SIMULATION IN SPECTRUM SHARING

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1. INTRODUCTION

The radio spectrum is a limited resource. Its regulation and management have become increasingly important as a result of an ever-growing demand for wireless communication applications [1, 2]. Access to the radio spectrum is based on the Table of Frequency Allocations of the International Telecommunications Union (ITU) Radio Regulations [3], where defined categories of radio service are allocated frequency bands in different parts of the spectrum. Due to scarcity of the frequency spectrum, many bands are allocated for more than one radio service and are, therefore, shared.

Spectrum sharing studies aim to identify technical or operational compatibilities that will enable radio services to operate in the same (or adjacent) frequency bands without causing unacceptable interference to each other. Often, sharing becomes possible when limits are placed on certain system parameters — for example, antenna radiation patterns, transmission power or antenna pointing.

Geostationary satellite systems have been used to provide a range of radio applications for many years. In recent years, there has been a growing interest in the use of Nongeostationary Orbits (NGSO) and several such satellite systems have been designed, for both mobile services and broadband multimedia delivery. These systems employ multibeam satellites orbiting in multiple, inclined planes and their advanced design features include continuous beam steering over service areas, fixed contiguous beam patterns, traffic handover, interference mitigation techniques, steerable user terminal antennas and the capability to vary power levels in order to compensate for increased path fading.

The increasing number and complexity of satellite and terrestrial radio systems have resulted in the widespread use of computer-based simulations to examine the feasibility of spectrum sharing. To assess the competing demands on the limited radio spectrum it is necessary to resort to a computer not only to model the above-mentioned advanced satellite system characteristics, but also to check for compliance with regulations that are often expressed in a form that can only be evaluated with the aid of a computer (e.g. ITU-R S.1325 [4]).

After this introduction, the paper identifies where computer-based calculations are required and outlines the principles of various simulation techniques. This is followed by an evaluation of the costs and benefits of different simulation procurement approaches. Finally, key conclusions are presented.

2. SHARING ANALYSIS APPROACHES

The traditional approach to sharing analysis has been the use of analytic calculation methods based on worst-case assumptions. Historically, this approach has been used to examine the sharing possibilities between fixed terrestrial radio systems and geostationary (GSO) satellite systems, where interference alignments depend on a static geometry.

Often, the worst-case situation is modelled by taking the most pessimistic value for each of a number of parameters involved in the interference analysis. These pessimistic values are then aggregated even though, statistically, they are not likely to occur simultaneously. As an example, Figure 1 illustrates possible worst-case alignments for a sharing scenario where interference from an NGSO satellite into a GSO Earth station receiver is considered.

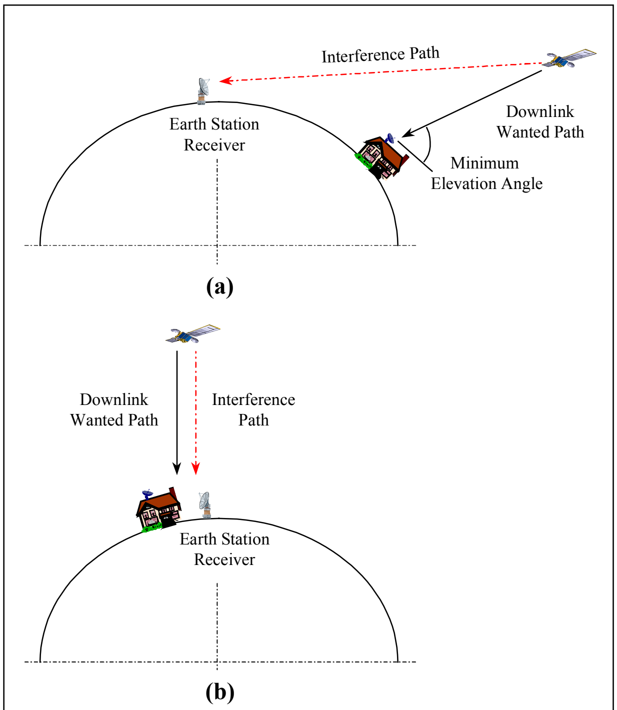

Fig. 1 : Worst-case Interference Alignments

As can be seen, the worst-case interference power will be determined by an interference entry originating from either the sidelobe of the satellite antenna located within the boresight of the Earth station receiver antenna (scenario a), or the boresight of the satellite antenna pointing towards an Earth station receiver (scenario b).

