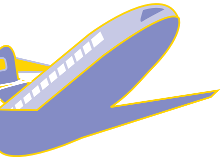
The hardships of co-exsistence

THE EMERGENCE OF NEW WIRELESS TECHNOLOGIES IS PUTTING A STRAIN ON RADIO SPECTRUM SHARING ENGINEERING

by Selçuk Kırtay

From large geostationary satellites to tiny car keys, millions of devices use the radio spectrum for a variety of purposes. Almost on a daily basis, more equipment joins the “wireless club”. Researchers all around the world are busy coming up with new ideas, many of which rely on the use of the radio spectrum.

Examples are numerous: replacing every single data cable in your house with wireless links, fitting each side of your car with a short-range radar (four to eight radars per car on average) and making your washing machines and fridges ‘intelligent’ with Bluetooth wireless technology. But, radio spectrum is a finite resource, isn’t it? So how do millions manage to gain access to it at their convenience?



The radio-wave spectrum is a valuable, limited, natural resource. It enables us to send a large number of data messages at the speed of light to distant locations. Access to limited resources brings about potential problems if the number of users starts to exceed various limits. The regulation, coordination and management of spectrum usage have become increasingly important as the result of ever-growing demand.

The limited radio spectrum causes conflicts between those who do and do not have access. Conflicts also arise between competing users of the spectrum. The nature of these conflicts may be commercial, political and technical. For the users whose needs have already been satisfied, the continuation of the existing status is the primary objective. On the other hand, for the newcomers, the principal aim is to eliminate the obstacles that prevent them from entering the competition.

Access to the radio spectrum is based on the Table of frequency allocations of the International Telecommunication Union (ITU) Radio Regulations, 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, a phenomenon known as spectrum sharing.

CHANGING THE ANALYSIS APPROACH

From a technical point of view, spectrum sharing analyses aim to identify technical and/or operational constraints 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.

Traditionally, simple analytic calculation methods based on worst-case assumptions have been employed to examine the feasibility of spectrum sharing. The worst-case scenario is modelled by taking the most pessimistic value for each of a number of parameters involved in the interference analysis. The simultaneous impact of these pessimistic values is then considered – even though, statistically, this is unlikely to occur.

> “WITH THE INCREASING CONGESTION OF THE RADIO SPECTRUM, THE USE OF WORST-CASE ANALYSIS ALONE IS NO LONGER APPROPRIATE TO DEFINE SHARING REQUIREMENTS”

As an example, Fig 1 illustrates a possible worst-case alignment for a sharing scenario where interference from a transmitter onboard an aircraft into a terrestrial fixed link receiver station is investigated. The worst-case interference power is the result of an interference entry originating from a sidelobe of the onboard aircraft transmit antenna located within the boresight of the fixed link receive antenna.

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 overprotected, as the overall effect of different parameters is exaggerated. For example, Fig 1 assumes that the transmit antenna discrimination towards the victim receiver is at a minimum and, at the same time, the aircraft is within the victim receiver antenna mainlobe (i.e. the victim receiver antenna gain is at a maximum). In real situations, this alignment will happen only for a very short period of time.

With the increasing congestion of the radio spectrum, the use of worst-case analysis alone is no longer appropriate to define sharing requirements. In order to model the interference environment with a view to achieving maximum spectral efficiency, more realistic interference analysis approaches need to be employed, taking into consideration the statistical effects of the parameters involved.

Computer-based simulation analyses are widely used to model complex dynamic sharing scenarios and derive statistical behaviour of output parameters of concern. In simulation analyses, a mixture of deterministic and probabilistic analysis methods is employed, sampled in various ways.

In a deterministic analysis, the system state is usually computed at regular intervals. For example, 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.

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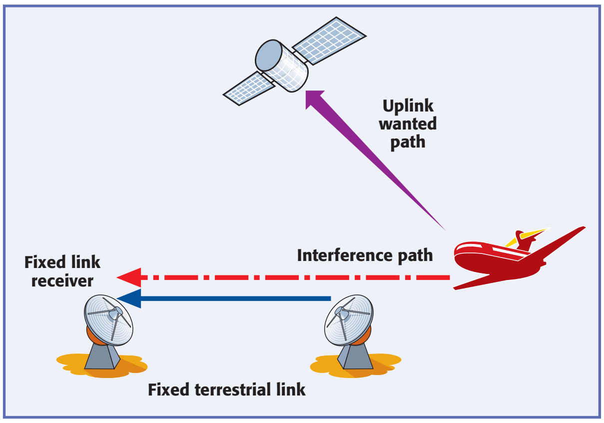

