5G Multi - Connectivity Operation

TP00005-V-1701 V0 - S05M01 Ed1

Learning objectives

Upon completion of this module, you should be able to:

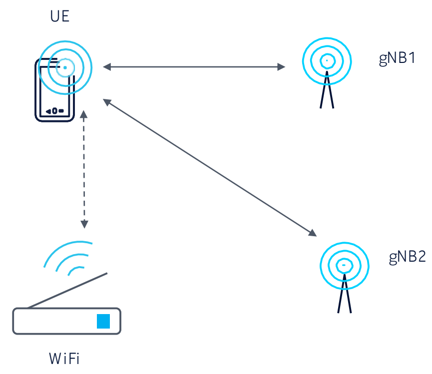
Review Multi-RAT (MR-DC) Dual Connectivity principles.
List MR Dual Connectivity variants.
Explain Radio-bearer types and protocol architecture
Describe MR-DC with EPC Operation
Describe MR-DC with 5GC Operation

Table of contents

Multi-Radio Dual Connectivity Principles

Multi-Radio Dual Connectivity Principles
Multi-connectivity Definition

Official 3GPP - proposal:	Mode of operation whereby a multiple RX/TX UE in the connected mode is configured to utilize radio resources amongst E-UTRA and/or NR provided by multiple distinct schedulers connected via non-ideal backhaul (R2-165931).
Commonly used definition:	Network operation where a given UE is configured with the radio resources from multiple network points, and where these network points might or might not be geographically separated (geographical separation or co-location can be interpreted as non-ideal or ideal backhaul connection)

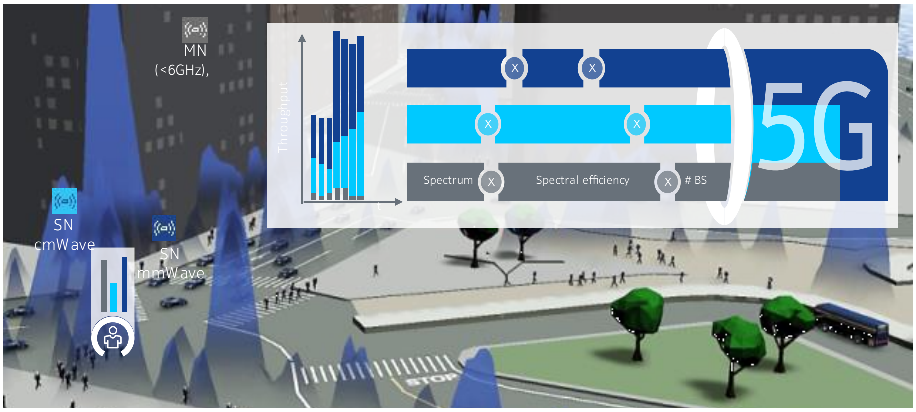


In current practice, multi-connectivity means dual connectivity

Multi-connectivity is referring to the network operation where a given User Equipment is configured and served by the radio resources from multiple network points, and where these network points might or might not be geographically separated (geographical separation or co-location can be interpreted as non-ideal or ideal backhaul connection).

In the 5G NR, Multi-Radio Dual Connectivity (MR-DC) is a generalization of the Intra-E-UTRA Dual Connectivity (DC) where a UE in RRC_CONNECTED is configured to utilize radio resources provided by two distinct schedulers, located in two different NG-RAN nodes connected via a non-ideal backhaul and providing either E-UTRA (i.e. if the node is an ng-eNB) or NR access (i.e. if the node is a gNB). One node acts as the Master Node (MN) and the other as the Secondary Node (SN). The MN and SN are connected via a network interface and at least the MN is connected to the core network.

Multi-Radio Dual Connectivity Principles
Multi-connectivity Benefits



Seamless mobility:

exploiting Heterogeneous Network (HetNet) environment e.g., connection to a large macro cell for mobility anchor and connection a local small cell for data transfer in optimal radio condition

Throughput enhancements:

using multiple radio resources (e.g. cellular + WiFi) to improve data rates experienced by users

Coverage and QoS enhancement:

transmission from multiple points or interference reduction, especially for users in the cell edge

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Why do we need multi-connectivity? And what are its benefits?

Briefly, Dual Connectivity or Multi-connectivity can be used for Coverage and Quality of Service enhancement. Also, it can ensure seamless mobility, exploiting Heterogeneous Network (HetNet) environment; connection to a large macro cell for mobility anchor and connection to a local small cell for data transfer in optimal radio condition. Thereby, multi-connectivity can provide a very fluent (no added data latency during handovers) and robust mobility (connection failures minimized).

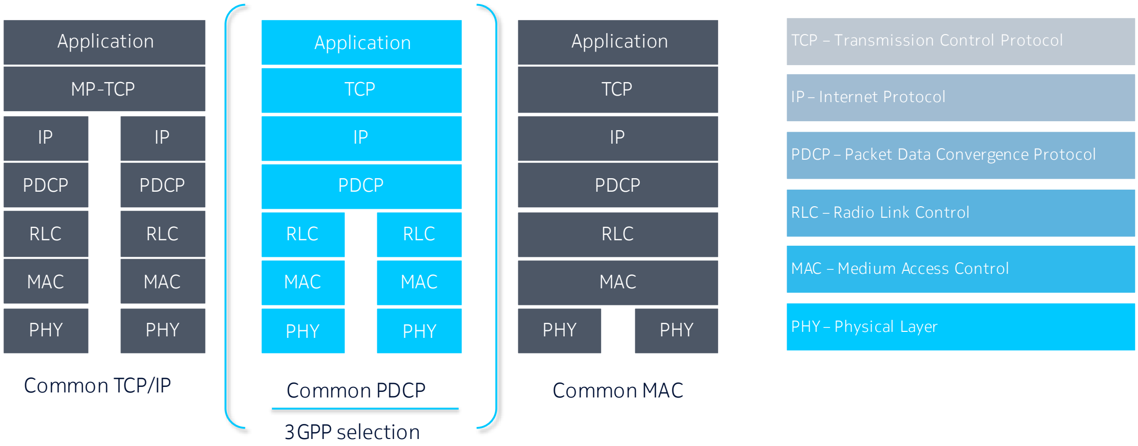
Lastly, Multi-connectivity also provides increased throughput; using multiple radio resources can obviously improve data rates experienced by users.

Multi-connectivity enhances throughput and the reliability of connection to improve the Quality of Service (QoS). The technology also provides seamless mobility by eliminating handover interruption delays and errors, and optimizes capacity, coverage and mobility for devices connected in a heterogeneous network.

Multi-connectivity supports the smooth introduction of 5G on top of LTE networks and enables 4G/5G real-time radio resource management with dynamic inter-RAT load balancing to maximize output.

Remember, Multi-connectivity is one key enabler meeting the requirements of 5G System, LTE can be leveraged as anchor layer for new cells on higher frequencies for smooth introduction of 5G System into the existing network apart from having new standalone 5G System. With Multi-connectivity data can be split over multiples bands to realize the multi-Gbps requirement for eMBB use case or even sent in parallel from multiples nodes to meets the ultra-reliability needs of uLLRC use case.

Multi-Radio Dual Connectivity Principles
Multi-connectivity Methods



Multi-Radio Dual Connectivity Principles
Multi-Radio Dual Connectivity

Multiple-RX/TX UE is configured with resources from one LTE eNB and one NR gNB

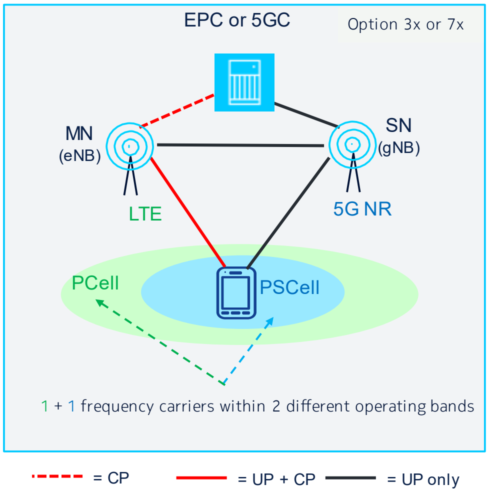
- The “resources” are typically serving cells but not necessarily

The eNB and gNB can be separated by non -ideal backhaul

One of the eNB and gNB acts as Master Node (MN) to the UE and provides UE’s

- C-plane connection to core network (EPC or 5GC);
- Master [Serving] Cell Group (MCG)

The non-MN is Secondary Node (SN) and may provide Secondary Cell Group (SCG)



In the 5G NR, Multi-RAT Dual Connectivity (MR-DC) is a generalization of the Intra-E-UTRA Dual Connectivity (DC) where a UE in RRC_CONNECTED is configured to utilize radio resources provided by two distinct schedulers, located in two different nodes connected via a non-ideal backhaul and providing either E-UTRA (i.e. if the node is an ng-eNB) or NR access (i.e. if the node is a gNB). One node acts as the Master Node (MN) and the other as the Secondary Node (SN). The MN and SN are connected via a network interface and at least the MN is connected to the core network.

MR Dual Connectivity Variants

MR Dual Connectivity Variants
Multi-Radio Dual Connectivity Variants

The following type of MR-DC is supported:

MR-DC with the EPC:
E-UTRA-NR Dual Connectivity (EN -DC).
eNB is master node (MN) and gNB is acting as secondary node (SN)

MR-DC with the 5GC:
- NG-RAN E-UTRA-NR Dual Connectivity (NGEN -DC):
  eNB is MN and gNB is SN.
- NR-E-UTRA Dual Connectivity (NE -DC):
  gNB is MN and eNB is SN.
- NR-NR Dual Connectivity (NR -DC) :
  one gNB acts as a MN and another gNB acts as a SN

For more details, refer to [3GPP TS 37.340]

It is noteworthy that in the introductory stages of 5G roll-out deployment, 5G coverage is expected to be spotty and UEs will need to rely on existing LTE macro coverage for Control Plane reliability. Initial deployments of 5G are not expected to be stand-alone small cells. Hence it is considered necessary to have a tight interworking with LTE and provide solutions that can enable fast handover and the means to switch services faster between the two Radio Access Technologies.

3GPP has defined close interworking between LTE and 5G, in fact a tighter interworking than with any earlier technology. 5G Devices will have simultaneous connection to LTE and 5G radios, based on the LTE Multi Connectivity functionality. 5G will use LTE for the control plane in Non Stand-Alone architecture, with the 5G radio used for boosting user plane data rates.

Tight inter-working between E-UTRA and NR is supported with Multi-Radio Dual Connectivity (MR-DC) operation using E-UTRA and NR. The following types of MR-DC are supported:

- MR-DC with the EPC:
  - E-UTRA-NR Dual Connectivity (EN-DC): eNB is master node (MN) and gNB is acting as secondary node (SN)
- MR-DC with the 5GC:
  - NG-RAN E-UTRA-NR Dual Connectivity (NGEN-DC): eNB is MN and gNB is SN.
  - NR-E-UTRA Dual Connectivity (NE-DC): gNB is MN and eNB is SN.
  - NR-NR Dual Connectivity (NR-DC): one gNB is MN and another gNB is SN

Similar to LTE dual connectivity, MN is responsible for handover and SN provides offloading to increase overall data rate

Control plane architecture: For MR-DC operation, eNB and gNB is communicated via X2-C interface for EN-DC and Xn-C for MR-DC with the 5GC. Single RRC state is maintained but both MN and SN has two RRC entities and can generate full RRC messages.

