Evaluation Methods for Spectrum Management Strategies.

(An appropriate balance between analytical computation and simulation)

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Abstract:

In a first paper, published in the 8th ICTS Newsletter (*An Alternative Spectrum Management Strategy*), I presented the most promising ways to improve the global spectrum availability for new systems. In each specific case, the selection of the best frequency allocation strategy supposes the availability of a reference evaluation method. This method must be able to assess the relative merits of the various possible management strategies.

Today, simulation seems the only available evaluation method. However, in many random scenarios used for electromagnetic compatibility evaluation, analytical computation produces better results than simulation.

This paper presents the relative merits of these two methods for various types of evaluation scenarios: deterministic scenarios, partially random scenarios and random scenarios. The conclusions are as follows:

- **Analytical computation is better for random scenarios,**
- **Simulation is mandatory for deterministic scenarios,**
- **The combination of the two methods is recommended for partially random scenarios.**

This paper opens with a presentation of the main advantages of simulation and analytical computation. From this analysis, it shows how the two methods have to be combined, for a better evaluation of frequency allocation management strategy.

Glossary:

- BER: Bit Error Rate,
- CDMA: Code Division Multiple Access,
- DFS: Dynamic Frequency Selection,
- GSM: Global System for Mobile Communications,
- HATA: Okumura-Hata Propagation Model,
- TDMA: Time Division Multiple Access,
- UMTS: Universal Mobile Telecommunication System,

Introduction:

Since the development of computers, scientists are becoming increasingly confident in simulation results. The extraordinary power of modern computers gives the impression that it is possible, on the basis of a small number of physical laws, to predict all behaviour of the external world.

In the radioelectric field, very sophisticated wave propagation method such as the parabolic equation methods have been developed. These methods are theoretically able to solve any propagation problem, as long as we have the requisite input data.

Unfortunately, our environment is so complex that it is impossible to collect all the necessary data. The Maxwell equations cannot be directly used to predict the propagation losses in the field.

In the electronic industry, computer-aided design is a very useful tool. However, the basic system structure can only be produced by a skilled team, on the basis of its own expertise and its preferred techniques. We remember the competition between CDMA and TDMA schemes for the mobile phones systems. Each team was able to demonstrate, on its own simulator, that its technique was the best one.

Electromagnetic compatibility studies between two systems or two users need common interference estimation methods. Two systems using the same frequency band have to agree on the estimation of propagation losses and on jamming criteria.

An electromagnetic compatibility study justifies its conclusions by specific simulation, supporting the proposed solution. However, the two involved parties' conclusions are often divergent for many reasons: propagation models can be different, system parameters ambiguous, but the most important point is the simulation scenario.

The simulation scenario is a strategic point. It defines essential parameters such as the transmitter locations, the system frequency management and sometimes how the system behaves when it is jammed. For example, the new hiperlan system uses DFS to find a free channel. This procedure efficiency can be estimated only if the other system uses fixed frequencies or if its own reactions to jamming are known.

This paper presents the relative merits of the simulation method and of the analytical computation method for the different types of evaluation scenarios: deterministic scenarios, partially random scenarios and random scenarios.

The conclusion points out the preferred field of both methods and provides some research orientations requested by the new adaptive systems increasing the spectrum effective capacity.

1 Random scenarios:

That type of scenario is widely used by electromagnetic compatibility studies. It can be adopted in many cases:

- As a first step in the study of any other scenario: when knowledge of a system is excessively limited, one is only able to suppose that frequencies, locations and activities of the transmitters are random variables (wireless phones, mobile radios, hiperlans, etc).
- When the studied system is too complex: for instance, when the number of potential jammers is very large (satellite receiver in terrestrial communications bands).
- To compare frequency allocation strategies: a general conclusion can only be based on a generic scenario, independent of the precise system implantation.

For these reasons, this type of scenario plays a very important role. It is particularly adapted to analytical computations.

