

REPORT ITU-R SM.2028-1

**Monte Carlo simulation methodology for the use in sharing
and compatibility studies between different
radio services or systems**

(Question ITU-R 211/1)

(2001-2002)

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Summary

In this Report background information on a Monte Carlo radio simulation methodology is given. Apart from giving general information this text also constitutes a specification for the first generation of spectrum engineering advanced Monte Carlo analysis tool (SEAMCAT) software which implements the Monte Carlo methodology applied to radiocommunication scenarios.

General

The problem of unwanted emissions, as a serious factor affecting the efficiency of radio spectrum use, is being treated in depth in various fora, internal and external to the European Conference of Postal and Telecommunications Administrations (CEPT). As the need to reassess the limits for unwanted emissions within Appendix 3 of the Radio Regulations (RR) is observed, it is widely recognized that a generic method is preferable for this purpose.

One of numerous reasons why generic methods are favoured is their *a priori* potential to treat new communication systems and technologies as they emerge. Another reason is that only a generic method can aspire to become a basis for a widely recognized analysis tool.

The Monte Carlo radio simulation tool described in this Report was developed, based on the above considerations, within the European Radiocommunication Committee (ERC) process.

SEAMCAT

SEAMCAT is the implementation of a Monte Carlo radio simulation model developed by the group of CEPT administrations, European Telecommunications Standards Institute (ETSI) members and international scientific bodies. SEAMCAT is a public object code software distributed by the CEPT European Radiocommunications Office (ERO), Copenhagen. The Web address is as follows:

<http://www.ero.dk>

The software is also available in the ITU-R software library. Further details can be provided by ERO, e-mail: ero@ero.dk.

1 Background

In order to reassess the limits for unwanted emissions within RR Appendix 3, it is desirable to develop an analytical tool to enable us to evaluate the level of interference which would be experienced by representative receivers. It has been agreed in the ITU-R that level of interference should be expressed in terms of the probability that reception capability of the receiver under consideration is impaired by the presence of an interferer. To arrive at this probability of interference, statistical modelling of interference scenarios will be required and this Report describes the methodology and offers a proposal for the tool architecture.

The statistical methodology described here and used for the tool development is best known as Monte Carlo technique. The term “Monte Carlo” was adopted by von Neumann and Ulan during World War II, as a code-name for the secret work on solving statistical problems related to atomic

bomb design. Since that time, the Monte Carlo method has been used for the simulation of random processes and is based upon the principle of taking samples of random variables from their defined probability density functions. The method may be described as the most powerful and commonly used technique for analysing complex statistical problems. The Monte Carlo approach does not have an alternative in the development of a methodology for analysing unwanted emission interference.

The approach is:

- generic: a diversity of possible interference scenarios can be handled by a single model.
- flexible: the approach is very flexible, and may be easily devised in a such way as to handle the composite interference scenarios.

2 Monte Carlo simulation methodology: An overview

This methodology is appropriate for addressing the following items in spectrum engineering:

- sharing and compatibility studies between different radio systems operating in the same or adjacent frequency bands, respectively;
- evaluation of transmitter and receiver masks;
- evaluation of limits for parameters such as unwanted (spurious and out-of-band) blocking or intermodulation levels.

The Monte Carlo method can address virtually all radio-interference scenarios. This flexibility is achieved by the way the parameters of the system are defined. The input form of each variable parameter (antenna pattern, radiated power, propagation path,...) is its statistical distribution function. It is therefore possible to model even very complex situations by relatively simple elementary functions. A number of diverse systems can be treated, such as:

- broadcasting (terrestrial and satellite);
- mobile (terrestrial and satellite);
- point-to-point;
- point-to-multipoint, etc.

The principle is best explained with the following example, which considers only unwanted emissions as the interfering mechanism. In general the Monte Carlo method addresses also other effects present in the radio environment such as out-of-band emissions, receiver blocking and intermodulation.

Some examples of applications of this methodology are:

- compatibility study between digital personal mobile radio (PMR) (TETRA) and GSM at 915 MHz;
- sharing study between FS and FSS;
- sharing study between short range devices (Bluetooth) and radio local area networks (RLANs) in the industrial, scientific and medical (ISM) band at 2.4 GHz;

