Dynamic Spectrum Sharing (DSS)

Practical Evaluation of Interference Effect and Mitigation in 5G NR Co-Existence with LTE

White Paper

Introduction

The industry has seen unprecedented growth and adoption of 5G. Compared to all its previous generations, 5G NR is the most accelerated cellular technology owing to its deployment flexibility and holistic use cases it can potentially address from mobile broadband to machine-type communications. Since 2019, the 5G deployment acceleration started with non-standalone (NSA) deployment "Option 3" for majority of carriers globally as it stands to be the quickest possible deployment in order to serve the user demands and to offer the 5G experience while established on the already mature LTE core and radio networks assistance. In addition, 5G standalone (SA) deployment such as "Options 2" is an end-to-end solution that offers a modernization to the radio and core network connectivity with a full connectivity to 5G core network. As of now, more than 400 operators are investing in 5G Networks and more than 150 operators have launched 5G services commercially in addition to around 70 operators are investing in advancing their networks to standalone deployment of 5G and the commercialization trend is expected to be keep increasing going forward.

One of the bottlenecks of deploying any new technology is typically subject to the availability of radio frequency spectrum. As most of the valuable frequency bands are occupied by LTE, it was important to find ways to deploy NR on the existing bands. Dynamic Spectrum Sharing (DSS) is a technique that enables "soft" re-farming of spectrum from LTE to NR by implementing the co-existence between these technologies in the same network without having to occupy the entire frequency band for either radio. Therefore, DSS has been one of the reasons for the acceleration of 5G NR deployment.

DSS concept is based on the flexible design of NR physical layer. It uses the idea that NR signals are transmitted over unused LTE resources. With LTE, the channels are statically assigned in the time-frequency domain, whereas the NR physical layer is extremely flexible for reference signals, data and control channels, thus allowing dynamic configurations that will minimize a chance of collision between the two technologies. DSS has been already adopted by many operators especially with Frequency Division Duplex (FDD) bands that are already assigned to LTE, the fact that by itself demonstrates that it is a successful technique that allows to achieve the deployment goals initially set. However, practical implementation of the feature in live networks has revealed several effects. The factors impacting 5G NR downlink throughput have been discussed in details in previous MediaTek white paper[1] , and some of which evaluated as:

1. Reduced PDSCH (Physical Downlink Shared Channel) Symbol Length to 11 symbols: due to NR/LTE PDCCH (Physical Downlink Control Channel) occupying the first 3 symbols. PD CCH is needed to convey scheduling information for data channel in the subframe.
2. No NR PDSCH Scheduling in MBSFN subframe carrying NR SSB reference signals: leading to reduced time scheduling rate.
3. Reduced NR Modulation and Coding Scheme (MCS) in normal subframe: due to LTE Cell Reference Signals (CRS) Rate Matching around NR PDSCH where the scheduled bits must also be reduced.
4. Reduced Resource Block (RB) Utilization in NR slots carrying other essential LTE signals: LTE synchronization signals.

[1] MediaTek White Paper "A Comprehensive Deployment Guide to Dynamic Spectrum Sharing."

The effect of this radio co-existence on the NR single-user downlink throughput in near-cell conditions have been evaluated to show throughput reduction by ~35% from a baseline of NR (without any resource sharing with LTE) deployed on the same band with same bandwidth. The overall effect is summarized in figure 1. Additionally, LTE single-user downlink throughput may experience a reduction of ~10% when MBSFN is applied to LTE cells due to muting several LTE subframes to accommodate NR reference signals.

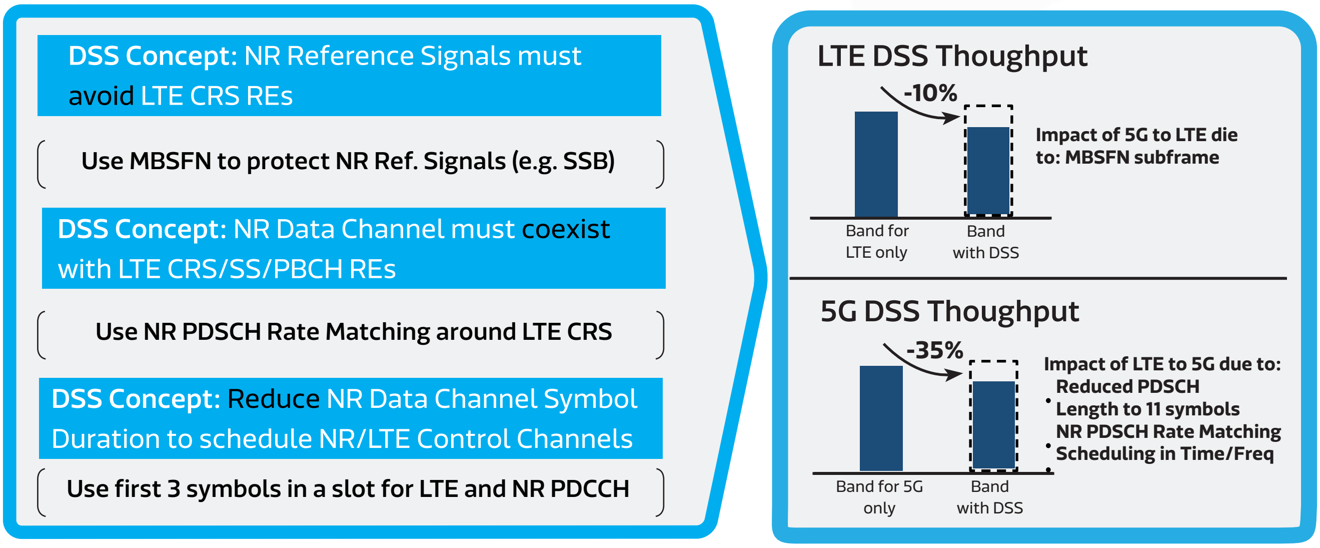

Figure 1. General Concepts of DSS Deployment Options and their Impact to Downlink Throughput

However, another challenge has been observed in live networks affecting NR downlink throughput even more. This challenge is related to the overall interference of neighbor LTE cells deployed around NR serving cell, all of which are with dynamic spectrum sharing on the same band. As DSS is designed to look for LTE serving cell's CRS patterns, the neighbor cells patterns including PCI (Physical Cell ID), signal strength, number of antenna ports are not directly conveyed to the NR serving cell, leaving it with unknown patterns of the CRS of these LTE neighbor cells. As a result, these CRS time-frequency locations that cannot be rate-matched within NR PDSCH slots will have another level of interference to the data channels affecting the NR downlink throughput. This challenge has been already raised by several operators and acknowledged to be studied by 3GPP[2] . In this paper, we study the effect of neighbor cell interference to NR downlink throughput and evaluate several techniques that can handle this phenomena from both device and network sides.

