Clarification on the interference criteria

1 METHODOLOGY ASSOCIATED TO THE (C/I) CRITERION

Four interference criteria are considered within SEAMCAT:

C/I

C/(I+N)

(N+I)/N

I/N

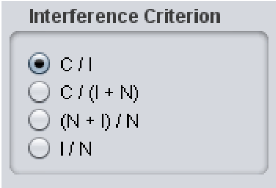


Figure 1: Interference criteria from the Interference Calculation Engine (ICE) control parameter dialogue box (see #6 of Figure 8 on page 6)

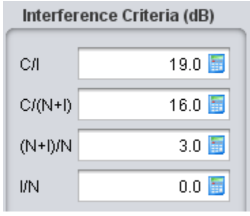


Figure 2: Interference criteria as provided by the user in the victim link dialog

The criterion for interference to occur is for the Vr to have a carrier to interference ratio (C/I) less than the minimum allowable value. In order to calculate the victim's C/I, it is necessary to establish the **victim's wanted signal strength/desired Received Signal Strength** (dRSS) corresponding to the C, as well as the **interfering signal strength** (iRSS) corresponding to the I.

Examples:

C/I may vary typically between 9 dB (e.g. for QPSK) to 26 dB or higher (e.g. for 64QAM…). Introducing noise (I/N), then C/I is desensitised by (N+I)/N resulting in C/(N+I). Note that the desensitisation is exactly the factor (N+I)/N (also = 1+I/N).

Considering that

$$\left[\frac{N+I}{I}\right]_{dB} = \left[\frac{N+I}{N}\right]_{dB} - \left[\frac{I}{N}\right]_{dB} \text{ and } \left[\frac{C}{N+I}\right]_{dB} = \left[\frac{C}{I}\right]_{dB} - \left[\frac{N+I}{I}\right]_{dB}$$

And assuming a C/I of 19 dB, the following examples may be considered:

- I/N = 0 dB, results in (N+I)/N = 3 dB and considering C/I = 19 dB, then C/(N+I) = C/I - 3 dB = 16 dB
- I/N = -6 dB, results in (N+I)/N ≈ 1 dB and considering C/I = 19 dB, then C/(N+I) = C/I - 7 dB = 12 dB
- I/N = -10 dB, results in (N+I)/N ≈ 0.4 dB and considering C/I = 19 dB, then C/(N+I) = C/I - 10 dB = 9 dB
- I/N = -20 dB, results in (N+I)/N = 0.04 ≈ 0.1 dB and considering C/I = 19 dB, then C/(N+I) = C/I - 20 dB = -1 dB

Note that the mathematical relations between these 4 criteria and also the algorithms of the consistency check are provided in Annex 1.

Note: *In case C/(I+N) is chosen as the protection criterion the impact of the interferer is negligible compared to the thermal noise (i.e. C/(I+N) ≈ C/N), if I/N ≤ -20 dB;*

if I/N > 10...20 dB, then C/(I+N) ≈ C/I (i.e. the interferer is more dominant than the thermal noise)

The position of the victim's wanted signal transmitter is identified and a link budget calculation completed. Having knowledge of both the interfering signal strength and the wanted signal strength allows the victim's C/I ratio to be computed. Figure 3 illustrates the various signal levels.

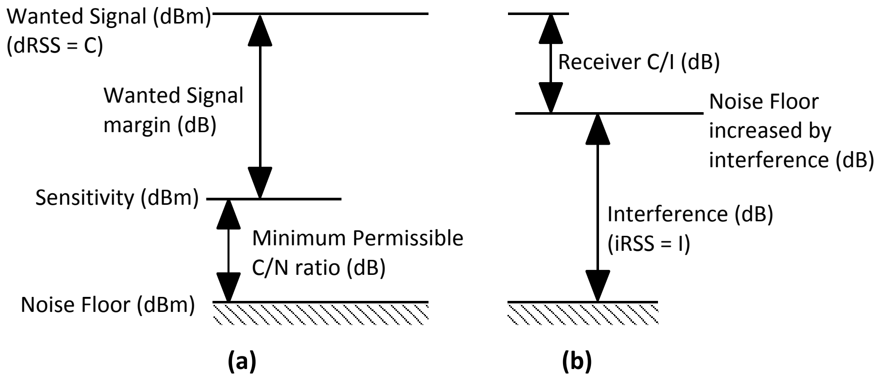


Figure 3: The signal levels used to determine whether or not interference is occurring

Figure 3 (a) represents the situation when there is no interference and the victim is receiving the desired signal with some margin. In this case the victim's Signal level is given by the sum of the Sensitivity and wanted signal margin l.

