# NR Static Simulations
# V2020 Q2 (10.0.4)

## Algorithms and Outputs relating to the Simulator

TEOCO
Pascal Place
Randalls Way
Leatherhead
Surrey KT22 7TW
ENGLAND

| | |
|---|---|
| Telephone: | +44 (0) 1932 442000 |
| Support Hotline: | +44 (0) 1932 442345 |
| Fax: | +44 (0) 1932 442005 |
| Web: | http://www.teoco.com |

# VERSION HISTORY

| Version | Date | Author | Comments |
|---|---|---|---|
| 1.0 | 20/11/2018 | A. Lawrow | **Version 10.0.2** |
| 1.1 | 03/12/2018 | A. Lawrow | Correct resource overlap factor between differing carriers. |
| 1.2 | 18/12/2018 | A. Lawrow | Updated to include effect of SSB index on interference. |
| 1.3 | 16/01/2019 | A. Lawrow | Revised formulas and notation for resource element overlap factors. |
| 1.4 | 11/04/2019 | A. Lawrow | Revised definition of resource element overlap factors to include SSB load factor, so interference formulas can be simplified. |
| 1.5 | 04/06/2019 | A. Lawrow | Correct formula for CSI-RSRP. |

# CONTENTS

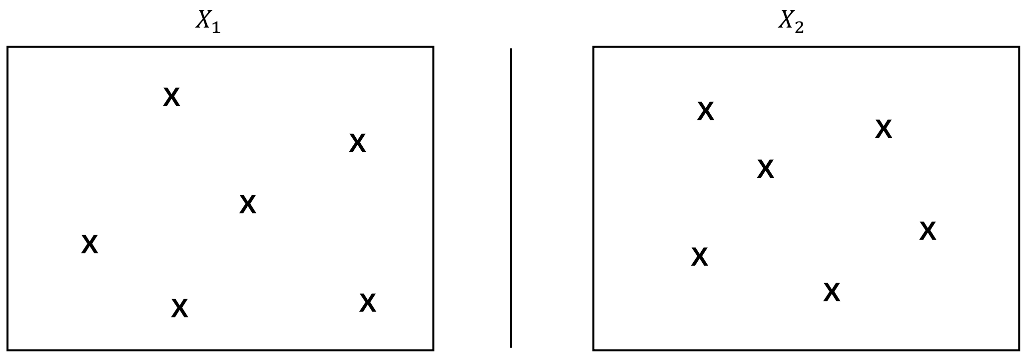
# 1 WHAT IS A SNAPSHOT?

## 1.1 RANDOMNESS IN A CELLULAR NETWORK

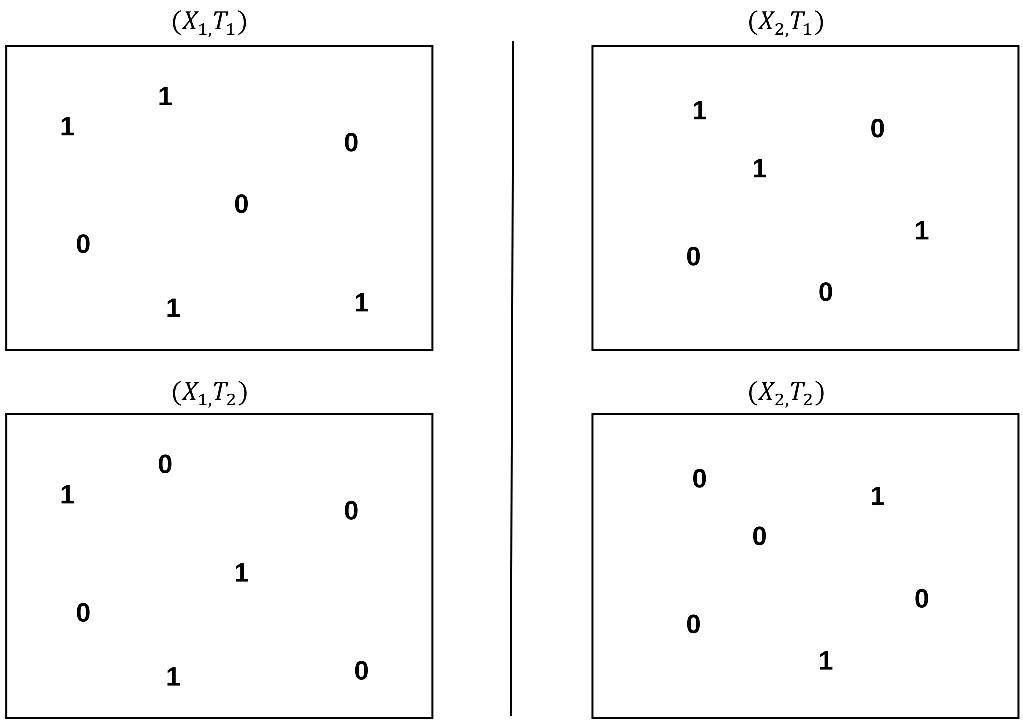
In a simulation of a cellular network there are two main types of randomness that one needs to consider.

- *Spatial randomness in the location of terminals.*
- *Temporal randomness in the activity of terminals.*

We shall consider the spatial domain to be discrete and consisting of a large number of pixels (bins) some of which will contain terminals. Each possible pattern of terminal locations has an associated probability of occurrence. We can label these spatial patterns $X_1$, $X_2$, etc and represent the corresponding probabilities of occurrence by $P(X_1), P(X_2)$, etc. An example of two spatial patterns $X_1$and $X_2$ are shown below.




Each spatial pattern has many possible configurations of transmitting and non-transmitting terminals. Two such configurations for the spatial patterns $X_1$and $X_2$ are shown below, with 1 representing a transmitting terminal, and 0 a non-transmitting terminal.



We call each of these patterns a *spatio-temporal pattern* to highlight the fact that we have specified spatial locations of terminals and also their temporal state (transmitting/non-transmitting). We can label the spatio-temporal patterns for spatial pattern $X_1$ as follows $(X_{1,}T_1)$, $(X_{1,}T_2)$ and etc and their probabilites of occurrence $P(X_{1,}T_1)$, $P(X_{1,}T_2)$ and etc. Note that the probability of occurrence of a spatio-temporal pattern $(X_{i,}T_j)$, is proportional to the probability of occurrence of the spatial pattern $X_i$:

$$P(X_{i,}T_j) = P(X_i)P(T_j \mid X_i). \quad \textbf{(1)}$$

One can think of a spatio-temporal pattern as being a picture of a real network at a random instant in time. This is what most people have in mind when one mentions a simulation 'snapshot', but a snapshot in our Simulator represents something slightly different, as explained below.

The *ideal* static simulation would calculate an average quantity (e.g. the average noise rise on a cell) by performing a *weighted sum* over the set of *all* possible spatio-temporal patterns $(X_{i,}T_j)$, with the weight for a pattern being its probability of occurrence. So the average of some quantity $F$ would be given by

$$\overline{F} = \sum_{X_{i,}T_j} F(X_{i,}T_j)P(X_{i,}T_j). \quad \textbf{(2)}$$

We can split this into separate spatial and temporal sums:

$$\overline{F} = \sum_{X_i} P(X_{i,}) \sum_{T_j} F(X_{i,}T_j)P(T_j|X_i). \quad \textbf{(3)}$$

The summations in (2) and (3) are over *every* conceivable pattern of terminal locations and activities, including the unlikely ones, so clearly some simplifications are necessary in any practical static simulator.

**Simplification 1: Model *spatial* randomness *explicitly* by sampling.**

This simplification is the most common one made in static simulations, and it is used universally. Instead of considering *all* spatial patterns, we consider a set of $N$ sample spatial patterns drawn from the distribution of all spatial patterns. The first weighted sum in (3) can then be approximated by a simple average over the set of $N$ sample spatial patterns:

$$\overline{F} \approx \frac{1}{N} \sum_{X_i} \sum_{T_j} F(X_{i,}T_j)P(T_j|X_i). \quad \textbf{(4)}$$

Spatial randomness is therefore handled *explicitly* by considering a set of sample spatial patterns that have been selected in a random and unbiased way. There is still the issue of how to handle the different temporal states for each sample spatial pattern. There are two main approaches we can use:

- Model temporal randomness *explicitly* by sampling. (Simplification 2).
- Model temporal randomness *implicitly* with time-averages. (Simplification 3).

**Simplification 2: Model *temporal* randomness *explicitly* by sampling.**

This simplification is fairly common but has some drawbacks as explained below. Firstly, as in the previous simplification, one selects a sample spatial pattern from the set of all possible spatial patterns, making sure that the selection is made in a random and unbiased way. One then assigns a random 'activity flag' (1 or 0) to each terminal in the pattern, to indicate if the terminal is transmitting or not. The probability of assigning a '1' to a terminal is just the service activity factor (% resource element [RE] usage) for that terminal. This ensures that activity flags are assigned in a random and unbiased way. The weighted sum over the set of all spatio-temporal patterns in (2) can be approximated by a simple average over the set of $N$ sample spatio-temporal patterns:

$$\overline{F} \approx \frac{1}{N} \sum_{X_i,T_j} F(X_i, T_j). \tag{5}$$

If we called a spatio-temporal pattern a 'snapshot' then the above formula simply says that we can approximate $\overline{F}$ by performing a simple average over the snapshots. This simple average works because the sample spatio-temporal patterns are selected in a random and unbiased way. Also note that this averaging *explicitly* accounts for spatial randomness and *explicitly* accounts for temporal randomness.

There are problems with assigning 'activity flags' to terminals however.

- For low activity services, the user can do 100s of snapshots and never set an activity flag, and therefore certain outputs may not have any results. For example, a simulation report may say that many users are served on a cell but that there is no throughput on the cell. Forcing the user to run 1000s of snapshots is unacceptable in a commercial tool, so we either have to remove the problem outputs or calculate them some other way.

For the above reasons, we do *not* use Simplification 2 and use the following simplification instead.

**Simplification 3: Model *temporal* randomness *implicitly* with time-averages.**

As before, one selects a sample spatial pattern from the set of all possible spatial patterns, but now we completely remove the activity flags from the randomly scattered terminals. Each terminal is therefore neither instantaneously active nor instantaneously inactive, but rather represents a sort of 'time-averaged' entity. Essentially, this means that when we examine the interference that the terminal produces, or the resources it consumes, we use the time-averages for these quantities, and we calculate these time-averages *implicitly* by using activity factors (*% RE usage*) to scale values.

So in our Simulator, a 'snapshot' does not represent a random instant in time for a random distribution of terminals, but rather '***the <u>average</u> instant in time for a random distribution of terminals***'. The snapshot represents the average instant because all the measures of system load (i.e. UL interference, DL interference, resource usage, and throughput) are time-averages.

It is still valid to perform simple averages of quantities over our snapshots. However, averaging over the snapshots now *explicitly* accounts for spatial randomness only. The temporal randomness is now handled *implicitly* <u>within</u> each snapshot through the use of time-averages in our calculations. Time-averages feature in the evaluation of both coverage and capacity as described below.

## 1.2 AVERAGING IN COVERAGE AND CAPACITY EVALUATIONS

All our link budgets (in SI units, not dB) are essentially of the form of

$$SINR = \frac{P}{L(N + I)}, \quad (6)$$

where

$SINR$ = Signal to interference ratio for the link in a period of *activity*,
$P$ = TX power in a period of *activity*,
$L$ = Linkloss,
$I$ = *Average* RX interference on the link.
$N$ = Thermal Noise

To check for coverage, we set $P$ to the maximum allowed link power and check that SINR meets requirements. In other words we examine the link assuming it is *active*. NR frames are two dimensional (*time and frequency*) entities and the averaging is considered for both dimensions.

- *Coverage Evaluation* is affected by averaging, only because we use the average interference $I$ in the link-budget.

- *Capacity Evaluation* is also done with average quantities. The capacity constraint is that the average resource (RBs) usage on each cell-carrier must not exceed the maximum limit.

Averages are calculated by scaling quantities (*i.e. powers transmitted and resources consumed*) by the *RE usage (%)* factors. One should remember that our snapshot contains no information about which REs are in use by a link. Only two things are known about each link:

- The power and resources required to service the link in a period of activity.
- The average interference and average resource consumption that the link produces.

## 1.3 WHY PRODUCE SNAPSHOTS?

The main purpose of a snapshot is to provide us with *measures of system load.* In particular, each snapshot provides:

- The total consumed DL transmission power of each traffic beam on cell.
- The total UL mean noise rise level (out-cell noise) on each traffic beam on each cell.
- The total UL and DL throughput on each cell.
- The total resource usage on each traffic beam on each cell.

By running many snapshots, values for these quantities are obtained for different spatial distributions of terminals which are further used to analyse the UL and DL coverage for the system.

# 2 FORMULAE

## 2.1 LIST OF PRINCIPAL SYMBOLS

| | |
|---|---|
| $n_C^{SSB}$ | Number of SSB beams on cell $C$. |
| $n_C^{TRAFFIC}$ | Number of traffic beams on cell $C$. |
| $T_C^{SSB}$ | SSB repetition period on cell $C$. |
| $T^{FRAME}$ | Frame duration. |
| $i_{C,k}^{SSB}$, $\left(\text{where } 0 \leq i_{C,k}^{SSB} < n_C^{SSB}\right)$ | Best SSB index for cell $C$ at terminal $k$. |
| $\overline{n_C^{SSB}} = n_C^{SSB} T^{FRAME} / T_C^{SSB}$ | Mean number of SSBs per frame on cell $C$. |
| $n_C^{DL\ RB}, n_C^{UL\ RB}$ | Number of resource blocks on cell $C$. |
| $n_C^{PDCCH\ RB}, n_C^{PUCCH\ RB}$ | Number of PDCCH/PUCCH resource blocks on cell $C$. |
| $n_C^{DL\ symbols/slot}, n_C^{UL\ symbols/slot}$ | Number symbols per slot on cell $C$. |
| $n_C^{DL\ slots/subframe}, n_C^{UL\ slots/subframe}$ | Number slots per subframe on cell $C$. |
| $n_p^{DL\ SC}, n_p^{UL\ SC}$ | Number of common subcarriers over all RBs of carrier p. |
| $W_p^{DL} = n_p^{DL\ SC} \Delta f_p^{DL}$ | DL bandwidth over all RBs of carrier $p$. |
| $W_p^{UL} = n_q^{UL\ SC} \Delta f_p^{UL}$ | UL bandwidth over all RBs of carrier $p$. |
| $\Delta f_p^{SSB}$ | SSB subcarrier spacing for carrier $p$. |
| $\Delta f_p^{DL}, \Delta f_p^{UL}$ | Common DL and UL subcarrier spacing for carrier $p$. |
| $L_{C,k}^{SSB}$ | DL linkloss for the best SSB beam on cell C to terminal $k$. |
| $L_{Cm,k}^{DL}, L_{Cm,k}^{UL}$ | DL/UL linkloss for traffic beam $m$ on cell $C$ to terminal $k$. |
| $OH_C^{PDSCH}, OH_C^{PUSCH}$ | PDSCH and PUSCH overhead (%) on cell $C$. |
| $\alpha_C^{DL}$ , $\alpha_C^{UL}$ | DL and UL percentage (TDD) on cell $C$. |
| $\delta_{C,p}^{PSS}$ | PSS EPRE offset on cell $C$ using carrier $p$. |
| $\delta_{C,p}^{PDCCH}$ | PDCCH TX EPRE offset on cell $C$ using carrier $p$. |
| $\delta_{C,p}^{PDSCH}$ | PDSCH TX EPRE offset on cell $C$ using carrier $p$. |
| $\delta_{C,p}^{CSI-RS}$ | CSI-RS TX EPRE offset on cell $C$ using carrier $p$. |
| $\varepsilon_{C,p}^{SSS}$ | SSS TX EPRE on cell $C$ using carrier $p$. |
| $\varepsilon_{C,p}^{PSS} = \varepsilon_{C,p}^{SSS} \delta_{C,p}^{PSS}$ | PSS TX EPRE on cell $C$ using carrier $p$. |
| $\varepsilon_{C,p}^{PBCH} = \varepsilon_{C,p}^{SSS}$ | PBCH TX EPRE on cell $C$ using carrier $p$. |

$\varepsilon_{C,p}^{PDCCH} = \varepsilon_{C,p}^{SSS}\delta_{C,p}^{PDCCH}$ PDCCH TX EPRE on cell $C$ using carrier $p$.

$\varepsilon_{C,p}^{PDSCH} = \varepsilon_{C,p}^{SSS}\delta_{C,p}^{PDSCH}$ PDSCH TX EPRE on cell $C$ using carrier $p$.

$\varepsilon_{C,p}^{CSI-RS} = \varepsilon_{C,p}^{SSS}\delta_{C,p}^{CSI-RS}$ CSI-RS TX EPRE on cell $C$ using carrier $p$.

$\varepsilon_{C,p}^{Type0-PDCCH} = \varepsilon_{C,p}^{SSS}$ Type0-PDCCH TX EPRE on cell $C$ using carrier $p$.

The tool allows the user to define a switched-beam antenna with multiple control-beam patterns, and the SSB indices assigned to these patterns may not be unique. In this situation, the available power for a given SSB index is taken to be shared equally between the control-beams with that SSB index. Therefore DL calculations involving control-beams use the following scaled EPRE values to account for this power sharing.

$$\varepsilon_{C,p,k}^{PSS} = \varepsilon_{C,p}^{PSS}/B\left(i_{C,k}^{SSB}\right)$$

$$\varepsilon_{C,p,k}^{SSS} = \varepsilon_{C,p}^{SSS}/B\left(i_{C,k}^{SSB}\right)$$

$$\varepsilon_{C,p,k}^{PBCH} = \varepsilon_{C,p}^{PBCH}/B\left(i_{C,k}^{SSB}\right)$$

$$\varepsilon_{C,p,k}^{Type0-PDCCH} = \varepsilon_{C,p}^{Type0-PDCCH}/B\left(i_{C,k}^{SSB}\right)$$

The integer $B\left(i_{C,k}^{SSB}\right)$ is the number of control beam patterns on cell $C$ using the SSB index $i_{C,k}^{SSB}$ (which is the best SSB index for cell $C$ at terminal $k$).

## 2.1 Mean Numbers of Cell Resource Elements per Frame

The following numbers of resource elements for a cell $C$ 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 cell $C$. |
| $N_C^{UL}$ | Total UL REs per frame for cell $C$. |
| $N_C^{SSB} = 960\,\overline{n_C^{SSB}}$ | Mean number of SSB REs per frame for cell $C$. |
| $N_C^{PSS} = (127/960) \times N_C^{SSB}$ | Mean number of PSS REs per frame for cell $C$. |
| $N_C^{SSS} = (127/960) \times N_C^{SSB}$ | Mean number of SSS REs per frame for cell $C$. |
| $N_C^{PBCH} = (576/960) \times N_C^{SSB}$ | Mean number of PBCH REs per frame for cell $C$. |
| $N_C^{PDCCH}$ | Mean number of PDCCH REs per frame for cell $C$. |
| $N_C^{PDSCH}$ | Mean number of PDSCH REs per frame for cell $C$. |
| $N_C^{PUCCH}$ | Mean number of PUCCH REs per frame for cell $C$. |
| $N_C^{PUSCH}$ | Mean number of PUSCH REs per frame for cell $C$. |

**Total Resource Elements per Frame in UL and DL**

$$N_C^{DL} = 12 \times n_C^{DL\,RB} \times 10 \times n_C^{DL\,slots/subframe} \times n_C^{DL\,symbols/slot}\,. \tag{7}$$

$$N_C^{UL} = 12 \times n_C^{UL\,RB} \times 10 \times n_C^{UL\,slots/subframe} \times n_C^{UL\,symbols/slot}\,. \tag{8}$$

There are 12 REs per resource block and 10 subframes per frame. Note that (7) and (8) will give identical values for TDD carriers, and so a further factor is required to account for the proportion of UL and DL resource elements. See (11) and (12).

**Total PDCCH and PUCCH Resource Elements per Frame**

$$N_C^{PDCCH} = 12 \times n_C^{PDCCH\,RB}\,. \tag{9}$$

$$N_C^{PUCCH} = 12 \times n_C^{PUCCH\,RB}\,. \tag{10}$$

**Number of PDSCH and PUSCH Resource Elements per Frame**

$$N_C^{PDSCH} = N_C^{DL} \times (\alpha_C^{DL}/100) - N_C^{PDCCH} - N_C^{SSB}. \tag{11}$$

$$N_C^{PUSCH} = N_C^{UL} \times (\alpha_C^{UL}/100) - N_C^{PUCCH}. \tag{12}$$

The percentages $\alpha_C^{DL}$ and $\alpha_C^{UL}$ only apply when the cell $C$ is using a carrier with a TDD frame structure.

## 2.2 Bearer Rates and Resource Consumption

The measures of system load depend on the resource consumption/usage of the frame. Resource consumption is defined as the ratio of the required service rate (*Minimum-GBR and Maximum-MBR*) and the maximum available bearer rate calculated by using the employed modulation and channel coding rate.

To model the average interference effects in the network without the exact knowledge of the time-frequency PRBs assigned to a specific connection, a simplification can be by made by reducing the two dimensional (time-frequency) frame into a single dimensional value of resource usage, either in the frequency domain or the time domain. The simplified resource consumption (*RE Usage*) can then be defined as

$$\alpha = \frac{Service\ Rate\ at\ Physical\ layer}{Bearer\ Rate}. \tag{13}$$

The service rate requirements $R^{service}$, are specified at application layer. The resource consumption is occuring at the physical layer and is therefore calculated based on the service rate at physical layer that is accounting for the applicable overheads:

$$R_{J,Physical\ layer}^{service} = R^{service}\left(1 + OH^{service}\right), \tag{14}$$

where $R_{J,Physical\ layer}^{service}$ is the service rate at physical layer for cell $J$. $OH^{service}$ is the service rate overhead.

