SAMSUNG

Technical White Paper

# Dynamic Spectrum Sharing

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# Introduction

The 5G system supports a wide range of services such as enhanced mobile broadband (eMBB), ultra-reliable low-latency communications (URLLC), and massive machine type communications (mMTC). Compared to its predecessor, 5G technology provides its users with enhanced experiences through faster data speeds, higher capacity, lower latency, and higher reliability. To arrive at such benefits without any disruption, service providers must find a seamless transition path from 4G long-term evolution (LTE) to 5G new radio (NR). However, newly released frequency bands for use in 5G deployments – such as the C-band (3-5 GHz) and millimeter wave (mmWave) band (24-40 GHz) – are higher than the current 4G frequency bands that sit below 3 GHz. This implies that while deploying 5G on the high frequencies with wider bandwidth may yield higher data rates, doing so will be inherently disadvantageous in terms of coverage due to the large amount of signal loss via propagation and penetration. A lower frequency spectrum, on the other hand, is favorable for 5G deployment, in that it provides a wide-area coverage. Therefore, for smooth transition, it is pivotal to deploy 5G in the lower frequency bands, which are mostly occupied by 4G frequencies

To this end, spectrum re-farming is the most logical and straightforward approach. As such, prior to 4G, spectrum re-farming was the conventional choice when transitioning from one communication generation to the next. Spectrum re-farming is done by draining all previous generation users from a frequency band and re-utilizing the same frequency band for next generation users. Re-farming is usually carried out at carrier levels, where a gradual reduction is made in the number of previous generation users, followed by a subsequent increase in the number of next generation users. For example, in Figure 1, in the second diagram from the left, a single LTE carrier is replaced with an NR spectrum to provide services to a few new NR users. As the number of NR users increases, more LTE carriers are replaced by NR carriers until the entirety of the frequency band is occupied by NR carriers and used for NR purposes.

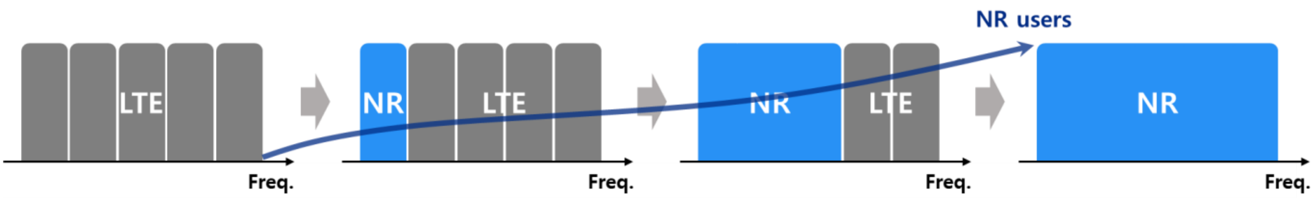


**Figure 1. Spectrum re-framing as NR growth**

Today, 4G services dominate most of the communications market and this trend is expected to continue for several years to come. At the early stages of 5G commercial deployment, LTE users outnumber NR users in a given network; therefore, allocating LTE carrier spectrums only for a small number of NR users significantly hinders LTE users.

Against this backdrop, LTE-NR spectrum sharing emerges as a technology that allows service providers to deploy LTE and NR in the same carriers and bands. That is to say, spectrum sharing enables both LTE and NR to be simultaneously deployed and share resources in the carrier, as shown in Figure 2. The time-frequency resources in the carrier are dynamically assigned to either LTE or NR according to their respective traffic demands. This dynamic allocation is known as dynamic spectrum sharing (DSS). In an early NR market, DSS is advantageous in that it allocates only the required amount of time-frequency resources to the few NR users, and reserves the remaining resources for LTE services. Over time, as the number of NR users increases, DSS accordingly allocates the required resources for NR purposes. In turn, this flexible spectrum sharing solution allows for a smooth 5G migration.


**Figure 2. LTE-NR spectrum sharing**

Considering the aforementioned reasons, DSS appears to be a promising technology that enables the coexistence of multiple radio access technologies and the utilization of low frequency band for NR – all the while eliminating the need for new spectrum allocation for 5G. However, DSS comes with its share of concerns that raises the question of whether or not it is worth incorporating the dynamic solution as a migration tool from LTE to NR.

In this paper, the overall benefits of DSS are presented. In addition, 3GPP standard functions that deal with the coexistence of LTE and NR – as well as the implications, design principles, and side effects that they dictate – are introduced. Lastly, the considerations, performance degrading factors, and concerns associated with DSS are discussed.

# DSS Overview

The primary advantage of DSS is that a smooth migration from LTE to NR is possible, along with the following key aspects.

Rapid deployment of 5G services using existing based deployment

Co-existence of LTE devices and standalone (SA) NR devices

Effective utilization of valuable low/mid band spectrum

- DSS enables network operators to simultaneously use a single legacy LTE carrier for both LTE and NR services,
- without the need for spectrum re-farming. To achieve simultaneous and high spectrum utilization, resources
- are dynamically coordinated between LTE and NR according to the change in LTE and NR traffic load. In addition, the issue of limited coverage that rises from deploying NR on mmWave or mid-band spectrum can be compensated for, by implementing DSS on low-band carriers and aggregating the low-band carrier with the higher band carrier.

## Coverage Benefit through Spectrum Sharing

In NR, services that require high-speed and high-capacity utilize frequency bands that are largely divided into three categories. The first is a low frequency band that sits below 3 GHz, which is primarily occupied by LTE services. This portion of the frequency band is mostly operated in a frequency division duplex (FDD) method. Next, there is the mid frequency band (mid-band) from 3 GHz to 5 GHz. Last, the mmWave frequency band (mmWave-band) is located between 24-40 GHz. Both the mid-band and mmWave-bands are operated by time division duplex (TDD).

In general, NR is co-deployed in LTE sites and reuses existing LTE infrastructure. In this scenario, if the NR were to only utilize the mid-band TDD carriers (since the low bands would be reserved for LTE use), it would have larger propagation and penetration losses, compared to when using low-band FDD carriers. This physical limitation of the mid-band frequency inevitably reduces its coverage, especially in the uplink (UL) transmission, resulting in coverage holes. Figure 3 depicts the coverage holes that would exist in the hypothetical situation mentioned previously, where NR is operated on mid-band only. The indoor coverage hole is a direct result of penetration loss found in mid-band frequency. It is also important to note that coverage reduction is much more increased in mmWave-band TDD carriers.

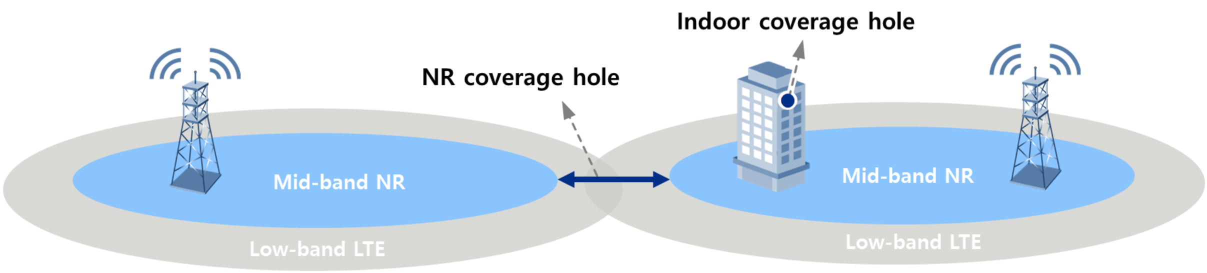


Figure 3. Coverage hole of mid-band NR

As a remedy to this shortcoming, mobile network operators need to secure additional low-band NR carriers or coverage densification solutions. Figure 4 depicts the extension in NR coverage that results from deploying NR on the low-band. As depicted by the first parabola, deploying SA NR on either mmWave-band or mid-band TDD alone garners the smallest UL coverage. However, if an operator had LTE deployed on low-band FDD, the operator could then deploy NR on either mmWave-band or mid-band TDD to utilize E-UTRA new radio-dual connectivity (EN-DC) and schedule NR UL data on the low–band as well, which in turn would extend NR coverage to Region 1 (second parabola). The operator can further enhance its coverage by utilizing LTE carrier aggregation (CA) on low-band FDD to enable UL control signaling on the FDD carrier as well, and extend coverage to Region 2. In the low-band NR carrier, NR SA operations can reap coverage extension benefits up to Region 3 due to the low frequency bands ability to capture wide coverage area.

