5G/NR - Interworking with LTE

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This is about one of NR deployment options where LTE work as a master and NR work as a secondary cell (In 3GPP terms, this is about EN-DC (EUTRA-NR Dual Connectivity) / MR-DC with EPC as described in 37.340). In this configuration, UE get connected to LTE network first and then connected to NR via RRC Connection Reconfiguration process. Further details on lower layer process is yet to be studied, but just looking into the conentents of RRCConnectionReconfiguration would give you some general idea about the mechanism.

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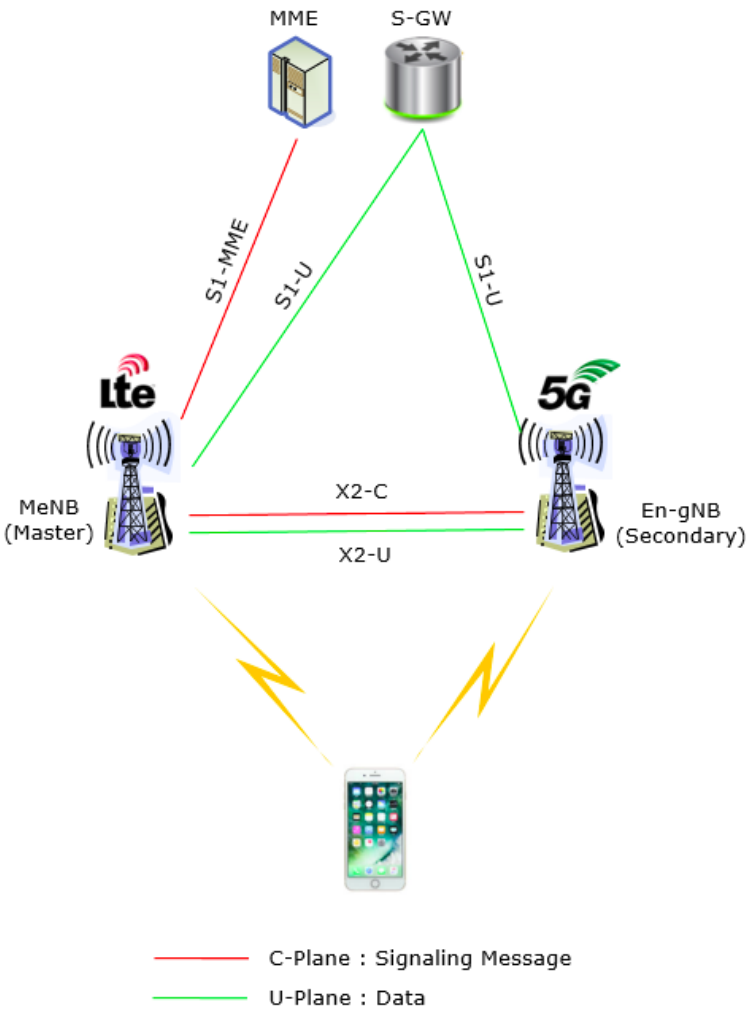
Overall Network Architecture

Overall RAN architecture of EN-DC can be illustrated as below (this is based on 37.340 - 4.3.1 and 4.3.2). As you see here, UE is communicating with both LTE eNB and NR gNB in Radio side, but all those communication (signaling and data) are going through LTE core network. Though not shown in this illustration, I would point out that LTE eNB and NR gNB are using their own PHY/MAC (i.e, independent MAC Scheduler)).
As you see here, in case of data plane both Master Node(LTE) and Secondary Node(gNB) has direct interface with LTE corenetwork(S-GW), but in case of control plane only Master Node(LTE) has direct interface with LTE core network(MME).

