OFDMA Simulation in SEAMCAT

SEAMCAT allows to simulate OFDMA using the 3GPP LTE standard. This is described in the following sections.

1 INTRODUCTION

The simulation of OFDMA systems is similar to that of the CDMA systems, except that after the overall two-tiers cellular system structure (incl. wrap-around) is built and populated with mobiles, the CDMA power tuning process is replaced in OFDMA case with an iterative process of assigning a variable number of traffic sub-carriers and calculating the overall carried traffic per base station.

The current OFDMA module has been designed for a Long Term Evolution (LTE) network from 3GPP [TR36.942]. Therefore E-UTRA RF coexistence studies can be performed with Monte-Carlo simulation methodology. The detailed simulation flow for DL and UL can be found in Annex 14 of the SEAMCAT handbook (January 2010). Further modules are planned for the future to allow for different OFDMA technologies, such as WiMAX.

2 METHODOLOGY AND ASSUMPTIONS

The general simulation assumptions are presented in this section to provide a guideline on how to perform the coexistence simulation. This OFDMA LTE algorithm is only valid for a 100% loaded system and each user is allocated with a fixed number of resource blocks. This is equivalent to modelling a Round Robin scheduler with full buffer traffic model and a frequency reuse of 1/1 (i.e. Single Frequency Network is assumed). Moreover, E-UTRA system is assumed to be a fully orthogonal system, which indicates that in the UL case only UEs allocated with the same sub-carriers (frequency resource block) could introduce other-cell, intra-system interference.

The network layout is similar to the one used for CDMA. The methodology assumes that the UEs are deployed randomly in the whole network region according to a uniform geographical distribution. The wrap around technique is employed to remove the network deployment edge effects.

Note that if the OFDMA is a DL interferer, the OFDMA is simulated as in “traditional” simulation with the BSs transmitting at full power. This decreases the simulation time of a full OFDMA simulation. In OFDMA DL interferer, only the position of the BSs will be calculated because full transmit power is assumed. For all other simulations (including UL) scenarios full OFDMA network simulation is required. Consequently, some of the input parameter of the GUI interface have been grey-out when the OFDMA DL interferer case is selected (see Figure 12).

Since it is arguable that some simulation assuming a rural environment would not need to assume full power transmission (i.e. full loaded network) when the system is DL and interferer, the user may need to manipulate either the input power or the spectrum mask (or both) in order to simulate the DL interferer case for rural deployment.

2.1 Pathloss and Effective Pathloss

In SEAMCAT, there is a distinction between the raw pathloss and the effective pathloss. The effective pathloss considers the minumum coupling loss (MCL) as defined in 3GPP. The MCL is the parameter describing the minimum loss in signal between BS and UE or UE and UE in the worst case and is defined as the minimum distance loss including antenna gains measured between antenna connectors.
The effective pathloss is defined such as:

$$effective\_pathloss(Tx, Rx) = \max\left(pathloss - G_{Tx} - G_{Rx}, MCL\right)$$

where:

- G_{Tx} : antenna gain at the transmitter (Tx) in dBi.
- G_{Rx} : antenna gain at the receiver (Rx) in dBi.

Note: The MCL is an iput parameter to SEAMCAT (see Figure 5 for system definition and Figure 13 for It->Vr path definition). Typical values of MCL can be found in 3GPP documents [TR36.942]. By defaults this value is 70 dB (i.e.

typical value for Macro cell Urban Area BS ↔ UE for frequency of 2000 MHz, e.g., there is a difference between 900 MHz and 2500 MHz with respect to MCL.) when defining the victim or interferer OFDMA system, but the vlaue is set to 0 dB, when the MCL is used in the It->Vr path.

2.2 DL C/I calculation

The relationship between the contributors of the interference in a OFDMA network is illustrated in Figure 1

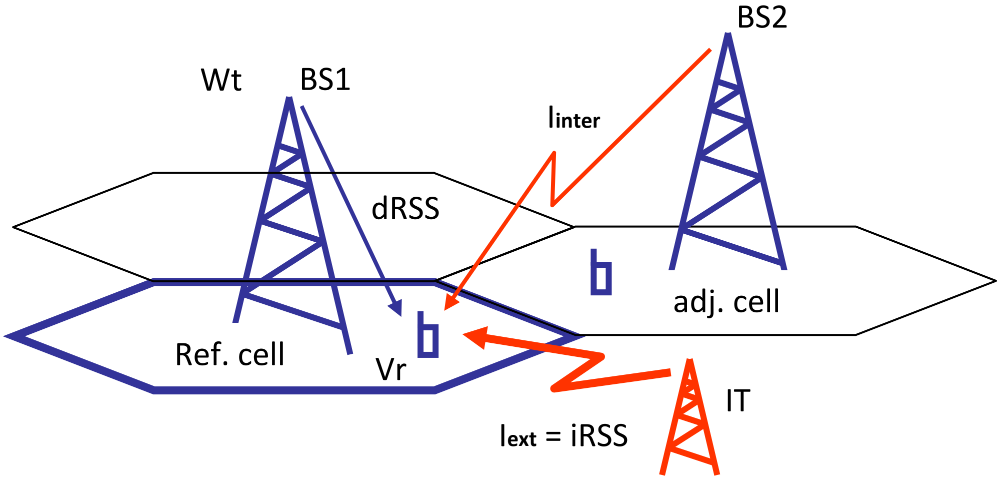

Figure 1: Illustration of the interference mechanism in the OFDMA module where the inter-system or also called self interference is noted "I_{inter}" and the interference from an "external" interference system is referred to as "I_{ext}".

In this SEAMCAT OFDMA implementation, the term "BS" and "cell" have the same meaning. The C/I calculation in DL is calculated as

$$C/I = \frac{C(j,k)}{I(j,k)}$$

where *C(j,k)* is the received power at the *k*-th user from the serving BS, i.e., the *j*-th BS

$$C(j,k) = P_{BS}^{UE} \times effective\_pathloss(BS_j, UE_{j,k})$$

$$C(j,k) = dRSS(BS_j, UE_{j,k})$$

and where P_{BS}^{UE} is the power of resource block. Note that the effective path loss includes shadowing.

I(j,k) is the sum of the interference power (power of resource block * effective pathloss including shadowing)

$$I(j,k) = I_{inter}(j,k) + I_{ext}(j,k) + N_t$$

which consists of adjacent cell interference I_{inter} *(j,k)* (from the same victim system, i.e. denoted inter-system interference)

$$I_{inter}(j,k) = \sum_{l=1, l \neq j}^{N_{cell}} P_{BS}^{UE} \times effective\_pathloss(BS_l, UE_{j,k}),$$

the interference from external interfering system(s) in adjacent channel $I_{ext}(j,k)$ (interference power into this resource block including ACIR). The ACIR (Adjacent Channel Interference Ratio) is implicitly taken into account when both unwanted and blocking mechanism are summed in the computation

$$I_{ext}(j,k) = \sum_{m=1}^{N_{External\_cell}} iRSS_{unwanted}(BS_m, UE_{j,k}) \times iRSS_{blocking}(BS_m, UE_{j,k})$$

where

$$iRSS_{unwanted}(BS_m, UE_{j,k}) = iRSS_{unwanted}(over\ the\ size\ of\ the\ UE\ resource\ blocks)$$

for each of the UE's frequency where the DL information is received and

$$iRSS_{blocking}(BS_m, UE_{j,k}) = iRSS_{blocking}(over\ system\ bandwidth) \times \frac{N}{M}$$

at the victim system frequency.

where N is the number of RBs (i.e. subcarriers) requested per UE, and M is the maximum number of RBs per BS and where $N_{external\ cell}$ is the number of external interfering BSs.

and the thermal noise N_t

$$N_t = 10\text{^}((-174 + 10\log 10(bandwith\ of\ N \times RBs) + NoiseFigure_{UE})/10)$$

where N is the number of RBs scheduled to a UE.