1.1 A very simple generic scenario :

1.1.1 Main parameters of scenarios :

In my first paper, I presented as an example a very simple generic scenario. Its parameters are as follows:

- All emitters are supposed to be uniformly implanted in the field (fig 1).
- All antennas are omni-directional.
- When several channels are available for a transmitter, his specific frequency is randomly selected among the available ones.
- The propagation model is statistically defined. For this example, the following model adopted by the ITU for a compatibility study has been selected (figure 2):
    - Mean value of propagation losses :

$$A : 128{,}1 + 37{,}6 \cdot \log(D)$$

    - An extra 10db random value is added to take into account the propagation statistical dispersion.

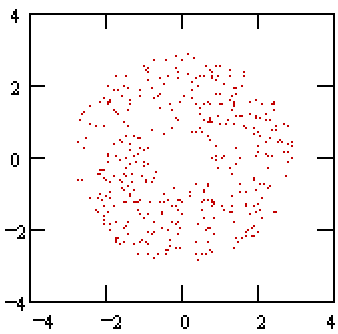

Fig1: Transmitter locations.

The selected propagation model is adapted to a ground-to-ground propagation between randomly selected sites. For this model, figure 2 shows the received level from a set of transmitters uniformly distributed in distance.

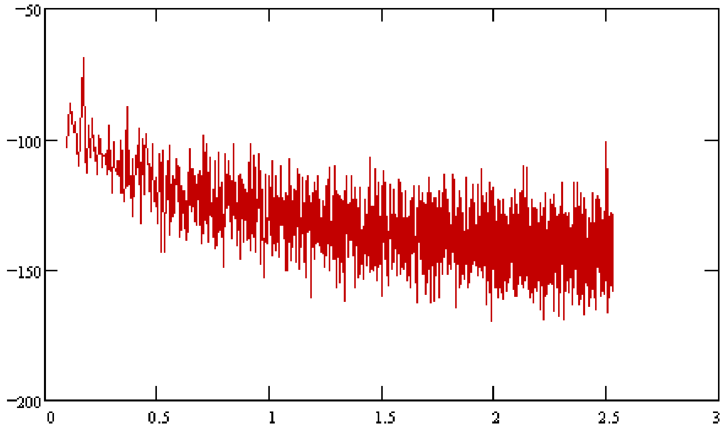

Figure 2:

1.1.2 Other parameters :

An initial analysis of the jamming power transmitted by a system needs to define the system parameters more precisely:

- The spatial transmitters density,
- The transmitters activity (usually 100% emission time).
- The minimal distance of the nearest transmitters from the studied receiver,
- For simulations, the number of transmitters simulated,
- For analytical evaluations, the radius of the studied zone.

1.2 Simulation results :

The main simulation results are based on the processing of a single file of propagation loss values. The spatial density of transmitters is supposed constant on the simulated area. If « k » is that density, the distance of the transmitter n from the studied receiver is:

$$r = \sqrt{\frac{n}{k\pi}}$$

Obviously, a random choice of transmitter locations would produce a slightly different result. However, this difference is entirely masked by the 10 dB random value introduced in the propagation losses algorithm in the statistical propagation model.

Figure 3 shows the histograms of this type of file.

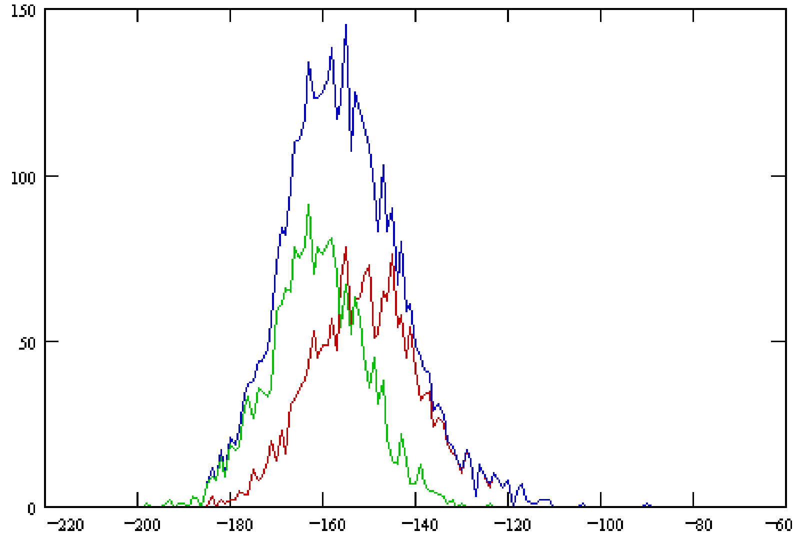

Figure 3:

n This chart indicates in red a received level histogram from the 2000 nearest transmitters set, in green the levels received from the 2000 next transmitters and in blue the global histogram. When the simulated zone is extended, the histogram new values are added, mostly in the lower received levels.

From this received signal level file it is very simple to test frequency allocation strategies. In my previous paper, I presented the results derived from this unique file. A convolution with the transmitted spectrum and the receiver bandwidths gives for all possible frequency the jamming level due to all unwanted transmitters.

For instance, figure 4 shows the received signal in a receiver when all transmitters use a set of 50 channels. As expected, the received signal is lower when the receiver is tuned to a frequency different to the channels central frequencies.

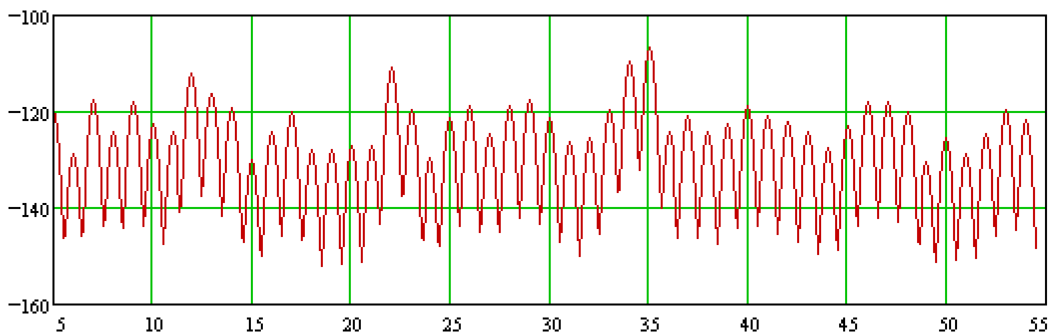

Figure 4:

If all transmitter frequencies are randomly selected in the allocated band, this spectrum is similar to a noise (figure 5).

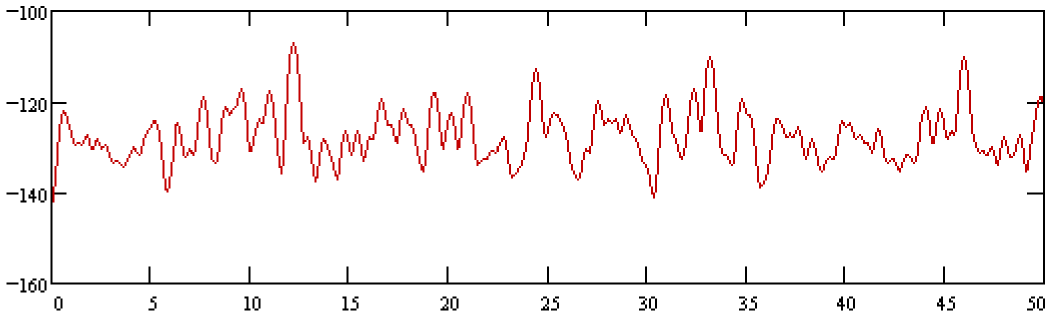

Figure 5:

1.3 Analytical computation results :

Nowadays, for many reasons, simulation is often preferred to analytical computation. The advantages of simulation are quite obvious:

- The simulation process is not supported by any hypothesis. The system is only described by its usual parameters: transmitted power, antenna gains, sensitivity, etc.
- Apparently it is of no real use to select the pertinent system parameters.
- If the system description is precise, the simulation results seem highly credible.