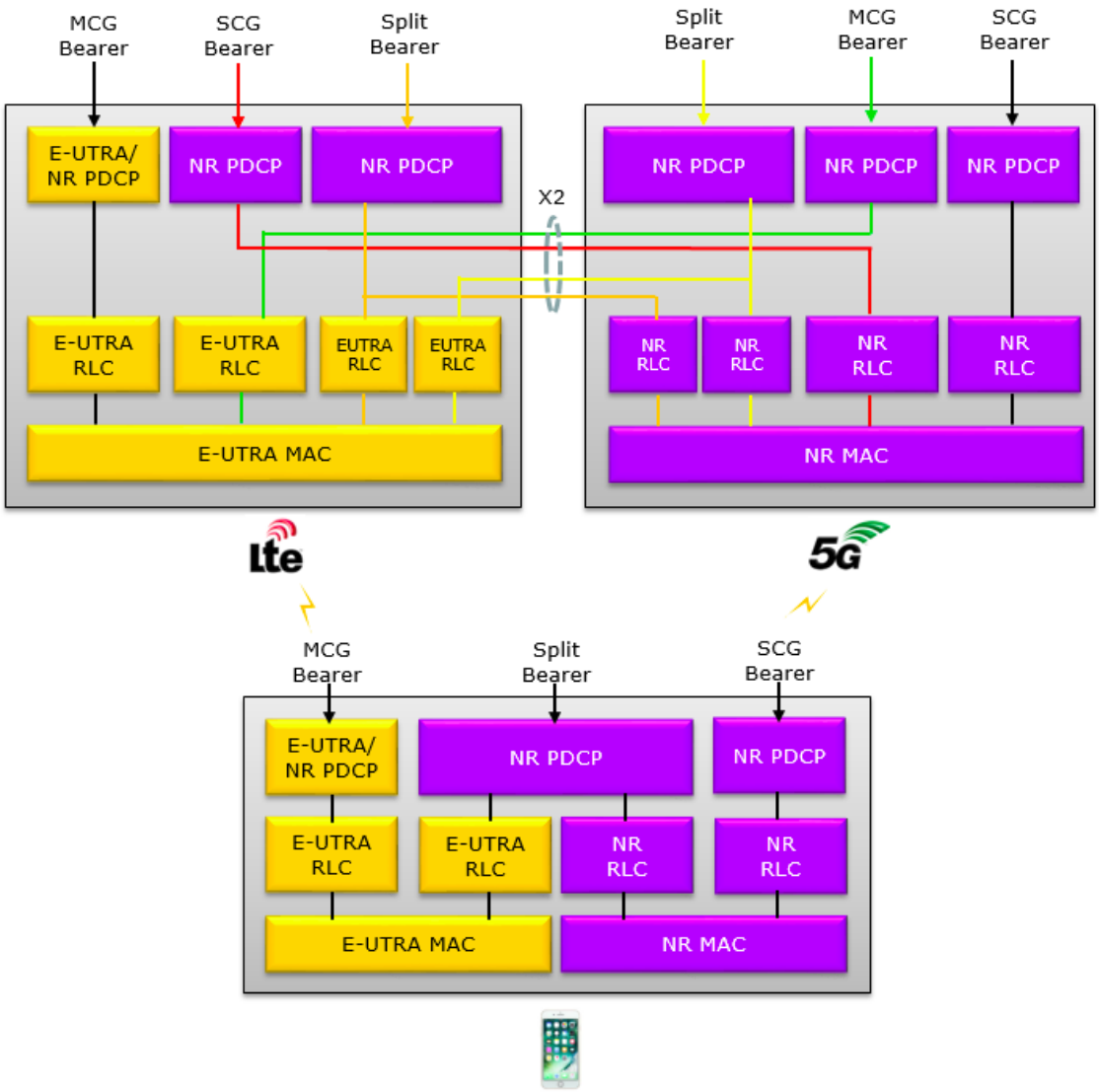


Now let's read the picture. If you take a close look at the illustration and just describe it in words, you would get the descrition as follows. If you don't like reading (like me :), just take 10 minutes (not 10 seconds) and look thorugh each and every part and lines of the picture.

- For C-Plane
  - There is an interface between MN(Master Node : MeNB in this csae) and the SN (Secondary Node : En-gNB in this case). This interface is called X2-C.
  - There is an interface between MN and CN(Core Network : MME in this case). This interface is called S1-MME.
  - There is NO direct interface(connection) between SN and CN
- For U-Plane
  - There is an interface between MN(Master Node : MeNB in this csae) and the SN (Secondary Node : En-gNB in this case). This interface is called X2-U.
  - There is an interface between MN and CN(Core Network : MME in this case). This interface is called S1-U
  - There is an interface(connection) between SN and CN. This interface is called S1-U.

Overall Layer 2 Architecture

Following is based on 37.340 - Figure 4.2.2-3 and Figure 4.2.2-1. As mentioned before, there are roughly two options when LTE and NR interplay. One option is to make LTE as a master and NR as a slave. The other option is to make NR as a master and LTE as a slave. In real deployment, especially at the early deployment, the first option (i.e, LTE Master and NR Slave) would be the major deployment option. This illustration is also to show the overal radio stack structure of LTE Master and NR Slave.



