

# **GTI Sub-6GHz 5G RAN White Paper**

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# White Paper of 5G RAN

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# 1 Introduction

In recent years, 4G has profoundly changed our daily life, and stimulate people’s desire for higher performance and better user experience for more innovative services and applications. Towards 2020, the mobile communication will rapidly penetrate to more and more elements of the human’s daily life and the society’s operation, which will create the opportunities for the mobile industry and other vertical industries. With the new capabilities, e.g. extremely high data rate, extremely low latency and extremely high reliability, massive connection and traffic density, the 5th generation mobile communication technology (5G) will shine a light on the great change on both our daily life and the whole society’s operation.

Targeting for commercial launch of 5G in 2020, the global telecommunication operators, network, chipset and device vendors, test instrument manufacturers and solution providers are deeply involved to promote end-to-end maturity of standard and industry. 5G technology development and trial activities comprise some main phases, such as Key technology feasibility validation, Prototype development and trials, Pre-commercial product development, Lab tests and Field trials for pre-commercial and commercial product, Commercial Launch and so on.

As a continuous effort to prompt global wireless ecosystem, GTI has set a plan for the roadmap of 5G PoC and trial and commercialization (as shown in Figure 1), and published the white paper of PoC in 2017. In the face of the field trials for pre-commercial in the near future, there are many new capabilities and performance requirements. We do believe a series of 5G technology white papers will benefit 5G industry and conduct activities by collaborating with industrial partners to accelerate the global momentum to make 5G into reality!

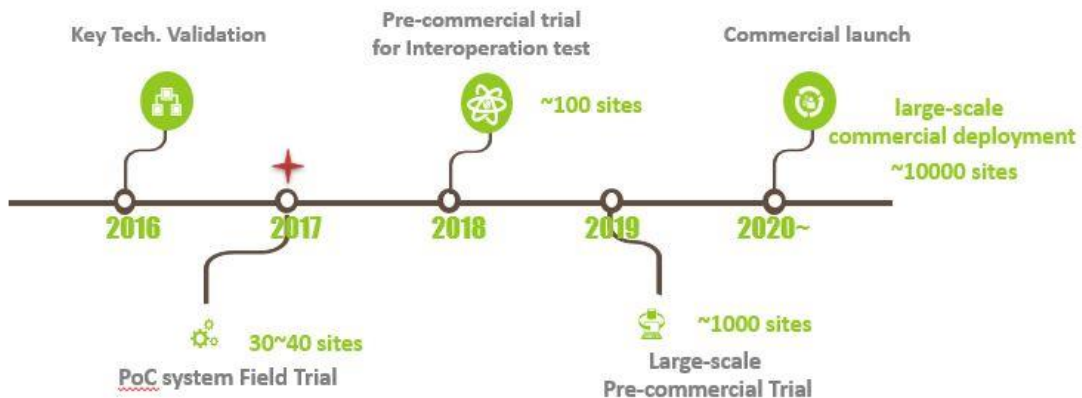


Figure 1: Timeline for 5G PoC Trial and Commercialization of GTI

As one of series of GTI Sub 6GHz 5G white paper, this 5G Radio Access Network whitepaper addresses outstanding aspects which are seen fundamental to corresponding work carried out with inclusion of three subclasses:

- Key performance requirements indexes need to be identified in 5G early trial.
- Essential features in compliant with 3GPP standards enabling the competence of 5G NR
- Substantial RAN solutions in early trial to identify issues may possibly hurdle 5G commercialization.

This whitepaper will be updated according to the progress of 3GPP 5G NR standardization and the findings from the development and trials.

## 2 Key performance requirements and capabilities

5G related forums and groups summarize tens of requirements and key capacities for different scenarios and inputs ITU for 5G requirements discussion. There are three main classes of new 5G applications: Extreme Mobile Broadband (eMBB), Ultra-Reliable Low Latency Communications (URLLC) and Massive Machine Type Communication (mMTC). Among all the 3 scenarios, eMBB poses high requirements for parts of the key capacities: high peak data rate, low latency, user experienced data rate, area traffic capacity, and related capacities like wideband operation.

5G infrastructure has significant benefits for a number of applications that are already limited in some capacity by existing 4G services. For eMBB applications that will benefit demand high bandwidth and/or low latency, for instance, 360-degree, 4K/8K resolution live entertainment and sports, Game-streaming services, Infotainment services for public and private transportation, Virtual, mixed and augmented reality. For further details the analysis of innovative services can refer to the “GTI research report of Innovative User Devices and Services for eMBB Applications”

With the recommended system configuration of 100MHz system bandwidth in C-Band and multi-antenna. This subsection will provide key system performance requirements of 5G Radio Access Network for 5G eMBB use case:

- **Peak data rate:** Maximum achievable data rate under ideal conditions per user/device (in Gbit/s).
- **Latency:** The contribution by the radio network to the time from when the source sends a packet to when the destination receives it (4ms for user plane).
- **Capacity performance:** e.g. Area traffic capacity -Total traffic throughput served per geographic area;

User experienced data rate - achievable data rate that is available ubiquitously across the coverage area to a mobile user, etc.

- **Coverage performance:** e.g. MaxCL in uplink and downlink between device and Base Station site (antenna connector(s)) for a data rate of 160bps; 5% percentile of the cumulative distribution function (CDF) of the normalized user throughput. etc.
- **Mobility performance:** Mobility interruption time -The shortest time duration supported by the system during which a user terminal cannot exchange user plane packets with any base station during transitions; Maximum speed and at which a defined QoS and seamless transfer between radio nodes which may belong to different layers and/or radio access technologies (multi-layer/-RAT) can be achieved.

## 3 NR key technologies and procedures

### 3.1 Waveform

Waveform is the basic physical feature for radio access technology. For 5G DL, CP-OFDM waveform is supported. For 5G UL, OFDM-based waveform is supported. Besides, DFT-S-OFDM based waveform is also supported in UL to achieve larger coverage. It is complementary to CP-OFDM waveform at least for eMBB uplink. CP-OFDM waveform can be used for a single port and multi-port transmissions. DFT-S-OFDM based waveform is limited to a single port transmissions (targeting for link budget limited cases). 5G System can indicate which one of CP-OFDM and DFT-S-OFDM based waveforms to be transmitted. Both CP-OFDM and DFT-S-OFDM based waveforms are required.

For downlink data share channel, the supported modulation schemes consists of QPSK, 16QAM, 64QAM and 256QAM. After detecting the CSI-RS and estimating the channel quality, UE reports the channel quality indicator (CQI) to gNodeB, which includes the information such as modulation scheme and code rate. To balance the overhead and the granularity of CQI indication, two CQI/MCS tables are adopted for eMBB, the modulation with the maximum order in one CQI/MCS table is 64QAM and that of another table is 256QAM. And the network side will instruct the UE to select CQI/MCS table through RRC signaling.

For uplink data share channel, the supported modulation schemes consists of are  $\pi/2$ -BPSK, QPSK, 16QAM, 64QAM and 256QAM. The  $\pi/2$ -BPSK modulation is only used when it is supported by UE and the waveform is the DFT-s-OFDM. The introduction of  $\pi/2$ -BPSK modulation scheme is to enhance the uplink coverage as its combination with DFT-s-OFDM waveform can reduce PAPR. Furthermore,  $\pi/2$ -BPSK

modulation is exclusive in the 256QAM MCS table.

## 3.2 Frame structure

Numerology refers to waveform parameterization for OFDM based system, which basically includes subcarrier spacing and cyclic prefix length. For numerology design, attributes, such as service types, carrier frequency, channel characteristics, inter-site distance, UE speeds and possible transmission schemes should be taken into account.

- Subcarrier spacing: Scalable subcarrier spacing ranges from 15 kHz to 240 kHz subcarrier spacing. All numerologies with 15 kHz and larger subcarrier spacing, regardless of CP overhead, are aligned on subframe boundaries every 1ms in NR carrier.

- CP length:
  - o Normal CP is supported for all numerology and procedures.
  - o Extended CP will be only supported for 60kHz subcarrier spacing in Rel-15. It could be enabled through RRC configuration for some procedures and numerology.

Multiple subcarrier spacings can be derived by scaling a basic subcarrier spacing by  $\alpha$  where  $\alpha$  ranges from 0 to 4. Scalable numerology should allow at least from 15 kHz to 240 kHz subcarrier spacing. The numerology used can be selected independently of the frequency band although it is assumed not to use a very low subcarrier spacing at very high carrier frequencies. Flexible network and UE channel bandwidth is supported.

Based on the above discussions, the observation is that one numerology may not be able to support wide range of service efficiently, and the 5G new radio framework should be configurable to different sets of numerologies. If it is required to multiplex multiple numerologies for multiple services in one carrier, both FDM and TDM manner can be considered.