**Bearer Rates**

$$R_C^{PDSCH} = N_C^{PDSCH} \times (1 - OH_C^{PDSCH}/100) \times M \times R^{coding}/T^{FRAME}. \tag{15}$$

$$R_C^{PUSCH} = N_C^{PUSCH} \times (1 - OH_C^{PUSCH}/100) \times M \times R^{coding}/T^{FRAME}. \tag{16}$$

where $M$ and $R^{coding}$ are the bearer modulation index and channel coding rate respectively.

**Resource Consumption for GBR and MBR**

$$\alpha_{C,min}^{DL\ bearer} = \frac{R_{min}^{DL\ service}\left(1 + OH^{DL\ service}\right)}{R_C^{PDSCH}}, \tag{17}$$

$$\alpha_{C,max}^{DL\ bearer} = \frac{R_{max}^{DL\ service}\left(1 + OH^{DL\ service}\right)}{R_C^{PDSCH}}, \tag{18}$$

where $\alpha_{C,min}^{DL\ bearer}$ and $\alpha_{C,max}^{DL\ bearer}$ are the minimum and maximum resource consumption for a bearer configured for cell $C$. $R_{min}^{DL\ service}$ and $R_{max}^{DL\ service}$ are Minimum-GBR and Maximum-MBR service rates. $OH^{DL\ service}$ is the DL service rate overhead.

$$\alpha_{C,min}^{UL\ bearer} = \frac{R_{min}^{UL\ service}\left(1 + OH^{UL\ service}\right)}{R_C^{PUSCH}}, \tag{19}$$

$$\alpha_{C,max}^{UL\ bearer} = \frac{R_{max}^{UL\ service}\left(1 + OH^{UL\ service}\right)}{R_C^{PUSCH}}, \tag{20}$$

where $\alpha_{C,min}^{UL\,bearer}$ and $\alpha_{C,max}^{UL\,bearer}$ are the minimum and maximum resource consumption for a bearer configured for carrier $p$ for cell $J$. $R_{min}^{UL\,service}$ and $R_{max}^{UL\,service}$ are the 'Minimum-GBR' and 'Maximum-MBR' service rates. $OH^{UL\,service}$ is the UL service rate overhead.

### 2.2.1 Carrier Aggregation

During CA operation the terminal is served over mulitple different carriers over potentially different bearers. The sets of DL and UL aggregated carriers for the terminal can be diffreent. This results in a reduced effective resouce consumption for a bearer over the individual carriers that is given by:

$$\alpha_{effective,min}^{DL} = \left(\sum_{C} \frac{1}{\alpha_{C,min}^{DL\,bearer}}\right)^{-1}, \qquad \alpha_{effective,max}^{DL} = \left(\sum_{C} \frac{1}{\alpha_{C,max}^{DL\,bearer}}\right)^{-1}, \tag{21}$$

$$\alpha_{effective,min}^{UL} = \left(\sum_{C} \frac{1}{\alpha_{C,min}^{UL\,bearer}}\right)^{-1}, \qquad \alpha_{effective,max}^{UL} = \left(\sum_{C} \frac{1}{\alpha_{C,max}^{UL\,bearer}}\right)^{-1}, \tag{22}$$

where $\alpha_{effective,min}^{DL}$ and $\alpha_{effective,max}^{DL}$ are the minimum and maximum effective resource consumption for the selected DL bearers of the DL aggregated cells $C$, and $\alpha_{effective,min}^{UL}$ and $\alpha_{effective,max}^{UL}$ are the minimum and maximum effective resource consumption for the selected UL bearers of the UL aggregated cells $C$.

## 2.3 Interference Between DL RE Types

When evaluating the DL for a terminal $k$, we must account for interference between different DL RE types, so we introduce *resource element overlap factors* (e.g. $O_{C\to J,k}^{PDCCH\to SSS}$) that are defined as follows.

$O_{C\to J,k}^{a\to v}$ For a terminal $k$, this is the probability that RE type "$a$" on aggressor cell $C$ interferes with RE type "$v$" on victim cell $J$ when both cells are at full DL load.

The factors are calculated taking both cells to be at full DL load so that they are *independent* of the DL loads. The way each factor is calculated depends on whether the aggressor and victim cell are on the same carrier, and is described in the following sections.

### 2.3.1 Victim and aggressor on different carriers

If the aggressor and victim are on different carriers, then the element overlap factor for any victim RE of type "$v$" on cell $J$ and any aggressor RE of type "$a$" on cell $C$ depends purely on the proportion of aggressor elements on the aggressor cell $C$.

$$O_{C\to J,k}^{a\to v} = \begin{cases} \dfrac{1}{n_C^{SSB}} \times \dfrac{N_C^{a}}{N_C^{DL}} & \text{if } a \in \{\text{PSS}, \text{SSS}, \text{PBCH}\} \\ \dfrac{N_C^{a}}{N_C^{DL}} & \text{if } a \in \{\text{PDCCH}, \text{PDSCH}\} \end{cases} ,\forall v\,. \tag{23}$$

### 2.3.2 Victim and aggressor on the same carrier

When the aggressor cell $C$ and the victim cell $J$ are on the same carrier, the element overlap factor depends on the SSB indexes ($i_{C,k}^{SSB}$ and $i_{J,k}^{SSB}$) of the two control beams affecting the terminal $k$.

For victim REs *inside* the SSB (i.e. PSS/SSS/PBCH) we first define the following *SSB overlap factor*

$$O_{C\to J,k}^{SSB\to SSB} \equiv \begin{cases} 1 & \text{if } i_{C,k}^{SSB} = i_{J,k}^{SSB}, \\ 0 & \text{if } i_{C,k}^{SSB} \neq i_{J,k}^{SSB}, \\ \dfrac{1}{\max\left(n_C^{SSB}, n_J^{SSB}\right)} & \text{if either } i_{C,k}^{SSB} \text{ or } i_{J,k}^{SSB} \text{ is unknown.} \end{cases} \quad (24)$$

If the victim and aggressor cells *both* have antennas where the SSB index has been specified, then the SSB overlap factor is either 1 or 0, and varies with location of the terminal $k$. If either SSB index is unknown at a location, then the SSB overlap factor is the probability that the victim SSB on cell $J$ receives interference from the aggressor SSB on cell $C$.

Similarly we define the following overlap factor between aggressor traffic resource elements and victim SSB resource elements.

$$O_{C\to J,k}^{TRAFFIC\to SSB} \equiv \begin{cases} 1 & \text{if } i_{J,k}^{SSB} \geq n_C^{SSB}, \\ 0 & \text{if } i_{J,k}^{SSB} < n_C^{SSB}, \\ \max\left(0, \dfrac{n_J^{SSB} - n_C^{SSB}}{n_J^{SSB}}\right) & \text{if either } i_{C,k}^{SSB} \text{ or } i_{J,k}^{SSB} \text{ is unknown.} \end{cases} \quad (25)$$

We then get the following element overlap factors for victim PSS/SSS/PBCH REs.

$$O_{C\to J,k}^{PSS\to SSS} = 0 \,. \quad (26)$$

$$O_{C\to J,k}^{PSS\to PBCH} = 0 \,. \quad (27)$$

$$O_{C\to J,k}^{SSS\to PSS} = 0 \,. \quad (28)$$

$$O_{C\to J,k}^{SSS\to PBCH} = 0 \,. \quad (29)$$

$$O_{C\to J,k}^{PBCH\to PSS} = 0 \,. \quad (30)$$

$$O_{C\to J,k}^{PBCH\to SSS} = 0 \,. \quad (31)$$

$$O_{C\to J,k}^{PSS\to PSS} = O_{C\to J,k}^{SSB\to SSB} \,. \quad (32)$$

$$O_{C\to J,k}^{SSS\to SSS} = O_{C\to J,k}^{SSB\to SSB} \,. \quad (33)$$

$$O_{C\to J,k}^{PBCH\to PBCH} = O_{C\to J,k}^{SSB\to SSB} \,. \quad (34)$$

$$O_{C\to J,k}^{PDCCH\to PSS} = O_{C\to J,k}^{TRAFFIC\to SSB} \times \frac{N_C^{PDCCH}}{N_C^{PDCCH} + N_C^{PDSCH}} \,. \quad (35)$$

$$O_{C\to J,k}^{PDCCH\to SSS} = O_{C\to J,k}^{TRAFFIC\to SSB} \times \frac{N_C^{PDCCH}}{N_C^{PDCCH} + N_C^{PDSCH}}. \tag{36}$$

$$O_{C\to J,k}^{PDCCH\to PBCH} = O_{C\to J,k}^{TRAFFIC\to SSB} \times \frac{N_C^{PDCCH}}{N_C^{PDCCH} + N_C^{PDSCH}}. \tag{37}$$

$$O_{C\to J,k}^{PDSCH\to PSS} = O_{C\to J,k}^{TRAFFIC\to SSB} \times \frac{N_C^{PDSCH}}{N_C^{PDCCH} + N_C^{PDSCH}}. \tag{38}$$

$$O_{C\to J,k}^{PDSCH\to SSS} = O_{C\to J,k}^{TRAFFIC\to SSB} \times \frac{N_C^{PDSCH}}{N_C^{PDCCH} + N_C^{PDSCH}}. \tag{39}$$

$$O_{C\to J,k}^{PDSCH\to PBCH} = O_{C\to J,k}^{TRAFFIC\to SSB} \times \frac{N_C^{PDSCH}}{N_C^{PDCCH} + N_C^{PDSCH}}. \tag{40}$$

For victim REs *outside* the SSB (i.e. PDCCH/PDSCH) we first define the following overlap factor to account for different numbers of traffic resource elements on the two cells.

$$O_{C\to J}^{TRAFFIC\to TRAFFIC} \equiv \min\left(1, \frac{N_C^{PDCCH} + N_C^{PDSCH}}{N_J^{PDCCH} + N_J^{PDSCH}}\right). \tag{41}$$

This factor is just the probability that any chosen traffic RE on cell $J$ receives interference from a traffic RE on aggressor cell $C$.

Similarly we define the following factor to give the overlap between aggressor SSB resource elements and victim traffic resource elements.

$$O_{C\to J,k}^{SSB\to TRAFFIC} \equiv \begin{cases} \dfrac{\left(1 - O_{C\to J}^{TRAFFIC\to TRAFFIC}\right)}{\left(n_C^{SSB} - n_J^{SSB}\right)} & \text{if } i_{C,k}^{SSB} \geq n_J^{SSB}, \\ 0 & \text{if } i_{C,k}^{SSB} < n_J^{SSB}, \\ \dfrac{\left(1 - O_{C\to J}^{TRAFFIC\to TRAFFIC}\right)}{n_C^{SSB}} & \text{if either } i_{C,k}^{SSB} \text{ or } i_{J,k}^{SSB} \text{ is unknown.} \end{cases} \tag{42}$$

We then get the following element overlap factors for victim PDCCH/PDSCH REs:

$$O_{C\to J,k}^{PSS\to PDCCH} = O_{C\to J,k}^{SSB\to TRAFFIC} \times \frac{N_C^{PSS}}{N_C^{SSB}}. \tag{43}$$

$$O_{C\to J,k}^{PSS\to PDSCH} = O_{C\to J,k}^{SSB\to TRAFFIC} \times \frac{N_C^{PSS}}{N_C^{SSB}}. \tag{44}$$

$$O_{C\to J,k}^{SSS\to PDCCH} = O_{C\to J,k}^{SSB\to TRAFFIC} \times \frac{N_C^{SSS}}{N_C^{SSB}}. \tag{45}$$

$$O_{C\to J,k}^{SSS\to PDSCH} = O_{C\to J,k}^{SSB\to TRAFFIC} \times \frac{N_C^{SSS}}{N_C^{SSB}}. \tag{46}$$

$$O_{C\to J,k}^{PBCH\to PDCCH} = O_{C\to J,k}^{SSB\to TRAFFIC} \times \frac{N_C^{PBCH}}{N_C^{SSB}}. \tag{47}$$

$$O_{C\to J,k}^{PBCH\to PDSCH} = O_{C\to J,k}^{SSB\to TRAFFIC} \times \frac{N_C^{PBCH}}{N_C^{SSB}}. \tag{48}$$

$$O_{C\to J,k}^{PDCCH\to PDCCH} = O_{C\to J}^{TRAFFIC\to TRAFFIC} \times \frac{N_C^{PDCCH}}{N_C^{PDCCH} + N_C^{PDSCH}}. \quad (49)$$

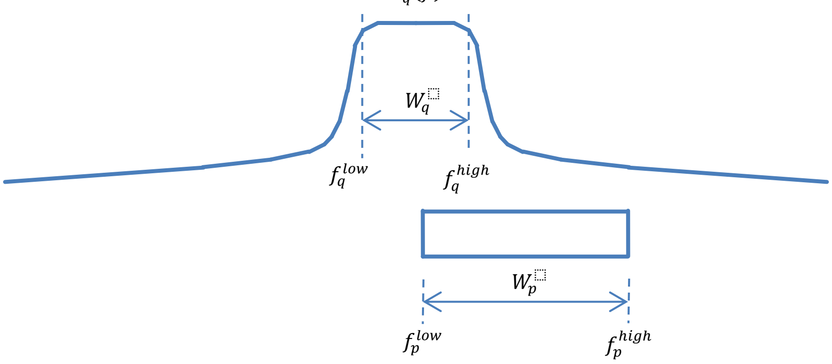
$$O_{C\to J,k}^{PDCCH\to PDSCH} = O_{C\to J}^{TRAFFIC\to TRAFFIC} \times \frac{N_C^{PDCCH}}{N_C^{PDCCH} + N_C^{PDSCH}}. \quad (50)$$

$$O_{C\to J,k}^{PDSCH\to PDCCH} = O_{C\to J}^{TRAFFIC\to TRAFFIC} \times \frac{N_C^{PDSCH}}{N_C^{PDCCH} + N_C^{PDSCH}}. \quad (51)$$

$$O_{C\to J,k}^{PDSCH\to PDSCH} = O_{C\to J}^{TRAFFIC\to TRAFFIC} \times \frac{N_C^{PDSCH}}{N_C^{PDCCH} + N_C^{PDSCH}}. \quad (52)$$

## 2.4 Calculation of Frequency-Overlap Factors

Consider an interfering carrier $q$ and a victim carrier $p$.




*Interferer transmission filter and victim carrier bandwidth*

The transmission filter of the interfering carrier is defined as a set of attenuation values at *normalised frequency* points. A normalised frequency of minus 1 corresponds to the frequency $f^{low}$ at the lowest end of the transmission bandwidth. A normalised frequency of plus 1 corresponds to the frequency $f^{high}$ at the highest end of the transmission bandwidth A normalised frequency of 0 corresponds to the centre frequency of the transmission bandwidth.

The filter attenuation values (from 200 dB to 0 dB) are mapped to corresponding gain factors in the range from 0 to 1, giving a transmission gain curve $G_q(f)$ for the interfering carrier $q$.

The UL and DL frequency-overlap factors ($O_{q\to p}^{UL\,freq}, O_{q\to p}^{DL\,freq}$) can be regarded as operators that map *power* from the bandwidth of the aggressor carrier $q$ to the bandwidth of the victim carrier $p$. Each is defined as the proportion of *power* in the aggressor carrier $q$ that affects the victim carrier $p$.

To calculate the frequency-overlap factor we calculate the area under $G_q(f)$ across the victim carrier bandwidth, and then normalise this with respect to the area under $G_q(f)$ across the interfering carrier bandwidth. This normalisation ensures that the self-overlap factor is 1.

$$O_{q\to p}^{freq} = \left(\int_{f_p^{low}}^{f_p^{high}} G_q(f)\,df\right) \Big/ \left(\int_{f_q^{low}}^{f_q^{high}} G_q(f)\,df\right) \quad (53)$$

If we need to map an *EPRE* value (without CP) from an aggressor carrier to a victim carrier then we need to use a slightly different frequency overlap factor. Consider the situation when we have a total transmission power of $P_q$ across the aggressor bandwidth $W_q$, with $P_p$ of this power affecting the victim bandwidth $W_p$. The frequency overlap factor in (53) relates these two powers as follows

$$P_p = O_{q\to p}^{freq} P_q . \tag{54}$$

We can express each power as a product of the carrier bandwidth and an EPRE (without CP) in that bandwidth. This is because EPRE (without CP) is just another name for power spectral density.

$$P_p = W_p \varepsilon_p . \tag{55}$$

and

$$P_q = W_q \varepsilon_q . \tag{56}$$

Substituting these into (54) gives this relation between EPRE values

$$\varepsilon_p = \left( \frac{O_{q\to p}^{freq} W_q}{W_p} \right) \varepsilon_q . \tag{57}$$

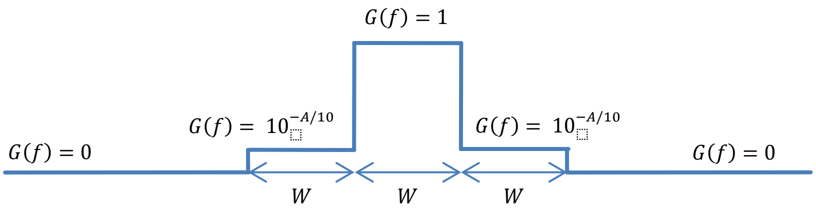
Therefore the operator that maps a DL EPRE value from an aggressor carrier $q$ to a victim carrier $p$ is given by

$$O_{q\to p}^{DL\,EPRE} = \frac{O_{q\to p}^{DL\,freq} W_q^{DL}}{W_p^{DL}} , \tag{58}$$

where $O_{q\to p}^{DL\,EPRE}$ is the *DL frequency-overlap factor for EPRE*.

### Transmission filters for other technology types

Other technologies in the tool have their transmission filters defined by a single attenuation value in dB. This corresponds to the transmission gain curve shown in the following figure.




*Default transmission filter for carrier of bandwidth W and attenuation of A dB.*

## 2.5 Load Factors

The proportion of cell traffic resources consumed by a traffic beam are represented by the following two load factors.

| | |
|---|---|
| $\Lambda_{Cm}^{DL}$ | DL load for traffic beam $m$ of cell $C$. Applies to PDCCH, PDSCH. |
| $\Lambda_{Cm}^{UL}$ | UL load for traffic beam $m$ of cell $C$. Applies to PUCCH, PUSCH. |

The load factors for a cell are defined as sums over all traffic beams on the cell.

| | |
|---|---|
| $\Lambda_{C}^{DL} \equiv \sum_{m \in C} \Lambda_{Cm}^{DL}$ | Total DL load for cell $C$. $(0 \leq \Lambda_{C}^{DL} \leq 1)$. |
| $\Lambda_{C}^{UL} \equiv \sum_{m \in C} \Lambda_{Cm}^{UL}$ | Total UL load for cell $C$. $(0 \leq \Lambda_{C}^{UL} \leq 1)$. |

The DL beam load factors $\Lambda_{Cm}^{DL}$ act as scale factors in the formula for DL interference produced to other cells by the PDCCH/PDSCH.

## 2.6 Beam Interference Reduction (ICIC) Factors

These depend on the location of the served terminal $k$. They only apply to the case when two cells ($J$ and $C$) have the same carrier ($p$) and we are considering interference between traffic resource elements on the two cells.

| | |
|---|---|
| $\Phi_{Cm \to Ji,k}^{DL}$ | This factor is between 0 and 1 and depends on the DL loads of the serving beam (beam $i$ on cell $J$) and the two most significant *aggressor* beams in the DL. |
| $\Phi_{Ji \to Cm,k}^{UL}$ | This factor is between 0 and 1 and depends on the UL loads of the serving beam (beam $i$ on cell $J$) and the two most significant *victim* beams in UL. |

### 2.6.1 Choice of Most Significant Beams

In the DL, the aggressor beams are ranked by mean received interfering PDSCH EPRE given by

$$\frac{\varepsilon_{C,p}^{PDSCH} \Lambda_{Cm}^{DL}}{L_{Cm,k}^{DL}}. \tag{59}$$

Once the two main aggressor beams for a terminal $k$ have been found, the factor $\Phi_{Cm \to Ji,k}^{DL}$ is calculated and used to reduce the DL interference from those two main aggressor beams. Note that the factor $\Phi_{Cm \to Ji,k}^{DL}$ does not apply to REs within the SSB (i.e. PSS/SSS/PBCH).

In the UL, the victim beams are ranked by mean received EPRE from the UE. This is equivalent to ranking by the inverse of the UL linkloss

$$\frac{1}{L_{Cm,k}^{UL}}. \tag{60}$$

Once the two main victim beams for a terminal $k$ have been found, the factor $\Phi_{Ji \to Cm,k}^{UL}$ is calculated and used to reduce the UL received interference that the terminal produces to the two victim beams.

### 2.6.2 Calculation of $\Phi^{DL}$ and $\Phi^{UL}$

Each beam interference reduction factor is a function of up to 3 beam loads (i.e. the serving beam and two most significant interfering/victim beams). Let $\Lambda_A$ be the load of the serving beam ($A$) and let $\Lambda_B$

and $\Lambda_C$ be the loads of the two main interfering/victim beams (*B* and *C*). Note that the extra subscripts has been dropped from the notation here for simplicity.

The overlap factor $\Lambda_{AB}$ gives the proportion of REs on beams *A* and *B* that are clashing (i.e. allocated to *both* beams) when there is perfect coordination between the three beams. The other two overlap factors $\Lambda_{BC}$ and $\Lambda_{CA}$ are defined in the same way.

