DYNAMIC SPECTRUM SHARING V2020 Q2 (10.0.4)

CALCULATIONS RELATING TO THE SIMULATOR

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VERSION HISTORY

Version	Date	Author	Comments
1.0	28/02/2020	A. Lawrow	**Version 1.0**

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1 DYNAMIC SPECTRUM SHARING

To model DSS between an LTE cell (L) and an NR cell (C) we define separate carriers and frame structures for the cells as usual, but make the following changes to how these two partnered cells are modelled in a simulation.

- For UL DSS, the terminals served on one cell cause no UL interference on the partner cell.
- For DL DSS, each cell causes no DL interference to the terminals served on its partner cell.
- We account for reductions in the numbers of traffic resources due to the DSS configuration.
- We account for the combined resource consumption of both cells when making connections.

A resource element (without cyclic-prefix) serves as a useful unit for measuring resource consumption in a radio frame because it always occupies 1 Hz-second of frame area regardless of numerology.

1.1 NUMBERS OF RESOURCE ELEMENTS PER FRAME

The following represent numbers of resource elements for an LTE cell L when it is *not* configured for MBSFN or DSS.

N_L^{DL}	Total DL REs per frame for LTE cell L.
N_L^{RS}	Total DL cell-specific RS REs per frame for LTE cell L.
$N_C^{BCH+SYNC}$	Total DL broadcast and sync REs per frame for LTE cell L.
N_L^{PDCCH}	Total PDCCH REs per frame for LTE ell L.
N_L^{PDSCH}	Total PDSCH REs per frame for LTE cell L.
N_L^{UL}	Total UL REs per frame for LTE cell L when not using DSS.
$N_L^{SRS+DMRS}$	Total UL SRS and DMRS REs per frame for LTE cell L.
N_L^{PUCCH}	Total PUCCH REs per frame for LTE cell L.
N_L^{PUSCH}	Total PUSCH REs per frame for LTE cell L.

The following represent numbers of resource elements for a NR cell C when it is *not* configured for DSS. Quantities are time-averages over many frames (i.e. they account for the SSB repetition period employed by the cell).

N_C^{DL}	Total DL REs per frame for NR cell C when not using DSS.
N_C^{SSB}	Number of SSB REs per frame for NR cell C.
N_C^{PDCCH}	Total PDCCH REs per frame for NR cell C.
N_C^{PDSCH}	Total PDSCH REs per frame for NR cell C.
N_C^{UL}	Total UL REs per frame for NR cell C when not using DSS.
N_C^{PUCCH}	Total PUCCH REs per frame for NR cell C.
N_C^{PUSCH}	Total PUSCH REs per frame for NR cell C.

1.2 Reserved Resource Elements Per Frame When Using DSS

The following numbers of resource elements for a LTE cell L when it is configured for DSS.

N_L^{PRACH}	Number of REs reserved for PRACH for LTE cell L.
$N_L^{non\ MBSFN}$	Minimum number of non-MBSFN REs in MBSFN subframes for LTE cell L.
$N_L^{min\ MBSFN}$	Minimum number of shared MBSFN REs for LTE cell L.
$N_L^{max\ MBSFN}$	Maximum number of shared MBSFN REs for LTE cell L (if not CRS rate matching).

The following numbers of resource elements for a NR cell C when it is configured for DSS.

N_C^{PRACH}	Number of REs reserved for PRACH for NR cell C.

