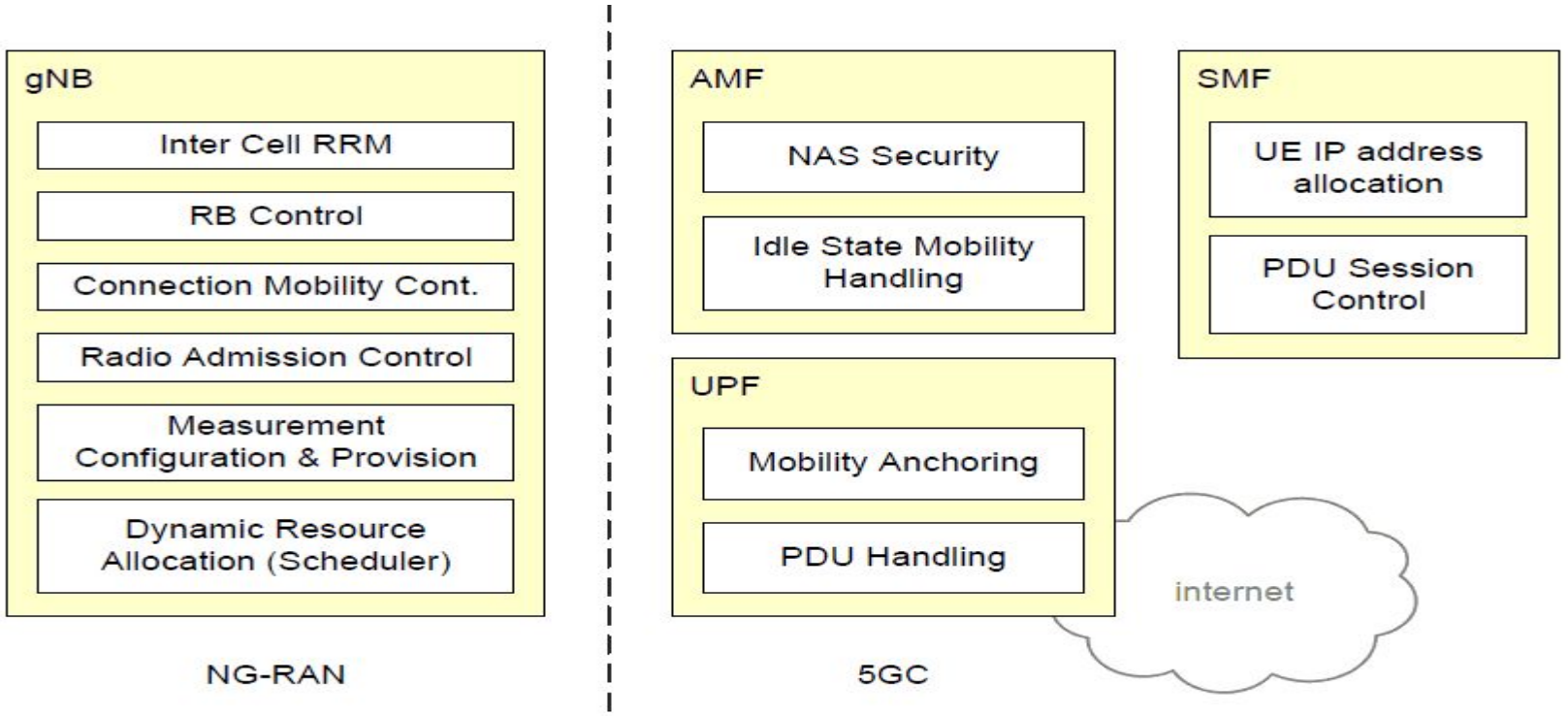
The UPF functions ：

- Traffic usage reporting
- Uplink classifier to support routing traffic flows to a data network.
- Branching point to support multi-homed PDU session.
- QoS handling for user plane e.g packet filtering, gating, UL/DL rate enforcement.

The SMF functions：

- Session management
- UE IP address allocation & management
- Selection and control of UP functions
- Configures traffic steering at UPF to route traffic to proper destination.
- Control part of policy enforcement and QoS.
- DL data notification

Functional split between NG-RAN & 5GC :

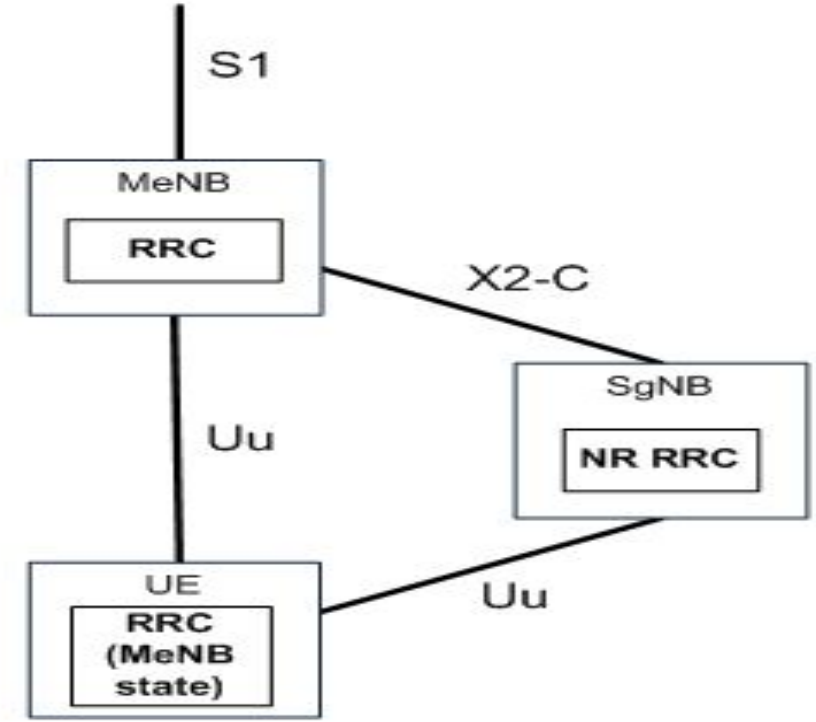


NSA radio protocol architecture

Control plane :

- In EN-DC , the UE has a single RRC state, based on MN RRC and a single C-plane connection towards the CN.
- Each radio node has its own RRC entity.

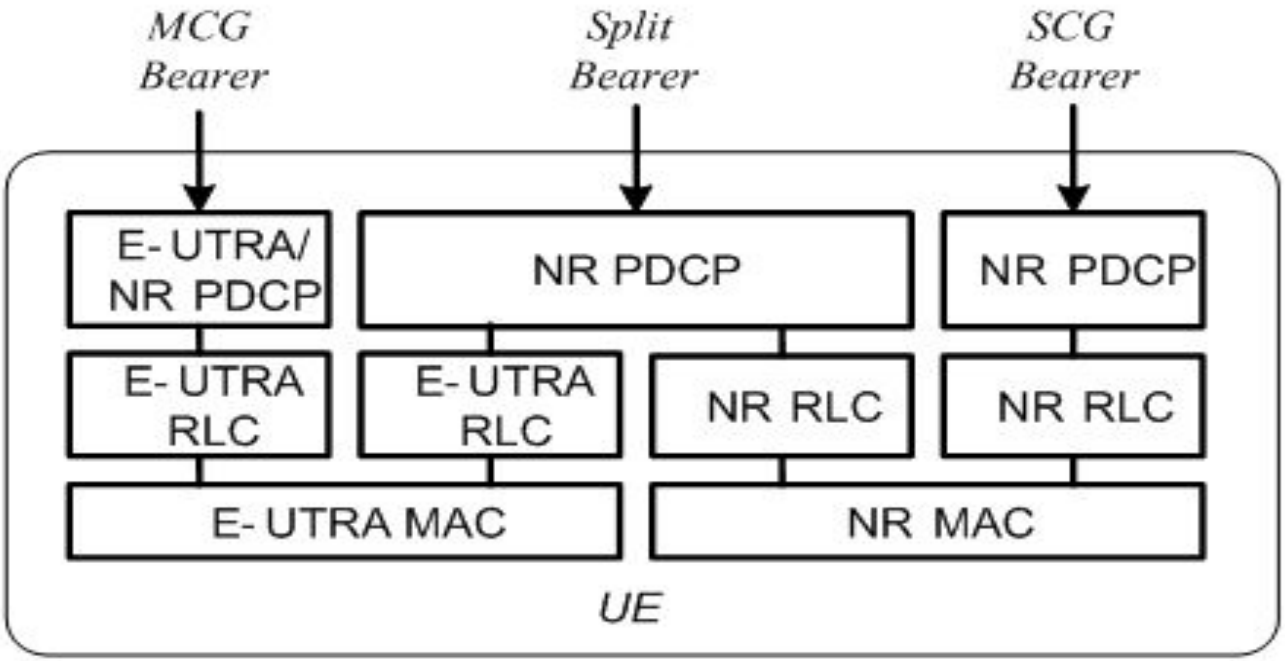
CP architecture for EN-DC :



User plane :

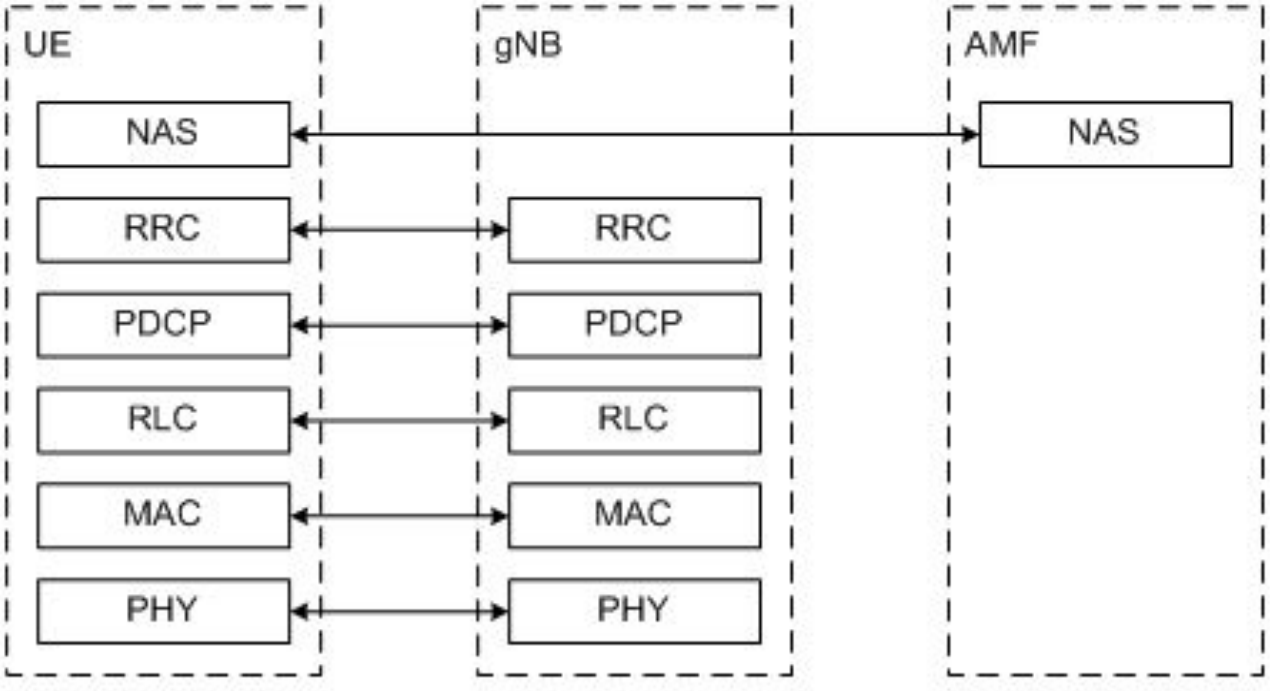
- In EN-DC , from a UE perspective , three bearer types exist : MCG bearer, SCG bearer and split bearer.
- For EN-DC, the network can configure either E-UTRA PDCP or NRPDCP for MCG bearers while NR PDCP is always used for SCG and split bearers.

Architecture :



SA radio protocol Architecture

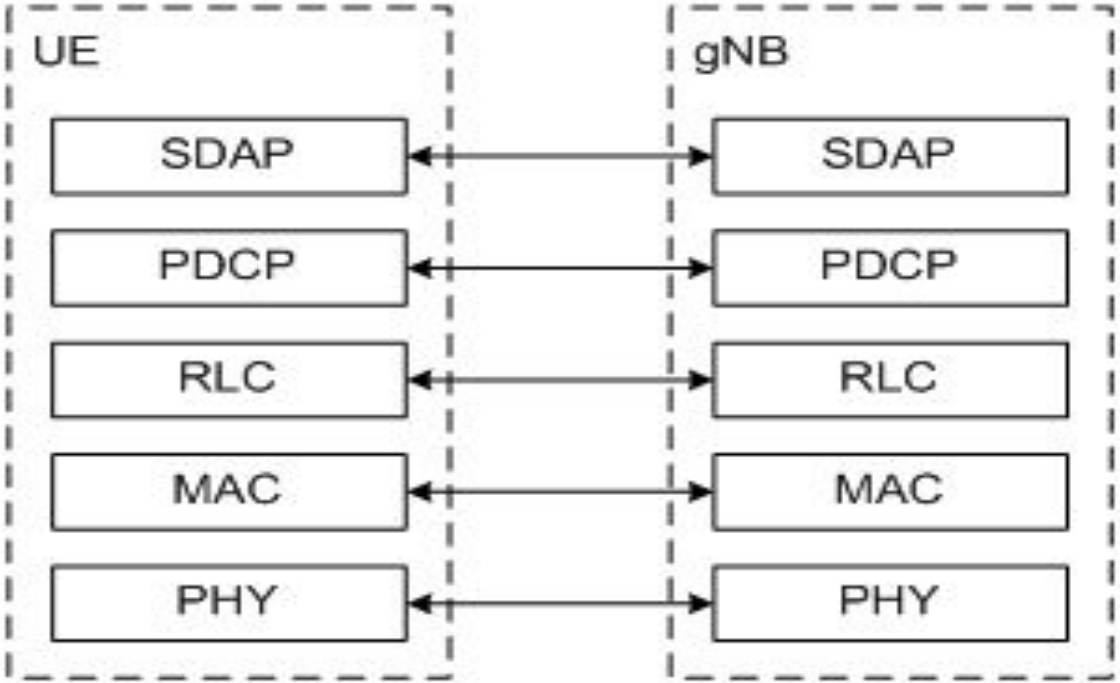
Control plane protocol stack :



Control plane :

- PDCP, RLC and MAC
- RRC
- NAS CP

User plane protocol stack :



User plane :

- SDAP
- PDCP
- RLC and MAC

Radio physical layer aspects

Numerologies , waveform & frame structure

Physical layer aspects :

- OFDM with CP is used for DL and in NR UL direction.
- Carrier spacing of 15 KHz , 30 KHz and 60 KHz can be used for network deployments operating in frequency bands below 6 GHz.
- Network deployments above 24 GHz, 60 KHz and 120 GHz subcarrier spacing can be used.

Physical layer aspects :

- One RB is defined as consecutive twelve subcarriers.
- NR supports both FDD & TDD operation with the same frame structure.
- Such very short transmissions mainly targets usage cases requiring low latency , such as some URLLC services.

Channel coding & modulation :

- In NR, LDPC coding is used for data (PDSCH/PUSCH) for L1 control signalling (PDCCH/PUCCH) .
- Polar coding is used in case of more than 11 information bits.
- QPSK, 16 QAM , 64 QAM and 256 QAM are supported for DL and UL.

Radio physical layer aspects

Initial access & mobility :

- NR synchronization signals i.e PSS & SSS are transmitted over 127 sub carriers and are designed to carry the PCID selected from 1008 candidates.
- PSS & SSS are transmitted together with PBCH and DMRS for PBCH as an SS/PBCH block for a carrier within four OFDM symbols in time domain and 240 subcarriers , corresponding to 20 resource blocks , in frequency domain.

Initial access & mobility :

- SIB 1 & other SIB 2 are carried by PDSCH which is scheduled for PDCCH.
- Paging message is carried by PDSCH which is scheduled by PDCCH.
- For random access in NR, a four step procedure (Msg 1, Msg 2, Msg 3 and Msg 4) similar to LTE is defined.

MIMO aspects：

- NR supports multi-layer transmission with a maximum of 8 to 4 transmission layers for DL & UL transmission directions respectively.
- RSs are specified assuming multi-antenna transmission.

MIMO aspects :

- CSI-RS can also be used for fine frequency/time tracking i.e Tracking RS, mobility measurements and beam management measurements.
- Beamforming / precoding is an important technique for achieving higher throughput and sufficient coverage.

MIMO aspects :

- Phase tracking RS can be used in both DL & UL to compensate for the increased phase noise for the higher frequency ranges.