Various types of Bearer for LTE-NR Interworking (EN-DC)

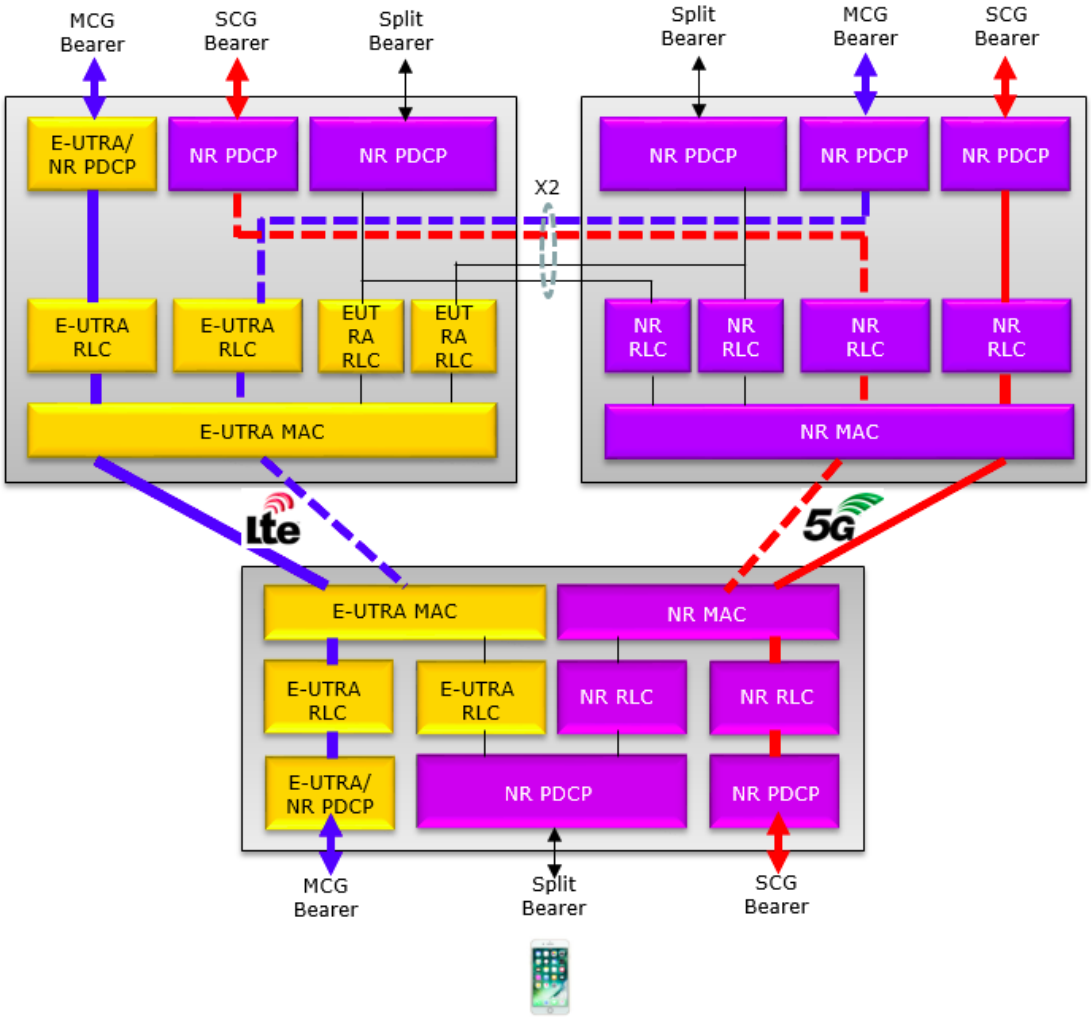
In terms of Over The Air(OTA) and Physical Layer perspective, LTE-NR interworking (EN-DC) in NSA(Non-StandAlone) is only one possibility (assuming that LTE always becomes the Anchor), but with the same OTA/Physical layer there can still be multiple possibilities of implementing higher layer bearer.

38.331 - 5.3.1.1 RRC connection control states as follows :