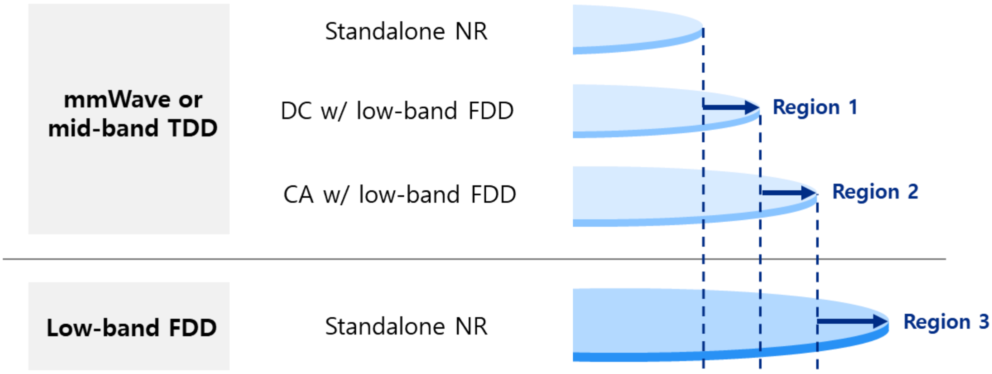


**Figure 4. Coverage extensions in different deployment scenarios**

Figure 4 shows that the mid-band coverage can be extended through DC and CA, but the coverage is still worse than that of deploying in the low-band. Particularly, if the mid-band cannot be secured as a new frequency band for NR deployment and only the mmWave-band can be used, the coverage difference is significantly increased. Therefore, the use of low-band carriers for NR services is suitable for network operators that do not have mid-band NR carriers or cannot secure sufficient coverage using only the mid-band. If all existing low-band carriers are reserved for LTE and is thus difficult to re-farm for NR services, then sharing a low-band spectrum between LTE and NR through DSS can be used to expand coverage of NR.

## Flexible Band Utilization for NR Traffic

DSS provides flexible resource management that corresponds accordingly to NR UE penetration and NR traffic demand, resulting in high spectrum utilization. Figure 5 shows the changes in LTE and NR traffic as the demand for NR gradually increases, and more importantly, how the spectrum would be utilized under re-farming and DSS scenarios.

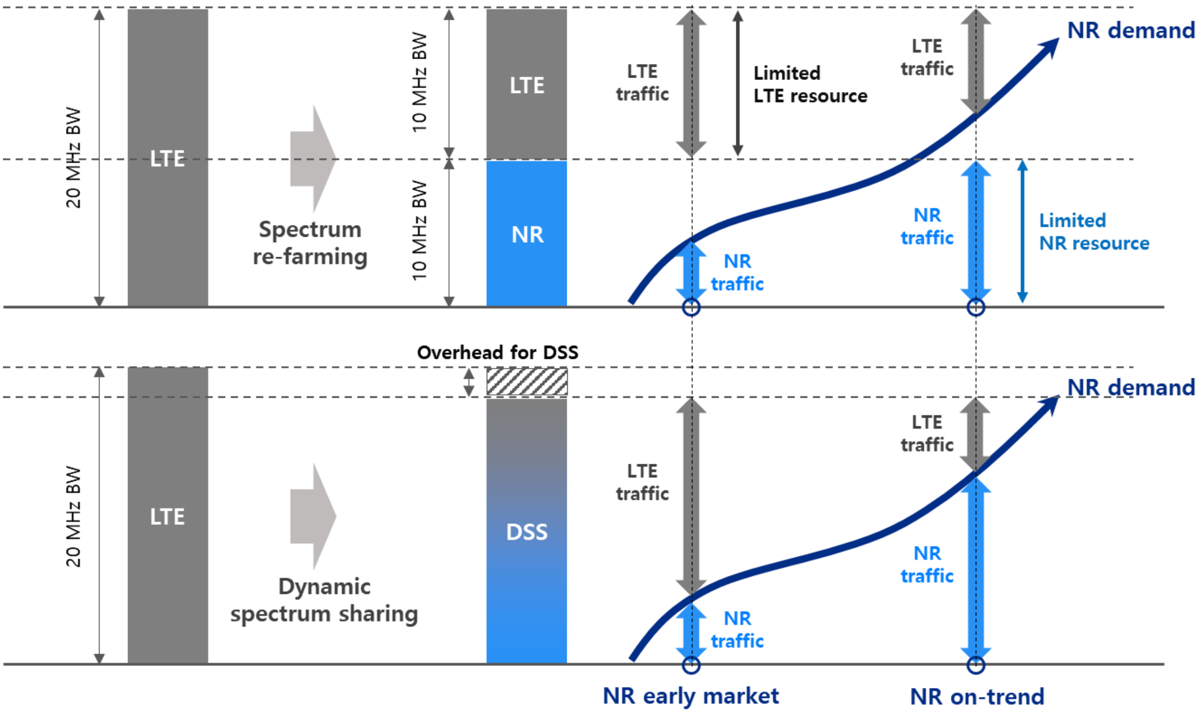


**Figure 5. DSS and spectrum re-farming as NR demand increase**

In early NR market, traffic demand of NR may not be explosive enough to require all of the available resources from the re-farmed band. Therefore, this can lead to underutilization of resources in the re-farmed band that could otherwise be used for LTE traffic. This is to say that so long as LTE traffic dominates the market, some resources will be left unused. On the other hand, when demand for NR surpasses that of LTE, in a re-farming scenario, there will be insufficient NR resources to handle all the NR traffic demand while some resources allocated to LTE will be left idle as LTE traffic demand subsides.

DSS overcomes this setback by dynamically allocating resources according to traffic demands between LTE and NR across the entire band. To enable this feature, LTE and NR schedulers must coordinate with each other in order to interchange traffic status or resource sharing status, as well as dynamically assign available resources in a synchronized manner. Through sophisticated coordination between schedulers, LTE resource allocation increases and NR resource allocation decreases when LTE traffic peaks; and vice versa when NR traffic peaks. This enables dynamic resource allocation for instantaneous NR traffic bursts that may occur even in early NR markets (Figure 6), as well as for the steady increase in NR demand over time as NR takes mainstream.

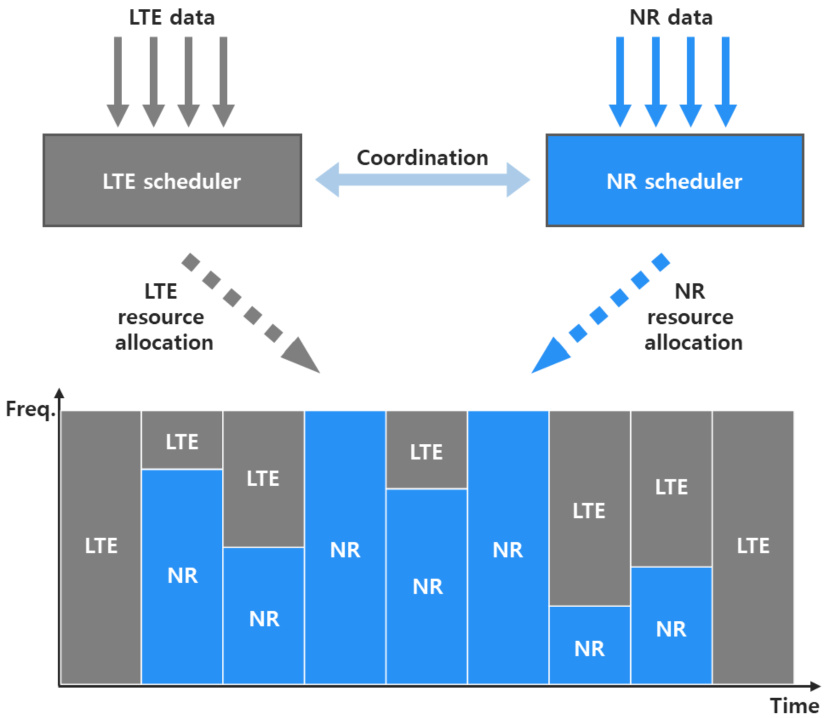


**Figure 6. An example of instantaneous dynamic resource allocation using DSS**

It is worth noting, however, that an inherent resource overhead exists in DSS operation, as shown by the rectangle with oblique lines in Figure 5. Though the dynamic switching is a key benefit in DSS, it does incur an operational deficiency that reduces the total available capacity of the band. Such impact of DSS overhead, as well as other considerations will be discussed in other sections of this paper.

# 3GPP Standards for DSS

Motivated by demand for LTE-NR spectrum sharing, the 3rd generation partnership project (3GPP) considered everything from basic numerology to efficient data multiplexing framework that would enable spectrum sharing in designing the NR. In this section, the specifications that enable DSS are introduced.

## LTE-NR Co-Existence Support in 3GPP Release 15

Initially, the NR adopted the orthogonal frequency division multiplexing (OFDM) waveform as its baseline, with the basic numerology of 15 kHz sub-carrier spacing (SCS) support (scalable by power of 2), which was compatible with the waveform and numerology of LTE. This enabled a highly aligned resource grid structure between LTE and NR, providing a fundamental basis to support LTE-NR co-existence.

Moreover, to support the efficient co-existence between LTE and NR, the following requirements were described in the NR standardization [1].

- Support co-existence of LTE UL and NR UL within the bandwidth of an LTE component carrier and co-existence of LTE DL and NR DL within the bandwidth of an LTE component carrier, and identify and specify at least one NR band/LTE-NR band combination for this operation
- Minimize impact to NR physical layer design to enable this co-existence
- No impact to the ability of legacy LTE devices to operate on the LTE carrier co-existing with NR
- No implication that all user equipments (UEs) have to support simultaneous connection of NR and LTE in the bandwidth of an LTE component carrier

It is noted that the term 'NR-LTE co-existence' was initially used and later also called 'LTE-NR spectrum sharing'. Hereafter, it is assumed that the terms 'NR-LTE (or LTE-NR) co-existence' and 'LTE-NR spectrum sharing' both mean that LTE and NR share the same carrier, and can be used interchangeably.

In NR Release 15 (Rel-15), the following functions are described as necessary for supporting LTE-NR co-existence in FDD bands.