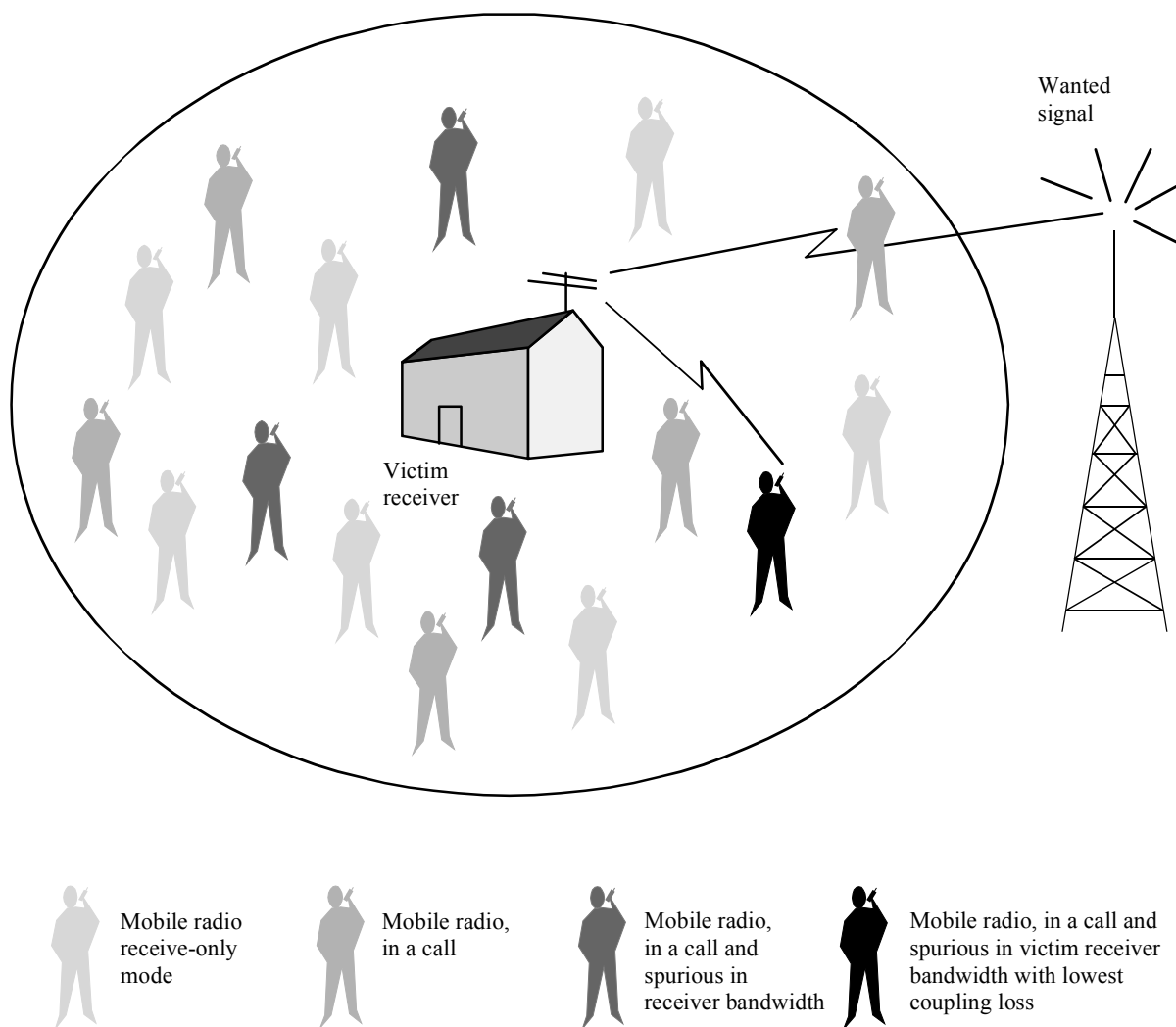
- compatibility study for International Mobile Telecommunications-2000 (IMT-2000) and PCS1900 around 1.9 GHz;
- compatibility study for ultra wideband systems and other radio systems operating in these frequency bands.

2.1 Illustrative example (only unwanted emissions, most influential interferer)

For interference to occur, it has been assumed that the minimum carrier-to-interference ratio, C/I , is not satisfied at the receiver input. In order to calculate the C/I experienced by the receiver, it is necessary to establish statistics of both the wanted signal and unwanted signal levels. Unwanted emissions considered in this simulation are assumed to result from active transmitters. Moreover, only spurs falling into the receiving bandwidth have been considered to contribute towards interference. For the mobile to fixed interference scenario, an example is shown in Fig. 1.

FIGURE 1

An example of interference scenario involving TV receiver and portable radios

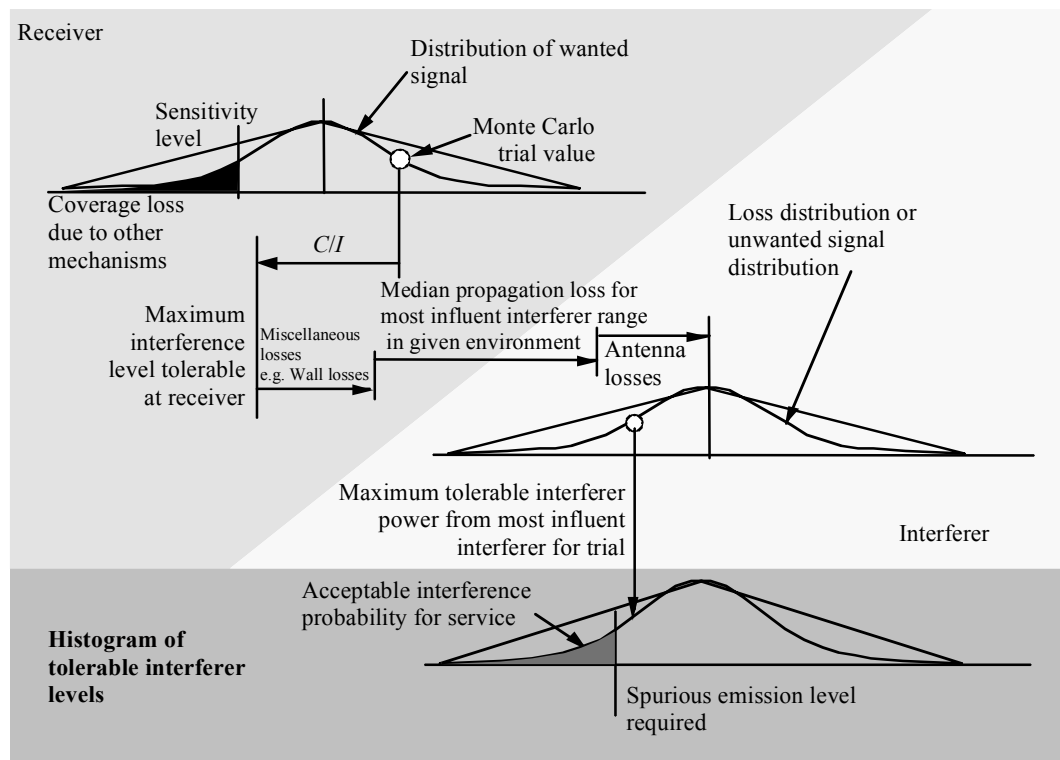


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Many potential mobile transmitters are illustrated. Only some of the transmitters are actively transmitting and still fewer emit unwanted energy in the victim receiver bandwidth. It is assumed that interference occurs as a result of unwanted emissions from the most influent transmitter with the lowest path loss (median propagation loss + additional attenuation variation + variation in transmit power) to the receiver.