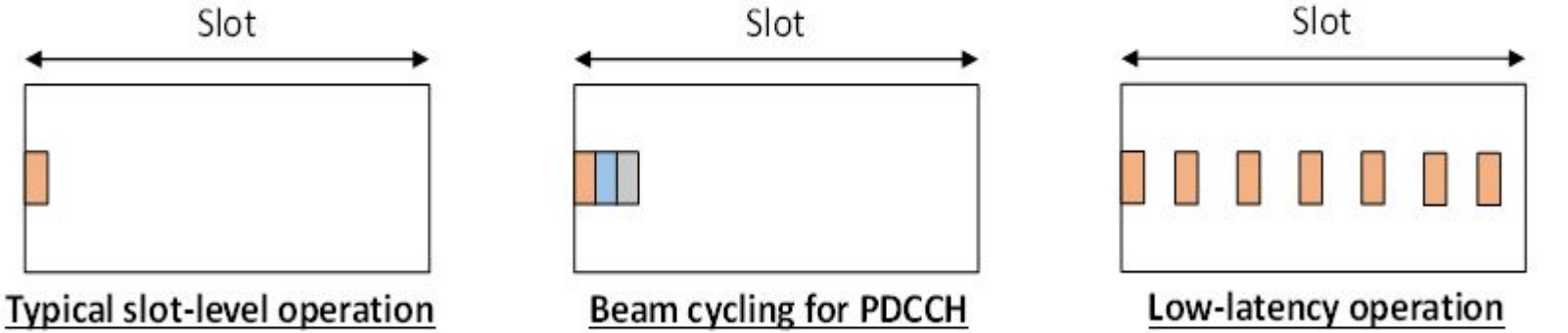
DL channels :

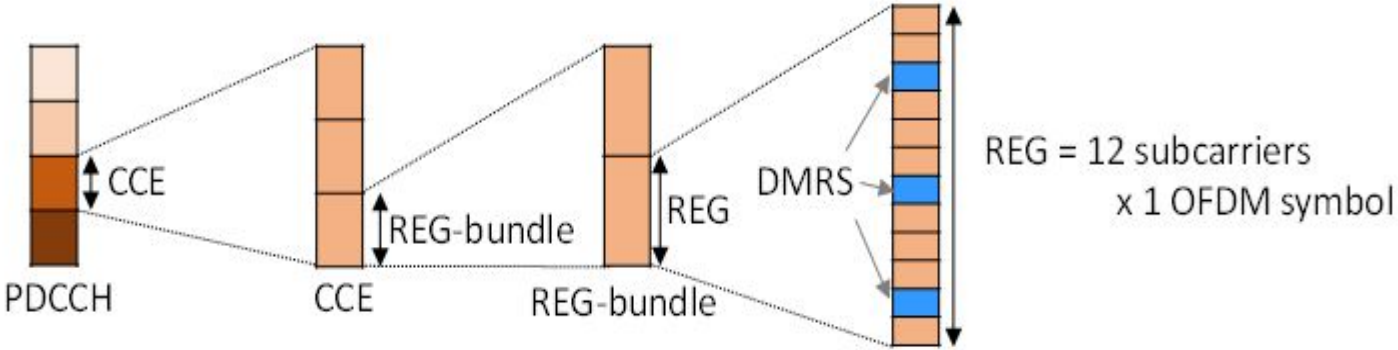
- The basic way of controlling data transmission in NR is scheduling in a similar way as in LTE.
- Each device monitors a no. of PDCCHs , typically once per slot.
- The PDCCHs are transmitted in one or more control resource sets, each of length one to three OFDM symbols.

NR DCI formats :

DCI format	RNTI
DCI format 0_0	RA-RNTI, TC-RNTI,C-RNTI,CS-RNTI
DCI format 0_1	C-RNTI , CS-RNTI
DCI format 1_0	SI-RNTI, RA-RNTI,P-RNTI, C-RNTI,CS-RNTI
DCI format 1_1	C-RNTI , SC-RNTI
DCI format 2_0	SFI-RNTI
DCI format 2_1	INT-RNTI
DCI format 2_2	TPC-PUSCH-RNTI, TPC-PUCCH-RNTI
DCI format 2_3	TPC-SRS-RNTI

General description of NR PDCCH :

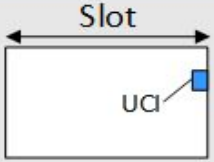
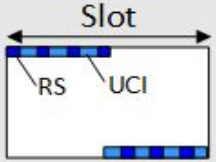
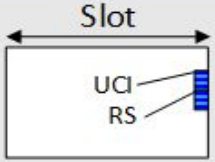
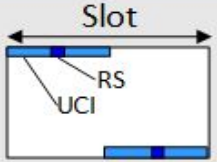
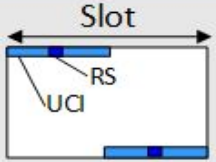




UL channels :

- In NR, PUCCH delivers UCI which consists of HARQ-ACK , SR or CSI.
- NR PUCCH supports durations of 1 to 2 symbols or 4 to 14 symbols.

UL channels :

	PUCCH format 0	PUCCH format 1	PUCCH format 2	PUCCH format 3	PUCCH format 4
Conceptual figures					
Use-case	Short-PUCCH HARQ/SR 1-2 bits	Long-PUCCH HARQ/SR 1-2 bits	Short-PUCCH Any UCI > 2 bits	Long-PUCCH Any UCI > 2 bits	Long-PUCCH Any UCI > 2 bits
Duration	1 – 2 symbols	4 – 14 symbols	1 – 2 symbols	4 – 14 symbols	4 – 14 symbols
Starting symbol	Anywhere unless the PUCCH cross slot boundary				
RB size	1 RB	1 RB	1 – 16 RBs	1 – 16 RBs	1 RB
CDM capacity	12	36 or 84	1	1	2 or 4
Mux method	Cyclic shift	Cyclic shift + TD-OCC	-	-	FD-OCC
Coding scheme	-	-	Read-Muller for up to 11 bits, Polar for more than 11 bits		
Note	RS-less format	LTE PF1 analogy	CP-OFDM	LTE PF4 analogy	LTE PF5 analogy

UL channels :

- Long PUCCH is used to improve coverage.
- Short PUCCH is used to reduce coverage.
- For a UE, TDM between long-PUCCH and short-PUCCH is also supported.

Scheduling / HARQ :

- DCI formats0_0/0_1 and 1_0/1_1 schedule PUSCH and PDSCH respectively.
- For each DCI format, frequency-domain and time-domain resource allocation fields are included.

Radio physical layer aspects

CA, BW parts & LTE/NR dual connectivity :

- In NR, the maximum BW of a NR carrier is 100 MHZ for carrier frequencies below 6 GHz and 400 MHZ for carrier frequencies above 24 GHZ respectively.
- Both intra-band CA & inter-band CA are supported.
- Both self-carrier scheduling & cross-carrier scheduling are supported.

CA,BW parts & LTE/NR dual connectivity :

- NR newly defines the concept of bandwidth part.
- Up to four BWP's can be configured for a UE per NR carrier for DL and UL respectively.

NR-LTE co-existence :

- Higher - layer signalling can be used to configure reserved resources and LTE CRS - related information to be rate - matched around.
- The corresponding backhaul signalling between eNodeB and gNodeB is also specified.
- PDSCH resource mapping in NR allows LTE, NB-IOT and LTE-M to operate on the same frequency as NR.

Supplementary DL :

- In this , an SDL carrier can be aggregated with CA together with another DL & UL carrier .

Supplementary UL :

- In SUL, the UE is configured with 2 ULs for one DL of the same cell and UL transmissions on those two ULs are controlled by the network to avoid overlapping PUSCH/PUCCH transmissions in time.

UL TPC :

- NR UL power control is designed to allow dynamic power adjustment and multiple power control processes e.g for switching.
- When UE supports dynamic power sharing, power allocations is dynamically adjusted on condition that the total transmission power never exceeds allowed value.

Higher layer aspects

Layer 2 related aspects

MAC sublayer :

- Mapping between logical channels and transport channels.
- Multiplexing / demultiplexing of MAC SDUs.
- Scheduling information reporting
- Error correction through HARQ
- Priority handling between UE's by means of dynamic scheduling.

RLC sublayer :

- Transfer of upper layer PDUs
- Sequence numbering independent of the one in PDCP (UM & AM)
- Error correction through ARQ (AM only)
- Reassembly of SDU (AM and UM)
- Protocol error detection.

PDCP sublayer :

- Transfer of user data
- Reordering and duplicate detection
- PDCP PDU routing
- Ciphering, deciphering
- Sequence numbering

SDAP sublayer :

- Mapping between a QoS flow and a data radio bearer.
- Marking QoS flow ID (QFI) in both DL and UL packets

Higher layer aspects

RRC related aspects :

- Broadcast of system information related to AS & NAS.
- Security functions including key management
- Establishment, configuration , maintenance and release of signalling radio bearers and data radio bearers.
- Mobility functions

Network interface related aspects :

X2 AP functions :

- EUTRA - NR dual connectivity function
- Secondary RAT data usage report function

Network interface related aspects :

S1 AP functions :

- Report of secondary RAT data volumes function

Network interface related aspects :

Xn AP functions :

- Xn setup function
- Error indication function
- Xn reset function
- Xn configuration data update function
- Handover preparation function
- RAN paging function’
- Energy savings function

Network interface related aspects :

NG AP functions :

- Paging function
- UE context management function
- Mobility management function
- PDU session management function
- NAS node selection function
- AMF management function

Network interface related aspects :

F1 AP functions :

- F1 interface management function
- System information management function
- F1 UE context management function
- RRC message transfer function

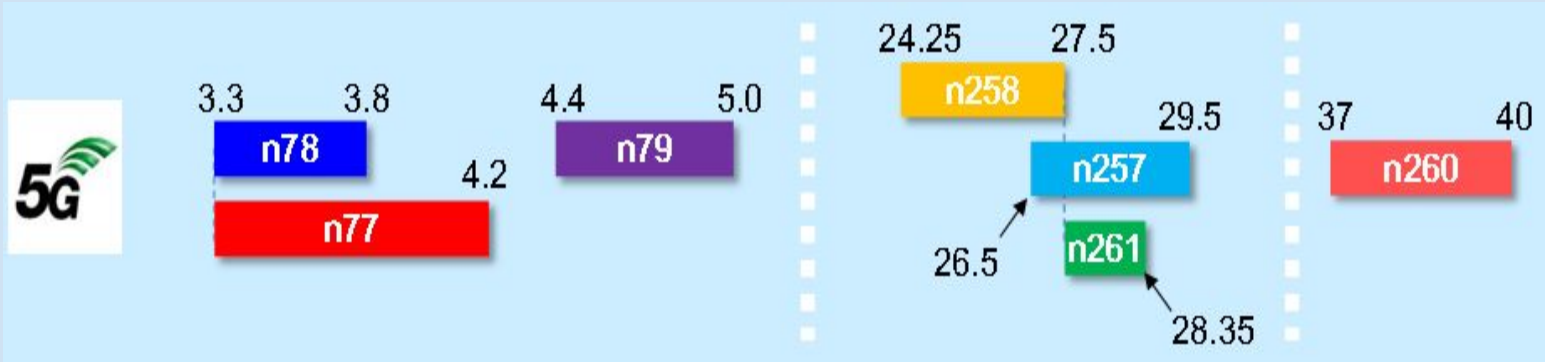
Frequency aspects

Frequency aspects :

- FR 1 : sub 6 GHz : 450-6000 MHz
- FR 2 : mm wave : 24250 - 52600 MHz
- Both conducted and over the air (OTA) methodologies can be utilized in FR1 , but only OTA can be utilized in FR2.

Frequency aspects :

- Ranges (65-256) and (257-512) are reserved as band number for NR new bands in FR1 and FR2 respectively.



NR bands :

NR operating band	Uplink (UL) operating band	Downlink (DL) operating band	Duplex Mode
n1	1920 MHz – 1980 MHz	2110 MHz – 2170 MHz	FDD
n2	1850 MHz – 1910 MHz	1930 MHz – 1990 MHz	FDD
n3	1710 MHz – 1785 MHz	1805 MHz – 1880 MHz	FDD
n5	824 MHz – 849 MHz	869 MHz – 894 MHz	FDD
n7	2500 MHz – 2570 MHz	2620 MHz – 2690 MHz	FDD
n8	880 MHz – 915 MHz	925 MHz – 960 MHz	FDD
n12	699 MHz – 716 MHz	729 MHz – 746 MHz	FDD
n20	832 MHz – 862 MHz	791 MHz – 821 MHz	FDD
n25	1850 MHz – 1915 MHz	1930 MHz – 1995 MHz	FDD

NR bands :

n28	703 MHz – 748 MHz	758 MHz – 803 MHz	FDD
n34	2010 MHz – 2025 MHz	2010 MHz – 2025 MHz	TDD
n38	2570 MHz – 2620 MHz	2570 MHz – 2620 MHz	TDD
n39	1880 MHz – 1920 MHz	1880 MHz – 1920 MHz	TDD
n40	2300 MHz – 2400 MHz	2300 MHz – 2400 MHz	TDD
n41	2496 MHz – 2690 MHz	2496 MHz – 2690 MHz	TDD
n50	1432 MHz – 1517 MHz	1432 MHz – 1517 MHz	TDD1
n51	1427 MHz – 1432 MHz	1427 MHz – 1432 MHz	TDD
n66	1710 MHz – 1780 MHz	2110 MHz – 2200 MHz	FDD
n70	1695 MHz – 1710 MHz	1995 MHz – 2020 MHz	FDD
n71	663 MHz – 698 MHz	617 MHz – 652 MHz	FDD
n74	1427 MHz – 1470 MHz	1475 MHz – 1518 MHz	FDD
n75	N/A	1432 MHz – 1517 MHz	SDL
n76	N/A	1427 MHz – 1432 MHz	SDL
n77	3300 MHz – 4200 MHz	3300 MHz – 4200 MHz	TDD
n78	3300 MHz – 3800 MHz	3300 MHz – 3800 MHz	TDD
n79	4400 MHz – 5000 MHz	4400 MHz – 5000 MHz	TDD
n80	1710 MHz – 1785 MHz	N/A	SUL
n81	880 MHz – 915 MHz	N/A	SUL
n82	832 MHz – 862 MHz	N/A	SUL
n83	703 MHz – 748 MHz	N/A	SUL

NR bands :

n84	1920 MHz – 1980 MHz	N/A	SUL
n86	1710 MHz – 1780MHz	N/A	SUL
n257	26500 MHz – 29500 MHz	26500 MHz – 29500 MHz	TDD
n258	24250 MHz – 27500 MHz	24250 MHz – 27500 MHz	TDD
n260	37000 MHz – 40000 MHz	37000 MHz – 40000 MHz	TDD
n261	27500 MHz – 28350 MHz	27500 MHz – 28350 MHz	TDD

LTE connectivity to 5G-CN (4G AN with 5G CN)

LTE connectivity :

- LTE connectivity to 5G-CN does not only allow RAN level interworking but provides a migration path where the core network is 5G-CN whereas the radio remains LTE.
- The feature “ LTE connectivity to 5G-CN” or the E-UTRA connected to 5GC, is supported as part of NG-RAN.

LTE connectivity to 5G-CN functionality :

- 5G NAS message transport
- Unified access control
- Flow based QoS
- Network slicing
- SDAP
- NR PDCP
- Support of UE's in RRC_INACTIVE state

Security aspects of 5G system - phase 1

Non - standalone NR security :

- The NSA architecture uses LTE as the master RAT , while NR serves as secondary RAT with UE's connected to both radios.

Evolution of the trust model :

- Moving on from the NSA deployment, in a SA 5G system, the trust model has evolved.
- The trust model in the UE is reasonably simple : there are two trust domains , the tamper proof of UICC on which the USIM resides as trust anchor and the ME.
- The ME and the USIM together form the UE.

Evolution of the trust model :

- The RAN is separated into DU and CU.
- DU and CU together form gNB the 5G base station.
- The DU does not have any access to customer communications.
- In the CN, the AMF serves as termination point for NAS security.

Evolution of the trust model :

- AMF is collocated with SEAF that holds the root key for the visited network.
- AUSF keeps a key for reuse.
- ARPF keeps the authentication credentials.

Critical communications

HRLLC :

The LTE_HRLLC work item provides solutions to support URLLC for LTE having requirements as :

- Semi - static CFI configuration
- PDSCH repetition
- UL SPS repetition
- PDCP packet duplication
- Granular time reference provision

Semi - static CFI :

- It indicates how many OFDM symbols are used for PDCCH.
- CFI is obtained by decoding PCFICH.
- The semi-static CFI value can be configured separately for MBSFN and non-MBSFN subframes for each cell.

PDSCH repetition :

- To improve the reliability of the DL data channel, PDSCH repetition can be configured to a UE for a given TTI length.

PDCP packet duplication :

- PDCP packet duplication is configured for a radio bearer by RRC where two logical channels are configured for the radio bearer.
- It is supported in cases as : SRBs using RLC AM, DRBs using RLC UM or AM.

MTC & IOT

Wake-up signalling for IDLE mode (FDD) :

- When a UE is in DRx or eDRx , it must regularly check if a paging message is arriving from the CN.
- This feature allows the eNB to send the UE a “wake - up - signal “ to monitor NPDCCH.

Scheduling request :

- NB-IOT , SR exists only as a higher layer procedure, which triggers a random access procedure to request UL resources to send BSR.
- The resources are activated and deactivated by dynamic signalling on NPDCCH.

Early data transmission :

- An idle mode UE is able to transmit data in msg 3 of random access procedure, carrying between 328 and 1000 bits.
- The eNB can allow the UE to transmit a smaller amount of data than the maximum permitted size in order to reduce the power spent transmitting padding bits.

Quick release of RRC connection :

- An NB-IOT UE has to wait upto 10 seconds, after the receipt of RRCconnectionrelease message.