2.3 UL C/I calculation

The C/I calculation in UL is calculated so that *C(j,k)* is the received power from the $UE_{j,k}$ at the j-th BS.

$$C(j,k) = P_t(j,k) \times effective\_pathloss(UE_{j,k}, BS_j)$$

$$C(j,k) = dRSS(UE_{j,k}, BS_j)$$

where P_t is the transmit power of the UE in dBm (see UL Power control below).

Similarly to DL, the interference is derived from

$$I(j,k) = I_{inter}(j,k) + I_{ext}(j,k) + N_t$$

where I_{inter} is the interference coming from UEs of the same system but from adjacent cells (i.e. the inter-system interference from other cells). Since a fully orthogonal system is assumed, only UEs which transmit in the same frequency subcarriers will introduce interference to each other, hence only UEs in other cells with the same k index are considered.

$$I_{inter}(j,k) = \sum_{l=1, l \neq j}^{N_{cell}} P_t(l,k) \times effective\_pathloss(UE_{l,k}, BS_j)$$

where I_{ext} is the interference from external interfering UEs.

$$I_{ext}(j,k) = \sum_{m=1}^{N_{External\_cell}} \sum_{v=1}^{K} iRSS_{blocking}(UE_{m,v}, BS_j) \times iRSS_{unwanted}(UE_{m,v}, BS_j)$$

where K is the number of UEs in the external interfering cells and the number of external cells is limited to $N_{External\ cell}$ and the thermal noise *Nt.*

$$N_t = 10\text{^}((-174 + 10\log 10(bandwith\ of\ N \times RBs) + NoiseFigure_{BS})/10)$$

Note: In UL, it is important to remember that for LTE technology, each user will be transmitting its own RB. In SEAMCAT, it is assumed that each UE transmit the same amount of RBs therefore they have the same emission spectrum mask.

Note: when the OFDMA UL is the victim system, one has to remember that the interferer will impair each of the signals transmitted by the UEs serving its own BS (i.e. the victim BS). Therefore, for a specifc link (UE_1 to BS_1) the interference caused by an external interferer will only affect the spectrum occupied by the RBs allocated to UE_1 for that link and not the whole system bandwidth at BS_1.

Note: The ACLR calculation is similar to the unwanted calculation BUT note that in 3GPP it is the integration of the interfering power in the adjacent channel where the bandwidth equal to the interfering emission bandwidth while the unwanted uses the victim bandwidth (See illustration from 3GPP TR36.942).

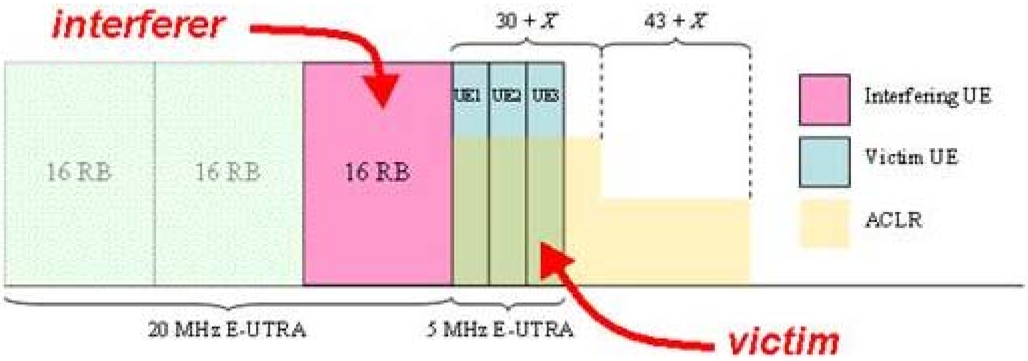

Figure 2: Illustration of the ACLR for a 20 MHz E-UTRA UE aggressor to 5 mHz E-UTRA UE vcitims ([TR36.942])

2.4 UL Power control

In OFDMA UL, power control is applied to the active users (i.e. the users with specific RBs) so that the UE Tx power is adjusted with respect to the path loss to the BS it is connected to. In 3GPP [TR36.942], the UL power control is defined so that the UE transmit power is set such as:

$$P_t = P_{\max} \times \min\left\{1, \max\left[R_{\min}, \left(\frac{PL}{PL_{x-ile}}\right)^{\gamma}\right]\right\}$$

where P_t is the UE Tx power in dBm, P_{max} is the maximum transmit power in dBm, R_{min} is the minimum power reduction ratio to prevent UEs with good channels to transmit at very low power level. R_{min} is set by P_{min} / P_{max}. *PL* is the path-loss in dB for the UE from its serving BS and $PL_{x\text{-ile}}$ is the x-percentile path-loss (plus shadowing) value. PLx-ile is defined here as the value in the CDF, which is greater than the path-loss of x percent of the MSs in the cell from the BS (i.e. it corresponds to the parameter "**power Scale Threshold**". It is set by default to 0.9, but the user can change it.

With this power control scheme, the 1-x percent of UEs that have a path-loss greater than $PL_{x\text{-ile}}$ will transmit at P_{max}, i.e. are not power controlled. In SEAMCAT, γ is assumed to equal 1.

2.5 Load of the OFDMA system

In the introduction it is mentioned that the system is assumed to be 100% loaded. The number of active users per serving BS simulated in SEAMCAT is the ratio between the Max subcarriers per Base Station and the Number of subcarriers per mobile. (both of these parameters are input see Figure 5).

For instance, with 24RBs at the BS and 8 RBs at the UE, the number of active users is 3 and the system is 100% loaded. In the case where there are 24 RB per BS and 7 RB, SEAMCAT generates 3 users per BS - but only 21 out of 24 RBs will be in use. Therefore the system load is equal to (21/24)*100 = 87.5%

2.6 OFDMA LTE Link-to-system level mapping

A look up table is used to map throughput in terms of spectral efficiency (bps per Hz) with respect to calculated SNIR (= C/(I+N)) (dB) level. This link leve data (bitrate mapping) is user selectable and can be modified depending on the simulation to perform.

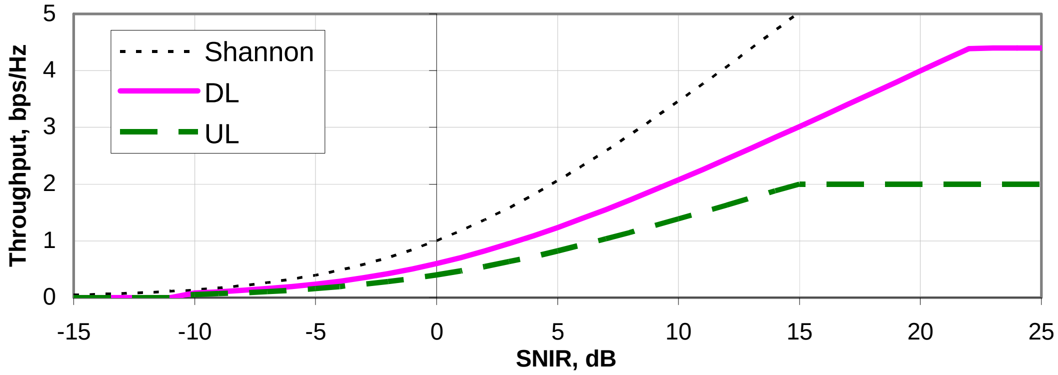

Figure 3: Throughput vs SNIR for Baseline E-UTRA Coexistence Studies (source: [TR36.942])

The achieved bit rate is calculated as follows:

$$BiteRate_{[kbps]} = \frac{N_{Subcarriers\_per\_UE}}{N_{total\_subcarriers}} \times \left(x_{bps/Hz}\right)_{SINR} \times BW_{[MHz]} \times bps\_to\_kbps\_conversion$$

3 SETTING UP SIMULATION FOR OFDMA AS VICTIM LINK

Figure 4 presents the SEAMCAT GUI where the user can select either CDMA or OFDMA and where the ACS (Adjacent Channel Selectivity) can be set-up for the victim link.