An example of Monte Carlo simulation process as applied to calculating the probability of interference due to unwanted emission is given in Fig. 2. For each trial, a random draw of the wanted signal level is made from an appropriate distribution. For a given wanted signal level, the maximum tolerable unwanted level at the receiver input is derived from the receiver's C/I figure.

FIGURE 2
An example formulation of the Monte Carlo evaluation process



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For the many interferers surrounding the victim, the isolation due to position, propagation loss (including any variations and additional losses) and antenna discrimination is computed. The lowest isolation determines the maximum unwanted level which may be radiated by any of the transmitters during this trial.

From many trials, it is then possible to derive a histogram of the unwanted levels and for a given probability of interference, then to determine the corresponding unwanted level.

By varying the values of the different input parameters to the model and given an appropriate density of interferers, it is possible to analyse a large spectra of interference scenarios.

3 Architecture requirements

One of the main requirements is to select such an architectural structure for the simulation tool which would be flexible enough to accommodate analysis of composite interference scenarios in which a mixture of radio equipment sharing the same habitat and/or multiple sources of interference (e.g. out-of-band emission, spurious emission, intermodulation, ...) are involved and can be treated concurrently.

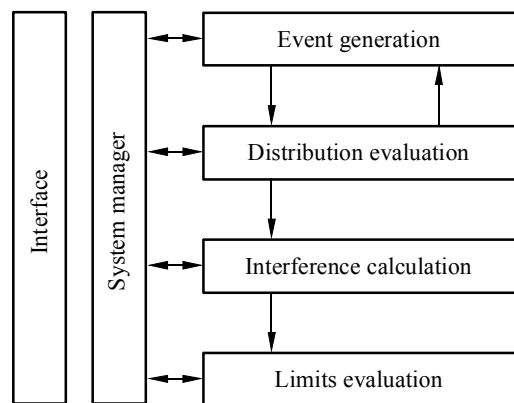
Other requirements would be that the proposed architecture consists of modular elements and is versatile enough to allow treatment of the composite interference scenarios.

The proposed Monte Carlo architecture which meets these constraints is presented in Fig. 3. The proposed architecture is basically of a sequential type and consists of four processing engines:

- event generation engine;
- distribution evaluation engine;
- interference calculation engine;
- limits evaluation engine.

The schematic view of the entire tool is in Fig. 3.

FIGURE 3
Architecture of the simulation tool



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The list of interference parameters and their relevance to one or more of the processing engines is shown in Annex 1.

3.1 Event generation engine

The event generation engine (EGE) takes the relevant parameters from the submitted interference scenario and generates information on the received signal strength (RSS) of the desired, as well as on the strength for each of the interfering, signals included in the composite interference scenario.

This process is repeated N times, where N is a number of trials which should be large enough to produce statistically significant results. Generated samples of the desired, as well as all interfering, signals are stored in separate data arrays of the length N .

The trials on parameters being common for desired and interfering radio paths are done concurrently in order to capture possible correlation between desired and interfering signals. Such an implementation will not cover those seldom cases of interference in which one interference mechanism is excited by another interference (e.g. a strong emission of the first transmitter mixes with a spurious emission of the second transmitter and produces an intermodulation type of interference).

The flow chart description and detailed algorithm description for the EGE are presented in Annex 2.

List of potential sources of interference to be found in a radio environment includes:

Transmitter interference phenomena:

- unwanted (spurious and out-of-band) emissions;
- wideband noise;
- intermodulation;
- adjacent channel;
- co-channel.

Receiver interference phenomena:

- spurious emission.

Background noise:

- antenna noise;
- man-made noise.

Other receiver interference susceptibility parameters:

- blocking;
- intermodulation rejection;
- adjacent and co-channel rejections;
- spurious response rejection.

All of the above sources can be classified into three generic interference mechanism categories: undesired emission, intermodulation and receiver susceptibility. Each of the above three categories requires a different model for physical processes being characteristic for that interfering mechanism. The man-made noise and the antenna temperature noise can be considered as an increase of the thermal noise level, decreasing thus the sensitivity of a receiver, and can be entered in the simulation when the criteria of interference is I/N (interference-to-noise ratio) or $C/(I + N)$ (wanted signal-to-interference + noise).

3.2 Distribution evaluation engine

The distribution evaluation engine (DEE) takes arrays of the data generated by the EGE and processes the data with the aim of:

- a) assessing whether or not the number of samples is sufficient to produce statistically stable results;
- b) calculating correlation between the desired signal and interfering signal data and between different types of the interfering signals (e.g. blocking vs. unwanted emissions);
- c) calculating a known continuous distribution function, e.g. Gaussian, as the best fit to the generated distributions of the desired and interfering signal data.

Items a) and c) can be achieved using well known goodness-of-fit algorithms for general distributions such as the Kolmogorov-Smirnov test. Applicability of the fit to this specific task is to be further investigated in the planned phase 2 of the development of the methodology.

If DEE detects unacceptable variation in discrete distribution parameters estimated in two successive estimations using N and $N + \Delta N$ sample sizes, the EGE is instructed to generate another ΔN of additional samples. This test is repeated until a tolerable variation of the parameters is measured over the pre-defined number of successive tests.

Three different kinds of outputs are possible from the DEE engine:

- data arrays of the wanted and interfering signals. This is the output in the case that a high degree of correlation is detected between the wanted and any of the interfering signals;
- discrete distributions of the wanted and interfering signals are passed in the case of a weak correlation between the signals or in the case that there was no correlation between the signals but no continuous distribution approximation with satisfactory accuracy was possible;
- continuous distribution functions of the wanted and interfering signals are passed to the interference calculation engine (ICE) in the case that signals were de-correlated and discrete distributions were successfully approximated with continuous distribution functions.

