What's yours could be mine (shared)

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Millions of devices ranging from a large satellite to a tiny earphone use the radio spectrum on a daily basis. Future mobile networks will require the radio spectrum for high-speed broadband services, low latency applications and massive machine type communications. There is also a mass use of Wi-Fi devices and sensors planned for smart city initiatives. Space networks aim to make increasing use of the radio spectrum to provide internet services via huge constellations of small satellites. Examples of radio spectrum use are numerous - broadcasting networks, public/private access mobile networks, air-to-ground communication systems, maritime applications, short range devices, disaster monitoring systems, cubesats and radars to name a few. But, the radio spectrum is not endless. So how can we all share this limited resource? This paper looks at the fundamentals of radio spectrum sharing and provides example sharing scenarios analysed by Plum, highlighting the challenges ahead.

Introduction

The radio spectrum ranges from few Hz to 300 GHz. It is a valuable natural resource that enables us to communicate at the speed of light (i.e. 300,000 km/sec). As with any other limited resource, uncontrolled access to the radio spectrum becomes problematic if the demand exceeds certain limits. Therefore, the regulation and management of spectrum use have become increasingly important over the years because of ever-growing demand.

Conflicts often arise between those who do and do not have access to certain parts of the radio spectrum, and also between competing users of the radio spectrum. The nature of these conflicts can be commercial, political and/or technical. For incumbent users, continuation of the existing status is generally the primary objective. On the other hand, new users aim to overcome obstacles efficiently in order to enter the market and compete.

At an international level, access to the radio spectrum is regulated by the International Telecommunication Union (ITU). The ITU Radio Regulations define radio service categories and allocated frequency bands – some of which cannot share the spectrum. However, in practice, due to the scarcity of the radio spectrum, many frequency bands are allocated for more than one radio service, a phenomenon known as ‘spectrum sharing’.

The objectives of spectrum sharing are maximising the use of radio spectrum while maintaining a certain level of service quality for the users. In order to achieve these aims, analysis of spectrum sharing conditions needs to be performed. These are then incorporated into national and international regulations that are used to manage access to the radio spectrum by different radio services.

Analysis of spectrum sharing conditions

The goal of spectrum sharing analysis is 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 feasible when limits are placed on certain system parameters, for example, transmission power level, duty cycle and antenna height and pointing direction.

At Plum, we employ various spectrum sharing analysis techniques depending on the sharing scenario under consideration.

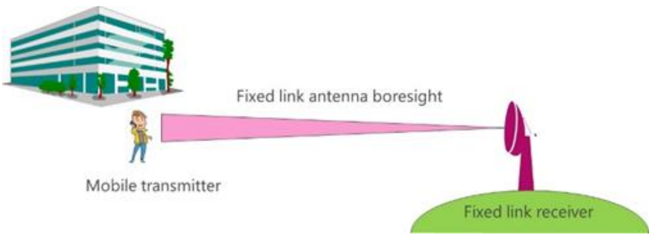
Minimum coupling loss analysis

Minimum coupling loss analysis is based on a simple deterministic analysis of a sharing scenario. It is often implemented with worst-case sharing assumptions 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 investigated – even though, statistically, this is unlikely to occur. Therefore, the outcome of this type of analysis is generally the most stringent sharing conditions.

With the increasing congestion of the radio spectrum, the use of worst-case analysis is, in most cases, no longer appropriate to define sharing requirements (and is often encountered where a spectrum incumbent is trying to make the case that sharing of ‘their’ spectrum is impossible).

An example worst-case scenario where a mobile transmitter interferes with a terrestrial fixed link receiver is shown in Figure 1.

Figure 1: Example worst-case scenario



In this alignment, the worst-case interference power is due to an interference entry originating from a mobile transmit antenna located within the boresight of the fixed link receive antenna. Any protection requirements (for example an exclusion area around the victim fixed link receiver) derived from this scenario will ensure that the potential for harmful interference is minimised but ignores the fact that this alignment is likely to happen only for a very short period of time which, in turn, means that the victim fixed link is overprotected.

Here at Plum, we use minimum coupling loss analysis to obtain an initial insight for the feasibility of sharing scenario. If analysis results are favourable this indicates that sharing is likely to be straightforward. If analysis results are not favourable, however, this does not necessarily imply that sharing will be problematic.