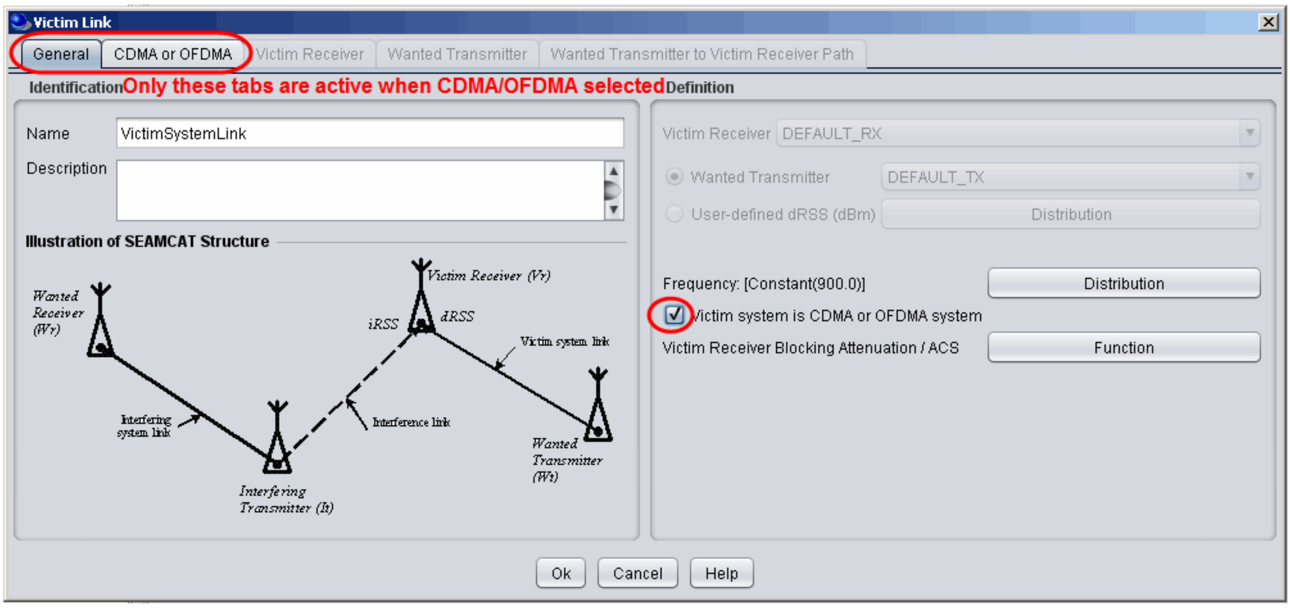

Figure 4: SEAMCAT interface to select the LTE OFDMA module and its ACS value as a victim.

3.1 General OFDMA Tab

The dialogue window of Figure 5 is used to define the necessary parameters for modelling the OFDMA system. These parameters have been divided into several related groups - each called by a separate sub-sheet tab.

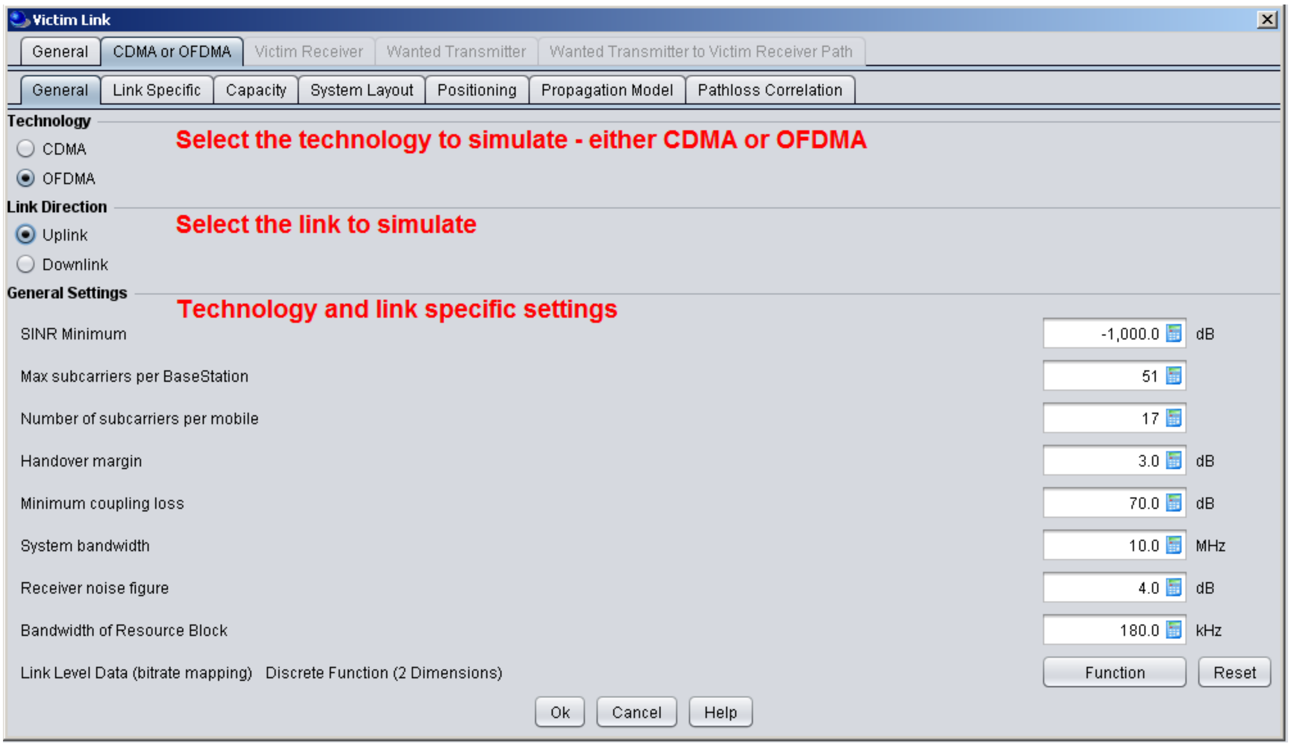

Figure 5: General OFDMA input parameters to SEAMCAT

The general setting for the OFDMA DL and UL are similar.