The proposed flow chart and detailed algorithm specification are presented in Annex 3.

3.3 Interference calculation engine (ICE)

The ICE is the heart of the proposed architecture. Here, information gathered by the EGE and processed by DEE are used to calculate probability of interference. Depending on which kind of information was passed from DEE to ICE, three possible modes of calculating the probability of interference are identified, as shown in Annex 4.

Mode 1: Data arrays for $dRSS$ (wanted signal) and i_nRSS (interfering signal resulting from n different systems) passed by the DEE to the ICE, and vector representing the composite interfering signal I is calculated as a sum of the i_nRSS data vectors.

Mode 2: Distribution function for the composite interfering signal is calculated by taking random samples for i_nRSS distributions and linearly adding them up.

Mode 3: The i_nRSS is calculated using numerical or analytical integration of the supplied distribution functions for each of the interference sources.

Mode 4: All signals are assumed to be mutually independent and the overall probability for interference is identified as the probability to be disturbed by at least one kind of interference.

Different criteria for calculation of interference probability can be accommodated within the processing engine. A cumulative probability functions (cpf) can be calculated for C/I , $C/(N+I)$, I/N or $N/(N+I)$ random variables.

The flow of information together with associated processes is shown in the form of a flow chart in Annex 4.

All interfering signal distributions are calculated with respect to reference levels, or functions, of unwanted (emission mask), blocking (receiver mask) or intermodulation attenuation. Interfering signal distributions for some other reference levels or functions can be derived by first order (unwanted or blocking) or third order (intermodulation) linear translation of the reference distributions (see Annex 4).

3.4 Limits evaluation engine (LEE)

The LEE is to play a very important role in two aspects of the tool development:

- selection of optimal values for the limits;
- verification of the tool.

Output from the ICE is presented as a multi-dimensional surface characterizing the dependence of the probability of interference versus the radio parameters. Two main features of the probability surface are:

- the same probability of interference is achieved by different sets of the limit values for the radio parameters under consideration;
- probability of interference parameter is not used in the radio system design and as such does not lend itself nicely for the validation through the system performance measurements. Instead, degradation in system coverage or traffic capacity seems to be more appropriate for understanding impact of a particular probability of interference to the radio system performance.

The radio variables are transformed from the probabilistic space into a system performance space enabling us to evaluate the system performance degradation due to presence of interference. When the inter-system compatibility is analysed (e.g. unwanted emission), radio coverage and/or traffic capacity can be used to evaluate the impact of the radio parameters limits. For the case of intra-system compatibility study (e.g. out-of-band emission), spectrum efficiency should be used to derive appropriate values for the radio parameters.

The limit values are derived by means of an optimization algorithm. For optimization to work, a criteria needs to be set. The criteria is usually termed the cost function and the optimization process has for a task to minimize this cost function. The cost function is a function of all radio parameters and their significance to the cost can be altered by means of the weight coefficients.

The weight coefficients can integrate any of the following aspects into the optimization process:

- system availability;
- traffic capacity;
- spectrum utilization;
- technological limitations;
- economic constraints.

The set of radio parameters values for which the cost function is minimized represents the optimal solution for the limit values.

The role of LEE is very important within the tool. However, since its various elements are still under consideration, it will not be possible to include LEE into the first phase of the implementation.

Annex 1

List of input parameters

The following rules are applied:

- a capital letter is used for a distribution function, e.g. P ;
- a small letter is a variable (result of a calculation or a trial), e.g. p ;
- the index refers to a player: wanted transmitter, victim receiver, wanted receiver and interfering transmitter.

Parameters for the wanted transmitter (wt)

$P_{wt}^{supplied}$: power level distribution for various transmitters (dBm)

$p_{wt}^{supplied}$: sample power level taken from the above distribution (dBm)

g_{wt}^{max} : maximum antenna gain (dBi)

$pattern_{wt}$: antenna directivity within operating bandwidth (dB) (supplied as a function or a look-up table)

H_{wt} : antenna height distribution (1/m)

R_{wt}^{max} : radius of the wanted transmitter coverage (km), (not required for point-to-point)

Parameters for the victim receiver (vr) C/I : protection ratio (dB) g_{vr}^{max} : maximum antenna gain (dBi) $pattern_{vr}$: antenna directivity within operating bandwidth (dB) (supplied as a function or a look-up table) H_{vr} : antenna height distribution (1/m) $block$: receiver frequency response (dB) a_{vr} : receiver susceptibility characteristic is expressed as a ratio between desired interfering signal levels producing unacceptable receiver performance and is n as a function of frequency separation between the two signals $intermod$: receiver intermodulation response (dB)

The intermodulation response is a measure of the capability of the receiver to receive a wanted modulated signal without exceeding a given degradation due to the presence of two unwanted signals with a specific frequency relationship to the wanted signal frequency

 f_{vr} : frequency (MHz) $sens_{vr}$: sensitivity of victim receiver (dBm) b_{vr} : bandwidth of victim receiver (kHz)*Parameters for the interfering transmitter (it)* $P_{it}^{supplied}$: power level distribution of various transmitters (dBm) $p_{it}^{t_hold}$: power control threshold (dBm) $p_{it}^{dyc_rg}$: power control dynamic range (dB) $p_{it}^{st_rg}$: power control step range (dB) g_{it}^{max} : maximum antenna gain (dBi) R_{it}^{max} : radius of the interfering transmitter coverage (km)

R_{simu} :	radius of the area where interferers are spread (km)
d_0 :	minimum protection in distance (km) between the victim receiver and interfering transmitter
$pattern_{it}$:	antenna directivity (dB) (supplied as a function or a look-up table)
$emission_rel_{it}$:	relative emission mask (dBc/(reference bandwidth)) only used for interferer and consists of the wanted signal level and all unwanted emissions including part of emission floor depending on the power control
$emission_floor_{it}$:	absolute emission floor (dBm/(reference bandwidth)) only used for interferer (unwanted emissions which would be emitted with the lowest possible power of the transmitter)
Note that up to Version 1.1.5 of SEAMCAT the reference bandwidth of the floor is fixed to 1 MHz.	
f_{it} :	frequency (MHz)
$dens_{it}$:	density (1/km ²)
p_{it}^{tx} :	probability of transmission (%), which is a statistical description of the smitter activities averaged over a large number of users and long period of time
$temp_{it}$:	normalized temporal activity variation function of time of the day (1/h)