The formulas for the 3 overlap factors depend on the value of the combined load defined as

$$\Lambda_{total} \equiv (\Lambda_A + \Lambda_B + \Lambda_C), \tag{61}$$

and the maximum individual load defined as

$$\Lambda_{max} \equiv \max(\Lambda_A, \Lambda_B, \Lambda_C). \tag{62}$$

There are three cases to consider:

***Case 1:* $\boldsymbol{\Lambda_{total} \leq 1}$ or $\boldsymbol{\Lambda_{total} \geq 2}$.**

In this case the optimal overlap factors can be calculated exactly using the following expressions

$$\Lambda_{AB} = \max(0, \Lambda_A + \Lambda_B - 1), \tag{63}$$

$$\Lambda_{BC} = \max(0, \Lambda_B + \Lambda_C - 1), \tag{64}$$

$$\Lambda_{CA} = \max(0, \Lambda_C + \Lambda_A - 1), \tag{65}$$

For the remaining two cases, we assume that non-clashing resources are distributed in proportion to the three loads.

***Case 2:* $\boldsymbol{1 < \Lambda_{total} < 2}$ and $\boldsymbol{\Lambda_{max} \leq \Lambda_{total}/2}$.**

This gives the following expressions for the 3 overlap factors.

$$\Lambda_{AB} = (\Lambda_{total} - 1)\left(\frac{2(\Lambda_A + \Lambda_B)}{\Lambda_{total}} - 1\right), \tag{66}$$

$$\Lambda_{BC} = (\Lambda_{total} - 1)\left(\frac{2(\Lambda_B + \Lambda_C)}{\Lambda_{total}} - 1\right), \tag{67}$$

$$\Lambda_{CA} = (\Lambda_{total} - 1)\left(\frac{2(\Lambda_C + \Lambda_A)}{\Lambda_{total}} - 1\right). \tag{68}$$

***Case 3:* $\boldsymbol{1 < \Lambda_{total} < 2}$ and $\boldsymbol{\Lambda_{max} > \Lambda_{total}/2}$.**

This gives the following expressions for the 3 overlap factors.

$$\Lambda_{AB} = \begin{cases} \dfrac{(\Lambda_{total} - 1)\Lambda_A\Lambda_B}{(\Lambda_{total} - \Lambda_{max})\Lambda_{max}} & \text{if } \Lambda_{max} \neq \Lambda_C, \\ 0 & \text{if } \Lambda_{max} = \Lambda_C \end{cases} \tag{69}$$

$$\Lambda_{BC} = \begin{cases} \dfrac{(\Lambda_{total} - 1)\Lambda_B \Lambda_C}{(\Lambda_{total} - \Lambda_{max})\Lambda_{max}} & \text{if } \Lambda_{max} \neq \Lambda_A \\ 0 & \text{if } \Lambda_{max} = \Lambda_A \end{cases}, \quad \textbf{(70)}$$

$$\Lambda_{CA} = \begin{cases} \dfrac{(\Lambda_{total} - 1)\Lambda_C \Lambda_A}{(\Lambda_{total} - \Lambda_{max})\Lambda_{max}} & \text{if } \Lambda_{max} \neq \Lambda_B \\ 0 & \text{if } \Lambda_{max} = \Lambda_B \end{cases}. \quad \textbf{(71)}$$

For the DL, the resulting interference reduction factors for aggressor beams B and C are given by

$$\Phi_{B\to A}^{DL} = (1 - \alpha) + \alpha \frac{\Lambda_{AB}}{\Lambda_A \Lambda_B}, \quad \textbf{(72)}$$

$$\Phi_{C\to A}^{DL} = (1 - \alpha) + \alpha \frac{\Lambda_{CA}}{\Lambda_C \Lambda_A}. \quad \textbf{(73)}$$

For the UL, the resulting interference reduction factors for victim beams B and C are given by

$$\Phi_{A\to B}^{UL} = (1 - \alpha) + \alpha \frac{\Lambda_{AB}}{\Lambda_A \Lambda_B}, \quad \textbf{(74)}$$

$$\Phi_{A\to C}^{UL} = (1 - \alpha) + \alpha \frac{\Lambda_{AC}}{\Lambda_A \Lambda_C}. \quad \textbf{(75)}$$

The user-specified *beam co-ordination factor* ($\alpha$) can be used to vary the interference reduction effect, from perfect co-ordination between beams ($\alpha = 1$) to no co-ordination between beams ($\alpha = 0$).

## 2.7 Downlink Formulae

### 2.7.1 Downlink Losses

**DL Loss (Ctrl)**

The DL loss for the best SSB beam of cell $J$ to terminal $k$ is given by

$$L_{J,k}^{SSB} = F(J,k,B)\left(\frac{L_{J,k}^{SSB\ pathloss}\ L_{J,k}^{SSB\ masking}}{G_J^{SSB\ antenna}} \times \frac{L_J^{feeder}\ L_J^{mha}}{G_J^{DL\ corr.}} \times \frac{L_k^{body}}{G_k^{antenna}\ G_k^{Rx\ Comb}}\right). \quad \textbf{(76)}$$

The quantity $\left(L_{J,k}^{SSB\ pathloss}\ L_{J,k}^{SSB\ antenna}\right)$ is the masked pathloss for the best SSB beam and is read from the prediction file. $G_J^{SSB\ antenna}$ is the corresponding antenna gain for the best SSB beam.

$F(J,k,B)$ is the selector function that depends on the directional antenna capabilities of the terminal $k$ and is given by (78).

**DL Loss (Traffic)**

The DL loss for traffic beam $m$ on cell $J$ and terminal $k$ is given by

$$L_{Jm,k}^{DL} = F(J,k,B)\left(\frac{L_{Jm,k}^{pathloss}\ L_{Jm,k}^{masking}}{G_{Jm}^{antenna}} \times \frac{L_J^{feeder}\ L_J^{mha}}{G_J^{DL\ corr.}} \times \frac{L_k^{body}}{G_k^{antenna}\ G_k^{Rx\ Comb}}\right). \quad \textbf{(77)}$$

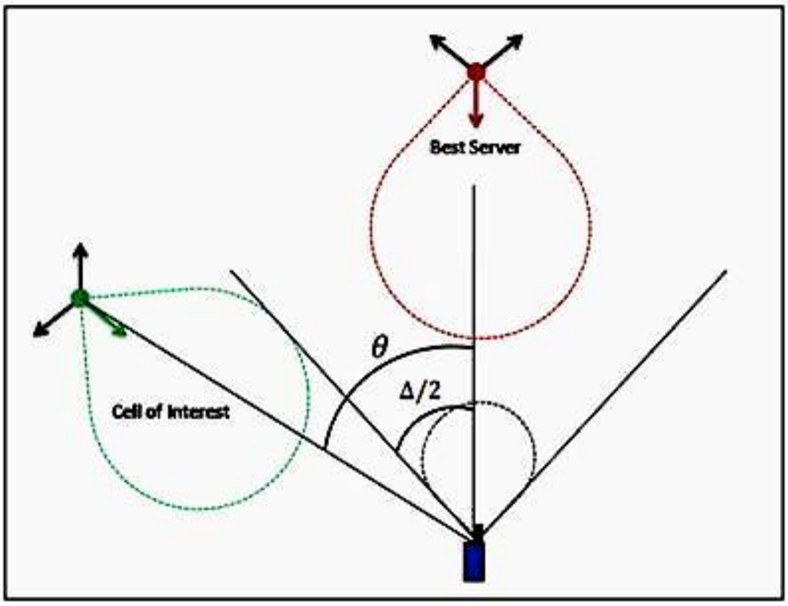
The quantity $\left(L_{Jm,k}^{pathloss}\ L_{Jm,k}^{antenna}\right)$ is the masked pathloss for traffic beam $m$ and is read from the prediction file. $G_{Jm}^{antenna}$ is the corresponding antenna gain for the traffic beam.
$F(J,k,B)$ is the selector function that depends on the directional antenna capabilities of the terminal $k$ and is given by (78).

**Terminals with Directional Antennas**

Terminals with directional antennas are handled using the *selector* function $F(J,k,B)$. This depends on the directional antenna capabilities of the terminal $k$ and is given by:

$$F(J,k,B) = \begin{cases} 1, & \text{if } |\theta| \le \frac{\Delta_k}{2} \\ \infty, & \text{otherwise} \end{cases}, \quad \textbf{(78)}$$

where $\Delta_k$ is the beamwidth of the terminal antenna. The azimuth of terminal antenna is always assumed to be pointing towards the serving/best server (sector $B$). The angle $\theta$ is the bearing of the cell of interest (sector $J$) as depicted in the figure below.




*Modelling of directional antennas on Terminal*

### 2.7.2 Downlink Received Quantities

**DL Thermal Noise EPRE**

$$\varepsilon_k^{thermal} = k\,T\,\eta_k \ , \tag{79}$$

where $\varepsilon_k^{thermal}$ is the DL thermal noise energy of a single resource element, and $\eta_k$ is the thermal noise figure of terminal $k$.

**SS-RSRP**

$$(RSRP)_{J,p,k}^{SSS} \equiv \frac{(PPRE)_{J,p}^{SSS}}{L_{J,k}^{SSB}} = \frac{\varepsilon_{J,p,k}^{SSS}\ \Delta f_p^{SSB}}{L_{J,k}^{SSB}}, \tag{80}$$

where $(RSRP)_{J,p,k}^{SSS}$ is the SS-RSRP for cell $J$ employing carrier $p$ measured by terminal $k$.

**CSI-RSRP**

$$(RSRP)_{Ji,p,k}^{CSI} \equiv \frac{(PPRE)_{J,p}^{CSI-RS}}{L_{Ji,k}^{DL}} = \frac{\varepsilon_{J,p,k}^{CSI-RS}\ \Delta f_p^{DL}}{L_{Ji,k}^{DL}}, \tag{81}$$

where $(RSRP)_{Ji,p,k}^{CSI}$ is the CSI-RSRP for traffic beam $i$ on cell $J$ employing carrier $p$ measured by terminal $k$.

**PDSCH Received PPRE**

$$(RX\ PPRE)_{Ji,p,k}^{PDSCH} \equiv \frac{(PPRE)_{J,p}^{PDSCH}}{L_{Ji,k}^{DL}} = \frac{\varepsilon_{J,p}^{PDSCH}\ \Delta f_p^{DL}}{L_{Ji,k}^{DL}}, \tag{82}$$

where $(RX\ PPRE)_{Ji,p,k}^{CSI}$ is the received PPRE of the PDSCH for traffic beam $i$ on cell $J$ employing carrier $p$ measured by terminal $k$.

**RSSI**

The RSSI used for the SS-RSRQ calculation is only measured in certain symbols and over certain RBs.

Assumptions:

- The measurement bandwidth $W_p^{RSSI}$ covers only the 20 SSB RBs of the serving beam on carrier $p$.
- The measurement is over the first 2 symbols of the slot containing the SSB for the serving beam. This corresponds to the first row of Table 5.1.3-1 in 3GPP 38.215. These first 2 symbols contain the Type0-PDCCH for the serving beam which is taken to be at the same EPRE as the SSS and independent of cell load.

The *serving beam* therefore contributes the following RX power to the RSSI measurement

$$P_{J,p}^{RSSI} = W_p^{RSSI} \times \left[\frac{\varepsilon_{J,p,k}^{Type0-PDCCH}}{L_{J,k}^{SSB}}\right], \tag{83}$$

where

$$W_p^{RSSI} = 240 \times \Delta f_p^{SSB}. \tag{84}$$

For *aggressor beams* we have different expressions for the contributing TX power depending on whether or not the aggressor beam is on the same carrier as the server.

If an aggressor beam $m$ on cell $C$ uses the *same carrier* ($p$) as the serving cell $J$, then we must use the *SSB overlap factor* to account for differing numbers of SSB beams on the two cells. We get the following RX power contribution to the RSSI measurement

$$P_{C,p}^{RSSI} = W_p^{RSSI} \times \left[ O_{C\to J,k}^{SSB\to SSB}\ \varepsilon_{C,p,k}^{Type0-PDCCH}\ \frac{1}{L_{C,k}^{SSB}} + \left(1 - O_{C\to J,k}^{SSB\to SSB}\right) \varepsilon_{C,p}^{PDCCH+PDSCH} \sum_{m\in C} \frac{\Lambda_{Cm}^{DL}}{L_{Cm,k}^{DL}} \right], \tag{85}$$

where

$$\varepsilon_{C,p}^{PDCCH+PDSCH} = \frac{N_C^{PDCCH}\, \varepsilon_{C,p}^{PDCCH} + N_C^{PDSCH}\, \varepsilon_{C,p}^{PDSCH}}{N_C^{PDCCH} + N_C^{PDSCH}}. \tag{86}$$

is the average EPRE across PDCCH and PDSCH resource elements on cell $C$. Note that the terms in square brackets in (85) represent the average TX EPRE for REs contributing to the RSSI measurement.

If an aggressor beam $m$ on cell $C$ uses a *different carrier* ($q$) to the serving cell $J$, then we work in terms of the average EPRE values of the aggressor beam *over a full frame*, and use the frequency overlap factor for EPRE ($O_{q\to p}^{DL\,EPRE}$) to map these to equivalent EPRE values in the bandwidth of the victim carrier $p$. The average RX power contribution to the RSSI measurement is then given by

$$P_{C,q\to p}^{RSSI} = W_p^{RSSI} \times O_{q\to p}^{DL\,EPRE} \times \left[ \varepsilon_{C,q,k}^{SSB} \times \frac{1}{L_{C,k}^{SSB}} + \varepsilon_{C,q}^{non-SSB} \sum_{m\in C} \frac{\Lambda_{Cm}^{DL}}{L_{Cm,k}^{DL}} \right]. \tag{87}$$

where

$$\varepsilon_{C,q}^{SSB} = \frac{1}{n_C^{SSB}} \times \frac{N_C^{PSS}\varepsilon_{C,q}^{PSS} + N_C^{SSS}\varepsilon_{C,q}^{SSS} + N_C^{PBCH}\varepsilon_{C,q}^{PBCH}}{N_C^{DL}}, \tag{88}$$

and

$$\varepsilon_{C,q}^{non-SSB} = \frac{N_C^{PDCCH}\varepsilon_{C,q}^{PDCCH} + N_C^{PDSCH}\varepsilon_{C,q}^{PDSCH}}{N_C^{DL}}. \tag{89}$$

Note that the factors weighting the EPRE values in (88) and (89) are precisely those given in (23). The resulting expression for RSSI at terminal $k$ is then given by adding received power contributions from all beams and cells to the thermal noise

$$(RSSI)_{J,p,k} = k\ T\ \eta_k\ W_p^{RSSI} + P_{J,p}^{RSSI} + \sum_{q=p} \sum_{C\neq J} P_{C,p}^{RSSI} + \sum_{q\neq p} \sum_{C\neq J} P_{C,q\to p}^{RSSI}, \tag{90}$$

where

| | |
|---|---|
| $k\ T$ | Boltzmann constant × Temperature. |
| $\eta_k$ | DL noise factor for terminal $k$. |
| $P_{J,p}^{RSSI}$ | RSSI TX power contribution from serving cell $J$ using carrier $p$. |
| $P_{C,p}^{RSSI}$ | RSSI TX power contribution from non-serving cell $C$ using the same carrier $p$. |

$P_{C,q\to p}^{RSSI}$ RSSI TX power contribution from non-serving cell $C$ using a different carrier $q$.

Although not mentioned in (90) for simplicity, the RSSI also includes power contributions from non-NR cells. The received power contribution to the RSSI from a non-NR cell $C$ using carrier $q$ is given by

$$W_p^{RSSI} \times O_{q\to p}^{DL\,EPRE} \times \left[\frac{\left(P_{C,q}^{average} / W_q^{DL}\right)}{L_{C,k}^{DL}}\right], \quad (91)$$

where $P_{C,q}^{average}$ is the average TX power of non-NR aggressor cell $C$ using carrier $q$. Comparing (91) with the right hand side of (87) one can see that the TX power spectral density of the aggressor cell $(P_{C,q}^{average} / W_q^{DL})$ plays an equivalent role to average TX EPRE.

**SS-RSRQ**

$$(SS\ RSRQ)_{J,p,k} = \frac{n_{J,p}^{RSSI\ RB}\ (RSRP)_{J,p,k}^{SSS}}{(RSSI)_{J,p,k}}, \quad (92)$$

where

$(SS\ RSRQ)_{J,p,k}$ is the SS-RSRQ for cell $J$ employing carrier $p$ and at the terminal $k$,

$n_{J,p}^{RSSI\ RB} = 20$ is the number of RBs (at SSB numerology) used for the RSSI measurement.

$(RSRP)_{J,p,k}^{SSS}$ is the SS-RSRP given by (80),

$(RSSI)_{J,p,k}$ is the RSSI given by (90).

**SS-SNR**

$$(SNR)_{J,p,k}^{SSS} = \frac{\varepsilon_{J,p,k}^{SSS}}{\varepsilon_k^{thermal} \times L_{J,k}^{SSB}}, \quad (93)$$

where

$(SNR)_{J,p,k}^{SSS}$ is the SS-SNR for cell $J$ employing carrier $p$ and at the terminal $k$,

$\varepsilon_{J,p,k}^{SSS}/L_{J,k}^{SSB}$ is the received SSS EPRE from serving cell $J$ using carrier $p$,

$\varepsilon_k^{thermal}$ is the thermal noise EPRE given by (79).

**General Expression for Total DL Received Interfering EPRE for DL SINR Formulas**

For the DL, the total received interfering EPRE for an RE of type $v$ served by beam $i$ on cell $J$ using carrier $p$ is a sum over all the other carriers ($q$), cells ($C$), beams on the cells ($m$), and aggressor RE types ($a$).

$$I^{v}_{Ji,p,k} = \sum_{q} O^{DL\,EPRE}_{q\to p} \sum_{C\neq J} \Bigg[ \left( O^{PSS\to v}_{C\to J,k}\ \varepsilon^{PSS}_{C,q,k} + O^{SSS\to v}_{C\to J,k}\ \varepsilon^{SSS}_{C,q,k} + O^{PBCH\to v}_{C\to J,k}\ \varepsilon^{PBCH}_{C,q,k} \right) \frac{1}{L^{SSB}_{C,k}} + \left( O^{PDCCH\to v}_{C\to J,k}\ \varepsilon^{PDCCH}_{C,q} + O^{PDSCH\to v}_{C\to J,k}\ \varepsilon^{PDSCH}_{C,q} \right) \sum_{m\in C} \frac{\Lambda^{DL}_{Cm}\ \Phi^{DL}_{Cm\to Ji}}{L^{DL}_{Cm,k}} \Bigg]. \quad \textbf{(94)}$$

where

| | |
|---|---|
| $I^{v}_{Ji,p,k}$ | is the interfering RX EPRE for victim RE type $v$ on terminal $k$ served by beam $i$ on cell $J$ with carrier $p$. |
| $O^{DL\,EPRE}_{q\to p}$ | is the frequency overlap factor to map DL EPRE from aggressor carrier $q$ to victim carrier $p$. |
| $O^{a\to v}_{C\to J,k}$ | is the resource element overlap factor to account for interference from element type '$a$' on the aggressor cell $C$ to the victim element type '$v$' on serving cell $J$ . |
| $\Lambda^{DL}_{Cm}$ | is the DL load factor for traffic beam $m$ of cell $C$. |
| $\Phi^{DL}_{Cm\to Ji}$ | is the beam interference reduction factor described in section 2.6. It only applies to the two most significant interferers. It is taken to be 1 for other interferers. |

**SS-SINR**

$$(SINR)^{SSS}_{J,p,k} = \frac{\left(\varepsilon^{SSS}_{J,p,k} / L^{SSB}_{J,k}\right)}{\varepsilon^{thermal}_{k} + I^{SSS}_{J,p,k}} \quad \textbf{(95)}$$

where

| | |
|---|---|
| $\varepsilon^{SSS}_{J,p,k}/L^{SSB}_{J,k}$ | is the received SSS EPRE from serving cell $J$ using carrier $p$, |
| $\varepsilon^{thermal}_{k}$ | is the thermal noise EPRE given by (79), |
| $I^{SSS}_{J,p,k}$ | is the total received interfering EPRE for the SSS, and is given by the general expression in (94) with the victim RE type $v$ set to $SSS$ |

**PDCCH SINR**

$$(SINR)^{PDCCH}_{Ji,p,k} = \frac{\left(\varepsilon^{PDCCH}_{J,p} / L^{DL}_{Ji,k}\right)}{\varepsilon^{thermal}_{k} + I^{PDCCH}_{Ji,p,k}} \ , \quad \textbf{(96)}$$

where

| | |
|---|---|
| $\varepsilon^{PDCCH}_{J,p}/L^{DL}_{Ji,k}$ | is the received PDCCH EPRE from serving beam $i$ on cell $J$ using carrier $p$, |
| $\varepsilon^{thermal}_{k}$ | is the thermal noise EPRE given by (79), |
| $I^{PDCCH}_{J,p,k}$ | is the total received interfering EPRE for the PDCCH, and is given by the general expression in (94) with the victim RE type $v$ set to $PDCCH$ |

**PDSCH SINR**

$$(SINR)_{Ji,p,k}^{PDSCH} = \frac{\left(\varepsilon_{J,p}^{PDSCH} / L_{Ji,k}^{DL}\right)}{\varepsilon_k^{thermal} + I_{Ji,p,k}^{PDSCH}} \quad , \tag{97}$$

where

$\varepsilon_{J,p}^{PDSCH} / L_{Ji,k}^{DL}$ is the received PDSCH EPRE from serving beam $i$ on cell $J$ using carrier $p$,

$\varepsilon_k^{thermal}$ is the thermal noise EPRE given by (79),

$I_{J,p,k}^{PDSCH}$ is the total received interfering EPRE for the PDSCH, and is given by the general expression in (94) with the victim RE type $v$ set to $PDSCH$.