Figure 3 (b) illustrates what happens when interference occurs. The interference adds to the noise floor. The difference between the wanted signal strength and the interference signal, measured in dB, defines the Signal to Interference ratio. This ratio must be greater than the required C/I threshold if interference is to be avoided. The Monte Carlo simulation tool checks for this condition and records whether or not interference is occurring. This is illustrated further in Figure 4.

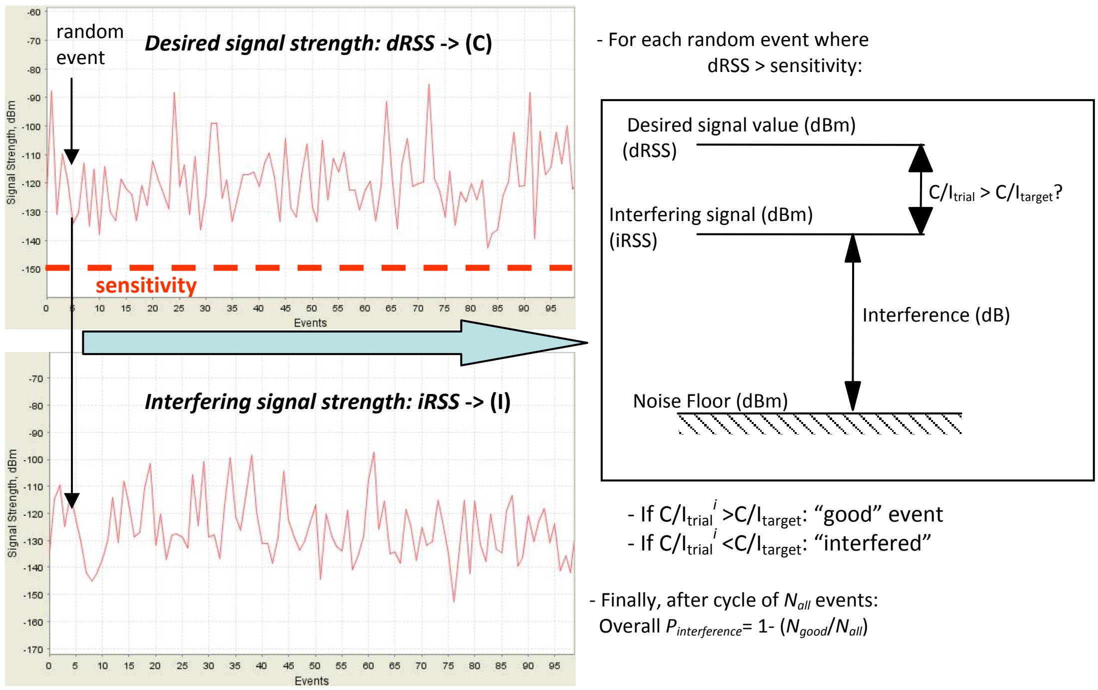


Figure 4: Illustrative summary of the interference criteria computation.

The Monte Carlo technique works by considering many independent instants in time (or in space). For each instant, or simulation trial, a scenario is built up using a number of different random variables, i.e. where the interferer is located with respect to the victim, how strong the wanted signal strength is, which channels the victim and interferer are using etc. If a sufficient number of simulation trials are considered then the probability of a certain event occurring can be calculated with a high level of accuracy.

In this way, the tool is able to quantify the ***probability of interference*** between radio systems and is able to help determine appropriate frequency planning rules or specify limits for transmitter / receiver performance. The

interfering modes (unwanted and blocking) as well as the ***interference criteria*** are selectable in SEAMCAT as shown in Figure 6 (p. 4) and Figure 8 (p. 6).

2 PROBABILITY OF INTERFERENCE

After the simulation of events has been completed by the EGE, the SEAMCAT workspace will have obtained and stored the vectors of wanted (dRSS) and unwanted (iRSS) signals. The user then may proceed to use the facilities of the ICE in order to evaluate the probability of interference for the simulated scenario.

The ICE interface may be found by selecting the Interference Calculations tab, which will open the dialog window as shown in Figure 5.