### NR 100 kHz channel raster for FDD bands

Any existing LTE FDD bands should be redefined for NR, as to allow the LTE and NR to share the same band. The channel raster defines a subset of reference frequencies that can be used to identify the radio frequency (RF) channel position in the UL and downlink (DL). The reference frequency for an RF channel maps to a resource element on the carrier. With the same 100 kHz channel raster (as in LTE), NR carrier can be deployed co-existent in the LTE carrier (same RF channel and center alignment as shown in Figure 7) [2].

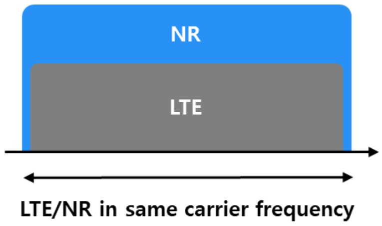


Figure 7. NR carrier co-existence with LTE carrier in the same RF channel

## Optional NR UL 7.5kHz shift for FDD bands

Orthogonal frequency division multiple access (OFDMA) which is the multiple access method adopted in LTE DL has a disadvantage of high peak to average power ratio (PAPR) despite of its benefits. A high PAPR means that power consumption is high, so the LTE UEs do not use OFDMA as their UL transmission but use a modified waveform named single carrier frequency division multiple access (SC-FDMA). Due to the use of only SC-FDMA, the channel raster of LTE UL is shifted by 7.5 kHz compared to DL.

In UL of NR, on the other hand, it was determined to use not only SD-FDMA but also general OFDMA, which does not require the 7.5 kHz shift, according to the use cases. Therefore, in UL of NR, optional 7.5 kHz channel raster shift is supported to ensure that NR UL grid is aligned with LTE UL gird in an orthogonal manner based on OFDM waveform, as shown in Figure 8 [2].

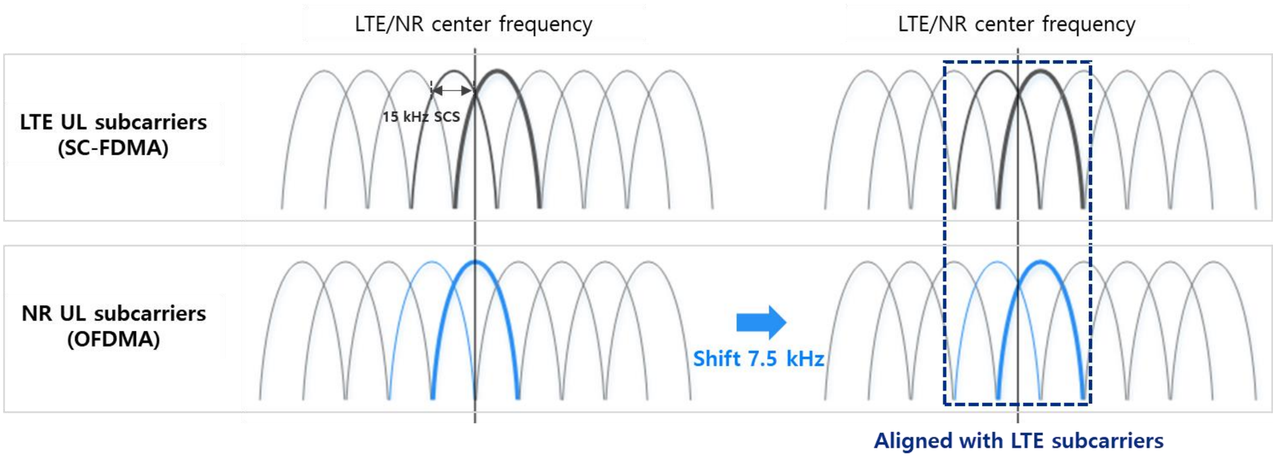


Figure 8. NR UL 7.5 kHz shift to align with LTE UL grid

## NR PDSCH with rate matching of LTE CRS

Cell-specific reference signal (CRS) is the most basic reference signal in LTE DL, and in order for NR transmission not to affect the existing LTE transmission, CRS should be avoided when allocating NR resources. Rate matching in physical downlink shared channel (PDSCH) is a baseband processing, and its basic function is to match the number of bits in transport block to the number of bits that can be transmitted in the given resource [3]. The rate matching enables data transmission of NR (i.e. NR PDSCH) to be allocated only to time-frequency resources where LTE CRS is not located. That is the most important feature of LTE-NR coexistence in the DL, because how the NR performs efficient data transmission by avoiding LTE always-on signal is the key operation.

CRS-related information, such as the number of CRS ports, CRS location, and LTE bandwidth is signaled to NR UEs for CRS rate matching via radio resource control (RRC) configuration [4]. Examples of NR PDSCH with CRS rate matching are shown in Figure 9.

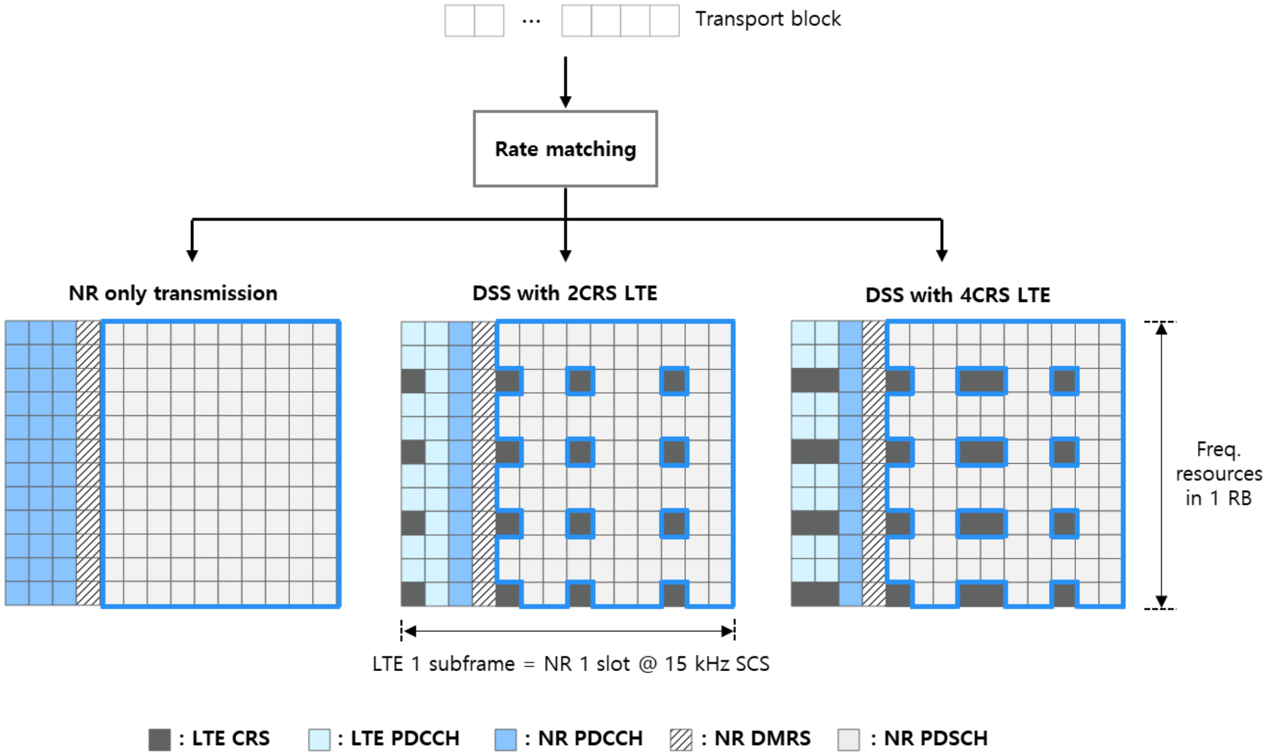


**Figure 9. Examples of NR PDSCH with CRS rate matching**

## NR PDSCH alternative additional DMRS symbol location

In NR PDSCH, when as additional demodulation reference signal (DMRS) symbol is configured, the symbol can be located in the 12$^{th}$ symbol of the slot, i.e., the same as the last symbol location for LTE CRS in a subframe. To support LTE-NR co-existence, an alternative additional DMRS symbol location is defined to avoid LTE CRS, by shifting to the 13$^{th}$ symbol [5]. Figure 10 shows a case that the additional DMRS symbol is shifted to the 13$^{th}$ symbol in the LTE 2CRS port configuration.

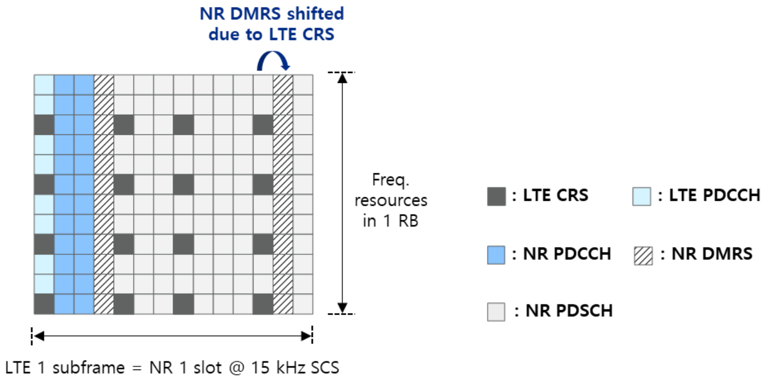


**Figure 10. NR PDSCH alternative additional DMRS symbol location**

## NR flexible CORESET/PDCCH resource configuration

NR control resource set (CORESET) carrying NR DL control data, i.e. physical downlink control channel (PDCCH), can be configured in terms of resource blocks (RBs) and symbols, which can be utilized in LTE-NR co-existence. For NR UEs, it is only mandatory to support CORESET configuration within the first three OFDM symbols. Assuming that UEs are only capable of this basic CORESET configuration, the first 3 OFDM symbols need to be divided into LTE PDCCH and NR PDCCH symbols. In Figure 9, NR PDCCH can be located in the 2$^{nd}$ and/or 3$^{rd}$ symbol, so long as it doesn't overlap with the CRS.