The above are given by the following formulas:

$$N_L^{PRACH} = N_L^{UL} \times n_L^{PRACH\ RBs} / n_L^{UL\ RBs} \quad \textbf{(1)}$$

$$N_L^{non\ MBSFN} = 12 \times n_L^{DL\ RBs} \times n_L^{non\ MBSFN} \times n_L^{min\ MBSFN\ SF} \quad \textbf{(2)}$$

$$N_L^{min\ MBSFN} = 12 \times n_L^{DL\ RBs} \times (14 - n_L^{non\ MBSFN}) \times n_L^{min\ MBSFN\ SF} \quad \textbf{(3)}$$

$$N_L^{max\ MBSFN} = 12 \times n_L^{DL\ RBs} \times (14 - n_L^{non\ MBSFN}) \times n_L^{max\ MBSFN\ SF} \quad \textbf{(4)}$$

$$N_C^{PRACH} = N_C^{UL} \times n_C^{PRACH\ RBs} / n_C^{UL\ RBs} \quad \textbf{(5)}$$

where

$n_L^{PRACH\ RBs}$	Number of PRACH RBs for LTE cell L.
$n_L^{UL\ RBs}$	Number of UL RBs for LTE cell L.
$n_L^{DL\ RBs}$	Number of DL RBs for LTE cell L.
$n_L^{non\ MBSFN}$	Number of non-MBSFN symbols per MBSFN subframe for LTE cell L.
$n_L^{min\ MBSFN\ SF}$	Minimum number of MBSFN subframes for LTE cell L.
$n_L^{max\ MBSFN\ SF}$	Maximum number of MBSFN subframes for LTE cell L.
$n_C^{PRACH\ RBs}$	Number of PRACH RBs for NR cell C.
$n_C^{UL\ RBs}$	Number of UL RBs for NR cell C.

To simplify some formulas, it is convenient to define the following factor describing the minimum proportion of DL subframes used for MBSFN.

$$\alpha_L^{min} = \frac{n_L^{min\ MBSFN\ SF}}{n_L^{DL\ SF}}. \quad (6)$$

where

$n_L^{DL\ SF}$ Number of DL subframes for LTE cell L.

1.3 Limits on Number of SSBs

If the LTE cell is configured for DSS using MBSFN subframes, then the SSBs are all located within the minimum MBSFN subframes. An MBSFN subframe can contain 2 SSBs of numerology 0, or 4 SSBs of numerology 1.

If using CRS rate-matching without MBSFN subframes, then the LTE frame can only support SSBs of numerology 1. The number of SSBs per LTE subframe is limited to 1 if the LTE cell has more than 2 TX elements, and limited to 2 if the LTE cell has no more than 2 TX elements.

1.4 Handling Bandwidth Mismatch

A pair of cells that are using DSS may have carriers with the same centre frequency and nominal bandwidth but they may use different proportions of that bandwidth. For example, a carrier with 10MHz nominal bandwidth and 15 kHz subcarriers will contain 52 NR resource blocks but only 50 LTE resource blocks. In this case only a portion of the NR spectrum will be dynamically shared with LTE. We only allow DSS if the LTE carrier does not have more RBs than the NR carrier.

2 Modelling RE Consumption

2.1 Definition of load factors when using DSS

We call any RE type whose consumption depends on the system load a *traffic RE* (i.e. PDCCH, PDSCH, PUCCH, PUSCH). The total number of traffic REs consumed by a cell depends on its DL and UL load factors. A *load factor* can be thought of as the probability that a traffic RE is used. For a cell L

- The DL load factor Λ_L^{DL} (in the range 0 to 1) scales the number of DL traffic REs used.
- The UL load factor Λ_L^{UL} (in the range 0 to 1) scales the number of UL traffic REs used.

The reserved traffic percentages on an LTE cell using DSS can be mapped directly to reserved loads in the range 0 to 1.

$\Lambda_L^{UL\ res}$ Reserved UL traffic load on cell L.

$\Lambda_L^{DL\ res}$ Reserved DL traffic load on cell L (if CRS rate matching).

For cells using DSS, the effective number of traffic REs available to each cell is reduced and the above load factors then scale the *effective number of traffic REs*. So if an LTE cell is using DSS and has 100% DL LTE load, then it consumes fewer DL LTE traffic REs than if the cell had 100% DL LTE load and was not configured for DSS. The effective numbers of[LA1] traffic REs are calculated as follows.