System enhancements

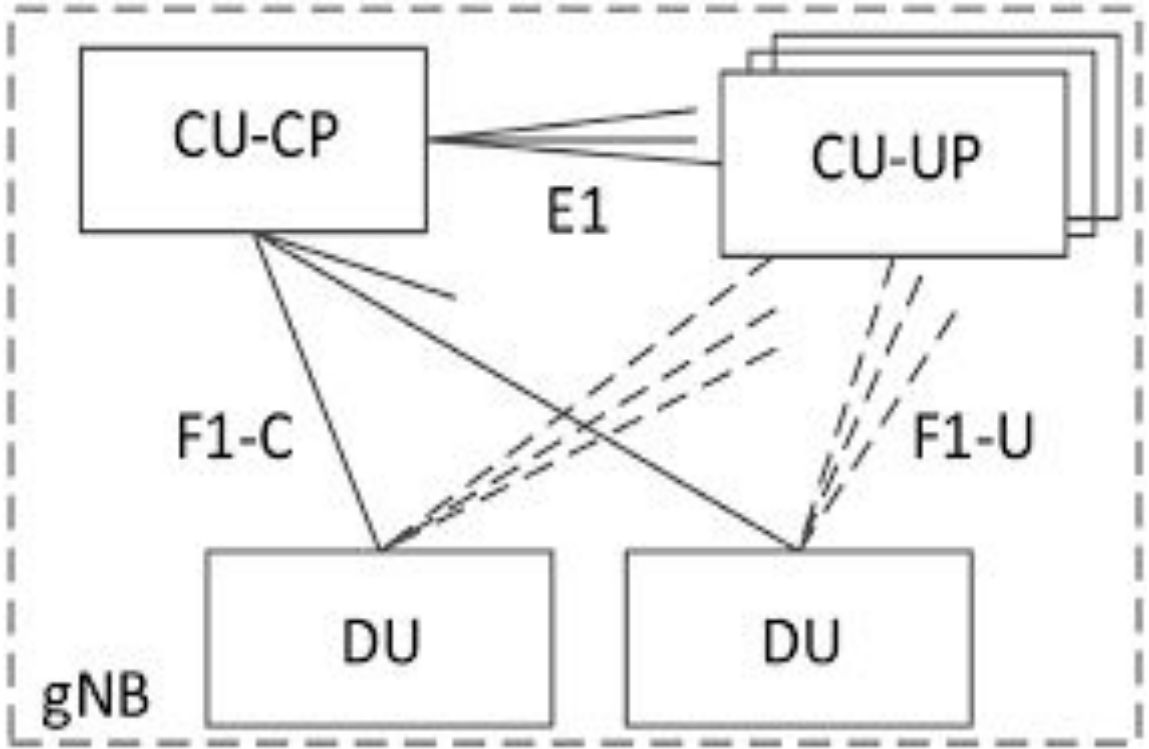
CP - UP separation :

- A new interface E1 , enables interconnecting a gNB-CU-CP and a gNB-CU-UP.
- The gNB-CU hosts the RRC, SDAP and PDCP radio protocols, while the gNB-DU hosts the PHY, RRC and MAC radio protocols.
- The gNB-CU and gNB-DU are connected via F1 interface.

Architecture deployment scenarios :

- Centralized gNB-CU-CP and gNB-CU-UP
- Distributed gNB-CU-CP and centralized gNB-CU-UP
- Centralized gNB-CU-CP and distributed gNB-CU-UP

Architecture :



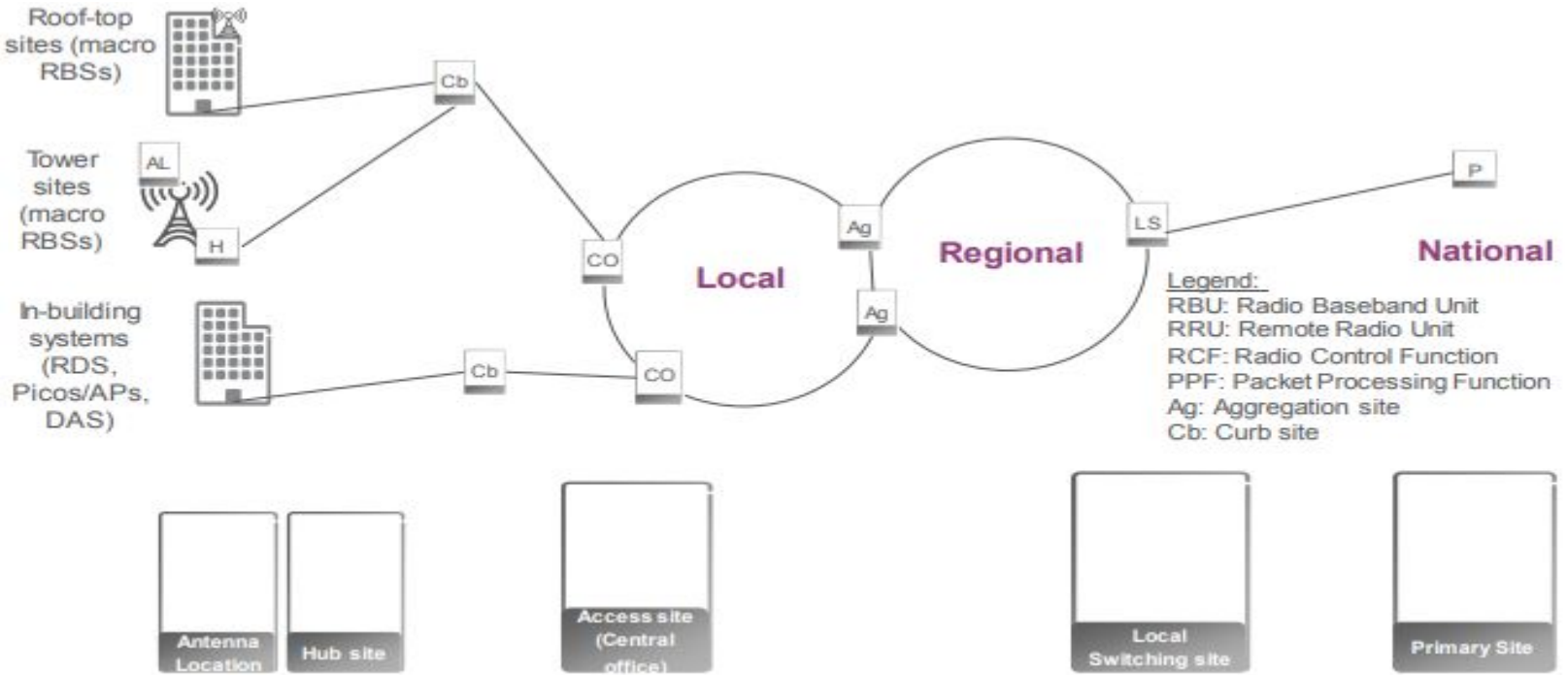
Quantitative KPI

Quantitative KPI :

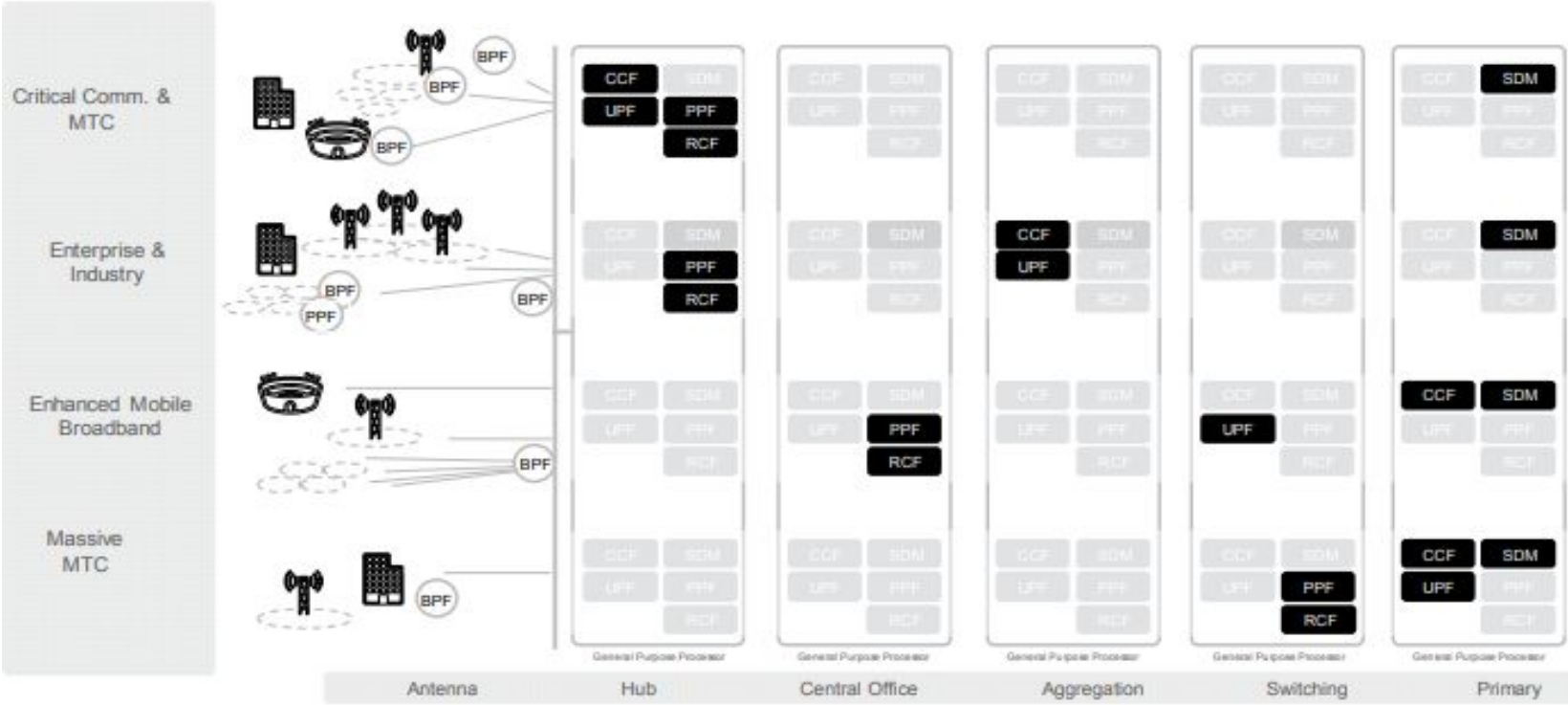
- Connection density : it refers to the number of devices fulfilling specific QoS per unit area (per km2) .
- Mobility : maximum user speed at which a defined QoS can be achieved in km/h.
- Network energy efficiency : the capacity is to minimize the RAN energy consumption while providing a much better area traffic capacity.

5G NR Deployments

5G Deployments :

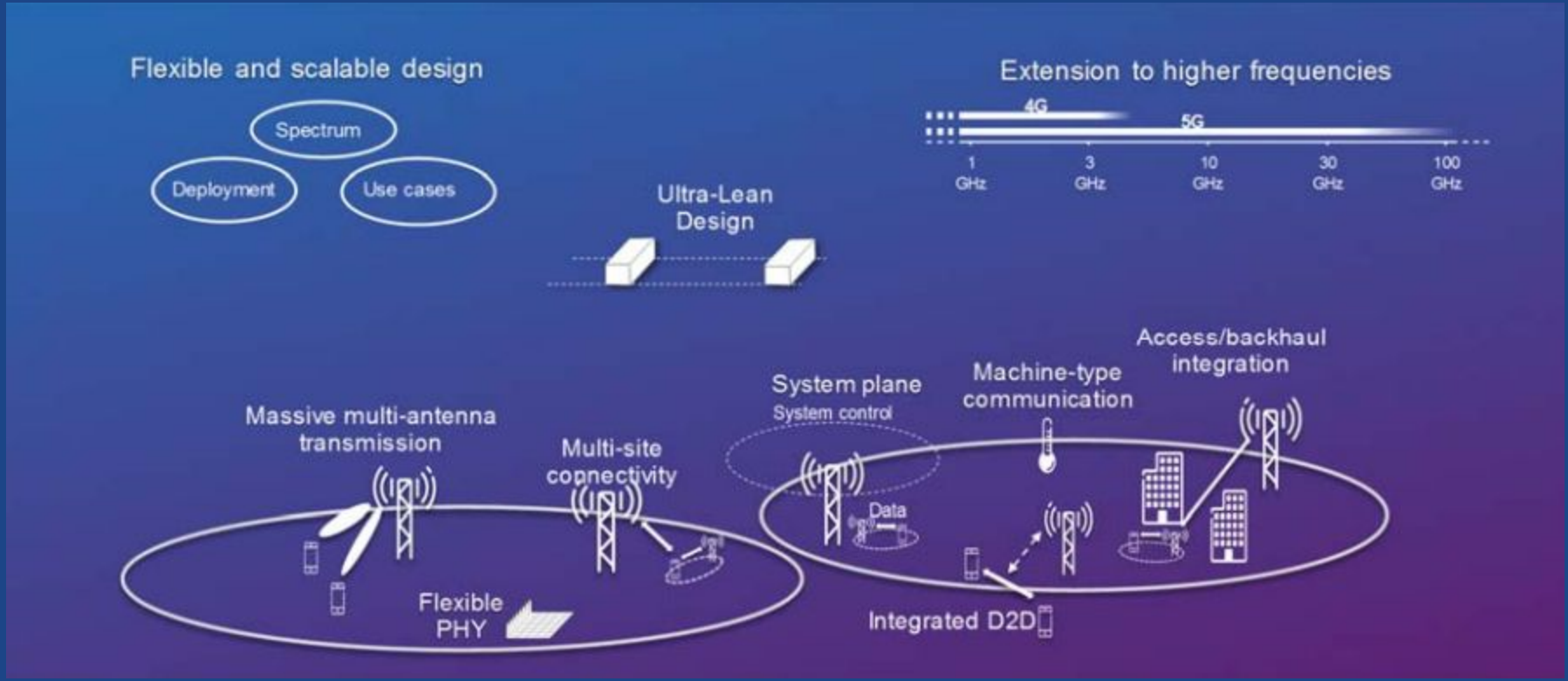


Virtualization :



Introduction to NR

5G NR :



5G NR :

- New spectrum is a target
- A main part of such spectrum will be available at higher frequencies (above 10 GHz)
- Flexible physical layer
- Spectrum flexibility
- Multi-antenna technologies
- Multi-site coordination

5G NR :

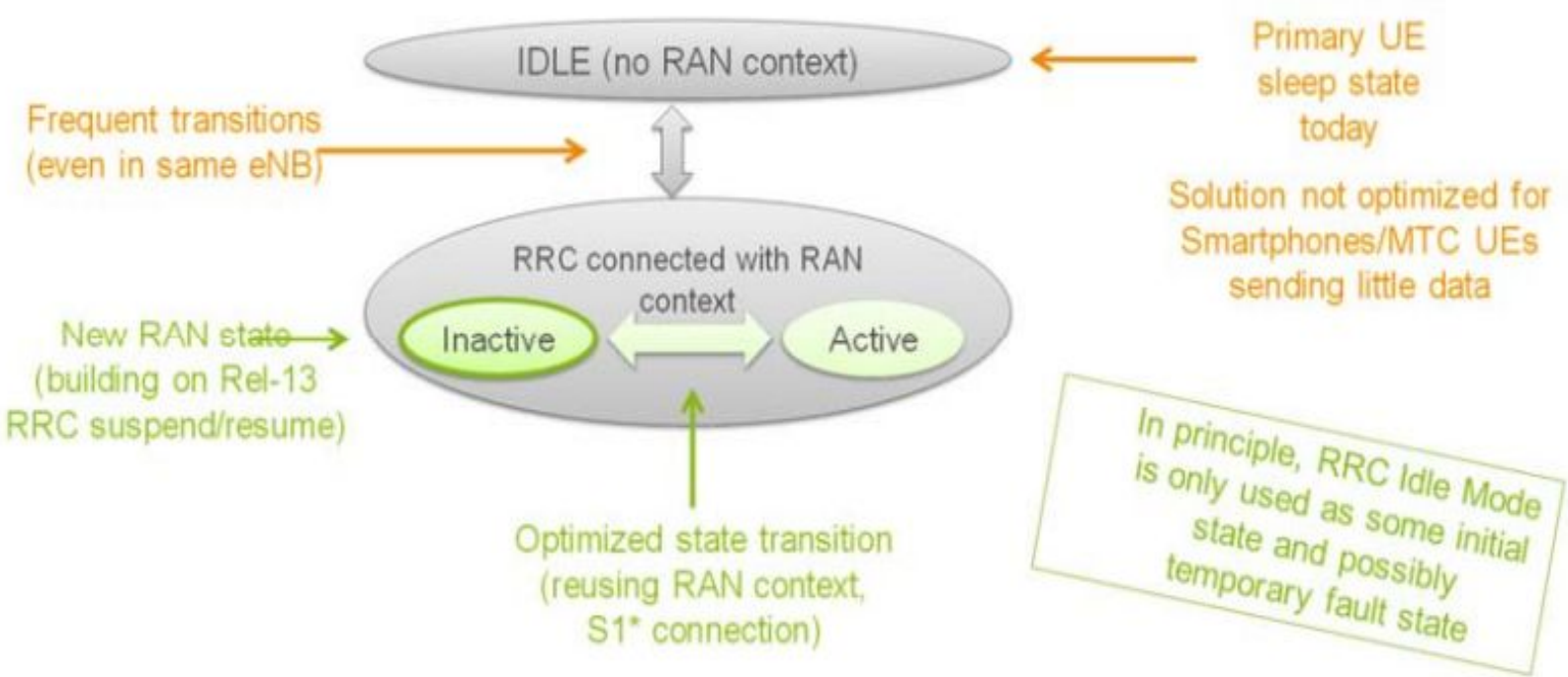
- Access/backhaul integration
- D2D communication
- Ultra lean design

5G RRC

RRC inactive state :

- In NR, evolution of new RRC state (RRC inactive or dormant state) keeping S1* connection up.