Usually, the beginning of a simulation is an exciting time. The simulation team build a complex project, all part of the system being described in a detailed way. However, when the project grows, they observe that the simulation of some parts is too difficult and even useless.

We will now see how the simulation results obtained on the proposed generic scenario can be obtained by analytical computation.

1.3.1 Power received from a large set of transmitters :

As in the simulation process, we suppose that the various transmitter distances are chosen to adjust their number in a circular zone surrounding the studied receiver to the selected density. That cumulative power can be estimated with the selected propagation model (figure 6, blue curve) or with a reduced model limited to the mean propagation loss value (figure 6, red curve).

As the model propagation loss distribution is gaussian in dB, both values are different.

The ratio between the two values is, for a random 10db loss dispersion:

$$\frac{P_2}{P_1} \approx 11.5db$$

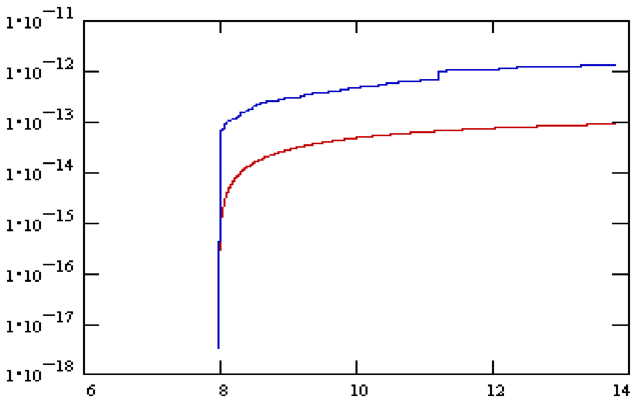

Figure 6:

Figure 7 shows the ratio of the two previous curves. Except when the number of transmitter contributions is too low, the 11.5db ratio between the two values is observed.

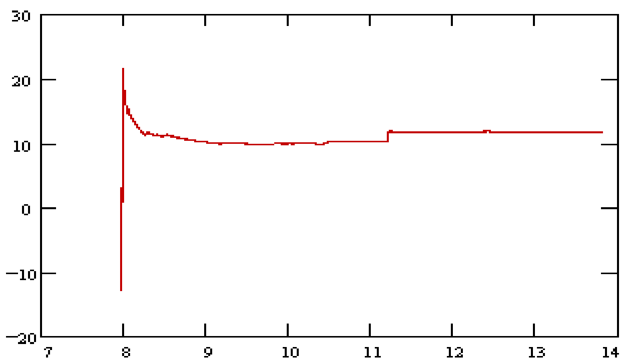

Figure 7:

With the selected scenario, the power received from a set of receivers can be analytically computed. The distribution function of that received power can be estimated according to the propagation statistical laws.

This result is very important. Compared with a simulation, this analytical computation process is able to produce results for any studied zone, as extended as needed, and to display the distribution function of the received power, allowing the estimation of low jamming probabilities.

To reach the same results by simulation, it would be necessary to realise a very large number of simulation runs and estimate the result dispersion.

1.3.2 Received power histograms computation :

The knowledge of the noise spectrum behind the receiver filter is a significant data. The simulation process is based on this effective jamming signal histogram.

With the simple scenario selected, it is possible to obtain analytically the simulation results. In a first step, the theoretical histogram would be the blue curve on figure 8, when the propagation model random value is omitted.

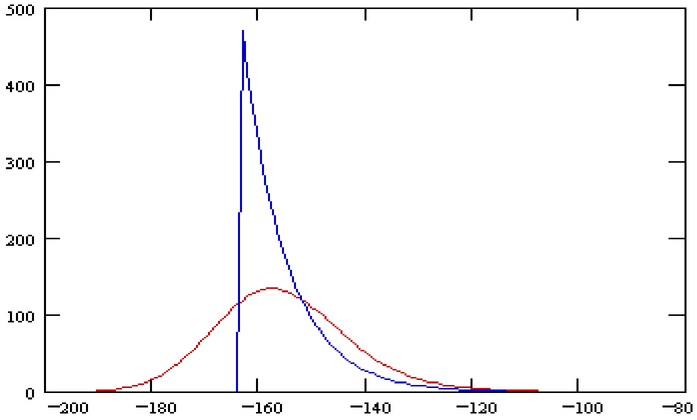

Figure 8:

The 10db random value dispersion of this model is given in figure 9.