In NR, the system timing is based on radio frame which is defined as 10 ms duration. One radio frame consists of 10 subframes each of 1 ms duration.

A slot contains 14 OFDM symbols, and depending on the numerology of the waveform, the slot duration scales accordingly. For example, for 15 kHz subcarrier spacing each slot is of 1 ms duration, and a radio frame contains 10 slots; for 30 kHz subcarrier spacing each slot is of 0.5 ms duration, and a radio frame consists of 20 slots, etc.

OFDM symbols in a slot can be classified as downlink, uplink, or flexible. A slot may contain all downlink symbols, all uplink symbols, all flexible symbols, or a combination of downlink, uplink, and flexible



symbols. Downlink and Uplink transmissions are organized in a TDD pattern which consists of one or more consecutive slots. The pattern always starts with downlink symbol and ends with uplink symbol. There is only 1 downlink-to-uplink switch point exists within the pattern period, and several guard symbols between the downlink and uplink symbols are not used for transmissions, which allows for uplink transmission in advance to compensate the propagation delay.

The supported periodicity of the pattern are {0.5, 0.625, 1, 1.25, 2, 2.5, 5, 10} ms. A smaller periodicity leads to more frequent downlink-to-uplink switch and thus lower round trip latency. This also results in higher guard symbol overhead and less spectrum utilization. Thus, the choice of frame structure should balance latency aspects and system performance in terms of e.g. spectrum utilization and data rate.

The TDD pattern can be broadcasted in system information with information on the number of downlink, flexible and uplink symbols. The flexible symbols may be overridden in configurations to UE to allow the flexibility to utilize these symbols. This may be performed by two procedures, i.e. via a semi-static slot format information (SFI) configuration in UE specific RRC signalling, or a dynamic configuration in downlink control information (DCI) sent in group common (GC-) PDCCH.

### 3.3 Reference signals

NR strives to minimize network transmissions that are not directly related to user data delivery. Unlike LTE where cell specific reference signals are always transmitted in every subframe, in NR, the reference signals are transmitted only when necessary. The only periodically transmitted signals are primary synchronization signal (PSS), secondary synchronization signal (SSS) and physical broadcast channel (PBCH) that together forms a synchronization signal and PBCH block (SSB). It can be used for UE to establish slot synchronization with gNB as well as for cell quality measurement. The periodicity and density of SSB is much lower than the always-on signals in LTE so that the interference is minimized in NR system and the energy efficiency is improved. All the other reference signal transmissions and measurements are scheduled by gNB when needed. There are four reference signals specified in 3GPP, i.e. demodulation reference signal (DMRS), phase-tracking reference signal (PTRS), sounding reference signal (SRS) and channel state information reference signal (CSI-RS).

- DMRS

DMRS is used to estimate the radio channel for demodulation. DMRS is confined in scheduled resources and transmitted only when necessary both in downlink and uplink.

To support multi-layer transmission for PUSCH and PDSCH, orthogonal DMRS ports can be scheduled, one for each layer. The DMRS orthogonality is achieved by FDM and CDM, where CDM may apply either cyclic shift of the base sequence or orthogonal cover codes. The basic DMRS pattern for PUSCH and PDSCH is front loaded where the design allows for early decoding of user data to support HARQ feedback. Additional DMRS symbols may be used for high speed scenarios, in order to track fast changes in the radio channel.

- PTRS

PTRS is introduced in NR to enable compensation of oscillator phase noise, which typically increases as a function of carrier frequency. Therefore, PTRS can be utilized at high carrier frequencies, such as mmWave to mitigate phase noise. Currently for sub-6 GHz systems it is not needed for gNB to schedule and transmit PTRS.

- SRS

SRS is transmitted in uplink for the gNB to measure and obtain the channel state information on the receiver side. SRS can also be utilized for reciprocity based measurement for massive MIMO.

- CSI-RS

CSI-RS are transmitted in downlink and are primarily intended for UE to acquire channel state information but could also serve other purposes, for example:

- o Effective channel/beam estimation at the UE used for e.g. channel quality, PMI and rank reporting;
- o Cell quality measurement for radio link monitoring or mobility purposes;
- o Fine time and frequency synchronization for demodulation, also known as Tracking Reference Signal (TRS).

NR supports periodic, aperiodic, and semi-persistent CSI-RS transmissions. The CSI-RS transmission may also be configured as wideband, partial-band.

### 3.4 Channel coding

The supported channel coding candidates for NR should consider many factors such as: decoding throughput, latency, error correction performance, flexibility and complexity. Compared to other coding candidates as in LTE, both LDPC and polar codes have better performance, lower latency and higher throughput etc. In particular, LDPC can satisfy NR's Key capacities that peak data rate is 20Gbps DL and 10Gbps UL. For very short control channel, repetition and RM code will be used.

For data share channel, channel coding scheme is quasi-cyclic LDPC codes with 2 base graphs and 8 sets of parity check matrices for each base graph, respectively. Lift sizes can support rout network with parallelism friend. One LDPC coding chain consists of code block segmentation, CRC attachment, LDPC coding, rate matching, interleaving and code block concatenation. The LDPC coding chain can support the same flexibility of code rate and code size as Turbo coding chain in LTE. For rate matching, self-decodable RV3 and multiple of lift size RVs are introduced. For interleaving, bit priority mapping has been introduced. Both Incremental Redundancy (IR) and Chase Combining (CC) HARQ are supported.

For broadcast channel and control channel, channel coding scheme is polar codes based on nested sequences. The Polar code construction schemes include distributed CA-Polar code, PC-CA Polar code, and CA-Polar code. The distributed CA-Polar code is used for broadcast channel and downlink control channel, PC-CA-Polar code is used for uplink control channel with small information block size, while CA-Polar code is applied for the remaining cases. The rate matching scheme consists of sub-block interleaving and bit selection. It is a unified design with puncturing, shortening and repetition. For uplink control channel, code block segmentation is applied to provide a better performance than excessive repetition, and the mapping order of CSI fields of one CSI report is carefully designed to exploit the reliability and successive decoding of polar codes.

### 3.5 Multi-antenna transmission

The massive MIMO is considered as one of the key technology to increase spectrum efficiency in 5G NR. A larger number of antennas can be employed in a given aperture, which increases the capability for beamforming and MU-MIMO. Meanwhile, the different antenna solutions and techniques depending on which part of the spectrum is used for its operation. For sub 6GHz band, if the spectrum allocations are of TDD type and digital beamforming solution is assumed. In this case, high-resolution CSI in the form of explicit channel estimations is acquired by UL channel sounding based on channel reciprocity. Such high-resolution CSI enables sophisticated precoding algorithms to be employed at the BS on sub 6GHz band.

To support these diverse use cases, NR feature enhanced DMRS and a highly flexible CSI framework. 8 orthogonal DMRS ports for SU and up to 12 orthogonal DMRS ports for MU data transmission has been agreed for NR system. On the other hand, CSI acquisition and interference measurement should be enhanced as well to support the high-order SU/MU data transmission. To improve CSI measurement and reporting, a high-resolution codebook design and an enhanced SRS design (i.e. increased SRS ports) for reciprocity based transmission are necessary in NR. Currently, type I codebook up to rank 8 and type II

codebook for rank 1&2 has been supported. Codebook for Beamformed CSI-RS can be used for linear combination of multiple beams. Moreover, the ZP&NZP CSI-RS for IM has been agreed in NR to enhance interference measurement. In addition, it is expected that the UE should at least has the Tx/Rx capability of 2T4R in NR.

The enhanced DMRS and CSI framework do not only enhance Mu-MIMO and beamforming performance, also supports more advanced schemes such as multi-point transmission which is another important topic for MIMO in NR.

The beam management is another feature in NR, which mainly prepared on analog beamforming for high band deployment. For sub-6GHz band, digital beamforming is assumed at gNB side, which can use full aperture to create UE specific beams, and process Tx and Rx beams in different directions simultaneously. So, beam management is not needed in general. In case SS/PBCH is bottleneck on link budget, the beam sweeping procedure may be used to enhance SSB coverage on mid band.

### 3.6 Wide band operation – BWP

With Bandwidth Adaptation (BA), the receive and transmit bandwidth of a UE need not be as large as the bandwidth of the cell and can be adjusted: the width can be ordered to change (e.g. to shrink during period of low activity to save power); the location can move in the frequency domain (e.g. to increase scheduling flexibility); and the subcarrier spacing can be ordered to change (e.g. to allow different services). A subset of the total cell bandwidth of a cell is referred to as a Bandwidth Part (BWP) and BA is achieved by configuring the UE with BWP(s) and telling the UE which of the configured BWPs is currently the active one.

Figure 2 below describes a scenario where 3 different BWPs are configured:

- BWP1 with a width of 40 MHz and subcarrier spacing of 15 kHz;
- BWP2 with a width of 10 MHz and subcarrier spacing of 15 kHz;
- BWP3 with a width of 20 MHz and subcarrier spacing of 60 kHz.