## 2.8 Uplink Formulae

**UL Loss (Traffic)**

The UL loss for traffic beam $i$ on cell $J$ and terminal $k$ is given by

$$L_{Ji,k}^{UL} = F(J,k,B)\left(\frac{L_{Ji,k}^{pathloss}\, L_{Ji,k}^{antenna}}{G_{Ji}^{antenna}} \times \frac{L_J^{feeder}}{G_J^{UL\;corr}\;\; G_J^{mha}} \times \frac{L_k^{body}}{G_k^{antenna}}\right). \tag{98}$$

The quantity $\left(L_{Ji,k}^{pathloss}\; L_{Ji,k}^{antenna}\right)$ is the masked pathloss for the traffic beam and is read from the prediction file. $G_{Ji}^{antenna}$ is the corresponding antenna gain for the traffic beam.
$F(J,k,B)$ is the selector function that depends on the directional antenna capabilities of the terminal $k$ and is given by (78).

**UL Thermal Noise Power**

$$N_{J,p}^{UL} = k\,T\,W_p^{UL}\,\eta_J \;, \tag{99}$$

where

$N_{J,p}^{UL}$ is the UL thermal noise power over the whole UL bandwidth of cell $J$ using carrier $p$.

$k\,T$ is the Boltzmann constant × Temperature.

$W_p^{UL}$ is the the UL bandwidth of carrier $p$.

$\eta_J$ is the thermal noise figure of cell $J$.

**UL Received Interference**

|The UL received interference only comes from out-of-cell terminals. The received UL interference power on beam $i$ of cell $J$ is given by summing the power received from terminals served by other cells $C$ as follows

$$I_{Ji,p}^{UL} = \sum_{q}\sum_{C\neq J}\sum_{m\in C}\sum_{k\in m} O_{q\to p}^{UL\;freq}\;\Phi_{Cm\to Ji}^{UL}\,\frac{P_{k\in Cm,q}^{average}}{L_{Ji,k}^{UL}}, \tag{100}$$

where

| | |
|---|---|
| $I_{Ji,p}^{UL}$ | is the UL received (inter-cell) interference power captured across the whole UL carrier bandwidth for victim beam $i$ on cell $J$ using carrier $p$. |
| $P_{k\in Cm,q}^{average}$ | is the mean UL TX power for terminal $k$ served by beam $m$ on cell $C$ using carrier $q$. |
| $L_{Ji,k}^{UL}$ | is the UL linkloss between victim beam $i$ on cell $J$ and the aggressor terminal $k$. |
| $O_{q\to p}^{UL\,freq}$ | is the frequency overlap factor mapping UL power from aggressor carrier $q$ to victim carrier $p$. |
| $\Phi_{Cm\to Ji}^{UL}$ | accounts for reduction in interference due to co-ordination between the victim and aggressor beams. The factor only applies to the two most significant victims. |

**UL Interference Level (Noise Rise) per Traffic Beam**

$$(NR)_{Ji,p} = \frac{I_{Ji,p}^{UL} + N_{J,p}^{UL}}{N_{J,p}^{UL}}\ , \qquad \textbf{(101)}$$

where

| | |
|---|---|
| $(NR)_{Ji,p}$ | is the UL noise rise for beam $i$ on cell $J$ using carrier $p$. |
| $N_{J,p}^{UL}$ | is the UL thermal noise over the whole UL bandwidth as given by (99). |
| $I_{Ji,p}^{UL}$ | is the UL received interference as given by (100). |

### 2.8.1 Uplink Bandwidth Allocation Method

The following describes the UL calculation for a terminal $k$ served by beam $i$ on cell $J$ using carrier $p$. The calculation depends on the selected UL bandwidth allocation method, which determines the number of resource blocks over which a terminal is instantaneously attempting to transmit. For a fixed TX power, increasing the number of allocated resource blocks will lower the TX power spectral density and therefore lower the achieved SINR. We first define the two quantities $n_p^{minimum\_RB}$ and $n_p^{maximum\_RB}$ on carrier $p$.

$$n_p^{minimum\_RB} = \left\lceil n_p^{RB}\ \alpha_p^{UL\,bearer} \right\rceil. \qquad \textbf{(102)}$$

$n_p^{minimum\_RB}$ is the minimum number of resource blocks over which the terminal can spread its transmission power while still meeting the required bearer resource consumption ($\alpha_p^{UL\,bearer}$). See (17) to (20).

$$n_p^{maximum\_RB} = \min\left(n_p^{RB}, \left\lfloor \frac{\left(P_k^{max}/L_{Ji,k}^{UL}\right)}{SINR_{req}^{UL\,bearer}\left(I_{Ji,p}^{UL} + N_{J,p}^{UL}\right)} \right\rfloor\right). \qquad \textbf{(103)}$$

$n_p^{maximum\_RB}$ is the maximum number of resource blocks over which the terminal can spread its transmission power ($P_k^{max}$) while still satisfying the SINR requirement of the bearer ($SINR_{req}^{UL\,bearer}$). This SINR requirement is modified depending on whether the connection makes use of an Advanced Antenna System (AAS) as explained in section 7.

- **Use Minimum Resource Blocks**

This method allocates the minimum number of resource blocks, so

$$n_p^{allocated\ RB} = n_p^{minimum\_RB}. \tag{104}$$

- **Use All Resource Blocks**

This method allocates all resource blocks, so

$$n_p^{allocated\ RB} = n_p^{RB}\ . \tag{105}$$

- **Maintain Connection**

This method allocates as many resource blocks as possible while still maintaining coverage, so

$$n_p^{allocated\ RB} = \min\left[n_p^{RB}, \max\left(n_p^{minimum\_RB}, n_p^{maximum\_RB}\right)\right]. \tag{106}$$

**UL Required TX Power**

The UL required TX power of terminal $k$ served by beam $i$ of cell $J$ using carrier $p$ is given by

$$P_{p,k}^{req} = SINR_{req}^{UL\ bearer}\left(I_{Ji,p}^{UL} + N_{J,p}^{UL}\right) L_{Ji,k}^{UL} \times \frac{n_p^{allocated\ RB}}{n_p^{RB}}, \tag{107}$$

where the terminal spreads its power over $n_p^{allocated\ RB}$ resource blocks according to the relevant bandwidth allocation method as given by (104) to (106). $SINR_{req}^{UL\ bearer}$ is the SINR requirement of the UL bearer. This SINR requirement is modified depending on whether the connection makes use of an Advanced Antenna System (AAS) as explained in section 7.

The actual transmit power of the terminal ($P_{p,k}^{PC}$) is restricted to the dynamic range of the terminal, so the peak UL TX power is given by

$$P_{p,k}^{PC} = \max\left(P_k^{min}, P_{p,k}^{req}\right), \tag{108}$$

where $P_k^{max}$ and $P_k^{min}$ are the maximum and minimum power of terminal $k$ with

$$P_k^{min} = \frac{P_k^{max}}{D_k}, \tag{109}$$

where $D_k$ is the dynamic range of the terminal transmit power.

The time average UL TX power is given by

$$P_{p,k}^{average} = P_{p,k}^{PC}\ \alpha_p^{UL\ bearer} \times \frac{n_p^{RB}}{n_p^{allocated\ RB}}. \tag{110}$$

**UL SINR (Power-Controlled)**

$$(SINR)^{UL}_{Jip,k} = \frac{\left(P^{PC}_{p,k}/L^{UL}_{Ji,k}\right)}{\left(I^{UL}_{Ji,p} + N^{UL}_{J,p}\right)} \times \frac{n^{RB}_{p}}{n^{allocated\ RB}_{p}}, \tag{111}$$

Where $(SINR)^{UL}_{Ji,p,k}$ is the UL PUSCH/PUCCH power-controlled $SINR$. This is calculated by using the power-controlled TX power $\left(P^{PC}_{p,k}\right)$ of terminal $k$ which is enough to meet the UL SINR requirement $SINR^{UL\ bearer}_{req}$ of the achievable UL bearer at a given location. See (107) to (110). $(SINR)^{UL}_{Ji,p,k}$ is compared against $SINR^{UL\ bearer}_{req}$ during bearer connections scenarios.

**UL SINR Margin**

The UL SINR margin in dB is defined as

$$P^{margin}_{p,k} = 10\log_{10}\left(\frac{P^{max}_{k}}{P^{req}_{p,k}}\right). \tag{112}$$

# 3 SNAPSHOT OVERVIEW

The key purpose of a snapshot is to provide us with measures of system load for a particular distribution of terminals. To obtain these measures of system load, we must calculate uplink and downlink transmission powers for all the links in the system. A snapshot involves the following stages:

- Creating a random terminal distribution.
- Setting random terminal parameters (speeds, shadow fades and etc.)
- Calculating link powers using *Power Iterations*
- Gathering results

## 3.1 RANDOM TERMINAL DISTRIBUTION

The first stage of a snapshot involves creating a random distribution of terminals representing the offered traffic in the network. The spatial distribution of terminals must be random, but more importantly it must be *unbiased*. In other words, it must be reasonable compared to the terminal density array provided by the user. To see how this can be achieved, we need to consider a single pixel (bin) in the simulation.

Consider a pixel that has a terminal density of $D$ terminal/km$^2$ and an area of $A$ km$^2$, so that the average number of terminals in the pixel is $DA$. We note that:

- Terminal occurrences within the pixel are independent of each other, and are spatially uniform within the pixel. In other words, a terminal is just as likely to be located at one point within the pixel as any other point within the pixel.
- The probability that two or more terminals are located at *exactly* the same point within a pixel is zero. This is simply because there are an infinite number of locations within the pixel.

These imply that terminal occurrence is a spatial Poisson process within the pixel. Therefore the total number of terminals in the pixel satisfies the Poisson distribution:

$$P(k \text{ terminals}) = (DA)^k \, e^{-DA} \,/\, k! \quad \textbf{(113)}$$

We choose the number of terminals to assign to the pixel by drawing a number from this Poisson distribution. Doing this at each pixel ensures our terminal distribution is unbiased. Since the sum of many Poisson distributions is also a Poisson distribution, the total number of terminals in the snapshot will also be Poisson distributed.

One may note that if the average number of terminals at a pixel is small ($DA \ll 1$), then working to first order in $DA$ ,

$$\begin{aligned} P(0 \text{ terminal}) &\approx (1 - DA), \\ P(1 \text{ terminal}) &\approx DA. \end{aligned} \quad \textbf{(114)}$$

So one is effectively making a binary decision about whether a terminal should be placed at the pixel. After creating the random distribution, the terminals are randomly sequenced. This determines the order in which they will be considered during the power iterations.

## 3.2 Random Speed Distribution

Each randomly scattered terminal in a simulation is given a random speed according to its terminal type and the clutter type in which it resides. For each combination of terminal type and clutter type, the user specifies the following parameters that determine the speed distribution. These are:

| | |
|---|---|
| $\mu_{\text{speed}}$ | Mean speed |
| $\sigma_{\text{speed}}$ | Standard deviation of the speed distribution |
| $s_{\min}$ | Minimum speed |
| $s_{\max}$ | Maximum speed |

A random speed is then given by

$$s = \min\left(s_{\max}, \max\left( s_{\min}, \mu_{\text{speed}} + \sigma_{\text{speed}} X\right)\right) \tag{115}$$

where $X$ is a random number drawn from a normal distribution of zero mean and unit variance.

Terminals are randomly assigned as being indoor or outdoor, according to their terminal type and the clutter type in which they reside. Indoor terminals are all given a speed of zero.

When defining a bearer, the user specifies how speed affects the SINR requirement for that bearer. The user enters values at speeds of (in SI units) 3 km/h, 50 km/h, 120 km/h. Values at other speeds are obtained by linear interpolation. Values are not extrapolated to speeds higher than 120 km/h or lower than 3 km/h, which explains the labels (0-3 km/h & >= 120km/h). Therefore stationary terminals will always use the values corresponding to 0-3km/h, and there is no difference between a stationary terminal and one travelling at 3 km/h. The output arrays for the simulation are available at 3 different speeds (0-3 km/h, 50 km/h, 120 km/h) so the user can more clearly see how coverage changes with speed.

## 3.3 Power Iterations

The main task in a snapshot is to assign a set of link powers satisfying the SINR requirements of the randomly spread terminals. Before commencing the power iterations, the system is placed in the state of an unloaded network by setting all link powers to zero, and making all resources available at the cells. The link powers in the system are then calculated iteratively by repeatedly cycling through the list of randomly spread terminals and applying the following logic to each terminal.

- If the terminal is already ‘connected’, then ‘disconnect’ it as follows:
  - Zero the UL & DL powers for the terminal.
  - Zero the cell resources used by the terminal.
  - Recalculate the UL interference on all cells (because the UL power for the terminal has been zeroed).
  - Recalculate the total DL power on all cells (because the DL powers for the terminal have been zeroed).
  - Recalculate resources available on all cells (because the terminal has released resources).

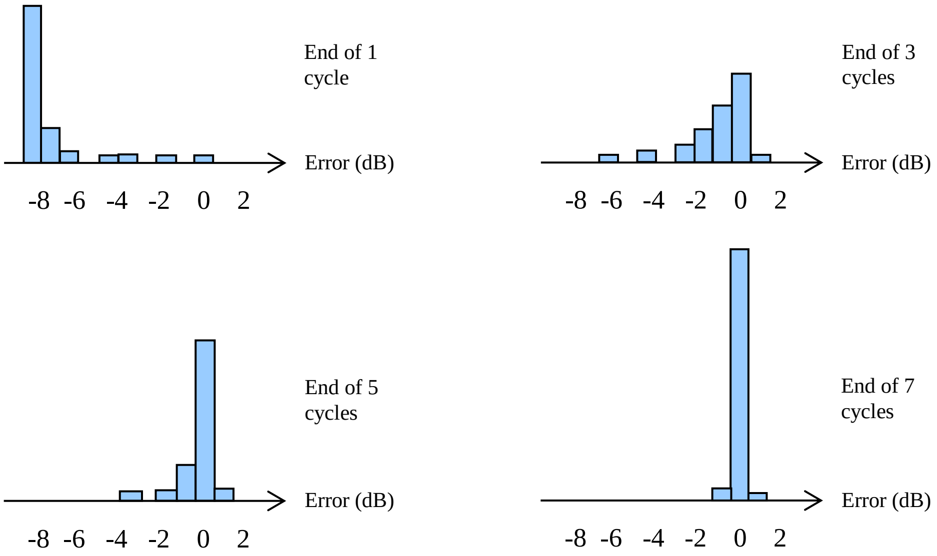
- Try and ‘connect’ the terminal to the network in the most favourable way possible. Note that this may be different to the way it was previously ‘connected’. For example, it may be preferable to use a different carrier if interference has increased since the last time the terminal was evaluated. The procedure for finding the most favourable method of connection is described in the section on *Connection Evaluation*.

- If a connection is possible, then ‘connect’ the terminal as follows:
  - Set the UL and DL powers for the terminal.
  - Set the cell resources used by the terminal.
  - Recalculate the UL interference on all cells (because the UL power for the terminal has been set).

- Recalculate the total DL power on all cells (because the DL powers for the terminal have been set).
- Recalculate resources available on all cells (because the terminal has consumed resources).

Several cycles through the list of terminals must be performed before a stable set of link powers emerge. The following diagram illustrates how a snapshot converges with successive cycles through the terminal list. The histograms show how ‘connected’ terminals underachieve their SINR requirements.

After the first cycle through the terminal list, the majority of ‘connected’ terminals underachieve their SINR requirements. This is because terminals in the first cycle see no interference and so have their link powers set to low values. Successive cycles through the terminal list produce increasingly accurate pictures of network interference. After a few cycles, practically all the ‘connected’ terminals have link powers that achieve the SINR requirements, and the system interference no longer changes significantly. The power iterations have converged to produce a plausible picture of served and failed terminals in the network.




### CONVERGENCE TEST

A good practical measure of convergence is to examine how the interference changes between cycles. This is considerably faster than measuring the distribution of achieved $SINR$ values described above.

ASSET now uses a much stronger convergence criterion for simulation snapshots, since both the UL and DL are checked. The user only needs to enter a single parameter ‘Max Power Change (%)’ on the Simulator wizard, which in fact refers to the acceptable power and interference changes between successive iterations. After each cycle through the terminal list, the percentage changes in total UL RX power and total DL TX power are noted. If these *both* fall within the user specified limit for several consecutive iterations, then the snapshot is considered to be converged. So the percentage changes in UL and DL noise must not only become small but must remain small also.

## 3.4 GATHERING OF RESULTS

The final stage of a snapshot involves gathering results. The information gathered includes cell information (e.g. resource usage, throughput, data rates, DL Power consumption, UL Interference levels and etc.) and the states of ‘connected’ terminals, and the reasons for failure of terminals which failed to be served.

# 4 CONNECTION EVALUATION IN A SNAPSHOT

## 4.1 CONNECTION SCENARIO PRIORITISATION

A *connection scenario* describes how a terminal 'connects' to the network and consists of the following set of parameters:

- The carrier used for connection
- The cell and beam used for connection
- The DL bearer used for connection
- The DL transmission mode used for connection
- The DL data rate of the connection (this is given by the DL bearer and DL transmission mode)
- The UL bearer used for connection
- The UL transmission mode used for connection
- The UL data rate of the connection (this is given by the UL bearer and UL transmission mode)

Typically, several connection scenarios are available to each terminal. Our snapshot attempts to connect the randomly spread terminals to the network in the most favourable way possible, so some logic is required for ranking the different scenarios that each terminal may use.

The rules for ranking scenarios during connection evaluation are (in order of decreasing importance):

- Prefer carriers with higher priorities to carriers with lower priorities
- Prefer cells with higher SS-RSRP levels to cells with lower SS-RSRP levels
- Prefer DL scenarios as described in 4.1.1 Bearer Selection Method
- Prefer UL scenarios as described in 4.1.1 Bearer Selection Method

The connection scenarios for each terminal are evaluated in turn (from most to least favoured) until one that permits a network connection is found. The scenario employed by a terminal may change each time it is evaluated in the power iterations, and this flexibility provides us with *link adaptation*.

### 4.1.1 Bearer Selection Method

The available Bearer Selection Methods are:

- Peak Data Rate:
  - Prefer scenarios (bearer and transmission mode combinations) achieving higher Peak Data Rates
  - If Peak Data Rates are the same, then the prefer scenarios with higher priority transmission modes
- Effective Data Rate:
  - Prefer scenarios (bearer and transmission mode combinations) achieving higher Effective Data Rates
  - This method accounts for the SINR to Error Rate mapping of the bearer: $EffectiveDateRate = PeakDataRate \times (1 - ErrorRate)$
  - If Effective Data Rates are the same, then the prefer scenarios with higher priority transmission modes

- Bearer Index: Prefer bearers with higher index (sorted on top) in the Service definition.
    - For the preferred bearer, prefer scenarios with higher priority transmission modes.

The transmission modes in order of decreasing priority are:

- SU-MIMO Multiplexing
- MU-MIMO
- SU-MIMO Diversity
- Single antenna

## 4.2 FAILURE REASONS

A connection scenario can fail for one or more of the following reasons:

- **SS RSRP**
  This means that SS-RSRP requirement specified on the terminal type is not satisfied.

- **SS RSRQ**
  This means that SS-RSRQ requirement specified on the terminal type is not satisfied.

- **SS SINR**
  This means that SS-SINR requirement specified on the terminal type is not satisfied.

- **PUSCH SINR**
  This means the terminal cannot meet the SINR requirement of the UL bearer, even if the terminal transmits at maximum power.

- **PDSCH SINR**
  This means the cell cannot meet the SINR requirement of the DL bearer.

- **UL Capacity**
  This means the cell has insufficient UL available resources (RBs) to serve the UL bearer.

- **DL Capacity**
  This means the cell has insufficient DL available resources (RBs) to serve the DL bearer.

- **User Limit**
  This means the number of served users on the cell has reached the limit specified by the *# Scheduled Users* cell parameter.

- **No valid scenarios**
  This failure reason deals with wrong/conflicting network setup which can result in terminals not being served, e.g. modulation scheme on the cells not supported by the terminal, carriers used by cells are not supported by the service, etc.

- **No pathloss data**
  This means that no pathloss data is available for the terminal's location.

If all of the connection scenarios available to a terminal fail to produce a connection, then the terminal is classified as a failure. Note that each possible scenario can fail for multiple reasons. Also, different scenarios can fail for different sets of reasons. ASSET only records the failure reasons of the top scenario, as in most cases this provides the most useful information as to why a terminal fails. The breakdown of all failure reasons except for '*No valid scenarios*' and '*No pathloss data*' are logged in respective failure reports.

# 5 OUTPUT ARRAYS AND REPORTS

## 5.1 ARRAY DEPENDENCIES

Practically all arrays are produced on a per carrier basis. Most arrays have a dependency on terminal-type because body loss and terminal antenna gain are always included in the linkloss. Many arrays depend on whether the terminal is taken to be indoor or outdoor. Indoor arrays use the in-building parameters for the clutter type at each location (i.e. indoor loss and indoor shadow-fading standard deviation). Indoor terminals are always taken to be slow moving.

Coverage arrays can be drawn even if no snapshots have been run, but the user should note that the arrays then refer to coverage in an *unloaded* system. To obtain coverage arrays for a *loaded* system the user must run some snapshots or define the loads manually. Remember that the key purpose of running snapshots is to provide measures of system load. Arrays for *coverage* tend to have a weak dependence on the number of snapshots run, and the arrays change little after a relatively small number of snapshots have been performed (10s of snapshots in most cases). This is because only a small number of snapshots are needed to get an idea of the 'Mean UL Interference Level (dB)' and 'Downlink Load (%)' on each cell.