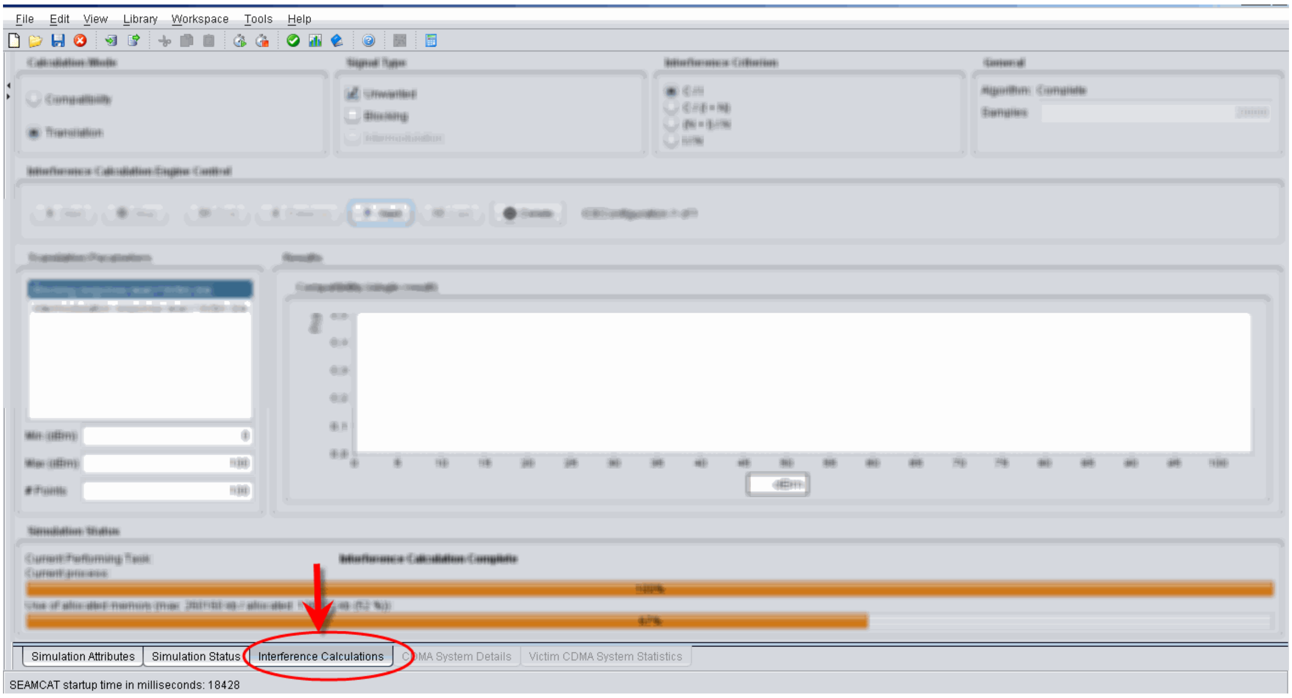


Figure 5: Interference calculation tabsheet.

The probability of interference could be calculated by the ICE with reference to the following choice of input parameters:

- Calculation mode: compatibility or translation
- Which type of interference signal is considered for calculation: unwanted, blocking, intermodulation or their combination
- Interference criterion: C/I, C/(N+I), (N+I)/N or I/N

2.1 Compatibility calculation mode

It is then possible to derive the C/I (i.e. dRSS/iRSS):

dRSS/iRSS = -53.5-(-54.5) = 1 dB

Since the resulting C/I is below the protection criteria (19 dB), the probability of interference calculated by SEAMCAT (compatibility calculation mode) is equal to 1 as shown in Figure 6.