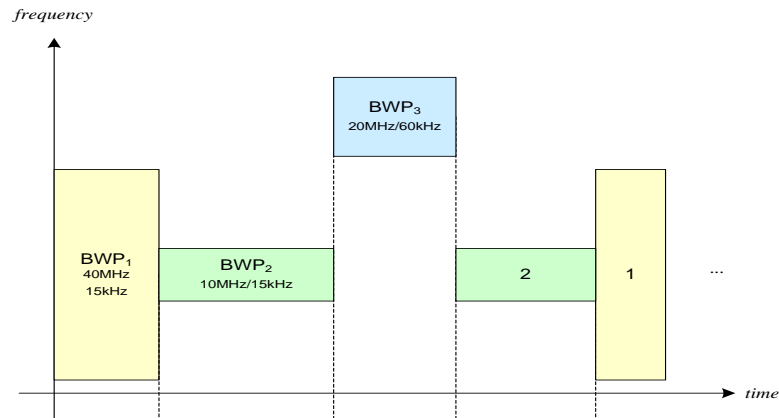


Figure 2: BA Example

A carrier bandwidth part is a contiguous set of physical resource blocks, selected from a contiguous subset of the common resource blocks for a given numerology on a given carrier.

A UE can be configured with up to four carrier bandwidth parts in the downlink with a single downlink carrier bandwidth part being active at a given time. The UE is not expected to receive PDSCH, PDCCH, CSI-RS, or TRS outside an active bandwidth part.

A UE can be configured with up to four carrier bandwidth parts in the uplink with a single uplink carrier bandwidth part being active at a given time. For initial access, and until the UE's configuration in a cell is received, initial bandwidth part detected from system information is used. If a UE is configured with a supplementary uplink, the UE can in addition be configured with up to four carrier bandwidth parts in the supplementary uplink with a single supplementary uplink carrier bandwidth part being active at a given time. The UE shall not transmit PUSCH or PUCCH outside an active bandwidth part.

### 3.7 Multi-band operation – CA

Carrier aggregation/dual connectivity operation within 5G carriers over e.g. around 1GHz contiguous and non- contiguous spectrum from both NW and UE perspectives should be supported. Carrier aggregation including different carriers having same or different numerologies should be supported. At least in physical layer, the maximum number of 5G carriers for CA and DC is 16. Maximum channel bandwidth per 5G carrier is at least 400 MHz. At least for single numerology case, candidates of the maximum number of subcarriers per 5G carrier is 3300.

The number of 5G CCs in any aggregation is independently configured for downlink and uplink. 5G channel designs should consider potential future compatibility of the maximum number of 5G carriers in later upgrade of system, allowing earlier handset to have access to new 5G network.

Cross-carrier scheduling and joint UCI feedback should be supported by 5G network. Per-carrier TB mapping is assumed.

In case of CA, the multi-carrier nature of the physical layer is only exposed to the MAC layer for which one HARQ entity is required per serving cell as depicted on Figure 3 and Figure 4 below:

- In both uplink and downlink, there is one independent hybrid-ARQ entity per serving cell and one transport block is generated per TTI per serving cell in the absence of spatial multiplexing. Each transport block and its potential HARQ retransmissions are mapped to a single serving cell.

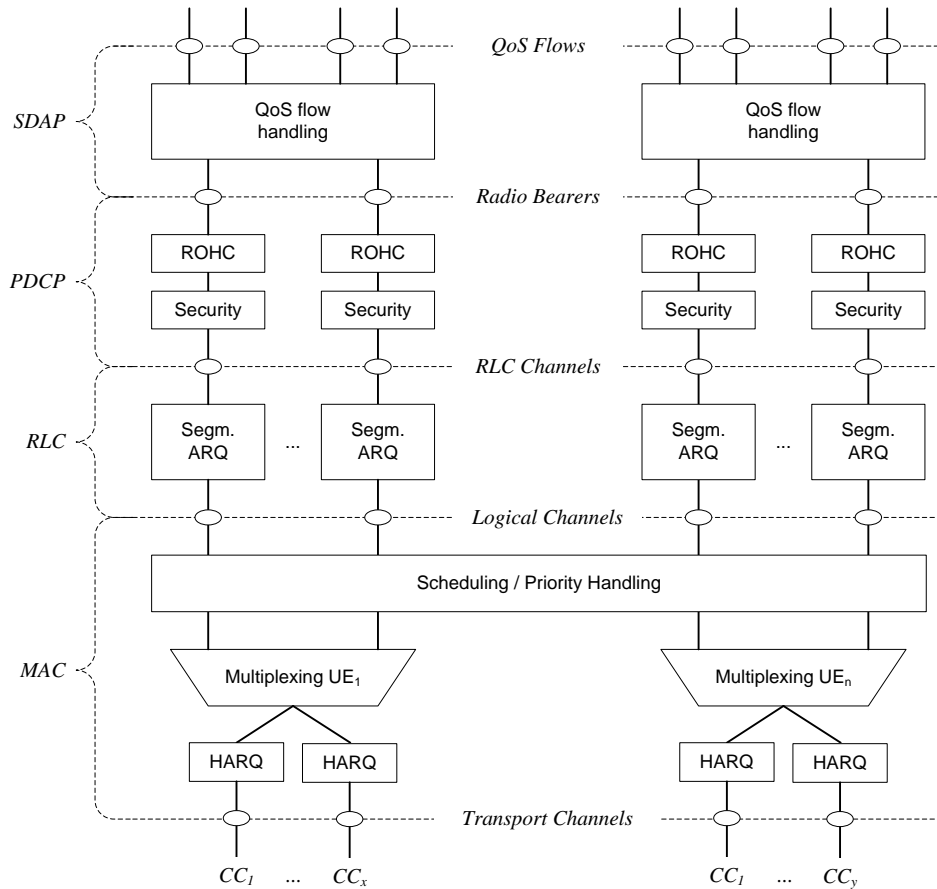


Figure 3: Layer 2 Structure for DL with CA configured

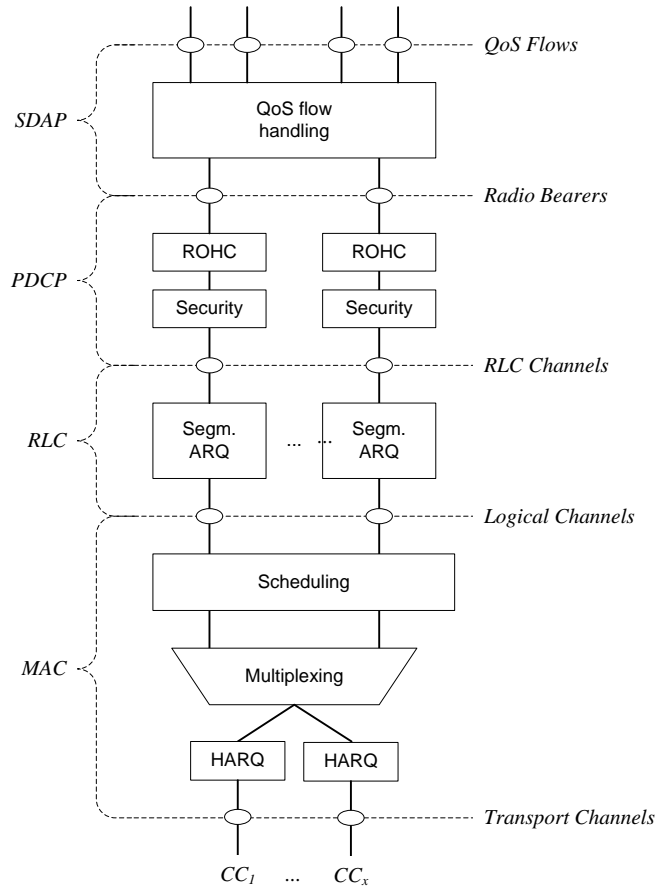


Figure 4: Layer 2 Structure for UL with CA configured

When CA is configured, the UE only has one RRC connection with the network. At RRC connection establishment/re-establishment/handover, one serving cell provides the NAS mobility information, and at RRC connection re-establishment/handover, one serving cell provides the security input. This cell is referred to as the Primary Cell (PCell). Depending on UE capabilities, Secondary Cells (SCells) can be configured to form together with the PCell a set of serving cells. The configured set of serving cells for a UE therefore always consists of one PCell and one or more SCells.

The reconfiguration, addition and removal of SCells can be performed by RRC. At intra-NR handover, RRC can also add, remove, or reconfigure SCells for usage with the target PCell. When adding a new SCell, dedicated RRC signalling is used for sending all required system information of the SCell i.e. while in connected mode, UEs need not acquire broadcasted system information directly from the SCells.