[2] 3GPP RP-210920 "Further enhancement on NR demodulation performance."

Dynamic Spectrum Sharing Rate Matching Overview

As illustrated in figure 1, the main concepts which conceived DSS design in 3GPP are:

- MBSFN (Multi-Broadcast Single-Frequency Network): the general idea of MBSFN is that specific subframes within an LTE frame reserve the last 12 OFDM symbols of such subframe to be free from other LTE channel transmission. These symbols were originally intended to be used for broadcast/multicast services and are "muted" for data transmission in other LTE UE (User Equipment). Now this idea was adjusted to be utilized in DSS design so that these reserved symbols are used for NR signals instead. While in general LTE PDCCH can occupy from 1 to 3 symbols (based on cell load), the first two OFDM symbols of such MBSFN subframe are used for LTE PDCCH, and DSS NR UE can use the third symbol. Using MBSFN is completely transparent to legacy LTE-only devices from 3GPP Release 9 onwards, as LTE UE knows that these subframes are used for other purposes. In this sense, using MBSFN subframes is the simplest way of deploying DSS. This method has disadvantages though. The main one is that if MBSFN subframes are used very frequently, it takes away resources from LTE user, heavily reducing LTE-only user throughput.
- NR PDSCH rate matching in non-MBSFN subframes around LTE CRS mainly, or around other LTE signals: in this option, the UE performs puncturing of those REs used by LTE CRS so that NR scheduler knows those REs are not available for NR data scheduling on PDSCH. The implementation of this option can be either:
    - NR PDSCH resource mapping with RB symbol level granularity: Resource Elements (REs) are declared not available for NR PDSCH data in the entire RB symbols that coincide with other LTE signals transmitted in the same subframe. In this paper, we refer to this method as **Symbol-level Rate Matching.**
    - NR PDSCH resource mapping with RE level granularity: few and specific REs are declared not available for NR PDSCH data in a symbol that coincides with mainly LTE CRS that is sparsely transmitted in RE patterns in every subframe. In this paper, we refer to this method as **RE-level Rate Matching.**

Now let's define the rate matching concept in NR. RE is the minimum unit for resource allocation and is corresponding to one subcarrier in frequency domain and one OFDM symbol in time domain. For 5G, the scheduling granularity takes place in one slot that can either be 15, 30, 60 or 120 kHz subcarrier spacing (SCS). The number of slots in a 1ms subframe can vary depending on the SCS, and also the slot duration. In every slot, there can be 12 subcarriers and 14 symbols in each Resource Block (RB) per slot for normal cyclic prefix. The number of RBs depend on the allocated bandwidth. Focusing on the NR PDSCH data channel, when the network schedules the UE with downlink assignment in every slot, it gives the UE prior information, through PDCCH, about the total number of RBs assigned as well as the symbol duration, in terms of starting symbol and the number of the symbols. As a result, with the other known channel overhead such as Demodulation Reference Signal (DMRS) associated with every PDSCH, the UE can then start the PDSCH resource mapping into REs and retrieve the overall Transport Block Size (TBS) associated with this allocation. When the NR network scheduler wishes to declare that some REs are not allocated to PDSCH during this process, it sends this information through proper signaling to the UE to know which REs are declared not available for PDSCH and hence the UE can rate-match PDSCH REs around those unavailable REs. This mutual understanding between the UE and scheduler will keep the scheduling mechanism running without possible interference to NR PDSCH when the unwanted REs are mutually eliminated in the calculations of TBS. The end result of such rate matching method is that the scheduler will reduce the NR PDSCH TBS as the number of REs available for scheduling become less in a slot. This TBS reduction is controlled by keeping an effective code rate to a level <0.95 within a slot (as stated in 3GPP TS 38.214 clause 5.1.3).

With respect to DSS, the support of RE-level Rate Matching is added in 3GPP in two phases:

- RE-level Rate Matching in 3GPP Release 15: only one rate matching pattern is available for each NR carrier
    - UE's support is indicated in UE Capability Information by *rateMatchingLTE-CRS.*
    - Network enables this method when REs indicated by the *RateMatchingPatternLTE-CRS* in *lte-CRS-ToMatchAround* in ServingCellConfig or ServingCellConfigCommon configuring common RS, in 15 kHz subcarrier spacing applicable only to 15 kHz subcarrier spacing PDSCH, of one LTE carrier in a serving cell are declared as not available for PDSCH.
- RE-level Rate Matching in 3GPP Release 16: for each NR carrier there can be up to three non-overlapping LTE carriers' CRS information signaled. Moreover, for each LTE carrier, one additional overlapping LTE CRS rate matching pattern can be specified, originally designed for Multiple Transmission/Reception Point (mTRP) scenario when there are different collocated LTE cells with same carrier frequency in different TRPs.
    - UE support is indicated in UE Capability Information by *multipleRateMatchingEUTRA-CRS-r16.*
    - Network enables this method when REs indicated by *RateMatchingPatternLTE-CRS* in two lists
        - A list of LTE CRS patterns around which the UE shall do rate matching for NR PDSCH specified by *lte-CRS-PatternList1*. The LTE CRS patterns in this list shall be non-overlapping in frequency.
        - A list of LTE CRS patterns around which the UE shall do rate matching for NR PDSCH scheduled with a DCI detected for mTRP scenario, specified by *lte-CRS-PatternList2*. The first LTE CRS pattern in this list shall be fully overlapping in frequency with the first LTE CRS pattern in *lte-CRS-PatternList1*, the second LTE CRS pattern in this list shall be fully overlapping in frequency with the second LTE CRS pattern in *lte-CRS-PatternList1*, and so on. Both lists combined can form up to two patterns for each LTE carrier (overlapping in frequency), and up to six total patterns across all LTE carriers in DSS with a NR carrier.

Additionally, each *RateMatchingPatternLTE-CRS* in the above methods (either in Release 15 or 16) contains the main parameters for the UE to determine the CRS position within the NR slot, where 15 kHz SCS slot corresponds to LTE subframe. The rate matching configuration contains information about LTE cell including:

- LTE cell bandwidth and center subcarrier location for UE to know the channel raster of LTE frequency band,
- v-shift allows the UE to know the RE location of the LTE CRS for rate matching on the collocated LTE cell, which essentially give information of the LTE PCI,
- *nrofCRS-Ports* consisting of LTE-CRS antenna port number (1, 2 or 4 ports).