2.2 Effective Number of LTE Traffic REs in the UL

For UL DSS, if LTE cell L and NR cell C are sharing spectrum then the number of usable UL traffic REs on the LTE cell is reduced by the number of reserved PRACH resources on the NR cell. So the *effective number of UL traffic REs* on the LTE cell is given by

$$N_L^{UL\,TRAF} \triangleq N_L^{PUCCH} + N_L^{PUSCH} - N_C^{PRACH}. \quad (7)$$

2.3 Effective Number of NR Traffic REs in the UL

For UL DSS, if LTE cell L and NR cell C are sharing spectrum then the number of usable UL traffic REs on the NR cell is reduced by the number of SRS, DMRS, reserved PRACH, and reserved UL traffic REs on the LTE cell. So the *effective number of UL traffic REs* on the NR cell is given by

$$N_C^{UL\,TRAF} \triangleq N_C^{PUCCH} + N_C^{PUSCH} - N_L^{SRS+DMRS} - N_L^{PRACH}(1 - \Lambda_L^{UL\,res}) - N_L^{UL\,TRAF}\Lambda_L^{UL\,res}. \quad (8)$$

2.4 Effective Number of LTE Traffic REs in the DL

Case 1: If the LTE cell has MBSFN configured: $(\alpha_L^{min} > 0)$

The total number of DL LTE resource elements is effectively reduced from

$$N_L^{BCH+SYNC} + N_L^{RS} + N_L^{PDCCH} + N_L^{PDSCH} \quad (9)$$

to

$$N_L^{BCH+SYNC} + N_L^{non\,MBSFN} + N_L^{RS*} + N_L^{DL\,TRAF} \quad (10)$$

where $N_L^{non\,MBSFN}$ represents the total number of REs in the non-MBSFN regions of the MBSFN subframes. We make the approximation that these REs are always fully used by the LTE cell regardless of its DL load. The other terms give the total number of REs in the non-MBSFN DL subframes. The terms N_L^{RS*} and $N_L^{DL\,TRAF}$ give the total number of cell-specific RS and effective traffic REs in the non-MBSFN subframes.

$$N_L^{RS*} \triangleq N_L^{RS}\left(1 - \alpha_L^{min}\right). \quad (11)$$

$$N_L^{DL\,TRAF} \triangleq (N_L^{PDCCH} + N_L^{PDSCH} + N_L^{BCH+SYNC})\left(1 - \alpha_L^{min}\right) - N_L^{BCH+SYNC}. \quad (12)$$

Note that when using MBSFN subframes, the SSBs are assumed to be contained entirely within the MBSFN subframes, so there is no need to explicitly subtract SSB REs in equations (11) and (12).

Case 2: If the LTE cell does not have MBSFN configured: $(\alpha_L^{min} = 0)$

In this case CRS rate-matching must be enabled, and the SSBs must then be explicitly subtracted from the LTE traffic REs, so instead of (11) and (12) we have the following expressions for N_L^{RS*} and $N_L^{DL\,TRAF}$.

$$N_L^{RS*} \triangleq N_L^{RS}, \qquad \textbf{(13)}$$

and

$$N_L^{DL\,TRAF} \triangleq N_L^{PDCCH} + N_L^{PDSCH} - N_C^{SSB}. \qquad \textbf{(14)}$$

2.5 Effective Number of NR Traffic REs in the DL

Case 1: If the LTE cell does not support CRS rate-matching:

There is no reserved DL load on the LTE cell in this case. The *effective number of DL traffic REs* available on the NR cell C is limited by the maximum number of MBSFN subframes on the LTE cell L.

$$N_C^{DL\,TRAF} \triangleq N_L^{max\,MBSFN} - N_C^{SSB} + (N_C^{DL} - N_L^{DL}). \qquad \textbf{(15)}$$

The term in brackets accounts for REs contained in NR resource blocks lying outside the set of resource blocks shared by LTE. For example if the LTE frame consists of 50 RBs and the NR frame has 52 RBs, then the term in brackets refers to REs in the 2 additional RBs available to NR.