### 3.8 Multi-band operation – SUL

To improve UL coverage for high frequency scenarios, SUL can be configured as 3GPP TS 38.101. In conjunction with a UL/DL carrier pair (FDD band) or a bidirectional carrier (TDD band), a UE may be configured with additional, supplemental uplink. Supplemental uplink differs from the aggregated uplink in

that the UE may be scheduled to transmit either on the supplemental uplink or on the uplink of the carrier being supplemented, but not on both at the same time.

With SUL, the UE is configured with 2 ULs for one DL of the same cell as depicted on Figure 5 below:

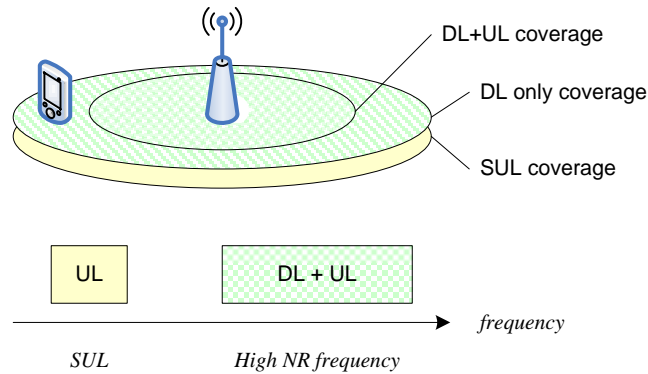


Figure 5: Example of Supplementary Uplink

To avoid the confliction for the UL procedure, 3GPP discussed the related UL procedure for SUL including:

**Initial access and RACH:** RACH configuration for the SUL carrier is broadcasted in RMSI. The configuration information for SUL carrier is sufficient for UEs to complete RACH procedure via only that SUL carrier. In particular the configuration information includes all necessary power control parameters and a threshold for SUL. The UE selects that SUL carrier for initial access if the RSRP measured by the UE on the DL carrier where the UE receives RMSI is lower than the threshold. Once started, all uplink transmissions of the Random Access procedure remain on the selected carrier.

**PUCCH and PUSCH:** PUSCH and PUCCH are not necessarily to be on the same UL carrier. UE specific RRC signaling (re-)configures the location of the PUCCH, either on the SUL carrier or on a non-SUL UL carrier in a SUL band combination. Meanwhile, UE specific RRC signaling may (de-)configure that PUSCH may be dynamically scheduled on the other (i.e. non-PUCCH) carrier in the same cell as the SUL.

**SRS:** SRS related RRC parameters are independently configured for SRS on the SUL carrier and SRS on the non-SUL UL carrier in the SUL band combination. Meanwhile, to facilitate the UL measurement SRS can be configured on the SUL carrier and non-SUL UL carrier, irrespective of the carrier configuration for PUSCH and PUCCH

During the discussion, band n78 + band n80 has been identified as the SUL combination example in RAN4. Related RF issues have been discussed including both Tx power and Rx sensitivity. For single carrier configured transmit power, as the UL carrier and SUL carrier is a same cell, the configured transmit power is



specified for each UL carrier in a serving cell. The configured transmit power requirement for serving cell is applied for each UL carrier.

### 3.9 Cell selection and network access

#### Initial Access

5G synchronization signal is based on CP-OFDM. The number of cell IDs should be at least around 1000. At least one broadcast channel is defined and is based on the fixed relationship with synchronization channel. In both single beam and multi-beam scenario, time division multiplexing of synchronization channel and broadcast is supported.

Multi-beam-based or single beam repetition based transmission/reception of synchronous and broadcast signals is a key feature of NR that differentiates from LTE. To facilitate multi-beam-based or single beam repetition based transmission, a synchronous signal (SS) burst set composed of multiple SS blocks is transmitted within 5ms window, which can perform a complete beam sweeping, as shown in Figure. Non-contiguous SS burst set structure is adopted in NR. The maximum number of SS blocks within an SS burst set depends on the corresponding frequency range (4 for sub3GHz, 8 for 3~6GHz and 64 for 6~52.6GHz). The SS burst set is transmitted periodically.

One SS block consists of one NR-PSS symbol, one NR-SSS symbol and two NR-PBCH symbols, which are multiplexed in time division manner, i.e. PSS+PBCH+SSS+PBCH. The transmission BW of NR-PBCH occupies 288 subcarriers while NR-PSS/SSS just occupy 127 subcarriers which is aligned with center frequency of NR-PBCH. Note that for each SS block, the TRP/beam is transparent to the UE since NR-PSS, NR-SSS and NR-PBCH in each SS block have the same single antenna port.

One or multiple SS block(s) compose an SS burst. One or multiple SS burst(s) further compose an SS burst set where the number of SS bursts within a SS burst set is finite. From physical layer specification perspective, at least one periodicity of SS burst set is supported. From UE perspective, SS burst set transmission is periodic and UE may assume that a given SS block is repeated with a SS burst set periodicity.

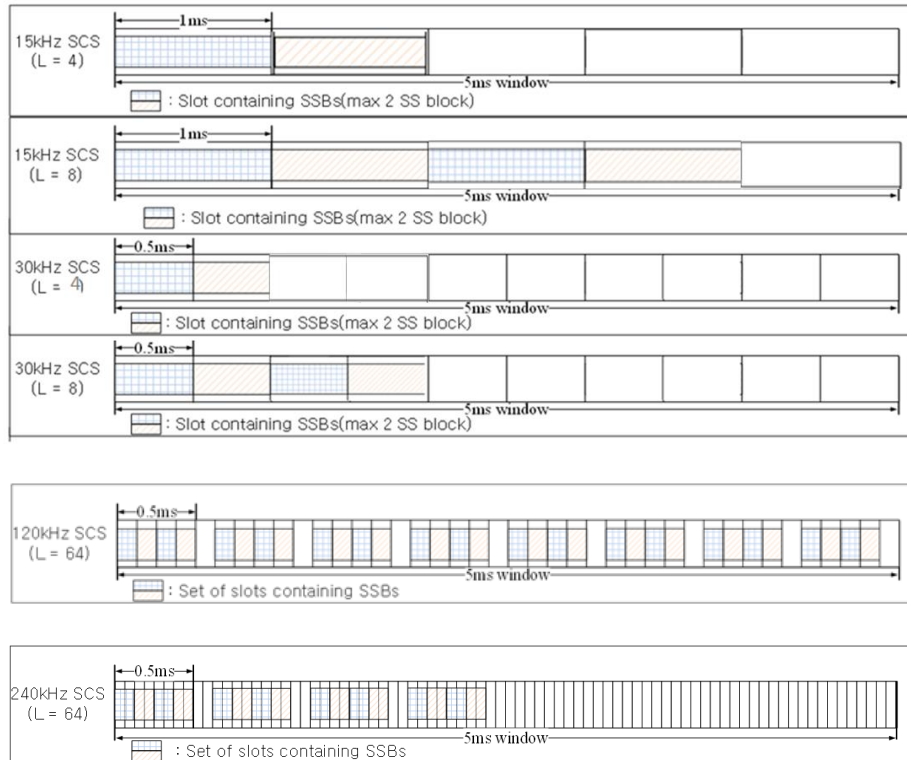


Figure 6 An SS burst set composition

NR cell corresponds one or multiple TRP(s). NR physical cell ID is extended to 1008 to facilitate flexible deployment, which is jointly carried by NR-PSS and NR-SSS, where NR-PSS is frequency domain-based pure BPSK M sequence and NR-SSS is Gold sequence. One default of four types subcarrier spacing (15kHz, 30kHz, 120kHz and 240kHz) associated with SS block transmission is defined for each frequency band to facilitate fast initial access in mixed numerology.

For the minimum system information delivery, part of minimum system information is transmitted in NR-PBCH. The remaining minimum system information (RMSI) is transmitted in shared downlink (DL) channel via NR-PDSCH.

NR supports 4 types of PRACH preamble formats with sequence length of 839 and 5/1.25kHz subcarrier spacing (SCS), where the formats with 5kHz SCS are defined for high speed (up to 500km/h) and medium cell radius (up to 14km). NR also support some PRACH preamble formats with shorter sequence length and 1, 2, 4, 6 and 12 OFDM symbols for 15/30/60/120kHz SCS. The PRACH preambles with shorter sequences are designed to support gNB Rx beam sweeping within a RACH occasion which are useful for small cell, high speed and high frequency cases. A 4-step RACH procedure is supported in NR and an association between SS block and a subset of RACH resources and/or preambles can be configured to facilitate the DL beam identification of the subsequent messages.

For RRM measurement, DL measurement is supported with the consideration on both single-beam based operation and multi-beam based operation. IDLE mode UE measures cells using cell-specific SS

block to derive cell level quality, without identifying multiple beams or multiple TRPs. CONNECTED mode UE can use UE-specific CSI-RS for L3 mobility, in addition to SS block. Up to two measurement window periodicities can be configured for intra-frequency CONNECTED mode measurement, providing the flexibility to UE to measure different cells. For paging in multi-beam operation, beam sweeping is supported for paging.