Parameters for the wanted receiver (wr) belonging to the interfering transmitter

g_{wr}^{max} :	maximum antenna gain (dBi)
$pattern_{wr}$:	antenna directivity (dB) (supplied as a function or a look-up table)
H_{wr} :	antenna height distribution (1/m)
$sens_{wr}$:	dynamic sensitivity of the wanted receiver, taking into account margin for the fast-fading and intra-system interference (dBm)

Environmental and propagation parameters

f_{propag} :	propagation law (median loss + variation) (given in Appendix 1 to Annex 2)
f_{median} :	propagation law (median loss only) (given in Appendix 1 to Annex 2)
env :	environment type (indoor/outdoor, urban/suburban/open area)

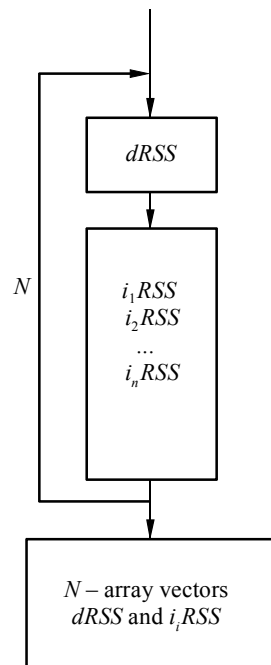
Annex 2

Event generation engine

Introduction

This Annex describes how to construct signals that are used in the interfering scenarios: the desired signal and the interfering signals due to unwanted emission, blocking and intermodulation. The calculated signals are stored in an array which serves as input to the DEE as shown in Fig. 4.

FIGURE 4
General flow chart of the EGE



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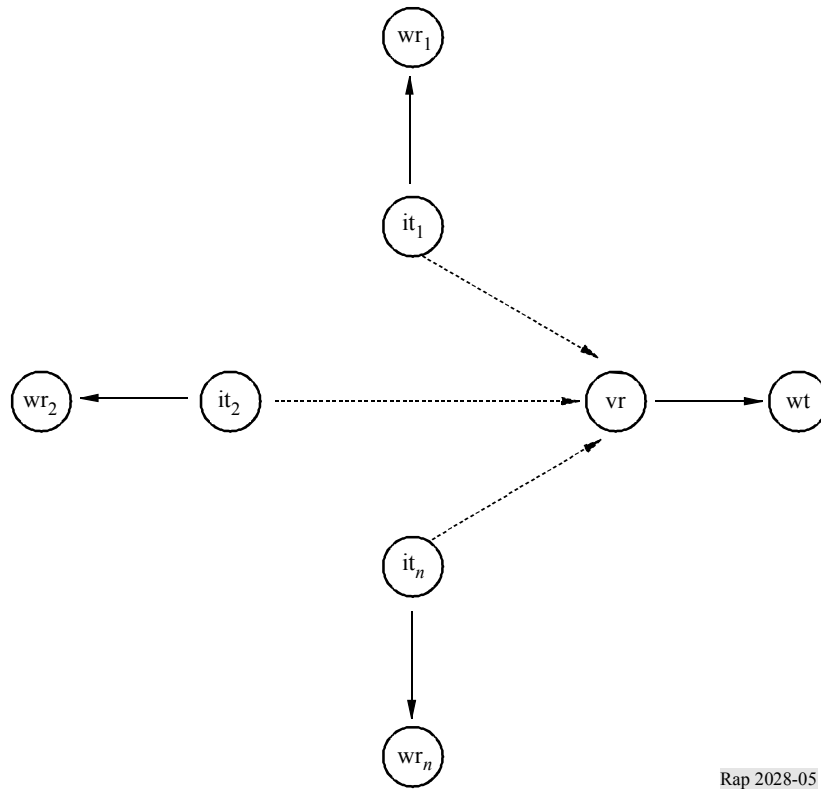
Inputs

The input parameters are defined in Annex 1. The different players are shown in Fig. 5.

Outputs

- $dRSS$: desired received signal strength (dBm)
- $iRSS_{spur}$: interfering received signal strength including unwanted emissions (dBm)
- $iRSS_{blocking}$: interfering received signal strength due to blocking (dBm)
- $iRSS_{intermod}$: interfering received signal strength due to intermodulation (dBm)

FIGURE 5
Different players participating in the EGE



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Calculation

In this section:

- T represents a trial from a given distribution (algorithm described in Appendix 4).
- Distributions $U(0,1)$, $G(\sigma)$ and $R(\sigma)$ are defined in Appendix 3.
- Flow chart of $dRSS$ calculation is given in Appendix 5 and flow charts of $iRSS$ calculations are given in Appendices 6 and 8.

NOTE 1 – Distances d between transmitters and receivers are applied with the unit in km.

a) $dRSS$ calculation

There are three different choices to determine $dRSS$: depending on a variable distance, for a fixed distance or using a given signal distribution (see Appendix 5).

Case of variable distance:

$$dRSS = f(p_{wt}^{supplied}, g_{wt \rightarrow vr}, pl_{wt \leftrightarrow vr}, g_{vr \leftrightarrow wt}) = p_{wt}^{supplied} + g_{wt \rightarrow vr}(f_{vr}) - pl_{wt \leftrightarrow vr}(f_{vr}) + g_{vr \rightarrow wt}(f_{vr})$$

If the received signal cannot exceed a given value (i.e. if it depends on the power control implemented in the victim system) then:

$$dRSS = \min(dRSS, DRSS_{max}) \quad \text{using } dRSS \text{ as calculated before}$$

where:

f_{vr} : frequency received in the victim receiver

$$f_{vr} = T(f_{vr})$$

This frequency can be set constant or determined by a certain distribution, e.g. the discrete frequency distribution (see Appendix 3). In general, the victim frequency should not be fixed but should be computed and randomly chosen as the interferer frequency using a discrete distribution (see also b)).