Case 2: If the LTE cell supports CRS rate-matching:

In this case the fixed and reserved DL resources on the LTE cell L limit the number of NR traffic REs.

$$N_C^{DL\,TRAF} \triangleq N_C^{PDCCH} + N_C^{PDSCH} - N_L^{BCH+SYNC} - N_L^{non\,MBSFN} - N_L^{RS*} - N_L^{DL\,TRAF}\Lambda_L^{DL\,res}. \qquad \textbf{(16)}$$

3 CONSTRAINTS ON RE USAGE WITH DSS

If an LTE cell L and an NR cell C are paired for DSS then we have the following constraints on resource consumption in the UL and DL in terms of the cell loads $(\Lambda_L^{UL}, \Lambda_L^{DL})$ and $(\Lambda_C^{UL}, \Lambda_C^{DL})$.

3.1 UL CONSTRAINT

$$N_L^{UL\,TRAF}\Lambda_L^{UL} + (N_C^{UL\,TRAF} + N_L^{UL} - N_C^{UL})\Lambda_C^{UL} \le (N_L^{UL} - N_L^{SRS+DMRS}). \quad \textbf{(17)}$$

The quantity $(N_C^{UL\,TRAF} + N_L^{UL} - N_C^{UL})$ represents UL NR resources lying within the LTE frame, and the quantity on the right represents the maximum number of shared UL traffic resources.

3.2 DL CONSTRAINT

$$N_L^{DL\,TRAF}\Lambda_L^{DL} + (N_C^{DL\,TRAF} + N_L^{DL} - N_C^{DL})\Lambda_C^{DL} \le \left(N_L^{DL} - N_{L,C}^{DL\,fixed}\right) \quad \textbf{(18)}$$

The quantity $(N_C^{DL\,TRAF} + N_L^{DL} - N_C^{DL})$ represents DL NR resources lying within the LTE frame, and the quantity on the right represents the maximum number of shared DL traffic resources, where

$$N_{L,C}^{DL\,fixed} = N_L^{BCH+SYNC} + N_L^{non\,MBSFN} + N_L^{RS*} + N_C^{SSB} \quad \textbf{(19)}$$

is the number of REs used regardless of load.

3.3 NORMALISED LOADS

The constraints (17) and (18) can be simplified by expressing them in terms of *normalised loads* on the two cells as follows

$$\Lambda_L^{UL\,norm} + \Lambda_C^{UL\,norm} \le 1. \quad \textbf{(20)}$$

$$\Lambda_L^{DL\,norm} + \Lambda_C^{DL\,norm} \le 1 \quad \textbf{(21)}$$

where the normalised loads are defined by

$$\Lambda_L^{UL\,norm} \triangleq \left(\frac{N_L^{UL\,TRAF}}{N_L^{UL} - N_L^{SRS+DMRS}}\right)\Lambda_L^{UL} \quad \textbf{(22)}$$

$$\Lambda_C^{UL\,norm} \triangleq \left(\frac{N_C^{UL\,TRAF} + N_L^{UL} - N_C^{UL}}{N_L^{UL} - N_L^{SRS+DMRS}}\right)\Lambda_C^{UL} \quad \textbf{(23)}$$

$$\Lambda_L^{DL\,norm} \triangleq \left(\frac{N_L^{DL\,TRAF}}{N_L^{DL} - N_{L,C}^{DL\,fixed}}\right)\Lambda_L^{DL} \quad \textbf{(24)}$$

$$\Lambda_C^{DL\,norm} \triangleq \left(\frac{N_C^{DL\,TRAF} + N_L^{DL} - N_C^{DL}}{N_L^{DL} - N_{L,C}^{DL\,fixed}}\right)\Lambda_C^{DL}. \quad \textbf{(25)}$$