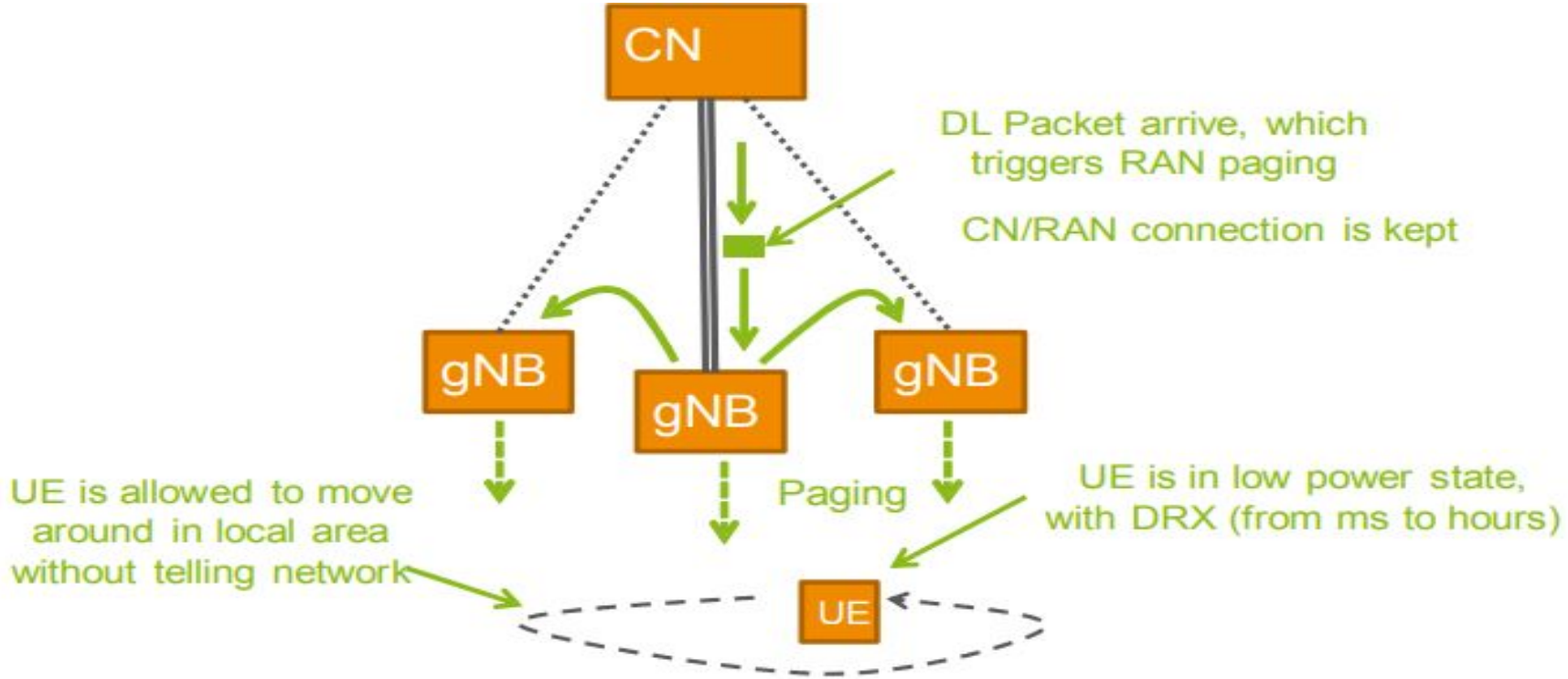
Need for RAN controlled sleep state :



5G sleep state should support :

- DRx with preferably lower power consumption than today.
- UE context is maintained in RAN.
- UE controlled mobility
- RAN paging within local areas.
- No CN signalling required

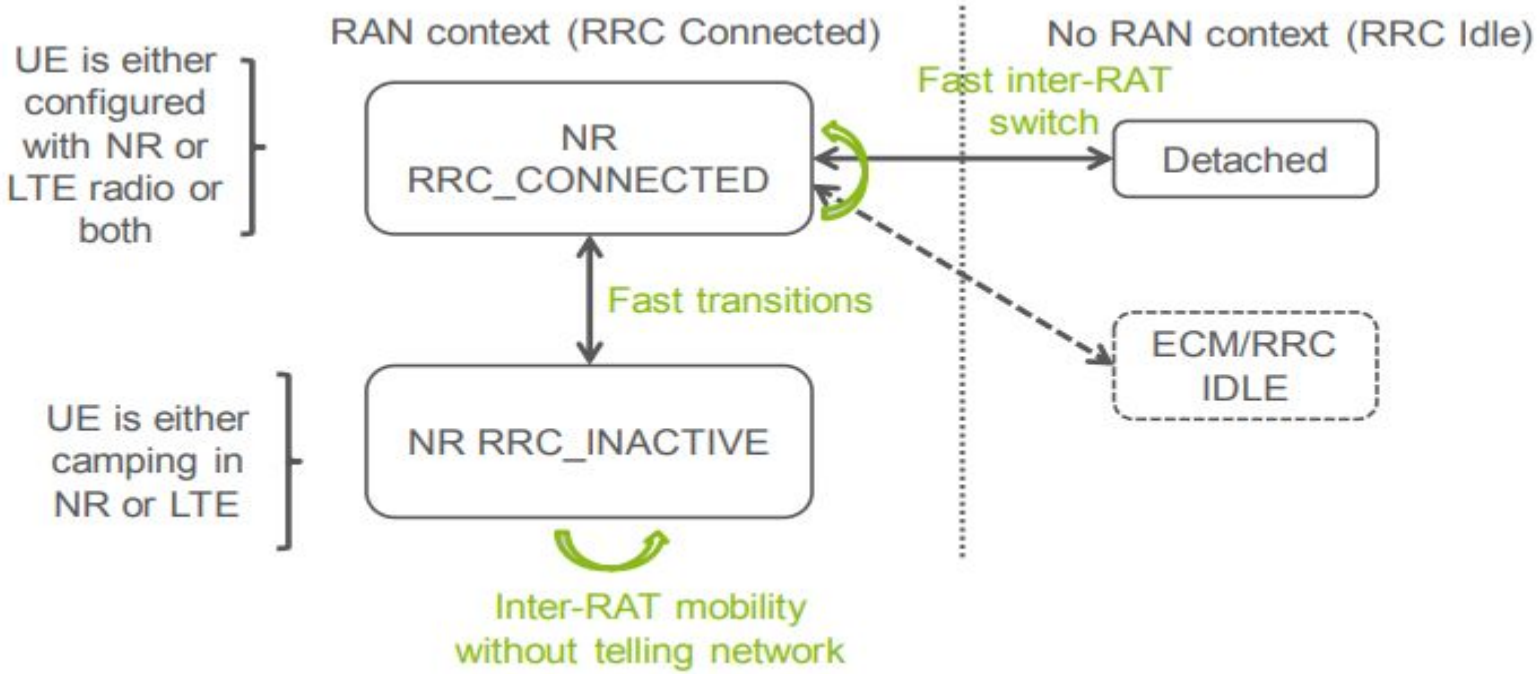
NR Dormant RRC state :



RRC states :

- RRC_IDLE
- RRC_INACTIVE
- RRC_CONNECTED

Combined LTE/NR states :



RRC states :

- RRC_IDLE
- RRC_INACTIVE
- RRC_CONNECTED

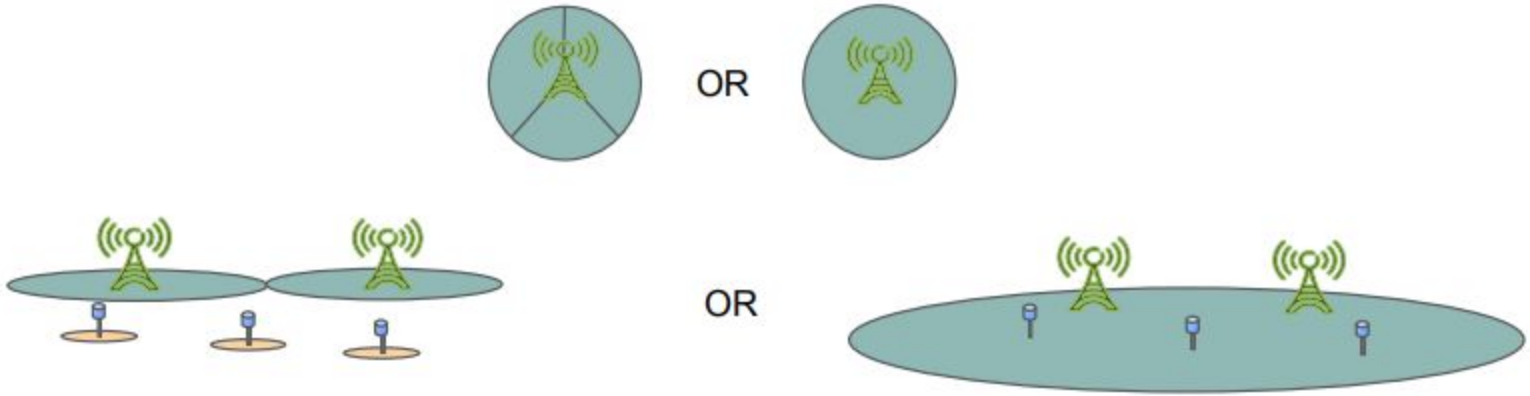
NR Cell

NR cell :

- It is defined by SS-Block and SIB table.
- Received time synchronized (within a cyclic prefix) or time orthogonal (analog beam sweep)
- Cells can have same access configuration
- SIB table doesn't need to be cell unique

NR cell size determined by :

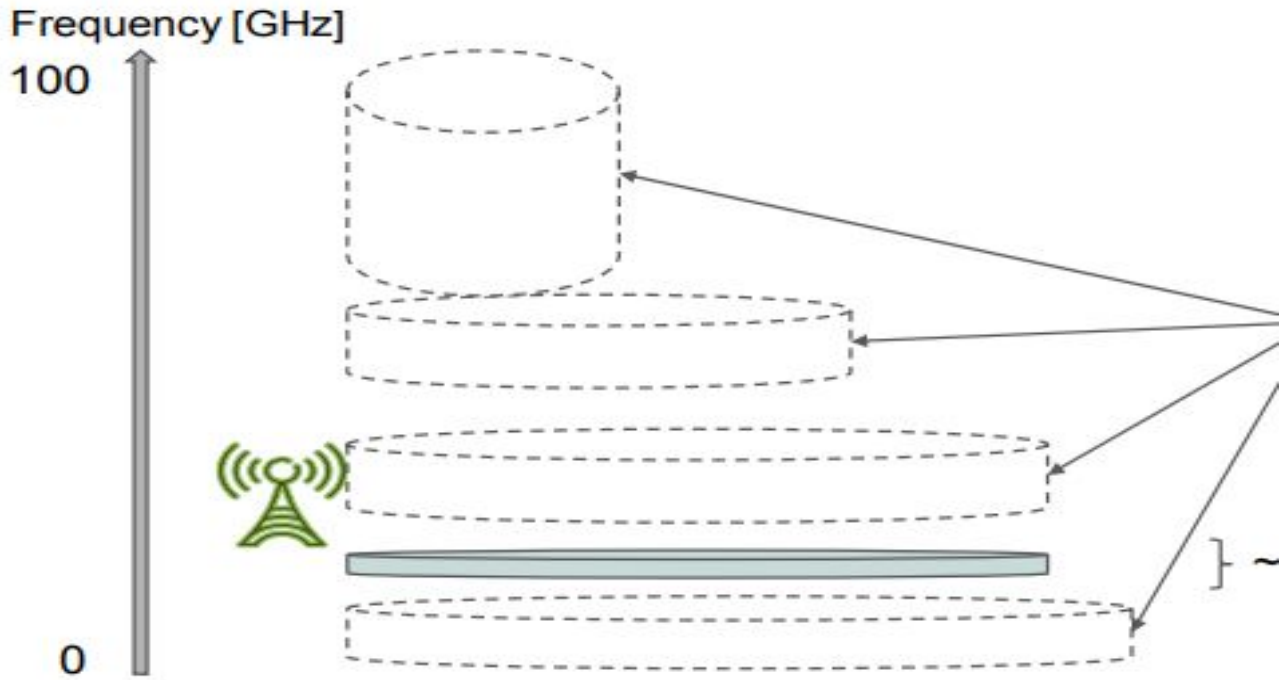
- IDLE/RRC INACTIVE control load
- Synchronized transmission timing



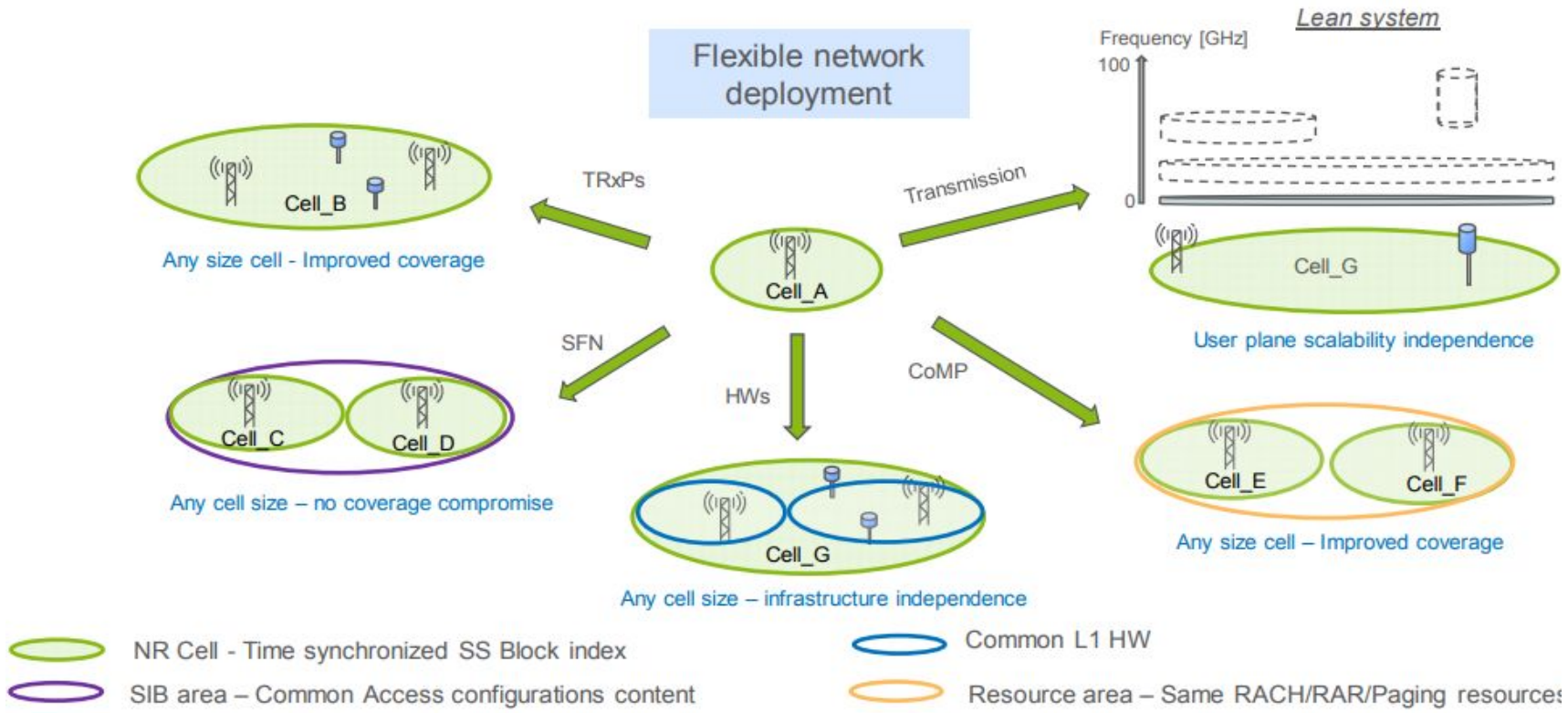
Frequency carrier # NR cell :

- NR cell : broadcast when IDLE UE's are expected to find/camp on it and report the carrier when doing frequency/cell search for IDLE mobility.
- Silent frequency carriers

Frequency carrier :



NR cell deployment summary :



System broadcast

System broadcast :

- To separate the CP and UP, system broadcast should be transmitted independently from the user plane data.
- System information is divided into ‘minimum SI’ and ‘ other SI’ .