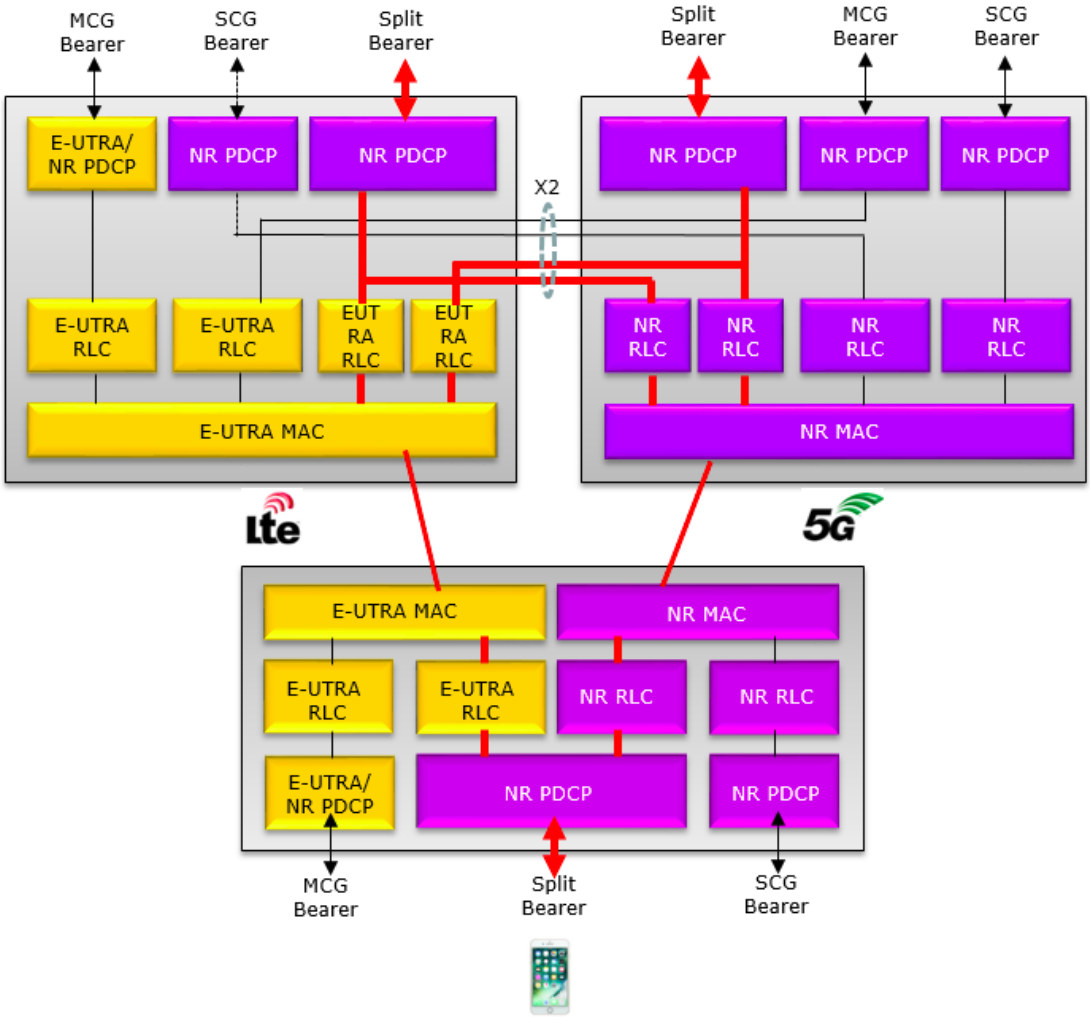
> *In case of EN-DC, the SCG cells use another RAT, namely NR. When configured with EN-DC, user data carried by a DRB may either be transferred via MCG, via NR SCG or via both MCG and NR SCG. Also RRC signalling carried by a SRB may either be transferred via MCG or via both MCG and NR SCG. When DRBs and SRBs are configured with transmission via both MCG and SCG, duplication may be used in both DL and UL.*

I just tried to turn this statement into illustration as follows (This illustration is based on 37.340 - Figure 4.2.2-3 and Figure 4.2.2-1) :

The statement '*DRB may either be transferred via MCG, via NR SCG or via both MCG and NR SCG*' can be illustrated as follows.



There is another bearer type called split Bearer (or split DRB). It can be illustrated as follows. You may find more details about this in Split Bearer page.



Types of NR(SCG) addition in EN-DC(LTE+NR Interworking)

In ENDC(Eutra NR Dual Connectivity), LTE would become a MCG(Master Cell Group) and NR would become a SCG(Secondary Cell Group). MCG work as the anchor and UE performs initial registration to this anchor cell group, and this anchor cell add one or more Secondary Cells (SCG). In 36.331-5.3.1.1, there are three different types(ways) of adding SCGs to the LTE anchor cell as follows.

Type 1 : Reconfiguration with sync and key change
- Perform RA Procedure to PScell
- Reset NR MAC
- Re-establish NR RLC
- Re-establish NR PDCP
- Refresh NR SCG security

Type 2 : Reconfiguration with sync but without key change
- Perform RA to the PSCell,
- Reset NR MAC
- Re-establish NR RLC re-establishment and
- Re-establish PDCP data recovery (for AM DRB)