Parameter	Description
OFDMA Link component	The type of OFDMA System. There are considerable differences between modelling of uplink and a downlink in OFDMA system. See Section 2.6 for a more detailed explanation of differences.
SINR Minimum	Lower boundary of SINR to take into account in the simulation. In DL, any UE with a C/I lower than the SINR minimum will be disconnected right away. In UL, the UE will get tagged with a *disconnect* flag. For a specific threshold (***Maximum allowed disconnection attempts*** – see Table 3) of disconnection, the UE is removed from the cell.
Max subcarriers per Base Station	Number of available Resource Blocks (RBs) per BS
Number of subcarriers per mobile	Number of RBs per UE. Note the ratio of Max subcarriers per Base Station/ Number of subcarriers per mobile gives the number of active users per serving BS.
Handover Margin	Specifies the maximum difference, in dB, between the links in users active list. The actual active-list selection is based on pathloss calculations.
Minimum coupling loss	The minimum path loss, specified in dB, such as pathloss = max(path loss, MCL)
System bandwidth	Specified in MHz
Receiver Noise Figure	Equipment-specific noise figure of receiver, specified in dB
Bandwidth of RBs	Specified in MHz
Link Level Data	Traffic (i.e. bit rate) per UE. Drop-down selection of Link level data look-up 2 dimensions functions from Library. The OFDMA Link level data has the same formats for uplink and downlink but with different values. It is the user's responsibility to choose an appropriate set of data.

Table 1: General OFDMA link settings.

3.2 Link Specific tab

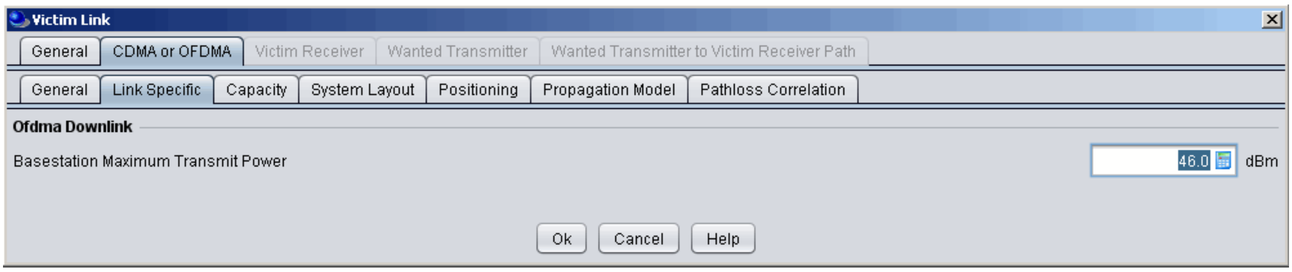

Figure 6: Setting up the OFDMA DL

Parameter	Description
Base Station Maximum transmit power	Specified in dBm

Table 2: Parameter of the link specific for OFDMA DL

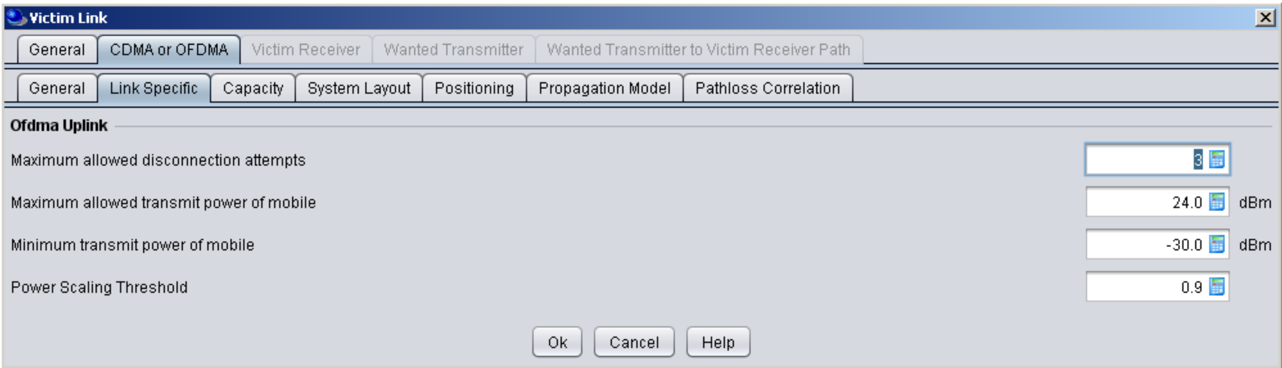

Figure 7: Setting up the OFDMA UL

Parameter	Description
Maximum allowed disconnection attempts	When the number of disconnection attempt is greater than this threshold, then the mobile is disconnected. This means that the UE is removed from the *served UE* list of that BS, The BS is marked with "got spare capacity" and the UE is added to the *disconnected UE* list.
Minimum transmit power of mobile	Minimum transmit power used in the power control.
Maximum allowed transmit power of mobile	Transmit power of the UE
Power Scaling Threshold	Used in the calculation of the path loss limit for the power control. It is a limit threshold compared to the value of the CDF used in the power control (see section 2.4)

Table 3: Parameter of the link specific for OFDMA UL

3.3 Capacity

Figure 8: Setting up the capacity of the OFDMA simulation

Parameter	Description
User per base station	Defines how many mobiles per cell should be generated in the system. For each BS, each UE will be added to *served UE* list of that BS. Depending on the propagation or handover conditions, a UE will either remain connected to the BS or will be disconnected.

Table 4: Parameter for the capacity of OFDMA (either UL or DL)

3.4 Path Loss Correlation

The concept of a simple correlation model for shadow fading has been widely adopted in LTE co-existence studies mostly employed in uplink case. The propagation attenuation is modelled as the product of the path loss and the shadow fading. The shadow fading is well approximated by a log-normal distribution [[12] of the SEAMCAT Handbook (January 2010)]. Let *z* denotes shadow fading in dB with zero mean and variance σ^2. Then the shadow fading of path from one UE to the *i*-th BS is expressed as $z_i = ax + by_i$, where $a^2 + b^2 = 1$ and x and y_i are independent Gaussian distributed variables, both with zero mean and variance σ^2. y_i and y_j for $i \neq j$ are independent as well.

Figure 9 presents how to set-up the pathloss correlation in SEAMCAT (only available for OFDMA).

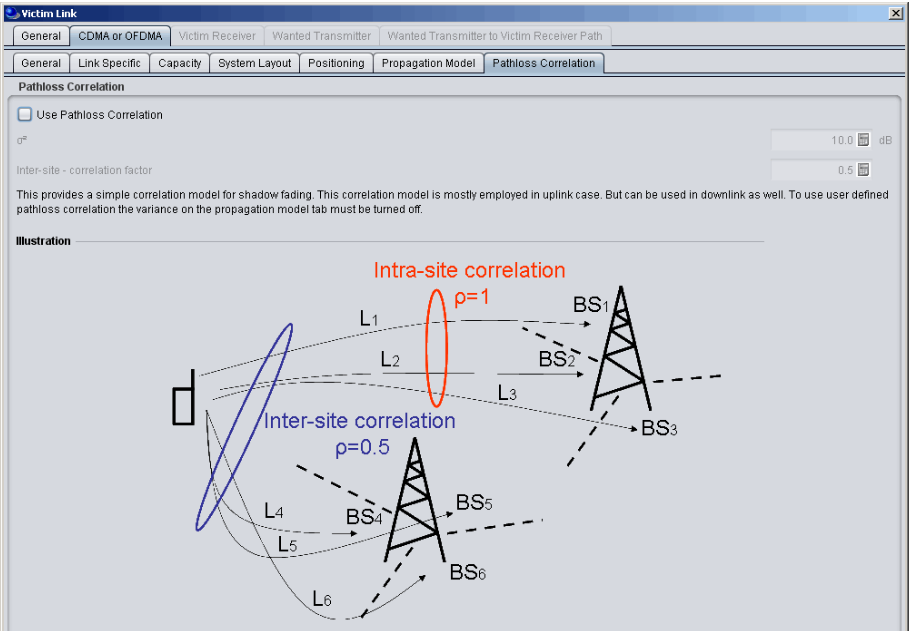

Figure 9: Path loss correlation interface for OFDMA simulation

Thus, the correlation coefficient of the shadow fading from one UE to two different BSs, i.e., the i th and j th BS, is $\frac{E(z_i z_j)}{E(z_i^2)} = a^2$. In most LTE studies, $a = b = \frac{1}{\sqrt{2}}$ is assumed [TR36.942].