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Simulation analysis

The use of minimum coupling analysis based on worst-case assumptions alone is not appropriate to define sharing conditions representative of real situations. Therefore, interference analysis based on more accurate modelling of the interference environment needs to be developed to derive more realistic sharing requirements and maximise spectrum efficiency.

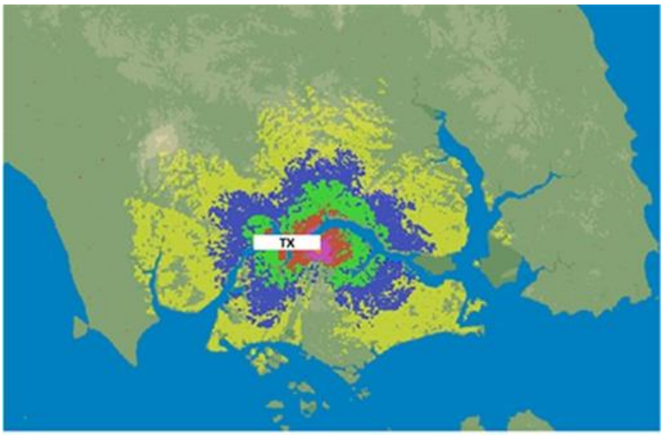
In this context, it is important to take account of the statistical characteristics of any particular spectrum sharing situation. This is necessarily complex as it not only requires the characterisation of the inputs to the analysis, but also a means to interpret the probabilistic output of the model – unlike the minimum coupling analysis there is no longer a binary result.

In simulations, we apply a mixture of deterministic and probabilistic analysis methods.

In a deterministic analysis we aim to build a detailed model that accurately represents the physics of a particular situation, and in such models calculations are often performed at regular intervals of space, time or both. For example, in an area-based simulation analysis, the simulation area, typically centred around an interfering transmitter, can be split into small pixels and the interference power at each pixel can be calculated. Calculations need to take account of propagation characteristics and usually interface with terrain and clutter databases to increase the accuracy of results. Calculated interference power levels are then compared against threshold values (typically derived from representative system characteristics) to check compliance in each pixel. Finally, based on the compliance analysis results, contours within which receivers could not be deployed without the risk of interference can be drawn.

Figure 2 shows a number of interference contours. Each contour shows an area within which a corresponding interference threshold is exceeded.

Figure 2: Example area-based deterministic simulation analysis result



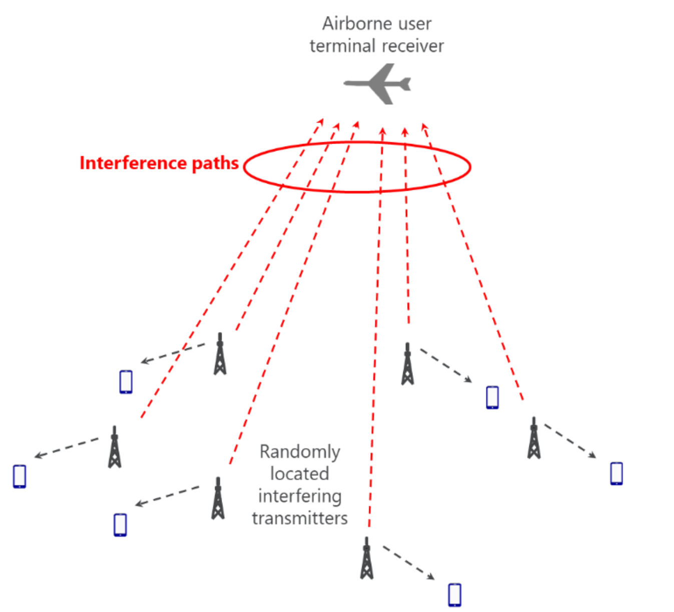
Although 'deterministic analysis' sounds conceptually straightforward it is something of a myth; we can never hope to know enough about our environment to characterise all the input parameters adequately. It will therefore be necessary for such models to contain large elements of statistical approximation (for propagation losses, receiver performance, user traffic, etc), and it is arguments over the exact form of these approximations that account for the majority of debate in the relevant ITU or CEPT groups.