User plane architecture: MR-DC supports MCG, SCG and split bearer. In case of split bearer, both MN and SN support RLC for the same radio bearer.

MR Dual Connectivity Variants

E-UTRA-NR Dual Connectivity

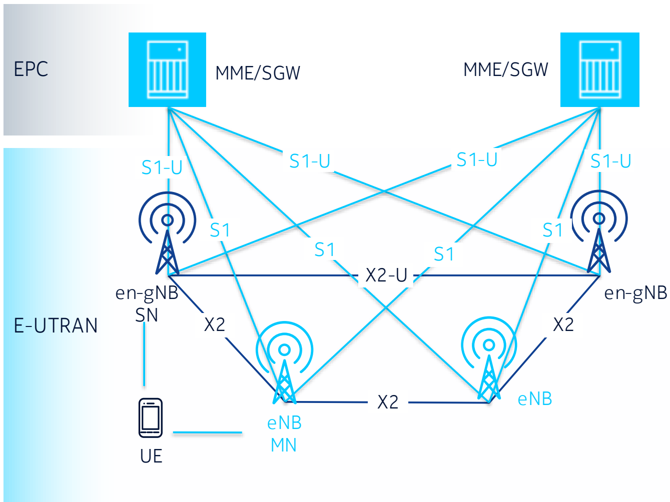
MR-DC with the EPC

EN-DC

- Is E-UTRAN (LTE) – NR (5G) Dual Connectivity
- eNB is master node (MN) and gNB is acting as secondary node (SN)

en-gNB

A gNB (SN) that is connected to X2 and S1-U



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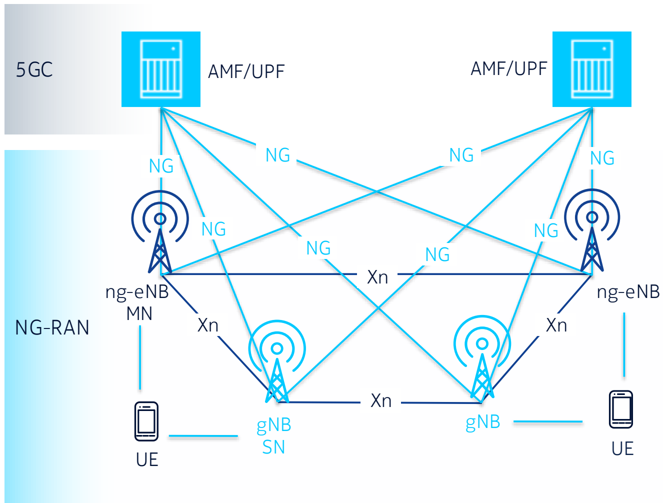
E-UTRAN supports MR-DC via E-UTRA-NR Dual Connectivity (EN-DC), in which a UE is connected to one eNB that acts as a MN and one en-gNB that acts as a SN. The eNB is connected to the EPC via the S1 interface and to the en-gNB via the X2 interface. The en-gNB might also be connected to the EPC via the S1-U interface and other en-gNBs via the X2-U interface.

In MR-DC, there is an interface between the MN and the SN for control plane signaling and coordination. For each MR-DC UE, there is also one control plane connection between the MN and a corresponding CN entity. The MN and the SN involved in MR-DC for a certain UE control their radio resources and are primarily responsible for allocating radio resources of their cells.

MR Dual Connectivity Variants
E-UTRA-NR Dual Connectivity

MR-DC with the 5GC	
NGEN-DC	• NG-RAN E-UTRA-NR Dual Connectivity • eNB is MN and gNB is SN
ng-eNB	• The ng-eNB is connected to the 5GC • and the gNB is connected to the ng-eNB via the Xn interface.



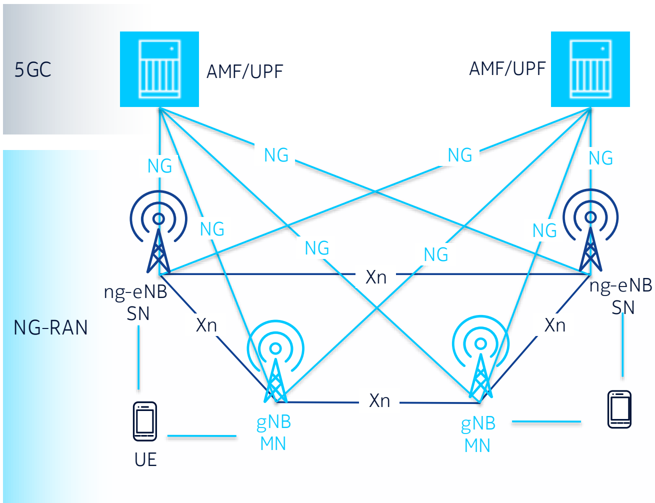
NG-RAN supports NG-RAN E-UTRA-NR Dual Connectivity (NGEN-DC), in which a UE is connected to one ng-eNB that acts as a MN and one gNB that acts as a SN. The ng-eNB is connected to the 5GC and the gNB is connected to the ng-eNB via the Xn interface.

Remember An eNB that is connected to Xn and NG is called "ng-eNB".

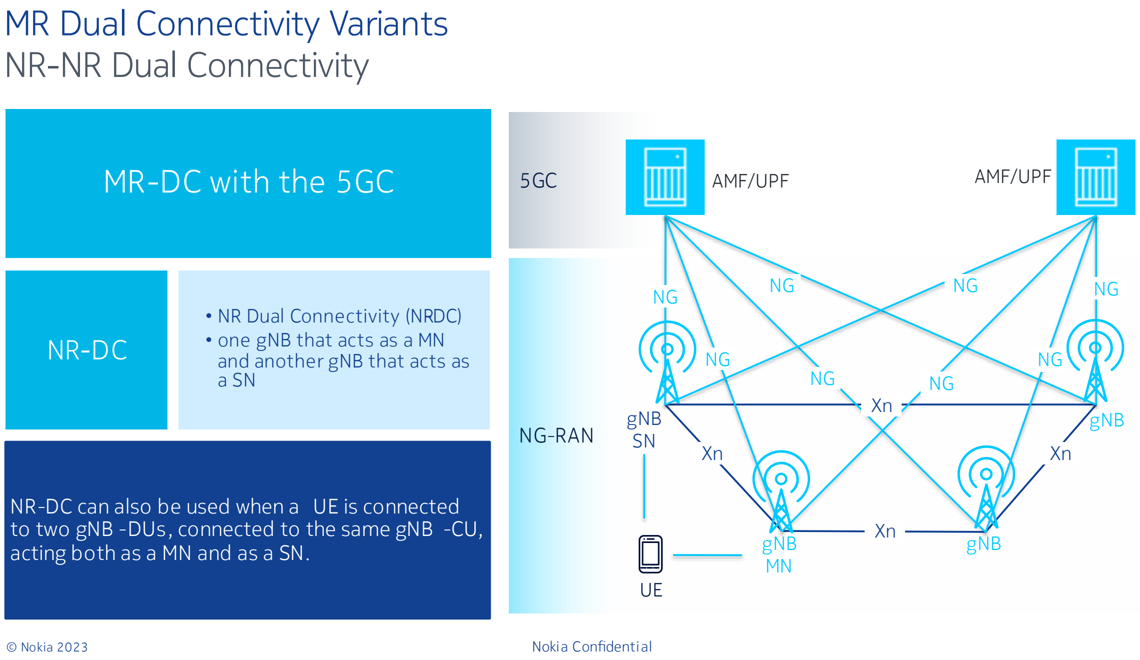
MR Dual Connectivity Variants

NR-E-UTRA Dual Connectivity

MR-DC with the 5GC	
NE-DC	• NR-E-UTRA Dual Connectivity (NE-DC) • gNB is MN and eNB is SN
ng-eNB	• The gNB is connected to 5GC • and the ng-eNB is connected to the gNB via the Xn interface.

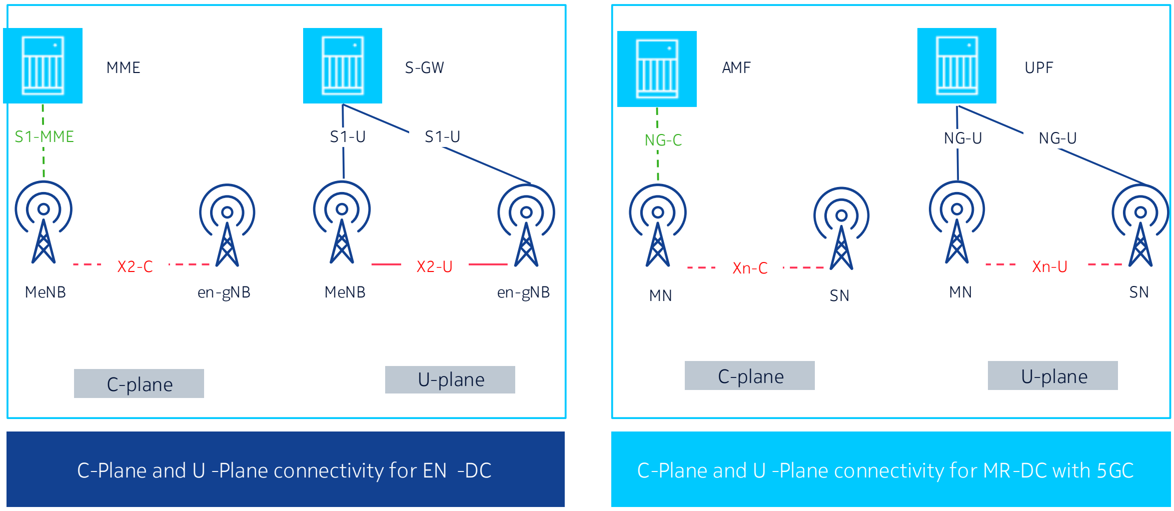


NG-RAN supports NR-E-UTRA Dual Connectivity (NE-DC), in which a UE is connected to one gNB that acts as a MN and one ng-eNB that acts as a SN. The gNB is connected to 5GC and the ng-eNB is connected to the gNB via the Xn interface.



As per the late drop of 3GPP Release 15, NG-RAN supports NR-NR Dual Connectivity (NR-DC), in which a UE is connected to one gNB that acts as a MN and another gNB that acts as a SN. The master gNB is connected to the 5GC via the NG interface and to the secondary gNB via the Xn interface. The secondary gNB might also be connected to the 5GC via the NG-U interface. In addition, NR-DC can also be used when a UE is connected to two gNB-DUs, one serving the MCG and the other serving the SCG, connected to the same gNB-CU, acting both as a MN and as a SN.

MR Dual Connectivity Variants
Network Interfaces



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The figures on the slide show Control-plane and User-please connectivity of MN and SN involved in MR-DC for a certain UE.

