Generic Interference Assessment Using a Wide-Range Propagation

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***Abstract*—It is generally accepted that allocation of licenses should be as free from technology constraints as possible. Nevertheless avoidance of harmful interference is crucial to the effective use of the radio spectrum. A method of assessing interference between different services sharing the same frequency bands is described together with a wide-range propagation model necessary to allow path loss predictions to be made in a wide variety of circumstances.**

Keywords-interference; propagation

I. INTRODUCTION

It is generally accepted that existing licensed users of the spectrum should not suffer harmful interference if a new technology is introduced to the same, or neighboring, frequencies. If the spectrum is to be shared between different services it is therefore necessary to be able to predict the interference between these services. Further, the quality of spectrum demanded will differ from one service to the other. In order to license and regulate in an increasingly liberalized environment it is vital that technology-neutral interference assessment methods are developed that allow the different technologies to specify service and spectrum quality requirements individually. This paper describes research, funded by Ofcom (the United Kingdom regulator), that demonstrates in principle how these requirements can be met. Most importantly, there is now confidence that technical interference assessment should not prove to be a barrier in the quest to further liberalize use of the radio spectrum.

II. DIFFERENT REGULATORY ENVIRONMENTS

A regulator in a “command and control” environment takes it on itself to make decisions regarding the use of certain frequency bands. Specific services will be selected and these, in turn, will be allocated to a particular block of spectrum within specific bands. It is feared that this approach may deliver sub-optimal use of the spectrum and could stifle innovation and incentivize political lobbying. It has become an aspiration of many regulators that use of the spectrum could be optimized by allowing it to become more market-driven. However, harmful interference should be avoided. A pre-requisite of such avoidance is that levels of interference could be predicted and a clear, unambiguous method of deciding whether these levels constitute harmful interference is established. License requests should be evaluated in a manner that is

- Transparent,
- Technologically Neutral and
- Evidence-driven.

III. DEVELOPMENT WORK AT OFCOM

A. *Generic Interference Assessment*

Ofcom’s first attempt to develop an interference-assessment methodology that would satisfy these requirements resulted in a tool that would allow devices that shared spectrum to be defined in a generic manner, both in terms of the nature of radio energy emitted and in terms of the quality of spectrum necessary in its receive frequency bands. Although technology-neutral it proved vital for the tool to be “technology aware” as it was necessary for any transmissions to be characterized in the tool by means of a generic template. The prototype developed proved capable of analyzing specific interference scenarios and of assessing compliance of any transmissions against technology-neutral spectrum usage rights that may be conferred upon a licensee. The decision as to whether any interference would be permitted was based on a Spectrum Quality Benchmark (SQB). This benchmark was generally defined in terms of power limits at the receiver such that the “interfering power should not exceed X dBW for more than Y% of the time”. More than one SQB could be specified. For example “interfering power should not exceed -130 dBW for more than 50 % of the time and should not exceed -105 dBW for more than 0.01% of the time”. In the case of point-to-area systems the benchmark had the additional criterion: “at more than Z% of locations”. This meant that licence applications would be judged on interference generated into existing systems. It is possible to derive spectrum quality benchmarks from existing interference thresholds. For example, Ofcom publishes Technical Frequency Assignment Criteria explaining the manner in which spectrum for Fixed, point-to-point, Services is managed. These are available on the Ofcom website: www.ofcom.org.uk. At the time of writing the link to the required document is http://www.ofcom.org.uk/radiocomms/ifi/tech/tfacs/ofw446.pdf . These criteria describe a “single-entry” method where each interferer is allowed to develop a certain amount of power at the victim receiver. An allowance would be made for multiple interferers.

B. Propagation Modelling Issues

One objective of the tool was to be able to produce interference assessments for a user-defined time percentage. The generic propagation prediction algorithm was therefore required to produce a cumulative distribution function (c.d.f.) of field strength over a wide range of time percentages (ideally 0 – 100%). Attempts to satisfy this requirement revealed shortcomings in currently-available propagation models.

Notably, existing methods regard signal enhancement phenomena and fading phenomena in isolation. Current research shows that it is not possible to simply "join them in the middle". Additionally, some fading mechanisms (such as rain) are treated statistically but in a way that suggests that some rain fading is possible 100% of the time. A list of examples of problems is given below. Note that this is not intended to be an exhaustive list.

- Existing methods concentrate on small percentages of time, leading to inconsistencies at the median level.
- Methods predicting signal enhancement and methods predicting signal fading will disagree regarding the median level on a particular path
- Phenomena such as rain fading and clear-air fading are considered in isolation
- Some rain attenuation is predicted for a wider range of time percentages than is logical
- Atmospheric absorption is regarded as constant when the physical characteristics of the atmosphere that cause absorption are known to vary.