As for the difference between RE-level Rate Matching in 3GPP release 15 and 16, figure 2 illustrates that initially in release 15, it is assumed that one LTE carrier overlaps one NR carrier. For example, both LTE and NR cells in DSS band-3 operate with 20 MHz carrier bandwidth. Hence, there was one pattern for RE-level Rate Matching transmitted to the UE in DSS operation in a given serving cell with LTE CRS information included in the *RateMatchingPatternLTE-CRS* fields explained before. Then the multiple patterns were introduced in 3GPP Release 16, designed to accommodate a wide NR carrier (more than 20 MHz, which is applicable to some NR bands) overlapping multiple LTE carriers (each carrier in LTE is with up to 20 MHz bandwidth) as indicated by Case 1 in figure 2. Alternatively, as shown by Case 2 in figure, both LTE and NR are of the same bandwidth, and the multiple LTE CRS patterns can be configured on the overlapped LTE frequency with different v-shift as explained before in the case of mTRP. Therefore, this flexibility of patterns allows the UE to be aware of the different LTE cell configurations that can affect NR PDSCH RE-level Rate Matching algorithm by providing information of the surrounding LTE bandwidth, PCI, and number of antenna ports for those multiple cells.

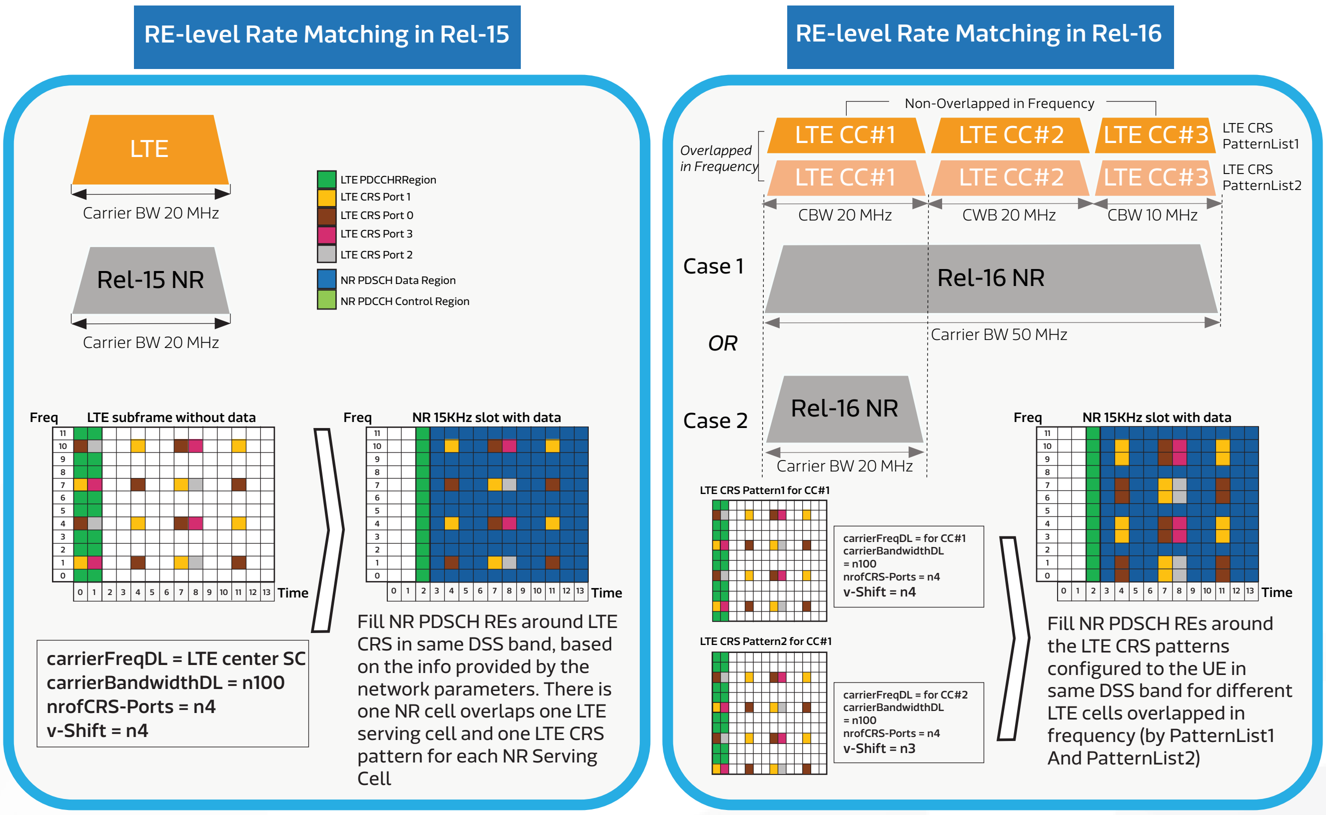

Figure 2. Illustration of NR PDSCH RE-level Rate Matching around LTE CRS

On the other hand, Symbol-level Rate Matching in DSS deployment is typically used for the case of scheduling LTE PSS/SSS and PBCH in the same slot alongside NR PDSCH, as these LTE channels occupy resources in terms of RBs mapped to several consecutive symbols within specific subframes. UE's support of Symbol-level Rate Matching is reported by *rateMatchingResrcSetSemi-Static* and the gNB may configure the UE with *rateMatchPatternToAddModList* with up to four *RateMatchPattern(s)* per bandwidth part (BWP) and up to four *RateMatchPattern(s)* per serving-cell. An example of the parameters is shown in table 1.

Table 1. RRC Configuration Example of Symbol-level Rate Matching

Pattern ID	RateMatchPattern Parameter	Configured Value
0	patternType	Bitmap
	resourceBlocks	000000000000**3f8**0000000000000000 00000000000000000...
	symbolsInResourceBlock	oneSlot: 0000 000**1** **111**0 00
	periodicityAndPattern	n10: **1**000 0000 00
	subcarrierSpacing	kHz15
1	patternType	Bitmap
	resourceBlocks	000000000000**3f8**0000000000000000 00000000000000000...
	symbolsInResourceBlock	oneSlot: 0000 0**11**0 0000 00
	periodicityAndPattern	n10: **1**000 0**1**00 00
	subcarrierSpacing	kHz15

The example in table 1 is explained as follows:

- resourceBlocks: A resource block level bitmap in the frequency domain. A bit in the bitmap set to 1 indicates that the UE shall apply rate matching in the corresponding resource block in accordance with the symbolsInResourceBlock bitmap. The first/leftmost bit corresponds to resource block 0, and so on. In this example, each bit corresponds to a bitmap of four RBs. Therefore, Symbol-level Rate Matching gates RBs 47-53 from use of NR, given that LTE PSS/SSS and PBCH occupy these RBs.
- periodicityAndPattern: A time domain repetition pattern at which the pattern defined by symbolsInResourceBlock and resourceBlocks recurs. This slot pattern repeats itself continuously.
- symbolsInResourceBlock: A symbol level bitmap in time domain. It indicates with a bit set to true that the UE shall rate match around the corresponding symbol. This pattern recurs (in time domain) with the configured periodicityAndPattern. The 14 bits represent the symbols within the slot. Therefore, according to the example in table 1, the patterns represent the following:

    - Pattern #0: Rate match the indicated RBs in subframe #0 with symbols 7-10 and repeated every 10ms.
    - Pattern #1: Rate match the indicated RBs in subframe #0 and #5 with symbols 5-6 and repeated every 10ms.