In MR-DC, there is an interface between the MN and the SN for control plane signaling and coordination. For each MR-DC UE, there is also one control plane connection between the MN and a corresponding CN entity. The MN and the SN involved in MR-DC for a certain UE control their radio resources and are primarily responsible for allocating radio resources of their cells

In MR-DC with EPC (EN-DC), the involved core network entity is the MME. S1-MME is terminated in MN and the MN and the SN are interconnected via X2-C.

In MR-DC with 5GC (NGEN-DC, NE-DC), the involved core network entity is the AMF. NG-C is terminated in the MN and the MN and the SN are interconnected via Xn-C.

When it comes to the user plane; There are different U-plane connectivity options of the MN and SN involved in MR-DC for a certain UE, as shown on the slide. The U-plane connectivity depends on the bearer option configured:

-For MN terminated bearers, the user plane connection to the CN entity is terminated in the MN;

-For SN terminated bearers, the user plane connection to the CN entity is terminated in the SN;

-The transport of user plane data over the Uu either involves MCG or SCG radio resources or both:

-For MCG bearers, only MCG radio resources are involved;

-For SCG bearers, only SCG radio resources are involved;

-For split bearers, both MCG and SCG radio resources are involved..

For split bearers, MN terminated SCG bearers and SN terminated MCG bearers, PDCP data is transferred between the MN and the SN via the MN-SN user plane interface.

For MR-DC with EPC (EN-DC), X2-U interface is the user plane interface between MN and SN, and S1-U is the user plane interface between the MN, the SN or both and the S-GW.

For MR-DC with 5GC (NGEN-DC, NE-DC), Xn-U interface is the user plane interface between MN and SN, and NG-U is the user plane interface between the MN, the SN or both and the UPF.

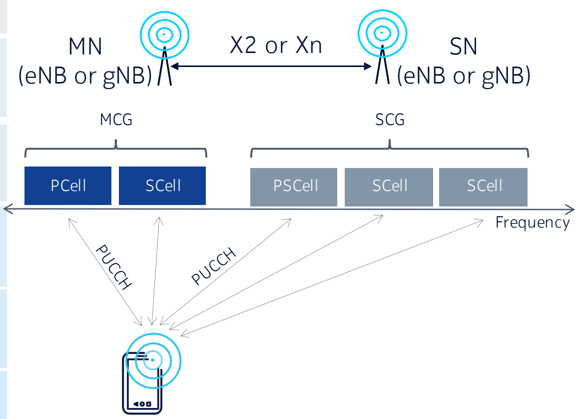
MR Dual Connectivity Variants
Quiz 1

1. Which of following apply to E -UTRA -NR Dual Connectivity (EN -DC)?
    a. MR-DC with the 5GC, eNB is master node (MN) and gNB is acting as secondary node (SN)
    b. MR-DC with the EPC, eNB is master node (MN) and gNB is acting as secondary node (SN)
    c. MR-DC with the 5GC, gNB is master node (MN) and eNB is acting as secondary node (SN)
2. Which of the following are correct statements in case of MR -DC with 5GC (NGEN -DC, NE -DC)?
    a. S1-MME is terminated in MN
    b. The MN and the SN are interconnected via X2 -C
    c. NG-C is terminated in the MN
    d. The MN and the SN are interconnected via Xn -C

Radio-bearer Types and Protocol Architecture

Radio-bearer Types and Protocol Architecture
Cell Group Types

Cell Group (CG):	group of serving cells associated with either the MN (Master Node) or the SN (Secondary Node)
Master Cell Group (MCG):	cell group associated with the MN, including Pcell
Secondary cell group (SCG):	cell group associated with the SN, including PSCell
PCell:	primary cell, in the MCG
Secondary cell (SCell):	in carrier aggregation, a cell aggregated with a PCell (or PSCell)
PSCell:	primary SCell, in the SCG



In DC, the radio protocol architecture that a radio bearer uses depends on how the radio bearer is setup. Four bearer types exist: MCG bearer, MCG split bearer, SCG bearer and SCG split bearer. The following terminology/definitions apply:

- Master Node: in dual connectivity, the Node which terminates at least NG-C or S1-MME.
- Secondary gNB: in dual connectivity, the gNB that is providing additional radio resources for the UE but is not the Master node.
- Master Cell Group (MCG): in dual connectivity, a group of serving cells associated with the Master Node
- Secondary Cell Group (SCG): in dual connectivity, a group of serving cells associated with the SgNB
- MCG bearer: in dual connectivity, a bearer whose radio protocols are only located in the MCG.
- MCG split bearer: in dual connectivity, a bearer whose radio protocols are split at the MgNB and belong to both MCG and SCG.
- SCG bearer: in dual connectivity, a bearer whose radio protocols are only located in the SCG.
- SCG split bearer: in dual connectivity, a bearer whose radio protocols are split at the SgNB and belong to both SCG and MCG.

In case of DC, the UE is configured with two MAC entities: one MAC entity for the MCG and one MAC entity for the SCG. For a split bearer, UE is configured over which link (or both) the UE transmits UL PDCP PDUs. On the link which is not responsible for UL PDCP PDUs transmission, the RLC layer only transmits corresponding ARQ feedback for the downlink data.

Radio-bearer Types and Protocol Architecture
Radio Bearers

- MCG bearer : a bearer whose radio protocols are only located in the MCG.
- MCG split bearer : a bearer whose radio protocols are split at the MN and belong to both the MCG and SCG.
- SCG bearer : a bearer whose radio protocols are only located in the SCG.
- SCG split bearer : a bearer whose radio protocols are split at the SgNB and belong to both the SCG and MCG.

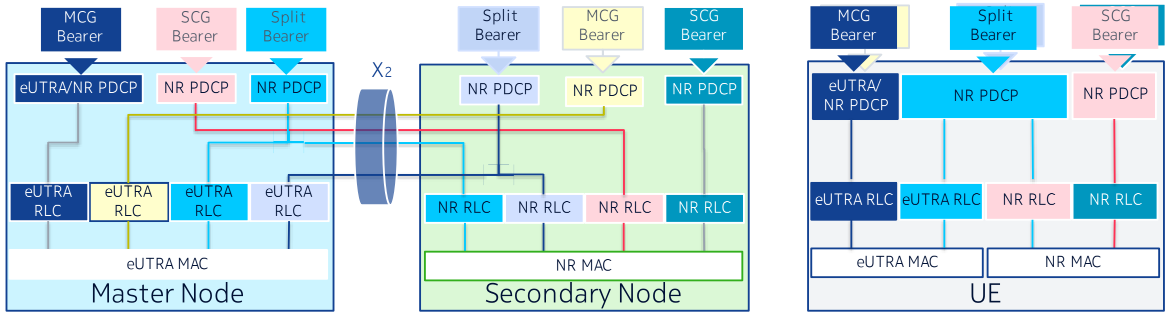
In Dual Connectivity, the radio protocol architecture that a radio bearer uses depends on how the radio bearer is set up. Four bearer types exist: MCG bearer, MCG split bearer, SCG bearer and SCG split bearer. The following terminology/definitions apply in dual connectivity:

- The Master gNB is the gNB which terminates at least the NG-C.
- The Secondary gNB is the gNB that is providing additional radio resources for the UE but is not the Master node.
- A Master Cell Group (MCG) is a group of serving cells associated with the MgNB.
- A Secondary Cell Group (SCG) is a group of serving cells associated with the SgNB
- The MCG bearer is a bearer whose radio protocols are only located in the MCG.
- The MCG split bearer is a bearer whose radio protocols are split at the MgNB and belong to both the MCG and SCG.
- The SCG bearer is a bearer whose radio protocols are only located in the SCG.
- The SCG split bearer is a bearer whose radio protocols are split at the SgNB and belong to both the SCG and MCG.

In case of DC, the UE is configured with two MAC entities: one MAC entity for the MCG and one MAC entity for the SCG. For a split bearer, the UE is configured over which link (or both) the UE transmits UL PDCP PDUs. On the link which is not responsible for UL PDCP PDUs transmission, the RLC layer only transmits the corresponding ARQ feedback for the downlink data.

Radio-bearer Types and Protocol Architecture

User Plane in MR-DC with EPC



Network side protocol termination options for MCG, SCG and split bearers in ENDC.	• MN decides type of each bearer • UE can have SN-terminated bearers even with no SCG configured

Radio Protocol Architecture for MCG, SCG and split bearers from a UE perspective in EN-DC

For MR-DC with EPC (EN-DC), X2-U interface is the user plane interface between MN and SN, and S1-U is the user plane interface between the MN, the SN or both and the S-GW.

In MR-DC, from a UE perspective, three bearer types exist: MCG bearer, SCG bearer and split bearer. These three bearer types are depicted in the Figure on right side of the slide.

For EN-DC, the network can configure either E-UTRA PDCP or NR PDCP for MCG bearers while NR PDCP is always used for SCG and split bearers.

From a network perspective, each bearer (MCG, SCG and split bearer) can be terminated either in MN or in SN. The Figure on left side of the slide depicts Network side protocol termination options for MCG, SCG and split bearers in MR-DC with EPC.

layer-2 related aspects:

MAC:

- Semi-persistent scheduling can be configured on the primary cell of both MCG and SCG
- BSR configuration, triggering and reporting are independently performed per cell group.
    - For split bearers, the available uplink data at PDCP is considered in BSR in the cell group(s) configured by RRC.
- Separate DRX configurations are provided for MCG and SCG.
- The primary cell of neither MCG or SCG can be deactivated.

RLC:

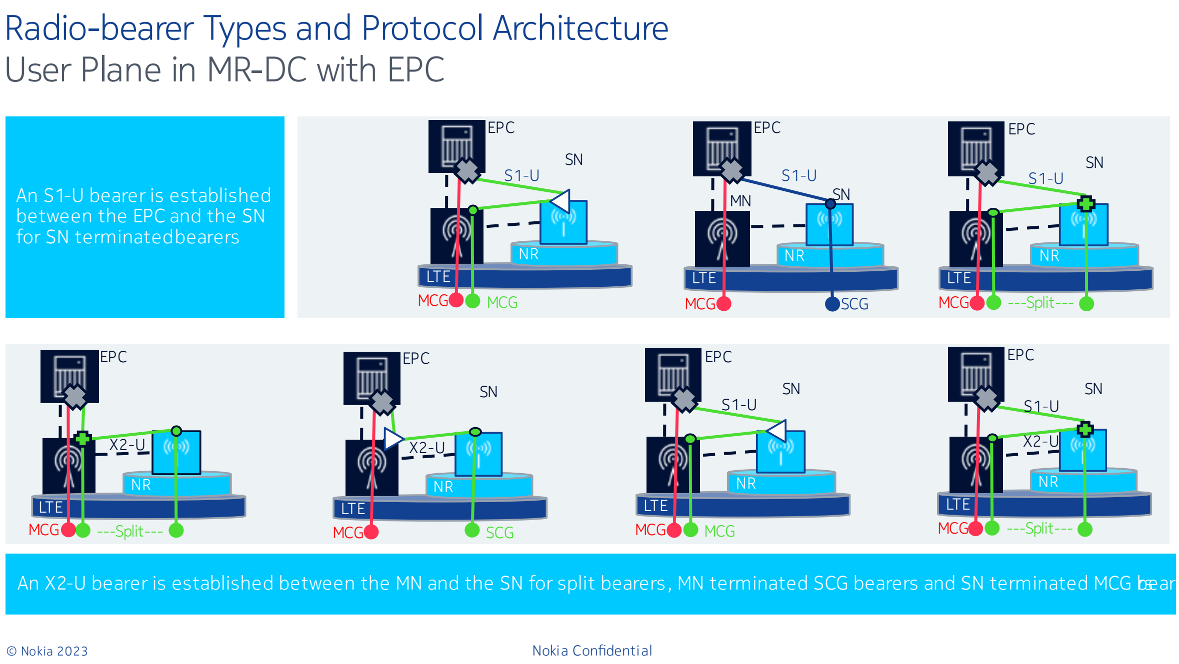
- RLC Acknowledged Mode (AM) and Unacknowledged Mode (UM) can equally be configured on any DRB type.