For cellular systems with three-sector antennas, the shadowing correlation between sites (equivalent to BS in Omni antenna system) is of 0.5 and correlation between sectors of the same site is consequently of 1.

3.5 Other tabs

Note: The **System Layout** tab, **Positioning** tab and **Propagation Model** tab are shared components with the CDMA module. Therefore please consult the CDMA section for further detail.

4 SETTING UP SIMULATION FOR OFDMA AS INTERFERING LINK

Figure 10 presents the SEAMCAT GUI where the user can select either CDMA or OFDMA and where the Unwanted Emission Mask (ACLR) can be set-up for the interfering link.

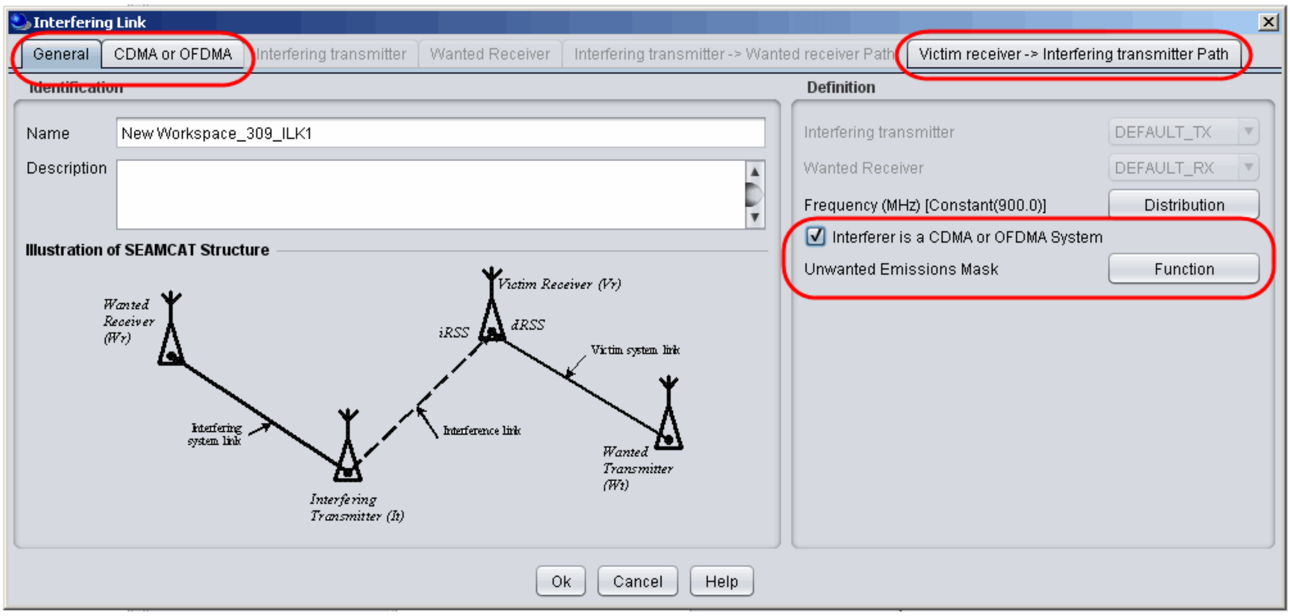

Figure 10: SEAMCAT interface to select the LTE OFDMA module and its Unwanted Emission Mask (ACLR) value as an interferer.

Depending on the direction of the interfering OFDMA link to be simulated, the user should pay attention to the emission bandwidth of the **unwanted emission mask** and the **system bandwidth**.

- When a DL simulation is considered, the unwanted emission mask corresponds to the BS transmitting over all the RBs (i.e. the emission bandwidth is the same as the System Bandwidth input from Figure 12)
- When a UL is considered, the emission bandwidth (i.e. in-band part of the unwanted emission mask) corresponds to the UE transmitting over a number of RBs (i.e. the emission bandwidth is equal to the RB bandwidth x Number of RBs requested per user) which is different from the DL where the system bandwidth is used as illustrated in Figure 11. Note that the system bandwidth is input to SEAMCAT and approximately RB bandwidth x the total Number of RBs (i.e. Max. subcarriers per BS input)

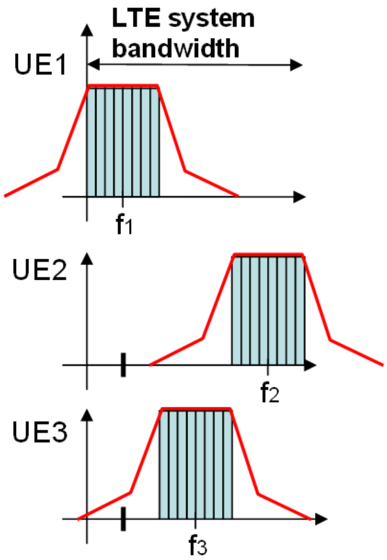

Figure 11: Illustration of the emission spectrum mask in UL for a LTE transmission

4.1 DL as interferer

When OFDMA is a DL interferer, the OFDMA is not simulated as it is assumed that the BSs are transmitting at full power and in order to decrease the simulation time a full OFDMA simulation is not required. In OFDMA DL interferer, the position of the BSs will be calculated only (see section 2).

Figure 12 presents the set-up of the OFDMA DL as an interferer. Note that only the system bandwidth is needed in this configuration. The rest of the tabs are not displayed since they are the same as for the Victim link.
When the DL is selected as interferer the **General**, **Link Specific** and **Positioning** tab and the rest is grey-out (not active).