In DSS, which typically adopts FDD frame structure for the cell, LTE PBCH is scheduled in subframes #0 and LTE PSS/SSS in subframes #0 and #5 in every frame. In subframe #0 where LTE PSS/SSS/PBCH occur, these channels occupy symbols 5-10, and in subframe #5 where only PSS/SSS occur, occupy symbols 5 and 6. Hence both patterns repeat every frame can cover these LTE channels. In the frequency domain, PSS/SSS/PBCH in these subframes occupy the center 6 RBs on LTE resource grid. On the NR frequency domain, the rate match pattern assigns RBs 47-53 (20MHz channel in this example, with 7 RBs on NR resource grid) to be declared unavailable for NR PDSCH in the indicated subframes and symbols. From this explanation, the implementation idea of Symbol-level Rate Matching is more or less similar to RE-level Rate Matching but the difference is in the underlying mechanism and parameters to give more flexibility to identify the unavailable PDSCH REs at RB symbol granularity within a given subframe periodicity.

For better spectral efficiency, RE-level Rate Matching is a preferred option compared to Symbol-level Rate Matching in NR PDCCH/PDSCH 15 kHz SCS. However for NR PDCCH/PDSCH of 30 kHz SCS, only Symbol-level Rate Matching is a suitable method because of difference in numerologies with LTE. Another application for Symbol-level Rate Matching is to avoid collisions with the other LTE synchronization channels (PSS/SSS/PBCH). Table 2 compares the available REs per RB in a slot for a given LTE CRS configuration. As shown in table 2, LTE CRS within an RB occupies four symbols (#0, 4, 7, 11) for one or two antenna ports and two additional symbols (#1, #8) for four CRS antenna ports. Each CRS symbol consists of two subcarriers for each antenna port. However, since the first two symbols are occupied by LTE PDCCH, they are not considered for rate matching overhead of the NR PDSCH data channel. The overall overhead from CRS to the available NR PDSCH symbols becomes 3 CRS symbols * 2 subcarriers = 6 RE for one antenna port, 3 CRS symbols * 4 subcarriers = 12 RE for two antenna ports, and 4 CRS symbols * 4 subcarriers = 16 RE for four antenna ports. NR PDSCH scheduling can only occur after the second symbol in the slot where the third symbols is occupied for NR PDCCH (first two symbols are for LTE PDCCH); as a result, NR PDCSCH is scheduled with 11 symbols out of the total 14 symbols available in a slot. Then, 12 RE * 11 Symbols results in 132 RE available in a slot for NR PDSCH. In the case of one LTE CRS antenna port, the total NR PDSCH REs available in a slot per one RB is 132-6 = 126 REs, 132-12 = 120 REs with two CRS antenna ports, and 132-16 = 116 REs with four CRS antenna ports. On the other hand, if the entire RB in a slot is being muted, 3 (one and two CRS ports) and 4 (otherwise) symbols will be rate matched, resulting in 12 RE per RB *(11 symbols available for PDSCH – 3 CRS symbols muted within NR slot) = 96 REs available for NR PDSCH with one or two CRS antenna ports, and 12 RE per RB *(11 symbols available for PDSCH – 4 CRS symbols muted within NR slot) = 84 REs available for NR PDSCH with four CRS antenna ports. This means that the transport block size for NR PDSCH will be higher in RE-level Rate Matching and hence better spectral efficiency. Additionally, the transport block size for NR PDSCH is higher when less number of LTE antenna ports are used.

Table 2. Overhead of RE-level vs. Symbol-level Rate Matching

LTE CRS Configuration	NR RE-level Rate Matching: Remaining PDSCH REs, Transport Block Size[3]	NR RB-level Rate Matching: Remaining PDSCH REs, Transport Block Size[3]
LTE 1 CRS port: 6 RE overhead in NR PDSCH region, or 3 symbols with RB Rate Matching	126 RE, 319784 bits	96 RE, 163976 bits
LTE 2 CRS port: 12 RE overhead in NR PDSCH region, or 3 symbols with RB Rate Matching	120 RE, 303240 bits	96 RE, 163976 bits
LTE 4 CRS port: 16 RE overhead in NR PDSCH region, or 4 symbols with RB Rate Matching	116 RE, 286976 bits	84 RE, 139376 bits

Finally, there is another RE-level Rate Matching method that is generally used for the purpose rate matching of NR reference signals (such as TRS, Tracking Reference Signal) around NR PDSCH. In this method, the UE may be configured with Zero-Power Channel State Information Reference Signal (ZP-CSI-RS) that indicate to the UE the REs that cannot be used for NR PDSCH. ZP-CSI-RS is an independent CSI-RS configured with certain time-frequency domain mapping. When sent, the UE shall assume that the resource elements are not used for PDSCH transmission. Then, UE performs the same measurement or reception on channels/signals except PDSCH regardless of whether they collide with ZP CSI-RS or not. Within a BWP, the UE can be configured with one or more ZP CSI-RS Resource Set configuration(s) for aperiodic, semi-persistent and periodic time-domain behaviors. The REs indicated by ZP-CSI-RS Resource Set are declared as unavailable for PDSCH periodically, or aperiodically when their triggering and activation are applied (e.g. on-demand through PDCCH).

Using one of the rate matching options does not eliminate others. Despite each one has its own advantages and disadvantages, they all can find their proper applicability and in some cases they can be mixed to enable an optimal DSS solution.

[3] TBS for NR PDSCH with 15 kHz SCS is determined assuming overhead of 24 REs from DMRS in two symbols with 4-layer MIMO and 256QAM modulation for 20 MHz NR Carrier Bandwidth.

Dynamic Spectrum Sharing Neighbor Cell Interference

Neighbor cell interference is not exclusive to DSS. In LTE only bands, any neighbor cell's CRS can introduce interference to the data channels. Several techniques are used in LTE to mitigate interference such as:

- Interference Avoidance by eNBs Coordination: several techniques such as Coordinated Multi Points Transmission (CoMP, Rel-11), Enhanced Coordinated Multi Points Transmission (eCoMP, Rel-12) and Further Enhanced Inter-cell Interference Coordination (FeICIC, Rel-11),
- Network-Assisted Interference Cancellation (NAIC, Rel-11): allows to identify the interfering cells for a given UE by providing relevant cell information for the UE to cancel the CRS from these neighbor cells on pilot REs, data REs or both. Feedback given to UE from eNB is related to PCI and number of Antenna Port.
- Network Assisted Interference Cancellation & Suppression (NAICS, Rel-12): allows to cancel the interference of Data Channels (PDSCH) from other cells or from other users in the same cell. eNB configures UE with parameters such as RB resource allocation, System bandwidth, PCI, Power Control.