PDCP:

- RoHC can be configured for all the bearer types.
- Packet duplication can be configured:
    - On split bearer for duplication over both MCG and SCG (“DC duplication”)
    - On MCG bearer configured with LTE PDCP, for duplication over different LTE carrier groups (“CA duplication”)
    - On SCG bearer for duplication over different NR carrier groups (“CA duplication”)
    - NOTE: DC duplication and LTE CA duplication cannot be used together as per the Initial 3GPP release for NR.
- Security keys.

The network configures: MN-terminated bearers with KeNB; SN-terminated bearers with S-KgNB, derived from KeNB. Change of KeNB implies change of S-KgNB, but not vice versa.

As long as PDCP-termination point at SN does not change, S-KgNB key refresh is not required (Similarly to stand-alone NR) E.g. at mobility where only SN’s DU changes.



- An S1-U bearer is established between the EPC and the SN for SN terminated bearers;
- An X2-U bearer is established between the MN and the SN for split bearers, MN terminated SCG bearers and SN terminated MCG bearers;
- MN terminated and SN terminated bearers may have either MCG or SCG radio resources or both, MCG and SCG radio resources, established;

QoS enforcement: non-GBR traffic:

UE AMBR is used for non-GBR traffic and defined per UE (separately for UL and DL)

In DL:

- Each PDCP entity handles its own UE AMBR limit for all controlled E-RABs.
- In case the same UE used both, MN- and SN-terminated bearers, the MN decides the limit for the SN-terminated bearers.
- Limiting the DL traffic is based on "throttling", i.e. the PDCP entity does not allow higher throughput than the limit (possibly discarding incoming overflown PDUs).

In UL:

- Each MAC entity handles its own UE AMBR limit for each served UE (at MAC, E-RABs are not visible).
- In case the UE has at least one SCG bearer, the MN allocates the limit for the SCG part.

QoS enforcement: GBR traffic:

- GBR is defined per E-RAB (separately for UL and DL).
- For non-split bearers, the case is straightforward: the node hosting radio resources must be able to offer the needed GBR policy.
- For split bearers, the nodes must negotiate the split of responsibilities. When adding a split bearer, the MeNB indicates to the SgNB the total GBR policy for the E-RAB and:
    - For an MN-terminated bearer, the share it requests the SgNB to handle. The SgNB accepts or rejects the addition
    - For an SN-terminated bearer, the share it offers to handle. The SgNB responds with the allocation for the MeNB, which shall not be higher than the offered quota.

Radio-bearer Types and Protocol Architecture
Control Plane in MR-DC with EPC

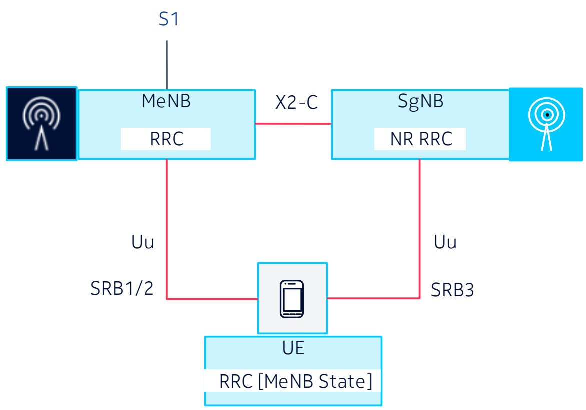
NR is different radio technology

- MeNB is not able to compile a common RRC message out of LTE RRC and NR RRC
- The SgNB must be responsible for providing the UE with the full NR RRC configuration on its own
- The SgNB must also be responsible for managing NR radio, e.g. setting and interpreting NR measurements received from the UE

However, the MeNB is the master

- Original call setup starts in the MeNB, the MeNB decides to start EN-DC operation
- The MeNB decides what bearer type is to be used

There is no direct signaling between the SgNB and the core network



Control plane architecture for ENDC

This Figure illustrates the Control plane architecture for MR-DC. In MR-DC, the UE has a single RRC state, based on the Master Node RRC and a single C-plane connection towards the Core Network. Each radio node has its own RRC entity (E-UTRA version if the node is an eNB or NR version if the node is a gNB) which can generate RRC PDUs to be sent to the UE.

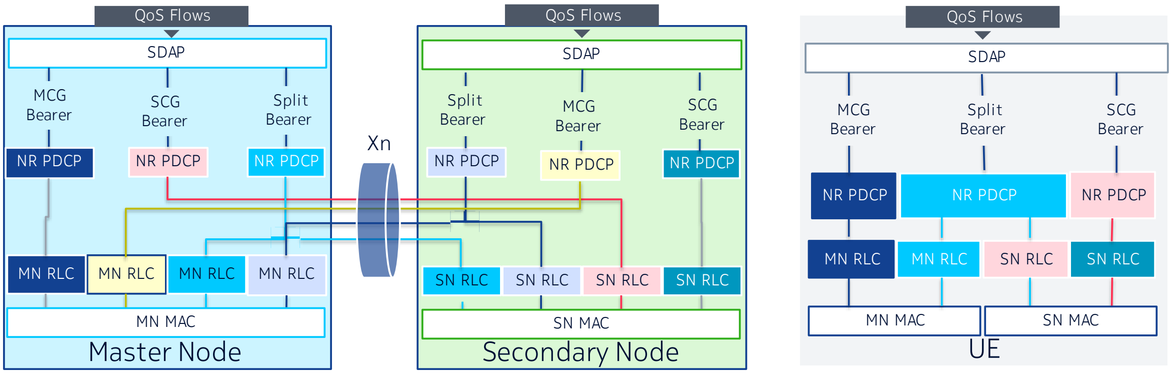
RRC PDUs generated by the Secondary Node can be transported via the Master Node to the UE. The Master Node always sends the initial Secondary Node RRC configuration via MCG SRB (SRB1), but subsequent reconfigurations may be transported via Master node or Secondary node. When transporting RRC PDU from the Secondary node, the Master node does not modify the UE configuration provided by the Secondary node.

To allow SN to change its radio reconfiguration without involving the MN, the UE can be configured to establish a SRB (SRB3) to enable RRC PDUs for the SN to be sent directly between the UE and the SN.

SN may use SRB3 only when the radio reconfiguration does not require MN to be involved/informed to ensure total UE capability is not exceeded.

SRB3 can be configured during SN addition and is allowed to carry RRC messages: Reconfiguration, Reconfiguration Complete and Measurement Report.

Radio-bearer Types and Protocol Architecture
User Plane MR-DC with 5GC



Network side protocol termination options for MCG, SCG and split bearers in MR-DC with 5GC (NGEN-DC, NE-DC)

Radio Protocol Architecture for MCG, SCG and split bearers from a UE perspective in MR-DC with 5GC (NGEN-DC, NE-DC)

In MR-DC with 5GC, NR PDCP is always used for all bearer types. In NGEN-DC, E-UTRA RLC/MAC is used in the MN while NR RLC/MAC is used in the SN. In NE-DC, NR RLC/MAC is used in the MN while E-UTRA RLC/MAC is used in the SN.

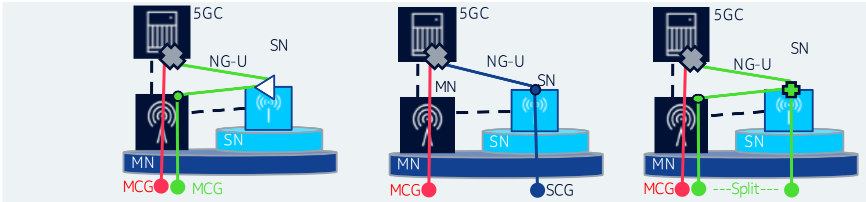
From a network perspective, each bearer (MCG, SCG and split bearer) can be terminated either in MN or in SN.

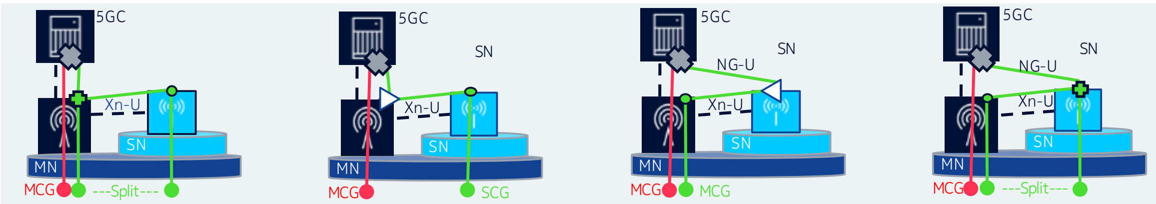
Please note that even if only SCG bearers are configured for a UE, for SRB1 and SRB2 the logical channels are always configured at least in the MCG, i.e. this is still an MR-DC configuration and a Pcell always exists.

Also, If only MCG bearers are configured for a UE, i.e. there is no SCG, this is still considered an MR-DC configuration, as long as at least one of the bearers is terminated in the SN.

Radio-bearer Types and Protocol Architecture
User Plane MR-DC with 5GC

- An NG-U bearer is established between the 5GC and the SN forSN terminatedbearers
- QoS flows belonging to the same PDU sessionmay be mapped to different bearer types





An Xn-U bearer is established between the MN and the SN for split bearers, MN terminated SCG bearers and SN terminated MCG bear

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QoS flows belonging to the same PDU session may be mapped to different bearer types. Therefore, there may be two different SDAP entities for the same PDU session: one at the MN and another one at the SN, in which case the MN decides which QoS flows are assigned to the SDAP entity in the SN. If the SN decides that its SDAP entity cannot host a given QoS flow any longer, the SN informs the MN and the MN cannot reject the request.

QoS flows belonging to the same PDU session may be mapped to different bearer types. To support that, MR-DC with 5GC provides the possibility for the MN to request the 5GC:

- For some PDU sessions of a UE: Direct the User Plane traffic of the whole PDU session either to the MN or to the SN. In that case, there is a single NG-U tunnel termination at the NG-RAN for such PDU session.
    - The MN may request to change this assignment during the life time of the PDU session.
- For some other PDU sessions of a UE: Direct the User Plane traffic of a subset of the QoS flows of the PDU session to the SN (respectively MN) while the rest of the QoS flows of the PDU session is directed to the MN (respectively SN). In that case, there are two NG-U tunnel terminations at the NG-RAN for such PDU session.
    - The MN may request to change this assignment during the life time of the PDU session.