### **Random access procedure**

5G system supports multiple RACH preamble formats, including at least RACH preamble formats with longer preamble length and shorter preamble length. Multiple/repeated RACH preambles in a RACH resource are supported. Numerology for RACH preamble can be different depending on frequency ranges. Numerology for RACH preamble can be different from or the same as that for the other UL data/control channels.

The random access procedure is triggered by a number of events, for instance:

- Initial access from RRC\_IDLE;
- RRC Connection Re-establishment procedure;
- Handover;
- DL or UL data arrival during RRC\_CONNECTED when UL synchronisation status is "non-synchronised";
- Transition from RRC\_INACTIVE;
- Request for Other SI.

Furthermore, the random access procedure takes two distinct forms: contention based and non-contention based. Normal DL/UL transmission can take place after the random access procedure.

For initial access in a cell configured with SUL, the UE selects the SUL carrier if and only if the measured quality of the DL is lower than a broadcast threshold. Once started, all uplink transmissions of the random access procedure remain on the selected carrier.

### **Access Control**

NG-RAN supports overload and access control functionality such as RACH back off, RRC Connection Reject, RRC Connection Release and UE based access barring mechanisms.

One unified access barring mechanism for NR addresses all the use cases and scenarios that E-UTRA addressed with different specialized mechanisms: each access attempt is categorized into one of Access Category.

In RRC\_IDLE, the UE NAS informs RRC of the access category and the Connection Request includes some information to enable the gNB to decide whether to reject the request.

### 3.10 HARQ

HARQ-ACK feedback with one bit per TB is supported. Operation of more than one DL HARQ processes is supported for a given UE while operation of one DL HARQ process is supported for some UEs. UE supports a set of minimum HARQ processing time. NR also supports different minimum HARQ processing time at least for across UEs. The HARQ processing time at least includes delay between DL data reception timing to the corresponding HARQ-ACK transmission timing and delay between UL grant reception timing to the corresponding UL data transmission timing. UE is required to indicate its capability of minimum HARQ processing time to gNB.

Code Block Group (CBG)-based transmission with single/multi-bit HARQ-ACK feedback is supported, which shall have the following characteristics:

- Only allow CBG based (re)-transmission for the same TB of a HARQ process
- CBG can include all CB of a TB regardless of the size of the TB. In such case, UE reports single HARQ ACK bit for the TB
- CBG can include one CB
- CBG granularity is configurable

Code Block Group (CBG)-based transmission with single/multi-bit HARQ-ACK feedback is supported. A CBG could be feedback with a single HARQ-ACK

### 3.11 Scheduling

NR supports at least same-slot and cross-slot scheduling for both DL and UL. Timing between DL assignment and corresponding DL data transmission can be indicated by a field in the DCI from a set of values and the set of values is configured by higher layer. In addition, it is also possible to allow the timing

between DL assignment and corresponding DL data transmission be configured by higher layer. The timings are defined at least for the case where the timings are unknown to the UE. Both contiguous and non-contiguous resource allocation for data with CP-OFDM is supported.

To achieve power saving at UE side, RF bandwidth adaptation is supported in NR. UE could operate on a smaller bandwidth to reduce power consumption and be switched to a larger bandwidth to transmit/receive signals. As illustrated in Figure, NR allows a UE to operate in a way where it receives at least downlink control information in a first RF bandwidth and where the UE is not expected to receive in a second RF bandwidth that is larger than the first RF bandwidth within less than  $X \mu\text{s}$

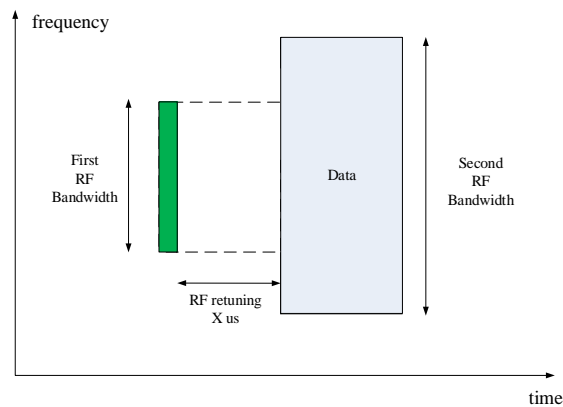


Figure 7 RF bandwidth adaptation

Indication of URLLC transmission overlapping the resources scheduled for an eMBB UE in downlink can be dynamically signaled by 5G system to facilitate demodulation and decoding. Indication can be dynamically signaled to a UE, whose assigned downlink resources have partially been preempted by another downlink transmission, to increase the likelihood of successful demodulation and decoding of the TB(s) transmitted within the above mentioned assigned resource.

In order to utilise radio resources efficiently, MAC in gNB includes dynamic resource schedulers that allocate physical layer resources for the downlink and the uplink.

#### Scheduler Operation:

- Taking into account the UE buffer status and the QoS requirements of each UE and associated radio bearers, schedulers assign resources between UEs;
- Schedulers may assign resources taking account the radio conditions at the UE identified through measurements made at the gNB and/or reported by the UE;
- Schedulers assign radio resources in a unit of TTI (e.g. one mini-slot, one slot, or multiple slots);
- Resource assignment consists of radio resources (resource blocks).

Signalling of Scheduler Decisions:

- UEs identify the resources by receiving a scheduling (resource assignment) channel.

Measurements to Support Scheduler Operation:

- Uplink buffer status reports (measuring the data that is buffered in the logical channel queues in the UE) are used to provide support for QoS-aware packet scheduling.

- The buffer reporting scheme used in uplink is flexible to support different types of data services.

Constraints on how often uplink buffer reports are signalled from the limits the overhead from sending the reports in the uplink.

### 3.12 Mobility and state transit

For NR SA, the Radio Resource Control (RRC) protocol supports 3 states, i.e. Idle, Inactive, and Connected. The RRC Inactive state is introduced in NR enabling efficient UE sleeping, reducing the latency that takes for UE to access the system, and reducing signalling overhead, i.e. optimized for data inactivity. The non-access stratum signalling connection is maintained when UE is in Inactive state, and the UE context is kept in the radio access network, thus the connection establishment procedure from Inactive to Connected state is optimized.

During Idle and Inactive mode, UE has minimum activities including cell selection, reselection, system information reception and paging monitoring to same power. The Idle state transition to connected mainly occurs during the first initial access, or as a fall-back case when the network or device cannot use previously stored UE context; while the Inactive state is used as a primary sleeping state for UE. State transition between RRC Inactive and Connected is light weight in terms of reduced amount of network signalling needed between the core network and radio access network as well as between radio access network and UE. This is expected to occur quite often to achieve an improved UE power save and reduced latency when UE moves out of sleeping mode.

For NR NSA, the RRC connection is on the LTE connection and the radio bearer for data transmission is setup on the NR connection with dual connectivity when needed. Thus the RRC state follows the LTE state machine, and when NR connection is used the UE is always in RRC Connected state.

Similarly for mobility in NSA, the addition and release of NR carriers is performed via the NR Secondary Cell Group configuration in RRC Connection Reconfiguration message in the LTE connection. Connected mode mobility with the present of NR carrier is indicated by updating the NR Secondary Cell Group configuration.

Mobility in NR SA mode is similar to that specified for LTE. In RRC Idle mode and Inactive mode, the mobility is a UE internal cell selection/reselection procedure with parameters configured by the network. UE typically do not need to inform the network about serving cell change unless the UE moves out of the tracking area in Idle mode, or the RAN notification area in Inactive mode.

In RRC Connected mode, mobility is controlled by the network typically with assistance from UE reporting the measurement of the serving and neighbouring cells. When the mobility decision is made, the source gNB initiates the handover by sending Handover Request message to the target gNB. Upon receiving the Handover Acknowledgement message the source gNB transmits the Handover Command to the UE containing information on how to access the target cell, and the handover procedure is completed when the target gNB receives the Handover Complete message from that UE.

The mobility decision on the source gNB normally relies on UE's measurement reports on the cell quality. Unlike LTE where UE's measurement is based on the cell specific reference signals, in NR the UE can be configured to measure either on the always-on SSBs, or on configured CSI-RS resources. The metrics to report can be RSRP, RSRQ or SINR for both SSB and CSI-RS measurements. There are 2 types of measurement reports that can be configured to UE, i.e. periodic report where UE sends the measurement metrics periodically, and event triggered report where the measurement report is sent only when a configured event threshold is met. The event configuration for intra-NR mobility should be similar to A1-A6 events that is specified in LTE standard.

Inter-RAT mobility is supported in NR to provide the same Idle/Inactive mode and Connected mode mobility framework to a node of a different radio access technology. In Release 15 the inter-RAT mobility is limited to LTE target.