These techniques in LTE can complement UE advanced receiver interference cancellation and Rx diversity techniques. All of which target improvements to downlink throughput, boost to the network capacity in heavily loaded cells, call drop rate reduction and improved handover success rate caused by inter-cell interference.

In 4G design, to avoid channel estimation performance degradation due to CRS collision from different neighbor cells to the data channel in the serving cell, the LTE UE is generally aware of the cells due to being able to measure all neighbors in the same serving band. In case of DSS, the network currently provides information about co-located LTE cell only. Thus NR UE which uses shared spectrum knows nothing about LTE CRS location for the neighbor cells. As shown in figure 2, if the UE is not provided LTE CRS configuration information for the other cells than the serving cell, then the LTE CRS from those cells cannot be rate-matched with NR PDSCH causing interference to these REs that are still used for NR PDSCH, which affects the NR downlink throughput in the areas where the coverage is overlapped between multiple cells.

Alternatively, mitigating any neighbor cell interference can be achieved by isolating NR transmission in MBSFN subframes. However, as aforementioned, MBSFN has its own negative impact especially on LTE user throughput, and hence there must be other considerations to mitigate such neighbor cell interference which are evaluated in next section.

Possible Solutions for Interference in DSS Deployment

Network-Assisted Mechanism for Interference Avoidance

To avoid interference between 5G data channel and any other co-band signals for a UE in DSS operation, there can be several possible network-assisted solutions, which are summarized as follows:

- Use the existing idea of NR PDSCH rate matching. Even though RE-level Rate Matching configuration can declare to the UE the known CRS patterns from co-located LTE serving cell, but that alone cannot resolve the neighbor cell interference coming from the undetected cells in the same band. Alternatively, the multiple rate matching patterns introduced in 3GPP Release 16 as part of *lte-CRS-PatternList-r16* can be extended to handle the interference and is evaluated in the simulations in next section. The parameters for this method have been explained in the previous section. The multiple patterns can be extended to define co-located LTE serving cell's CRS information and other LTE neighbor cell's CRS information within the same band. This means, as shown in figure 2 for example, that NR carrier can operate with 20 MHz, and the CRS patterns sent from LTE consist of serving and neighbor cells parameters for the same 20 MHz band.
- Use a general Symbol-level Rate Matching at the RB symbol granularity per slot can also be suitable to evaluate as a network-assisted mechanism to cancel the neighbor cell interference. The full parameters are explained in the previous section.
- To complement RE-level Rate Matching in Rel-15 where only one LTE CRS pattern is available, ZP-CSI-RS can be an alternative method used by the scheduler (e.g. periodic ZP-CSI-RS that can be configured by RRC layer when the interference conditions occur) to indicate to the UE that REs coming from another LTE neighbor cell are not available for NR PDSCH. In this condition, the scheduler can trigger ZP-CSI-RS on all REs in symbols #4, 7, 8 and 11 without having to specifically indicate those are unused REs due to LTE CRS patterns so that any LTE neighbor cell with any CRS pattern in time-frequency domain would be considered in these symbols. This can be configured with multiple ZP-CSI-RS resources where each resource set indicate a symbol applicable. If ZP-CSI-RS needs to apply to spe cific REs in order to reduce the total unused REs within these four LTE CRS symbols (e.g. in case only two LTE neighbors are overlapping with the NR serving cell), the RRC configuration for ZP-CSI-RS becomes complex. In conclusion, as this method has the same effect as either RE-level or Symbol-level Rate Matching, we consider it to have the same perfomance as Symbol-level Rate Matching, within the scope of this paper, where ZP-CSI-RS applies to all REs in the four overlapping symbols.

PDSCH resource mapping with RE-level granularity and Symbol-level Rate Matching with RB Symbol granularity look to be compelling implementations due to the fact they are already used in current networks for the sake of declaring NR PDSCH REs as unavailable in certain symbols per subframe when LTE CRS/PSS/SSS/PBCH are scheduled. The advantage of Symbol-level Rate Matching is that the gNB and UE do not have to know the precise frequency resource location of the CRS from neighbor cells. RE-level Rate Matching on the other hand has the advantage of canceling only several REs in the slot rather than the entire RB symbol, and therefore provides less overhead to the overall NR downlink throughput.

Advanced UE Receiver for Interference Mitigation

Alongside the network-assisted mechanisms, UE can potentially handle LTE interference with several methods. Two of the interference mitigation methods of advanced UE receivers are Interference Rejection Combination (IRC) and Interference Cancellation (IC). IRC aims to suppress colored noise in spatial domain while IC is designed to directly remove LTE CRS from received signals.

In order to support IC, UE needs to get LTE CRS info, estimate channel response from neighbor LTE cells and rebuild interferences. IRC is an effective method to mitigate interference or colored noise in spatial domain including that of neighboring LTE CRS in DSS. Conceptually, an IRC receiver aims to whiten the colored noise. Once it is whitened, ML (Maximum-Likelihood) receivers can be utilized to demodulate and decode 5G PDSCH data. Thus in IRC the spatial diversity gain is traded for noise whitening, which results in considerable performance degradation.

Advanced UE receivers have to firstly search for neighbor LTE cells for a prior information of interference existence and interfered REs. The locations of interfered REs can be determined once neighbor LTE cell ID and its CRS port numbers are available. The major encumbrances to support IRC or IC in a UE are to estimate long-term channel statistics or instantaneous channel state information of neighbor LTE cells. Hence, both IRC and IC mechanism are extremely complex and resource demanding, especially when there are multiple neighbor LTE cells. Such implementation may inevitably impact cost efficiency of the UE production.

Practical Evaluation of Interference Handling Techniques

In this section a comparison between various interference handling techniques impact on 5G NR downlink throughput is provided taking into consideration different possible deployment scenarios. For fair comparison, the DSS scenarios defined in figure 3 and table 3 are taken into account in the simulations. In the assumed deployment, there are two common types, i.e., homogeneous network (HomNet) and heterogeneous network (HetNet). In urban scenario, cell radius is as small inter-site distance as few kilometers due to the high population density. Therefore, in case A/B/C, high SNR (Signal to Noise Ratio) is considered. For HetNet, the received signal could be severely interfered by micro/pico LTE cell, i.e. case D/E is of low SIR (Signal to Interference Ratio). In contrary to urban scenario, suburban deployment can have large cell radius up to 20km. Thus, we consider medium to low SNR in case F/G/H.