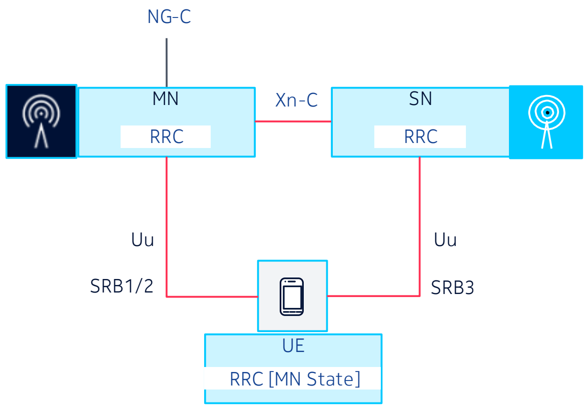
To support notification control indication for GBR QoS flows for MR-DC with 5GC, SN and MN may mutually indicate whenever QoS requirements for GBR QoS flows cannot be fulfilled anymore or can be fulfilled again.

Radio-bearer Types and Protocol Architecture
Control Plane MR-DC with 5GC

If the SN is a gNB, the UE can be configured to establish a SRB with the SN (SRB3) to enable RRC PDUs for the SN to be sent directly between the UE and the SN

Measurement reporting for mobility within the SN can be done directly from the UE to the SN if SRB3 is configured.

Split SRB is supported for all MR -DC options, allowing duplication of RRC PDUs generated by the MN, via the direct path and via the SN. Split SRB uses NR PDCP.



Control plane architecture for MRDC with 5GC

In EN-DC and NGEN-DC, at initial connection establishment SRB1 uses E-UTRA PDCP. After initial connection establishment MCG SRB (SRB1 and SRB2) can be configured by the network to use either E-UTRA PDCP or NR PDCP. A PDCP version change (release of old PDCP and establish of new PDCP) of SRBs can be supported in either direction (i.e. from E-UTRA PDCP to NR PDCP or vice versa) via a handover procedure (reconfiguration with mobility) or, for the initial change from E-UTRA PDCP to NR PDCP, with a reconfiguration without mobility, when the network knows there is no UL data in buffer. For EN-DC capable UEs, NR PDCP can be configured for DRBs and SRBs also before EN-DC is configured.

If the SN is a gNB (i.e. for EN-DC and NGEN-DC), the UE can be configured to establish a SRB with the SN (SRB3) to enable RRC PDUs for the SN to be sent directly between the UE and the SN. RRC PDUs for the SN can only be transported directly to the UE for SN RRC reconfiguration not requiring any coordination with the MN. Measurement reporting for mobility within the SN can be done directly from the UE to the SN if SRB3 is configured.

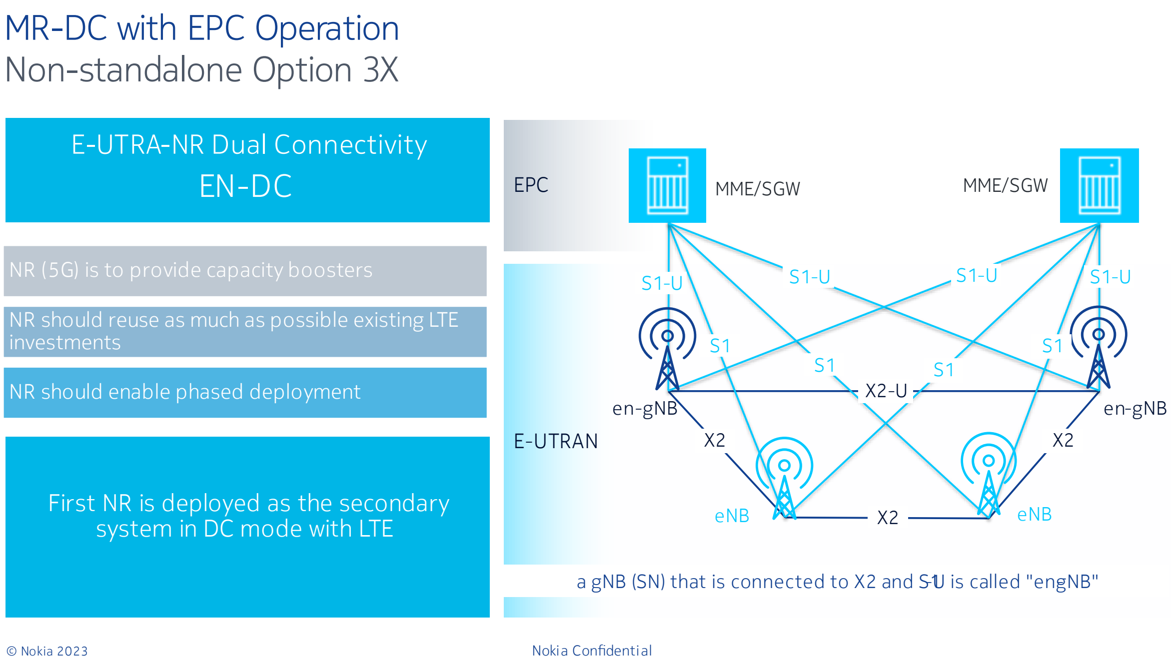
Split SRB is supported for all MR-DC options, allowing duplication of RRC PDUs generated by the MN, via the direct path and via the SN. Split SRB uses NR PDCP. This version of the specification does not support the duplication of RRC PDUs generated by the SN via the MN and SN paths.

In EN-DC, the SCG configuration is kept in the UE during suspension. The UE releases the SCG configuration (but not the radio bearer configuration) during resumption initiation.

Radio-bearer Types and Protocol Architecture
Quiz 2

1. What is the best definition for the SCG bearer?
   a. in DC, a radio bearer with an RLC bearer only in the SCG
   b. in DC, a radio bearer with RLC bearers both in MCG and SCG
   c. in DC, a radio bearer with an RLC bearer only in the MCG
2. What is the best definition for the split bearer?
   a. in DC, a radio bearer with an RLC bearer only in the SCG
   b. in DC, a radio bearer with RLC bearers both in MCG and SCG
   c. in DC, a radio bearer with an RLC bearer only in the MCG
3. What is the best definition for the SN terminated bearer?
   a. in DC, a radio bearer for which PDCP is located in the MN
   b. in DC, a radio bearer for which RLC is located in the MN
   c. in DC, a radio bearer for which PDCP is located in the SN
   d. in DC, a radio bearer for which RLC is located in the SN

MR-DC with EPC Operation



Non-standalone Option 3X is a dual connectivity deployment with E-UTRA as the anchor RAT and NR as the secondary RAT in a non-standalone configuration in EPS. This deployment allows to reuse existing Evolved Packet Core (EPC). Both 5G base stations (gNodeB) and LTE base stations (eNodeB) are connected to the EPC. The control plane goes via LTE.

5G NR is to provide capacity boosters. LTE is assumed to offer sufficient coverage, however capacity is not sufficient in hotspots.

NR should reuse as much as possible existing LTE investments. Same as always, since 3G time, it is too expensive to build a completely new, separated network in parallel to the existing one.

Remember: Within option 3 variants, the UE is connected to one eNB that acts as a Master Node and one gNodeB that acts as a Secondary Node. From a UE perspective, three bearer types exist: a radio bearer with an RLC bearer only in the Master Node, a radio bearer with an RLC bearer only in the Secondary Node and split bearer with RLC bearers both in Master and Secondary Node.

- In Option 3: there is a Master Node split: EPC establishes the bearer to Master LTE eNodeB, then Master LTE ENodeB splits the bearer for forwarding packets to LTE radio and/or 5G radio.

- In Option 3a: there is user plane traffic split at core network: EPC establishes separate bearers to LTE and 5G as depicted in the figure in the middle of the slide.

- In Option 3x: The user plane goes via both eNodeB and gNodeB with bearer split at gNodeB.

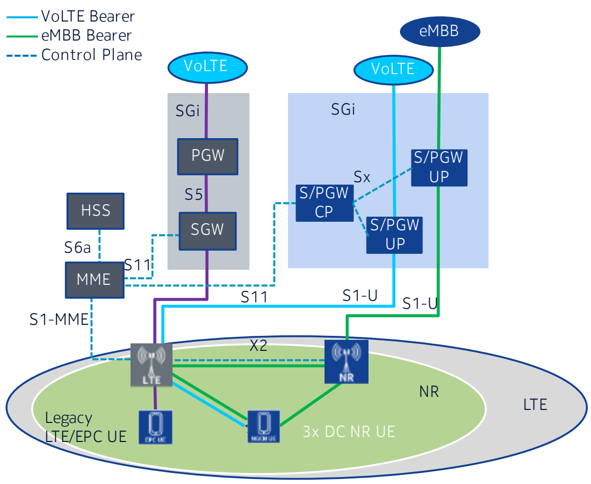
MR-DC with EPC Operation
Non-standalone Option 3X

VoLTE and eMBB PDN connections:

VoLTE APN may be maintained on LTE only access.

LTE eNB acts as Master and controls which S1-U bearers are handled by each radio (LTE/NR) based on QoS.

Based on LTE eNB instructions (via E-RAB Modification Indication) MME informs S-GW where to establish S1-U bearers i.e. towards LTE eNB or NR



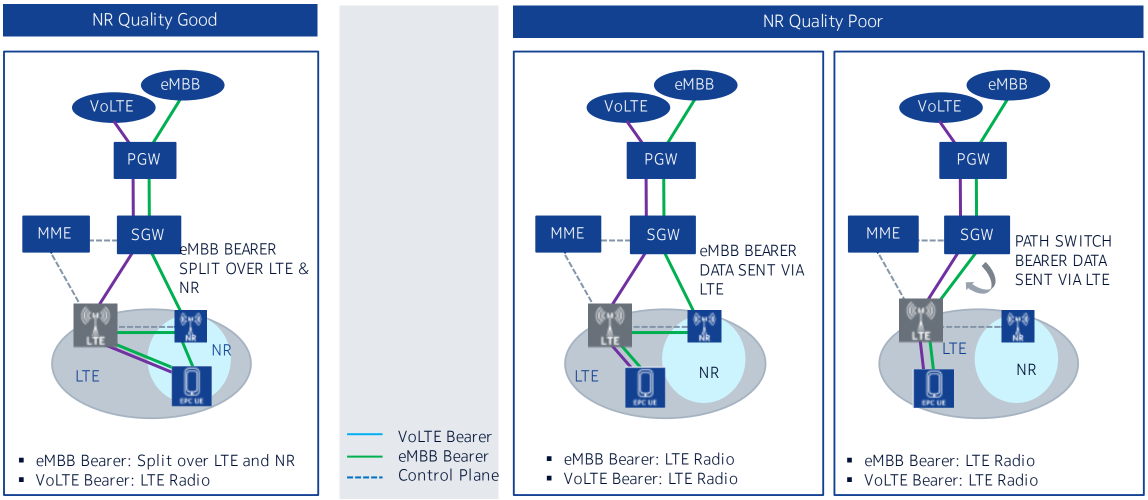
LTE eNB acts as Master and controls which S1-U bearers are handled by each radio (LTE/NR) based on QoS. Same handling applies in both directions downlink and uplink.