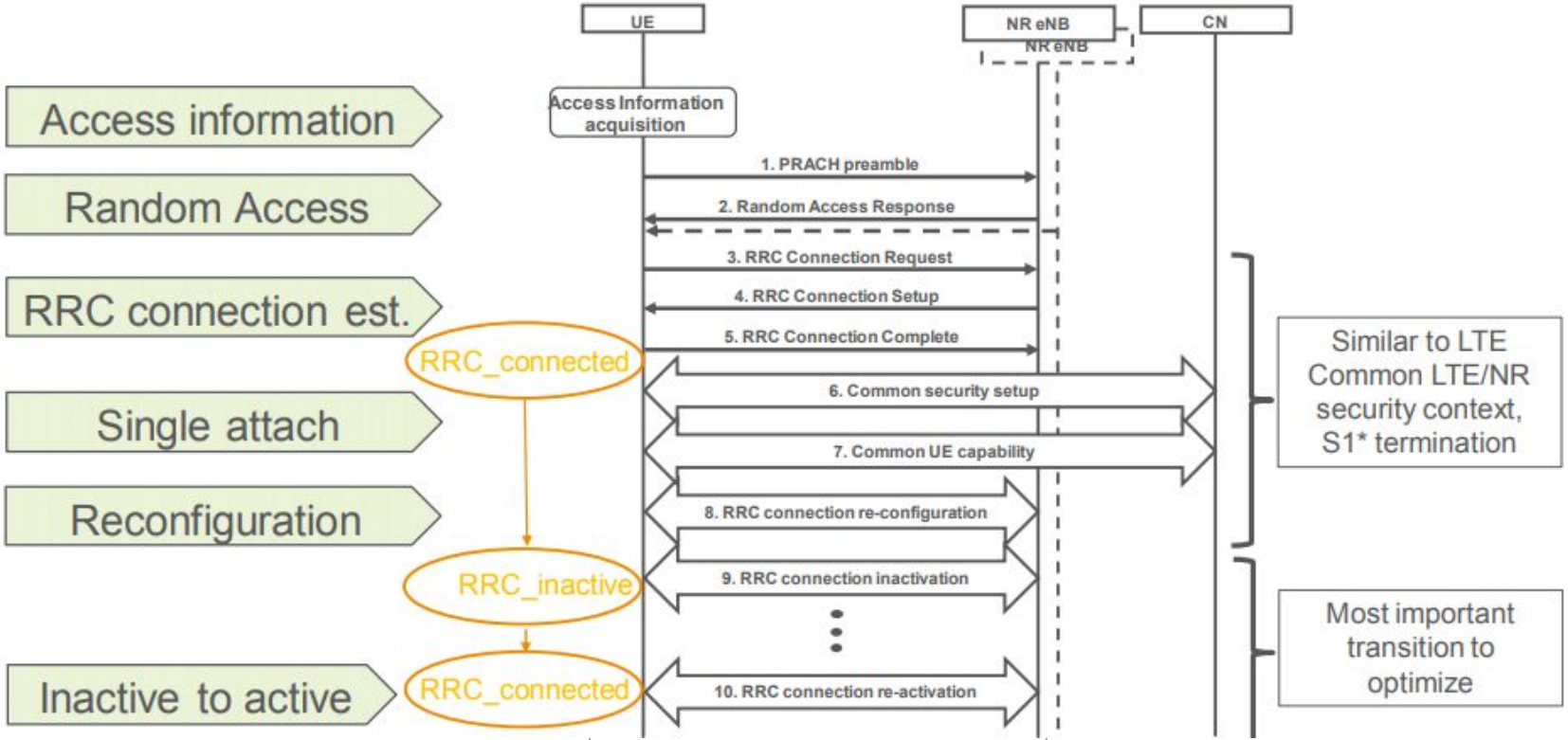
SS Block :

- SS : NR-PSS / NR-SSS
- NR-PBCH : contains a MIB
- Transmitted every X ms { e.g 5 or 80 ms}

SIB Block :

- Contain the configuration for system access
- May contain SI for more than one cell
- A SIB can contain several access configurations

Connection establishment overview :

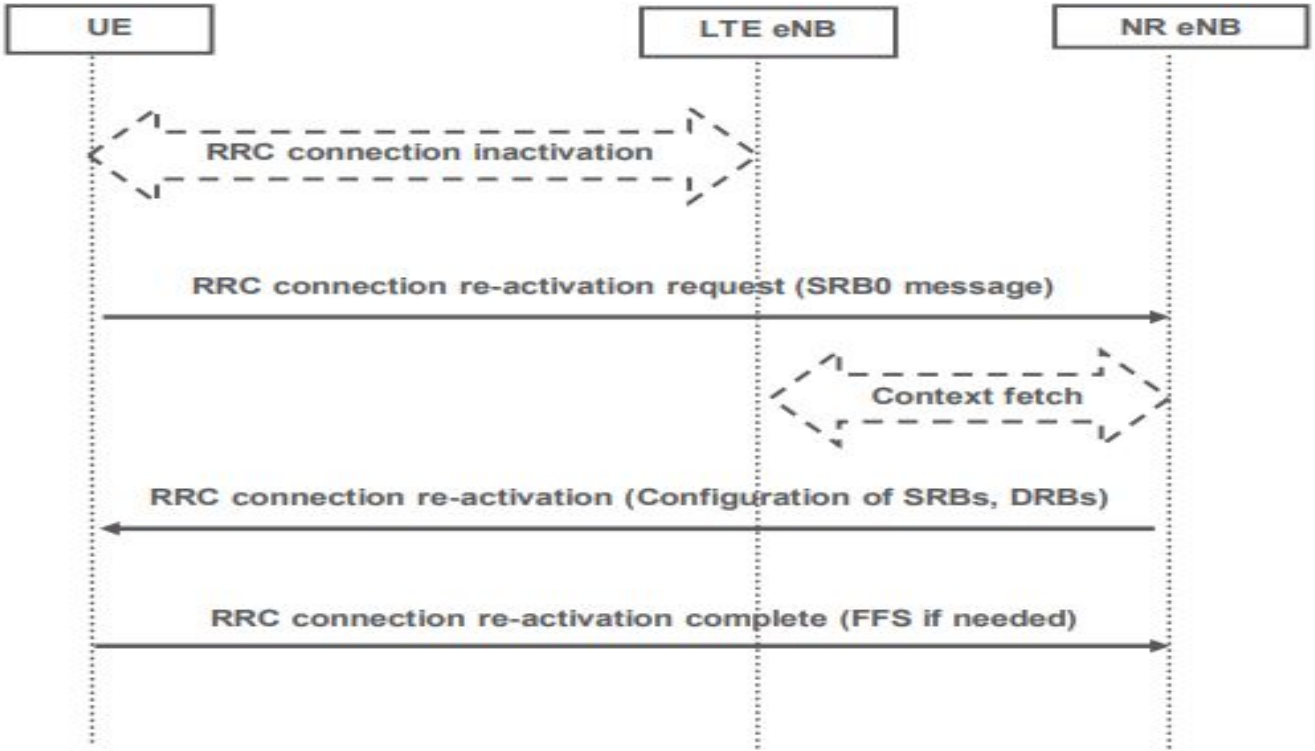


Connection establishment :

- Inactive state : RRC connected, SRBs & DRBs maintained
  Support for very long DRx
  UE connected mobility

- RRC connection re-activation : single RRC procedure to re-establish signalling & data radio bearers
  UE RRC context ID used to locate UE context
  Includes security re-activation

Inactive to active :

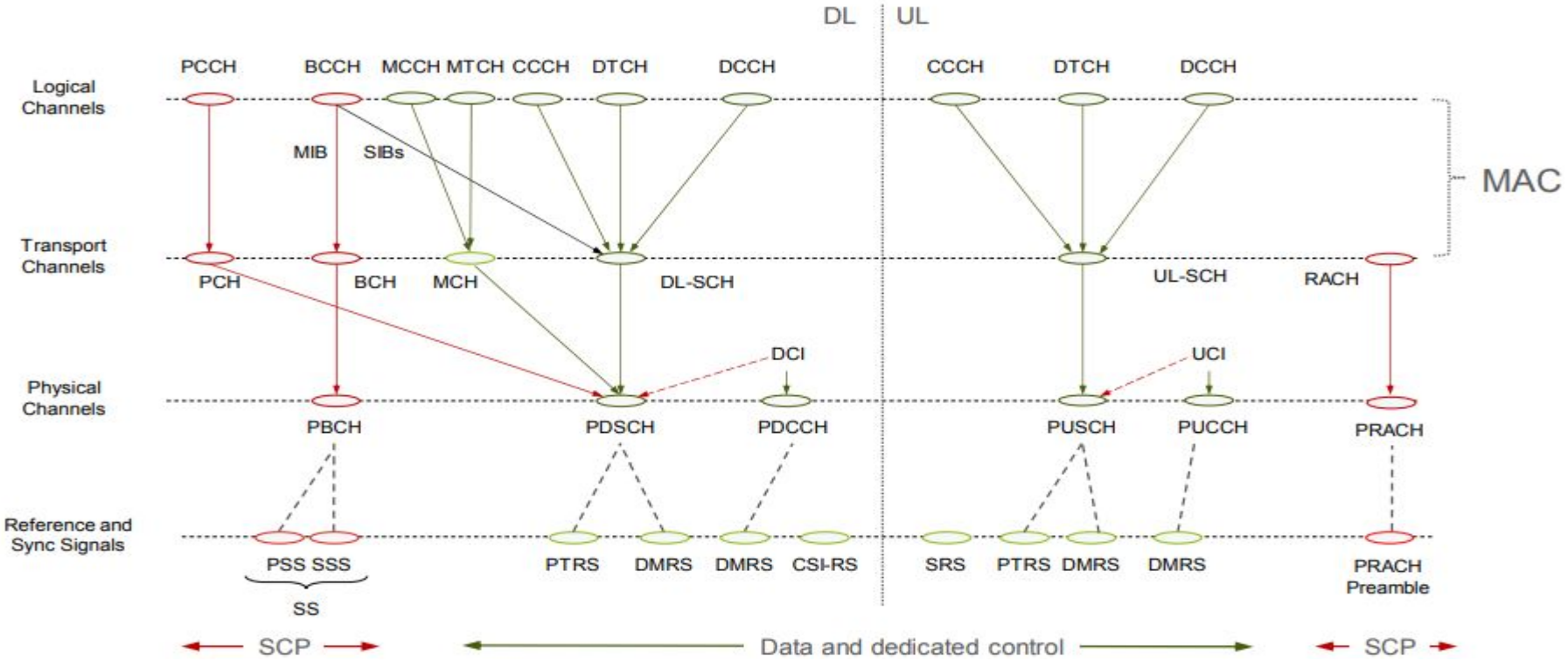


Channel structure

Channel structure :

- PBCH : used for MIB distribution
- System information can be distributed via PDSCH or via PDCH , depending on the UE state.
- The MIB is periodically broadcasted in PBCH.

Channel structure :



Channel structure :

- PDCCH schedules PDSCH and PUSCH.
- A PDCCH spans only a fraction of the system bandwidth and has its own demodulation reference signals enabling user-specific beamforming.
- PDCCH is transmitted preferably in the first OFDM symbol in an NR DL slot .
- space/frequency resources unused for PDCCH transmission may be used for PDSCH transmission.

DL reference & sync signals :

- SS
- PSS
- SSS
- PTRS
- DMRS for PDCCH
- CSI-RS
- DMRS for PDSCH

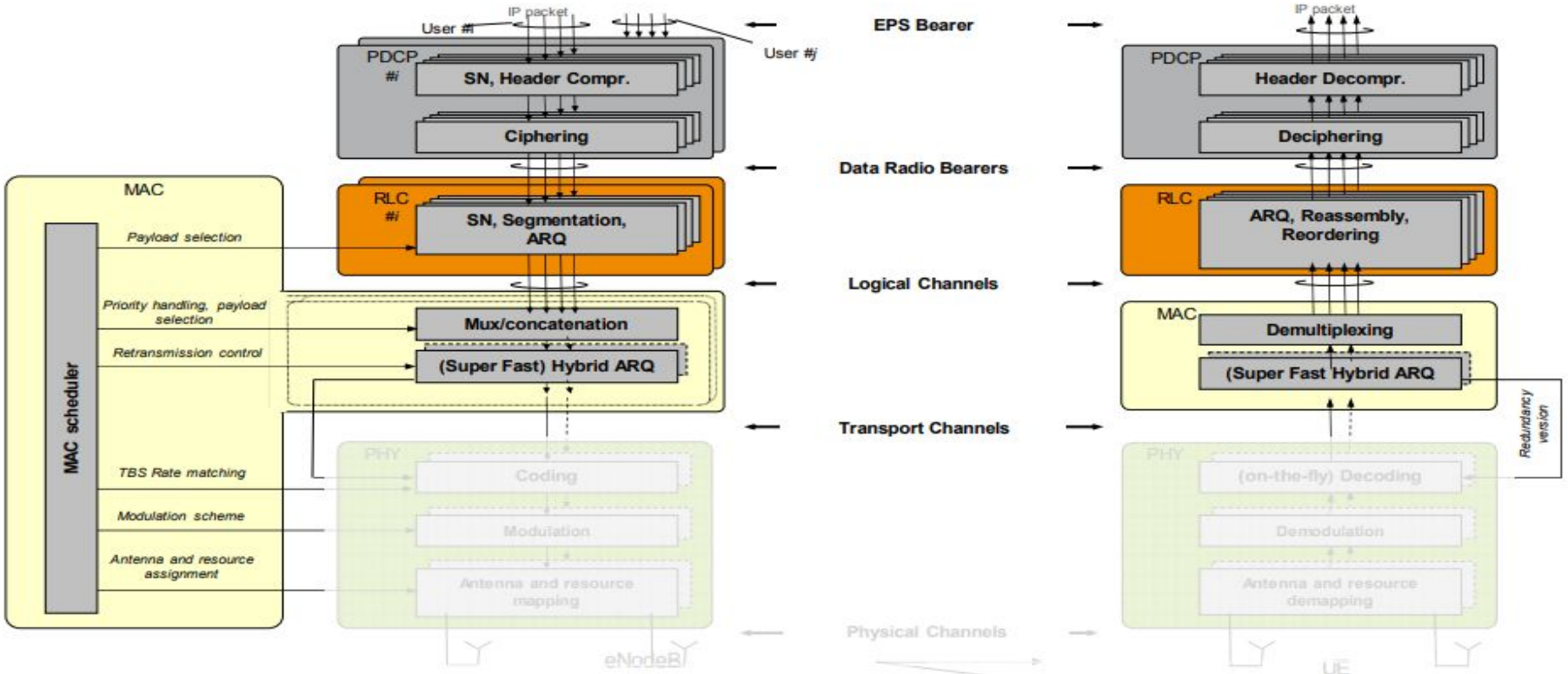
UL reference & sync signals :

- PRACH preamble
- SRS
- DMRS for PUCCH
- DMRS for PUSCH
- PTRS

Physical channels :

- PBCH
- PDCCH
- PUCCH
- PDSCH/PUSCH

Layer 2 functions :



Radio interface structure - using EPC :

- The protocols performing the functions in the radio interface for the UP are :
  PDCP, RLC , MAC & Physical layer
- For control signaling the RRC is used to transfer the NAS information over the radio interface as well as the AS signaling.

Radio interface structure - using EPC :

- The physical layer maps the transport channel onto a physical channel & performs channel coding , modulation etc.
- For NR, not only the protocol overhead but also the processing complexity and processing latency of the UP protocol stack were concerned.

Services & functions of AS sublayer :

- Mapping between a QoS flow and a data radio bearer.
- Marking QoS flow ID in both DL and UL packets.

5G QoS Indicator Parameters

5G QoS indicator parameters :

- The 5GI is the standardized value range have one - to- one mapping to a standardized combination of 5G QoS characteristics.
- The QoS parameter ARP contains information about priority level.

Reference signals

DMRS :

- Variable / configuration DM-RS patterns for data demodulation are supported.
- Front - loaded DM-RS is mapped over 1 or 2 adjacent OFDM symbols.
- DM-RS configuration can be upto maximum number of DM-RS ports.

CSI-RS :

- These are transmitted in DL and are primarily intended to be used by UE's to acquire CSI but could also serve other purposes.
- Effective channel estimation at the UE.
- Discovery signal

Massive MIMO :

- MIMO - beamforming , diversity , SMUX , precoding , SU-MIMO, MU-MIMO.
- Analog & digital beamforming
- CSI acquisition
- Antenna ports

Massive MIMO/beamforming for 5G :

- A predefined set of fixed beams seems to be the preferred solution for massive MIMO.
- The link beam can typically have rank 1-8.