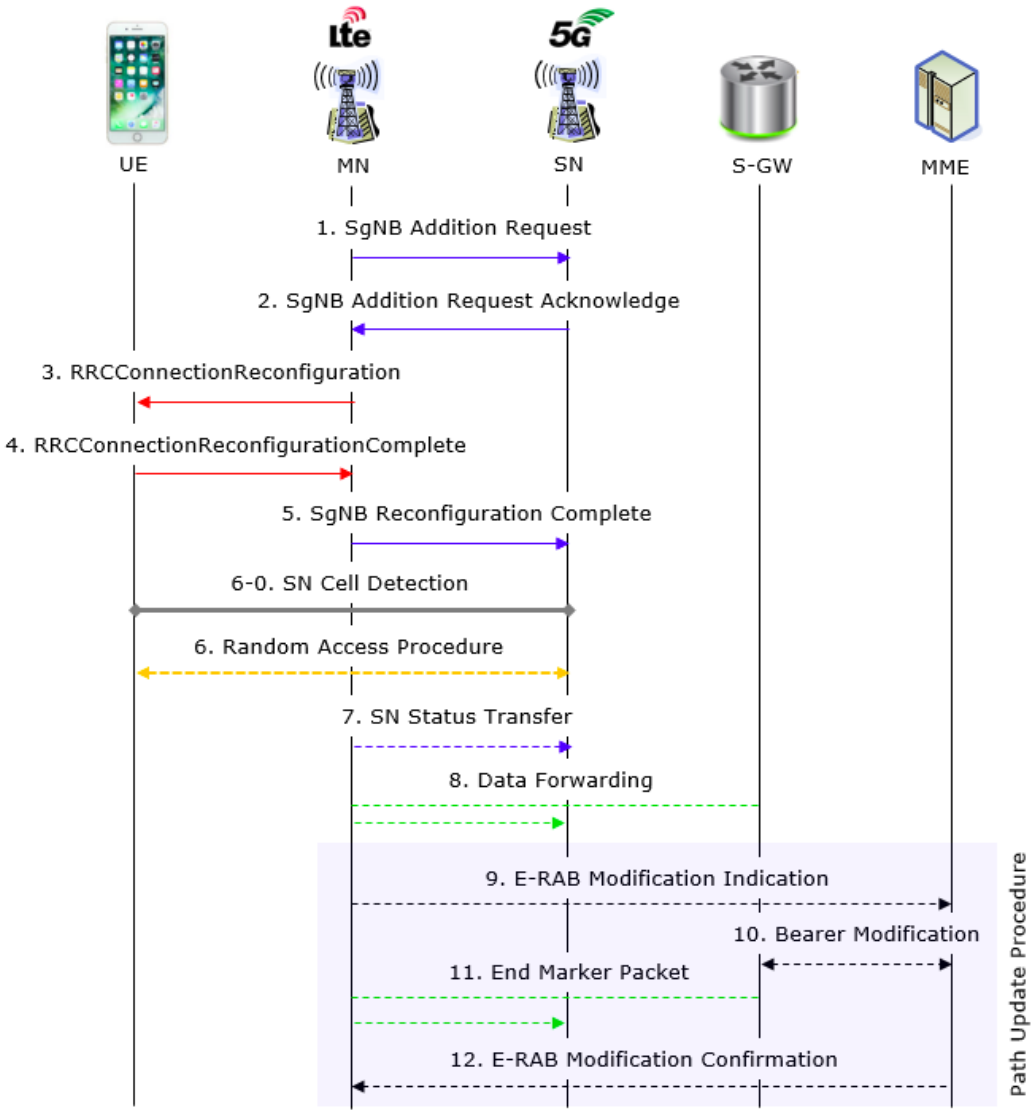
Type 3 : Regular NR SCG reconfiguration without Sync / SCG Security
- Does not perform RA to the PScell
- Does not refresh NR SCG security
- Reset NR MAC
- Re-establish NR RLC

Overall Signaling Procedure

This section is about how to add NR cell(Secondary Node) to an existing LTE Cell.(Master Note). Overall signaling

flow is illustrated below. This flow is based on 37.340 - 10.2.1 except the step 6-0 which is added by me. As you may notice,the process is iniated by MN (Master Node : LTE eNB in this case) and final confirmation is done by MME.

< 37.340 - Figure 10.2.1-1: Secondary Node Addition procedure >



Step 1 : MN (Master Node : LTE eNB) send SgNB Addition Request to SN (Secondary Node : NR gNB in this case). LTE eNB forward following informations to NR gNB.

- E-RAB Characteristics (E-RAB Parameters, TNL address information)
- The requested SCG configuration information including the entire UE capabilities and UE capability coordination result
- The latest measurement result for SN to choose
- Securiy Information to enable SRB3
- In case of bearer option that requires X2-U between MN and SN
  - X2-U TNS address information
- In case of SN terminated split bearers,
  - the maximum supportable QoS level

Step 2 : (If SN decided to accept the request), it sends SgNB Addition Request Acknowlege performing followings

- Allocate the necessary radio resources transport network resources
- decides Pscell and other SCG Scells and provide the new SCG radio resource configuration to MN
- In case of bearer options that requires X2-U between MN and SN
  - provides X2-U TNS address informations
- In case of SCG radio resources being requested
  - provide SCG radio resource configuration

Step 3 : If NR gNB accept the SN addition request and provides all the necessary information to LTE eNB, LTE eNB generate RRC Connection Reconfiguation message carrying all the necessary information and send it to UE. This message carries NR RRC Connection Cofiguration in it so that UE can figure out the necessary configuration information for NR gNB.