The protection requirements based on the worst-case analysis ensure that the potential for harmful interference is minimised, but they also result in systems being over-protected, as the overall effect of different parameters is exaggerated. For example, Figure 1(a) assumes that the interferer is transmitting towards a user terminal operating at the minimum allowed elevation (i.e. the satellite transmit antenna discrimination towards the victim receiver is minimum, hence the gain is maximum) and, at the same time, the satellite is within the victim receiver antenna mainlobe (i.e. the victim receiver antenna gain is maximum). This alignment does happen but very short period of time.

With the increasing congestion of the radio spectrum, coupled with an ever more complex sharing environment, it is no longer appropriate to define the requirements for the feasibility of spectrum sharing on the basis of worst-case analysis only. In order to model the interference environment with a view to achieving maximum spectral efficiency, more realistic interference analysis approaches need to be employed, where the statistical effects of the parameters involved are taken into consideration.

For instance, when developing sharing scenarios involving NGSO satellite systems, the following parameters might need to be modelled: the implications of constellation parameters (including orbit altitude and inclination, number of satellites and satellite phasing between orbital planes), radio characteristics (including transmitter power levels, antenna gains and radiation patterns), operational characteristics (including mitigation techniques, power control schemes, minimum operating elevation angles and beam frequency re-use patterns), together with the statistical nature of the radiowave propagation on the wanted and interfering paths.

The most common way of defining regulatory interference protection requirements is to specify a 'maximum percentage of time for which a given level of interference is allowed to be exceeded'. For a given sharing scenario, in order to check the compliance against such interference criteria, it is necessary to derive interference statistics based on calculations representing a reasonably long period (as the simulated period increases, the minimum detectable percentage decreases). For example, Figure 2 compares aggregate interference statistics (calculated from 800,000 samples of interference alignments over approximately 10 days) at a fixed terrestrial link receiver resulting from NGSO satellite transmissions against the receiver interference thresholds.

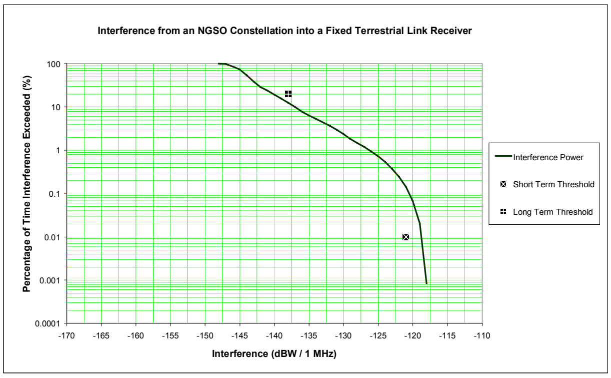

Fig. 2 : Interference Statistics Compared Against Receiver Protection Criteria

The need to model a complex dynamic sharing environment, coupled with the necessity to derive the statistical behaviour of a number of output parameters (e.g. there are two criteria in Figure 3), make computer-based simulations key sharing analysis tools. In addition, simulation analysis is the only practical mechanism to examine the implications of certain parameters, for example, the duration of interference events between satellite networks.

3. SHARING ANALYSIS SIMULATION TECHNIQUES

Simulation techniques used in spectrum sharing studies employ a mixture of deterministic and probabilistic analysis methods, sampled in various ways.

In a deterministic simulation the system state is usually computed at regular intervals (a fixed time interval for time-dependent simulations, or a regular grid for an area simulation).

In a time-based simulation, the period is specified typically long enough to cover a representative set of geometries. The relative position information together with radio characteristics and operational techniques are used to calculate the parameters of concern (for example, the magnitude and the duration of interference events). The results are then analysed and presented in the form of statistical distributions (for example, probability density or cumulative distribution functions). These statistics are then compared against the threshold values (based on the regulations) to check compliance.

GSO satellite network co-ordination, in which geographic areas visible to the satellites are sampled regularly to determine if frequency co-ordination is required, is an example where area-based deterministic simulation is used.

A probabilistic simulation is used when some input parameters have been defined statistically for increased generality or where a parameter can only be defined statistically. For instance, a sharing analysis involving calculation of exclusion areas around a GSO Earth station transmitter (where there is a risk of interference into receivers operating in other systems) may require a computer-based simulation where input parameters related to propagation effects are modelled using statistical distributions. A second example is ITU-R Rec. S.1529 [5], which uses a probabilistic model for satellite position as an alternative to traditional time-based orbit propagation techniques.

In practice, most probabilistic simulations are implemented using Monte Carlo sampling (i.e. a large number of trials are made, in each of which the statistical distributions are sampled to assign values to some input parameters), although convolution is an alternative for simpler problems. For example, sharing analyses concerning interference aggregation from a randomly located and randomly pointing population of transmitters into a victim receiver typically use the Monte Carlo approach, for the evaluation of compatibility among terrestrial radio systems as well as between satellite ground terminals and terrestrial systems.