Repository CSI :

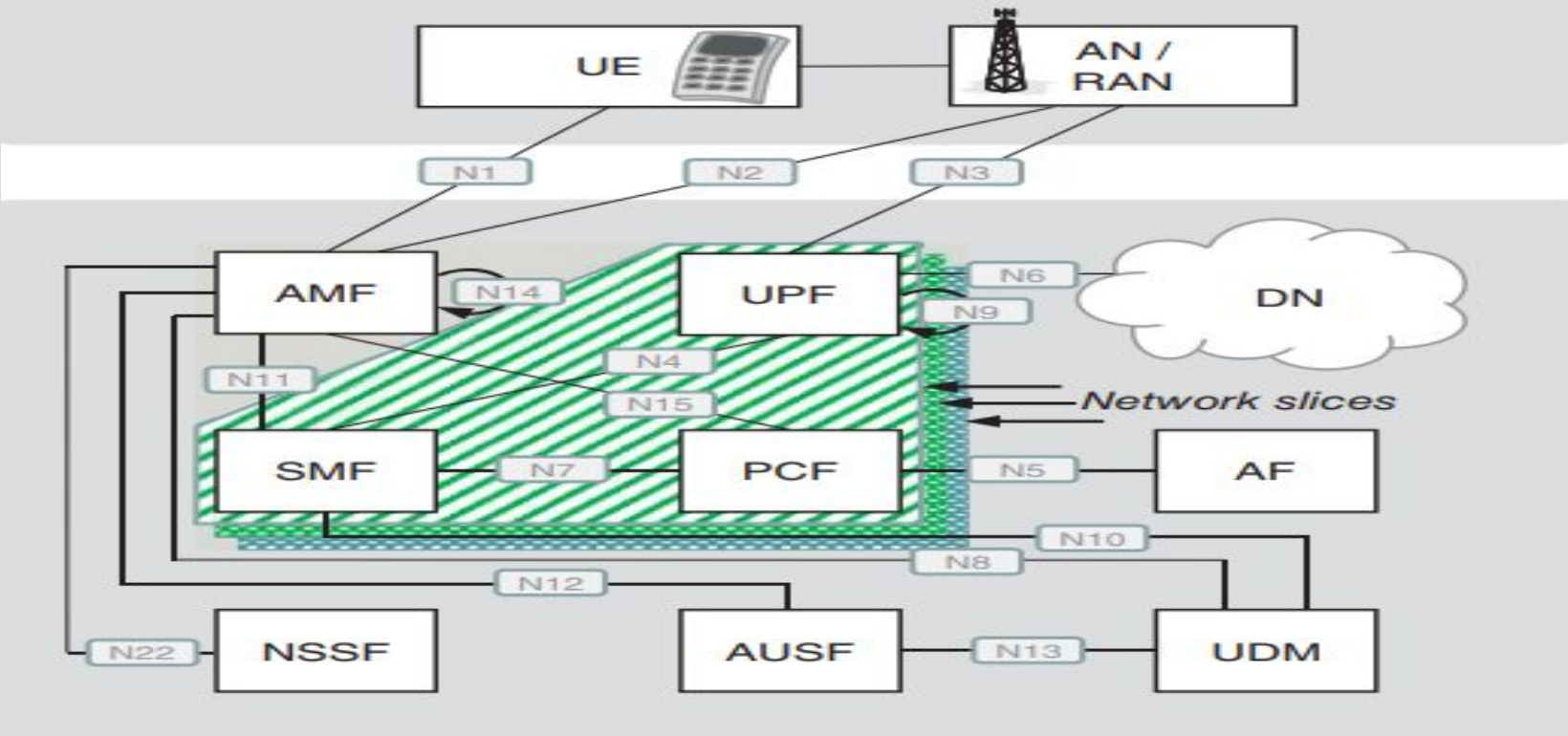
- Repository is when an estimate of the UL channel can be used when designing the DL transmission.
- Different levels are coherent , stationary and directional
- It is the strongest form of reciprocity and it is only possible to achieve in TDD.

5G Functionalities implemented in 5G Core

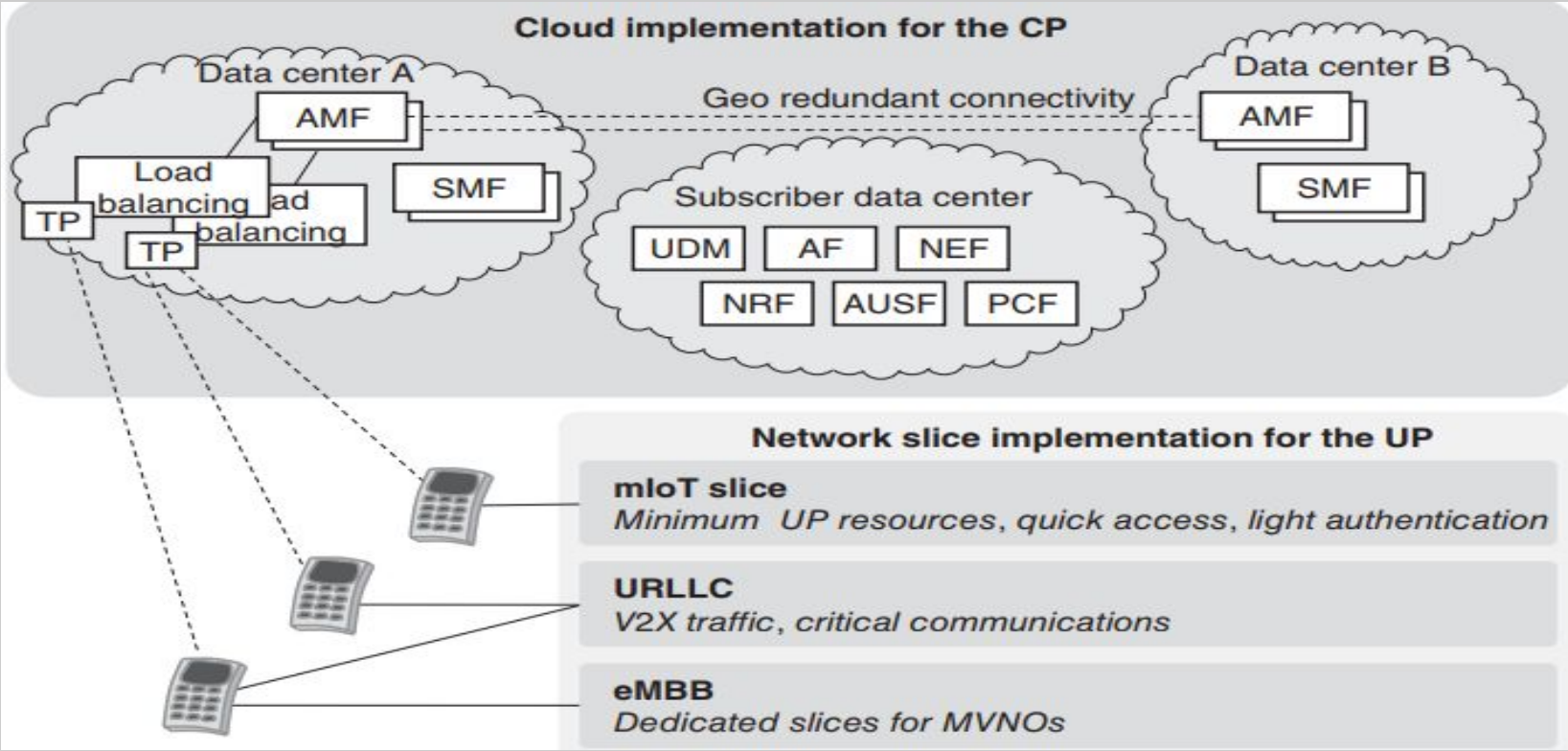
Network Slicing :

- The network slicing provides the possibility of isolating network resources for certain services.
- The user plane nodes can work on services within dedicated slices.
- The slice can be instantiated , updated and deleted acc to NFV concept, which makes it possible to differentiate the QoS in a fluent way.

Network slicing in core network deployment :



Network slice set & cloud implementation :



Optimization of the core & transport :

- Techniques include programmable transport, transport aware radio and dynamic load balancing.
- Transport - aware radio refers to the enhanced functionality in X2 interface i.e between base station elements.
- Dynamic load balancing method is beneficial, e.g in non - predictable weather conditions that might negatively affect the radio link , lowering the planned data rate due to attenuation of rain.

Transport network

Transport network :

- The role of transport network is to interconnect the radio access and the core network.
- Transport network requires higher grade of flexibility , simple service configurations , new operations model support and cross domain orchestration.
-

Transport network :

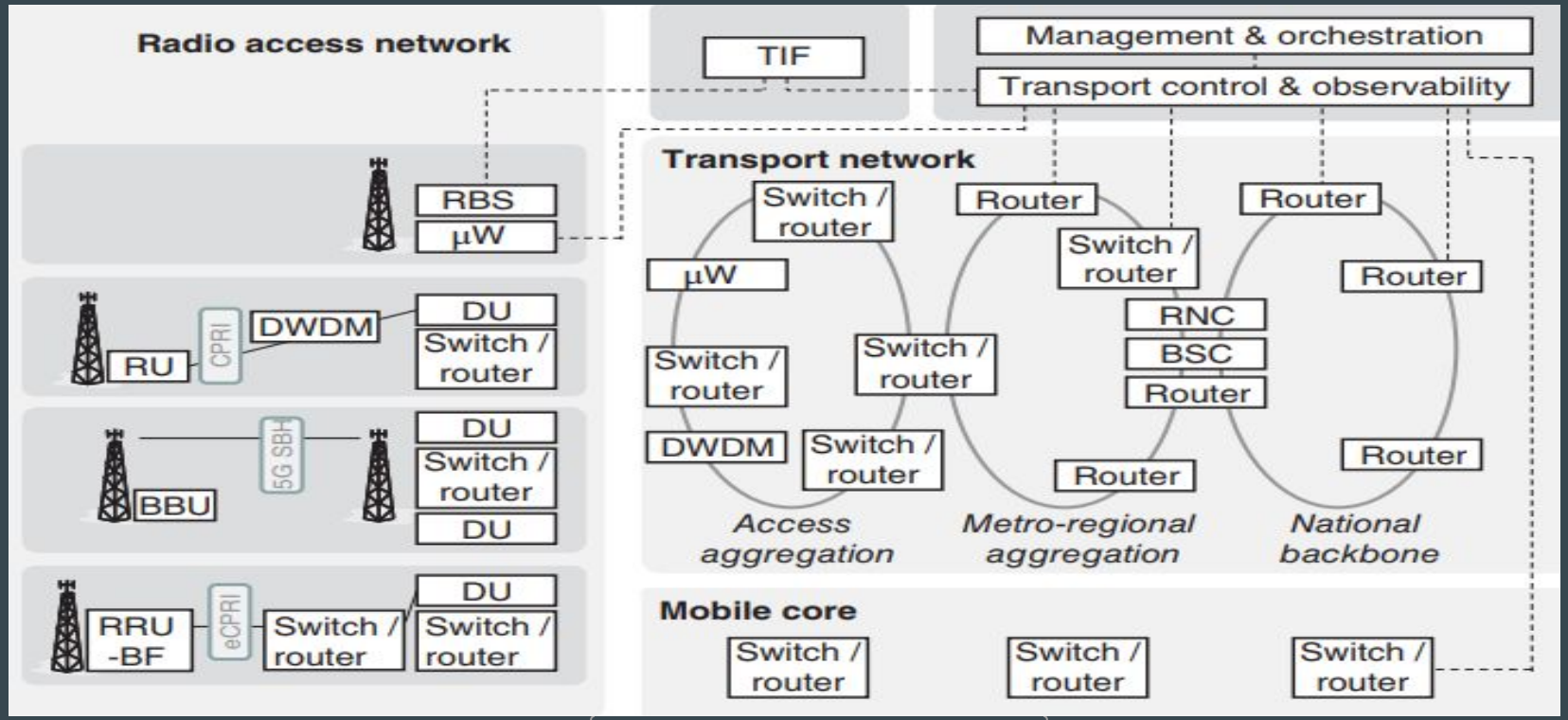
- An intelligent application referred as transport intelligence function (TIF) , in an effort to optimize 5G transport network design.
- The service & characteristics aware overlay is handled by SDN controller with the TIF application and this creates a dynamically controlled and orchestrated transport network that requires minimum manual interaction.

Cross domain communication :

- The TIF is a cross-domain function located between radio access & transport networks.
- The TIF receives RAN connectivity requests via cross domain communication bus.

Conceptual examples

Cross domain communication :



Cross domain communication :

- The TIF is a cross-domain function located between radio access & transport networks.
- The TIF receives RAN connectivity requests via cross domain communication bus.

Microwave transport network :

- The transport network must not create bottlenecks in the end - to - end performance.
- The demands increase along with the 5G, relying more on edge computing as well as onto the introduction of centralized and cloud RAN to the previous distributed RAN.

Massive transport network :

- The rural & marginal areas and long-haul data transfer al require microwave transport solutions.
- Frequency bands located above 4GHz upto V-band (60 GHz) and E-band (70-80 GHz) which are considered as mm wave bands.
- W-band (90 GHz) and D-band (140 - 170 GHz)

5G Services

General network procedures :

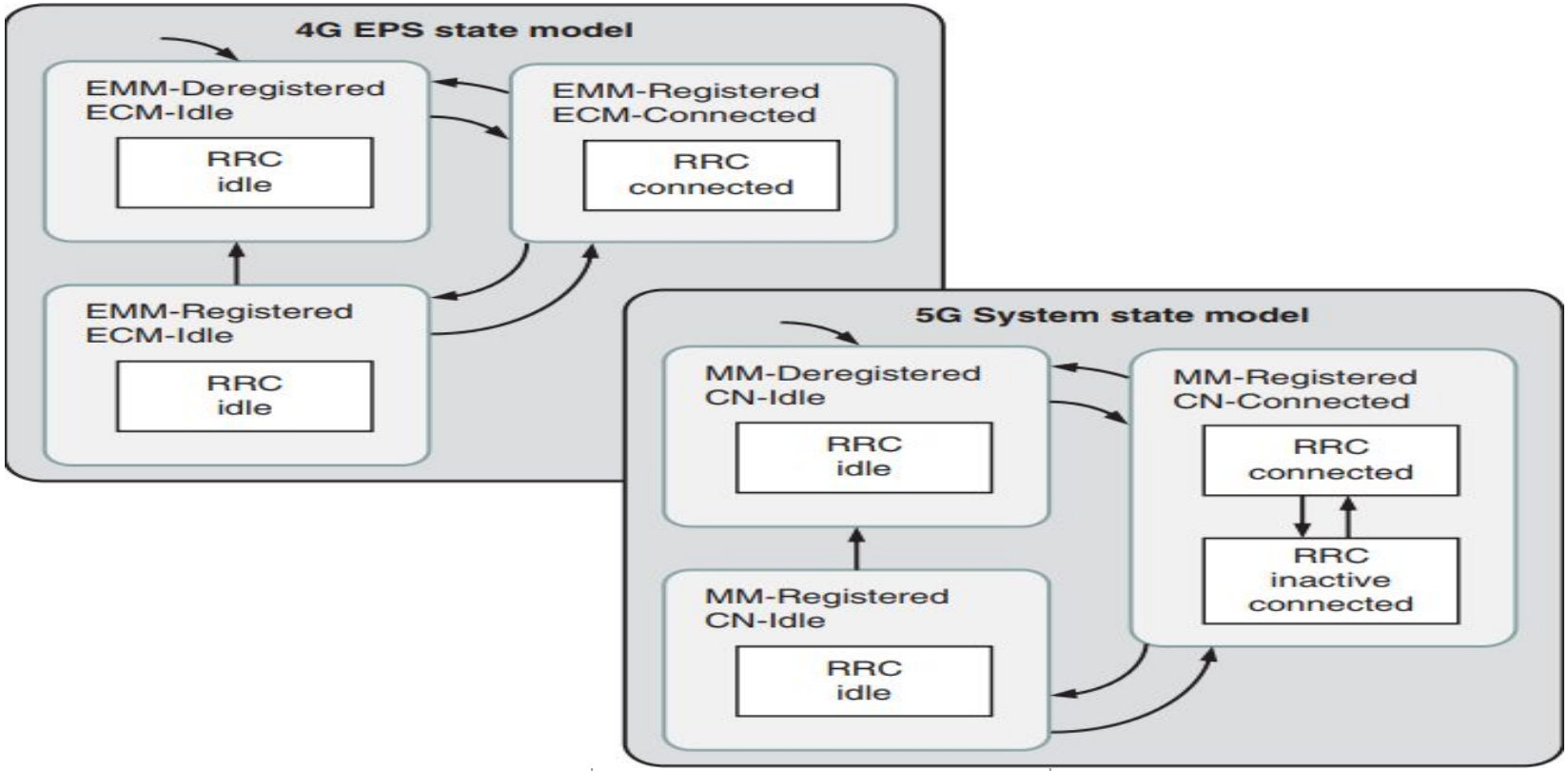
These procedures include the following :

- Registration management
- Service request
- UE configuration update
- Reachability
- Access network (AN) release
- N2
- Feature specific UE and RAN information & compatibility

5G states :

- The 3GPP defines the signalling flows for the 5G connections , including initial attachment to the network referred to as registration , call establishment , mobility management procedures in idle and connected modes, PDU session establishment , termination of the sessions and deregistering from the network .

5G states :



Registration & mobility management :

Registration procedure :

- The registration & deregistration procedures provide the functionality to register or deregister a UE with the 5G system , together with additional functionality to support also registration management for non-3GPP access.

Registration & mobility management :

De-registration procedure :

- It is designed for UE to inform the network to stop accessing the 5G core and the 5G core to inform the UE about the released access.