$p_{wt}^{supplied}$: maximum power level distribution supplied to the wanted transmitter antenna

$$p_{wt}^{supplied} = T(p_{wt}^{supplied})$$

$pl_{wt \leftrightarrow vr}$: path loss between the wanted transmitter and the victim receiver (propagation loss, slow fading and clutter losses taken into account). Depending on whether the criteria of interference will apply to the instantaneous $dRSS$ (Rayleigh fading excluded) or to the mean $dRSS$

$$pl_{wt \leftrightarrow vr} = f_{propag}(f_{vr}, h_{vr}, h_{wt}, d_{wt \leftrightarrow vr}, env)$$

or

$$pl_{wt \leftrightarrow vr} = f_{median}(f_{vr}, h_{vr}, h_{wt}, d_{wt \leftrightarrow vr}, env)$$

where:

h_{vr} : victim receiver antenna height

$$h_{vr} = T(H_{vr})$$

$$\text{e.g.: } h_{vr} = T(U(h_{vr}^{min}, h_{vr}^{max})) = h_{vr}^{min} + (h_{vr}^{max} - h_{vr}^{min}) T(U(0, 1))$$

h_{wt} : wanted transmitter antenna height

$$h_{wt} = T(H_{wt})$$

$$\text{e.g.: } h_{wt} = T(U(h_{wt}^{min}, h_{wt}^{max})) = h_{wt}^{min} + (h_{wt}^{max} - h_{wt}^{min}) T(U(0, 1))$$

$d_{wt \leftrightarrow vr}$: distance between the victim receiver and the wanted transmitter

$$d_{wt \leftrightarrow vr} = T(R_{max}^{wt})$$

$$\text{e.g.: } d_{wt \leftrightarrow vr} = R_{max}^{wt} \sqrt{T(U(0, 1))}$$

Three different choices for R_{max}^{wt} are considered:

Choice 1: Given distance R_{max}^{wt}

Choice 2: Noise limited network

R_{max}^{wt} is determined by the following equation:

$$f_{median}(f_{vr}, h_{vr}, h_{wt}, d_{wt \leftrightarrow vr}, env) + f_{slowfading}(X\%) = P_{wt}^{supplied} + g_{wt}^{max} + g_{vr}^{max} - sens_{vr}$$

where:

f_{median} : propagation loss not including slow fading

$f_{slowfading}(X\%)$: fading margin to be used for 1-X% coverage loss.

In the case of lognormal fading and a 95% coverage loss at the edge of the coverage, for large distances, the value $f_{slowfading}$ is well known 1.64 times the standard deviation of the propagation loss. Further details of the determination of the radio cell size in a noise limited network are given in Appendix 11.

Choice 3: Traffic limited network

$$R_{max}^{wt} = \sqrt{\frac{n_{channels} n_{userperchannel}}{\pi dens_{max} clusterfrequency}}$$

$g_{wt \rightarrow vr}$: wanted transmitter antenna gain in the victim receiver direction

$$g_{wt \rightarrow vr} = f(g_{wt}^{max}, pattern_{wt}) = g_{wt}^{max} \times pattern_{wt}(\theta_{wt \rightarrow vr}, \phi_{wt \rightarrow vr}, f_{vr})$$

where:

$(\theta_{wt \rightarrow vr}, \phi_{wt \rightarrow vr})$: azimuth and elevation angles between the top of the wanted transmitter antenna and the top of the victim receiver antenna:

e.g.: $\theta_{wt \rightarrow vr} = T(U(0, 2\pi)) = 2\pi \times T(U(0, 1))$

$$\phi_{wt \rightarrow vr} = T\left(U\left(-\frac{\pi}{2}, \frac{\pi}{2}\right)\right) = \pi \times T(U(0, 1)) - \frac{\pi}{2}$$

For the computation of the gain symmetric antenna patterns see Appendix 12.

$g_{vr \rightarrow wt}$: victim receiver antenna gain in the wanted transmitter direction

$$g_{vr \rightarrow wt} = f(g_{vr}^{max}, pattern_{vr}) = g_{vr}^{max} \times pattern_{vr}(\theta_{wt \rightarrow vr} + \pi, -\phi_{wt \rightarrow vr}, f_{vr})$$

Case of fixed distances:

$P_{wt}^{nominal}$: nominal power distribution

$f_{fading, fixed link}$: fading distribution

$$dRSS = f(P_{wt}^{nominal}, f_{fading, fixed link}) = T(P_{wt}^{nominal}) - T(f_{fading, fixed link})$$

Case of given dRSS: distribution to be given by the user.

b) ***iRSS*_{block} calculation**

$$iRSS_{block} = \sum_{j=1}^{n_{interferers}} f\left(p_{it}^{supplied}, g_{it}^{PC}, g_{it \rightarrow vr}, pl_{it \leftrightarrow vr}, a_{vr}, g_{vr \rightarrow it}\right)_j = 10 \log \sum_{j=1}^{n_{interferers}} 10^{i_{block}/10}$$

where the j -th interferer signal is given by:

$$i_{block_j} \equiv \left(p_{it}^{supplied} + g_{it}^{PC} + g_{it \rightarrow vr}(f_{it}) - pl_{it \leftrightarrow vr} - a_{vr} + g_{vr \rightarrow it}(f_{it})\right)_j$$

where for each interferer:

f_{it} : interferer transmitting frequency

$$f_{it} = T(f_{it})$$

For the discrete frequency distribution see Appendix 3.