Based on LTE eNB instructions (via E-RAB Modification Indication) MME informs S-GW where to establish S1-U bearers i.e. towards LTE eNB or NR.

For the VoLTE APN the LTE eNB might decide to split the video bearer and forward it via NR Combined 3, 3X scenario: 3 for VoLTE APN for the video bearer, 3X for the eMBB APN. Decision is on bearer level.

Idle/connected state applies at the UE level, i.e. either the UE goes idle and all PDN connections are becoming idle or the UE is connected and all PDN connections are in connected state.

MR-DC with EPC Operation
Non-standalone Option 3X



If NR radio quality becomes sub-optimal S1-U bearer towards NR may be either split at NR and sent entirely over X2 to LTE eNB or alternatively switched back to LTE eNB (master cell decision).

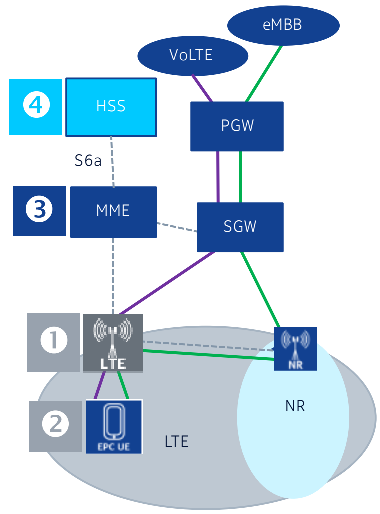
When 5G coverage is lost, NR in 3X could keep receiving eMBB/5G traffic from the core and forward it to the LTE eNB in order to reach the UE.

In this scenario uplink traffic follows the same path, i.e. from the UE to LTE eNB, from there to NR and from there to the core. The core does not realize that 5G coverage is lost and the LTE eNB is used.

Alternatively, upon 5G coverage lost the LTE eNB might decide to switch the eMBB/5G traffic to it.

MR-DC with EPC Operation
Subscription Controlled Access to 5G

1	• An E-UTRAN cell, based on operator configuration, broadcasts DC capability
2	• UE radio capability IE includes UE's support of NR
3	• If the MME has Access Restriction for NR for a UE the MME signals this to the E-UTRAN and to the UE
4	• A new feature is introduced on S6a: NR as Secondary RAT



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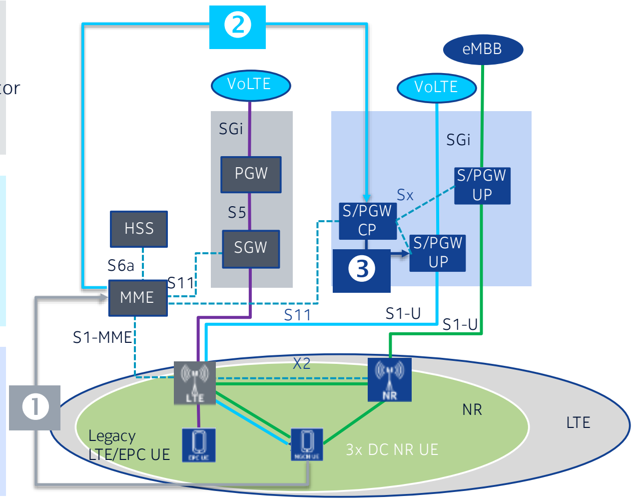
The authorization for connectivity of the subscriber to the 5GC and the authorization for the services that the user is allowed to access based on subscription (e.g. Operator Determined Barrings, Roaming restrictions, Access Type and RAT Type currently in use) is evaluated once the user is successfully identified and authenticated. This authorization is executed during UE Registration procedure.

1. An E-UTRAN cell, based on operator configuration, broadcasts whether it is capable of supporting dual connectivity with locally available NR secondary cell(s).
2. UE radio capability IE includes UE's support of NR: An eNB supporting Dual Connectivity with NR checks whether the UE is allowed to use NR. If the UE is not allowed to use NR, the eNB shall not establish Dual Connectivity with NR as a secondary RAT.
3. If the MME has Access Restriction for NR for a UE the MME signals this to the E-UTRAN and to the UE (as part of Handover Restriction List and to the UE in Attach and TAU Accept)
4. A new feature is introduced on S6a/S6d: NR as Secondary RAT.

The E-UTRAN uses the per-UE information supplied by the MME and local E-UTRAN configuration data to determine whether or not to use Dual Connectivity for that UE, and, on a per EPS bearer basis the E-UTRAN decides whether to use an MCG bearer or SCG bearer, and, whether or not that bearer is a "split bearer".

MR-DC with EPC Operation
NR Capable GW Selection

➊	• If a UE supports dual connectivity with NR, then the UE shall indicate its support in a NAS indicator
➋	• MME forwards UE’s capability to support NR to the SGW-C and from there to the PGW-C, in order to select the appropriate User Plane Functions which support high bitrates
➌	• The SGW-C/PGW-C may select a specific SGW-U/PGW-U for UE supporting DC with NR.



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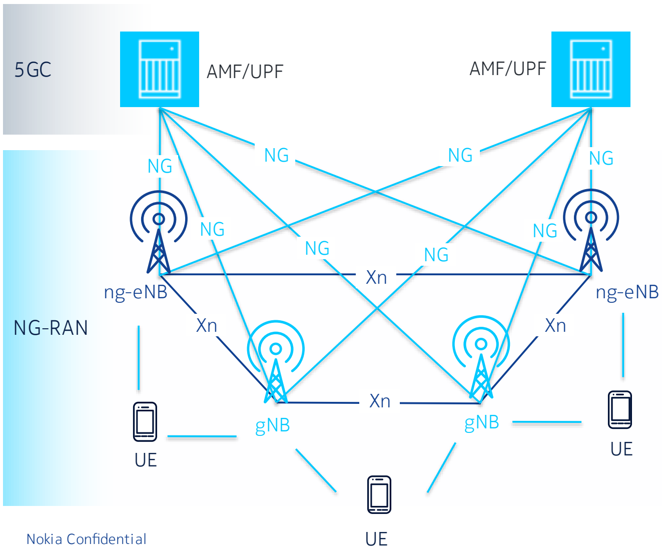
The eNB, at which the S1-MME terminates, performs all necessary S1-MME related functions (as specified for any serving eNB) such as mobility management, relaying of NAS signaling, E-RAB handling, etc. and manages the handling of user plane connection of S1-U.

If a UE supports dual connectivity with NR, then the UE shall indicate its support in a NAS indicator. The MME uses "UE support for dual connectivity with NR" for SGW and PGW selection when the UE indicates support for NR and there is no Access Restriction for NR for the UE. MME forwards UE’s capability to support NR to the SGW-C and from there to the PGW-C, in order to select the appropriate User Plane Functions which support high bitrates. The SGW-C/PGW-C may select a specific SGW-U/PGW-U for UE supporting DC with NR.

MR-DC with 5GC operation

MR-DC with 5GC

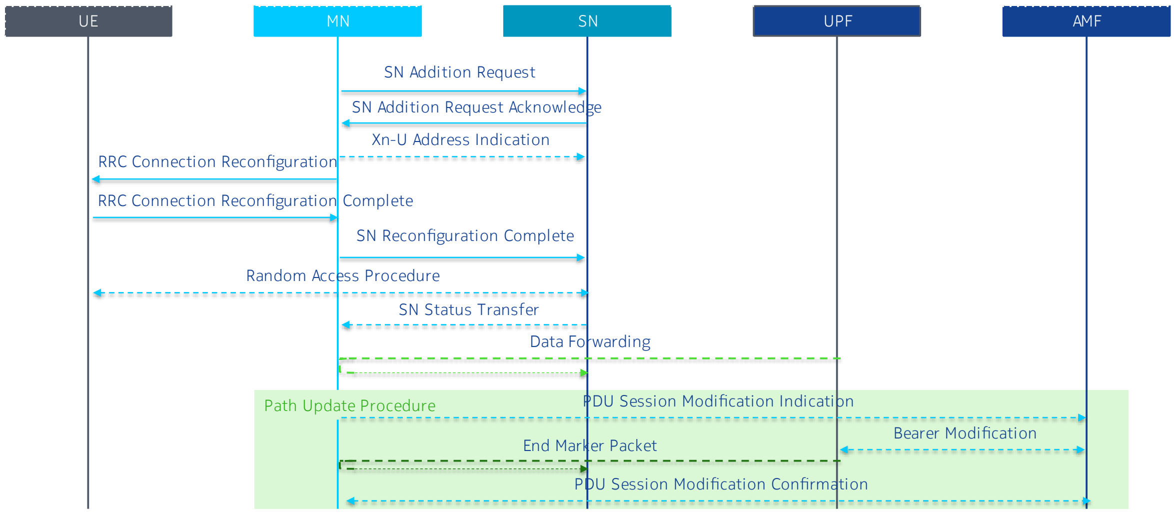
MR-DC with the 5GC	
NGEN-DC	• NG-RAN E-UTRA-NR Dual Connectivity • eNB is MN and gNB is SN
NE-DC	• NR-E-UTRA Dual Connectivity (NE-DC) • gNB is MN and eNB is SN
NR-DC	• NR-NR Dual Connectivity (NR-DC) • gNB is MN and gNB is SN



In MR-DC with 5GC (NGEN-DC, NE-DC), the involved core network entity is the AMF. NG-C is terminated in the MN and the MN and the SN are interconnected via Xn-C.

For MR-DC with 5GC (NGEN-DC, NE-DC), Xn-U interface is the user plane interface between MN and SN, and NG-U is the user plane interface between the MN, the SN or both and the UPF.

Secondary Node Addition procedure

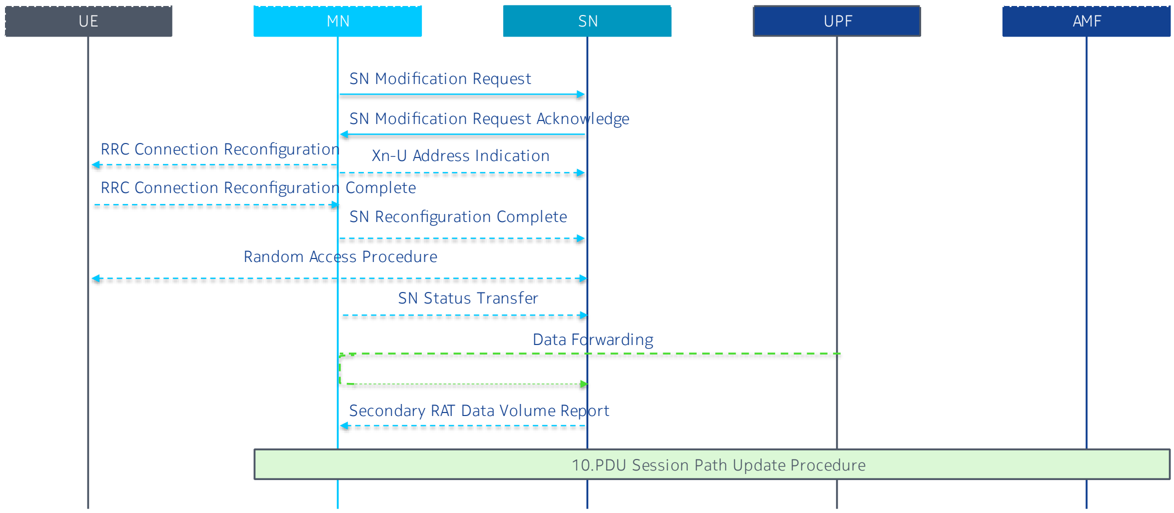


As already outlined, the SN Addition procedure is initiated by the MN and is used to establish a UE context at the SN in order to provide resources from the SN to the UE. For bearers requiring SCG radio resources, this procedure is used to add at least the initial SCG serving cell of the SCG. This procedure can also be used to configure an SN terminated MCG bearer (where no SCG configuration is needed).