In a probabilistic analysis, the physical models are discarded altogether, and parameters within the model are defined only in stochastic terms. Probabilistic analyses are often implemented with Monte Carlo sampling where a large number of trials are made for each of which statistical distributions are sampled to assign values to some input parameters. This can appear to be a great simplification, but introduces other complexities and challenges. It is necessary, firstly, to obtain the necessary statistical characterisation of parameters and this will often involve time-consuming measurement efforts (and further debate in international bodies as to the most representative statistical distribution). The question of how to handle varying degrees of correlation between variables, on a pairwise or multivariate basis, is also a large and active area of research.

> **The outcome of sharing analysis is rarely a Yes/No decision, but an evaluation of how to overcome the potential for interference and facilitate sharing.**

Figure 3 shows an example Monte Carlo analysis scenario where interference is aggregated from transmitters assumed to be supporting different traffic levels and located randomly below an airborne victim receiver.

Figure 3: Example probabilistic analysis scenario



When undertaking spectrum sharing studies we often apply 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.

New sharing approaches and challenges

As the demand for radio spectrum increases new sharing methods are put forward by stakeholders, mainly new spectrum users. Spectrum scarcity is also leading to new technologies with enhanced spectrum efficiency.

Sharing of radio spectrum dynamically has been considered to maximise the spectrum use. For instance, with the help of a database where details of incumbent spectrum users are recorded, it is possible to identify the location and time interval where the spectrum is not fully utilised. This information can then be used to allow additional use. Difficulties of this approach are ensuring an adequate protection for the incumbent licensed services and regulating this type of dynamic use under a national licensing regime.

Limiting the use of spectrum for some users to allow only indoor deployments is one of the approaches considered by regulators to facilitate sharing among different radio services in recent years. This aims to enable low-powered indoor devices to share the band with relatively high power outdoor networks by taking advantage of additional propagation losses introduced by building penetration and internal walls.

Introduction of additional filtering for receivers with wide front-end filters is another mechanism to facilitate adjacent band sharing in scenarios where incumbents have been operating over many years with negligible threat of interference. Example scenarios include aeronautical radars and domestic satellite TV receivers potentially being interfered with by new terrestrial 4G and 5G mobile networks.

In recent years, stakeholders have also shown an increasing interest in technologies enabling the use of both licensed and unlicensed frequency bands. For example, mobile operators have developed standards for extending LTE operation from licensed to unlicensed spectrum to meet the growing traffic demand. This has required detailed sharing investigations to achieve a fair coexistence with incumbent Wi-Fi networks. The issue of utilising an increasing number of licensed and unlicensed frequency bands spread over different parts of the radio spectrum is also highly desirable and challenging for 5G systems.

One of the new technologies introduced for 5G networks is active antenna systems which enable dynamically configured antenna beams. The key benefit is the ability to concentrate power where needed based on instantaneous changes in user traffic and propagation, thus optimising the use of power and spectrum resources. However, the implications for inter-system interference need to be considered carefully; such dynamic targeting of power might impact other networks operating nearby but this will be mitigated by the small periods of time for which the beam is likely to be directed at a 'victim' receiver and the fact that a lower power is being transmitted in all other directions.

In optimising the use of spectrum, technical, economic and political dimensions need to be considered and balance needs to be struck.

Final word

Optimising the use of radio spectrum is not a simple task. Apart from technical aspects, there are economic and political dimensions that need to be considered and balance needs to be struck.

In technical analysis, there is no single, comprehensive approach that can be used to assess all sharing scenarios. Appropriate sharing analysis methods need to be developed and applied for likely interference scenarios to investigate the feasibility of co-existence in the same and/or adjacent frequency bands.

As computer power increases, and more environmental information becomes cheaply available, the boundaries between statistical and deterministic modelling are continually changing; mathematical techniques must keep pace with this and with increasing radio system complexity.

About Plum

We are a leading independent consulting firm, focused on the telecommunications, media, technology, and adjacent sectors. We apply rigorous analysis to address challenges and opportunities across regulatory, radio spectrum, economic, commercial, and technology domains.

We have built an extensive knowledge on issues related to radio spectrum sharing over the years through numerous studies undertaken for regulators, operators and manufacturers. We are capable of designing sharing scenarios, developing appropriate analysis methods, implementing sharing analysis, preparing reports and drafting contributions for national and international meetings and representing our clients' interests in these meetings.

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