Note that it is clear that the trial of the $dRSS$ frequency, f_{vr} , occurs once and only once on each simulation round, i.e. f_{vr} is tried once as the wanted victim positions, the wanted transmit power, and other distributions pertaining to the victim link. These values then tried from the $dRSS$ -distributions apply to $>N$ trials of $iRSS$ (where N is the number of interferers).

If randomness of some parameters could be limited, then the model could not be used also for simulation only, but also for more exact calculations. This feature would allow an easier check of the validity of the simulation results.

$P_{it}^{supplied}$: maximum power supplied to the interfering transmitter antenna (before power control)

$$P_{it}^{supplied} = T(P_{it}^{supplied})$$

g_{ic}^{PC} : power control gain for the interfering transmitter

$$g_{it}^{PC} = f_{pc} \left(p_{it}^{supplied}, g_{it \rightarrow vr}, pl_{it \leftrightarrow vr}, g_{vr \rightarrow it}, pc_{it}^{t_hold}, pc_{it}^{dyc_rg}, pc_{it}^{st_rg}\right)$$

where:

f_{pc} : power control function (given in Appendix 2)

$pl_{it \leftrightarrow vr}$: path loss between the interfering transmitter and the wanted receiver (propagation loss, slow fading and clutter losses taken into account). Depending on the power control implementation, this can be either mean path loss or instantaneous path loss (Rayleigh fading excluded):

$$pl_{it \leftrightarrow vr} = f_{propag}(f_{it}, h_{vr}, h_{it}, d_{it \leftrightarrow vr}, env) + f_{clutter}(env)$$

or

$$pl_{it \leftrightarrow vr} = f_{mean}(f_{it}, h_{vr}, h_{it}, d_{it \leftrightarrow vr}, env) + f_{clutter}(env)$$

where:

h_{wr} : antenna height of wanted transmitter

$$h_{wr} = T(H_{wr})$$

$$\text{e.g.: } h_{wr} = T(U(h_{wr}^{\min}, h_{wr}^{\max})) = h_{wr}^{\min} + (h_{wr}^{\max} - h_{wr}^{\min}) T(U(0, 1))$$

h_{it} : interfering transmitter antenna height

$$h_{it} = T(H_{it})$$

$$\text{e.g.: } h_{it} = T(U(h_{it}^{\min}, h_{it}^{\max})) = h_{it}^{\min} + (h_{it}^{\max} - h_{it}^{\min}) T(U(0, 1))$$

$d_{it \leftrightarrow wr}$: distance between the interfering transmitter and the wanted receiver

$$d_{it \leftrightarrow wr} = T(R_{max}^{it})$$

$$\text{e.g.: } d_{it \leftrightarrow wr} = R_{max}^{it} \sqrt{T(U(0, 1))}$$

Three different choices for R_{max}^{it} are made:

Choice 1: Given distance R_{max}^{it}

Choice 2: Noise limited network

Choice 3: Traffic limited network

For further details of the cell size determination see a).

$g_{it \rightarrow wr}$: interfering transmitter antenna gain in the direction of the closest base station

$$g_{wr \rightarrow it} = f(g_{wr}^{\max}, pattern_{wr}) = g_{wr}^{\max} \times pattern_{wr}(\theta_{it \rightarrow wr} + \pi, \varphi_{it \rightarrow wr}, f_{it})$$

where:

$(\theta_{it \rightarrow wr}, \varphi_{it \rightarrow wr})$: azimuth and elevation angles between the top of the interfering transmitter antenna and the top of the wanted receiver antenna

$$\text{e.g.: } \theta_{it \rightarrow wr} = T(U(0, 2\pi)) = 2\pi \times T(U(0, 1))$$

$$\varphi_{it \leftrightarrow wr} = T\left(U\left(-\frac{\pi}{2}, \frac{\pi}{2}\right)\right) = \pi T \times (U(0, 1)) - \frac{\pi}{2}$$

For the computation of the gain for symmetric antenna patterns see Appendix 12.

$g_{wr \rightarrow it}$: base station antenna gain in the interfering transmitter direction

$$g_{wr \rightarrow it} = f(g_{wr}^{\max}, pattern_{wr}) = g_{wr}^{\max} \times pattern_{wr}(\theta_{it \rightarrow wr} + \pi, -\varphi_{it \rightarrow wr}, f_{it})$$

$pl_{it \leftrightarrow vr}$: path loss between the interfering transmitter i and the victim receiver (propagation loss, slow fading and clutter losses taken into account).

$$pl_{it \leftrightarrow vr} = f_{propag}(f_{it}, h_{vr}, h_{it}, d_{it \leftrightarrow vr}, env)$$

or

$$pl_{wt \leftrightarrow vr} = f_{median}(f_{vr}, h_{vr}, h_{wt}, d_{wt \leftrightarrow vr}, env)$$

The choice between f_{median} and f_{propag} would depend on the criteria of interference, and is closely related to the choice made for assessment of $dRSS$, e.g. whether ICE will evaluate:

$$\frac{dRSS_{mean}}{iRSS_{mean}}, \frac{dRSS_{propag}}{iRSS_{propag}}, \frac{dRSS_{mean}}{iRSS_{propag}};$$

where:

h_{vr} : victim receiver antenna height (defined in the $dRSS$ calculation)

h_{it} : interfering transmitter antenna height (defined previously)

$d_{it \leftrightarrow vr}$: distance between the victim receiver and the interfering transmitter.

Three different ways to choose $d_{it \leftrightarrow vr}$:

1. The most common case is when there is no spatial correlation between the elements of the victim system and the elements of the interfering system.