As an optional feature, NR CORESET with up to three contiguous symbols can be configured beyond the first three OFDM symbols, which relaxes the limitation that LTE and NR PDCCH should share the first three OFDM symbols and hence provides more PDCCH capacity to both LTE and NR.

# Enhancement in 3GPP Release 16 and Release 17

After standardization of Rel-15, several changes were made and a number of potential enhancements were identified. Eventually, they have been discussed and written in Release 16 (Rel-16) and Rel-17 of the 3GPP specification. In this section, the additional features for spectrum sharing approved in Rel-16 are described. In addition, further enhancements proposed for DSS in Rel-17 are also considered.

## Multiple CRS rate matching patterns in an NR carrier

In Rel-15, LTE CRS rate matching is configured only when NR has a bandwidth of the same size as an LTE carrier component (CC). Assuming that an NR carrier has a larger bandwidth, e.g. 50 MHz, the NR carrier may co-exist with multiple LTE carriers with 10 MHz and 20 MHz(max) bandwidth, as shown in Figure 11. This brings the need of CRS rate matching from multiple LTE CCs. In Rel-16, LTE CRS rate matching patterns are defined for a wideband in which NR bandwidth includes multiple CCs using CA. It was agreed that up to three LTE CRS rate matching patterns can be configured within a NR carrier.

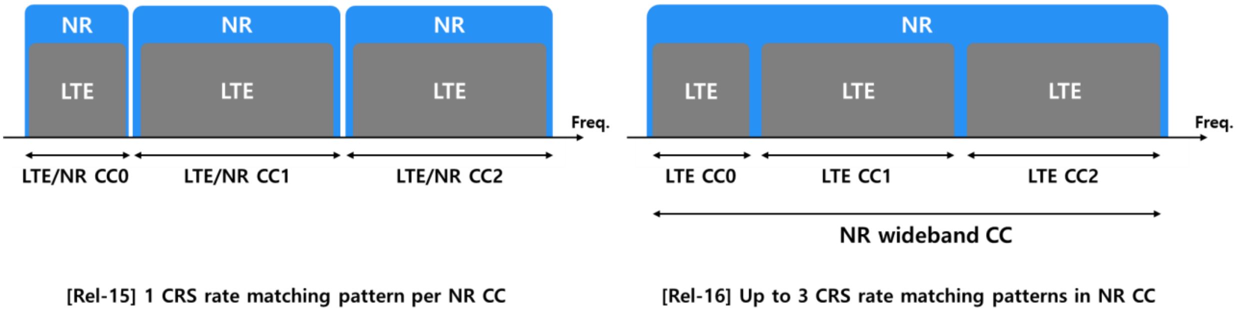


Figure 11. NR carrier with one or multiple CRS rate matching patterns

## Enhancement of PDSCH mapping type B

When PDCCH beyond the first three OFDM symbols are used, PDSCH mapping type B is used. For example, 2-symbol NR PDCCH can be located in the 3rd and 4th symbols as shown in Figure 12. However, in Rel-15, only the cases of 2, 4, and 7 symbol duration were defined for PDSCH mapping type B, which is insufficient, as the possible combinations cannot fully utilize the remaining resources of a slot. The left side in Figure 12 shows an example of resources being unutilized as a result of PDSCH combinations with 2, 4, and 7 symbol length that cannot make 10 symbol length.

In Rel-16, additional symbol length for PDSCH mapping type B is defined, e.g., 10 symbol PDSCH, so that fully utilized transmission is possible as shown in the right side of Figure 12.

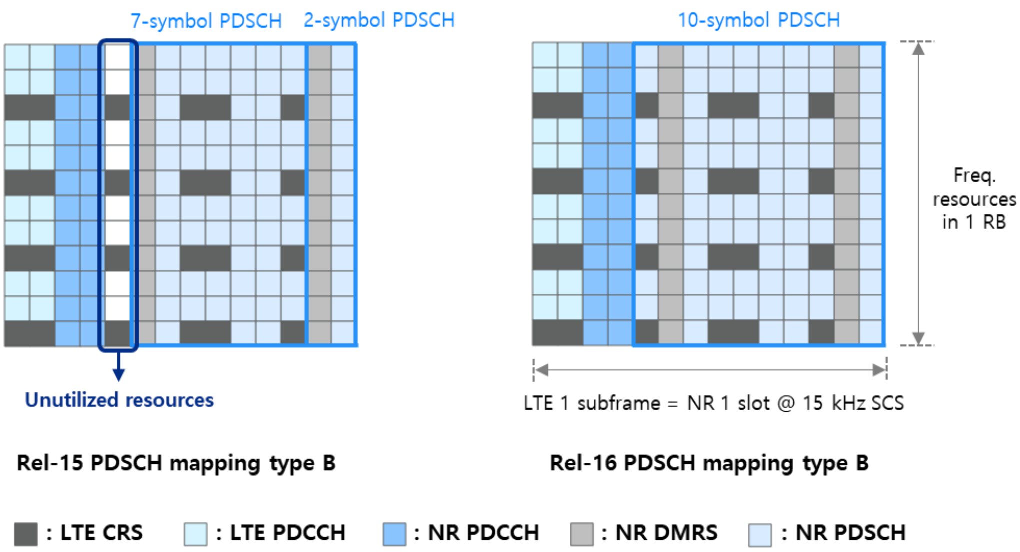


Figure 12. PDCCH beyond first 3 symbols and Rel-16 enhancement of PDSCH mapping type B

## Cross-carrier scheduling

As the number of NR devices in a network increases there are not enough NR scheduling resources in the shared carriers, because the PDCCHs of NR and LTE share limited resources. (The problem due to the sharing of PDCCH symbols will be discussed in more detail in the next section.) Therefore, as a way to increase the scheduling capacity of NR UEs in the shared carrier, cross-carrier scheduling has been discussed in Rel-17. The cross-carrier scheduling, which overcomes the PDCCH resource limitation of NR primary cell (PCell) with the help of secondary cells (SCells), is summarized as follows, and it is illustrated in Figure 13.

- PDCCH of SCell schedules PDSCH or physical uplink shared channel (PUSCH) on P(S)Cell
- PDCCH of P(S)Cell/SCell schedules PDSCH on multiple cells using a single downlink control information (DCI)

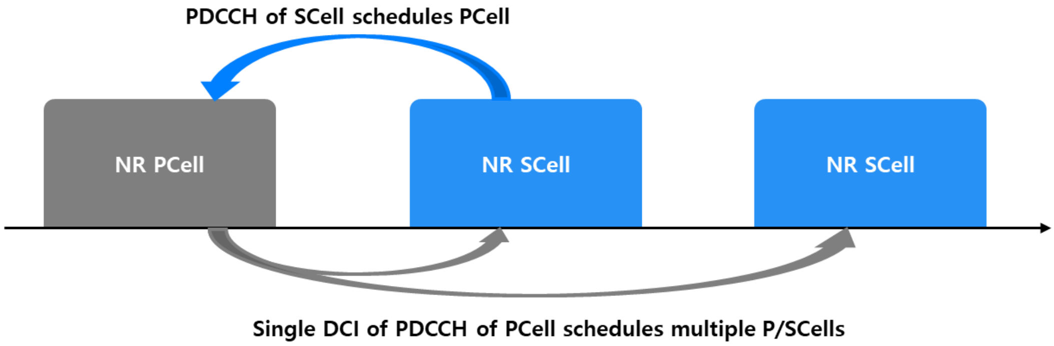


Figure 13. Cross carrier scheduling for improving NR scheduling capacity

# Mid-band TDD DSS

Most of the existing or initial deployment of DSS is low band FDD. However, several of the operators who have already deployed LTE in mid-band have also shown interest in deploying DSS in mid-band, which is mainly TDD.

In 3GPP, UL 7.5 kHz shift is mandatory for FDD and few TDD bands only to resolve interference between 15 kHz SCS NR and LTE operation.

In 3GPP, n41 and TDD bands above 3 GHz doesn't support 100kHz raster size (15 kHz and 30 kHz are supported instead). Hence it is not straight forward to align NR and LTE center frequencies. This limits the deployable frequency for LTE-NR coexistence. In certain scenarios 3GPP have defined a new band for the same TDD frequency range with 15 kHz and 30 kHz raster size.

# DSS Design and Effect

NR standardization defines the features and methods that are necessary for LTE-NR co-existence, as shown in the preceding section. The most crucial factor in LTE-NR co-existence is being able to share the limited resources used for existing LTE systems with the user data and signals required for NR operations, without impacting LTE operation. And to achieve this, considerations on how to place NR signals and channels in time and frequency domain on top of an existing LTE framework should be made. In this section, the principles that need to be followed when designing DSS according to the defined specifications are introduced. Further, the implications and considerations that these principles impose on DSS operation, as compared to the operation of NR or LTE only operation, are also discussed in this chapter.