The following table lists the types of array that are available in the Simulator, and shows some of their dependencies. The following array dependencies: 'Carrier', 'Terminal', 'Service', 'Velocity' and 'Indoor' indicate that there are per Carrier, per Terminal, per Service, per Velocity and per Indoor instances of the array.

- 'Fading' means the array depends on the standard deviation of shadow fading for the clutter type.

- 'Reliability level' means the array depends on the coverage reliability threshold in the array settings dialog. The user can change this parameter and then redraw the array without running any more snapshots.

- 'Load Levels' means the results of the array are dependent on the load levels defined in the Site Database.

- 'Snapshots': '*P*' means that the presence of the array depends on whether snapshots have been run or not. The results and accuracy of the array are dependent on the number of snapshots done.
  '*X*' means that the results and accuracy of the array are dependent on the number of snapshots done.
- 'Other Tech' means that the presence of the array is dependent on the inclusion of other technology types in the Simulation. Other technology types can be GSM, UMTS and Wi-Fi.

**Cell Load Levels** (Wizard Step 2)

- If you chose to use cell load levels specified in the database, the arrays are now available for analysis using the Map View.

- If you chose to calculate the cell load levels by running snapshots, you now have a simulation in memory that represents an "unloaded" network, although some arrays are already available for analysis at this stage. At this stage the network is "unloaded" with respect to its own technology type, but still considers any inter-technology DL/UL Noise Rise values that have been set in the Site Database. You can eliminate the effect of inter-technology DL/UL Noise Rise by deselecting the 'Allow Inter-technology Interference' option on the second step of the Simulator wizard. The Simulation Control Panel dialog box appears, and you are now ready to run snapshots to create a simulation of a "loaded" network.

| | | | | |
|---|---|---|---|---|
| **C**=**C**arrier | **T**=**T**erminal | **S**=**S**ervice | **V**=Speed/**V**elocity | **I**=**I**ndoor |
| **F**=**F**ading | **R**=**R**eliability level | **L**=**L**oad levels | **n**=S**n**apshots | **O**=Other Tech |

| | **C** | **T** | **S** | **V** | **I** | **F** | **R** | **L** | **n** | **O** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Linkloss Arrays** | | | | | | | | | | |
| DL Loss (Ctrl) | X | X | | | X | | | | | |
| DL Loss (Traffic) | X | X | | | X | | | | | |
| Nth DL Loss (Ctrl) | X | X | | | X | | | | | |
| Nth DL Loss (Traffic) | X | X | | | X | | | | | |
| Line of Sight | X | X | | | X | | | | | |
| **Downlink Reference Signal Coverage Arrays** | | | | | | | | | | |
| Best Server by SS-RSRP | X | X | | | X | | | | | |
| Nth Best Server by SS-RSRP | X | X | | | X | | | | | |
| Best SS-RSRP | X | X | | | X | | | | | |
| Nth Best SS-RSRP | X | X | | | X | | | | | |
| Nth Best SS-RSRP adjusted by CRE | X | X | | | X | | | | | |
| CRE Delta | X | X | | | X | | | | | |
| SS-RSRP Coverage Probability | X | X | | | X | X | | | | |
| SS-RSRP OK | X | X | | | X | X | X | | | |
| Number of SS-RSRP OK | X | X | | | X | X | X | | | |
| Cell Interferers | X | X | | | X | | | | | |
| Best RSRQ | X | X | | | X | | | X | X | |
| Nth Best RSRQ | X | X | | | X | | | X | X | |
| SS-RSRQ Coverage Probability | X | X | | | X | X | | X | X | |
| SS-RSRQ OK | X | X | | | X | X | X | X | X | |
| Number of SS-RSRQ OK | X | X | | | X | X | X | X | X | |
| SS-SNR | X | X | | | X | | | | | |
| SS-SINR | X | X | | | X | | | X | X | |
| CSI-RSRP | X | X | | | X | | | | | |
| DL Beam Index (Ctrl) | X | X | | | X | | | | | |
| DL Beam Index (Traffic) | X | X | | | X | | | | | |
| Nth PDSCH Received PPRE | X | X | | | X | | | | | |
| **Downlink Noise Array** | | | | | | | | | | |
| RSSI | X | X | | | X | | | X | X | |
| **Uplink Coverage Arrays** | | | | | | | | | | |
| Cell for Achievable UL Bearer | X | X | X | X | X | X | X | X | X | |
| Achievable UL Bearer | X | X | X | X | X | X | X | X | X | |
| PUSCH SINR (Power Controlled) | X | X | X | X | X | X | X | X | X | |
| PUSCH SINR Margin | X | X | X | X | X | X | X | X | X | |
| UL Req TX Power | X | X | X | X | X | X | X | X | X | |
| UL Transmission Mode | X | X | X | X | X | X | X | X | X | |
| UL MIMO Order | X | X | X | X | X | X | X | X | X | |
| UL RBs Required for Coverage | X | X | X | X | X | X | X | X | X | |
| **Downlink Coverage Arrays** | | | | | | | | | | |
| Cell for Achievable DL Bearer | X | X | X | X | X | X | X | X | X | |
| Achievable DL Bearer | X | X | X | X | X | X | X | X | X | |
| PDSCH SINR | X | X | | | X | | | X | X | |
| PDCCH SINR | X | X | | | X | | | X | X | |
| DL Transmission Mode | X | X | X | X | X | X | X | X | X | |
| DL MIMO Order | X | X | X | X | X | X | X | X | X | |
| **Downlink Throughput and Data Rate Arrays** | | | | | | | | | | |
| DL Achievable Throughput (Application) (kbps) | X | X | X | X | X | X | X | X | X | |
| DL Achievable Throughput (Effective) (kbps) | X | X | X | X | X | X | X | X | X | |
| DL Achievable Throughput (Peak) (kbps) | X | X | X | X | X | X | X | X | X | |
| DL Multi-User Rate Gain | X | X | X | X | X | X | X | | P | |
| **Uplink Throughput and Data Rate Arrays** | | | | | | | | | | |
| UL Achievable Throughput (Application) (kbps) | X | X | X | X | X | X | X | X | X | |
| UL Achievable Throughput (Effective) (kbps) | X | X | X | X | X | X | X | X | X | |
| UL Achievable Throughput (Peak) (kbps) | X | X | X | X | X | X | X | X | X | |
| UL Multi-User Rate Gain | X | X | X | X | X | X | X | | P | |
| UL RBs Used (Time-Average) | X | X | X | X | X | X | X | X | X | |
| **Miscellaneous Arrays** | | | | | | | | | | |
| Coverage Balance | X | X | X | X | X | X | X | X | X | |
| All Servers | X | X | | | X | | | | | |
| | **C** | **T** | **S** | **V** | **I** | **F** | **R** | **L** | **n** | **O** |

| | C | T | S | V | I | F | R | L | n | O |
|---|---|---|---|---|---|---|---|---|---|---|
| **Carrier Aggregation / Dual Connectivity Arrays** | | | | | | | | | | |
| CA/DC: DC Type | | X | X | X | X | X | X | X | X | |
| CA/DC: Best Cell (MCG) | | X | X | X | X | X | X | X | X | |
| CA/DC: Best Cell (SCG) | | X | X | X | X | X | X | X | X | |
| CA/DC: Number of DL Carriers (MCG) | | X | X | X | X | X | X | X | X | |
| CA/DC: Number of DL Carriers (SCG) | | X | X | X | X | X | X | X | X | |
| CA/DC: Number of UL Carriers (MCG) | | X | X | X | X | X | X | X | X | |
| CA/DC: Number of UL Carriers (SCG) | | X | X | X | X | X | X | X | X | |
| CA/DC: Total DL Throughput (Application) (kbps) | | X | X | X | X | X | X | X | X | |
| CA/DC: Total DL Throughput (Effective) (kbps) | | X | X | X | X | X | X | X | X | |
| CA/DC: Total DL Throughput (Peak) (kbps) | | X | X | X | X | X | X | X | X | |
| CA/DC: Total UL Throughput (Application) (kbps) | | X | X | X | X | X | X | X | X | |
| CA/DC: Total UL Throughput (Effective) (kbps) | | X | X | X | X | X | X | X | X | |
| CA/DC: Total UL Throughput (Peak) (kbps) | | X | X | X | X | X | X | X | X | |
| **Composite Tech Arrays** | | | | | | | | | | |
| Composite: Best Server | | X | X | | X | X | X | X | X | |
| Composite: Tech Type | | X | X | | X | X | X | X | X | X |
| Composite: All Tech Types | | X | X | | X | X | X | X | X | X |
| Composite: Best Carrier / Cell-Layer | | X | X | | X | X | X | X | X | |
| **Terminal Info Arrays** | | | | | | | | | | |
| Terminal Info: Failure Rate | | X | | | | | | | P | |
| Terminal Info: Failure Reason | | X | | | | | | | P | |
| Terminal Info: Speed (km/h) | | X | | | | | | | P | |
| Terminal Info: Tech Type (Failed) | | X | | | | | | | P | X |
| Terminal Info: Tech Type (Served) | | X | | | | | | | P | X |
| Terminal Info: Percentage Served (GSM) | | X | | | | | | | P | X |
| Terminal Info: Percentage Served (UMTS) | | X | | | | | | | P | X |
| Terminal Info: Percentage Served (LTE) | | X | | | | | | | P | X |
| Terminal Info: Percentage Served (Wi-Fi) | | X | | | | | | | P | X |
| Terminal Info: Percentage Served (5G) | | X | | | | | | | P | X |
| Terminal Info: Percentage Served (No Tech) | | X | | | | | | | P | X |
| | **C** | **T** | **S** | **V** | **I** | **F** | **R** | **L** | **n** | **O** |

## 5.2 LINKLOSS ARRAYS

**DL Loss (Ctrl) & Nth DL Loss (Ctrl)**
Dependencies: Terminal, Carrier, Indoor

These are the downlink losses as calculated by (76) for the best control beam of the Best Server and the Nth Best Server by SS-RSRP They represent average values and are therefore calculated with fades of 0 dB.

**DL Loss (Traffic) & Nth DL Loss (Traffic)**
Dependencies: Terminal, Carrier, Indoor

These are the downlink losses as calculated by (77) for the best traffic beam of the Best Server and the Nth Best Server by SS-RSRP. They represent average values and are therefore calculated with fades of 0 dB.

**Line of Sight**
Dependencies: Terminal, Carrier, Indoor

This is a two-valued array (LOS, non-LOS) for the *Best Server by SS-RSRP*. The indoor instance is non-LOS everywhere. The array is available with Enhanced Macrocell, MYRIAD and Volcano propagation model predictions.

## 5.3 Downlink Reference Signal Coverage Arrays

These arrays provide information on SSS levels and coverage probabilities. There are two types of quantity relating to the SSS, i.e. SS-RSRP and SS-RSRQ. Following arrays are provided for these.

**Best Server & Nth Best Server by SS-RSRP**
Dependencies: Terminal, Carrier, Indoor

This array reports the cell that provides the highest (and Nth highest) SS-RSRP for the terminal, based on the *Best SS-RSRP* & *Nth Best SS-RSRP* arrays.
If Cell Range Extension cell-specific SS-RSRP offsets have been set in the Site DB, then the determination of the server is based on the *Nth Best SS-RSRP adjusted by CRE* arrays.

**Best SS-RSRP & Nth Best SS-RSRP**
Dependencies: Terminal, Carrier, Indoor

These are the highest (and Nth highest) SS-RSRP levels as calculated by (80). They represent average values and are therefore calculated with fades of 0 dB.

**Nth Best SS-RSRP adjusted by CRE**
Dependencies: Terminal, Carrier, Indoor

These are Nth highest SS-RSRP levels as calculated by (80) after accounting for the Cell Range Extension cell-specific SS-RSRP offset. They represent average values and are therefore calculated with fades of 0 dB.

**CRE Delta**
Dependencies: Terminal, Carrier, Indoor

This is the difference in area coverage due to the Cell Range Extension cell-specific SS-RSRP offset. This difference is the result of the comparison of the Best Server by SS-RSRP with and without the effect of the Cell Range Extension cell-specific SS-RSRP offset.

**SS-RSRP Coverage Probability**
Dependencies: Terminal, Carrier, Indoor, Fading

This is the probability that the *Best Server by SS-RSRP* satisfies the SS-RSRP requirement specified on the terminal type. This probability depends on the standard deviation of shadow fading for the clutter type at the location. If this standard deviation has been set to zero, then there are only three possible coverage probabilities: 0% if the requirement is not satisfied, 50% if the requirement is satisfied exactly, and 100% if the requirement is exceeded.

**SS-RSRP Coverage OK**
Dependencies: Terminal, Carrier, Indoor, Fading, Reliability

This is a thresholded version of the *SS-RSRP Coverage Probability* array and has just two values (Yes/No). It has the advantage of being quicker to calculate than the *SS-RSRP Coverage Probability* array. A value of ‘Yes’ means that the SS-RSRP coverage probability meets the coverage reliability level specified in *Array Settings→Sim Display Settings*.

**Number of SS-RSRP OK**
Dependencies: Terminal, Carrier, Indoor, Fading, Reliability

This is the number of covering cells with a satisfactory SS-RSRP. A cell is counted as having a satisfactory SS-RSRP if its SS-RSRP coverage probability meets the coverage reliability level specified in *Array Settings → Sim Display Settings.*

**Cell Interferers**
Dependencies: Terminal, Carrier, Indoor

This is the number of Cell Interferers. That is the number of cells, excluding the serving cell, providing an SS-RSRP value within *x* dB of the SS-RSRP value of the serving cell or higher than the SS-RSRP value of the serving cell. The *x* dB threshold is relative and specified at the Simulator Wizard.

**SS-RSRQ**
Dependencies: Terminal, Carrier, Indoor, Snapshots/Load levels

This is the SS-RSRQ value as calculated by (92) for the *Best Server by SS-RSRP*. It represents an average value and is therefore calculated with fades of 0 dB.

**Nth Best SS-RSRQ**
Dependencies: Terminal, Carrier, Indoor, Snapshots/Load levels

This is the SS-RSRQ value as calculated by (92) for the *Nth Best Server by SS-RSRP*. It represents an average value and is therefore calculated with fades of 0 dB.

**SS-RSRQ Coverage Probability**
Dependencies: Terminal, Carrier, Indoor, Fading, Snapshots/Load levels

This is the probability that the *Best Server by SS-RSRP* satisfies the SS-RSRQ requirement specified on the terminal type. This probability depends on the standard deviation of shadow fading for the clutter type at the location. If this standard deviation has been set to zero, then there are only three possible coverage probabilities: 0% if the requirement is not satisfied, 50% if the requirement is satisfied exactly, and 100% if the requirement is exceeded.

**SS-RSRQ Coverage OK**
Dependencies: Terminal, Carrier, Indoor, Fading, Reliability, Snapshots/Load levels

This is a thresholded version of the SS-*RSRQ Coverage Probability* array and has just two values (Yes/No). It has the advantage of being quicker to calculate than the *SS-RSRQ Coverage Probability* array. A value of 'Yes' means that the SS-RSRQ coverage probability meets the coverage reliability level specified in *Array Settings → Sim Display Settings*.

**Number of SS-RSRQ OK**
Dependencies: Terminal, Carrier, Indoor, Fading, Reliability, Snapshots/Load levels

This is the number of covering cells with a satisfactory SS-RSRQ. A cell is counted as having a satisfactory SS-RSRQ if its SS-RSRQ coverage probability meets the coverage reliability level specified in *Array Settings → Sim Display Settings.*

**SS-SNR**
Dependencies: Terminal, Carrier, Indoor, Snapshots/Load levels

This is the SS-SNR level as calculated by (93) for the *Best Server by SS-RSRP*. This does not include the interference (i.e. Best SS-RSRP levels divided by the thermal noise); represents an average value and is therefore calculated with fades of 0 dB.

**SS-SINR**
Dependencies: Terminal, Carrier, Indoor, Snapshots/Load levels

This is the SS-SINR level as calculated by (95) for the *Best Server by SS-RSRP*. This includes the Inter-cell interference (i.e. Best SS-RSRP levels divided by the thermal noise plus Inter-cell Interference); represents an average value and is therefore calculated with fades of 0 dB.

**CSI-RSRP**
Dependencies: Terminal, Carrier, Indoor

This is the CSI-RSRP level as calculated by (81) for the *Best Server by SS-RSRP*. It represents an average value and is therefore calculated with fades of 0 dB.

**Nth PDSCH Received PPRE**
Dependencies: Terminal, Carrier, Indoor

This is the received signal strength of the PDSCH as calculated by (82) for the *Nth Best Server by SS-RSRP*.

**DL Beam Index (Ctrl)**
Dependencies: Terminal, Carrier, Indoor

This is the beam index of the best SSB beam of the *Best Server by SS-RSRP*.

**DL Beam Index (Traffic)**
Dependencies: Terminal, Carrier, Indoor

This is the beam index of the best traffic beam of the *Best Server by SS-RSRP*.

## 5.4 DOWNLINK NOISE ARRAYS

**RSSI (Downlink Received Power)**
Dependencies: Terminal, Carrier, Indoor, Snapshots/Load levels

This is the RSSI as calculated by (90). This represents average values and is therefore calculated with fades of 0 dB.

## 5.5 UL Coverage Arrays

**Cell for Achievable UL Bearer**
Dependencies: Terminal, Carrier, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

This is required for the Achievable UL Bearer array. It is similar to *Best Server by SS-RSRP* array but includes all bearers' dependencies and shows the server which provides the connection for the UL bearer at a given location.

**Achievable UL Bearer**
Dependencies: Terminal, Carrier, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

The purpose of this array is to provide a combined coverage plot for the UL bearers of the service. The array shows the best bearer with acceptable UL coverage, i.e. with *UL coverage probability* meeting the reliability level specified in *Array Settings → Sim Display Settings.* Bearers are ranked based on the Bearer Selection Method as described in section 4.1.

**PUSCH SINR (Power Controlled)**
Dependencies: Terminal, Carrier, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

This is the achieved UL SINR level assuming that the terminal transmits at the power controlled power level, i.e. when the terminal is using the *Achievable UL Bearer*. Uplink is powered controlled and the terminal transmits just at the level required to meet the SINR of the bearer. The achieved SINR is equal to the bearer SINR requirement after all MIMO adjustments.

**PUSCH SINR Margin**
Dependencies: Terminal, Carrier, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

This is given by (112) and shows by how much the maximum UL TX power of the terminal exceeds the *UL Req TX power* at a given location.

**UL Req TX power**
Dependencies: Terminal, Carrier, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

This is the required UL TX power of the terminal to serve the achievable UL bearer at a given location as calculated via (107).

**UL Transmission Mode**
Dependencies: Terminal, Carrier, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

This shows the achievable UL Advanced Antenna Systems (AAS) mode at a given location. The supported UL transmission modes are 'Single Antenna', 'SU-MIMO Diversity', 'SU-MIMO Multiplexing' and 'MU-MIMO'. This array can be used in conjunction with the *Achievable UL Bearer* array to determine the achievable UL bearer and transmission mode at a given location.

**UL MIMO Order**
Dependencies: Terminal, Carrier, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

This shows the number of TX and RX antennas for the *UL Transmission Mode* with the category "MxN" indicating there are M transmit elements and N receive elements. Only the most common values of M and N are reported (i.e. 1,2,4,8). All other cases are grouped together in the category "Other".

**UL RBs Required for Coverage**
Dependencies: Terminal, Carrier, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

This shows the maximum required number of UL Resource Blocks, for the highest achievable UL bearer, over which the terminal can transmit (spread its power) without losing coverage of the bearer. The required number of RBs is restricted by the employed carrier bandwidth and the ICIC settings.

## 5.6 DL Coverage Arrays

**Cell for Achievable DL Bearer**
Dependencies: Terminal, Carrier, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

This is required for the Achievable DL Bearer array. It is similar to *Best Server by SS-RSRP* array and shows the server which provides the connection for the DL bearer at a given location.

**Achievable DL Bearer**
Dependencies: Terminal, Carrier, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

The purpose of this array is to provide a combined coverage plot for the DL bearers of the service. The array shows the best bearer with acceptable DL coverage, i.e. with *DL coverage probability* meeting the reliability level specified in *Array Settings → Sim Display Settings.* Bearers are ranked based on the Bearer Selection Method as described in section 4.1.

**PDSCH SINR**
Dependencies: Terminal, Carrier, Indoor, Snapshots/Load levels

This is the highest PDSCH SINR levels as calculated by (97). This represents an average value and is therefore calculated with fades of 0 dB.

**PDCCH SINR**
Dependencies: Terminal, Carrier, Indoor, Snapshots/Load levels

This is the highest PDCCH SINR levels as calculated by (96). This represents an average value and is therefore calculated with fades of 0 dB.

**DL Transmission Mode**
Dependencies: Terminal, Carrier, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

This shows the achievable DL Advanced Antenna Systems (AAS) mode at a given location. The supported DL transmission modes are 'Single Antenna', 'SU-MIMO Diversity', 'SU-MIMO Multiplexing' and 'MU-MIMO'. This array can be used in conjunction with the *Achievable DL Bearer* array to determine the achievable DL bearer and transmission mode at a given location.

**DL MIMO Order**
Dependencies: Terminal, Carrier, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

This shows the number of TX and RX antennas for the *DL Transmission Mode* with the category "MxN" indicating there are M transmit elements and N receive elements. Only the most common values of M and N are reported (i.e. 1,2,4,8). All other cases are grouped together in the category "Other".