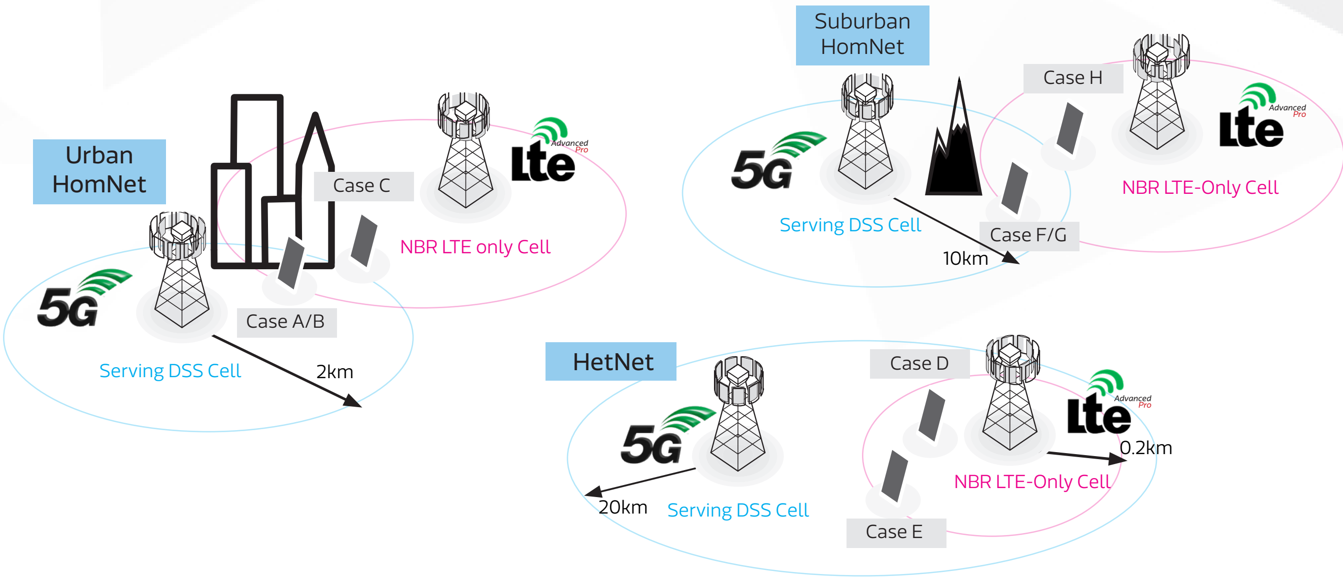

Figure 3. DSS Interference Scenario Definition

For each of those scenario, the following handling techniques are evaluated:

- No Handling: to be a baseline network deployment, i.e. a UE with IRC receiver.
- Symbol-level Rate Matching: Network enables RB-level Rate Matching patterns as explained in previous section. We consider this as a possible network solution evaluated for interference cancellation in Release 15.
- RE-level Rate Matching: Network enables RE-level Rate Matching around the known CRS patterns configured by network. We consider this as a possible network solution evaluated for interference cancellation in Release 16.
- Practical CRS-IC: CRS estimation and subtraction with practical estimation error at the UE receiver.

Table 3. DSS Scenario Definition

Case Index	**Urban (cell center + sector edge)**			**HetNet**		**Suburban**		
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
SNR (dB)	30	20	10	15	5	10	0	0
SIR (dB)	5	0	-5	-5	-5	0	0	-5

The downlink throughput results from the simulations are based on the parameters and assumptions highlighted in table 4. Two MIMO cases are considered: 2-layers and 4-layers cases, each with one or two non-colliding neighbor LTE cells. Given channel quality information reported by UE (i.e. CQI), the network scheduler can determine optimal Modulation and Coding Scheme (MCS) in terms of achievable throughput for PDSCH transmission, so called link adaptation. With link adaptation, we can compare throughput among these mechanisms under certain pairs of SNR (transmitted signal power to noise power ratio of a subcarrier) and SIR (transmitted signal power to interference power ratio).

Table 4. Simulation parameters

<table>
<tr><th colspan="2">Parameter</th><th>Value</th></tr>
<tr><td colspan="2">Carrier Bandwidth and SCS</td><td>10MHz with 15kHz in FDD band</td></tr>
<tr><td colspan="2">Antenna configuration</td><td>4x4, ULA low</td></tr>
<tr><td colspan="2">Channel model</td><td>TDLA30-10</td></tr>
<tr><td rowspan="4">Serving cell PDSCH parameters</td><td>Time Domain Mapping type</td><td>Type A</td></tr>
<tr><td>Rank</td><td>2-layer or 4-layer</td></tr>
<tr><td>MCS</td><td>OLLA (outer loop link adaptation) with target 10% BLER</td></tr>
<tr><td>Number of additional DMRS</td><td>1</td></tr>
<tr><td rowspan="5">Interference modelling (OC0 and OC1)</td><td>SIR (NR signal power to an OC interference power ratio)</td><td>-5dB, 0dB, 5dB
(OC0 SIR = OC1 SIR)</td></tr>
<tr><td>Probability of occurrence of transmission</td><td>20% with fixed patterns</td></tr>
<tr><td>Rank</td><td>Same as serving cell</td></tr>
<tr><td>MCS</td><td>10 for OC0 and 5 for OC1 (16QAM based)</td></tr>
<tr><td>Number of additional DMRS</td><td>0</td></tr>
<tr><td colspan="2">Number of CRS APs</td><td>Up to 4</td></tr>
<tr><td colspan="2">Number of CRS RBs</td><td>50</td></tr>
</table>

Both LTE and NR use 10 MHz channel bandwidth and are synchronous in both time and frequency. Sub-carrier spacing is 15 kHz for both LTE and NR, which is typically used in DSS deployments. NR PDCCH is transmitted at 2^{nd} OFDM symbol in a slot, and data channel transmitted from 3^{rd} OFDM symbol to 13^{th} OFDM symbol, with NR DMRS transmitted at 3^{rd} and 12^{th} OFDM symbols in a slot. Four-by-four MIMO channel composed of four base station (BS) transmitter antenna and four UE receiver antenna is assumed in the simulation to support up to four layers data streams. Meanwhile, as interference, the neighbor LTE cell transmits on two or four ports CRS without data traffic (unloaded LTE).

Case #1: Interference Evaluation with 2-Layers and One Interfering Cell

The performance difference between RE-level RM and Practical CRS-IC is limited as shown in figure 4. RM overhead is not huge in 1OC cases. This indicates that the performance impact is limited. Therefore, its performance is comparable to CRS-IC's. When the SINR is not high, receiver performance becomes less sensitive to CRS-IC accuracy. Therefore, CRS-IC performs better than RE-level RM in high SNR region and in high SIR cases.