3.4 Maximum Allowed Load

From (20)-(25) we can write the maximum allowed normalised load for a cell in terms of the normalised load on its partner cell. This allows us to calculate the maximum achievable throughput of a cell in terms of the load on its partner cell.

$$\Lambda_L^{UL\,norm}|_{max} = \min\left[1 - \Lambda_C^{UL\,norm}, \left(\frac{N_L^{UL\,TRAF}}{N_L^{UL} - N_L^{SRS+DMRS}}\right)\right] \tag{26}$$

$$\Lambda_C^{UL\,norm}|_{max} = \min\left[1 - \Lambda_L^{UL\,norm}, \left(\frac{N_C^{UL\,TRAF} + N_L^{UL} - N_C^{UL}}{N_L^{UL} - N_L^{SRS+DMRS}}\right)\right] \tag{27}$$

$$\Lambda_L^{DL\,norm}|_{max} = \min\left[1 - \Lambda_C^{DL\,norm}, \left(\frac{N_L^{DL\,TRAF}}{N_L^{DL} - N_{L,C}^{DL\,fixed}}\right)\right] \tag{28}$$

$$\Lambda_C^{DL\,norm}|_{max} = \min\left[1 - \Lambda_L^{DL\,norm}, \left(\frac{N_C^{DL\,TRAF} + N_L^{DL} - N_C^{DL}}{N_L^{DL} - N_{L,C}^{DL\,fixed}}\right)\right] \tag{29}$$

4 Scheduling with DSS

The scheduling methods in Asset determine how a set of served terminals achieving their minimum service rate requirement (GBR) are allocated additional resources to help them achieve their maximum service rate (MBR).
The starting point is a set of served terminals served by a cell, with each terminal allocated enough resources to satisfy its GBR. Unused resources on the cell can then be distributed to the upgradeable terminals (i.e. those that have not yet attained their MBR). The different scheduling methods distribute unused cell resources to the upgradeable terminals in different ways. For DSS, the rules used to distribute resources must consider the set of terminals served by both the LTE cell and its NR partner.

Since the constraints on RE usage (17) and (18) are essentially of the same form, we can write things down in a way that applies to both UL and DL. So we consider the general constraint

$$N_L \Lambda_L + N_C \Lambda_C \leq N \tag{30}$$

with the quantities in (30) simply being a short-hand notation for the quantities in (17) and (18). For a given pair of load levels (Λ_L and Λ_C) the unused resources can be split into 3 distinct sets.

Unused resources that are available to LTE only

$$N_L^* \triangleq \max[0, \min(N_L, N - N_C) - N_L \Lambda_L]. \tag{31}$$

Unused resources that are available to NR only:

$$N_C^* \triangleq \max[0, \min(N_C, N - N_L) - N_C \Lambda_C]. \tag{32}$$

Unused resources that are available to both LTE and NR:

$$N_{L+C}^* \triangleq \min[N_L(1 - \Lambda_L), D] + \min[N_C(1 - \Lambda_C), D] - D. \tag{33}$$

where

$$D = \max(0, N_L + N_C - N). \tag{34}$$

4.1 Round Robin

Unused resources are distributed using the following recursive procedure. If there are n_L upgradeable LTE terminals and n_C upgradeable NR terminals, then the additional resources made available to each LTE terminal are given by

$$N_L^* \left(\frac{1}{n_L}\right) + N_{L+C}^* \left(\frac{1}{n_L + n_C}\right) \tag{35}$$

and the additional resources made available to each NR terminal are given by

$$N_C^* \left(\frac{1}{n_C}\right) + N_{L+C}^* \left(\frac{1}{n_L + n_C}\right). \tag{36}$$

Each terminal uses the additional resources to try and achieve its MBR, and the load levels Λ_L and Λ_C increase as a result. Any terminals that satisfy their MBR requirement are then removed from the upgrade process, and the remaining unused resources are then redistributed amongst the remaining upgradeable terminals using the same procedure. The process repeats until all terminals achieve their MBR, or there are no more resources left to distribute.