FIG 1 WORST-CASE INTERFERENCE ALIGNMENT

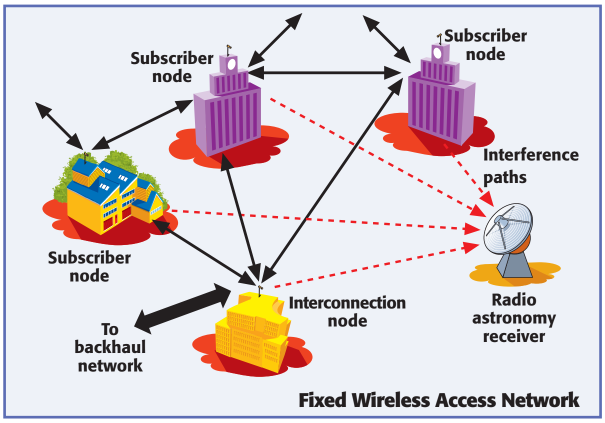

FIG 2 FIXED WIRELESS ACCESS SYSTEM INTERFERENCE INTO RADIO ASTRONOMY RECEIVER

A probabilistic analysis 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 an exclusion area around a mobile basestation receiver (where transmitters of other systems cannot operate without the risk of causing harmful interference) may require a computer-based simulation where input parameters related to propagation effects are modelled using statistical distributions.

In general, probabilistic analyses are implemented using Monte Carlo sampling (i.e. a large number of trials are made, for each of which the statistical distributions are sampled to assign values to some input parameters), although convolution is an alternative for simpler problems. Figure 2 shows the example of an analysis of interference aggregation from a randomly located and randomly pointed population of fixed wireless access system transmitters into a victim radio astronomy service receiver station, where typically the Monte Carlo approach could be used.

In practice, sharing analysis often requires a combination of analytic calculations and simulation analysis. The outcome is rarely a Yes/No decision, but an evaluation of how to overcome the potential for interference and facilitate sharing.

CHALLENGES AHEAD

One consequence of the limited radio spectrum is the development of new technologies to increase efficiency of use. As far as sharing analyses are concerned, this may, in turn, give rise to new challenges.

Ultra Wide Band (UWB) technology, for instance, has attracted growing attention in recent years. It is based on the use of very narrow pulses (typically in the order of nanoseconds) as a basic signal structure. These pulses result in spectral components covering a very wide bandwidth in the frequency domain. The objective of spreading the energy across an extremely large bandwidth is to ensure that the transmitted signal power density is well below the noise floor and the presence of the transmitted signal is undetectable to traditional frequency-selective radio receivers. It is argued that this feature will enable UWB systems to co-exist with other radio systems in the same parts of the spectrum without causing harmful interference.

In a conventional sharing scenario, interfering signals are assumed to add linearly to the receiver thermal noise power. However, questions have arisen regarding the additive nature of UWB signals due to its impulsive nature and consequential spectral characteristics (i.e. spectral spikes).

Given the non-conventional nature of UWB signals, the key challenge from a sharing analysis point of view is how the impact of UWB signals on other terrestrial receivers (for example, GPS, mobile phones and microwave landing systems) can be modelled accurately. Extensive measurement campaigns and simulation analyses have revealed that there is a complex relationship between the victim receive bandwidth, UWB pulse repetition factor and measurement reference bandwidth, and this relationship has a significant impact on how impulsive the received UWB signal is. Currently, the accurate modelling of UWB emissions is a subject of intense debate.

In addition to the development of spectrally efficient radio technologies, various attempts have been made to explore new sharing methods with a view to achieving optimal use of the radio spectrum. The concept of reverse band sharing can be considered as an example.

In typical sharing scenarios where, for instance, interference between geostationary orbit fixed satellite service (GSO FSS) systems is examined, interference paths from earth stations to satellites and vice versa occur, as shown in Fig 3. In these scenarios, sharing primarily relies on antenna discrimination at both ends of the interference paths.

However, in reverse band sharing scenarios, the interference paths are different and occur between satellites and earth stations of different systems, as shown in Fig 4. In these cases, the distance between satellites and the antenna discrimination at both ends of the space interference path are less problematic than the ground path interference, where the spacing and antenna discrimination may not be large enough to reduce interference to acceptable levels.

HOPPING FREQUENCIES

Another example of new sharing methods is the increasingly popular concept of ‘self-frequency management’. The idea is that, to avoid unacceptable interference, a system should be able to detect another system’s presence and move to another available frequency (i.e. dynamic frequency selection). One of the areas where this technique has been proposed is to avoid interference from wireless local area networks (W-LANs) into radar systems operating in the 5 GHz band.

One of the key challenges of spectrum sharing is to develop new and suitable measures to limit transmissions from a system using a new technology, if existing measures are proved to be inadequate to characterise the new sharing environment. A good example of this is the operational compatibility between GSO and non-geostationary (NGSO) systems. A few years ago, plans for introducing NGSO FSS broadband satellite systems into bands where GSO FSS systems operate sparked lively debates at an international level.