Step 4 : After UE received RRCConnectionReconfiguration, it checks if all the configurations in the message is doable in UE side, it sends RRCConnectionReconfigurationComplete message. This message includes NR RRC Response as well.

Step 5 : Once MN (LTE eNB) received RRCConnectionReconfigurationComplete from UE, the MN informs SN(NR gNB) that UE has completed the reconfiguration procedure.

Step 6-0 : Based on the information contained in NR RRCConnectionConfiguration within RRC Connection Reconfiguration message, UE detects SSBlock(PSS, SSS and PBCH) of NR gNB. For the details of SSBlock, see SSBlock page.

Step 6 : Once it successfully detects PSS, SSH, PBCH of NR gNB, it performs RACH procedure to PSCell of the SN (NR gNB). UE aquire all the information required for RACH procedure from RRC Connection Reconfiguration message instead of SIB, this process is described in RACH Process for LTE-Interworking(SNDC) .

LTE RRC Configuration

The major role of RRC in LTE-NR Interworking(more specifically ENDC) is to add NR as a secondary cell to LTE Anchor cell. The major IE(information elements) related to this process are

- nr-Config
- nr-SecondaryCellGroupConfig
- nr-RadioBearerConfig1

These few IEs has very complicated structures in it and carries so much information. Basically they carries all the information that combines MIB, SIB and RRC Configuration messages in standalone NR. I will take a while to get the detailed understanding on each and every elements of informations in it. Followings are rough summary of informations carried by the RRC Connection Reconfiguration message.

Function (Information)	Description
Frequency and Bandwidth in NR Downlink	spCellConfigCommon.frequencyInfoDL spCellConfigCommon.initialDownlinkBWP
Frequency and Bandwidth in NR Uplink	spCellConfigCommon.uplinkConfigCommon.frequencyInfoUL spCellConfigCommon.uplinkConfigCommon.initialUplinkBWP
PRACH to NR	spCellConfigCommon.uplinkConfigCommon.initialUplinkBWP.rach-ConfigCommon
PDCCH Configuration to decode RAR(PDSCH)	spCellConfigCommon.initialDownlinkBWP.pdcch-ConfigCommon
PDSCH Configuration to send RAR(PDSCH)	spCellConfigCommon.initialDownlinkBWP.pdsch-ConfigCommon
PUSCH Configruation for Common Channel	spCellConfigCommon.uplinkConfigCommon.initialUplinkBWP.PUSCH-ConfigCommon
PDCCH Configuration for dedicated channels (msg4 and onwards)	spCellConfigDedicated.initialDownlinkBWP.pdcch-Config
PDSCH Configuration for dedicated channels (msg4 and onwards)	spCellConfigDedicated.initialDownlinkBWP.pdsch-Config
PUCCH Configruation for Dedicated Channel (msg4 Ack/Nack and onwards)	spCellConfigDedicated.initialDownlinkBWP.pdcch-Config
PUSCH Configruation for Dedicated Channel (msg4 Ack/Nack and onwards)	spCellConfigDedicated.initialDownlinkBWP.pdcch-Config
tdd UL/DL Configuration	spCellConfigCommn.tdd-UL-DL-ConfigurationCommon spCellConfigDedicated.tdd-UL-DL-ConfigurationDedicated

```
RRCConnectionReconfiguration-v1430-IEs ::= SEQUENCE {
   sl-V2X-ConfigDedicated-r14      SL-V2X-ConfigDedicated-r14      OPTIONAL,   -- Need ON
   sCellToAddModListExt-v1430      SCellToAddModListExt-v1430      OPTIONAL,   -- Need ON
   perCC-GapIndicationRequest-r14  ENUMERATED{true}                OPTIONAL,   -- Need ON
   systemInformationBlockType2Dedicated-r14
                        OCTET STRING (CONTAINING SystemInformationBlockType2)  OPTIONAL,
```

```
   nonCriticalExtension          RRCConnectionReconfiguration-v15x0-IEs      OPTIONAL
}


RRCConnectionReconfiguration-v1510-IEs ::= SEQUENCE {
   nr-Config-r15                 CHOICE {
      release                    NULL,
      setup                      SEQUENCE {
         endc-ReleaseAndAdd-r15  BOOLEAN,
         nr-SecondaryCellGroupConfig-r15 OCTET STRING       OPTIONAL,   -- Need ON
         p-MaxEUTRA-r15              P-Max             OPTIONAL    -- Need ON
      }
   }                                          OPTIONAL,   -- Need ON
   sk-Counter-r15               INTEGER (0.. 65535)        OPTIONAL,   -- Need ON
   nr-RadioBearerConfig1-r15      OCTET STRING             OPTIONAL,   -- Need ON
   nr-RadioBearerConfig2-r15      OCTET STRING             OPTIONAL,   -- Need ON
   tdm-PatternConfig-r15         CHOICE {
      release                    NULL,
      setup                      SEQUENCE {
         subframeAssignment-r15        SubframeAssignment-r15,
         harq-Offset-r15              INTEGER (0.. 9)
      }
   }                                          OPTIONAL,   -- Need ON
   nonCriticalExtension          SEQUENCE {}              OPTIONAL
}


RRCConnectionReconfiguration-v15x0-IEs ::= SEQUENCE {
   endc-Config-r15           SEQUENCE {
      scg-ConfigReleaseNR-r15           BOOLEAN,
      sk-Counter-r15                 INTEGER (0.. 65535)    OPTIONAL,   -- Need ON
      nr-SecondaryCellGroupConfig-r15     OCTET STRING          OPTIONAL,   -- Need ON
      nr-RadioBearerConfig-r15           OCTET STRING          OPTIONAL,   -- Need ON
      nr-RadioBearerConfigS-r15          OCTET STRING          OPTIONAL,   -- Need ON
      tdm-PatternSingle-Tx-r15          SEQUENCE {
         subframeAssignment-r15            SubframeAssignment-r15,
         harq-Offset-r15                INTEGER (0.. 9)    OPTIONAL    -- Need ON
         }                    OPTIONAL    -- Need ON
   }                                          OPTIONAL    -- Need ON
      nonCriticalExtension          SEQUENCE {}              OPTIONAL
}
```