In practice, interference analysis often requires a combination of analytic calculations and simulation analysis, for example, as shown in Figure 3.

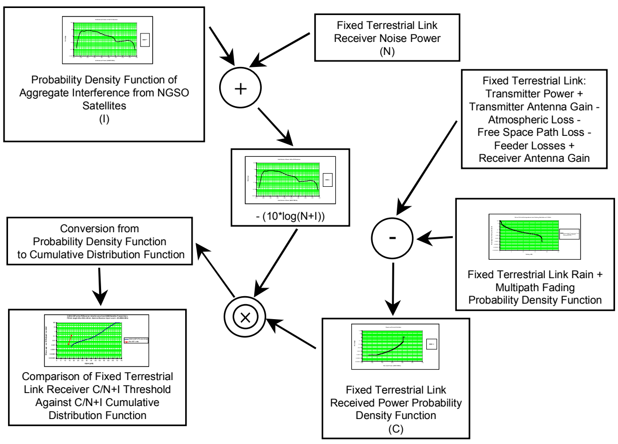

Fig. 3 : Interference Analysis Example Combining Simulation Analysis with Analytic Calculations

This example shows an examination of the impact of NGSO downlink interference into a fixed terrestrial link. It is based on calculating the joint effect of aggregate NGSO interference and fixed link received power statistics.

Step 1. Aggregate interference statistics are derived from a deterministic simulation analysis, where the NGSO constellation is modelled fully by taking individual beam patterns and transmission characteristics into account.

Step 2. At the fixed terrestrial link receiver, wanted power statistics are derived from the application of a probabilistic approach by assuming that multipath and rain mechanisms are the significant propagation effects. Propagation mechanisms are modelled using empirical models based on long-term measurements. These models are defined in Recommendations produced by the International Telecommunications Union Radicommunications Division (ITU-R).

Step 3. The interference analysis is completed by applying an analytical process where the aggregate interference and the fixed terrestrial link path fading probability density functions are convolved (assuming both are statistically independent).

Another example of the use of the convolution of independent statistical functions is the calculation of the probability of interference from a tracking NGSO Earth station into fixed radio relay links by convolving antenna gain statistics (obtained from simulation analysis) with fixed link fading statistics derived from ITU-R Recommendations.

4. SIMULATOR PROCUREMENT

Having established that a computer-based analysis is needed, where do the simulation tools come from? The procurement choice is essentially between ‘commercial off-the-shelf’ software (COTS) and bespoke software (either in-house or third party).

COTS software includes such general-purpose tools as Microsoft Excel, Mathcad and OPNET Modeler, as well as specialist tools such as Visualyse or Satellite Tool Kit. The scope of bespoke software is very wide and every technical organisation is likely to have some simulation software of its own: spreadsheets, C/C++, FORTRAN and Visual Basic, and project-specific configurations of COTS products.

In general, COTS products offer relatively lower cost for a single user (as compared with the cost of a bespoke product), good reliability, broad functionality — and instant availability. However, the cost of a COTS product and its associated training and support may become a burden as the number of users increases, particularly if, as in Figure 3, more than one tool is needed.

Bespoke products typically offer greater flexibility and specialisation, because the software can, in principle, be tailored to the requirements of a specific task (however, implementation standards vary greatly, and the life of many bespoke simulators is lamentably — and expensively — short). Tailoring is increasingly a feature of COTS products, but in practice users often limit themselves to the standard product offering. Also, because vendors aim to satisfy as wide a market as possible, COTS software tends to become increasingly generic, and it can become difficult to configure the tool even for relatively straightforward tasks.

The engineer's choice in a spectrum sharing analysis is often less complicated than this discussion suggests: if the radio systems being investigated are new but not novel, existing products may have the right functionality — if not, a new bespoke development begins.

5. CONCLUSIONS

It is commonly recognised that software tools developed for simulation analysis have become key elements of the commercial and technical planning of the radio spectrum — which has a direct impact on the exploitation of satellite communications technology.

This paper has identified some of the spectrum sharing situations involving satellite systems where computer-based simulations are needed. It has been concluded that both deterministic and probabilistic analysis approaches now need to be used in practical sharing scenarios.

A brief discussion has compared the advantages and disadvantages of COTS and bespoke spectrum sharing analysis software. It has been argued that while, in general, COTS products offer lower costs and more features, bespoke software offers flexibility and specialisation.

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