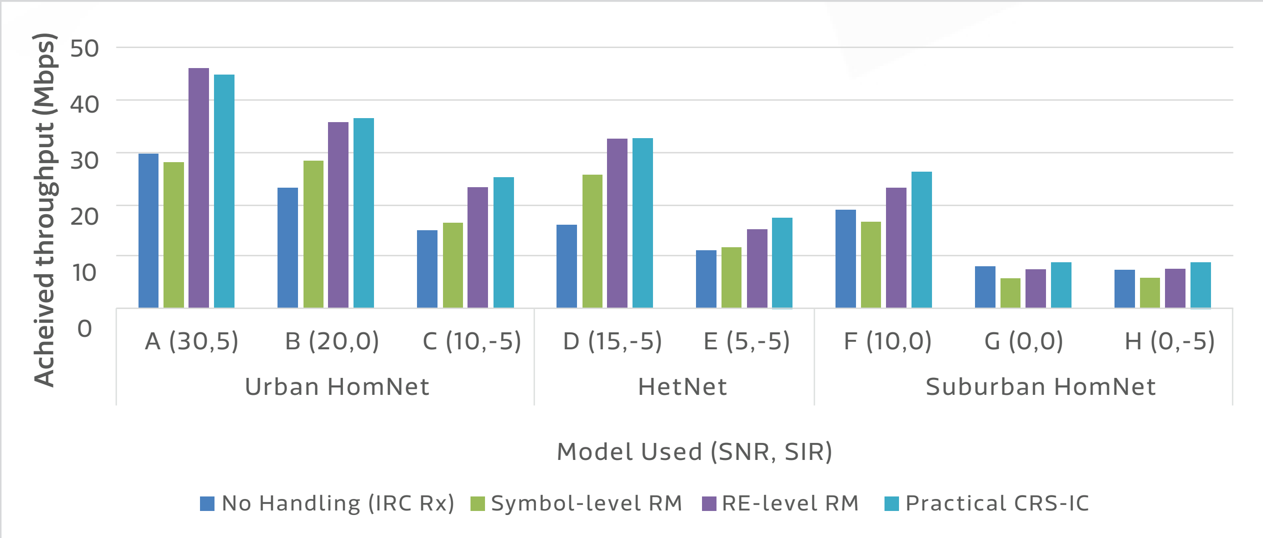

Figure 4. Simulation Results of 2-layer, 10 MHz Carrier Bandwidth, 1 OC

Case #2: Interference Evaluation with 2-Layers and Two Interfering Cell

With 2 non-colliding LTE neighbor cells, RE-level RM is equivalent to Symbol-level RM, and lower throughput is expected. But again when LTE OC number increases from 1 to 2, CRS-IC error also increases and results in worse NR receiver performance, as shown in figure 5. RM can outperform CRS-IC in some cases for 2-layer 2OC (like in case B, C, D, F), while CRS-IC is better in low SNR and low SIR. It is observed as well that IRC receiver severe impact in such SIR (-5dB~5dB) and 2OC cases, It further points out how LTE CRS interference can impact on NR users severely in DSS.

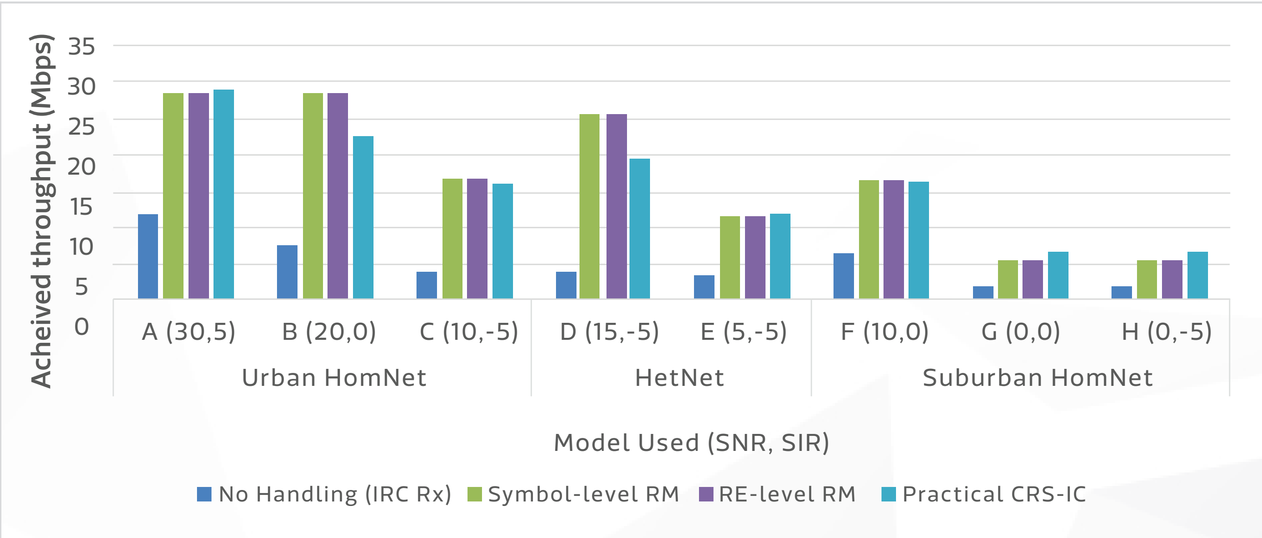

Figure 5. Simulation Results of 2-layer, 10 MHz Carrier Bandwidth, 2 OC

Case #3: Interference Evaluation with 4-Layers and One Interfering Cell

The conclusion for 4-layers in figure 6 is almost similar to the 2-layer case, where CRS-IC performs poorly in high SNR and low SIR scenarios, in which RM outperforms it (case A and B), while for the rest of the cases CRS-IC outperforms RM. But overall it could be said that performance is comparable.