Further, current models often fail to encompass a sufficiently wide frequency range necessary to avoid discontinuities. Additionally, models are often focused on either enhancement or fading of field strength experienced for only small time percentages on a particular path. It quickly became apparent that, in order to exploit the functionality offered by the generic interference assessment tool a new propagation model would need to be developed. The scope of the new model was identified as: wide frequency range (30 MHz to 50 GHz); large range of distances (at least up to 1000 km); outputs c.d.f. of path loss between any two points against time over a wide range of time percentages ("0% to 100%"); will use a general path profile together with geographic characteristics (e.g. rain rates) as inputs; free of discontinuities and non-monotonic behavior; software-implementable; efficient to run on a computer.

C. Propagation Mechanisms

The approach taken was, firstly, to identify the significant propagation mechanisms before attempting to establish how the different mechanisms should be combined. The major mechanisms identified are: line-of-sight; gaseous absorption; clear-air enhancements and fading; diffraction; ducting; tropospheric scatter; rain attenuation; sporadic-E. With the exception of the line-of-sight mechanism, all are time-varying. Further, some (such as rain and clear-air fading) are thought to be mutually exclusive whereas others (e.g. ducting and diffraction) may be correlated. Additionally, there is the possibility that some mechanisms may prove to be statistically independent. Each individual mechanism has been the subject of much study and modeling over many years. A significant contribution made by the study described here is that models of each mechanism were re-analyzed in depth and much thought and work was put into addressing the question of how best to model these mechanisms in combination. The work commenced in May 2008 and completed in March 2010. A full report is available from Ofcom. As an example of the type of work undertaken, work packages dealing with diffraction and ducting are highlighted.

The difficulty of predicting the strength of a diffracted field is often underestimated, possibly because of the existence of canonical situations for which near-exact solutions exist. However, we needed a method of predicting diffraction loss when the input is a path profile extracted from a terrain database without any expert input regarding whether obstacles would be best described as cylinders or wedges etc. There exist in ITU-R P.526 a number of possible methods. Often they include an empirical correction based on distance. For long- distance paths this empirical correction forms the major component of the predicted loss. However, there is a near-exact solution for a smooth earth. This was exploited in the development of a "delta method". An appropriate algorithm was used to compute the diffraction loss using an extracted path profile. Then, the error was estimated by setting all terrain points to the average height and using the same algorithm. The prediction for this situation was then compared with the smooth earth algorithm. This error ("delta") was then used to correct the prediction for the actual path profile. This eliminates the need for any empirical correction. The Bullington method is currently the proposed choice regarding the diffraction algorithm as it does not produce discontinuities when the terrain heights vary by small amounts.

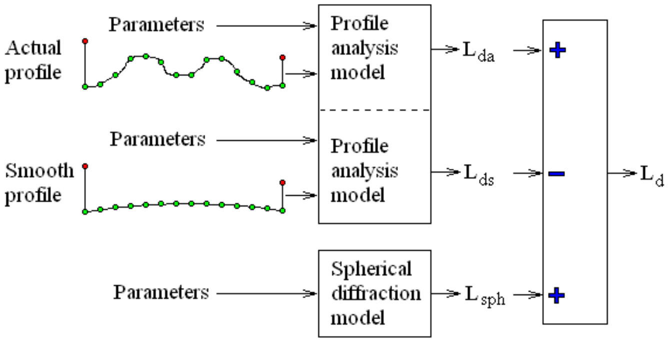

Figure 1. The Delta method of predicting diffraction loss

Figure 1 illustrates the principle of the Delta method, which is in three parts:

1. The profile of the path plus associated parameters, such as frequency and antenna heights, are input to the profile-analysis model, as indicated against “Actual profile”. The resulting predicted diffraction loss is Lda.
2. A smooth profile consisting of the same distances but zero heights is input to the same profile-analysis model. Most associated parameters will be as for the actual profile. The antenna heights should be the ‘effective heights’, that is, their heights above a smooth-surface fit to the actual profile. The resulting predicted diffraction loss is Lds.
3. The appropriate parameters, including the above ‘effective’ antenna heights, plus other inputs such as electrical properties, are input to the spherical-earth diffraction model. The resulting predicted diffraction loss is Lsph.

The overall diffraction loss is then given by:

$$L_d = L_{da} - L_{ds} + L_{sph} \text{ (dB)} \tag{1}$$

One interesting additional finding from the work was that the way in which the transition from line of sight to over-the-horizon paths was handled in the smooth earth method had to be changed. Although the curve connecting the two situations appeared to be logical for a single frequency, when the curves for many frequencies were plotted on the same graph they were seen to cross. This is illogical and the anomaly was corrected by adopting a different method of interpolating.

As a second example, the ducting sub-model is considered. The phenomenon of ducting is considered in ITU-R P.452. The lower frequency limit is 100 MHz, recently (October 2009) reduced to this figure from a value of 700 MHz. We need a ducting model that is usable at frequencies as low as 30 MHz. The accuracy of the prediction method used in ITU-R P.452 has been questioned when it is used to predict field strength exceeded for small time percentages at the lower frequencies. In order to investigate this, it was necessary to refer to the original measurement campaigns. It was found that the majority of measurements used to produce the model were obtained from a single campaign that used five links, each operating at four different frequencies between 94 MHz and 774 MHz. These revealed that while, on a trans-horizon path at 774 MHz, the difference between the median level and the level received for not more than 0.01% may be as much as 60 dB, at 94 MHz the difference between the two levels would be approximately 35 dB. The model was adjusted to accommodate this by including a frequency-dependent empirical correction.