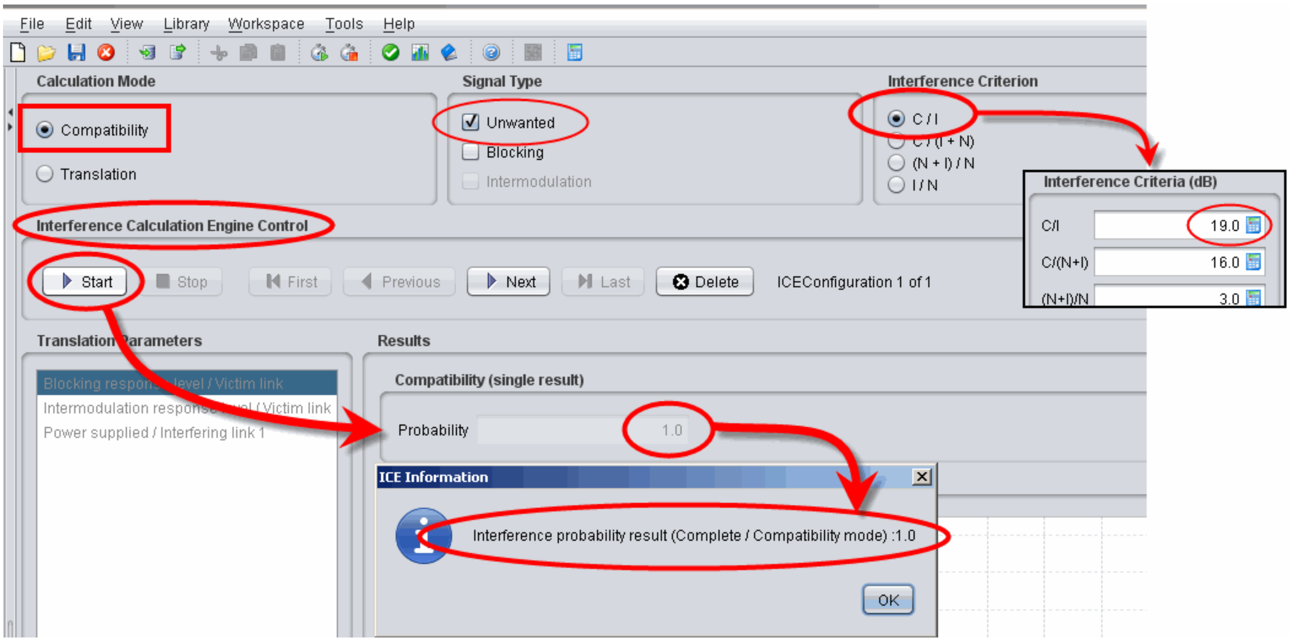


Figure 6: Probability of interference

2.2 Translation calculation mode

When the Translation mode is chosen, the user may calculate and display a chart of the probability of interference as a function of one of the following input parameters:

- Output power of Interfering transmitter;
- Blocking response level of Victim receiver;
- Intermodulation response level of Victim receiver.

The translation function, as shown as (**#1**) in Figure 7, allows investigation of the probability of interference for varying power supplied (**#2**) to the interfering transmitter. The power supplied (**#3**) to the interfering transmitter should be equal to 15 dBm, which is 18 dB below the value used in the simulation (33 dBm). Effectively the C/I will be increased by 18 dB and reaches the level of 19 dB, i.e. the value which was provided by the user in the victim link dialog.