## 4 NR RAN Architecture and System Solutions

### 4.1 NG-RAN architecture

The deployment and usage of 5G NR techniques are phase-wise, depending on various objective conditions from cellular industry.

There is one type of special E-UTRA node: en-gNB, which provides NR user plane and control plane protocol that terminates towards the UE, but still being connected to eNB or EPC via LTE network interfaces. The en-gNB cannot be operated in SA mode and always be operated as secondary node (SgNB) in NSA mode. The relevant architecture is depicted in Figure as shown below:

In Figure 8, en-gNB can be connected with master eNB via X2 interface and with S-GW via S1-U interface. It can be also connected with neighboring en-gNB via X2-U interface. Hence the X2-C interface with master eNB provides only control plane for en-gNB on NW side.

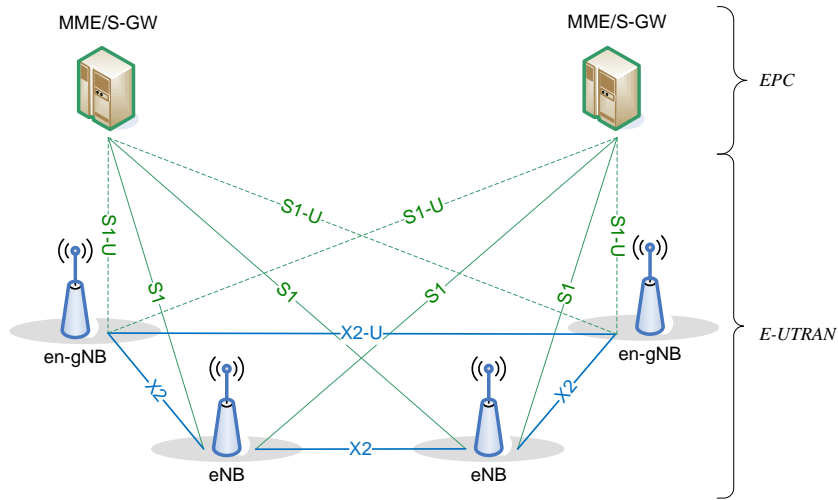


Figure 8 RAN architecture support en-gNB

The deployment and usage of en-gNB corresponds to the migration path option 3 where its dual connectivity mode is described as EN-DC: E-UTRA NR - dual connectivity. Unlike single RRC model for legacy LTE DC, EN-DC supports dual RRC model where the NR RRC entity in en-gNB is de-coupled and isolated from E-UTRA RRC entity in eNB, i.e. both RRC protocols can evolve independently.

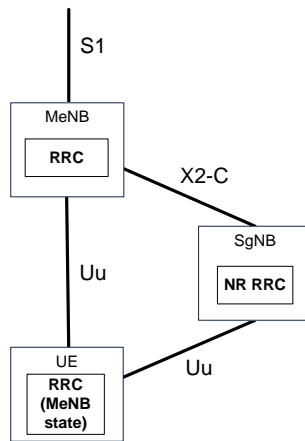


Figure 9 Migration path option 3

Option 3 is deemed as initial phase of using 5G NR techniques, when 5GC and full 5G business mode are not commercially ready yet. So the en-gNB is used mainly for eMBB purpose such as increasing NW capacity and end user throughput.

There are two types of NG-RAN nodes so far in 3GPP Rel-15: gNB and ng-eNB. The gNB provides the NR user plane and control plane protocol that terminates towards the UE and can be operated in both SA and NSA mode. The ng-eNB provides the E-UTRA user plane and control plane protocol that terminates



towards the UE and can also be operated in both SA and NSA mode. The relevant architecture is depicted in Figure 10 as shown below.

The gNBs and ng-eNBs are interconnected with each other by means of the Xn interface. The gNBs and ng-eNBs are also connected by means of the NG interfaces to the 5GC, more specifically to the AMF (Access and Mobility Management Function) by means of the NG-C interface and to the UPF (User Plane Function) by means of the NG-U interface.

The SA deployment and usage of ng-eNB corresponds to the migration path option 5 where the largely deployed eNB today can be upgraded to ng-eNB by supporting 5GC and 5G new NW interfaces.

The SA deployment and usage of gNB corresponds to the migration path option 2 where fresh new logic nodes are deployed and can only connect with 5GC and 5G new NW interfaces. The AS layer with gNB is NR based, hence its basic operations and radio performances can conform entirely to 5G various requirements.

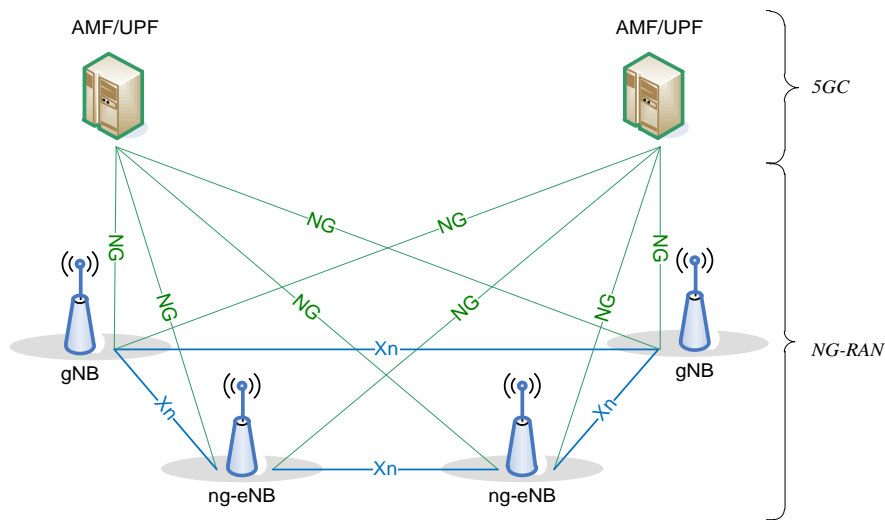


Figure 10 NG-RAN architecture with option 2

The NSA deployment and usage of ng-eNB as master node corresponds to the migration path option 7, where its dual connectivity mode is described as NGEN-DC: NG E-UTRA NR - dual connectivity. NGEN-DC inherits most of the characteristics of EN-DC. It can also support 5G specific features in addition, such as new QoS framework and NW Slice etc. Option 7 is deemed as subsequent phase of Option 3, when 5GC and full 5G business mode are commercially ready. Since in 5G early phase, there are still a lot of macro ng-eNBs in field, operators intend to configure ng-eNB as MN.

The NSA deployment and usage of gNB as master node corresponds to the migration path option 4, where its dual connectivity mode is described as NE-DC: NR E-UTRA - dual connectivity. NE-DC inherits most of the characteristics of NGEN-DC, so it can also support 5G specific features in addition. However, option 4 has more limitations than option 7 and 3 such as not supporting SN terminated bearers, SRB3.

Besides option 7 and 4 as described above, there is another type of intra-NR deployment, called NN-DC: NR DC - dual connectivity. Its architecture model can be harmonized with option 7 as much as possible. The relevant architecture with option 7 on NW side is depicted in Figure 11 as shown below:

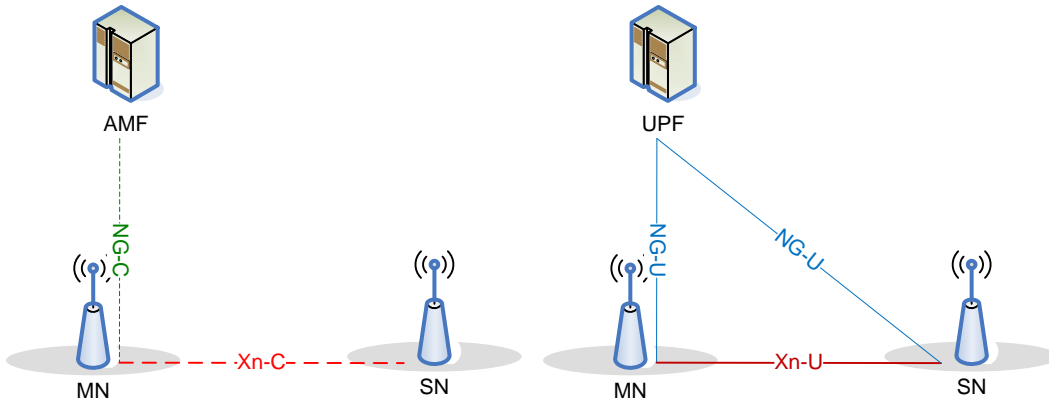


Figure 11 NG-RAN architecture with option 7 on NW side

The relevant architecture with option 7 on radio side is depicted in Figure 12 as shown below:

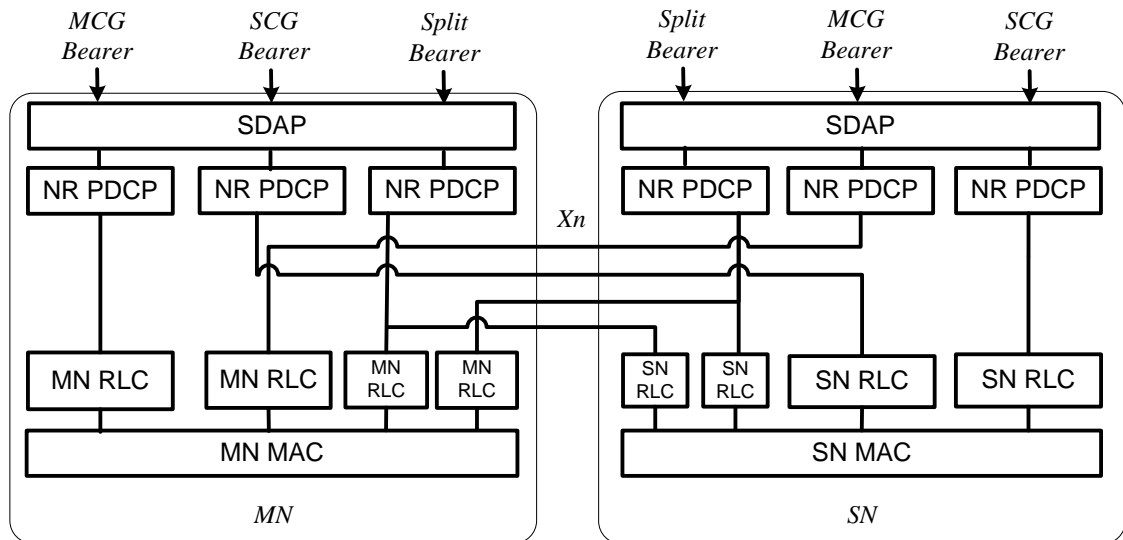


Figure 12 NG-RAN architecture with option 7 on radio side

As part of NG-RAN architecture, the logic of RAN Split and Cloud RAN are also discussed. The RAN split refers to RAN logical separation, and the cloud RAN concerns about cloud framework based virtualization technology.

Cloud RAN architecture allows for the use of NFV techniques and data center processing capabilities such as coordination, centralization and virtualization in mobile networks. It supports resource pooling (more cost-efficient processor sharing), scalability (more flexible hardware capacity expansion), layer interworking (tighter coupling between the application layer and the RAN) and spectral efficiency.

The Cloud RAN can support different network architecture functional splits, as outlined in Figure 13, including different levels of functionality implemented as NFVs. By utilizing Cloud RAN, operators can centralize the control plane (seen together with PDCP split in Figure 13) – which does not have extreme bitrate requirements – to bring RAN functionality closer to applications, or further distribute the physical layer closer to the antenna (PHY split in Figure 13) to enable massive beamforming.

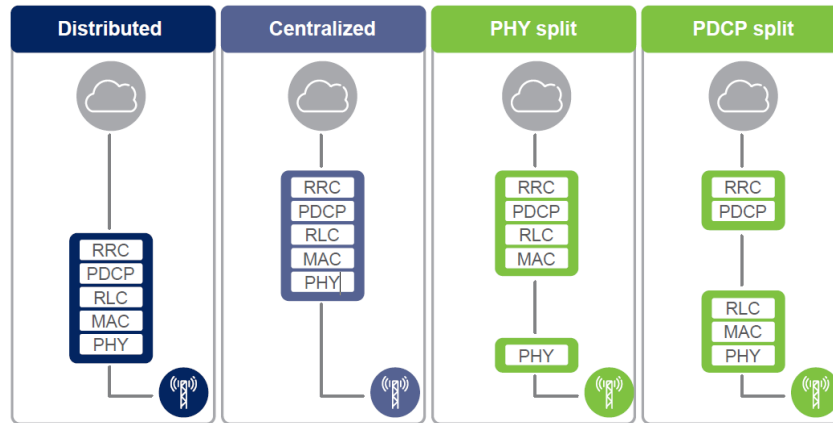


Figure 13 Examples of functional splits of the radio access protocol layer in a Cloud RAN

Cloud core and NFV frameworks also bring applications closer to the RAN, and this proximity enables scalable and shared common and commercial-off-the-shelf (COTS) execution platforms to be used and leveraged for cost-effectiveness and flexibility. For instance, if cloud core functions are pushed out into the network and RAN is centralized to some degree, there will eventually be some degree of colocation of core and RAN functionality – either with RAN and core together on a server in a distributed fashion, or with RAN and core executing in a centralized data center environment. This will enable substantially lower latencies for the interconnection between RAN and core.

## 4.2 Basestation Hardware introduction

Baseband Unit (BBU) is responsible for baseband signal processing and it needs to support the whole protocol functions including control plane and user plane, as well as the extended capability to support high-layer protocol split.

One BBU should at least support 3 cells with 64 paths and 100MHz bandwidth. It should have the capability to support network functions and key performance requirements defined in section 2, including: dual connection, seamless handover, multi Giga bits per seconds peak data rates, low latency for user plane and so on. In addition, BBU needs to support synchronization schemes, including BDS (BeiDou Navigation Satellite System), GPS and IEEE 1588v2.

For the rapid and agile deployment of new business service, the 5G NR needs to have the capability of the end to end network slicing. With the introduction of CU/DU re-split and NGFI concept, it should be clarified that the deployment location and form factor of CU/DU, aligned with the deployment strategy of core network.

The RF & Antenna system should support the frequency C band, and up to 100MHz signal bandwidth per NR carrier. The number of antenna ports is up to 64T/64R. Broadcast channel (or common control channel) can support beam sweeping by TDM mode. Data channel supports multi-beam transmission. The dynamic range of vertical and horizontal beam sweeping is configurable to support various scenarios. The minimum requirement for transmitter transient period shall be shorter than 10 us. After antenna calibration, the amplitude error is less than 0.5 dB and the phase error is less than 5 degrees.

### 4.3 Capacity solution

Compared with LTE, NR capacity or spectrum efficiency is enhanced by virtue of various advanced features especially from PHY layer design.

- Higher spectrum utilization via new waveform design with better time-domain or frequency-domain filter if it's necessary;
- Higher ratio of available data resources via new channel and signal design with lower overhead of reference signals and control channels.
  - No need of LTE CRS-like fixed wideband RS transmission
  - Multiplexing of control and data in frequency domain is allowed
  - Multiplexing of DMRS and data in frequency domain is allowed
- Lower overhead of broadcasting channel and control channel via better support of wideband operation
  - NR supports larger bandwidth for a single carrier which reduces the need of aggregation of multiple small carriers. Then the overhead of broadcasting channel and control channel in each aggregated carriers is saved.
  - Also the guard bands between neighboring aggregated carriers are saved.
- More reliable channel coding schemes for both data and control
  - Polar code is used for PBCH and control channels

- LDPC code is used for data transmission where higher-coding-rate MCS is supported
- More orthogonal layers are supported for MU MIMO transmission
  - NR supports 12 orthogonal layers and LTE only supports 4 orthogonal layers (plus 4 non-orthogonal layers)
  - NR could further increase the spatial streams via non-orthogonal-layer design.
- More accurate SRS measurement and CSI feedback as well as finer codebook indication schemes are introduced
  - This significantly improves the precoding performance
- More efficient HARQ scheme via CBG-based retransmission instead of TB-based retransmission
  - This reduces the overhead of retransmission since only partial TB is retransmitted
- More flexible cooperation among TRPs
  - This is especially suitable to improve the cell-edge performance

By integrating the above benefits, NR capacity (bps/Hz) is expected to be as high as 3X over LTE. With the cooperation between GTI partners, we have got encouraging trial results of capacity. The trial results are close to requirements defined in GTI PoC white paper, where scheduling algorithms and system capacity for 5G prototypes still have room for improvement.

<b>Trial Item</b>	<b>Max. DL stream / UE</b>	<b>Modulation</b>	<b>Theoretical Throughput</b>	<b>Trial Result</b>
<b>DL user peak Throughput</b>	4	256QAM	1.36Gbps	1.22Gbps
<b>DL user peak Throughput</b>	8	64QAM	2.10Gbps	1.86Gbps

Table 1 Example of NR DL user peak throughput test result

<b>Trial Item</b>	<b>Max. Layers</b>	<b>Modulation</b>	<b>Theoretical Throughput</b>	<b>Trial Result</b>
<b>DL Cell peak Throughput</b>	24	64QAM	6.24Gbps	5.91Gbps

Table 2 Example of NR DL cell peak throughput test result

Note: More details of trial results and test conditions could be found from the document at 20<sup>th</sup> GTI Workshop.