Then, $d_{it \leftrightarrow vr}$ is a result of a trial:

$$d_{it \leftrightarrow vr} = R_{simu} \sqrt{T(U(0, 1))}$$

where:

R_{simu} : radius of the area where interferers are spread

$$R_{simu} = \sqrt{\frac{n^{active}}{\pi dens_{it}^{active}}}$$

where:

n^{active} : number of active interferers considered in the simulation

n^{active} : should be sufficiently large so that the $n + 1$ interferer would bring a negligible additional interfering power

$$dens_{it}^{active} = dens_{it} \times p_{it}^{tx} \times temp_{it}(time)$$

If a minimum protection, $d_{it \leftrightarrow vr} \geq d_0$ between the victim receiver and interfering transmitter is introduced then R_{simu} results in:

$$R_{simu} = \sqrt{\frac{n^{active}}{\pi dens_{it}^{active}}} + d_0^2$$

Note that each trial of $d_{it \leftrightarrow vr} < d_0$ has to be rejected and repeated for another trial $d_{it \leftrightarrow vr} \geq d_0$.

Note that if the protection distance $d_0 > 0$ then a uniform distribution of the interfering transmitter has to be chosen.

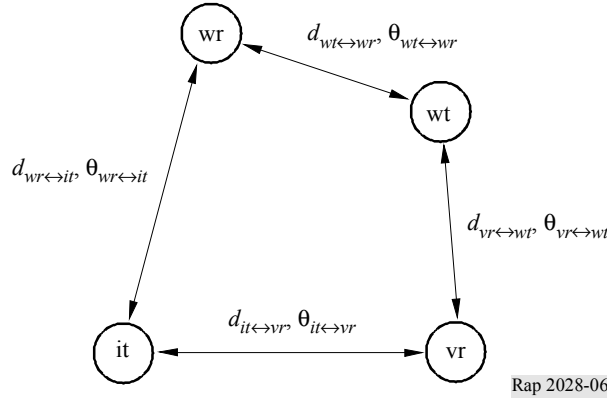
2. This case deals with the situation where the victim system and the interfering system are geographically correlated (e.g. co-located base stations).

This correlation is assumed to be only between one element (victim or wanted transmitter) of the victim system and one element (interferer or wanted receiver) of the interfering system.

A trial (if the distance is not fixed) of the distances and angles between the two correlated elements is made (e.g. $d_{wr \leftrightarrow vr}$, $\theta_{wr \leftrightarrow vr}$). The knowledge of $d_{it \leftrightarrow wr}$, $d_{vr \leftrightarrow wt}$, $\theta_{it \leftrightarrow wr}$, $\theta_{vr \leftrightarrow wt}$ enables to derive the missing coordinates (e.g. $d_{it \leftrightarrow vr}$, $\theta_{it \leftrightarrow vr}$).

FIGURE 6

Interfering scenario with a geographical correlation between the victim and the interfering systems



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3. Closest interferer

The influence of the closest interferer can be estimated by having a distance $d_{it \leftrightarrow vr}$ following a Rayleigh distribution $R(\sigma)$ defined in Appendix 3 and where the parameter σ is related to the density of transmitters. This is an alternative method for calculating the relative location of the interfering transmitter respect to the victim receiver in non correlated mode which should avoid to perform multiple trials on the number of interferers.

In this case the distribution for the distance between *it* and *vr* in the simulation area is always a Rayleigh distribution:

$$d_{it \leftrightarrow vr} = R_{simu} \times R(\sigma)$$

where standard deviation σ is related to the density of active transmitters:

$$\sigma = \frac{1}{\sqrt{2\pi \text{dens}_{it}^{active}}}$$

Note that the simulation radius is useless but associated parameters (density, activity and probability) are still required for calculation of the density of active transmitters.

$$dens_{it}^{active} = dens_{it} \times p_{it} \times activity$$

$g_{it \rightarrow vr}(f_{it})$: interfering transmitter antenna gain in the victim receiver direction

$$g_{it \rightarrow vr} = f(g_{it}^{max}, pattern_{it}) = g_{it}^{max} \times pattern_{it}(\theta_{it \rightarrow vr}, \varphi_{it \rightarrow vr}, f_{it})$$

where:

$(\theta_{it \rightarrow vr}, \varphi_{it \rightarrow vr})$: azimuth and elevation angles between the top of the closest interfering transmitter antenna and the top of the victim receiver antenna

e.g.: $\theta_{it \rightarrow vr} = T(U(0, 2\pi)) = 2\pi \times T(U(0, 1))$

$$\varphi_{it \leftrightarrow vr} = T\left(U\left(-\frac{\pi}{2}, \frac{\pi}{2}\right)\right) = \pi \times T(U(0, 1)) - \frac{\pi}{2}$$

$a_{vr}(f_{it}, f_{vr})$: attenuation of the victim receiver.

Three possible ways are considered for calculating this attenuation:

1. a_{vr} is given by the user.
2. Blocking is given in terms of blocking attenuation or protection ratio. For a wanted signal 3 dB above the sensitivity, the attenuation a_{vr} can be derived from the following equation (see Appendix 7):

$$a_{vr} = f\left(\frac{C}{N+I}, block_{att}\right) = 3 + \frac{C}{N+I} + block_{att}(f_{it}, f_{vr})$$

3. Blocking is given in terms of absolute level of blocking:

$$a_{vr} = f\left(\frac{C}{N+I}, block_{abs}\right) = \frac{C}{N+I} + block_{abs}(f_{it}, f_{vr}) - sens_{vr}$$

Two cases are envisaged:

Case 1: $block$ is a mask which is a function of $\Delta f = (f_{it} - f_{vr})$. It is introduced to enable calculations of interference between systems in adjacent bands;

Case 2: $block$ is a fixed value (e.g. 80 dBm). It is used to derive generic limits.

$g_{vr \rightarrow it}(f_{it})$: victim receiver antenna gain in the interfering transmitter direction

$$g_{vr \rightarrow it} = f(g_{vr}^{max}, pattern_{vr}) = g_{vr}^{max} \times pattern_{vr}(\theta_{it \rightarrow vr}, \varphi_{it \rightarrow vr}, f_{it})$$