4.2 Proportional Fair

This is modelled in a similar fashion to round robin but there are additional factors (PFS gain, multi-user gain) that give a capacity gain.

4.3 Max SINR

The upgradeable terminals are first ranked in order of decreasing SINR. The terminals are then allocated resources one at a time, starting with the one with the strongest SINR. If this terminal is an LTE terminal it will have

$$N_L^* + N_{L+C}^* \tag{37}$$

additional resources made available to it, and if it is an NR terminal it will have

$$N_C^* + N_{L+C}^* \tag{38}$$

additional resources made available to it.

The terminal uses as many of these resources as necessary to try and achieve its MBR, and the system load increases as a result. The terminal is then removed from the list of upgradeable terminals, and the process repeated for the remaining terminals.

4.4 Proportional Rate

The procedure is similar to the round-robin algorithm, except the resources are shared according to the relative bitrates of the terminals. So for an LTE terminal k, the additional resources allocated to it are given by

$$N_L^* \left(\frac{r_k}{\sum_{m \in L} r_m} \right) + N_{L+C}^* \left(\frac{r_k}{\sum_{m \in L,C} r_m} \right) \tag{39}$$

where r_k is the achievable bitrate of terminal k. The summation in the first denominator of (39) is the sum of achievable bitrates of all upgradeable LTE terminals on the cell. The summation in the second denominator is the sum of achievable bitrates of *all* upgradeable terminals (LTE and NR) on the cell and its DSS partner.

Similarly, for an NR terminal k, the additional resources allocated to it are given by

$$N_C^* \left(\frac{r_k}{\sum_{m \in C} r_m} \right) + N_{L+C}^* \left(\frac{r_k}{\sum_{m \in L,C} r_m} \right). \tag{40}$$

4.5 PROPORTIONAL DEMAND

The resources are shared according to the relative resource demands of the upgradeable terminals. For an LTE terminal k, the additional resources allocated to it are given by

$$N_L^* \left(\frac{x_k}{\sum_{m \in L} x_m} \right) + N_{L+C}^* \left(\frac{x_k}{\sum_{m \in L,C} x_m} \right) \quad \textbf{(41)}$$

where x_k represents the additional number of resources required to achieve its MBR. This can be expressed as the difference between its current contribution to the load (λ_k) and the corresponding load contribution if it achieved its MBR (λ_k^{Max}).

For an LTE terminal, the number of additional resources required to achieve the MBR is given by

$$x_k = (\lambda_k^{Max} - \lambda_k) N_L^*. \quad \textbf{(42)}$$

For an NR terminal, the number of additional resources required to achieve the MBR is given by

$$x_k = (\lambda_k^{Max} - \lambda_k) N_C^*. \quad \textbf{(43)}$$

5 DSS WITH MISMATCHED FRAME CONFIGURATIONS

All above formulas require compatibility between the NR and LTE frame types. Note that all the constraint formulas have a clear separation between UL and DL. For example, the *LTE UL Constraint* depends only on UL parameters for LTE and NR cell, not the DL. So the formulas for DSS can only work in certain cases:

LTE Frame Type	*NR Frame Type*	*DSS UL*	*DSS DL*
FDD	**FDD**	**Y**	**Y**
FDD	**SUL**	**Y**	N
FDD	**SDL**	N	**Y**
FDD	TDD	N	N
TDD	FDD	N	N
TDD	SUL	N	N
TDD	SDL	N	N
TDD	**TDD**	**Y**	**Y**

In the last case, the constraint formulas will work as long as the UL and DL slot parameters for the NR cell agree with the subframe pattern of the LTE cell. For example, if an LTE cell has subframe pattern

D S U D D D S U D D

then a compatible NR cell must have TDD slots percentages of 60% for the DL and 20% for the UL.