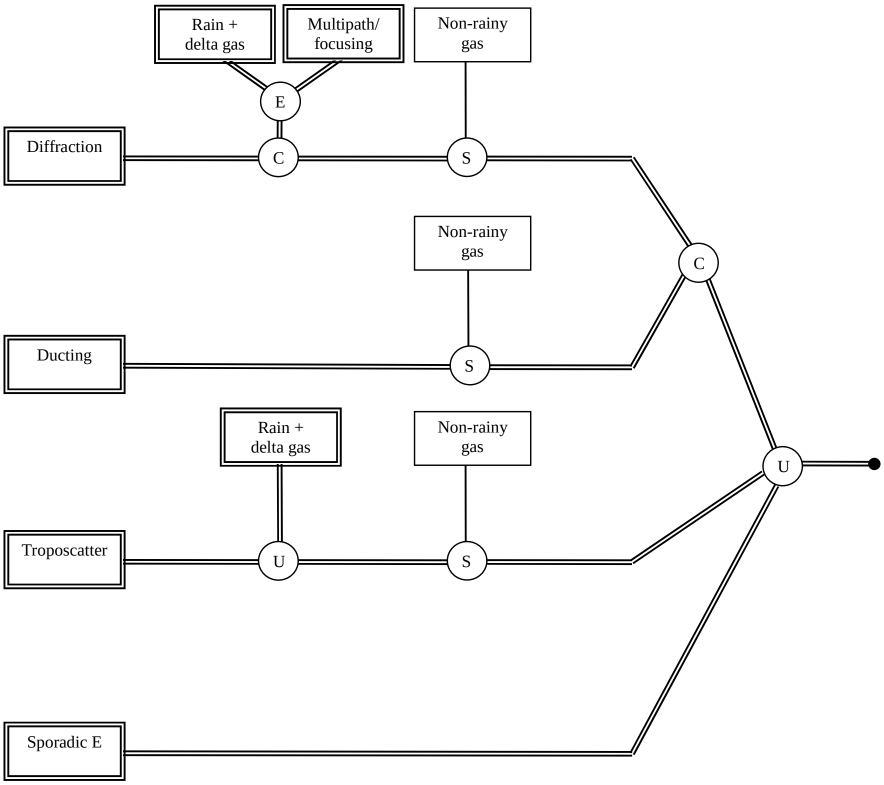

Figure 2. Combination of Propagation Mechanisms

D. Combination of Mechanisms

Once the necessary sub-models had been studied, the major challenge of combining them to form a single method remained. In summary, the individual mechanisms are:

- Diffraction – This mechanism is considered to include all paths close to the ground, and therefore includes the effects of the variation in the refractive index of the atmosphere. Signals propagating by this mechanism are subject to precipitation fading, gaseous attenuation and the multipath and focusing effects that lead to clear air enhancements and fading. The model is based on the Bullington method combined with the Spherical diffraction model in ITU.R P.526. Rain and clear air fading are based on the rain/sleet and clear air models given in ITU-R P.530.
- Ducting – This mechanism bypasses the close to the ground diffraction mechanism. It is subject to gaseous attenuation. There is no precipitation fading as in the Wide-range Propagation Model (WRPM) rain and ducting are considered mutually exclusive. The model is largely based on the method given in ITU-R P.452.
- Tropo-scatter – This is a further bypass mechanism to the propagation close to the surface. It is present at all times and is therefore subject to precipitation fading and gaseous attenuation. This model is based on ITU-R P.617.
- Sporadic-E – This is an ionospheric propagation mode that is only significant at VHF and below. There is no precipitation fading or gaseous attenuation because these mechanisms are not significant at these frequencies. The model is based on ITU-R P.534.

In all cases the gaseous attenuation is based on a simplification of recommendation ITU-R P.676.

Figure 2 shows that the mechanisms are combined using methods “C”, “E”, “S” and “U”. These represent the Correlated, Exclusive, Summation and Uncorrelated cases respectively. A Monte-Carlo simulation is the only true way to combine these mechanisms to give a complete probability distribution. It is recognized that this can be time consuming which is not always convenient. A combination mechanism designed to produce a good approximation to the probability distribution has also been developed.
The WRPM has been developed into a step by step procedure appropriate for implementation in a computer program.

IV. CONCLUSION AND NEXT STEPS

Development work has enabled the assessment of interference between different services sharing the same spectrum to be made in a technology-neutral manner. This has involved the development of a new assessment process that revealed shortcomings in currently-available propagation mechanisms. Further work has led to the development of an improved path loss prediction process valid over a wide range of time percentages between frequencies of 30 MHz and 50 GHz. The method presented here is expected to be discussed and subject to further international peer review at the next meeting of working parties attached to ITU-R Study Group 3 in November 2010. When combined with the generic interference assessment tool it represents a significant increase in the ability to assess mutual interference in a liberalized radio environment.

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