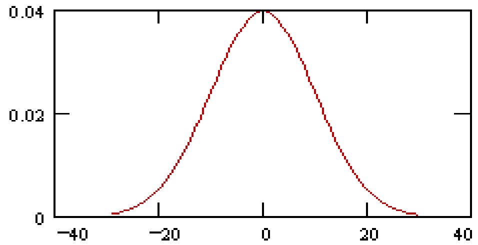

Figure 9:

The real histogram is the result of the convolution of that previous histogram by that dispersion function. It is the red curve of figure 8.

That theoretical histogram is the mean value of the experimental histogram obtained after a single run of the simulation. A large number of runs of the simulation would be needed to obtain a comparable result.

It is interesting to compare both results.

Figure 10 displays with the same scale in blue the previous received levels histograms obtained by simulation and in red the theoretical value. Figure 11 is identical, but with a pseudo-logarithmic vertical scale, allowing a better analysis of distribution tails.

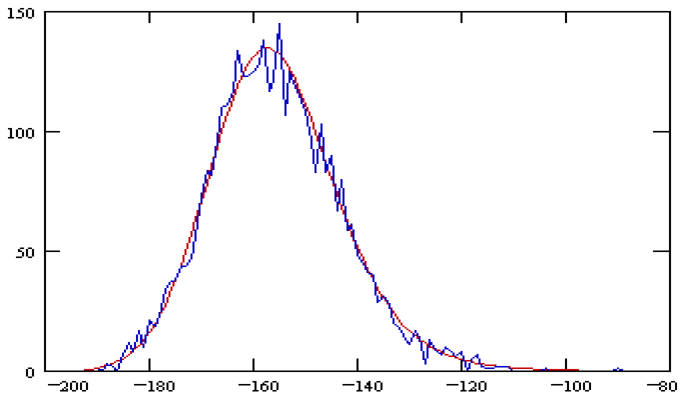

Figure 10:

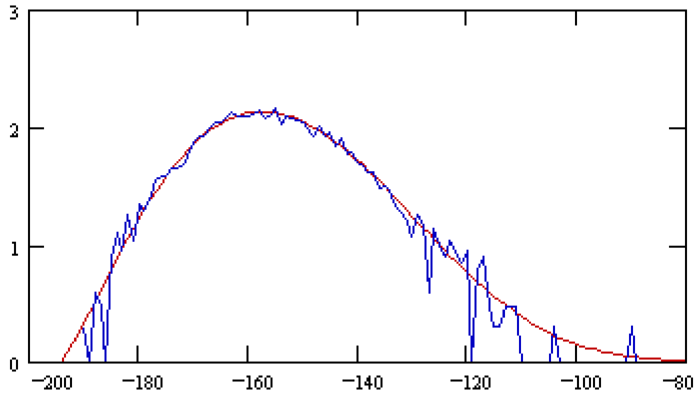

Figure 11:

Both methods produce exactly the same results. A fine simulation will be useful only when it is able to take into account adaptive systems or frequency manager behaviour introducing major distortions in the frequency allocation process. For instance, in defence systems, if a jammer specifically built for that purpose transmits the interfering signal, it can be necessary to use a dynamic simulation to estimate its efficiency against a given system.

In most cases, simulation can be easier to implement, but more computer time-consuming and less precise. For a relative evaluation of different techniques, the precision of simulation is often too limited, and the reasons of observed differences from run to run difficult to identify.

The received power can also be as estimated by analytical computation in the simulation way. Figure 12 shows in red the simulation result for each histogram point and in blue the computed mean value. The horizontal axis is the received level and the vertical axis the power due to the mean number of transmitters received with that level.