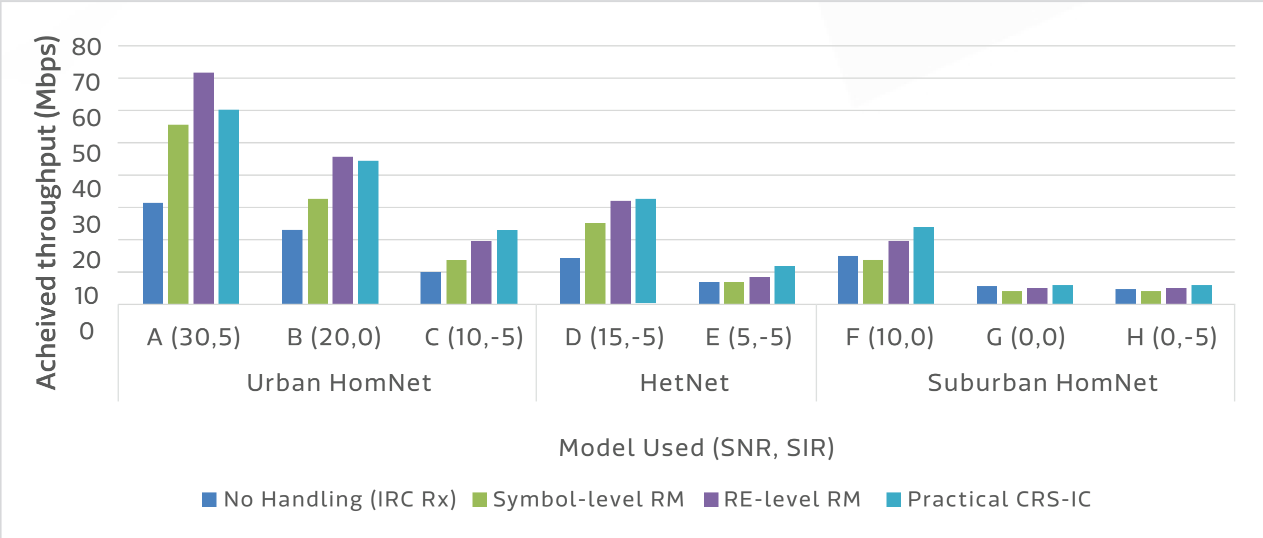

Figure 6. Simulation Results of 4-layer, 10 MHz Carrier Bandwidth, 1 OC

Case #4: Interference Evaluation with 4-Layers and Two Interfering Cell

The case of 4-layers shown in figure 7 is similar to the 2-layer case, where RE-level RM and Symbol-level RM are equivalent, and CRS-IC performance is decreased with 2OCs. RM outperforms CRS-IC in some scenarios (case A, B, D, G, H), but again overall performance could be seen as comparable.

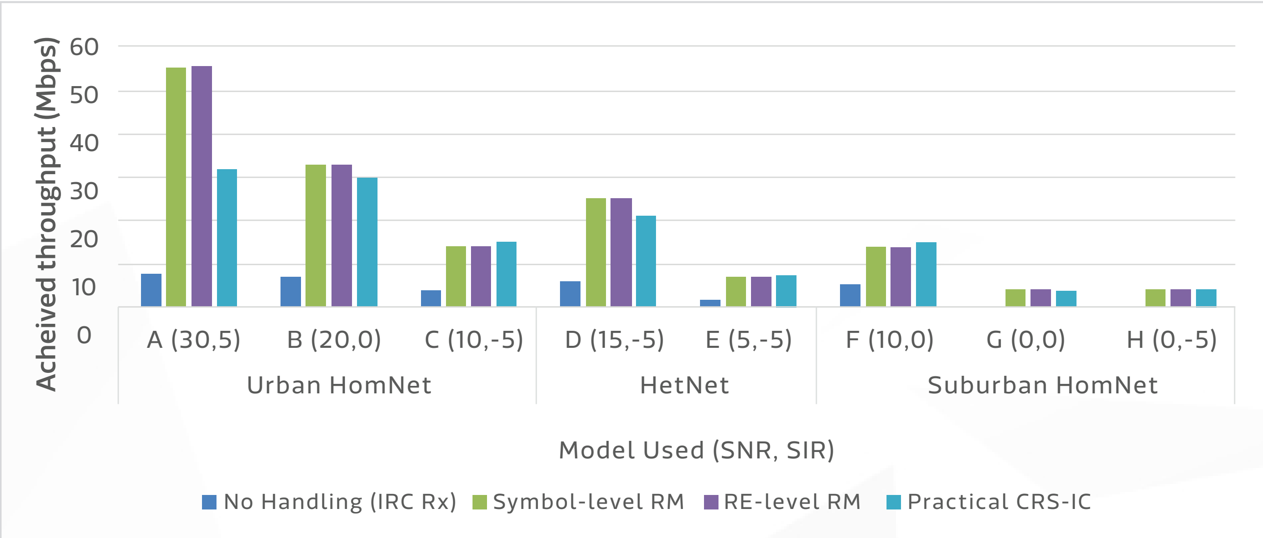

Figure 7. Simulation Results of 4-layer, 10 MHz Carrier Bandwidth, 2 OC

The conclusions for the different simulations are summarized in tables 5 and 6. In table 5, we conclude the performance comparison between RE-level RM solution and Practical CRS-IC considering different scenarios of high/medium/low SIR and SNR ranges. In table 6, we summarize the performance comparison for cases of different OC and layer numbers.

Table 5. Summary among SIR/SNR ranges

SIR/SNR		Observation (RM solution vs. CRS-IC) for throughput performance
SIR range	**SNR range**	
SIR >> 0dB (>=10dB)	ANY	Similar performance. RM solution is not expected to be enabled by network signaling in such scenario
SIR ~= 0dB (-5 ~ 5dB)	High SNR (30/20dB)	• RM solution outperforms CRS-IC in high Throughput cases • **Performance degradation is significant due to IC error**
	Medium SNR (15/10dB)	• 1OC: CRS-IC slightly better • 2OCs: RM solution slightly better • **In case of 2OCs, IC error becomes larger and results in considerable performance degradation.**
	Low SNR (5/0dB)	• CRS-IC slightly better • **Large noise** makes CRS interference less important and **overhead loss by RM** becomes dominating factor.
SIR << 0dB (<=-10dB)	ANY	Can be negligible as handover is expected to happen to the stronger neighbor cell

Table 6. Summary among different layer and OC numbers

# of Layers	# of OCs	
	1 OC	**2 OCs**
2	CRS-IC Slightly better	Comparable performance
4	• **RM-Solution much better @ SNR=30dB** • **RM-Solution slightly better @ SNR=20dB** • Comparable performance @ SNR<20dB	

In this paper, the interference problem resulted from neighbor LTE CRS in DSS network is addressed. The possible solutions such as network-assisted mechanisms and advanced UE receivers, are analyzed. According to the evaluation results, the Network-assisted rate matching mechanism provides better throughput performance than the advanced UE receiver, with the least UE complexity for UEs not equipped with CRS-IC such as existing NR UEs. However, in some scenarios such mechanism results in extra unused resources, becoming yet another source of degradation of throughput performance. This is because if this mechanism is always used even in the cell center where interference is not detected, then the throughput degradation will have more negative impact to DSS. As a result, this mechanism can be accompanied with another level of gNB detection of UE being at cell edge in order to enable the usage of rate matching patterns and enable the UE to cancel PDSCH REs that are more or less prone to neighbor cell's CRS interference. This detection can be either based on UE measurements or through detecting high NR PDSCH BLER (Block Error Rate, typically set at 10%) which is an indication of the existence of external strong interference to the data channel.