## NR Broadcast and Signaling Message Transmission

The first consideration to keep in mind when designing for NR-LTE co-existence is supporting NR common signal transmission and initial access procedure while taking into account the LTE frame structure and signal transmission properties. CRS is the basic DL reference signal in LTE. When designing DSS without degrading NR performance, NR signals and channels should be placed in a way that does not overlap with the CRS in the frequency-time resources. By doing so, LTE operation will not be affected when NR operation requires sharing of LTE's resources. In the previous section, rate matching was introduced as a method to avoid CRS. However, during the initial access phase, an NR device does not know whether or not it has accessed a clean NR cell or an LTE-NR shared cell. Therefore, the NR device cannot simply assume any CRS rate matching to avoid LTE CRS.

The NR synchronization signal block (SSB) - the essential broadcast signal that allows NR devices to detect a cell - is a one-shot transmission with a default 20ms cycle when assuming 15 kHz SCS is used for spectrum sharing. To guarantee the necessary detection performance, SSB needs to be transmitted without any collision with legacy LTE signals. The SSB occupies 20 RBs and 4 OFDM symbols, which unfortunately cannot be transmitted in a normal subframe due to the conflict with LTE CRS transmission, as shown in Figure 14. To avoid such collision, SSB can be located in an LTE multicast-broadcast single-frequency network (MBSFN) subframe, which only contains LTE CRS in the LTE control region presented by LTE PDCCH in Figure 14. MBFSN is a legacy LTE functionality which helps regular LTE device to skip (or not to expect CRS) certain subframe pattern as described in the LTE system information messages. DSS can utilize this functionality to use the whole subframe (except the LTE PDCCH region) for NR dedicated use.

Broadcast channels and signaling messages (including SSB) transmitted during the initial access process before the RRC connection setup are specified in Table 1. In an EN-DC non-standalone (NSA) system where LTE serves as the control anchor, SSB and random access response (RAR) transmissions of NR are required, where as in an NR SA system, additional messages such as system information block 1 (SIB1), other system information (OSI), and paging channel are transmitted. Since the LTE CRS rate matching for these signals are not defined for SSB, they have to be transmitted through the LTE MBSFN subframe.

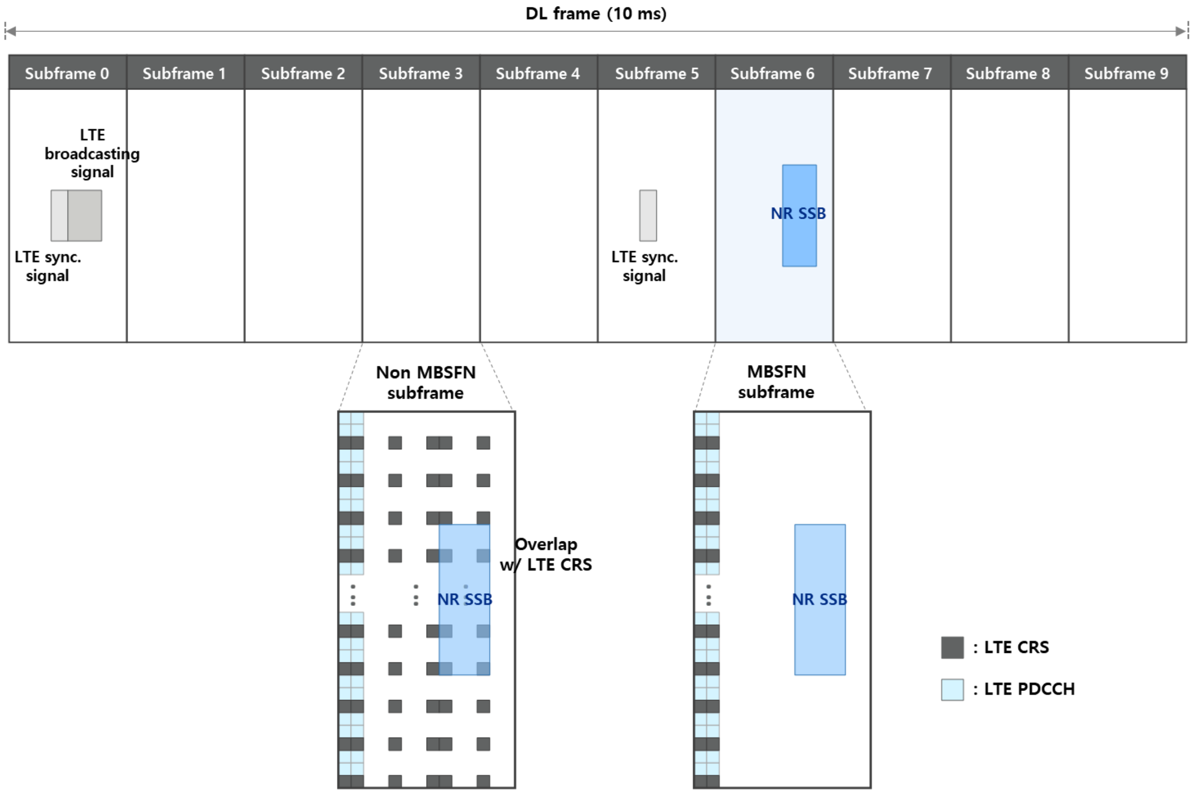


**Figure 14. NR SSB and broadcast signal transmission in MBSFN subframe**

**Table 1. NR broadcast channels or signaling messages**

| Signal/Channel | SA/NSA |
|---|---|
| SSB | SA and NSA |
| RAR | SA and NSA |
| SIB1 | SA |
| OSI | SA |
| Paging | SA |

While the signals above are essential signals that must be transmitted for NR support, they serve as overhead on the LTE system. That is to say, compared to operating a spectrum entirely comprised of LTE, operating DSS on the spectrum requires additional resource allocation for the NR signals.

The signals and channels of Table 1 are transmitted with certain transmission periods defined in the standards. For an EN-DC NSA case, SSB is transmitted every 20ms - that is 2-frame duration and 20-subframe duration as well. The RAR transmission cycle can also be 20ms, assuming that it is the same as the physical random access channel (PRACH) cycle. To reduce unnecessary overhead, RAR transmission can be performed through the MBSFN subframe where the SSB is located. In doing so, only one MBSFN subframe will be required for every 20-

subframe duration. Still, a DSS overhead of 5% will incur. If the network requests these signals with shorter periods, more MBSFN subframes can be required for transmission of the signals, so that leads a larger overhead to LTE transmission.

For a SA NR case, the SIB1, OSI, and paging channel have to be transmitted in the MBSFN subframe, in addition to SSB and RAR - thus causing a greater overhead. Figure 15 shows an example of NR essential signal transmission.

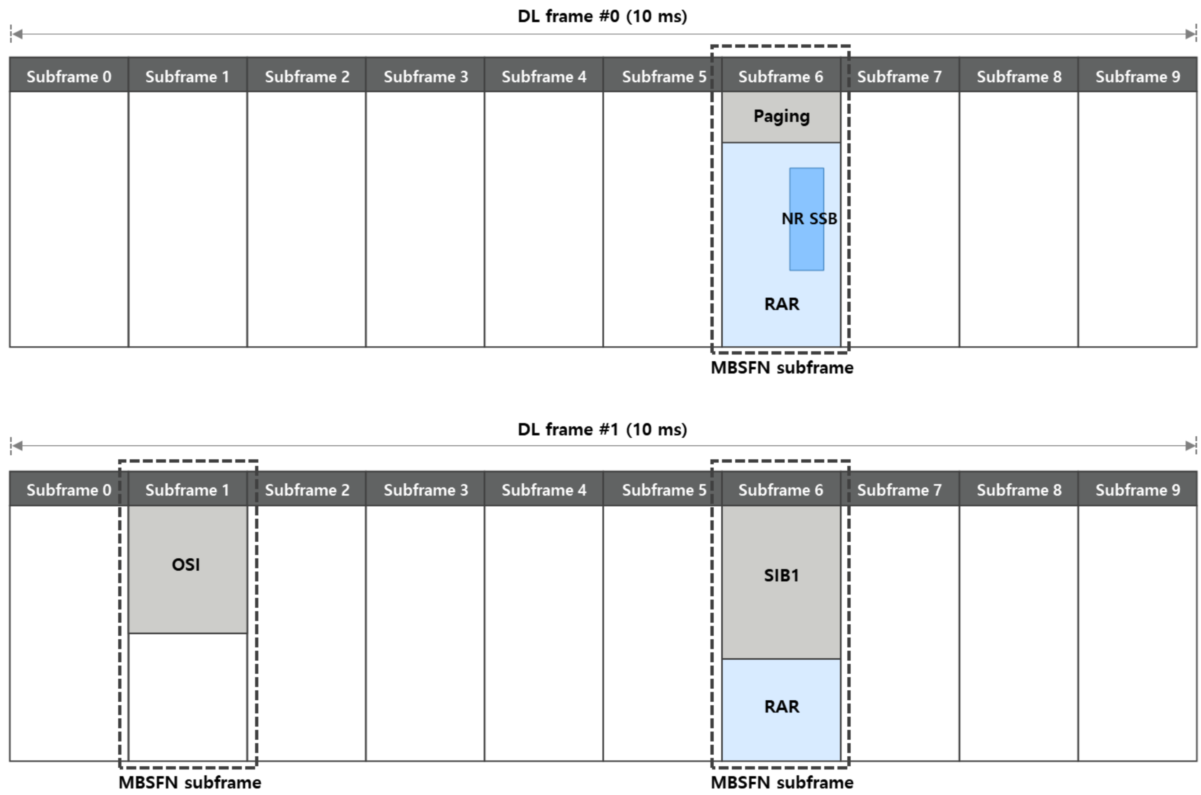


**Figure 15. An example of NR essential signal transmission in MBSFN subframe**

The overhead incurred from the transmission of signals necessary for NR operation is NR minimum overhead even when there is no NR DL transmission, and it causes a loss in DL peak throughput for LTE devices, whereas a LTE-only operation does not impose such loss. Figure 16 shows the expected DL peak throughput degradation of LTE devices in a DSS operation environment for NSA and NR SA systems, respectively. It can be expected that the DL peak throughput would be lower as the more signals required for the NR essential transmission.