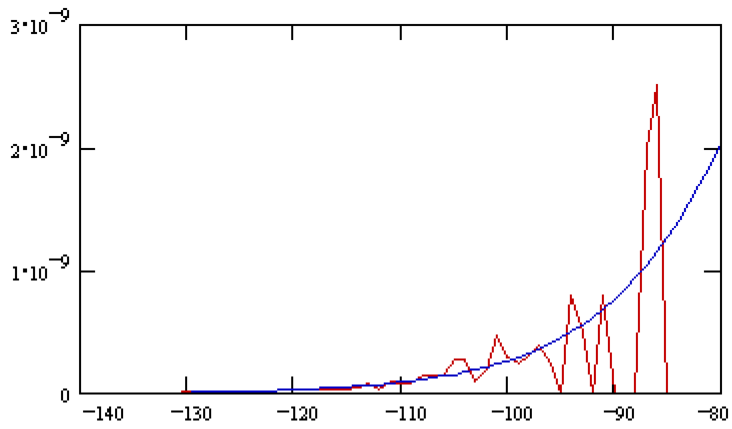

Figure 12:

The red and blue curves of figure 13 are the cumulated power from –140db up to the X axis value. On a single simulation result, both methods give perfectly coherent results.

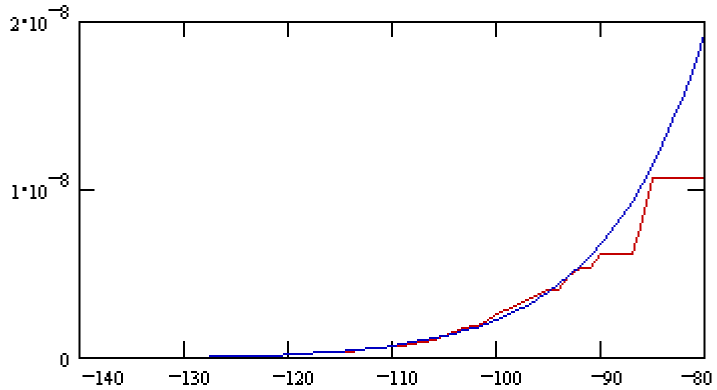

Figure 13:

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1.4 Extended random scenarios :

1.4.1 Definition of more precise propagation models :

Both simulation and analytical computation allow the use of more complicated propagation models. For instance, several segments constitute the HATA model supported by the European community. For the analytical method, the contributions of each segment can be computed and the results added.

Correlation between propagation losses for different distances or directions could be introduced in this model, even though it is not usually the case. For instance, in a good radio-electric location, both expected and jamming signals could be statistically higher, and the jamming probability computed accordingly.

1.4.2 Extension of the studied area :

When the number of transmitters contributing to the jamming power is high, it is useless to simulate all of them. In this case, the analytical method allows the fast estimation of the received power.

In a first stage, we suppose the studied receiver surrounded by a circular zone where transmitters do not use the studied channel. Outside this zone, the transmitter density is constant up to an infinite distance.

We suppose that the mean propagation losses are approximated by the following function:

$$A = k \cdot D^{\alpha}$$

(α being a positive real and k a constant)

In the simple model adopted in the example, the value of α is 3.76. For that type of propagation law, the power received from the transmitters surrounding the central zone is:

$$P_t = \frac{n}{\alpha - 2} \cdot P_r$$

- P_r: power of the nearest transmitter.
- α : slope of the propagation law.
- *n* : the number of virtual transmitters in the central zone.

As expected, this formula diverges for the free space propagation model. This paradoxical result is due to the fact that if we place in a plane an infinity of antennas, most of them will be masked for the receiving antenna and the power effectively received limited.

1.4.3 Use of directive antennas :

In our basic random scenario, we supposed that the systems use omni-directional antennas. In fact, the analytical computation method still applies with directive antennas. Let us analyse a RADAR receiver. The antenna pattern is as follows (figure 14).