The Secondary Node Addition procedure is performed as follow:

- The MN decides to request the target SN to allocate resources for one or more specific PDU Sessions/QoS Flows, indicating QoS Flows characteristics (QoS Flow Level QoS parameters, PDU session level TNL address information, and PDU session level Network Slice info). For bearers requiring SCG radio resources, MN indicates the requested SCG configuration information, including the entire UE capabilities and the UE capability coordination result
- If the RRM entity in the SN is able to admit the resource request, it allocates respective radio resources and, dependent on the bearer type options, respective transport network resources. For bearers requiring SCG radio resources the SN triggers UE Random Access so that synchronization of the SN radio resource configuration can be performed. The SN decides for the PScell and other SCG Scells and provides the new SCG radio resource configuration to the MN in a SN RRC configuration message contained in the SN Addition Request Acknowledge message.
- For SN terminated bearers using MCG resources, the MN provides Xn-U DL TNL address information in the Xn-U Address Indication message
- The MN sends the MN RRC reconfiguration message to the UE including the SN RRC configuration message
- The UE applies the new configuration and replies to MN with MN RRC reconfiguration complete message
- The MN informs the SN that the UE has completed the reconfiguration procedure successfully via SN Reconfiguration Complete message
- If configured with bearers requiring SCG radio resources, the UE performs synchronization towards the PSCell configured by the SN
- In case of SN terminated bearers using RLC AM, the MN sends SN Status Transfer
- In case of SN terminated bearers using RLC AM, and dependent on the bearer characteristics of the respective QoS Flows, the MN may take actions to minimise service interruption due to activation of MR-DC (Data forwarding).
- For SN terminated bearers, the update of the UP path towards the 5GC is performed via PDU Session Path Update procedure

Secondary Node Modification procedure - MN initiated



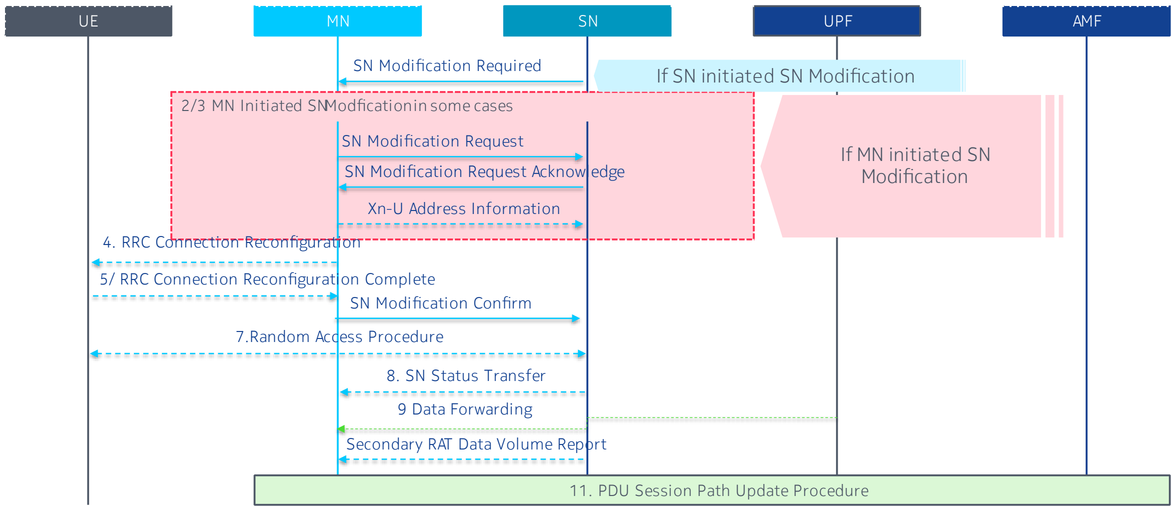
The Secondary Node Modification procedure could be triggered by either MN or SN. It does not necessarily need to involve signaling towards the UE.

The SN Modification procedure may be initiated either by the MN or by the SN and be used to modify the current user plane resource configuration (e.g. related to PDU session, QoS flow or DRB) or to modify other properties of the UE context within the same SN. It may also be used to transfer an NR RRC message from the SN to the UE via the MN and the response from the UE via MN to the SN (e.g. when SRB3 is not used).

To perform the MN initiated Secondary Node Modification:

- The MN sends the SN Modification Request message, which may contain user plane resource configuration related or other UE context related information, data forwarding address information (if applicable), PDU session level Network Slice info and the requested SCG configuration information, including the UE capabilities coordination result to be used as basis for the reconfiguration by the SN
- The SN responds with the SN Modification Request Acknowledge message, which may contain new SCG radio configuration information within a SN RRC configuration message, and data forwarding address information (if applicable).
- For SN terminated MCG bearers, the MN provides Xn-U DL TNL address information in the Xn-U Address Indication message
- The MN initiates the RRC connection reconfiguration procedure, including SN RRC configuration message. The UE applies the new configuration and replies with MN RRC reconfiguration complete message, including a SN RRC response message, if needed
- Upon successful completion of the reconfiguration, the success of the procedure is indicated in the SN Reconfiguration Complete message
- If instructed, the UE performs synchronization towards the PSCell of the SN. Otherwise, the UE may perform UL transmission after having applied the new configuration.
- If PDCP termination point is changed for bearers using RLC AM, and when RRC full configuration is not used, the MN sends the SN Status transfer.
- If applicable, data forwarding between MN and the SN takes place
- The SN sends the Secondary RAT Data Volume Report message to the MN and includes the data volumes delivered to the UE for the QoS flows to be released.
- If applicable, a PDU Session path update procedure is performed

Secondary Node Modification procedure - NN initiated



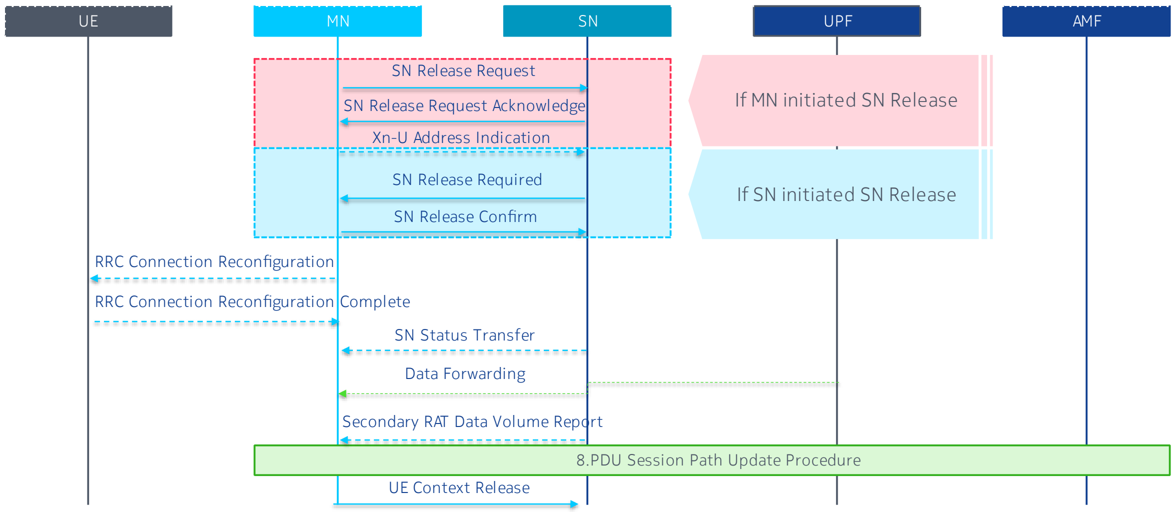
SN Modification; Could be triggered by either of MN or SN

The MN initiates the procedure by sending the SN Modification Request message. While, the SN initiates the procedure by sending the SN Modification Required message.

In case of SN Modification procedure - SN initiated with MN involvement:

- The SN sends the SN Modification Required message including a SN RRC configuration message, which may contain user plane resource configuration related context, other UE context related information and the new radio resource configuration of SCG
- The MN initiated SN Modification procedure may be triggered by SN Modification Required message, e.g. when a SN security key change needs to be applied
- The MN sends the MN RRC reconfiguration message to the UE including the SN RRC configuration message the new SCG radio resource configuration
- The UE applies the new configuration and sends the MN RRC reconfiguration complete message, including an encoded SN RRC response message, if needed
- Upon successful completion of the reconfiguration, the success of the procedure is indicated in the SN Modification Confirm message containing the encoded SN RRC response message, if received from the UE
- If instructed, the UE performs synchronization towards the PSCell configured by the SN. Otherwise, the UE may perform UL transmission directly after having applied the new configuration
- If PDCP termination point is changed for bearers using RLC AM, and when RRC full configuration is not used, the SN sends the MN Status transfer
- If applicable, data forwarding between MN and the SN takes place
- The SN sends the Secondary RAT Data Volume Report message to the MN and includes the data volumes delivered to the UE for the QoS flows to be released
- If applicable, a PDU Session path update procedure is performed

Secondary Node Release procedure

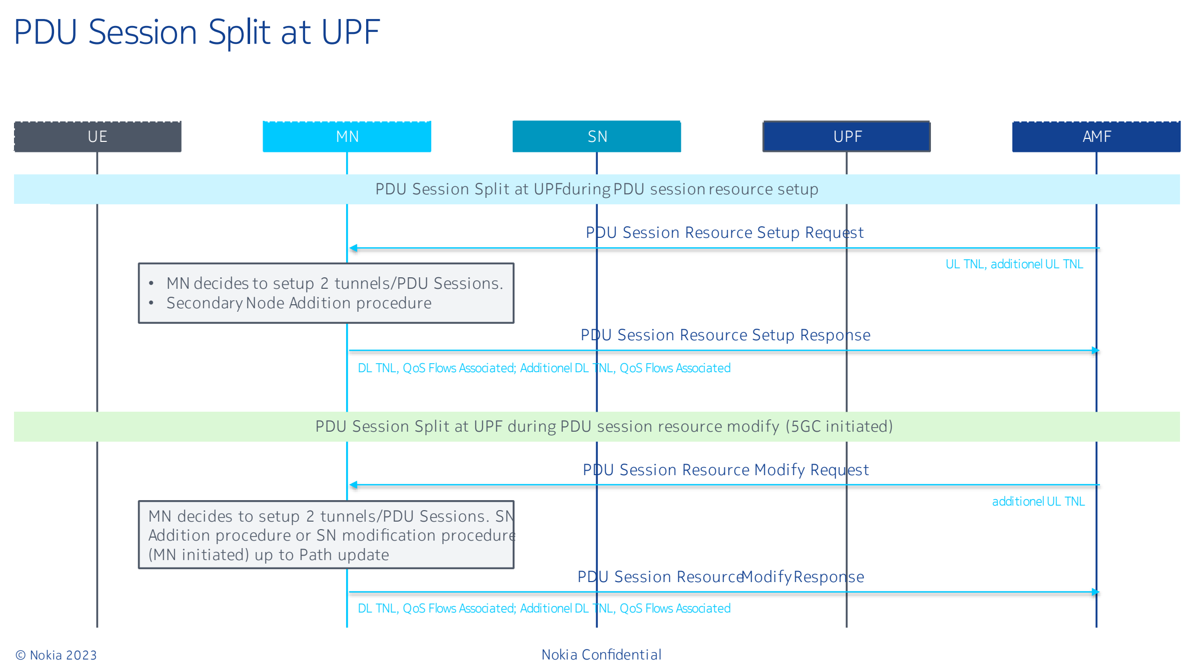


The Secondary Node Release procedure can be triggered either by the MN or by the SN and is used to initiate the release of the UE context at the SN.