## 5.7 Downlink Throughput and Data Rate Arrays

This category of arrays is tiered at Peak, Effective and Application level, and the generic relation between the levels is given by:

$Peak_R$ = BearerRate
$Effective_R$ = $Peak_R \cdot$ (1- ErrorRate)
$Application_R$ = $Effective_R$ / (1+ ServiceOverheads) ·

**DL Achievable Throughput (Application) (kbps)**
Dependencies: Terminal, Carrier, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

This is the application throughput that a user can achieve at a location using the highest achievable DL bearer and the employed SU/MU-MIMO and ICIC settings. This also takes into account the SINR to Error Rate mapping defined on the DL bearers and service overheads. The reported value is not limited by the service MBR.

**DL Achievable Throughput (Effective) (kbps)**
Dependencies: Terminal, Carrier, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

This is the effective throughput that a user can achieve at a location using the highest achievable DL bearer and the employed SU/MU-MIMO and ICIC settings. This also takes into account the SINR to Error Rate mapping defined on the DL bearers but not the service overheads. The reported value is not limited by the service MBR.

**DL Achievable Throughput (Peak) (kbps)**
Dependencies: Terminal, Carrier, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

This is the peak throughput, at physical layer, that a user can achieve at a location using the highest achievable DL bearer and the employed SU/MU-MIMO and ICIC settings. The peak throughput is reported without taking into account the SINR to Error Rate mapping defined on the DL bearers and service overheads. The reported value is not limited by the service MBR.

**DL Multi-User Rate Gain**
Dependencies: Terminal, Carrier, Service, Indoor, Speed, Fading, Reliability, Snapshots

This is DL Multi User Gain for cells with Proportional Fair scheduler, as calculated by (119).

## 5.8 UPLINK THROUGHPUT AND DATA RATE ARRAYS

This category of arrays is tiered at Peak, Effective and Application level, and the generic relation between the levels is given by:

$\text{Peak}_R$ = BearerRate
$\text{Effective}_R$ = $\text{Peak}_R \cdot$ (1- ErrorRate)
$\text{Application}_R$ = $\text{Effective}_R$ / (1+ ServiceOverheads) ·

**UL Achievable Throughput (Application) (kbps)**
Dependencies: Terminal, Carrier, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

This is the application throughput that a user can achieve at a location using the highest achievable UL bearer and the employed SU/MU-MIMO settings. This also takes into account the SINR to Error Rate mapping defined on the UL bearers and service overheads. The reported value is not limited by the service MBR. The *UL Achievable Throughput (Application)* is achievable over the RBs that have been calculated by the *UL RBs Required for Coverage* array.

**UL Achievable Throughput (Effective) (kbps)**
Dependencies: Terminal, Carrier, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

This is the effective throughput that a user can achieve at a location using the highest achievable UL bearer and the employed SU/MU-MIMO settings. This also takes into account the SINR to Error Rate mapping defined on the UL bearers but not the service overheads. The reported value is not limited by the service MBR. The *UL Achievable Throughput (Effective)* is achievable over the RBs that have been calculated by the *UL RBs Required for Coverage* array.

**UL Achievable Throughput (Peak) (kbps)**
Dependencies: Terminal, Carrier, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

This is the peak throughput, at physical layer, that a user can achieve at a location using the highest achievable UL bearer and the employed SU/MU-MIMO settings. The peak throughput is reported without taking into account the SINR to Error Rate mapping defined on the UL bearers and service overheads. The reported value is not limited by the service MBR. The *UL Achievable Throughput (Peak)* is achievable over the RBs that have been calculated by the *UL RBs Required for Coverage* array.

**UL Multi-User Rate Gain**
Dependencies: Terminal, Carrier, Service, Indoor, Speed, Fading, Reliability, Snapshots

This is UL Multi User Gain for cells with Proportional Fair scheduler, as calculated by (119).

**UL RBs Used (Time-Average)**
Dependencies: Terminal, Carrier, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

This shows the time-average number of UL Resource Blocks required by the highest achievable UL bearer in order to achieve the service GBR. In case of SU-MIMO Spatial Multiplexing the value is reduced by the UL SM Rate Gain. The *UL RBs Used (Time-Average)* at a location is always less than or equal to the *UL RBs Required for Coverage*.

## 5.9 MISCELLANEOUS ARRAYS

**Coverage Balance**
Dependencies: Terminal, Carrier, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

The purpose of this array is to provide a composite uplink/downlink coverage plot for a service. The uplink is deemed to have coverage if *any* of the uplink bearers on the service have *UL Coverage Probability* meeting the coverage reliability level specified in *Array Settings → Sim Display Settings.* Similarly, the downlink is deemed to have coverage if *any* of the downlink bearers on the service have *DL Coverage Probability* meeting the coverage reliability level specified in *Array Settings → Sim Display Settings.*

**All Servers**
Dependencies: Terminal, Carrier, Indoor

This is not a true array, since it is sensitive to the location of mouse cursor. It displays information about which cells are 'covering' each pixel based on the 'All Servers' display properties (*either RSRP or RSRQ*). A set of lines is drawn between all possible serving cells to the simulation pixel where the mouse cursor is located. For pixels with more than one covering cell, the line thickness increases proportionally.

## 5.10 Carrier Aggregation/Dual Connectivity Arrays

When a terminal is using Dual Connectivity (DC) it has connections to cells belonging to two groups, the Master Cell Group (MCG) and the Secondary Cell Group (SCG). The cells within each group belong to the same MU-Node. Carrier Aggregation (CA) occurs when more than one carrier is used within a cell group. The following set of arrays handle both multi-carrier (i.e. DC and CA) and single-carrier connections.

**CA/DC: DC Type**
Dependencies: Terminal, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

There are 6 categories with the following meaning.

| | | | |
|---|---|---|---|
| LTE-DC | Dual-connectivity. | MCG is LTE. | SCG is LTE. |
| EN-DC | Dual-connectivity. | MCG is LTE. | SCG is NR. |
| NE-DC | Dual-connectivity. | MCG is NR. | SCG is LTE. |
| NR-DC | Dual-connectivity. | MCG is NR. | SCG is NR |
| LTE (No DC) | No dual-connectivity. | MCG is LTE. | No SCG. |
| NR (No DC) | No dual-connectivity. | MCG is NR. | No SCG. |

**CA/DC: Best Cell (MCG)**
Dependencies: Terminal, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

This is the best cell in the MCG with the cells ranked by the carrier priorities specified on the service type and by SS-RSRP. If CA is used in the MCG then the reported cell will be the *primary cell* and have a carrier in the set of allowed P-Cell carriers specified on the terminal type.
Note that this plot reports a value even if there is no dual-connectivity (i.e. when all connections are of the same technology and on the same node), or even for single-carrier situations in which case the plot simply reports the cell used for connection.

**CA/DC: Best Cell (SCG)**
Dependencies: Terminal, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

This is the best cell in the SCG with the cells ranked by the carrier priorities specified on the service type and by SS-RSRP. If CA is used in the SCG then the reported cell will be the *primary cell* and have a carrier in the set of allowed P-Cell carriers specified on the terminal type.
Note that this plot will not report a value if there is no dual-connectivity.

**CA/DC: Number of DL Carriers (MCG)**
Dependencies: Terminal, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

This is the number of carriers/cells used for the downlink in the MCG. Each carrier must be supported by the terminal and the service, and there must be an achievable DL bearer for the carrier.
If the reported value is greater than one then this indicates that DL CA is being used in the MCG. When CA is being used, the carrier of the primary cell will be in the set of allowed P-Cell carriers specified on the terminal type, and the remaining (secondary) cells in the MCG will have carriers in the set of allowed S-Cell carriers specified on the terminal type.

**CA/DC: Number of DL Carriers (SCG)**
Dependencies: Terminal, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

This is the number of carriers/cells used for the downlink in the SCG. Each carrier must be supported by the terminal and the service, and there must be an achievable DL bearer for the carrier.
If the reported value is greater than one then this indicates that DL CA is being used in the SCG. When CA is being used, the carrier of the primary cell will be in the set of allowed P-Cell carriers specified

on the terminal type, and the remaining (secondary) cells in the SCG will have carriers in the set of allowed S-Cell carriers specified on the terminal type.
Note that this plot will report a value of zero if there is no dual-connectivity.

**CA/DC: Number of UL Carriers (MCG)**
Dependencies: Terminal, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

This is the number of carriers/cells used for the uplink in the MCG. Each carrier must be supported by the terminal and the service, and there must be an achievable UL bearer for the carrier.
If the reported value is greater than one then this indicates that UL CA is being used in the MCG. When CA is being used, the carrier of the primary cell will be in the set of allowed P-Cell carriers specified on the terminal type, and the remaining (secondary) cells in the MCG will have carriers in the set of allowed S-Cell carriers specified on the terminal type.
The total power transmitted over all carriers in the UL must not exceed the power limits specified on the terminal.

**CA/DC: Number of UL Carriers (SCG)**
Dependencies: Terminal, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

This is the number of carriers/cells used for the uplink in the SCG. Each carrier must be supported by the terminal and the service, and there must be an achievable UL bearer for the carrier.
If the reported value is greater than one then this indicates that UL CA is being used in the SCG. When CA is being used, the carrier of the primary cell will be in the set of allowed P-Cell carriers specified on the terminal type, and the remaining (secondary) cells in the SCG will have carriers in the set of allowed S-Cell carriers specified on the terminal type.
The total power transmitted over all carriers in the UL must not exceed the power limits specified on the terminal.
Note that this plot will report a value of zero if there is no dual-connectivity.

**CA/DC Throughput Arrays**

The following throughput arrays are tiered at Peak, Effective and Application level, and the generic relation between the levels is given by:

$\text{Peak}_R = \text{BearerRate}$
$\text{Effective}_R = \text{Peak}_R \cdot (1- \text{ErrorRate})$
$\text{Application}_R = \text{Effective}_R / [\ (1+ \text{ServiceOverheads}) \cdot (1+ \text{TTIbundlingOverheads})\ ]$

**CA/DC: Total DL Throughput (Application) (kbps)**
Dependencies: Terminal, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

This is the application throughput that a user can achieve at a location using the best achievable set of DL bearers and the employed SU/MU-MIMO settings. This also takes into account the SINR to Error Rate mapping defined on the DL bearers and service overheads. The reported value is not limited by the service MBR.

**CA/DC: Total DL Throughput (Effective) (kbps)**
Dependencies: Terminal, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

This is the effective throughput that a user can achieve at a location using the best achievable set of DL bearers and the employed SU/MU-MIMO settings. This also takes into account the SINR to Error Rate mapping defined on the DL bearers but not the service overheads. The reported value is not limited by the service MBR.

**CA/DC: Total DL Throughput (Peak) (kbps)**
Dependencies: Terminal, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

This is the peak throughput, at physical layer, that a user can achieve at a location using the best achievable set of DL bearers and the employed SU/MU-MIMO settings. The peak throughput is reported without taking into account the SINR to Error Rate mapping defined on the DL bearers and service overheads. The reported value is not limited by the service MBR.

**CA/DC: Total UL Throughput (Application) (kbps)**
Dependencies: Terminal, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

This is the application throughput that a user can achieve at a location using the best achievable set of UL bearers and the employed SU/MU-MIMO settings. This also takes into account the SINR to Error Rate mapping defined on the UL bearers and service overheads. The reported value is not limited by the service MBR.

**CA/DC: Total UL Throughput (Effective) (kbps)**
Dependencies: Terminal, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

This is the effective throughput that a user can achieve at a location using the best achievable set of UL bearers and the employed SU/MU-MIMO settings. This also takes into account the SINR to Error Rate mapping defined on the UL bearers but not the service overheads. The reported value is not limited by the service MBR.

**CA/DC: Total UL Throughput (Peak) (kbps)**
Dependencies: Terminal, Service, Indoor, Speed, Fading, Reliability, Snapshots/Load levels

This is the peak throughput, at physical layer, that a user can achieve at a location using the best achievable set of DL bearers and the employed SU/MU-MIMO settings. The peak throughput is reported without taking into account the SINR to Error Rate mapping defined on the DL bearers and service overheads. The reported value is not limited by the service MBR.

## 5.11 Composite Tech Arrays

Composite Tech Arrays can account for GSM, UMTS, LTE, 5G and Wi-Fi cells collectively.

**Composite: Best Server**
Dependencies: Terminal, Indoor, Service, Fading, Reliability, Snapshots/Load levels

This is the serving cell identity. Cell ranking is primarily based on the carrier/cell layer priorities which are specified off the Service. Secondarily, cells of a specific technology type are ordered by Signal Strength (GSM: RSS, UMTS: RSCP, LTE: RSRP, 5G: SS-RSRP, Wi-Fi: DL RSS). The terminal's requirements must be met for the respective technology (GSM: Receiver RSS Sensitivity, UMTS: Required RSCP, Ec/Io and Pilot SIR, LTE: Required RSRP, RSRQ and BCH/SCH SINR, 5G: Required SS-RSRP, SS-RSRQ and RS-SINR, Wi-Fi: Required Signal Strength). The array has a dependency on Cell Load Levels, due to the interference-related terminal requirements. The display thresholds are set for each technology type individually in *Array Settings→Sim Display Settings*.

**Composite: Tech Type**
Dependencies: Terminal, Indoor, Service, Fading, Reliability, Snapshots/Load levels, Other Tech

This is the technology type of the serving cell as determined in the *Composite: Best Server* array.

**Composite: All Tech Types**
Dependencies: Terminal, Indoor, Service, Fading, Reliability, Snapshots/Load levels, Other Tech

This is the combination (not ordered list) of achieved technology types. It is a superset of the *Composite: Tech Type* array.

**Composite: Best Carrier / Cell-Layer**
Dependencies: Terminal, Indoor, Service, Fading, Reliability, Snapshots/Load levels

This is the Carrier in case of UMTS, LTE, 5G and Wi-Fi, or Cell-Layer in case of GSM of the serving cell as determined in *Composite: Best Server* array.

## 5.12 TERMINAL INFO ARRAYS

**Terminal Info: Failure Rate**
Dependencies: Terminal, Snapshots

The failure rate is the proportion of attempted terminals at a pixel that failed to make a connection. It is calculated as a percentage as follows:

Failure Rate (%) = 100 * (Failed Terminals) / (Attempted Terminals)

The accuracy of the result at a pixel is clearly limited by the number of attempts made at the pixel. For example, if only one attempt has been made, the result will either be 0% or 100%. So the *Failure Rate* array gives a rough visualisation of the problem areas of the network.

**Terminal Info: Failure Reason**
Dependencies: Terminal, Snapshots

This plot shows failures and successes in a single plot. The value shown at a pixel is determined by the last terminal that was attempted there, regardless of the snapshot in which it was attempted. So if the last terminal that was attempted at a pixel succeeded, then the pixel will be labelled a success, regardless of how many terminals may have failed there in other snapshots. Likewise, if the last terminal at a pixel failed, then the pixel will be labelled as a failure, regardless of how many terminals succeeded there in other snapshots. Therefore locations that are more likely to serve terminals in a snapshot rather than fail them are more likely to be labelled as successes than failures.

A terminal can fail for multiple reasons. When this occurs, only a single reason is reported when writing a value at the pixel. This is achieved by sensibly ranking the failure reasons for the terminal and using the most dominant one. For example, there is no point in indicating a capacity failure for a terminal if it does not have coverage. In other words, coverage failures rank more highly than capacity failures.

The failure reason categories are ranked as follows (most dominant failure reasons first). For clarity, the categories in the legend are shown in the same order.

- Success
- No pathloss data
- No valid scenarios
- SS RSRP
- SS RSRQ
- SS SINR
- PUSCH SINR
- PDSCH SINR
- UL Capacity
- DL Capacity
- User Limit

**Terminal Info: Speed (km/h)**
Dependencies: Terminal, Snapshots

This plot shows the speed of the terminal in the corresponding *Failure Reason* plot. The value shown at a pixel is determined by last terminal that was attempted there, regardless of the snapshot in which it was attempted.

**Terminal Info: Tech Type**

This category comprises two arrays, the *Terminal Info: Tech Type (Served)* and the *Terminal Info: Tech Type (Failed)*. After a terminal has been evaluated in a snapshot, it will be marked in precisely one of the following ways:

1) As failure due to “No Valid Scenarios / No Covering Cells” in the *Tech Type (Failed)* array.
   It will also appear as a “No Valid Scenarios / No Covering Cells” failure in the *Failure Reason* array of every individual technology.
2) As a success in *Tech Type (Served)* array, showing the tech type used for connection.
   The *Failure Reason* array for that technology will show “Success”.
3) As a failure in the *Tech Type (Failed)* array, showing the tech of the most relevant failure reason.
   The *Failure Reason* array for that technology will show the according failure reason.

**Terminal Info: Tech Type (Served)**
Dependencies: Terminal, Snapshots, Other Tech

This array shows the serving technology type (GSM, UMTS, LTE, 5G or Wi-Fi) where
the *Terminal Info (GSM): Failure Reason* array is reporting Success or
the *Terminal Info (UMTS): Failure Reason* array is reporting Success or
the *Terminal Info (LTE): Failure Reason* array is reporting Success or
the *Terminal Info (5G): Failure Reason* array is reporting Success or
the *Terminal Info (Wi-Fi): Failure Reason* array is reporting Success.
There is a separate category to show locations with No Valid Scenarios / No Covering Cells.

**Terminal Info: Tech Type (Failed)**
Dependencies: Terminal, Snapshots, Other Tech

This array shows the failed technology type (GSM, UMTS, LTE, 5G or Wi-Fi) where
the *Terminal Info (GSM): Failure Reason* array is not reporting Success or
the *Terminal Info (UMTS): Failure* Reason array not reporting Success or
the *Terminal Info (LTE): Failure Reason* array not reporting Success or
the *Terminal Info (5G): Failure Reason* array not reporting Success or
the *Terminal Info (Wi-Fi): Failure Reason* array not reporting Success.
There is a separate category to show locations with No Valid Scenarios / No Covering Cells.

**Terminal Info: Percentage Served**
Dependencies: Terminal, Snapshots, Other Tech

This category comprises five arrays. The presence of the individual array instances depends on the technology types that are included in the simulation.
*Terminal Info: Percentage Served (GSM)*
*Terminal Info: Percentage Served (UMTS)*
*Terminal Info: Percentage Served (LTE)*
*Terminal Info: Percentage Served (5G)*
*Terminal Info: Percentage Served (Wi-Fi)*
*Terminal Info: Percentage Served (No Tech)*

After a terminal has been evaluated in a snapshot, it will be marked by precisely one technology type or as ‘No Tech’. The value shown at a pixel is determined by the all terminals that were attempted there, regardless of the snapshot in which they were attempted.

$$Percentage\ Served\ \left(Tech_J\right) = \frac{Served\ Attempts\ on\ Tech_J}{Total\ Attempts}\ ,$$

where

$Tech_J = \{GSM, UMTS, LTE, 5G, Wi\text{-}Fi, NoTech\}$ and $\sum_J Percentage\ Served\ (Tech_J) = 1.$

## 5.13 Simulator Reports

Reports depicting the network performance are available after running the Monte Carlo Simulator in the snapshot mode. This section presents the available network performance reports and their description.

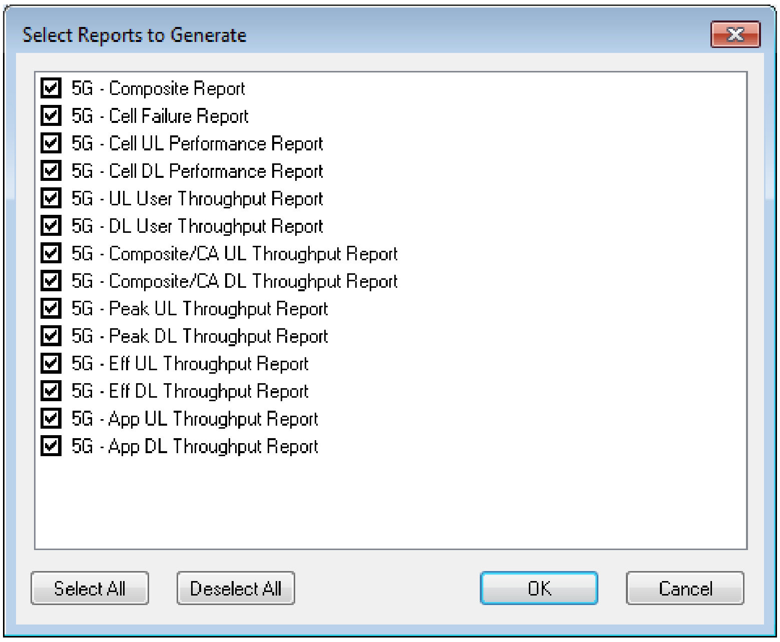



*Figure 12: Available Network analysis reports*

**5G - Composite Report**
Dependencies: Service

This report provides the summary of each service in terms of 'Mean Attempted', 'Mean Served' and 'Mean Failed', terminals. The 'Contributions to Failure' section lists the possible reasons, as explained in section 4.2, and their percentages that contribute to terminals not being served. Terminals can fail to connect for multiple reasons so the failure reason percentages can sum to more than 100%.

**5G - Cell Failure Report**
Dependencies: Service

This provides a breakdown of the 'Composite Report' and lists the per cell failure reasons for 'Mean Failed' terminals. Failure reasons and their respective percentages that contribute to terminals not being served are logged against each cell and per service.

**5G - Cell Uplink Performance Report**

This report provides the UL noise rise level and UL load information for each traffic beam on each cell. The UL load summed over all beams on a cell will not exceed 100%. For each cell, the *highest* per-beam noise rise can be applied to the Site Database (since there is only a single noise rise value stored for each cell in the database).