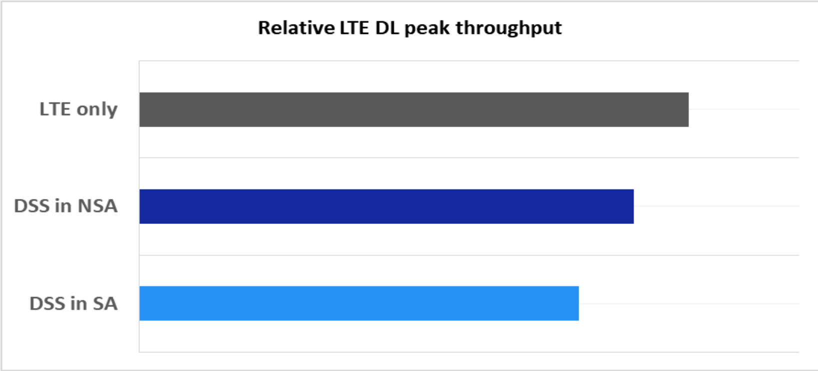


Figure 16. Expected LTE DL peak throughput by NR minimum transmission

## NR DL Control and Data Transmission

In DSS, the resources used for the NR DL control transmission (e.g. PDCCH) should not collide with the resources used for LTE CRS. Given that the PDCCH of NR is very flexible, CORESET configurations can be used as a method to avoid collision with the LTE CRS. Because the specification mandates a UE to monitor the first three OFDM symbols for NR PDCCH, the NR PDCCH may be configured in either one or two symbols, depending on the LTE PDCCH configuration. For example, in the 2CRS port configuration cases, the NR PDCCH can be assigned to the second and third symbols of a slot/subframe, or located across the third symbol, depending on how many symbols are allocated for LTE PDCCH. For the 4CRS port configuration case, the NR PDCCH can be located in the third symbol. Figure 17 depicts the cases in which the NR PDCCH can be allocated on one or two symbols without colliding with LTE CRS.

In case an additional DMRS configuration is required for NR DL data transmission (e.g. PDSCH), the additional DMRS must be shifted to the 13$^{th}$ symbol as to avoid the LTE CRS, as shown in Figure 17. In the MBSFN subframe where CRS does not exist, LTE CRS rate matching is not required for NR PDSCH transmission. However, the additional DMRS, if required at all, must be located in the 13$^{th}$ symbol as to stay in sync with any additional DMRS that may exist in the non-MBSFN subframes.

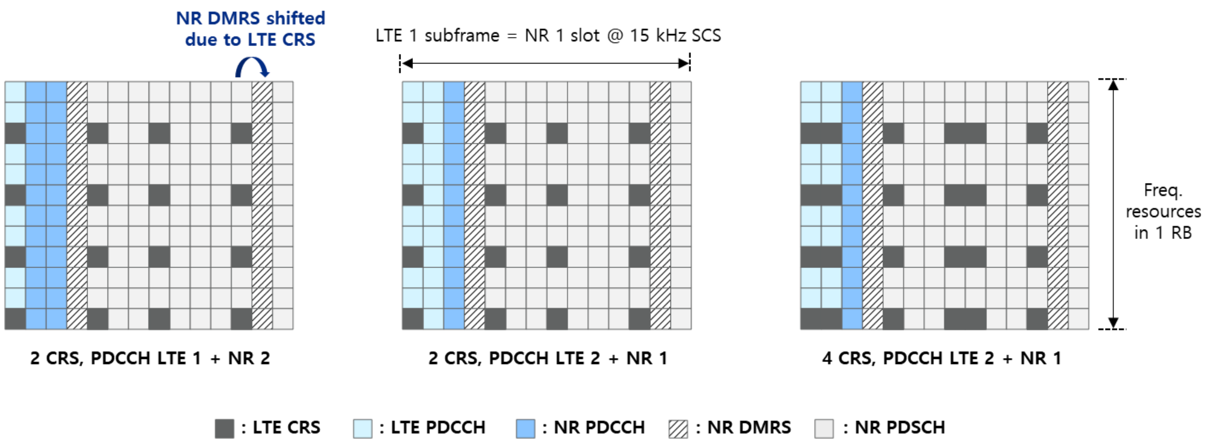


Figure 17. Designs of NR PDCCH and PDSCH transmission

Since both LTE and NR PDCCH share the first three OFDM symbols, the PDCCH capacity in DSS can be somewhat limited compared to that of the capacity in non-DSS, especially for low channel bandwidth case. A PDCCH corresponding to a UE is transmitted on an aggregation of one or several consecutive control channel elements (CCEs). The CCE is a unit of frequency-time resource elements, and the number of CCEs allocated to one PDCCH can be 1-8 according to the PDCCH aggregation level. The aggregation level depends of the channel condition of each UE. For a UE with good channel condition, the aggregation level can be lowered, which requires a small number of resource elements for its control channel. On the other hand, high aggregation level is required for PDCCH of UE with poor channel condition, which leads up to 8 times more resource elements.

As shown in Figure 17, when operating DSS with 4CRS LTE, NR can use only one PDCCH symbol and can intuitively support only one third of UEs compared to the case of non-DSS. In addition, assuming that the number of CCE available for one PDCCH symbol is limited to eight using a small bandwidth, only one UE required the largest aggregation level might be supported. Figure 18(a) briefly shows an example of such a case that only a UE with weak channel needed aggregation level of eight is serviced in network. On the other hand, in NR only transmission, which enables NR to use three symbols for its PDCCH region, it is shown that many other UEs are available to support via being allocated their PDCCH resources, even after allocating PDCCH to the UE with weak channel condition as shown in Figure 18(b).

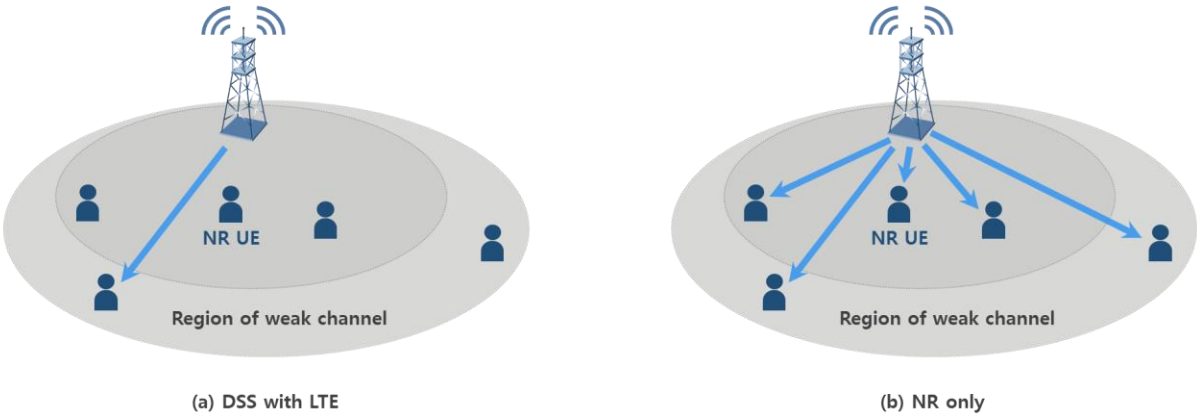


**Figure 18. Limitation of supportable UEs in DSS**

In an early market, the number of NR devices is few and therefore, the PDCCH capacity limitation may not be very critical. However, as NR devices increase over time, the PDCCH capacity limitation can restrain services for the many NR UEs that operate under various channel conditions. As such, PDCCH capacity enhancement features such as optional NR CORESET to configure OFDM symbols beyond the first three symbols may be considered for future implementation by network vendors. With such implementation, the 10-symbol PDSCH mapping type B with shifted DMRS defined in Rel-16 can be used together with the NR CORESET for a more efficient DSS operation.