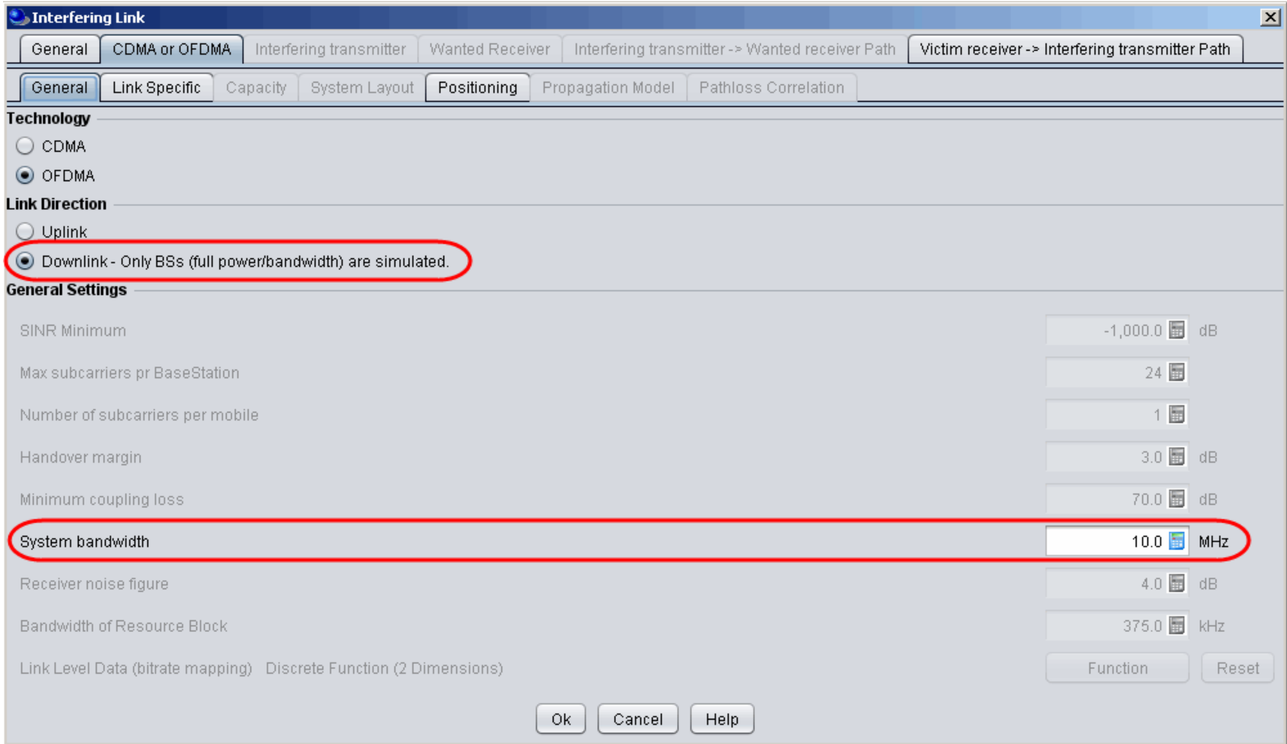

Figure 12: Setting up the OFDMA DL as interferer.
Note that only the system bandwidth is needed in this configuration.

4.2 UL as interferer

When OFDMA UL is the interferer, it is important to simulate the whole interfering network (i.e. power control) so that the interfering emission power from the UE is optimized (see section 2.4 for the power control algorithm). The GUI interface is similar to the victim one (see Figure 5).

4.3 Vr → It path

Figure 13 presents the interface to select the path characteristics of the interferers to the victim. Tabs **#1** and **#2** are standard tabs.

- Tab **#1** allows two set up for the relative positioning of the interfering link (i.e. reference cell) to the victim Wt. It can either be fixed or dynamical (i.e. position of the reference BS following some distance and angle distribution to the Wt). The difference in the option is shown in Figure 14. Note that in both cases, it is possible to input a MCL value.
- Tab **#2** defines the propagation model between the interferer and the victim.
- Tab **#3**. allows to set the path loss correlation between the interferer and the victim. In the case where the victim system is a UL OFDMA, this means that any interferer has a degree a path loss (shadowing) correlation towards each of the sectors of a BS as decribed in section 3.4.

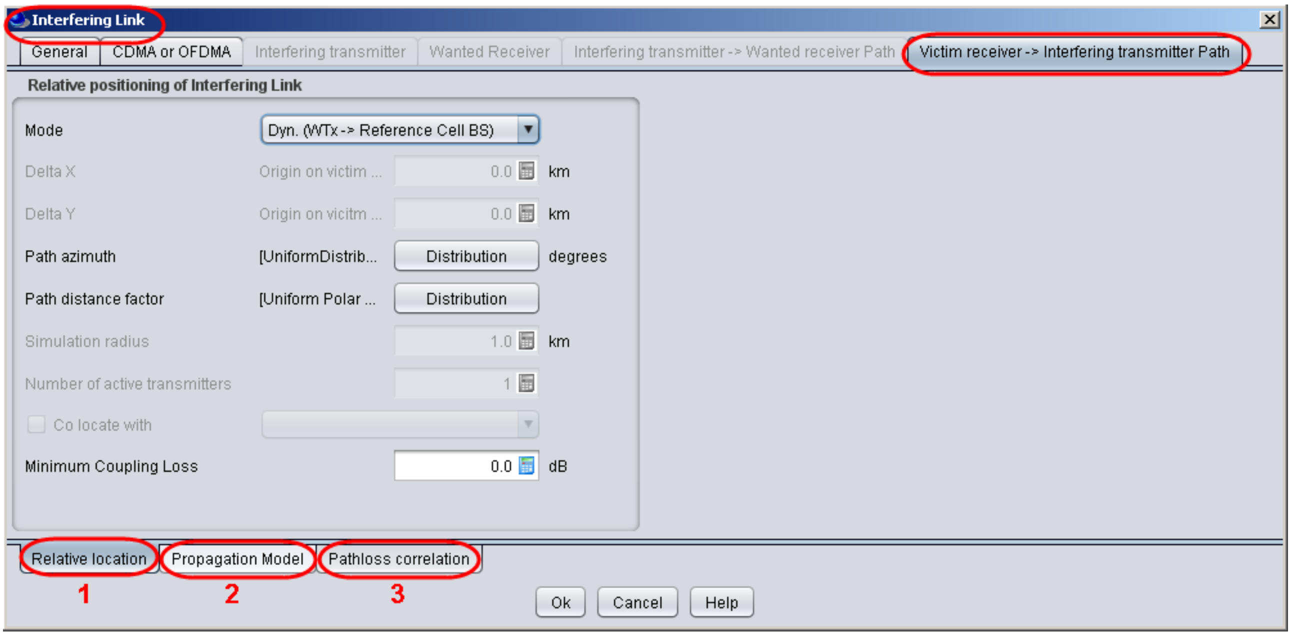

Figure 13: SEAMCAT interface to select the characteristics of the interferers to the victim. The pathloss correlation is only activated when a LTE OFDMA UL victim is simulated.

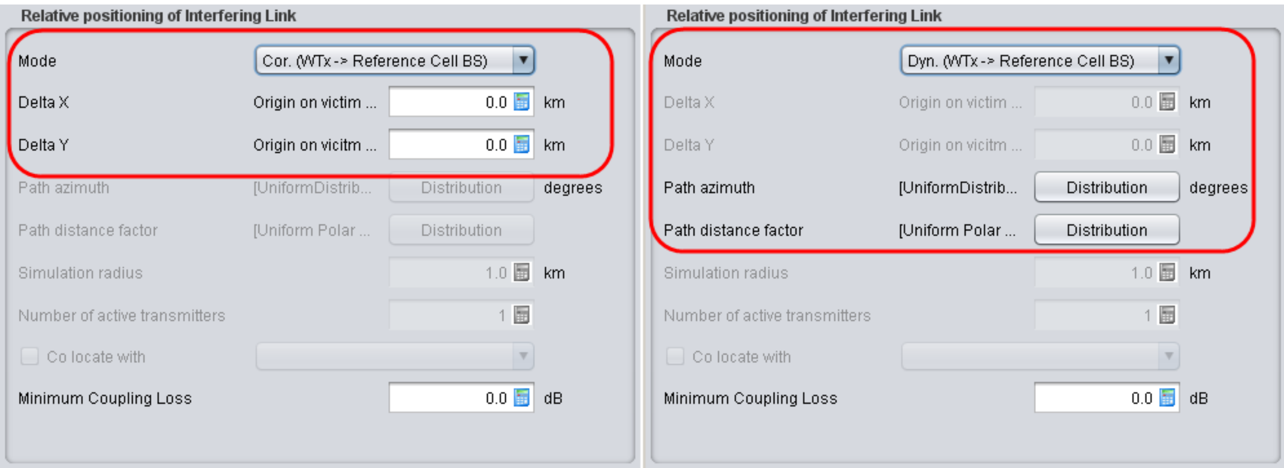

Figure 14: Relative positioning of the Interfering OFDMA system to the victm Wt (or ref. cell of the victim system).