Connection establishment : session mgt :

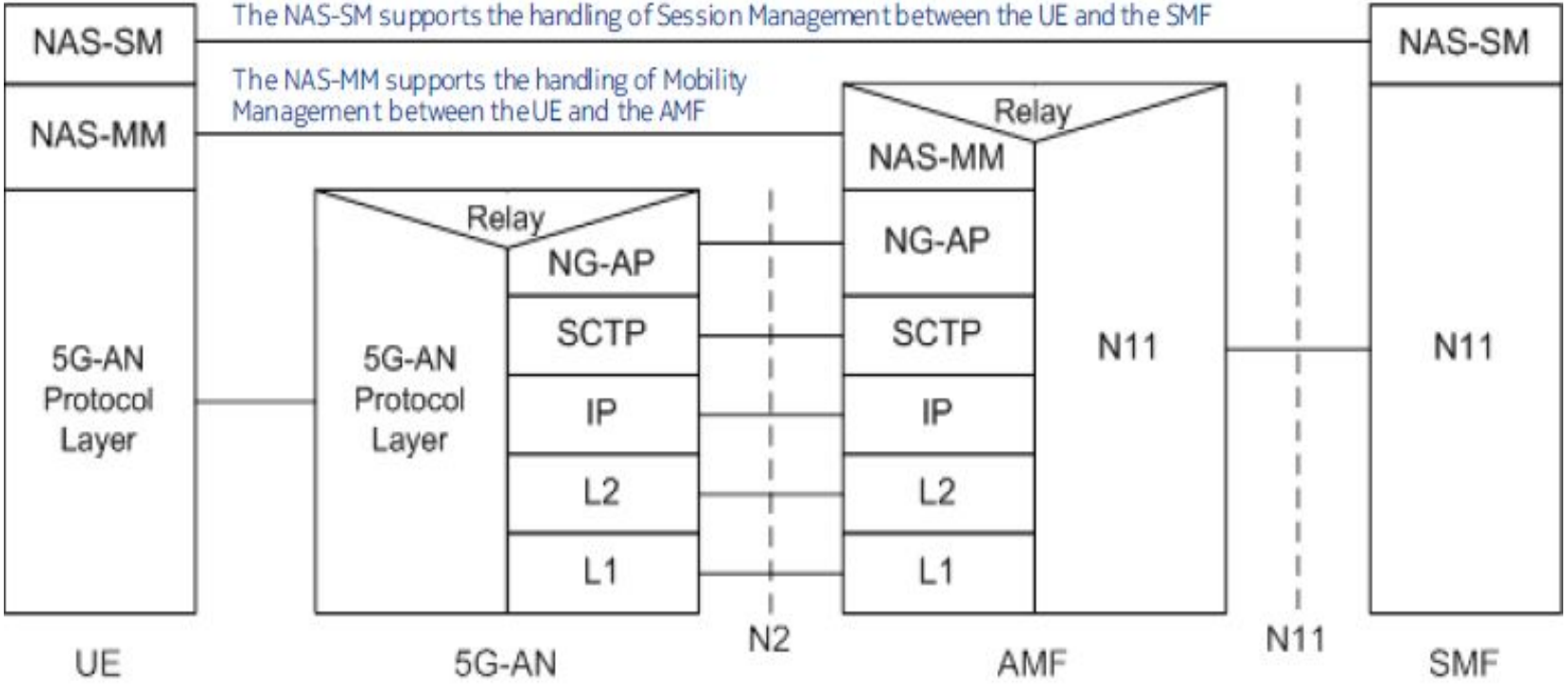
- For V-SMF and H-SMF , there is indication of NAS SM signalling for PDU session establishment , PDU type etc.
- H-SMF provides the V-SMF with the IPV6 prefix for the respective PDU session for facilitating data storage in visited country.

PDU session establishment :

- PDU session establishment procedure
- PDU session handover procedure between 3GPP and non 3GPP
- PDU session handover from EPS to 5GS

Protocol stacks between the UE and the 5GC

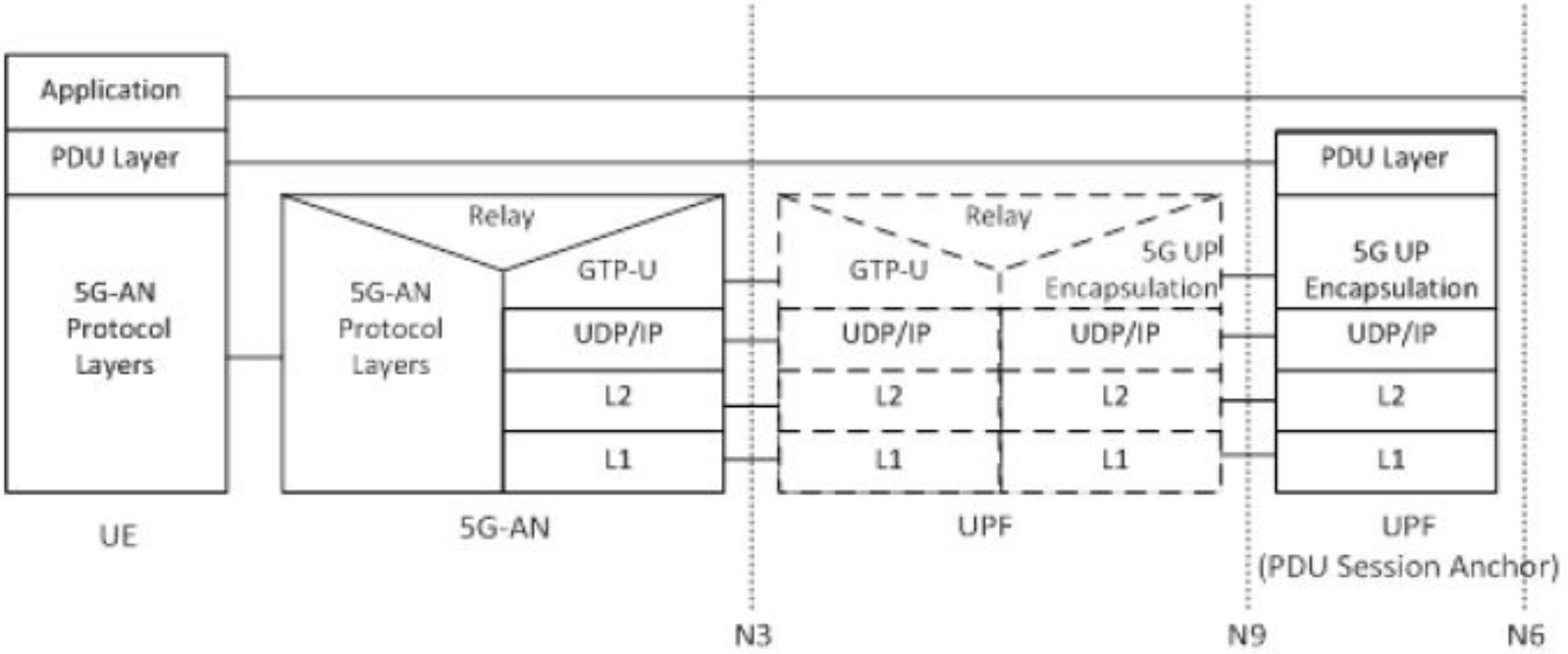
Control plane protocol stack :



Control plane protocol stack :

- The NAS protocol comprises a NAS - MM and a NAS - SM components.
- NAS-SM
- NAS-MM

User plane protocol stack :

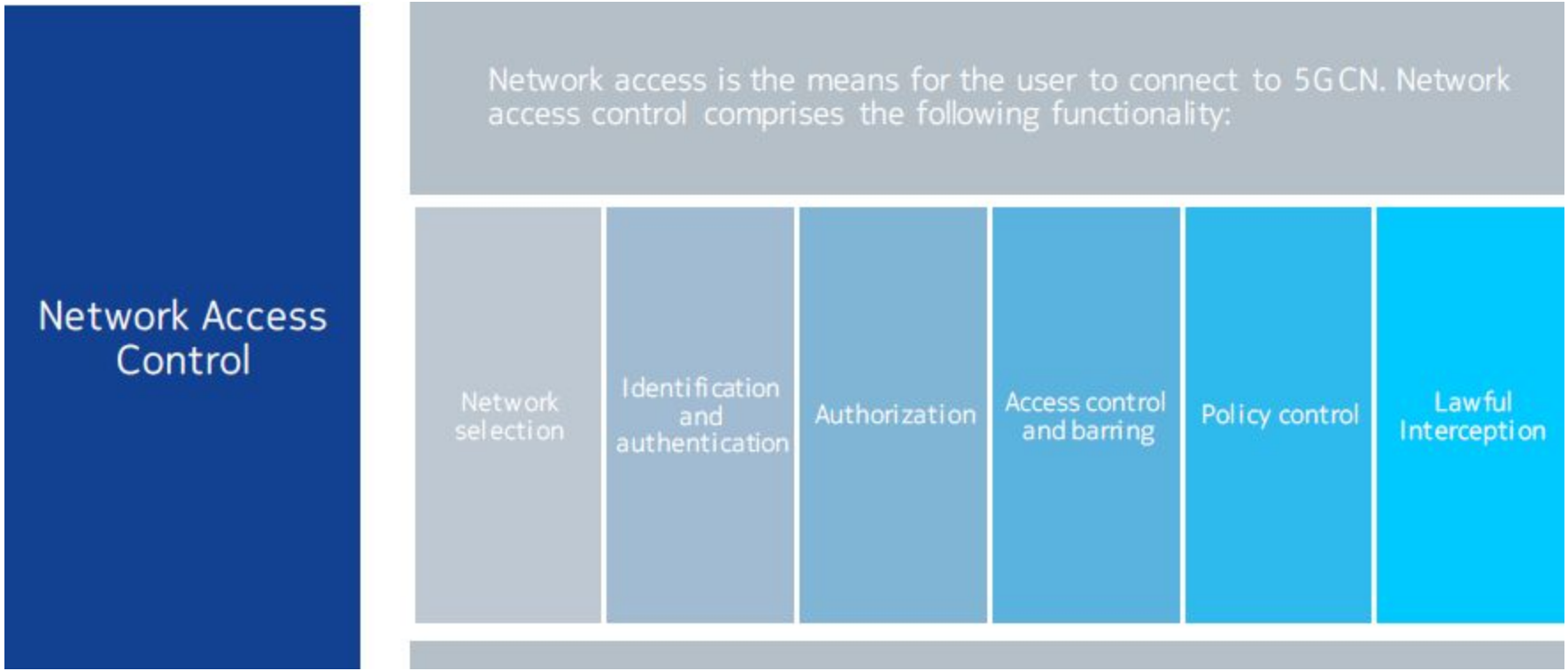


User plane protocol stack :

- PDU layer corresponds to the PDU carried between the UE and the data network over the PDU session.
- GTP-U supports multiplexing traffic of different PDU sessions.
- GTP encapsulation layer supports multiplexing traffic of different PDU sessions over N9.

5GS Mobility management procedures

Network access control :



5GS Mobility Management :

5GMM specific procedures

At any time only one UE initiated 5GMM specific procedure can be running for each of the access network(s) that the UE is camping in. The procedures belonging to this type are:

Registration:

Initiated by the UE and used e.g. to register to the network for 5GS services and establish a 5GMM context, to update the location/parameter(s) of the UE

De-registration:

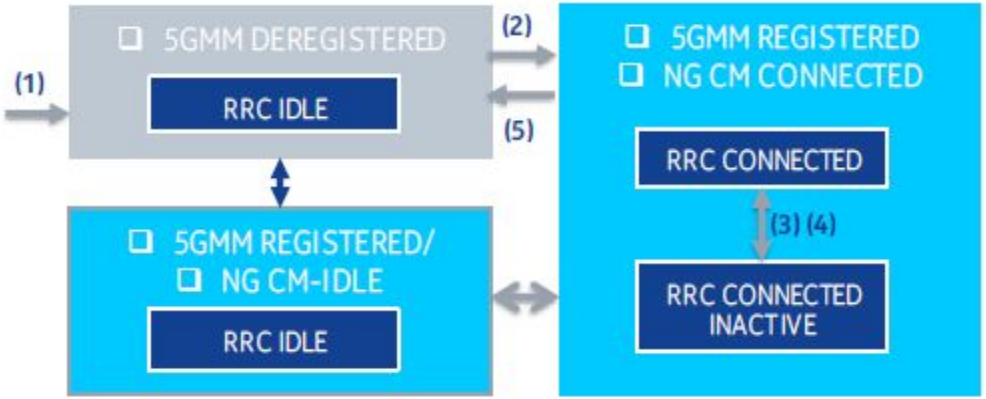
Initiated by the UE or the network and used to deregister from the network for 5GS services and to release a 5GMM context

5GS Mobility Management :

5GMM Connection Management procedures

Service request	Paging	Notification
▪ Initiated by the UE and used to establish a secure connection to the network or to request the resource reservation for sending data, or both	▪ Initiated by the network and used to request the establishment of an N1 NAS signaling connection or to prompt the UE to perform re-registration if necessary as a result of a network failure or to request re-establishment of the PDU session(s) associated with non-3GPP access over 3GPP access; not applicable for the non-3GPP access network:	▪ Initiated by the network and used to request re-establishment the PDU session(s) associated with non-3GPP access over 3GPP access when the UE is in 5GMM-CONNECTED mode over 3GPP access and in 5GMM-IDLE mode over non-3GPP access; or ▪ Initiated by the network and used to request re-establishment of the PDU session(s) associated with 3GPP access over 3GPP access when the UE is in 5GMM-CONNECTED mode over non-3GPP access and in 5GMM-IDLE mode over 3GPP access

5G Mobility Management state machine :



State Transitions:

(1) UE powers on, performs PLMN/cell selection and camps in a suitable cell.
(2) UE registers (attaches) with the network. UE transmits and receives data in RRC connected
(3) Inactivity results in transitions to RRC inactive connected
(4) MT/MO trigger to transmit data results in transition to connected for Tx/Rx
(5) Detach/Power off

UE in "connected inactive mode" consumes reduced resources and supports seamless transition to connected mode to transmit data

Characteristics of the new RRC Connected Inactive state :

- **Configurable** based on the **service requested** by the device
- **U-plane and C-plane connections between RAN and core are kept established**
- **UE based mobility** with UE measurements and cell reselection procedure with configuration from network
- When configured for the **fast system access** the device will monitor paging
- **RAN stores the UE context** during the RRC Connected Inactive state
- Light-weight **RRC Connected Inactive to RRC Connected state transition**

Registration procedure :

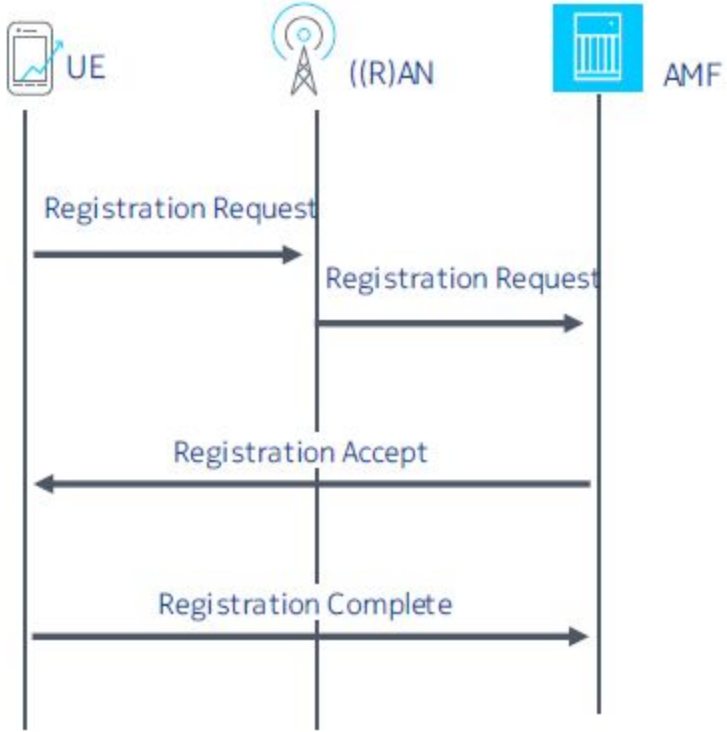
A UE needs to register with the network to receive services that requires registration.

Once registered and if applicable the UE updates its registration with the network :

- periodically, in order to remain reachable (**Periodic Registration Update**); or
- upon mobility (**Mobility Registration Update**); or
- to update its capabilities or re-negotiate protocol parameters.

An AMF associates multiple access-specific RM contexts for an UE with:

- a 5G-GUTI that is common to both 3GPP and Non-3GPP accesses. This 5G-GUTI is globally unique.
- a Registration state per access type (3GPP / Non-3GPP)
- a Registration Area (RA) per access type (independent RA).
- timers for 3GPP access:
  - a Periodic Registration timer; and
  - a Mobile Reachable timer and an Implicit Deregistration timer.
- timers for non-3GPP access:
  - a UE Non-3GPP Deregistration timer; and
  - a Network Non-3GPP Implicit Deregistration timer



Registration procedure :

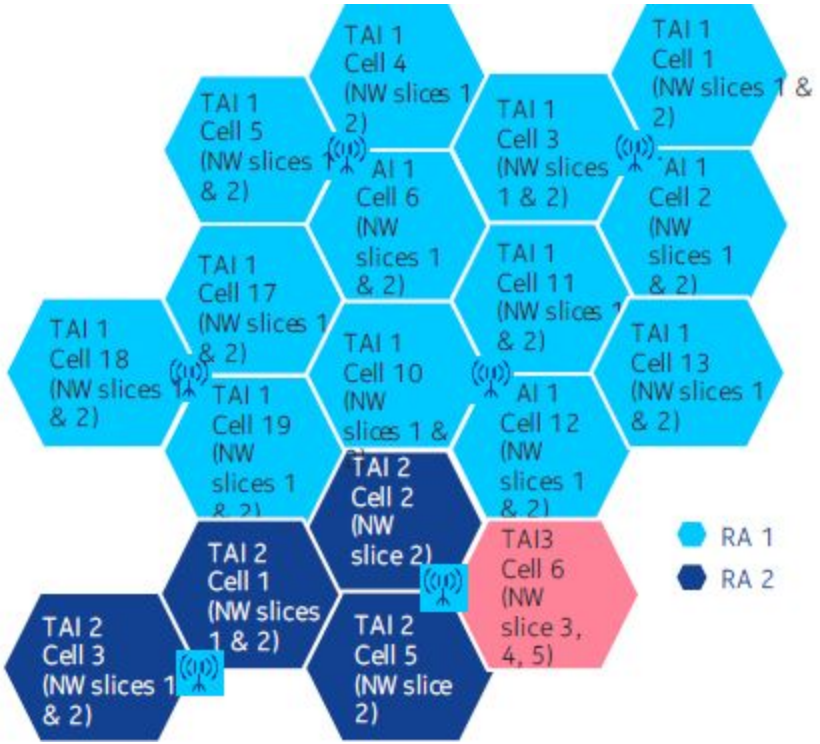
- The initial registration procedure involves execution of Network Access Control functions.
- As a result of the Registration procedure, the identifier of the serving AMF serving the UE in the access through which the UE has registered will be registered in UDM.