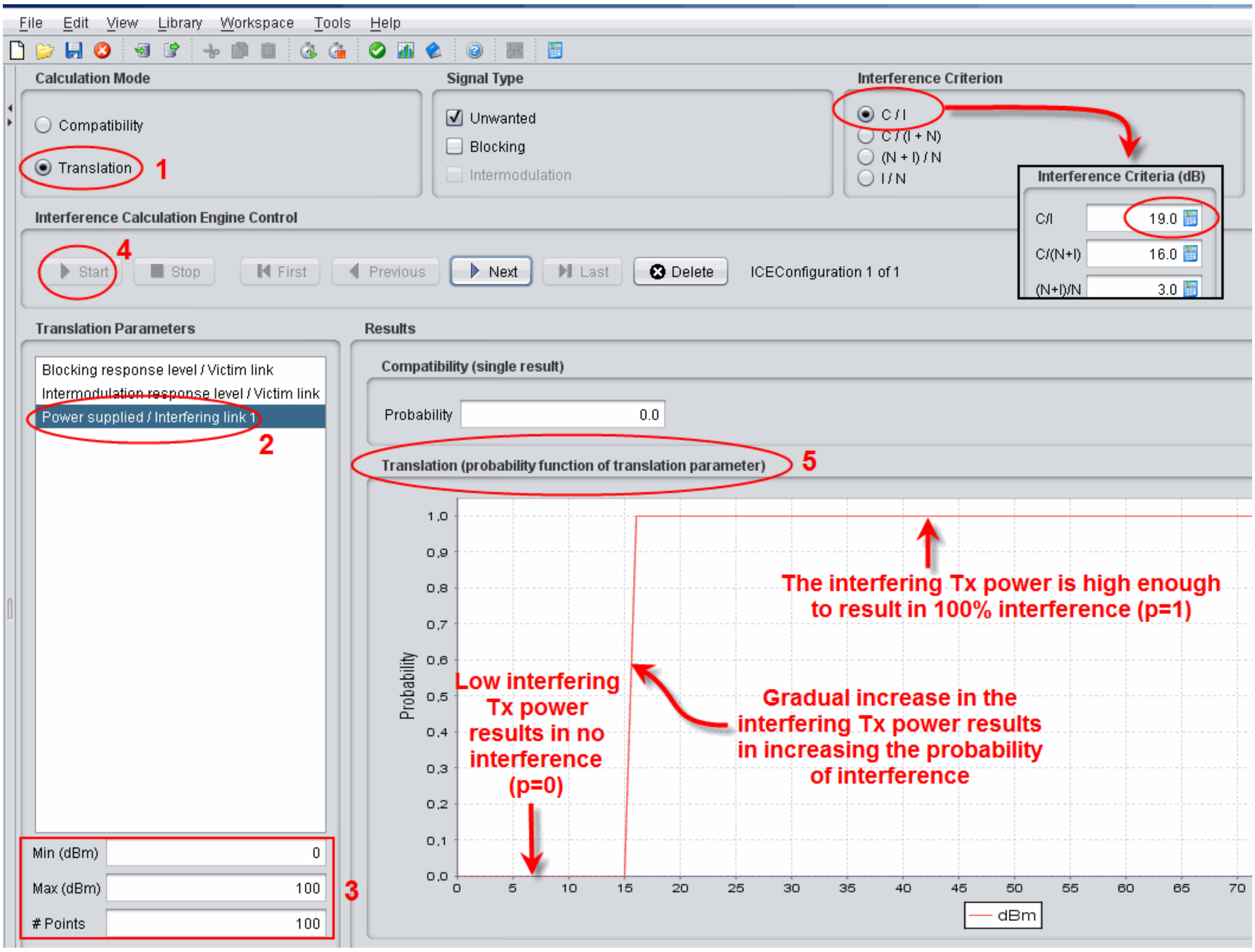


Figure 7: Translation function

Annex 1 : ICE Control Parameters

A.1.1 ICE Graphical User Interface

After completing the EGE simulations, it is possible to proceed with calculation of probability of interference, using the SEAMCAT Interference Calculation Engine (ICE) function. It is the ultimate part of the SEAMCAT architecture when applied to non-CDMA victim systems. The ICE control parameters are described in this annex. An illustration of the ICE Control dialog window is presented below:

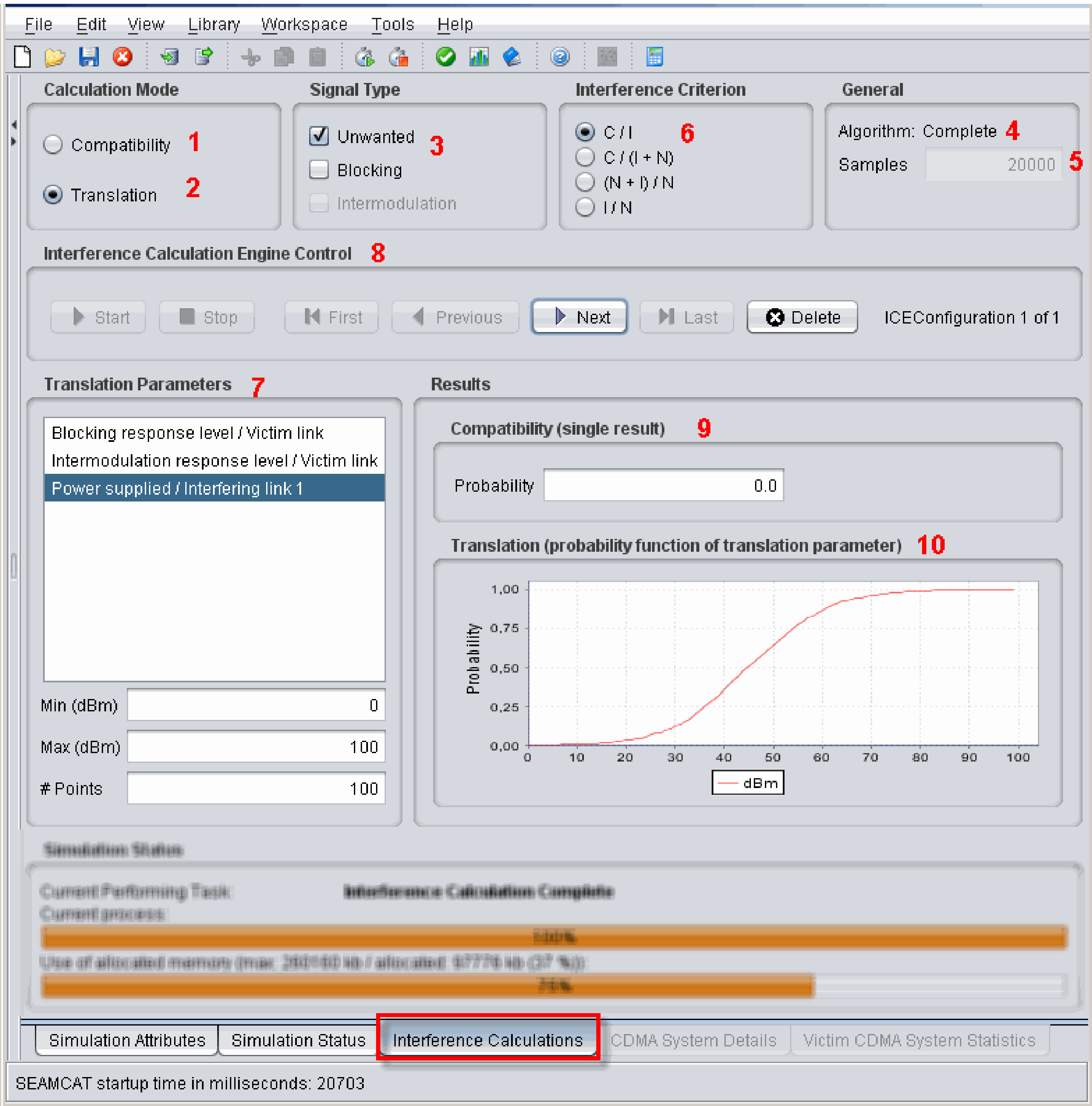


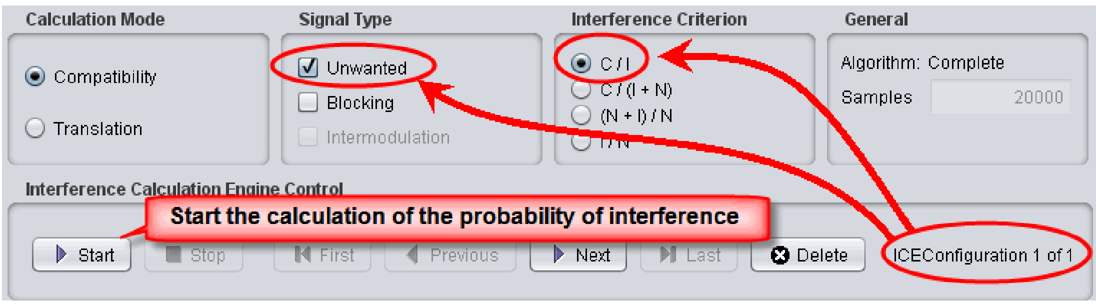
Figure 8: ICE control dialogue box

ID	Description	Comments
1	**Calculation mode/Compatibility:** The result is a probability of interference.	Compatibility: Gives the probability of being interfered by the Blocking interference and/or by the Unwanted interference and/or by intermodulation interference.
2	**Calculation mode/Translations**: the result is a graph. In this case all the following parameters should be independent from frequencies: Receiver blocking response mask, Receiver intermodulation rejection mask, power distribution of interfering transmitter, Unwanted emission floor mask.	Calculation of the probability of interference as a function of the reference parameters: • Power supplied by the It for the unwanted, • Blocking response level of the Vr for the Blocking, • And intermodulation rejection level for the Vr. These parameters are varying on user-defined definition domain defined by the number of points where the software has to calculate the probability.
3	**Signal type**	Choose the interference studied: Unwanted and/or Blocking and/or Intermodulation.
4	**Algorithm**	formerly known as “Complete 1”
5	Samples	It represents the number of events to calculate the probability from. The accuracy of the probability results derives from this parameters..
6	**Interference criterion**	Choose between C/I, C/(N+I), (N+I)/N, I/N)
7	**Translation parameters**: If translation was chosen	Number of points between the min and max, where the software will calculate the probability.
8	**Calculation control**	Delete a result, and see the last results
9	**Result/Compatibility**	Probability of interference: 1 - always interfered, 0 - never interfered
10	**Result/Translation**	Gives the graph, showing the resulting probability of interference vs. the selected values of translation parameter. The average of the graph depends of the number of points, but the higher the number is, the longer the calculations are.