5 OUTPUT PARAMETERS

The results of the OFDMA simulation are given in terms of capacity/throughput loss of the OFDMA victim. Figure 15 presents an overview of the simulation results. The window has been divided in 4 areas.

- **#1** presents the evolution of the achieved bitrate in the reference cell per snapshot (or event),
- **#2** presents the evolution of the achieved bite rate for the whole system per event.
- **#3** allows the user to extract various vectors for post analysis. These vectors are for the achieved bitrate (with or without external interference) and the cell capacity (i.e. the number of active users per cell) with or without interference for the reference cell or the whole system .
- **#4** presents a summary of the average of the capacity and bit rate loss expressed in percentage for both the reference cell and the entire OFDMA network (i.e. the whole system). The percentage calculation is performed for each snapshot and the mean of the percentage over all the snaphsots is deduced.

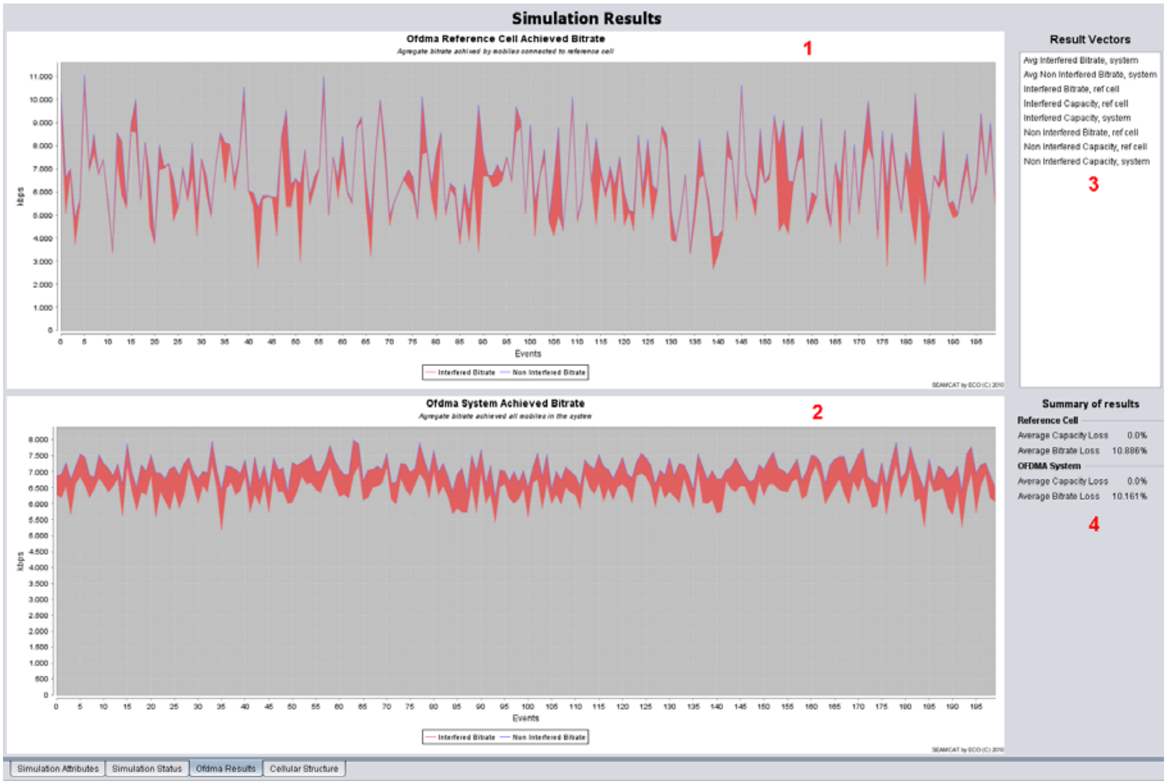

Figure 15: Overview of the OFDMA simulation results

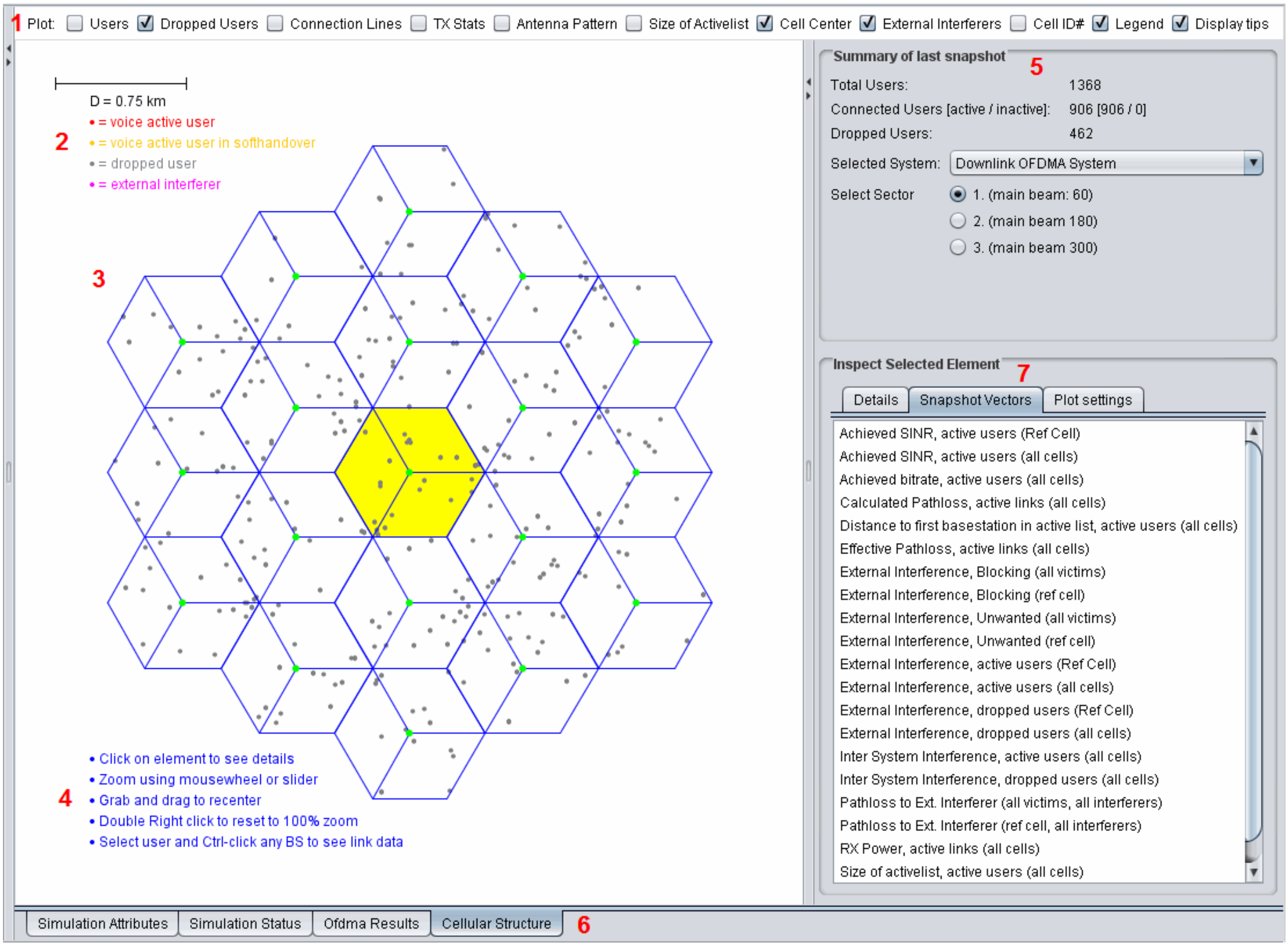

Figure 16: OFDMA system details and ouput vector for the last event

Elements #1 to #6 of Figure 16 are shared components from the CDMA module. Component #6, presents the user with a flexible access to vector results of the OFDMA module, so that users are able to probe various elements of the simulation.