In order to reduce the impact of interference into other systems, satellite transmissions are restricted by power flux density (PFD) limits. Historically, the use of PFD limits is based on static interference alignments between GSO satellites and fixed terrestrial radio stations. PFD limits are specified for a single satellite as a function of interference path elevation angle as seen from a fixed point on the Earth’s surface. However, interference scenarios involving NGSO and GSO systems require a different approach because the sharing environment is no longer static. Therefore, after lengthy discussions, the concept of equivalent power flux density (EPFD) was introduced to reflect the dynamic nature of the sharing environment.

The EPFD takes account of both NGSO transmitter and GSO receiver antenna pointing, which are time-varying parameters. It is defined as the sum of the power flux densities produced at a receive station on the Earth’s surface or in geostationary orbit by all the transmit stations within an NGSO satellite system, taking the off-axis discrimination of a reference receiving antenna into account.

Achieving the optimal use of radio spectrum is not a simple task. Apart from the technical aspects involved, economic and political dimensions need to be considered when assessing the extent to which spectral efficiency is being achieved.

There is no single, comprehensive approach that can be used to assess all sharing situations. Depending on likely interference scenarios, different sharing analysis methods need to be developed to examine the feasibility of multi-system co-existence in the same frequency band. And these methods need to embrace technical features of emerging radio technologies.

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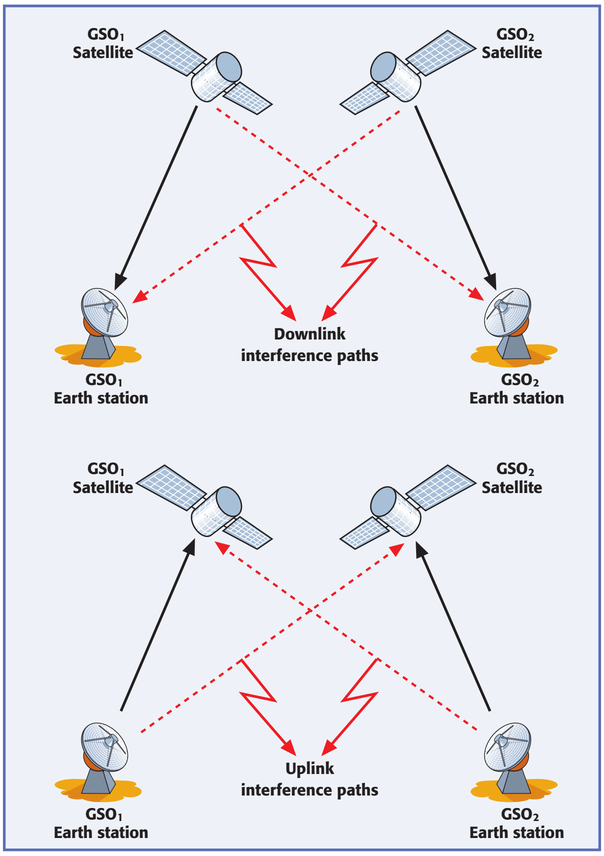

FIG 3 GSO FSS SHARING INTERFERENCE ALIGNMENTS

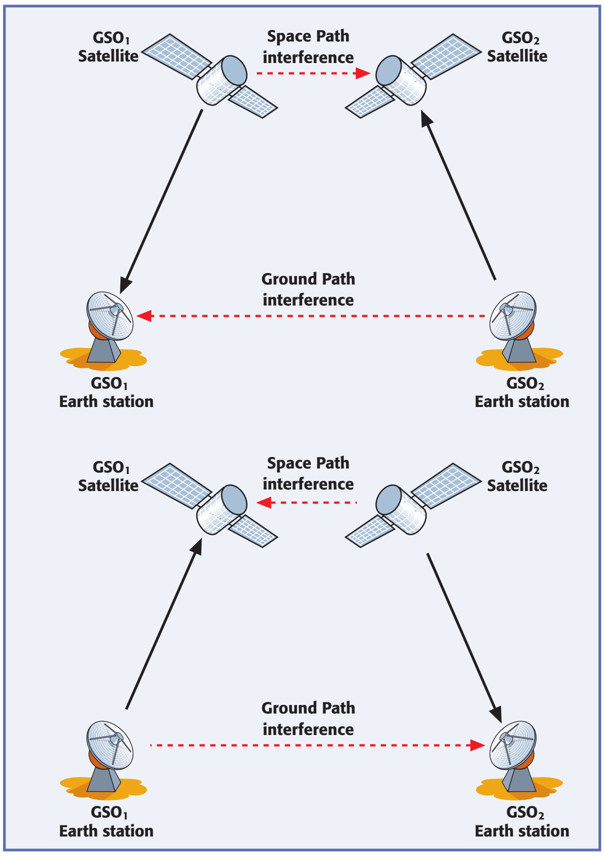

FIG 4 GSO FSS REVERSE BAND SHARING INTERFERENCE ALIGNMENTS