nr-SecondaryCellGroupConfig1-r15,nr-SecondaryCellGroupConfig2-r15 : Includes NR RRCReconfiguration message.
The field includes the configuration of RBs configured with NR PDCP.
nr-RadioBearerConfig : Include NR RadioBearerConfig. Mainly for DRB, EPS, NR PDCP Configuration

```
RRCConnectionResume-v15x0-IEs ::= SEQUENCE {
   sk-Counter-r15                 INTEGER (0.. 65535)        OPTIONAL,   -- Need ON
   nr-RadioBearerConfig-r15          OCTET STRING             OPTIONAL,   -- Need ON
   nr-RadioBearerConfigS-r15          OCTET STRING             OPTIONAL,   -- Need ON
   nonCriticalExtension              SEQUENCE {}              OPTIONAL
}
```

Example >

As mentioned above, RRC Connection Reconfiguration in LTE for Adding NR Cell carries only a couple of container that carries a huge tree of NR RRC message. Due to the complicated RRC structure in NR, I found it difficult to put the whole structure and description of any NR RRC message in a single page. In this example, you will see a couple of starting points of NR RRC part as shown below and you should follow the link until you reach the final destination.

```
rrcConnectionReconfiguration
   measConfig
   mobilityControlInfo
   dedicatedInfoNASList
   radioResourceConfigDedicated
   nonCriticalExtension
      laterNonCriticalExtension
      nonCriticalExtension
         otherConfig-r9
```