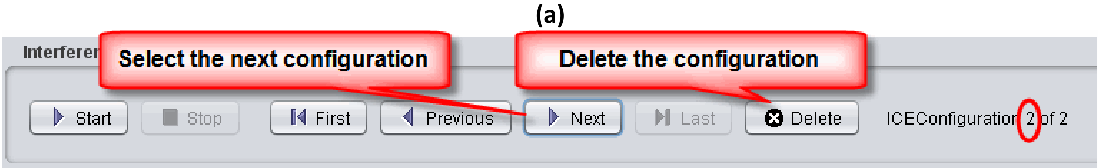
Table 1: Parameters to calculate the probability of interference

A.1.2 Interference Calculation Engine Control

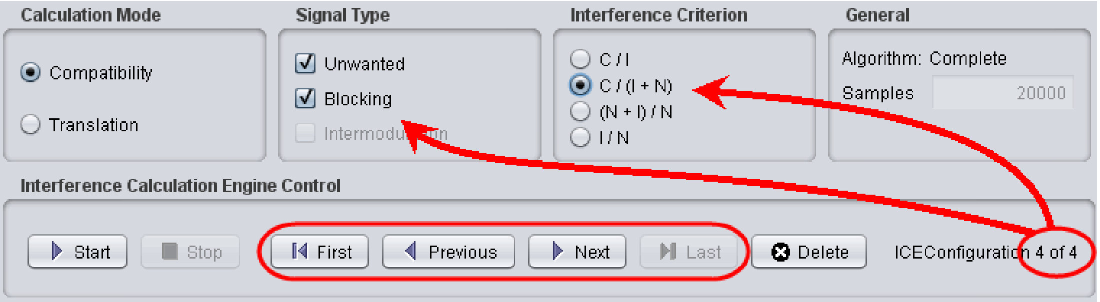
It allows the user to calculate the probability of interference for several ICE configuration (i.e. different signal type, interference criteria, etc..) for the same simulation. Figure 9 presents two examples on how the control box is to be used. When several ICE configuration are computed, then the user can jump from one to another without recomputing them by selecting the “**first**”, “**previous**”, “**next**” and “**last**” buttons.



(a)



(b)



(c)

Figure 9: Example (a), (b) and (c) on using the Interference Calculation Engine Control

A.1.3 Interference Calculation Engine

The ICE processes the information gathered by the EGE to calculate the probability of interference. In this engine, according to their statistical nature, the data arrays related to the interfering mechanism ($iRSS_i$) are summed over the number of active interfering transmitter to build up the data array $iRSS_{comp}$ (composite Interfering Received Signal Strength), which is used in the interference probability calculation.

The samples of wanted (*dRSS*) and unwanted (*iRSS*) signals generated by the EGE are compared against the relevant signal-to-noise criteria (specified in the scenario, such as *C/I, C/(I+N), (N+I)/N* and *I/N*) to calculate the actual probability of interference with the condition that the desired received signal strengths is greater than the sensitivity of the victim receiver (*dRSS* > sens).

An illustration of the summary of the interference criteria computation process is presented in Figure 4 in the introduction of the handbook. This probability can be calculated for the different interference mechanisms.

SEAMCAT calculates the probability of interference (p_I) of the victim receiver as follows:

$$p_I = 1 - p_{NI}$$

were p_{NI} is the probability of Non Interference (*NI*) of the receiver.

When a C/I criterion is considered, p_{NI} is defined as:

$$p_{NI} = P\left(\frac{dRSS}{iRSS_{comp}} > \frac{C}{I} \middle| dRSS > sens \right)$$

since by definition P(A|B)=P(A∩B)/P(B), p_{NI} becomes:

$$p_{NI} = \frac{P\left(\frac{dRSS}{iRSS_{comp}} > \frac{C}{I}, \quad dRSS > sens \right)}{P(dRSS > sens)}$$

with $iRSS_{comp} = \sum_{j=1}^{P} iRSS_j$ where *P* is the number of interferers (i.e. active transmitters).

Note that the Monte Carlo method is applied individually to the numerator and to the denominator of the expression of p_{NI}. The result obtained is an estimation of p_{NI} by using the following equations (p'_{NI}):

$$p'_{NI} = \frac{\frac{1}{M} \sum_{i=1}^{M} 1_{\left\{ \frac{dRSS(i)}{iRSS_{comp}(i)} > \frac{C}{I}, \quad dRSS(i) > sens \right\}}}{\frac{1}{M} \sum_{i=1}^{M} 1_{\{dRSS(i) > sens\}}} = \frac{\sum_{i=1}^{M} 1_{\left\{ \frac{dRSS(i)}{iRSS_{comp}(i)} > \frac{C}{I}, \quad dRSS(i) > sens \right\}}}{\sum_{i=1}^{M} 1_{\{dRSS(i) > sens\}}}$$

with *M* the number of events (or snapshots) and where

$$1\{condition\} = \begin{cases} 1, & \text{if condition is satisfied} \\ 0, & \text{else} \end{cases}$$