**5G - Cell Downlink Performance Report**

This report provides the DL load level and DL traffic (PDCCH and PDSCH) power for each traffic beam on each cell. The DL load summed over all beams on a cell will not exceed 100%. For each cell, the *total* DL load (summed over all traffic beams) can be applied to the Site Database.

### 5.13.1 Throughput Reports

The available throughput reports are tiered at Peak, Effective and Application level, and the generic relation between the levels is given by:

$Application_R$ = ServiceRate
$Effective_R$ = $Application_R$ · (1+ ServiceOverheads).
$Peak_R$ = $Effective_R$ / (1- ErrorRate)

**5G - UL / DL User Throughput Report (kbps)**
Dependencies: Service

These reports provide the per cell average user throughputs for each service. The peak, effective and application user throughputs are reported.

**5G - UL / DL Composite Throughput Report (kbps)**
Dependencies: Service

These composite reports provide the summary of per cell offered and served throughput for a given service. Offered throughput of a cell is calculated as the MBR rate of the service increased by the service overhead and multiplied by ‘Mean number of Attempts’. First the GBR demands of terminals are attempted and if resources are still available to allocate, terminals are upgraded to serve potentially up to their MBR demands. Summary of throughputs are presented for ‘Peak’ (at physical layer), ‘Effective’ and ‘Application’ levels.

**5G - UL / DL CA (Intra) Throughput Report (kbps)**

These CA reports provide the summary of served throughput for a given service processed at the logical Intra-gNodeB CA-group level, for carrier-aggregated cells belonging to the same gNodeB. These throughputs are reported separately for SC (Single Carrier) connections and CA (Carrier Aggregation) connections.

**5G - UL / DL CA (Inter) Throughput Report (kbps)**

These CA reports provide the summary of served throughput for a given service processed at the logical Inter-gNodeB CA-group level, for carrier-aggregated cells belonging to multiple gNodeBs.

**5G - UL / DL Cell Throughput Type Report (kbps)**

These CA reports provide the summary of served throughput per cell for a given service. The Total cell throughputs are separated for SC (Single Carrier) connections, CA Intra (Intra-gNodeB Carrier Aggregation) connections and CA Inter (Inter-gNodeB Carrier Aggregation) connections. Summary of throughputs are presented for ‘Peak’ (at physical layer), ‘Effective’ and ‘Application’ levels.

**5G - UL/DL Peak Throughput Report (kbps)**
Dependencies: Service, Bearer

These reports provide the breakdown of per cell served peak, at physical layer, throughputs for each service. The breakdown is given in terms of served peak throughput by each bearer.

**5G - UL/DL Effective Throughput Report (kbps)**
Dependencies: Service, Bearer

These reports provide the breakdown of per cell served effective throughputs for each service. The breakdown is given in terms of served effective throughput by each bearer.

**5G - UL/DL Application Throughput Report (kbps)**
Dependencies: Service, Bearer

These reports provide the breakdown of per cell served application throughputs for each service. The breakdown is given in terms of served application throughput by each bearer.

# 6 SCHEDULING AND RADIO RESOURCE MANAGEMENT

5G support in ASSET follows a complex and state-of-the-art QoS architecture to replicate the scheduling and Radio Resource Management (RRM) methodologies of real networks. This includes service prioritisation based on the QoS Class Indicator (QCI) associated with each LTE service. It also includes the management and distribution of resources among the terminals, depending on the traffic type of the service. Different scheduling algorithms are available to determine the allocation of these resources and to simulate network capacity for a mixture of services/traffic types and varying load levels.

LTE services consist of two traffic types

- Real Time
- Non-Real Time

Real Time services and Non-Real Time service have an associated Maximum Bitrate (MBR) demand in addition to the (minimum) Guaranteed Bitrate (GBR).

When running a simulation, ASSET first attempts to serve the GBR demands of the services, taking into account the Priority values of the different services. Resources are first allocated to the service with the highest priority, and then to the next highest priority service, and so on. Terminals are only served if there are enough resources available to satisfy their GBR demand. In the event that there are not enough resources to fulfil the GBR demand of all Real Time and Non-Real Time services, then only the Priority values of the services determine the precedence of resource allocation.

If resources are still available after the GBR demands have been met, then different scheduling algorithms can be employed to attempt to upgrade the service rate in order to serve the MBR demands. This is where Scheduling and Radio Resource Management (RRM) are relevant. Here is an illustration:

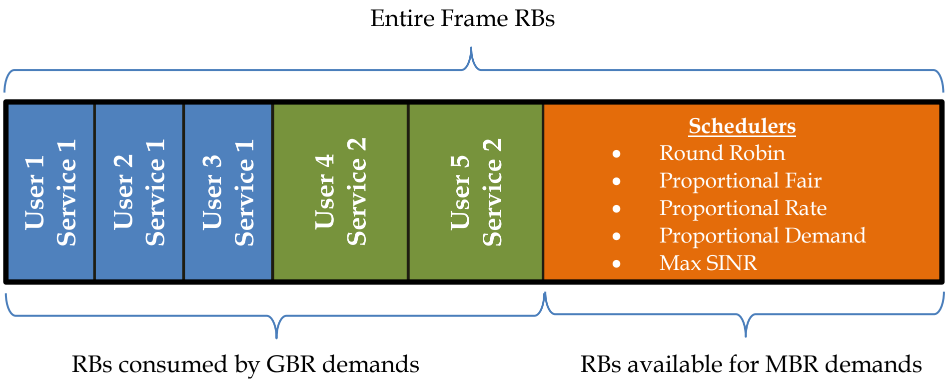



*Illustration of Scheduling and RRM methodology*

If MBR is set equal to GBR for a service, then as far as the GBR is served, no further upgrading of the service is rate is attempted.

To satisfy the MBR of the services, there are five different scheduling algorithms available:

- Round Robin
- Proportional Fair
- Proportional Rate
- Proportional Demand
- Max SINR

## 6.1 Round Robin

The aim of this scheduler is to share the remaining unused resources equally among the terminals in order to satisfy their MBR demand. This is a recursive algorithm and continues to share resources equally among terminals, until all MBR demands have been met or there are no more resources left to allocate. This can be explained as follows:

The scheduler progressively increases the resource usage factors $\alpha_k^{DL}$ and $\alpha_k^{UL}$ allocated to terminals. At the start of the recursive procedure, terminals have resource usage factors corresponding to the minimum values $\alpha_{p,min}^{DL\,bearer,tx}$ and $\alpha_{p,min}^{UL\,bearer}$ given in (17) and (19) respectively. The recursion then proceeds as follows:

**STEP 1:** Calculate the DL and UL unused resources, $RE^{DL\,unused}$ and $RE^{UL\,unused}$.

**STEP 2:** If there are a total of $K$ upgradeable terminals, then the $k$th terminal is assigned extra resources given by

$$\begin{aligned} &\min\left(\Omega_k^{DL}, \frac{RE^{DL\,unused}}{K}\right), \qquad \text{in the DL} \\ &\min\left(\Omega_k^{UL}, \frac{RE^{UL\,unused}}{K}\right), \qquad \text{in the UL} \end{aligned} \tag{116}$$

where the additional resource demands $\Omega_k^{DL}$ and $\Omega_k^{UL}$ are given by

$$\Omega_k^{DL} = RE_p^{DL\,traffic}\left[\alpha_{p,max}^{DL\,bearer,tx} - \alpha_k^{DL}\right], \tag{117}$$

and

$$\Omega_k^{UL} = RE_p^{UL\,traffic}\left[\min\left(\alpha_{Cap}, \alpha_{p,max}^{UL\,bearer}\right) - \alpha_k^{UL}\right], \tag{118}$$

where $\alpha_{p,max}^{DL\,bearer,tx}$ and $\alpha_{p,max}^{UL\,bearer}$ are the maximum resource usages given in (18) and (20) respectively. Finally, $\alpha_{Cap}$ which is only applicable in the UL is defined as the maximum resource usage that can be assigned in the UL while maintaining coverage.

**STEP 3:** Go to STEP 1.

## 6.2 PROPORTIONAL FAIR

The aim of this Scheduler is to allocate the remaining unused resources as fairly as possible in such a way that, on average, each terminal gets the highest possible throughput achievable under the channel conditions.

This scheduler builds on the principles of the Round Robin scheduler and additionally exploits the fast fading characteristics of the propagation channel by resourcefully choosing the most favourable (in terms of radio conditions) users for transmission at each instant. The effect of transmitting at instants of positive fade can result in reduced average resource consumption because higher data rates are instantaneously achieved. As a result of this scheduling algorithm, a Multi User Gain is achieved.

### 6.2.1 Multi User Gain

The Multi User Gain for terminal $k$ is given by:

$$MUG_k^{DL} = 1 + f_{J,k}^{NRA} \; g_{J,k}^{DL,\; SINR\,\&\,MIMO} \; g_J^{N-Users}$$
$$MUG_k^{UL} = 1 + f_{J,k}^{NRA} \; g_{J,k}^{UL,\; SINR\,\&\,MIMO} \; g_J^{N-Users} \quad , \qquad \textbf{(119)}$$

where

$f_{J,k}^{NRA}$ is the 'MUG non-Rayleigh Adjustment' for cell $J$ at the location of terminal $k$. The Multi User Gain for Proportional Fair scheduler relies on a low correlation between the signal paths to the antenna elements (Rayleigh environment). Locations that are in Line of Sight or that have high SINR are more likely to have highly correlated signal paths (non-Rayleigh environment). If the cell is using the Proportional Fair scheduler, you can select options to adjust the Multi User Gain under non-Rayleigh conditions in the *MUG non-Rayleigh Adjustment for Proportional Fair* cell parameters. If the options are not set or if the terminal is in Rayleigh conditions then $f_{J,k}^{NRA}$ is 1.

$g_{J,k}^{DL/UL,SINR\,\&\,MIMO}$ is the 'MUG SINR & MIMO Dependence' that is the Multi User Gain Dependence on Traffic & Control SINR conditions and MIMO order for terminal $k$ served by cell $J$, in the downlink and in the uplink respectively. This is an internal table of values for all applicable DL and UL MIMO configurations and SINR ranges. This table can be overridden by one generic value by selecting the 'Override SINR and MIMO Dependence' option and setting a value in *Configuration → Lookup Tables and Curves → LTE PF Scheduler Multi User Gain*.

$g_J^{N-Users}$ is the 'MUG Number-of-Users Dependence' that is a function of the number of served users by cell $J$. The values for 'MUG Number-of-Users Dependence' are specified in *Configuration → Lookup Tables and Curves → LTE PF Scheduler Multi User Gain.*

The reduced average resource consumption due to the instantaneously higher data rates for terminal $k$ for a bearer configured for carrier $p$ is given by:

$$\alpha_{p,k}^{DL\,bearer,tx,MUG} = \frac{\alpha_p^{DL\,bearer,tx}}{MUG_k^{DL}}$$
$$\alpha_{p,k}^{UL\,bearer,tx,MUG} = \frac{\alpha_p^{UL\,bearer,tx}}{MUG_k^{UL}} \quad , \qquad \textbf{(120)}$$

## 6.3 Proportional Rate

The aim of this Scheduler is to allocate the remaining unused resources in proportion to the achievable bearer data rate under the channel conditions.

This is a recursive algorithm. The remaining resources are shared between the terminals in proportion to their bearer data rates. Terminals with higher data rates get a larger share of the available resources. Each terminal gets either the resources it needs to satisfy its MBR demand, or its weighted portion of the available/unused resources, whichever is smaller. This recursive allocation process continues until all MBR demands have been met or there are no more resources left to allocate.

The scheduler progressively increases the resource usage factors $\alpha_k^{DL}$ and $\alpha_k^{UL}$ allocated to terminals. At the start of the recursive procedure, terminals have resource usage factors corresponding to the minimum values $\alpha_{p,min}^{DL\,bearer,tx}$ and $\alpha_{p,min}^{UL\,bearer}$ given in (17) and (19) respectively. The recursion then proceeds as follows:

**STEP 1:** Calculate the DL and UL unused resources, $RE^{DL\,unused}$ and $RE^{UL\,unused}$.

**STEP 2:** Each upgradeable terminal $k$ is assigned extra resources given by

$$\begin{aligned}
&\min\left(\Omega_k^{DL}\,,\ RE^{DL\,unused}\left(\frac{R_k^{DL\,bearer,tx}}{\sum_i R_i^{DL\,bearer,tx}}\right)\right), \qquad \text{in the DL}\\
&\min\left(\Omega_k^{UL}\,,\ RE^{UL\,unused}\left(\frac{R_k^{UL\,bearer,tx}}{\sum_i R_i^{UL\,bearer,tx}}\right)\right), \qquad \text{in the UL}
\end{aligned} \tag{121}$$

where the additional resource demands $\Omega_k^{DL}$ and $\Omega_k^{UL}$ are given by

$$\Omega_k^{DL} = RE_p^{DL\,traffic}\left[\alpha_{p,max}^{DL\,bearer,tx} - \alpha_k^{DL}\right], \tag{122}$$

and

$$\Omega_k^{UL} = RE_p^{UL\,traffic}\left[\min\left(\alpha_{Cap}\,, \alpha_{p,max}^{UL\,bearer}\right) - \alpha_k^{UL}\right], \tag{123}$$

where $\alpha_{p,max}^{DL\,bearer,tx}$ and $\alpha_{p,max}^{UL\,bearer}$ are the maximum resource usages given in (17) and (19) respectively. Finally, $\alpha_{Cap}$ which is only applicable in the UL is defined as the maximum resource usage that can be assigned in the UL while maintaining coverage.

**STEP 3:** Go to STEP 1.

## 6.4 PROPORTIONAL DEMAND

The aim of this scheduler is to allocate the remaining unused resources to terminals in proportion to their additional resource demands. This is a non-recursive allocation process and results in either satisfying the MBR demands of all terminals or the consumption of all of the resources. This resource allocation is done in two steps:

**STEP 1:** Calculate the DL and UL unused resources, $RE^{DL\,unused}$ and $RE^{UL\,unused}$.

**STEP 2:** Each of the upgradeable terminal is $k$ assigned extra resources given by

$$\begin{cases} \min\left(\Omega_k^{DL}\,,\; RE^{DL\,unused}\left(\frac{\Omega_k^{DL}}{\sum_i \Omega_i^{DL}}\right)\right), & \text{in the DL} \\ \min\left(\Omega_k^{UL}\,,\; RE^{UL\,unused}\left(\frac{\Omega_k^{DL}}{\sum_i \Omega_i^{DL}}\right)\right), & \text{in the UL} \end{cases}, \tag{124}$$

where the additional resource demands $\Omega_k^{DL}$ and $\Omega_k^{UL}$ are given by

$$\{\Omega_k^{DL} = RE_p^{DL\,traffic}\left[\alpha_{p,max}^{DL\,bearer,tx} - \alpha_k^{DL}\right], \tag{125}$$

and

$$\Omega_k^{UL} = RE_p^{UL\,traffic}\left[\min\left(\alpha_{Cap}\,,\alpha_{p,max}^{UL\,bearer}\right) - \alpha_k^{UL}\right]\,, \tag{126}$$

where $\alpha_{p,max}^{DL\,bearer,tx}$ and $\alpha_{p,max}^{UL\,bearer}$ are the maximum resource usages given in (17) and (19) respectively. Finally, $\alpha_{Cap}$ which is only applicable in the UL is defined as the maximum resource usage that can be assigned in the UL while maintaining coverage.

## 6.5 Max SINR

The aim of this Scheduler is to maximise the average cell throughput. This is a non-recursive resource allocation process where terminals with higher bearer rates (and consequently higher SINR) are preferred over terminals with lower bearer rates (and consequently lower SINR). This means that resources are allocated first to those terminals with better SINR/channel conditions, thereby maximising the throughput. The extra resources allocated to the *k*th upgradeable terminal are given by

$$\begin{cases} \min\left(\Omega_k^{DL}, RE^{DL\,unused}\right), & \text{in the DL} \\ \min\left(\Omega_k^{UL}, RE^{UL\,unused}\right), & \text{in the UL} \end{cases} \tag{127}$$

where the additional resource demands $\Omega_k^{DL}$ and $\Omega_k^{UL}$ are given by

$$\Omega_k^{DL} = RE_p^{DL\,traffic}\left[\alpha_{p,max}^{DL\,bearer,tx} - \alpha_k^{DL}\right], \tag{128}$$

and

$$\Omega_k^{UL} = RE_{p,q}^{UL\,traffic}\left[\min\left(\alpha_{Cap}, \alpha_{p,max}^{UL\,bearer}\right) - \alpha_k^{UL}\right] , \tag{129}$$

where $\alpha_{p,max}^{DL\,bearer,tx}$ and $\alpha_{p,max}^{UL\,bearer}$ are the maximum resource usages given in (17) and (19) respectively. Finally, $\alpha_{Cap}$ which is only applicable in the UL is defined as the maximum resource usage that can be assigned in the UL while maintaining coverage

# 7 Advanced Antenna Systems

Advanced Antenna Systems (AAS) such as Single-User (SU) MIMO and Multi-User (MU) MIMO architecture is the key for providing higher peak data rates and improved coverage in LTE systems. SU-MIMO refers to all spatial diversity and multiplexing schemes where the MIMO channel is solely assigned to a single user/terminal. In contrast, MU-MIMO employs the same time-frequency resources to serve multiple users/terminals.

The following AAS modes are supported in ASSET for both link directions:

- SU-MIMO
    - Spatial Multiplexing (SM)
    - Spatial Diversity (SD) for transmit and/or receive.
    - Adaptive Switching between (SD and SM)
- MU-MIMO

Certain modes can be combined as described in the section on mode selection. Note that beamforming is covered in detail in a separate section of this document.

## 7.1 SU-MIMO

This includes spatial multiplexing (SM), spatial diversity (SD) and the adaptive switching between these two MIMO modes. Release 9 of 3GPP standards supports spatial multiplexing only in DL, however ASSET allows the users to model all modes of SU-MIMO in both link directions. This is due to the fact that spatial multiplexing in the UL will be supported in future releases.

### 7.1.1 Spatial Multiplexing (SM)

This increases the per user data rate/throughput by transmitting multiple streams of data dedicated for a single user from multiple antennas at the transmitter and receiver sides. LTE DL transmission modes support closed-loop and open-loop spatial multiplexing (SM). The former requires the availability of both the Precoding Matrix Indicator (PMI) and Rank Indicator (RI) whereas the latter requires only the

RI. Assuming the path gains between individual antenna pairs are independent and identically distributed (i.i.d.) Rayleigh distributed, a SM rate gain $G^{SM}$ can be realized in the high $SINR$ regime, where $G^{SM} = \min(N^{tx}, N^{rx})$ with $N^{tx}$ and $N^{rx}$ are the number of transmit and receive antennas respectively.

In ASSET, the special multiplexing gain (*enhanced data rate*) $G^{SM}$ is modelled by modifying the minimum and maximum resource consumptions/usage of DL and UL bearers i.e. $\alpha_{p,min}^{DL\ bearer,tx}$, $\alpha_{p,max}^{DL\ bearer,tx}$, $\alpha_{p,min}^{UL\ bearer}$, $\alpha_{p,max}^{UL\ bearer}$ as calculated in (17) and (19) respectively. The modified minimum and maximum resource consumptions in the DL and UL can be expressed as:

$$\alpha_{p,min}^{DL\ bearer,tx,SM} = \frac{\alpha_{p,min}^{DL\ bearer,tx}}{G^{SM,DL}\ C_{corr}^{SM,DL}} \quad \text{and} \quad \alpha_{p,max}^{DL\ bearer,tx\ ,SM} = \frac{\alpha_{p,max}^{DL\ bearer,tx}}{G^{SM,DL}\ C_{corr}^{SM,DL}}\ , \tag{130}$$

and

$$\alpha_{p,min}^{UL\ bearer,tx,SM} = \frac{\alpha_{p,min}^{UL\ bearer,tx}}{G^{SM,UL}\ C_{corr}^{SM,UL}} \quad \text{and} \quad \alpha_{p,max}^{UL\ bearer,tx\ ,SM} = \frac{\alpha_{p,max}^{UL\ bearer,tx}}{G^{SM,UL}\ C_{corr}^{SM,UL}}\ , \tag{131}$$

where $\alpha_{p,min}^{DL\ bearer,tx\ ,SM}$, $\alpha_{p,max}^{DL\ bearer,tx\ ,SM}$, $\alpha_{p,min}^{UL\ bearer,SM}$ and $\alpha_{p,max}^{UL\ bearer,SM}$ are the modified DL and UL minimum and maximum resource consumptions/usage when employing SM. $G^{SM,DL}$ and $G^{SM,UL}$ are SM gain values read from the respective UL and DL '*SM Rate Gain*' tables. The provided default values relate to the theoretical maximum possible throughput gain that can be achieved by employing given numbers of transmit and receive antennas at the gNodeB and terminals (*and vice versa*). Finally, $C_{corr}^{SM,DL}$ and $C_{corr}^{SM,UL}$ are the clutter specific DL and UL rate gain adjustments.