Registration area management :

- Registration Area consist of one or more Tracking Areas
- Each Tracking area is defined by TA Identifier (TAI) which is broadcasted in each cell
- TAI format consisting of MCC, MNC and a 3-byte TAC only

Registration Area management comprises the functions to allocate and reallocate a Registration area to a UE.

Registration area is managed per access type i.e., 3GPP access or Non-3GPP access.



Registration area management :

- It comprises the functions to allocate and reallocate a registration area to a UE.
- Registration area is managed per access type i.e 3GPP access or non-3GPP access.

5GS session management procedures

5GS session management :

5GS Session Management

The 5GSM comprises procedures for:

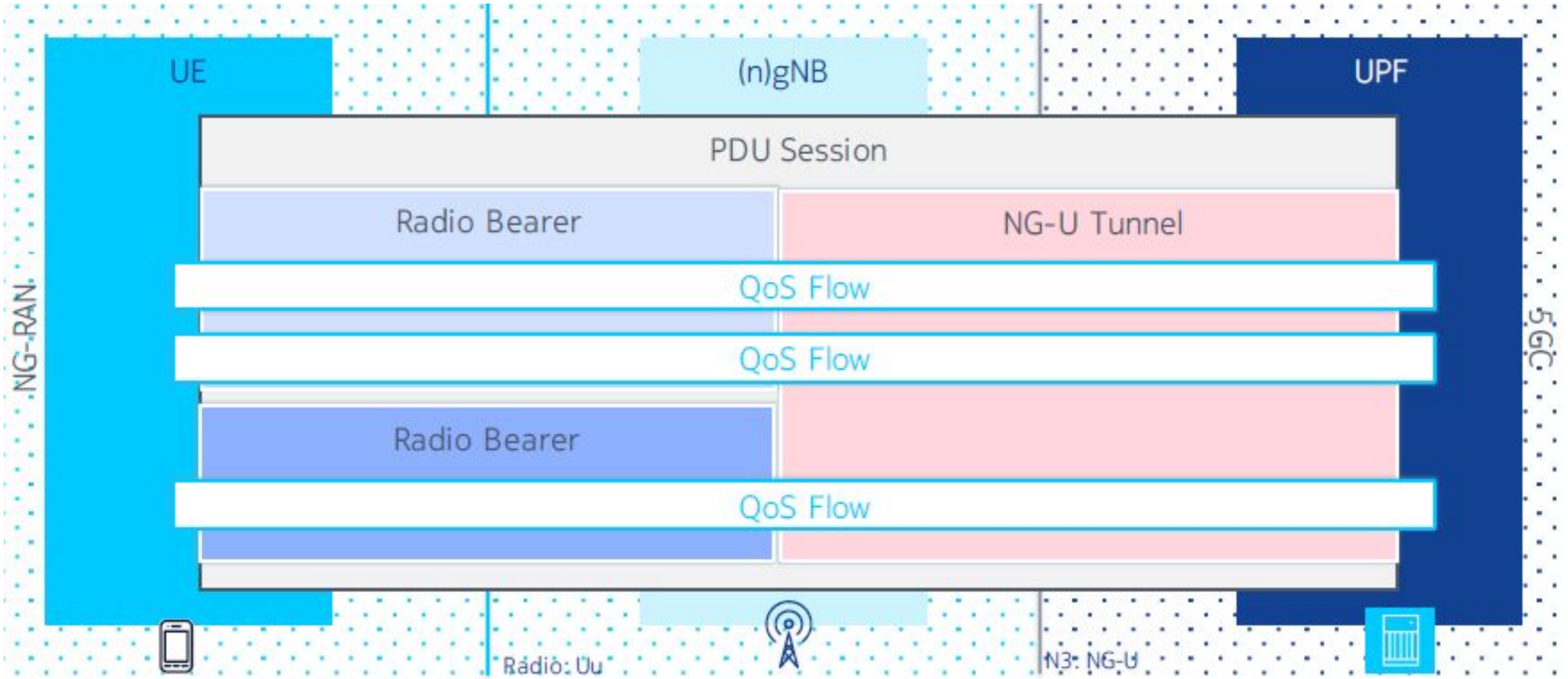
- The authentication and authorization,
- establishment,
- modification
- and release of PDU sessions

- Request for performing handover of an existing PDU session between 3GPP access and non-3GPP access
- or to transfer an existing PDN connection in the EPS to the 5GS

5GS Session management :

- The 5GC supports a PDU connectivity service i.e a service that provides exchange of PDUs between a UE and data network identified by Data network name (DNN).
- 5GSM procedures can be performed only if a 5GMM context has been established between the UE and the AMF , and the secure exchange of NAS messages has been initiated by the AMF.

PDU session :



PDU session :

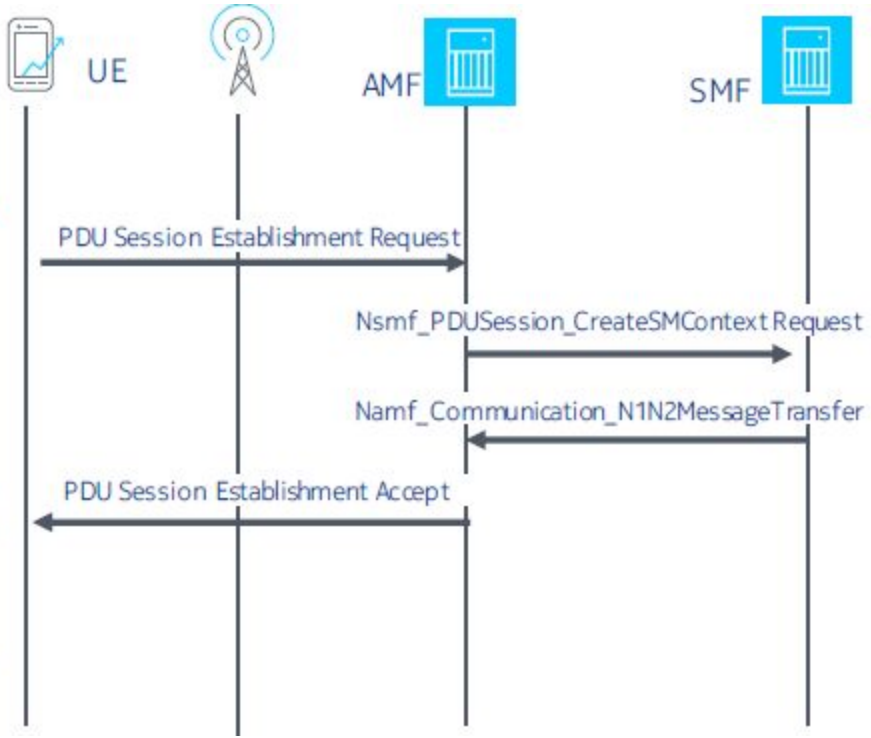
- A PDU session is an association between the UE and a data network that provides a PDU connectivity service.
- For each UE, 5GC establishes one or more PDU sessions.

PDU session establishment :

A PDU Session establishment may correspond to:

- a UE initiated PDU Session Establishment procedure.
- a UE initiated PDU Session handover between 3GPP and non-3GPP.
- a UE initiated PDU Session handover from EPS to 5GS.
- a Network triggered PDU Session Establishment procedure.

- Each PDU Session supports a single PDU Session type i.e. supports the exchange of a single type of PDU requested by the UE at the establishment of the PDU Session. The following PDU Session types are defined: **IPv4, IPv6, IPv4v6, Ethernet, Unstructured**.

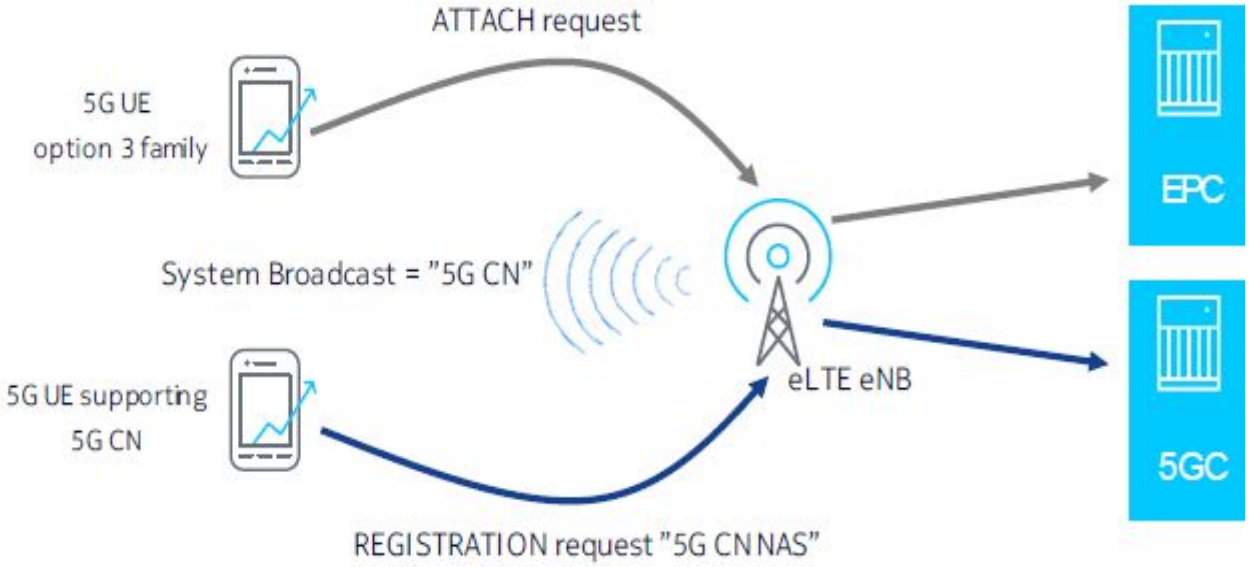


Interworking between 5GS & EPC

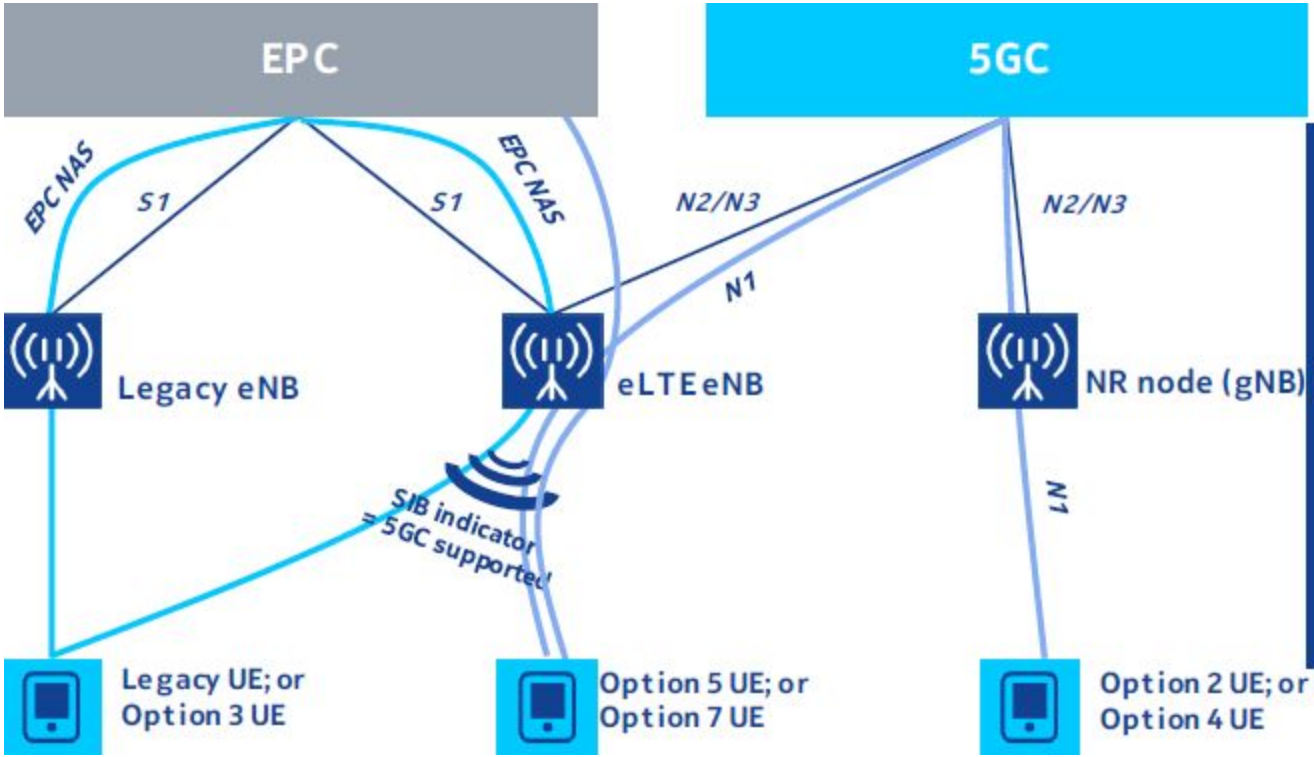
Core network selection :

Option 3 only UE does not need to understand new broadcast information

5G UE option 3 family does not provide this "5G CN NAS" at Access Stratum when it performs initial access and therefore eNB uses the "default" CN selection mechanism to direct this UE to an MME

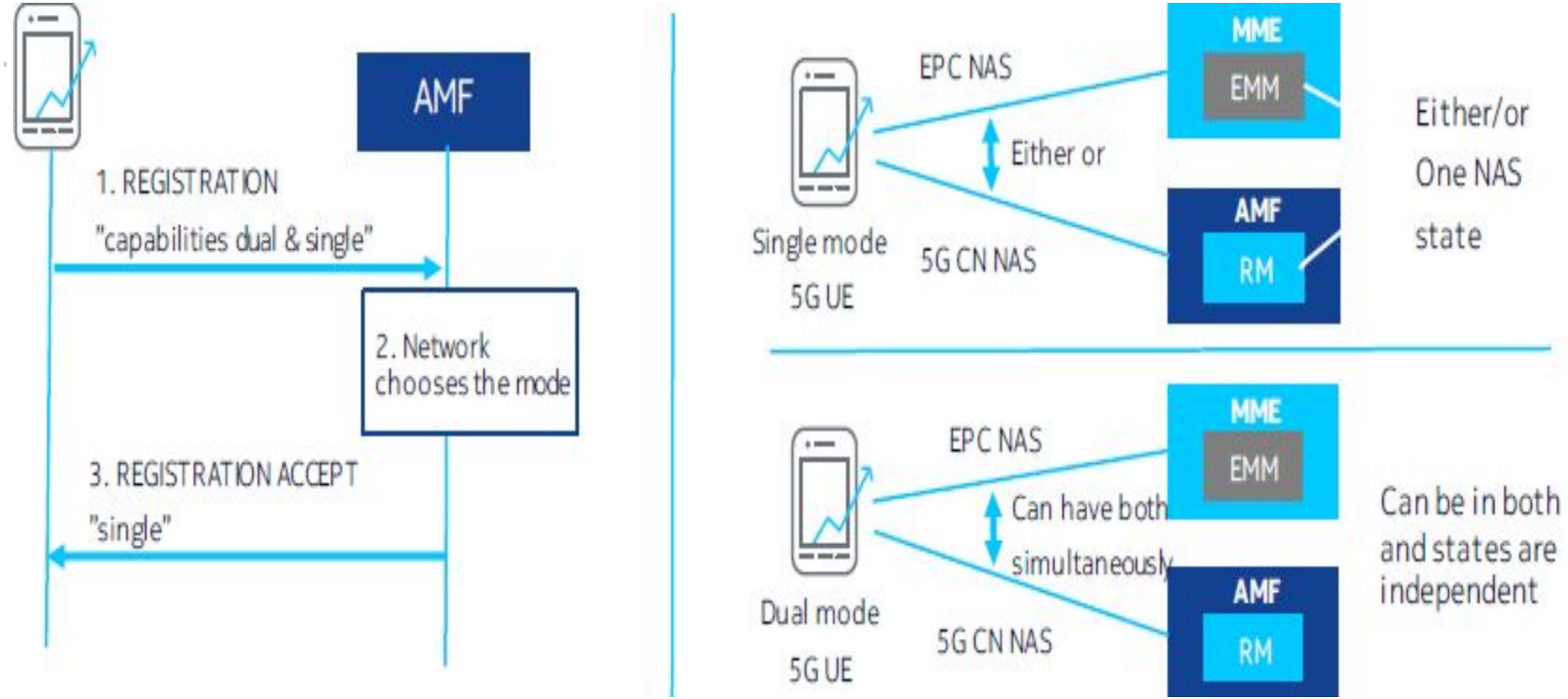


Core network selection :



- The 5G UE performs initial access through **evolved E-UTRA** (options 5 and 7) or **NR** (options 2 and 4) in 5G-RAN
- The 5G UE may perform initial access through **legacy E-UTRA** if the 5G UE also supports EPC NAS
- The eLTE eNB sends an **indication** that it supports 5GC via **SIB**
- The 5G UE accessing through evolved E-UTRA **indicates that it requests N1**

Single & dual registration :



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