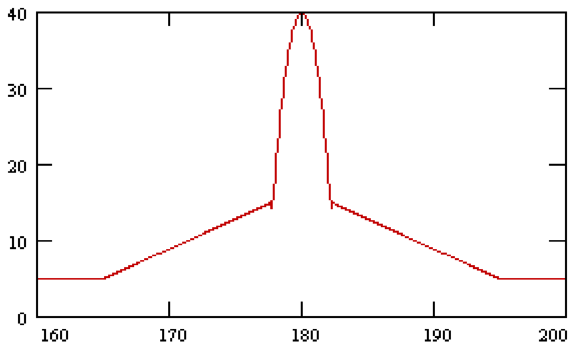

Figure 14:

The horizontal axis is the azimuths angle in degrees and the vertical axis the antenna gain.

Figure 15 is the histogram of the azimuth gain values of that antenna.

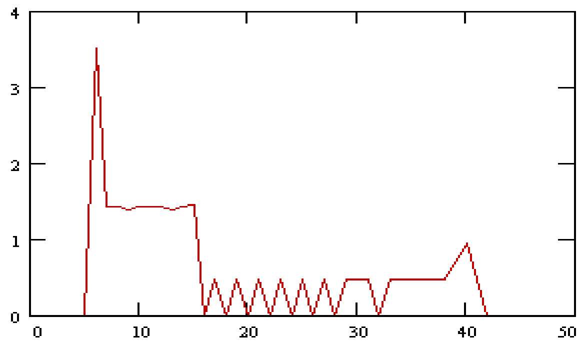

Figure 15:

As most of the gain values are 5db, the vertical scale is a non-linear scale, the displayed value being:

$$Y = \log(N + 1)$$

The received signals histogram is obtained by convolution of the previous received power histogram by the antenna gain histogram.

The result is presented on figure 16. Sometimes, a transmitter is received with a much higher level than previously, but with a lower probability. The spurious lobes of the RADAR receive a huge number of transmitters. However, their contribution to the received mean power is low, as it is shown in figure 17.

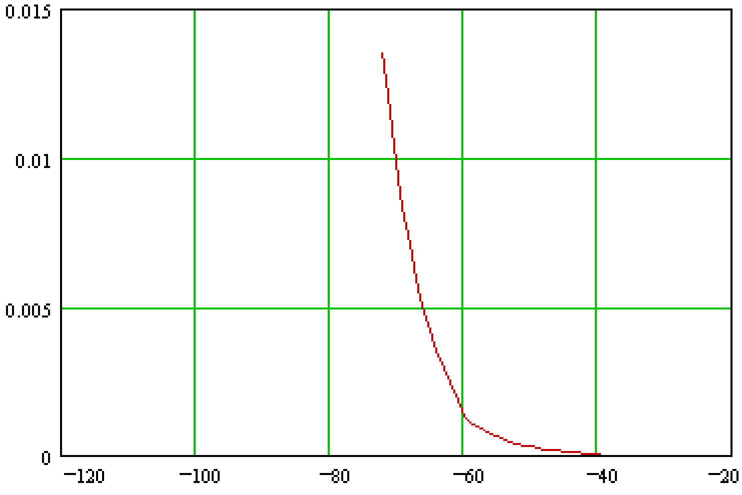

Figure 16:

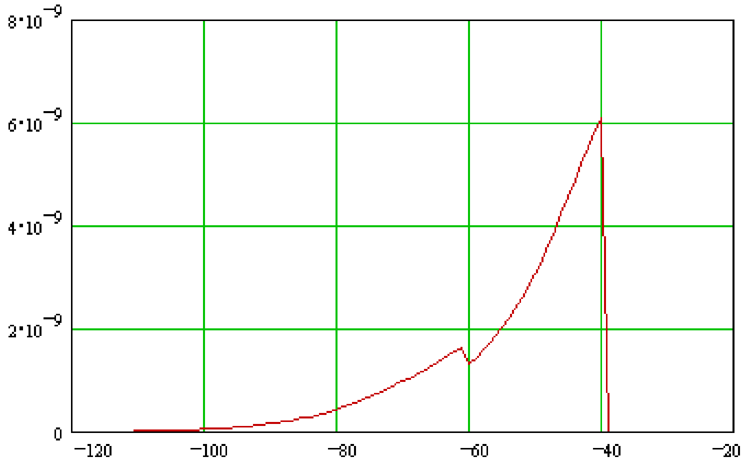

Figure 17:

1.4.4 Adaptation between generic scenarios and analytical computation :

As far as the selected scenario is a random scenario, analytical methods are faster and give more precise results.

However, some dynamic interference can occur in adaptive systems. The active military jammer is an obvious example of such system behaviour influence. In some cases, it will be necessary to combine simulation and analytical computation.

2 Deterministic scenarios :

These scenarios are used to describe fixed systems such as radio-relay networks. All transmitters are supposed to be in permanent use. This type of scenario is implicitly adopted by current frequency allocation methods.

More sophisticated deterministic scenarios can be used (including transmitters emission times, mobiles sets, etc).

All deterministic scenarios suppose the knowledge of a real of fictive digital terrain and the use of a deterministic propagation model.

To study that type of scenario, simulation is the only available method. However, the spectrum management process efficiency cannot be estimated. The compromise between the accepted jamming probability and the spectrum need for a given telecommunication traffic or RADAR coverage cannot be optimise on a single run.

For these deterministic scenarios, the simulation method is used to establish frequency plans of systems as radio-relay networks. For the spectrum manager, the frequency plan is established on the basis of the network simulation. Assuming there is a maximum error between the simulation and reality, margins for simulation errors are introduced.

However, the analytical method is still useful to estimate the penalty due to these simulations errors margins. It is easy to test the selected frequency plan by reference to an ideal case without errors or with a measurement in the field of propagation losses between all transmitters and receivers.

3 Partially random scenarios:

The real world is neither totally random nor deterministic. A parameter can be described as a random process only if its value is influenced by many independent inputs. In the real world, most phenomena are correlated.

Radio-electric systems designed to use the same frequency band in the same area can be influenced by identical factors as terrain shielding or local industrial noise.

New systems are increasingly designed to adapt to their environment. For this reason, they are becoming less independent.

The random scenario supposes that all transmitter frequencies are randomly selected in the allocated frequency band. This is increasingly unjustified. A better knowledge of system compatibility needs a system behaviour model capable of reproducing the real system dynamic response to jamming.

Only a dynamic simulation is able to analyse how systems adapt to their environment. However, this type of simulation is very difficult and needs to be carefully tested on generic cases. A drastic parameters number reduction is necessary for the following two main reasons:

- To reduce simulation complexity.
- To allow analysis of the results.

In the future, analysis of partially random scenarios will be increasingly necessary. A combination of all computation strategies, simulation and analytical computation will be necessary.

4 Conclusion :

This preliminary evaluation of spectrum management methods has produced some surprising conclusions, as summarised below, in an executive summary format:

- First of all, the simulation method is not always the most efficient method. On random scenarios used in electromagnetic compatibility evaluation, analytical computation gives better results and is the only method able to estimate the jamming probability dispersion function.

- Scenarios are the key points. Usually, opposing conclusions of compatibility studies are the result of different scenario parameters, the two evaluation methods of intersystem jamming being equally credible.

- A new type of dynamic simulation will be needed by adaptive systems using procedures as DFS. Scenarios for dynamic evaluation of intersystem interference are an open question. To reach credible conclusions on the electromagnetic compatibility of adaptive systems, it will be necessary to identify the key technical points and to focus on them.

This brief overview of the spectrum management evaluation method shows that there is a large field for research. The electromagnetic compatibility between ever more complex systems such as GSM and UMTS mobile radio systems or modern phase array Radar needs some new theoretical analysis. Simulation of the radioelectric environment created by a huge number of mobile and sporadic transmitters belonging to adaptive systems is far from simple, but it is our job to undertake this task.

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