In addition to SM rate gain, ASSET also models the change in bearers' SINR requirements when using SM, i.e. a higher/lower SINR requirement of bearers as compared to single antenna transmission. These modified DL and UL bearers requirements can be expressed as (in dBs)

$$SINR_{req}^{DL\ bearer,SM}(dB) = SINR_{req}^{DL\ bearer}(dB) + SINR_{SM\ delta}^{DL\ bearer}(dB) + SINR_{SM\ offset}^{DL,clutter}(dB)\ , \tag{132}$$

and

$$SINR_{req}^{UL\ bearer,SM}(dB) = SINR_{req}^{UL\ bearer}(dB) + SINR_{SM\ delta}^{UL\ bearer}(dB) + SINR_{SM\ offset}^{UL,clutter}(dB)\ , \tag{133}$$

where

| | |
|---|---|
| $SINR_{req}^{DL\ bearer}$ , $SINR_{req}^{UL\ bearer}$ | DL & UL bearers' SINR requirements without SM |
| $SINR_{req}^{DL\ bearer,SM}$ , $SINR_{req}^{UL\ bearer,SM}$ | Modified DL & UL bearers SINR requirements with SM |
| $SINR_{SM\ delta}^{DL\ bearer}$ , $SINR_{SM\ delta}^{DL\ bearer}$ | DL & UL SU-MIMO (SM) bearers SINR deltas |
| $SINR_{SM\ offset}^{DL,clutter}$ , $SINR_{SM\ offset}^{UL,clutter}$ | DL & UL clutter specific SM SINR offsets |

### 7.1.2 Spatial Diversity (SD)

These techniques improve the SINR by transmitting the same stream of single user data from multiple antennas at the transmitter, receiver or both sides. Assuming the path gains between individual antenna pairs are i.i.d. Rayleigh distributed, a maximal diversity gain/order of $G^{SD}$ can be achieved which makes the average error probability to decay as $SINR^{-G^{SD}}$ at high SINRs, in contrast to the $SINR^{-1}$ for a single-antenna fading channel, where $G^{SD} = N^{tx} \times N^{rx}$, with $N^{tx}$ and $N^{rx}$ representing the number of transmit and receive antennas respectively.

In ASSET, spatial diversity gain/order $G^{SD}$ is modelled by modifying the raw SINR requirements of DL and UL bearers. The modified requirements when employing SD can be expressed as

$$SINR_{req}^{DL\,bearer,SD} = \frac{SINR_{req}^{DL\,bearer}}{G^{SD,DL}C_{corr}^{DL,SD}} \text{ and } SINR_{req}^{UL\,bearer,SD} = \frac{SINR_{req}^{UL\,bearer}}{G^{SD,UL}C_{corr}^{UL,SD}}, \tag{134}$$

where $SINR_{req}^{DL\,bearer}$, $SINR_{req}^{UL\,bearer}$ and $SINR_{req}^{DL\,bearer,SD}$, $SINR_{req}^{UL\,bearer,SD}$ are the raw and modified DL and UL bearers' SINR requirements. $G^{SD,DL}$ and $G^{SD,UL}$ are SD orders/gain values read from the respective UL and DL '*SD SINR Adjustment*' tables. The provided default values relate to the theoretical maximum possible diversity order that can be achieved by employing given numbers of transmit and receive antennas at the gNodeB and terminals (*and vice versa*). Finally, $C_{corr}^{SD,DL}$ and $C_{corr}^{SD,UL}$ are the clutter specific DL and UL SD SINR adjustments.

### 7.1.3 Adaptive Switching

This enables the SM and SD to be implemented in an adaptive fashion which is vital to maximize throughput of LTE networks. Adaptive switching has to be enabled on both LTE cells and terminals. ASSET always attempts to utilise a bearer in SM mode before attempting SD for a given terminal. In addition to this, the cell level '*Adaptive SU-MIMO RS SNR*' threshold can be employed to control the switching from SM to SD and when enabled, SM is employed above the threshold while SD below the threshold.

## 7.2 MU-MIMO

This architecture serves multiple users (*separated in the spatial domain in both link direction*) sharing the same time-frequency resource. It employs multiple narrow beams to separate users in the spatial domain and can be considered as a hybrid of beamforming and spatial multiplexing. By scheduling multiple terminals, MU-MIMO serves more terminals with the same resources, which in turns increases the cell capacity/throughput. This is normally suitable for highly loaded cells and for scenarios where number of served terminals is more important than peak user data rates.

In ASSET, the MU-MIMO gain (*increased served terminals*) $G^{MU}$ is modelled by modifying the minimum and maximum resource consumptions/usage of DL and UL bearers. i.e. $\alpha_{p,min}^{DL\,bearer,tx}$, $\alpha_{p,max}^{DL\,bearer,tx}$ $\alpha_{p,min}^{UL\,bearer}$, $\alpha_{p,max}^{UL\,bearer}$ as calculated in (17) and (19) respectively. The modified minimum and maximum resource consumptions in the DL and UL can be expressed as:

$$\alpha_{p,min}^{DL\,bearer,tx,MU} = \frac{\alpha_{p,min}^{DL\,bearer,tx}}{G^{MU,DL}} \text{ and } \alpha_{p,max}^{DL\,bearer,tx,MU} = \frac{\alpha_{p,max}^{DL\,bearer,tx}}{G^{MU,DL}}, \tag{135}$$

and

$$\alpha_{p,min}^{UL\,bearer,tx,MU} = \frac{\alpha_{p,min}^{UL\,bearer,tx}}{G^{MU,UL}} \text{ and } \alpha_{p,max}^{UL\,bearer,tx,MU} = \frac{\alpha_{p,max}^{UL\,bearer,tx}}{G^{MU,UL}}, \tag{136}$$

where $\alpha_{p,min}^{DL\,bearer,tx,MU}$, $\alpha_{p,max}^{DL\,bearer,tx,MU}$, $\alpha_{p,min}^{UL\,bearer,MU}$ and $\alpha_{p,max}^{DL\,bearer,tx,MU}$ are the modified DL and UL minimum and maximum resource consumptions/usage when employing MU-MIMO. $G^{MU,DL}$ and $G^{MU,UL}$ are cell specific '*Average Co-scheduled Terminals*'.

In addition to '*Average Co-scheduled Terminals*', ASSET also models the change in bearers' SINR requirements when using MU-MIMO. i.e. a higher/lower SINR requirement of bearers as compared to single antenna transmission. These modified DL and UL bearer requirements can be expressed as

$$SINR_{req}^{DL\,bearer,MU}(dB) = SINR_{req}^{DL\,bearer}(dB) + SINR_{MU\,delta}^{DL\,bearer}(dB) + SINR_{MU\,offset}^{DL,clutter}(dB)\ , \tag{137}$$

and

$$SINR_{req}^{UL\,bearer,MU}(dB) = SINR_{req}^{UL\,bearer}(dB) + SINR_{MU\,delta}^{UL\,bearer}(dB) + SINR_{MU\,offset}^{UL,clutter}(dB)\ , \tag{138}$$

where

| | |
|---|---|
| $SINR_{req}^{DL\,bearer}$ , $SINR_{req}^{UL\,bearer}$ | DL & UL bearers' SINR requirements without MU-MIMO |
| $SINR_{req}^{DL\,bearer,MU}$ , $SINR_{req}^{UL\,bearer,MU}$ | Modified DL & UL bearers' SINR requirements with MU-MIMO |
| $SINR_{MU\,delta}^{DL\,bearer}$ , $SINR_{MU\,delta}^{UL\,bearer}$ | DL & UL MU-MIMO (SM) bearers SINR deltas |
| $SINR_{MU\,offset}^{DL,clutter}$ , $SINR_{MU\,offset}^{UL,clutter}$ | DL & UL clutter specific MU-MIMO SINR offsets |

## 7.3 AAS Mode Selection

The Simulator will attempt to use the enabled AAS modes in sequence with a broad underlying aim of maximising throughput.

For any given bearer, the possible (composite) transmission modes are listed below and ranked from the most desirable to the least desirable. Generally speaking, SU-MIMO SM modes are preferred since they increase the data rate of the connection. If SM is not possible, then MU-MIMO modes are the next most preferred because although the data rate of the user is not improved, the overall cell capacity is used more effectively.  If neither SM nor MU-MIMO, are possible then the aim is to improve the reliability of the link using through either a SINR improvement due to beamforming or through the use of SD or both.

| **Transmission Mode Ranking for a Specific Bearer** |
|---|
| SU-MIMO SM |
| MU-MIMO |
| SU-MIMO SD |
| Single Antenna (i.e. No MIMO or Beamforming) |

There exist cell-specific MIMO thresholds that can be enabled to control the range of MIMO modes. These thresholds will affect simulation results and should only be enabled by experienced/advanced users because they can cause suboptimal network performance.

| **Cell-Specific Threshold** | **Effect of Cell-Specific Threshold** |
|---|---|
| Adaptive SU-MIMO | Any mode involving SM is not allowed ***below*** the specified threshold. |
| MU-MIMO | Any mode involving MU-MIMO is not allowed ***below*** the specified threshold. |

The threshold controlling parameter can be one of the following:

- DL Traffic SINR (PDSCH SINR) as given (97).
- UL Traffic SINR (PUSCH SINR) as described in (111).

# 8 COVERAGE PROBABILITY CALCULATIONS

The coverage probability describes the probability of receiving a signal being of sufficient strength/quality given that it has been transmitted through a wireless channel where the signal is subject to large and small scale fading, e.g. shadow fading, fast fading and etc.

Coverage probabilities are calculated *analytically*.

The Simulator can run in two different modes

- Using Cell Load levels as specified in the Site Database
- Calculating Cell Load Levels by running snapshots

In the second mode coverage plots can be obtained after running a very small number of snapshots (typically 10s) and plots converge very quickly. If no snapshots have been run, then coverage plots are still available but they give the coverage probabilities in an unloaded system. The network is unloaded with respect to own technology type but is still considering any Inter-technology DL/UL Noise Rise Cell Loads from the Site Database

We introduce the following notation to represent the probability density function for a normally distributed random variable with mean $\mu$ and standard deviation $\sigma$.

$$N(x;\mu,\sigma) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(\frac{-(x-\mu)^2}{2\sigma^2}\right), \tag{139}$$

## 8.1 FADES IN THE SIMULATION SNAPSHOTS

Shadow fading is modelled in a snapshot by randomising the pathlosses experienced by the randomly scattered terminals. Shadow fades are log-normally distributed, and the user specifies the shadow fading standard deviation for indoor and outdoor terminals in each clutter type. In reality, the fades between a terminal and the cells that cover it will exhibit a degree of correlation. In particular, a terminal is likely to have similar fades to cells that are located on the same site. To account for this, the user specifies two parameters in the Monte Carlo Wizard:

- The normalised inter-site correlation coefficient $c^{inter}$ which is the correlation between fades to cells on different sites.

i. The normalised intra-site correlation coefficient $c^{intra}$ which is the correlation between fades to cells on the same site.

These two parameters must satisfy the constraints $0 \le c^{inter} \le c^{intra} \le 1$. For each randomly scattered terminal in a snapshot, a set of correlated fades to the covering cells is generated using the following procedure. All the random numbers mentioned below are independent and normally distributed with zero mean and unit variance, and $\sigma$ is the standard deviation of the shadow fading at the pixel in dB.

- Generate a random number $X$.
- For each site $I$, generate a random number $Y_I$.
- For each cell $J$, generate a random number $Z_J$.

The fade (in dB) to cell $J$ on site $I$ is then set to

$$\sigma\left(\sqrt{c^{inter}}X + \sqrt{c^{intra} - c^{inter}}Y_I + \sqrt{1 - c^{intra}}Z_J\right) \tag{140}$$

The above procedure is performed for each of the randomly scattered terminals at the beginning of a snapshot. Fades for different terminals are uncorrelated even if they are located in the same pixel.

## 8.2 Fades in Arrays for Mean Values

Arrays showing the mean level of a quantity (e.g. DL linkloss, SS-RSRP, SS-RSRQ, etc) are calculated with all fades set to 0 dB.

## 8.3 Fades in Coverage Array Calculations

### SS-RSRP Coverage Probability

In the absence of fading, let the SS-RSRP (in Watts) for cell $J$ be represented by $R_J^{SSS}$. If cell $J$ has a fade of $F_J$ dB, then the SS-RSRP is given by $R_J^{SSS}\left(10^{-F_J/10}\right)$.

We can calculate a coverage probability for the SS-RSRP as follows:

- Find the fade $F_J$ that causes the SS-RSRP to *exactly* satisfy the requirement specified on the terminal type. Call this fade $F^*$. Note that $F^*$ may be positive or negative. Any fade bigger than $F^*$ will give an inadequate RSRP.

Since $F_J$ is normally-distributed with a mean of 0 dB and standard deviation of $\sigma$ dB, the probability that $F_J > F^*$ is given by

$$P\left(F_J > F^*\right) = \int_{F^*}^{\infty} N(x; 0, \sigma)\, \partial F_J \tag{141}$$

This is the probability that the SS-RSRP does not meet the requirement.

### RSRQ Coverage Probability

This is calculated by following the same approach as described above for the SS-RSRP coverage probability.

# 9 Inter-Technology Interference

## 9.1 Introduction

The Multiple Technology Simulator allows considering the effects of inter-carrier interference for carriers of the same technology and carriers of different technologies. The considered technologies are GSM, UMTS, LTE and Wi-Fi. The selection in Step 2 of the Simulator Wizard determines the technology types that are considered for the subsequent calculations.

Carriers can be fully, partially or non-overlapping. Non-overlapping carriers can still be adjacent, hence interfering with each other. The relative position of carriers is determined by their Low and High frequencies that specify the operative range of the carrier.

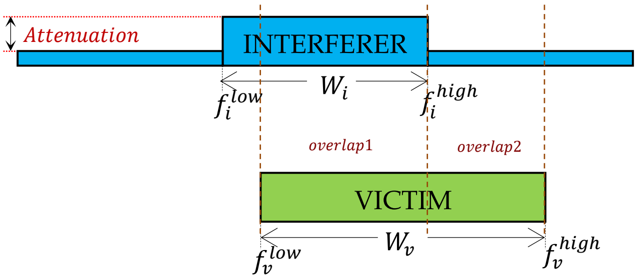
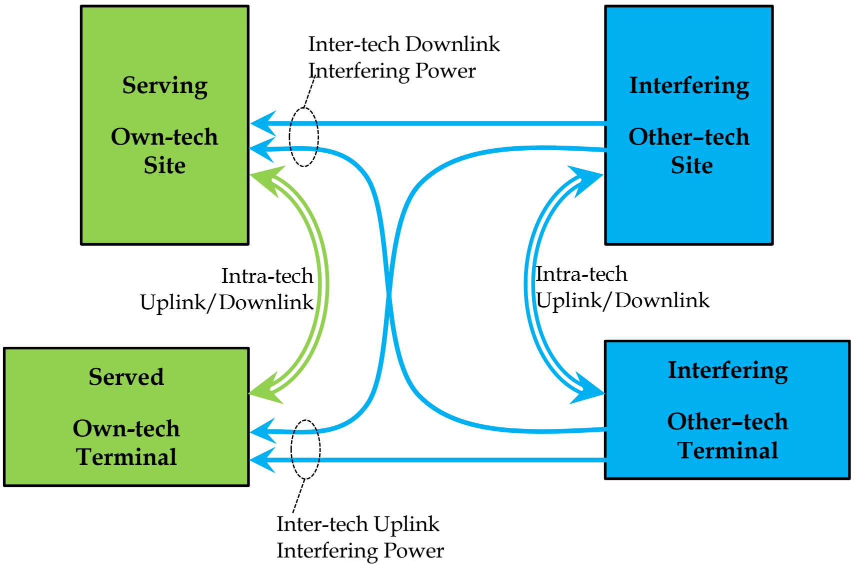



*Illustration of overlapping carriers*

The following figure is generic to all technology types.




*UL and DL Inter-technology Interference*

Assuming 5G to be the reference technology in the context of the current document, the other interfering technologies can be GSM, UMTS, LTE and Wi-Fi.

Note: The uplink is not modelled for GSM and Wi-Fi, which means that GSM and Wi-Fi terminals' uplink transmission is not considered for interference.

## 9.2 Inter-Technology Interference Formulae

By selecting the appropriate option in the Simulator Wizard, carriers of the rest of the selected technologies are considered and the resulting inter-technology interference component is added to any intra-technology or own-technology interference.

$\sum_{tech \neq own}$ denotes the summation over the technologies that have been selected in the Simulator Wizard, excluding $own$, where $own = \{5G\}$ and $other = \{GSM, UMTS, LTE, Wi\text{-}Fi\}$ in the context of the current document.

### 9.2.1 Uplink Received Interference

This is the interference received in the uplink by $own$ cells and consists of two components

**i.** UL-UL: The uplink of $other$-technology terminals interfering with the uplink of $own$ cells

**ii.** DL-UL: The downlink of $other$-technology cells interfering with the uplink of $own$ cells

The combined effect of these two components is modelled via $(NR)_{J,p}^{UL,\ Tech}$, the Inter-technology UL Noise Rise due to cells and terminals of $other$ technologies and it is specified in the Site DB.

$$I_{J,p}^{UL\ inter\ tech} = \sum_{tech \neq own} (CP)_{J,p}^{tech} \times \left[(NR)_{J,p}^{UL\ tech} - 1\right] \times N_{J,p}^{UL} \ , \qquad \textbf{(142)}$$

where

$I_{J,p}^{UL\ inter\ tech}$ is the inter-technology UL received interference power of cell $J$ employing carrier $p$ due to cells and terminals of $other$ technologies.

$(CP)_{J,p}^{tech}$ is the Channel Protection factor for the $other$ technologies and it is input from Site DB for cell $J$.

$(NR)_{J,p}^{UL\ tech}$ is the UL Noise Rise due to the $other$ technologies and it is input from Site DB for cell $J$.

$N_{J,p}^{UL}$ is the UL thermal noise power.

On the $own$ cell, in Site DB, the combined inter-technology total UL Noise Rise, disregarding any Channel Protection factors, is reported as:

$$(NR)_{J,p}^{UL\ inter\ tech\ total} = 1 + \sum_{tech \neq own} \left[(NR)_{J,p}^{UL\ tech} - 1\right]. \qquad \textbf{(143)}$$

On the $own$ cell, in Site DB, the combined UL Noise Rise for all included technologies, disregarding any Channel Protection factors, is reported as:

$$(NR)_{J,p}^{UL\ all\ techs} = 1 + \sum_{tech = all} \left[(NR)_{J,p}^{UL\ tech} - 1\right]. \qquad \textbf{(144)}$$

### 9.2.2 Downlink Received Interference

This is the interference received in the downlink by $own$ terminals and consists of two components:

**i.** UL-DL: The uplink of $other$-technology terminals interfering with the downlink of $own$ terminals

The effect of these this component is modelled via $(NR)_{J,p}^{DL\ tech\ terms}$, the inter-technology DL Noise Rise due to terminals of $other$ technologies and it is specified in the Site DB.

$$I_{J,p,k}^{DL\ inter\ tech\ terms} = \sum_{Tech \neq own} (CP)_{J,p}^{tech} \times \left[(NR)_{J,p}^{DL\ tech\ terms} - 1\right] \times N_{p,k}^{DL}\ , \qquad \textbf{(145)}$$

where

$I_{J,p,k}^{DL\ inter\ tech\ terms}$ is the inter-technology DL received interference power for terminal $k$ served by cell $J$ employing carrier $p$ due to terminals of $other$ technologies.

$(CP)_{J,p}^{tech}$ is the Channel Protection factor for the $other$ technologies and it is input from Site DB for cell $J$.

$(NR)_{J,p}^{DL\ tech\ terms}$ is the DL Noise Rise due to terminals of the $other$ technologies and it is input from Site DB for cell $J$.

$N_{p,k}^{DL}$ is the DL thermal noise power.

On the $own$ cell, in Site DB, the combined inter-technology total DL Noise due to $other$-technology terminals, disregarding any Channel Protection factors, is reported as:

$$(NR)_{J,p}^{DL\ inter\ tech\ total\ terms} = 1 + \sum_{tech \neq own} \left[(NR)_{J,p}^{DL\ tech\ terms} - 1\right]. \qquad \textbf{(146)}$$

**ii.** DL-DL: The downlink of $other$-technology cells interfering with the downlink of the $own$ terminals

The effect of this component is calculated as

$$I_{J,p,k}^{DL\ inter\ tech\ cells} = \sum_{tech \neq own} \sum_{q} (CP)_{J,p}^{tech}\ O_{q \to p}^{freq} \sum_{C \neq J} \frac{P_C}{L_{Ck}^{DL}}\ , \qquad \textbf{(147)}$$

where

$I_{J,p,k}^{DL\ inter\ tech\ cells}$ is the received DL interference power for terminal $k$ served by cell $J$ employing carrier $p$ due to terminals of $other$ technologies.

$(CP)_{J,p}^{tech}$ is the Channel Protection factor for the $other$ technologies and it is input from Site DB for cell $J$.

$O_{q \to p}^{freq}$ is the DL frequency overlap factor for victim carrier $p$ and interfering carrier $q$.

$P_C$ is the total time-average transmitted power of $other$-technology cell $C$.

$L_{Ck}^{DL}$ is the link loss between $other$-technology cell $C$ and $own$ terminal $k$.

The summation of $I_{J,p,k}^{DL\,inter\,tech\,terms}$ and $I_{J,p,k}^{DL\,inter\,tech\,cells}$ is the total interference power received in the downlink by $own$ terminal $k$ due to terminals and cells of $other$ technologies.

$$I_{J,p,k}^{DL\,inter\,tech} = I_{J,p,k}^{DL\,inter\,tech\,terms} + I_{J,p,k}^{DL\,inter\,tech\,cells}\,. \tag{148}$$

Note that $I_{J,p,k}^{DL\,inter\,tech}$ is the interference power over the full victim bandwidth $W_p^{DL}$. Formulas for DL quantities such as SINR are typically expressed as of a ratio of received EPRE values rather than power levels over the full bandwidth. So $I_{J,p,k}^{DL\,inter\,tech}$ must be transformed to an interfering EPRE for use in those formulas as follows

$$\varepsilon_{J,p,k}^{DL\,inter\,tech} = I_{J,p,k}^{DL\,inter\,tech} / W_p^{DL}. \tag{149}$$

The resulting EPRE can then be included alongside other interfering EPRE values in the SINR formulas.