## NR DL Reference Signal On-Demand Transmission

The NR DL reference signals, including channel state information reference signal (CSI-RS) and tracking reference signal (TRS), are managed to be transmitted with minimum impact to LTE DL transmission. NR CSI-RS can be transmitted in the last symbol in the MBSFN subframe. For TRS, it is periodically transmitted in two consecutive slots to allow UE to track and compensate for variations in time and frequency. To minimize the impact to LTE DL transmission, the NR TRS is transmitted in two slots where there are no essential LTE signal transmission (e.g., subframe 1 and subframe 2) every 20ms or 40ms. When TRS is transmitted, the corresponding RBs containing TRS cannot be used by LTE, while can be used by NR. Therefore, it is desirable to transmit TRS in an on-demand manner hand hence to minimize the impact to LTE when there is no NR UEs. Only if there is connected UEs on the NR cell, the TRS is transmitted.

## LTE Always-on Signal Transmission

The LTE CRS is always transmitted via specific frequency-time resource when the base station is turned on, regardless of the number of connected UEs and network status. As presented in the previous section, NR channels cannot be allocated to the frequency-time resource in which the CRS is located, which means that the CRS becomes an overhead for NR transmission. That is, additional loss occurs in frequency-time resource usage due to DSS with LTE, even when the spectrum is used by NR alone. In addition, the PDCCH of LTE, which is allocated for the purpose of controlling channel symbols, also becomes an overhead for NR transmission.

The locations of the PDCCH and CRS - according to the CRS configuration of LTE for the MBSFN subframe and the normal subframe (non-MBSFN subframe) in a RB - are described in Figure 19. In an MBSFN subframe, for a 4CRS configuration, the LTE CRS and PDCCH occupy 24 out of 168 resource elements. In a non-MBSFN subframe 40 resource elements are required. If one MBSFN subframe is transmitted in one frame, the overhead occupied by the CRS and PDCCH of LTE, as an average of one frame, is around 23%. Similarly, Table 2 shows the overhead on NR transmission due to the use of DSS compared to NR only transmission for the configuration of each CRS and PDCCH, under the assumption that one MBSFN subframe is transmitted in one frame.

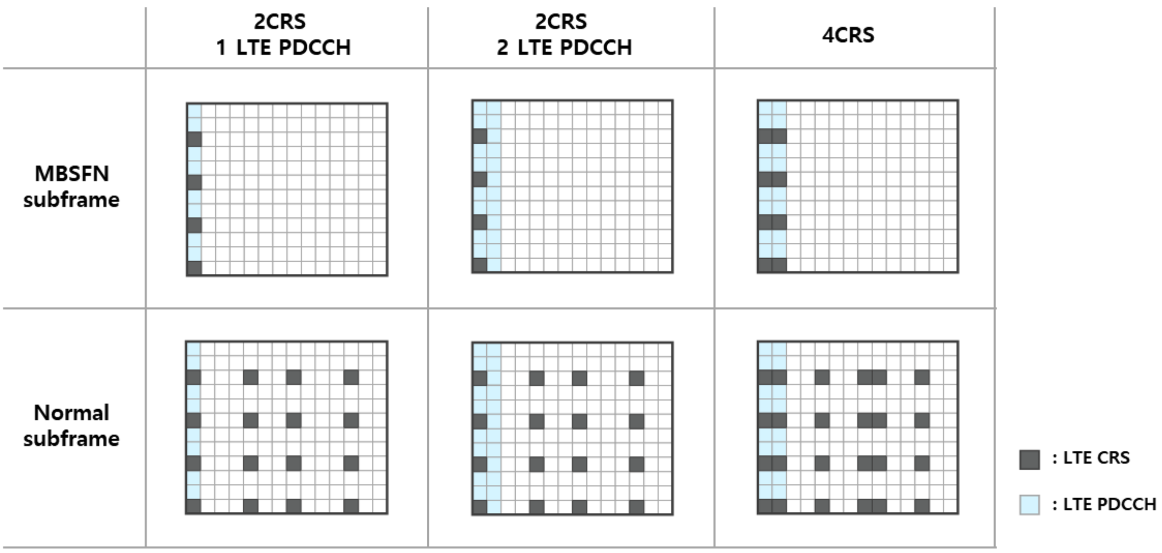

Figure 19. Resource occupancy of LTE CRS and PDCCH

Table 2. NR DL overhead and peak throughput reduction by LTE CRS and PDCCH

| Configuration | Average overhead in a RB |
|---|---|
| 2 CRS, 1 LTE PDCCH | 14% |
| 2 CRS, 2 LTE PDCCH | 21% |
| 4 CRS | 23% |

In addition, the ratio of LTE CRS and PDCCH among the available resources for NR PDSCH affects NR DL peak throughput. Among the three possible (CRS, PDCCH) LTE configurations in DSS, the LTE overhead to NR increases from (2CRS, 1PDCCH) to (2CRS, 2PDCCH) and (4CRS, 2PDCCH). The expected NR DL peak throughput, therefore, might decrease in that order even though the peak throughput is not directly calculated with the overhead alone, as shown in Figure 20.

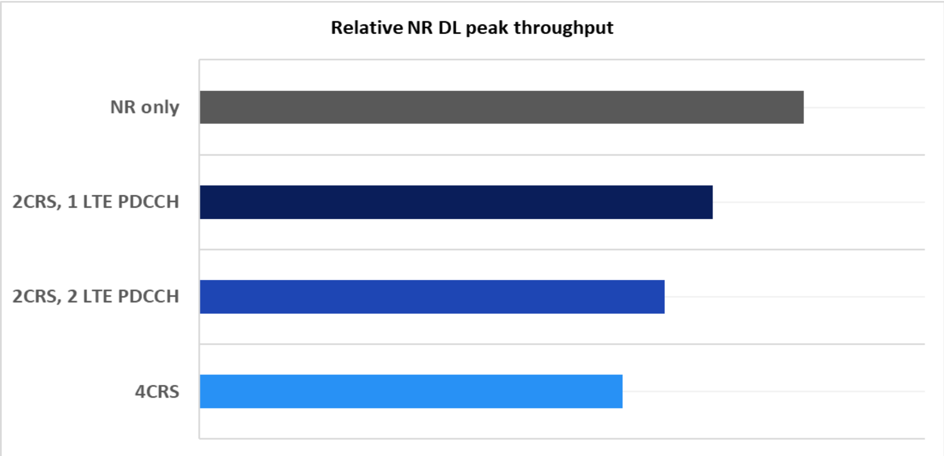


Figure 20. Expected NR DL peak throughput by LTE minimum transmission

In the case of DSS operation, the CRS of LTE may cause additional adjacent cell interference compared to when the network is re-farmed to NR, where there is no interference caused by the CRS. The position of the CRS for each cell can be different in order not to interfere with the CRS. If the CRS position of the neighboring cell is different from that of the serving cell, the neighboring cell's CRS coincides with the serving cell's data, thereby causing CRS interference. This interference is a characteristic of the LTE system as a result of its always-on CRS transmission that would not have occurred if the carrier was entirely replaced with NR.

# Considerations for DSS

## Capacity Aspect

Considering the aforementioned overhead of the DSS, the use of DSS sometimes results in reduction in capacity, despite its flexible spectrum utilization. For instance, if LTE and NR traffic are evenly distributed in the network, an operator may be able to achieve a larger capacity by equally dividing the spectrum into LTE and NR bands and evenly allocating LTE and NR users to their respective spectrums, rather than by operating DSS. If the spectrum is evenly divided, the total capacity simply becomes the sum of the capacities that each system can achieve within its spectrum band. In the case of the DSS spectrum, due to the inevitable overhead caused by the DSS, the total amount of resources that can be allocated to the two systems is reduced. When NR and LTE traffic are similar, the two systems will almost evenly divide the entire resource, so that the capacity is reduced by the ratio of DSS overhead. Likewise, as the traffic demand of the network and the cell loading increase, total cell capacity deteriorates as a result of the DSS overhead.

This deterioration not only degrades total cell capacity but also directly reduces the peak data rate of the NR and LTE UE by affecting the burst-traffic transmission performance. When the frequency band is statically divided into NR and LTE, it is possible to achieve peak data rate by aggregation of NR and LTE carriers, but when using DSS, peak rate deterioration occurs. For example, Figure 21 shows that when a 20 MHz low frequency band is allocated for NR and LTE, 10 MHz each, dual connectivity (DC) of NR and LTE enables possible peak data rate in the entire 20 MHz band.

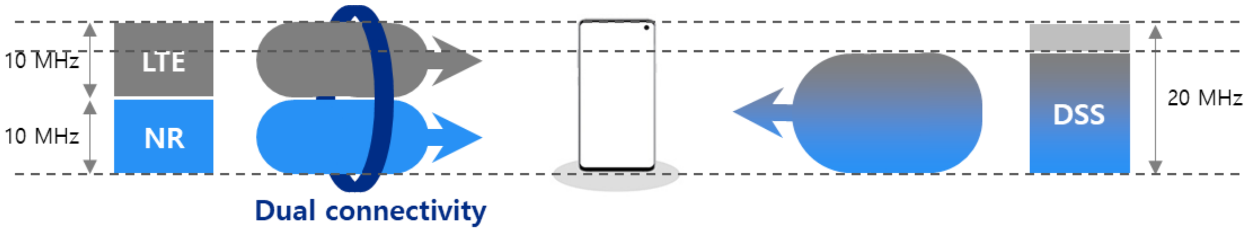


**Figure 21. Comparison of data rates between low-band DC and DSS**

Another point of consideration is that operating DSS on multiple spectrum bands does not always guarantee the expected benefits. The graph on the left in Figure 22 shows the amount of LTE and NR traffic that a base station can handle when operating both bands under DSS as NR demand gradually increases. The graph on the right shows the traffic when one band is operated as DSS and the other is re-farmed from LTE to NR as the NR market reaches maturity. In both cases, when NR demand is relatively low, it is possible to allocate resources flexibly and efficiently. When both bands are operated as DSS, however, there is a greater overhead that eats into the available LTE resources and ultimately reduces the total available capacity.