fullConfig-r9
nonCriticalExtension
  sCellToReleaseList-r10
  sCellToAddModList-r10
  nonCriticalExtension
    systemInformationBlockType1Dedicated-r11
    nonCriticalExtension
      wlan-OffloadInfo-r12
      scg-Configuration-r12
      sl-SyncTxConfrol-r12
      sl-DiscConfig-r12
      sl-CommonConfig-r12
      nonCriticalExtension
        sCellToReleaseListExt-r13
        sCellToAddModListExt-r13
        lwa-Configuration-r13
        lwip-Configuration-r13
        rdwi-Configuration-r13
        nonCriticalExtension
          sl-V2X-ConfigDedicated-r14
          sCellToAddModListExt-v1430
          perCC-GapIndicationRequest-r14
          systemInformationBlockType2Dedicated-r14
          nonCriticalExtension
            nr-Config-r15
              endc-ReleaseAndAdd-r15
              nr_SecondaryCellGroupConfig-r15
                cellGroupID
                rlc-BearerToAddModList
                mac-CellGroupConfig
                physicalCellGroupConfig
                spCellConfig
                  servCellIndeix
                  reconfigurationWithSync
                    spCellConfigCommon
                      physCellId
                      frequencyInfoDL
                      initialDownlinkBWP
                        genericParameters
                        pdcch_ConfigCommon
                          setup
                            commonControlResources
                            commonSearchSpaces
                            searchSpaceSIB1
                            searchSpaceOtherSystemInformation
                            pagingSearchSpace
                            ra_ConfrolResourceSet
                            ra_SearchSpace
                        pdsch_ConfigCommon
                          setup
                            pdsch_AllocationList
                      uplinkConfigCommon
                        frequencyInfoUL
                        initialUplinkBWP
                        supplementaryUplinkConfig
                      supplementaryUplinkConfig
                      ssb_PositionsInBurst
                      ssb_periodicityServingCell
                      dmrs_TypeA_Position
                      lte_CRS_ToMatchAround
                      rateMatchPatternToAddModList
                      rateMatchPatternToReleaseList
                      subcarrierSpacing
                      tdd_UL_DL_ConfigurationCommon
                        referenceSubcarrierSpacing
                        dl_UL_TransmissionPeriodicity
                        nrofDownlinkSlots
                        nrofDownlinkSymbols
                        nrofUplinkSlots
                        nrofUplinkSymbols
                      tdd_UL_DL_ConfigurationCommon2
                      ss_PBCH_BlockPower
                      newUE_Identity
                      t304

rach_ConfigDedicated
rlf-TimersAndConstants
rlmInSyncOutOfSyncThreshold
spCellConfigDedicated
tdd_UL_DL_ConfigurationDedicated
initialDownlinkBWP
pdcch_Config
pdsch_Config
sps_Config
radioLinkMonitoringConfig
downlinkBWP_ToReleaseList
downlinkBWP_ToAddModList
firstActiveDownlinkBWP_Id
bwp_InactivityTimer
defaultDownlinkBWP_Id
uplinkConfig
initialUplinkBWP
uplinkBWP_ToReleaseList
uplinkBWP_ToAddModList
firstActiveUplinkBWP_Id
pusch_ServingCellConfig
supplementaryUplink
pdsch_ServingCellConfig
csi_MeasConfig
carrierSwitching
sCellDeactivationTimer
crossCarrierScheduleConfig
tag_Id
ue_BeamLockFunction
pathlossReferenceLinking
p_MaxEUTRA-r15
sk-Counter-r15
nr-RadioBearerConfig1-r15
nr-RadioBearerConfig2-r15
tdm-PatternConfig-r15
nonCriticalExtension

Measurement (LTE-NR Measurement)

In real operation, it is expected for LTE to perform the measurement of the NR cell before it tries adding it. When it comes to measurement, first we need to think of what kind of measurement event to be used. And since this is interfrequency/interRAT from the point of LTE we need to think of measurement gap.
In terms of measurement event, we are using the existing event B1 and B2 and not new event is defined for NR measurement(see here for the details), but in terms of measurement gap, we got a lot of new gap patterns for NR measurement(see here for the details).

SCG Failure

Various type of failure can happen during NR addition after UE recieves RRC Connection Reconfiguration. When this happens, UE send SCG Failure Information message with various failure cause as listed below. This is based on 38.331 5.7.3.3. You should see 38.331 v15.4 or higher)

Failure type of SCG-FailureInformation		
	t310-Expiry	
	synchReconfigFailure-SCG	
	randomAccessProblem	
	rlc-MaxNumRetx	
	srb3-IntegrityFailure	
	scg-reconfigFailure	

Carrier Aggregation Setup in NR

After you add NR cell to LTE Anchor completing ENDC, you can add other NR cells to establish Carrer Aggregation(CA). The addition of secondary NR cells can be done at the same step as ENDC establishment or done separately after the ENDC Setup. This NR CA process is very similar to LTE CA establishment process. Overall

procedure is as shown below.

Step	Direction	Procedure
1	UE <-> NW	Establish ENDC Connection (NR Primary Cell + NR Secondary Cells)
2	UE < NW	NR Secondary Cell Activation by MAC CE

RRC Connection Message Structure for NR Secondary Cells
spCellConfig
reconfigurationWithSync
spCellConfigCommon
spcellConfigDedicated
sCellToAddModList[0]
sCellIndex
sCellConfigCommon
sCellConfigDedicated
sCellToAddModList[1]
sCellIndex
sCellConfigCommon
sCellConfigDedicated
....
sCellToAddModList[n]
sCellIndex
sCellConfigCommon
sCellConfigDedicated

Reference

[1] LTE-NR tight-interworking and the first steps to 5G (Errisson Research Blog)
[2] 4G-5G Interworking (SamSung)