## 4.4 Coverage solution

Similar as capacity, NR coverage is also enhanced by virtue of several advanced features such as:

- Beam-based transmission for control and data via DMRS-based channel estimation is the most important feature for coverage enhancement.
  - The beamforming directional gain is in proportion to the number of array antennas.
- Different beam shaping for multiple SS\_block should be supported, for high building scenario, multiple beams in vertical need to support and multiple beams in horizontal could be considered support; for low building scenario, use one beam to cover vertical area and use more beams to cover horizontal area could be considered.
- Both DL and UL data repetition transmission can be scheduled to span one or multiple slots
  - Repetition transmission is most suitable to improve the coverage especially for uplink voice traffic
- Long PUCCH can be transmitted over up to 8 slots which is very suitable to the extreme coverage case
- More flexible slot format with varying length of GP supports various coverage ranges.
- For DL control channels, larger CCE size and aggregation level for DCI payload are defined, and precoder-cycling transmission in frequency domain helps to exploit the diversity gain.
- For initial access, there is an association between an SS block and RACH resources from which network can derive the best transmit beam(s) based on the RACH resource.
  - Initial access benefits from directional transmission
- For uplink data transmission,  $\pi/2$ -bpsk DFT-s-OFDM waveform are supported
  - Lower MCS and better PAPR result in larger uplink coverage
- Paging range is enhanced via beam-sweeping-based transmission
- For a given data rate requirement, lower overhead in NR various channel and signal design, e.g., control channel, DMRS signals, etc means lower code rate, thus better coverage is achieved without degrades the target BLER.
- SUL could also be considered to enhance UL coverage of C-Band if less pathloss and penetration.

Therefore, NR coverage for both data and control channels are expected to be significantly enhanced to compensate the pathloss weakness in higher frequency bands. In the field trial to compare the coverage between 3.5GHz NR and 2.6GHz TD-LTE, the trial results show some gain of throughput in cell edge, as well as high penetration scenario of outdoor to indoor.

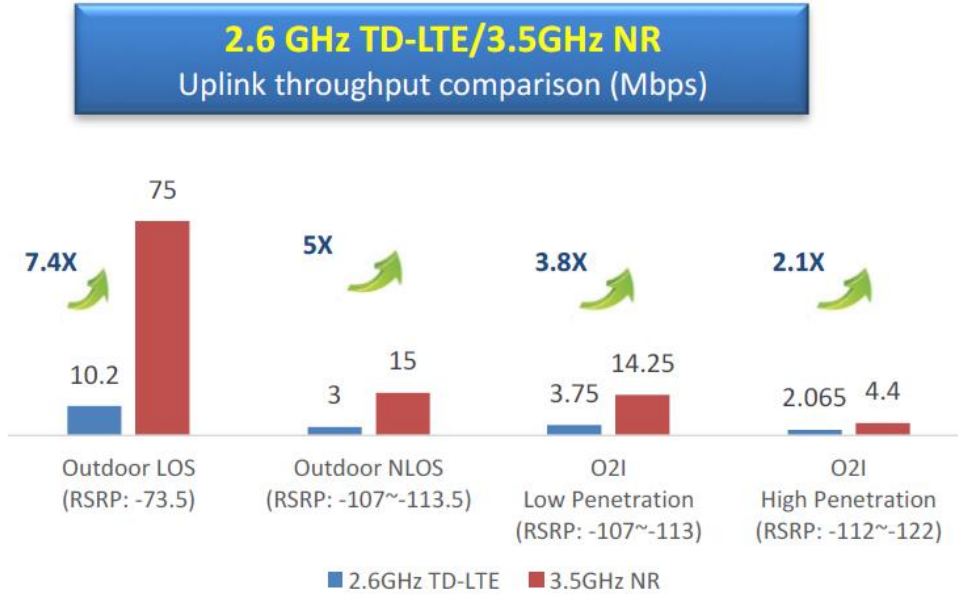


Figure 14 Example of NR Coverage Trial result

Test condition:

2.6GHz: BS (8TRx, 20 MHz, 40W), Device (1T2R 23dBm)

3.5GHz: BS (64 TRx, 100MHz, 200W, PDCCH with power boost), Device (2T4R 26dBm)

## 4.5 Mobility solution

### For NSA Mobility Solution:

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.

When UE moves from serving secondary cell to another cell in same Secondary Node, secondary cell group can be changed modified without data interruption. Secondary Node Modification procedure can be applied to perform this intra Secondary Node mobility. The Secondary Node Modification procedure may be initiated either by the MN or by the SN based on the measurement results and be used to modify, establish or release bearer contexts, to transfer bearer contexts to and from the SN or to modify other

properties of the UE context within the same SN. MN initiated SN Modification/, SN initiated SN Modification with MN involvement/ and SN initiated SN Modification without MN involvement should be supported. In case the SRB3 is configured by SN, the SN is able to perform intra SN mobility with SCG reconfiguration message transmission to UE directly via SRB3.

When UE moves from serving secondary cell to another cell belonging to different Secondary Node, secondary cell group can be changed without data interruption with key refresh. Secondary Node Change procedure can be applied to perform inter Secondary Node mobility.; The Secondary Node Change procedure is initiated either by MN or SN and used to transfer a UE context from a source SN to a target SN and to change the SCG configuration in UE from one SN to another. MN initiated SN Change and/ SN initiated SN Change should be supported. Secondary Node change always involves signaling over MCG SRB towards the UE.

When UE moves from serving master cell to another cell belonging to different Master node, Inter-Master Node handover with/without Secondary Node Change procedure should be applied. Inter-Master Node handover with/without MN initiated Secondary Node change is used to transfer context data from a source MN to a target MN while the context at the SN is kept or moved to another SN. During an Inter-Master Node handover, the target MN decides whether to keep or change the SN. In case the target Master Node decides to release the SN, the Master Node to eNB Change procedure should be applied. In case in the source eNB, there is no Secondary Node configured and the target eNB decides to add Secondary Node for the UE during the handover procedure, the eNB to Master Node change should be applied. Inter-Master Node handover with/without Secondary Node change, Master Node to eNB change and eNB to Master Node change should be supported.

When UE moves out the serving Secondary Node coverage and no other potential Secondary Node available, the Secondary Node can be released using the Secondary Node Release procedure. Secondary Node release procedure can be initiated either by Master Node or Secondary Node and is used to initiate the release of the UE context at the SN. Master Node initiated Secondary Node Release and Secondary Node initiated Secondary Node Release should be supported.

#### **For SA Mobility Solution:**

Interruption and reliability are two important features for mobile network, especially considering various new services, e.g. industrial automation/control, drone, remote control and etc. 0ms mobility interruption is required by IMT-2020, and it is the essential goal to be achieved. Enhanced mobility solutions such as RACH-less and Make Before Break(MBB) can reduce the interruption to some extent in some special scenarios, generally, RACH-less handover is applied only when the TA value of the target cell is zero or equals to the TA value of the source cell, and MBB is only applicable for the intra-frequency scenario. For low implementation complexity, one uniform solution should be supported for all scenarios.



Simultaneous transmission/reception with the source cell and target cell during handover procedure is the key point to realize the absolute 0ms interruption, dual connectivity based handover is one proper solution since DC is maturely deployed in realistic network, and expanding DC based scheme into mobility has minimal impact. Besides interruption reduction, DC based handover can also reduce packet loss and handover failure rate since target cell is prepared in advance and L2 handling is avoided during handover. Split SRB can be applied to improve the signaling reliability, e.g. handover command, and decrease the handover failure rate.

**For CloudRAN Mobility Solution:**

When the UE moves from one gNB-CU to another gNB-CU, inter-gNB handover procedure should be supported.

When the UE moves from one gNB-DU to another gNB-DU within the same gNB-CU, the source gNB-DU sends an Uplink RRC Transfer message to the gNB-CU to convey the received Measurement Report from the UE, then the gNB-CU performs UE Context Setup procedure with the target gNB-DU. After receiving an UE Context Setup Response message, the gNB-CU sends a UE Context Modification Request message to the source gNB-DU, which includes a generated RRCConnectionReconfiguration message, and the source gNB-DU forwards the received RRCConnectionReconfiguration to the UE. When the UE performs random access procedure towards the target gNB-DU successfully, the UE responds to the target gNB-DU with an RRCConnectionReconfigurationComplete message. Finally, UE Context Release procedure would be performed between the gNB-CU and the source gNB-DU.

When the UE moves from one cell to another cell within the same gNB-DU, UE Context Modification (gNB-CU initiated) procedure should be supported.

## 5 Summary

GTI Sub-6GHz 5G Radio Access Network Whitepaper targets enhanced Mobile Broadband (eMBB) scenario for Sub-6GHz. This document is conducted to be the technical references for the development of 5G RAN and the basis for the 5G pre-commercial and commercial products specs. According to the progress of 3GPP 5G NR standardization and the findings from the development and trials, there will be more key issues need to be discussed in the updated version of this Whitepaper in the next step.