Similarly, when a C/(I+N) criterion is considered, p_{NI} is defined as:

$$p_{NI} = \frac{P\left(\frac{dRSS}{iRSS_{comp} + N} > \frac{C}{I + N},\quad dRSS > sens\right)}{P(dRSS > sens)}$$

When a (I+N)/N criterion is considered, p_{NI} is defined as:

$$p_{NI} = \frac{P\left(\frac{iRSS_{comp} + N}{N} > \frac{I + N}{N},\quad dRSS > sens\right)}{P(dRSS > sens)}$$

When a I/N criterion is considered, p_{NI} is defined as:

$$p_{NI} = \frac{P\left(\frac{iRSS_{comp}}{N} > \frac{I}{N},\quad dRSS > sens\right)}{P(dRSS > sens)}$$

A.1.4 Interference criteria C/I, C/(N+I), (N+I)/N ,I/N relationship

The user defines protection criteria and chooses one of then when conducting the evaluation of the probability of interference (C/I, C/(N+I), (N+I)/N ,I/N). SEAMCAT performs a consistency checking between the interference criteria.

For example, we may calculate the (N+I)/N when we know the value of C/I and C/(N+I). If we assume that:

C/I = 19 dB *C/(N+I) = 16 dB*

Using the equation:

$$\frac{N+I}{N} = 10\log_{10}\left[1 + \frac{1}{10^{\frac{\frac{C}{I} - \frac{C}{N+I}}{10}} - 1}\right] \qquad (1)$$

This gives:

$$\frac{N+I}{N} = 10\log_{10}\left[1 + \frac{1}{10^{0.3} - 1}\right] = 3dB$$

Therefore, if the user provides a value for each of these parameters (C/I, C/(N+I) and (N+I)/N), SEAMCAT using the equation (1) checks the consistency of these parameters.

Taking into account this value of (I+N)/N and using the equation:

$$\left[\frac{N+I}{N}\right]_{dB} = 10\times\log_{10}\left[\frac{N+I}{N}\right] = 10\times\log_{10}\left[1 + \frac{I}{N}\right] = 10\times\log_{10}\left[1 + 10^{\frac{\left[\frac{I}{N}\right]_{dB}}{10}}\right] \qquad (2)$$

Considering

$$\left[\frac{I}{N}\right]_{dB} = 10\times\log_{10}\left[\frac{I}{N}\right] = 10\times\log_{10}\left[\frac{I+N-N}{N}\right] = 10\times\log_{10}\left[\frac{N+I}{N} - 1\right] = 10\times\log_{10}\left[10^{\frac{\left[\frac{N+I}{N}\right]_{dB}}{10}} - 1\right]$$

and that

$$\left[\frac{N+I}{N}\right]_{dB} = \left[\frac{N+I}{C}\right]_{dB} + \left[\frac{C}{N}\right]_{dB} = -\left[\frac{C}{N+I}\right]_{dB} + \left[\frac{C}{N}\right]_{dB}$$

Therefore, this leads to

$$\left[\frac{I}{N}\right]_{dB} = -10 \times \log_{10}\left[\frac{N}{I}\right] = -10 \times \log_{10}\left[\frac{N+I-I}{I}\right] = -10 \times \log_{10}\left[\frac{N+I}{I} - 1\right]$$

$$\left[\frac{I}{N}\right]_{dB} = -10 \times \log_{10}\left[10^{\frac{\left[\frac{N+I}{I}\right]_{dB}}{10}} - 1\right] = -10 \times \log_{10}\left[10^{\frac{\left[\frac{C}{I}+\frac{N+I}{C}\right]_{dB}}{10}} - 1\right] = -10 \times \log_{10}\left[10^{\frac{\left[\frac{C}{I}-\frac{C}{I+N}\right]_{dB}}{10}} - 1\right]$$

$$\left[\frac{I}{N}\right]_{dB} = -10 \times \log_{10}\left[10^{0.3} - 1\right] = 0dB$$

Therefore, if the user provides a value for (N+I)/N and I/N, SEAMCAT using the equation (2) checks the consistency of these parameters.

The following default values for the C/I, C/(N+I), (N+I)/N and I/N of 19 dB, 16 dB, 3 dB and 0 dB respectively avoid the display of a warning.