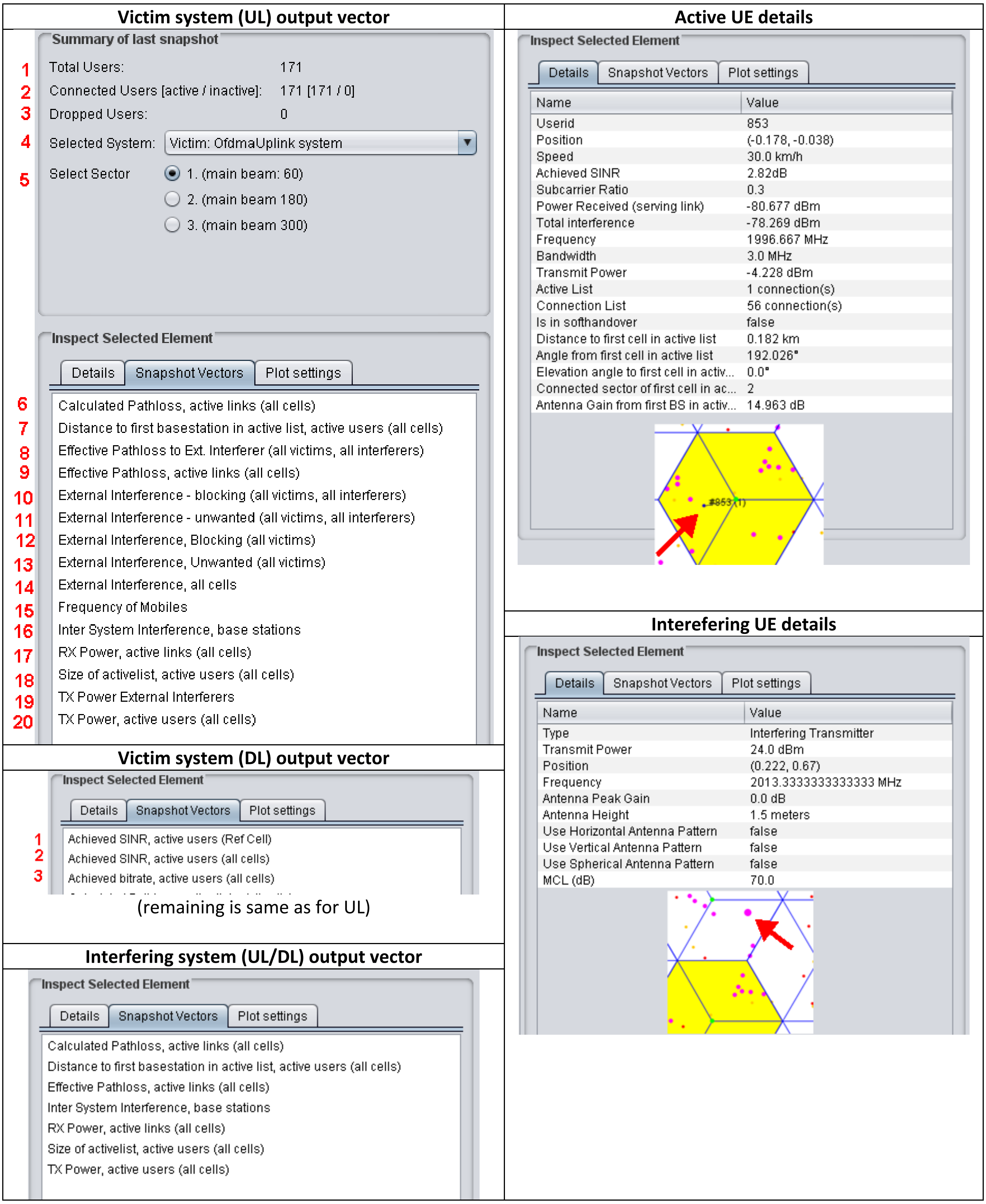

Figure 17: OFDMA UL snapshot vector for the last event.

#	item	description
1	Total users	Number of active users
2	Connected Users [active/inactive]	In OFDMA there is not inactive users (this is a shared component with CDMA). All users are active.
3	Dropped users	Number of droped users (Note: the purpose of the OFDMA is to look at the

		bitrate/throughput loss and not to look at the number of dropped users, but it is possible to drop users depending on the input set-up.)
4	Selected system	The user can choose to visualise either the victim or the interfering system which has been simulated. When the user select the victim system, it is also possible to see the position of the interferer
5	Selected sector	As in CDMA, selecte the beam of interest (for vixualisation purpose only)
6	Calculated pathloss	Raw parthloss for all the active links (i.e. active UE to ist serving BS)
7	Distance to first BS	Distance from UE to its serving BS (first refer to cases where tri-sector is active)
8	Effective Pathloss to Ext. interferer (all victims, all interefers)	Effective pathloss between all the victims and all the external interferers
9	Effective pathloss, active links	Effective pathloss between all the victims and there respective serving BSs. Results of the below equation for all the active links $effective\_pathloss(Tx,Rx) = \max\left(pathloss - G_{Tx} - G_{Rx}, MCL\right)$
10	External interference – blocking (all victims – all interferers)	$iRSS_{blocking}$ for each of the victim UE interferered by each interferer
11	External interference – unwanted (all victims – all interferers)	$iRSS_{unwanted}$ for each of the victim UE interferered by each interferer
12	External interference – blocking (all victims)	Aggregate external interference $iRSS_{blocking}$ for each of the victim UE. Sum over all the interferers
13	External interference – unwanted (all victims)	Aggregate external interference $iRSS_{unwanted}$ for each of the victim UE. Sum over all the interferers
14	External interference, all cells	Sum of the $iRSS_{blocking}$ and $iRSS_{unwanted}$ at each victim cell
15	Frequency mobiles	Vector of the frequency of the UE (in UL) for each active link
16	Inter System Interference	Evaluate $I_{inter}(j,k) = \sum_{l=1, l \neq j}^{N_{cell}} P_t(l,k) \times effective\_pathloss(UE_{l,k}, BS_j)$
17	Rx power, active links	Received power at the victim serving BS (UL) or active UE (DL) from its own system (used for investigating the inter-system interference from other cells)
18	Size of active list	Size of active list
19	Tx power external interferers	Tx power from the interferer
20	Tx power, active users	Tx power from its own system

Table 5: Output results for UL.

Note that for the position information (x,y) of the active UE details, all coordinates are always shown in the SEAMCAT coordinate system which by definition either the WT or the victim reference cell in (0,0). Therefore, the position of the elements of an interfering CDMA or OFDMA system is based on the victim reference cell and not its "internal" reference cell.

#	item	description
1	Achieved SINR, active users (ref cell)	Achieved SINR in the ref cell only
2	Achieved SINR, active users (all cells)	Achieved SINR for the all system
3	Achieved bitrate, active users (all cells)	Achieved bit rate for the all system

Table 6: Output results for DL (the rest of the vectors are like for the UL).