Over time, when traffic demand for NR gradually increases and exceeds the capacity offered by the DSS band, re-farming the LTE band as NR band can satisfy the greater NR traffic. This can also increase the total capacity of the system compared to a multi-band DSS.

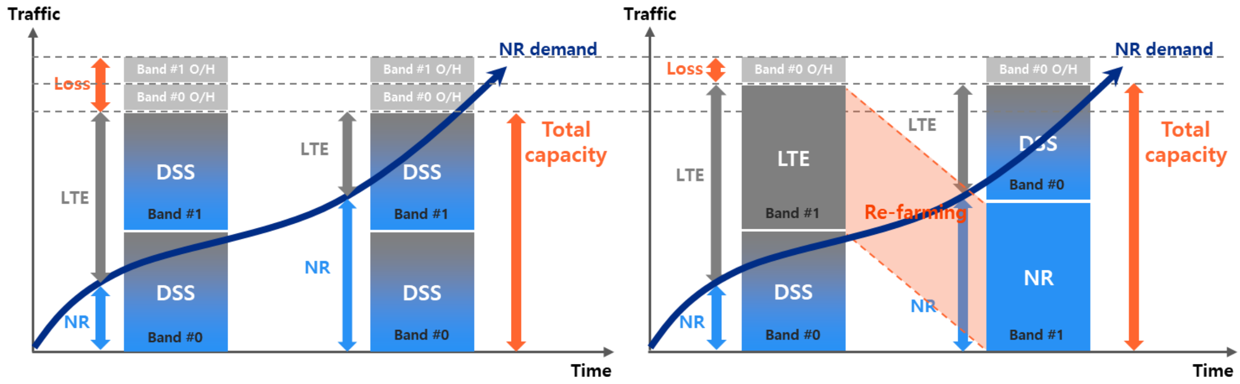


**Figure 22. Comparison of capacity between single-band and multi-band DSS operation**

In addition, although it is a slightly different issue from capacity, considering the limitation of NR PDCCH symbol resources discussed in the previous section, it should be borne in mind that even very few users can only connect to the network. In this case, NR traffic serviced to the network is very limited.

Capacity and peak-rate reduction due to overhead, and resource constraints incurred by the need of sharing limited resources between two systems are major weaknesses of DSS. In some cases, it is necessary to consider that re-farming parts of the low-band to NR, and increasing capacity and using flexible spectrum through DC and CA may be a more efficient alternative solution.

## Deployment and Operation

The DSS, in addition, has its share of concerns in terms of deployment and service operation.

First, the migration costs and time-to-deployment associated with the DSS are high. Although hardware/site configurations and dimensioning vary from one mobile network to another, DSS deployments generally need extra investment and are time consuming as hardware replacement/addition and major LTE software upgrades are required. In some cases, legacy radio units need to be replaced with new radio units that support NR and new baseband unit deployment is needed to accommodate additional low-band NR cells. Also, in some cases, it is necessary to secure a real-time signaling interface and synchronization for resource coordination between LTE and NR. In other cases, where LTE carrier needs to be moved to a new set of hardware for DSS with NR, new LTE software needs to be developed for DSS to provide feature parity with commercial LTE software. From an operator’s perspective, the changes that DSS imposes to its systems are both financially and technically burdensome.

Second, DSS can affect both LTE and NR services. To function optimally, DSS requires dynamic resource changes via real-time coordination between LTE and NR. This dynamic resource change for DSS, however, can disturb resource-coordinated LTE and NR services, and especially may lead to the loss of key NR feature of low-latency. In order to achieve ultra-low latency for URLLC, the NR defines several means to prioritize resource allocation for immediate data transmission. These NR specific methods, however, are not applicable in LTE, where transmission prioritization is determined differently. Therefore, when operating in DSS, if the LTE decides to transmit specific resources, on which urgent NR transmission depends, features such as low latency will be expensed. In addition, coexistence with LTE makes it difficult to use the above 15 kHz SCS defined for low latency (due to LTE 15 kHz SCS). The biggest challenge for operators will be in adopting these resource coordinated features and DSS simultaneously, without experiencing an overall quality or performance degradation to its networks. In this respect, it may be contradictory that DSS is considered as a promising technology for seamless transition to 5G.

The third concern is the vendor lock-in nature of this method. Tight interworking between LTE and NR is a prerequisite for the successful execution of DSS. And because such interworking is only guaranteed via vendor proprietary interface or unified scheduling, the chances of an open ecosystem in which multiple vendors can partake in DSS together are rendered slim, if not, none.

# Summary

This paper highlights the principles and effects of DSS, which enables the co-existence of 4G LTE and 5G NR on single frequency carrier.

Newly released frequency bands for 5G NR have physically low coverage due to the high propagation and penetration loss, which is why operators are in need of a 5G solution that utilizes low frequency bands. The DSS technology enables a 5G service in a low frequency band, which is mostly used for LTE services, without interrupting service of LTE users in the corresponding band. It allows LTE and NR to co-exist and share frequency-time resources on the same carrier. The resource sharing is done dynamically according to the traffic conditions of LTE and NR in the network, thereby enabling flexible resource utilization suitable for market penetration of new NR users.

For the application of DSS technology, several functions that enable the coexistence of LTE and NR have been discussed and released in 3GPP standards. The basic principle is that even though the two systems share the same resources, they should not affect each other. To this end, the promises to align the NR with the LTE carrier and the standards for allocating the NR resource by avoiding the frequency-time resource in which the CRS of the LTE is located, are defined.

Despite the great advantages of DSS, resource limitation is caused in the fact that the two systems share finite resources, and that initial access-related and reference signals that should be transmitted in LTE and NR create overhead that prevents resources of the other system from being fully utilized. Therefore, the use of DSS may cause damage in terms of the overall capacity of the network. In addition, the cost and time needed in replacing and adding hardware/software are high in the deployment of DSS. Further, dynamic resource allocation of DSS may lead to the deterioration of services that require immediate and continuous resource allocation in each of LTE/NR.

In conclusion, DSS can be a solution that enables operators without mid-band NR carriers or with poor mid-band coverage to secure low frequency bands and provide 5G services early. Samsung hardware and software provide the solution that ensures low-band NR by DSS. Moreover, Samsung Radio enables this solution through a software upgrade on its legacy unit. However, since deploying and operating DSS on LTE carriers incur cost, time, and performance degradation, careful consideration should be made in implementing DSS on carriers as a means to supplement coverage.

# Abbreviations

| | |
|---|---|
| 3GPP | 3rd Generation Partnership Project |
| 4G | 4th Generation |
| 5G | 5th Generation |
| CA | Carrier Aggregation |
| CC | Component Carrier |
| CORESET | Control Resource Set |
| CRS | Cell-specific Reference Signal |
| CSI-RS | Channel State Information Reference Signal |
| DC | Dual Connectivity |
| DL | Downlink |
| DMRS | Demodulation Reference Signal |
| DSS | Dynamic Spectrum Sharing |
| eMBB | enhanced Mobile Broadband |
| eMBMS | enhanced Multimedia Broadcast and Multicast Service |
| eMTC | enhanced Machine Type Communication |
| EN-DC | E-UTRA New Radio-Dual Connectivity |
| E-UTRA | Evolved Universal Terrestrial Radio Access |
| FDD | Frequency Division Duplex |
| LTE | Long Term Evolution |
| MBSFN | Multicast Broadcast Single Frequency Network |
| mMTC | massive Machine Type Communication |
| mmWave | millimeter Wave |
| NB-IoT | Narrow Band-Internet of Things |
| NR | New Radio |
| NSA | Non-Standalone |
| OFDM | Orthogonal Frequency Division Multiplexing |
| OFDMA | Orthogonal Frequency Division Multiple Access |
| OSI | Other System Information |
| PDCCH | Physical Downlink Control Channel |
| PDSCH | Physical Downlink Shared Channel |
| PUSCH | Physical Uplink Shared Channel |
| PRS | Positioning Reference Signal |
| RB | Resource Block |
| RF | Radio Frequency |
| RRC | Radio Resource Control |
| SA | Standalone |
| SC-FDMA | Single Carrier-Frequency Division Multiple Access |
| SCS | Sub-Carrier Spacing |
| SIB | System Information Block |
| SSB | Synchronization Signal Block |
| TRS | Tracking Reference Signal |
| UE | User Equipment |
| UL | Uplink |
| URLLC | Ultra-Reliable Low-Latency Communication |
| VoLTE | Voice over LTE |
| VoNR | Voice over NR |

# References


[1] 3GPP TR 38.912. “Study on New Radio (NR) access technology”

[2] 3GPP TS 38.101. “User Equipment (UE) radio transmission and reception; Part 1: Range 1 Standalone”

[3] 3GPP TS 38.212. “Multiplexing and channel coding”

[4] 3GPP TS 38.331. “Radio Resource Control (RRC) protocol specification”

[5] 3GPP TS 38.211. “Physical channels and modulation”

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