For the SN release initiated by MN:

- The MN initiates the procedure by sending the SN Release Request message.
- The SN confirms SN Release by sending the SN Release Request Acknowledge message.
- When applicable, the MN provides forwarding address information to the SN (The MN may send the Data Forwarding Address Indication message to provide forwarding address information)
- If required, the MN indicates in the MN RRC reconfiguration message towards the UE that the UE shall release the entire SCG configuration
- If the released bearers use RLC AM, the SN sends the SN Status transfer
- Data forwarding from the SN to the MN takes place
- The SN sends the Secondary RAT Data Volume Report message to the MN and includes the data volumes delivered to the UE for the related QoS flows
- If applicable, the PDU Session path update procedure is initiated
- Upon reception of the UE Context Release message, the SN can release radio and C-plane related resource associated to the UE context. Any ongoing data forwarding may continue

As mentioned earlier, the Secondary Node Release procedure can be triggered by SN: The SN may also initiate the release with a SN Release Required sent to the MN, and the MN replies with SN Release Confirm and the same following exchanges.



PDU Session Split at UPF during PDU session resource setup:

When a new PDU session needs to be established, in order to allow for PDU session split, the 5GC (may) provides two UL TEID addresses during PDU Session Resource Setup. If the MN decides to split the PDU session, the MN provides two DL TEID addresses and also the QoS flows associated with the tunnel.

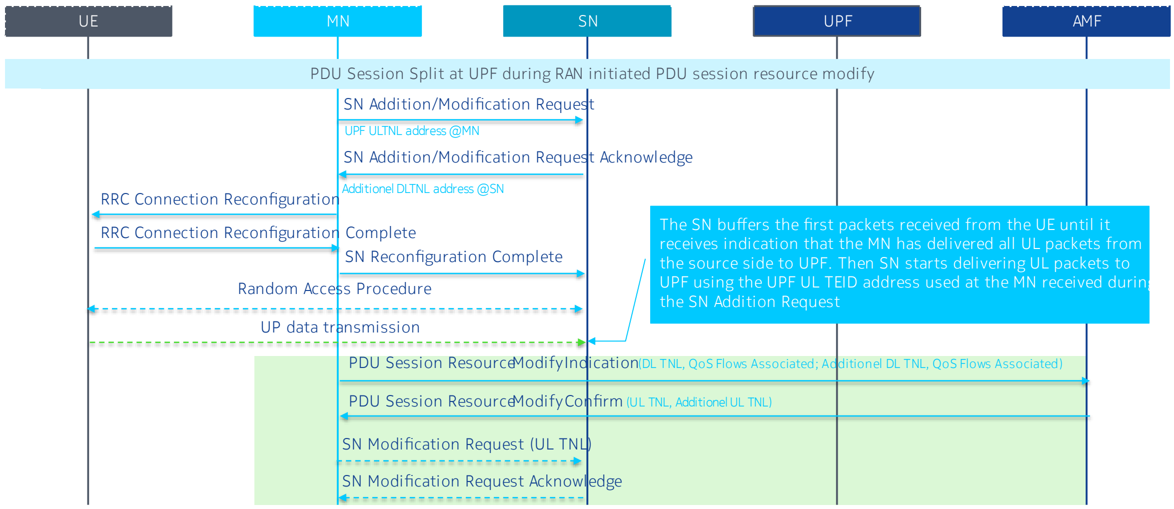
- The 5GC provides two UL TEID addresses during PDU Session Resource Setup, to be applied as the first UL tunnel on the NG-U interface and the additional NG-U tunnel in case the MN decides to split the PDU session.
- The MN decides to setup two tunnels. MN uses the SN Addition procedure or SN Modification procedure.
- The MN provides a DL TEID address to be applied as the first and an additional DL tunnel address on the NG-U interface along with QoS flows associated with each tunnel.

PDU Session Split at UPF during PDU session resource modify (5GC initiated)

When PDU sessions resource modification procedure is invoked, the 5GC (may) provides an additional UL TEID address during PDU Session Resource Modify Request in order to allow the MN to split the PDU session. The MN may perform the SN Addition or SN modification procedure. If the MN decides to use PDU session split, the MN provides a DL TEID address to be applied as the additional DL tunnel address and the QoS flows associated to the tunnel

- The 5GC provides an additional UL TEID address during PDU Session Resource Modify Request, to be applied as the additional NG-U tunnel in case the MN decides to split the PDU session.
- The MN decides to setup two tunnels. If the new tunnel is to be setup at SN, the MN may perform SN Addition or the MN performs SN modification.
- The MN provides a DL TEID address to be applied as the additional DL tunnel address on the NG-U interface and the QoS flows associated with it.

PDU Session Split at UPF

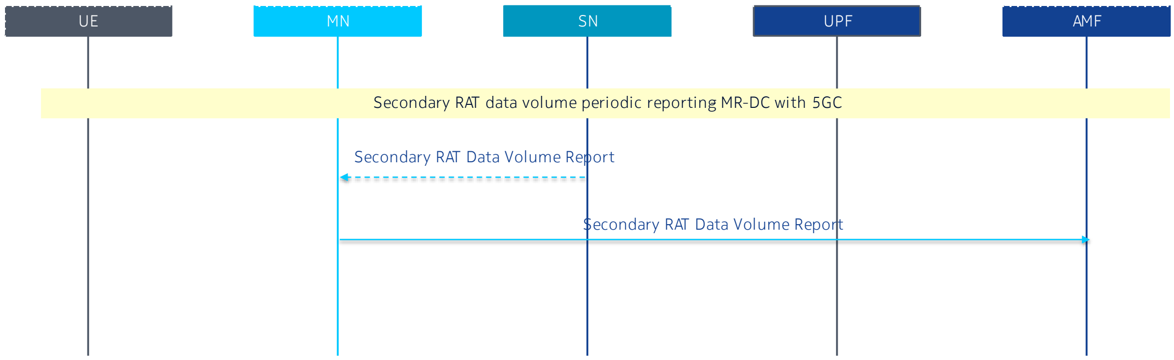


RAN initiated PDU Session Split at UPF:

When the MN decides to split the PDU session into two NG-U tunnels, the MN sends the SN Addition/Modification Request message including UPF UL TEID address used at MN. Later on, if the MN receives the new UL TEID in the PDU Session Modification Confirm message, the MN will decide to either use the new UL TEID by itself or provide the new UL TEID to SN.

- The MN decides to split the PDU session, it uses the SN Addition procedure or SN modification procedure, including current UPF UL NG-U tunnel used at the MN.
- The SN buffers the first packets received from the UE until it receives indication that the MN has delivered all UL packets from the source side to UPF. Then SN starts delivering UL packets to UPF using the UPF UL TEID address used at the MN received during the SN Addition Request.
- The MN uses the PDU Session Resource Modify Indication to inform the 5GC that the PDU session is split into two tunnels, request an Additional UL tunnel and indicate which QoS flows are associated with which DL/UL tunnel. The 5GC confirms with PDU Session Resource Modify Confirm.
- If the MN receives the new UL TEID in the PDU Session Modify Confirm message, the MN will either use the UL TEID by itself and then SN Modification procedure are not needed, or provide the new UL TEID to the SN in a subsequent SN Modification Request message and then the SN switches to use the new UL TEID to deliver UL packets.

Secondary RAT data volume reporting in MR-DC with 5GC



If periodic reporting is configured, then the SN periodically sends the Secondary RAT Data Volume Report message to the MN and includes the data volumes of used radio resources

The secondary RAT data volume reporting procedure is used to report the data volume of secondary RAT to the 5GC. In MR-DC with 5GC, if configured, the MN reports the uplink and downlink data volumes of used resources to the 5GC.

Secondary RAT data volume reporting indicates the secondary RAT type. Periodic reporting is performed by periodically sending the Secondary RAT Data Volume Report messages to the 5GC.

The data volume is counted by the node hosting PDCP. Downlink data volume is counted in bytes of SDAP SDUs successfully delivered/transmitted to the UE. Uplink data volume is counted in bytes of SDAP SDUs received by the node hosting PDCP. Forwarded packets shall not be counted when PDCP entity is relocated. When PDCP duplication is activated, packets shall be counted only once.

The slide shows an example of signaling flow for secondary RAT data volume periodic reporting:

- For SN terminated bearers, the SN sends the Secondary RAT Data Usage Report message to the MN and includes the data volumes of used secondary RAT resources for QoS flows mapped to SN-terminated bearers. If periodic reporting is configured, then the SN periodically sends the Secondary RAT Data Volume Report message to the MN and includes the data volumes of used radio resources.
- The MN sends the Secondary RAT Data Volume Report message (Which may also include secondary RAT data volumes of used secondary RAT resources for MN terminated bearers) to the 5GC to provide information on the used radio resources.

Quiz 5

1. Which of the following are correct statements? (tick 2)
    a. The secondary RAT data volume reporting function is used to report the data volume of secondary RAT to CN
    b. The MN reports the uplink and downlink data volumes of used NR resources to the EPC on a per EPS bearer basis
    c. The SN reports the uplink and downlink data volumes of used NR resources to the EPC on a per EPS bearer basis
    d. The UE reports the uplink and downlink data volumes of used NR resources to the EPC on a per EPS bearer basis
2. Which node (MN or SN) counts the data volume for the secondary RAT data volume reporting?
    a. The data volume is always counted by MN
    b. The data volume is always counted by SN
    c. The data volume is counted by the node hosting PDCP
    d. The data volume is counted by the node hosting RLC bearer(s)
3. What does MN provide if it decides to split the PDU session at the UPF?
    a. The MN provides one DL TEID
    b. The MN provides two DL TEID
    c. The MN provides two UL TEID
    d. The MN provides two UL TEID

Wrap-up

In this module we have covered the following items

- Review Multi-RAT (MR-DC) Dual Connectivity principles.
- List MR Dual Connectivity variants.
- Explain Radio-bearer types and protocol architecture
- Describe MR-DC with EPC Operation
- Describe MR-DC with 5GC Operation