Propagation Prediction Method Development in Support of International Spectrum Management

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Abstract

With the growth of wireless technology for an ever-increasing range of devices, services, applications and users, the role of spectrum management is becoming more complex and difficult. National and international spectrum regulations define the use of frequencies from 9 kHz to 275 GHz, and most spectrum bands are allocated to two or more services. Furthermore, new technologies and growing technologies seek new spectrum allocations, sharing with existing services.

To support the development of new technologies and to assist in spectrum planning decisions, Radiocommunication Study Group 3 of the International Telecommunication Union (ITU-R SG 3) has developed and continues to improve a number of radiowave propagation prediction methods. Many of these methods are useful for system design, for example, to calculate the required link margin or the expected coverage area of a new system.

A key technical aspect of spectrum management is understanding and predicting the potential for interference between different services in the same band. There is therefore a growing need for propagation prediction methods which can estimate the likelihood of signal levels able to cause interference from one system to another.

Supporting these prediction methods are models of the natural variability of the environment, including climatic effects, terrain, building materials and vegetation.

This paper will review a number of Study Group 3 Recommendations relating to both system planning and to interference prediction. It will discuss recent developments and identify areas for future work.

1. Introduction

The radio spectrum is used by a wide range of services and technologies. In addition to the ubiquitous mobile phones and WLANs, radiocommunications include such diverse uses as maritime and aeronautical communications, broadcasting (television and audio), radar, satellites (to fixed or mobile earth stations, or for broadcasting), remote sensing, navigation, telemetry, point-to-point links, RFID and radioastronomy. Each of these services has specific requirements for availability, reliability, and tolerance to interference. Across the frequency spectrum 9 kHz to 275 GHz, which is regulated internationally by the ITU and nationally by government agencies, most frequency segments are shared by at least two and often three or four of these services [1].

At the international level, technical work to support decisions on spectrum management is carried out by Study Groups of the International Telecommunication Union, Radiocommunication Sector (ITU-R) [2]. Most of these Study Groups consider the operational characteristics and requirements of a particular class of service. For example, Study Group 4 addresses fixed satellite services, and Study Group 6 addresses broadcasting services. However, Study Group 3 considers propagation issues relating to all radiocommunication services. As a result, Study Group 3 prepares internationally agreed propagation prediction methods for all types of radio systems, in the form of Recommendations[1] which can be used for system design and for the assessment of interference between services.

Study Group 3 consists of propagation researchers from around the world. The Recommendations are tested against a database maintained by Study Group 3, and are then approved by a rigorous international ballot process. They are intended to represent the most accurate and comprehensive advice at the time, but are also subject to frequent improvement and extension. The sections below will identify some areas where further work is required. Research results and measurements which can assist in these activities are always welcome.

2. Prediction methods for system design

Study Group 3 has well-developed propagation prediction methods for fixed radio links, satellite systems,

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[1] All numbered Recommendations cited in this paper are available at http://www.itu.int/rec/recommendation.asp?type=products&parent=R-REC-P . New Recommendations will be available following an international approval process in 2006.

broadcasting and land-mobile services. These have been improved and extended over many years, on the basis of extensive measurement campaigns and modelling of climatic parameters.

In more recent years, with the growing interest in ubiquitous mobile radiocommunications, Study Group 3 has developed propagation prediction methods for indoor and short-range outdoor environments, Broadband Wireless Access (BWA) systems and ultrawideband technology.

2.1 Short-range services

Recommendation ITU-R P.1238 provides advice and prediction methods for indoor communication systems, intended particularly for WLAN and mobile phone services. It covers the range 900 MHz to 100 GHz, and has specific data for 900 MHz, 1–2, 4–5, 60 and 70 GHz, based on measurements. The prediction methods include a site-general model for loss, including loss between floors of a building, and for delay spread. The Recommendation also provides extensive advice on the use of site-specific (e.g. ray-tracing) models, the effect of polarisation and antenna pattern, the effect of building materials and furnishings (including a table of the complex permittivity of a number of materials at a wide range of frequencies) and the effect of the movement of people in the room.

Current work to extend Recommendation P.1238 includes a model for angular spread, particularly for MIMO (Multiple-Input Multiple-Output) systems, and further measurements of path loss coefficients at the frequencies of interest. In addition, there is a need to address diversity (space, polarization, antenna sector and frequency) and the reflection characteristics of rough surfaces. For the purposes of interference analysis, there is also a requirement to consider indoor interference arising from distributed emissions, such as those which may be caused by Digital Subscriber Line (DSL), broadband-over-powerline systems and high speed data networks.

Recommendation ITU-R P.1411 gives prediction methods and advice for short-range (up to 1 km) outdoor environments, including urban high-rise, urban/suburban low-rise, residential and rural. It covers the frequency range 300 MHz to 100 GHz, with specific measurement results at key frequency bands. Prediction methods are provided for path loss and delay spread on line-of-sight and non-line-of-sight scenarios, including over rooftops and urban street canyons. General advice is given on the effects of vegetation, with reference to a more detailed Recommendation. Finally, the Recommendation provides some measured results, provided by CSIRO, of indoor-to-outdoor building material loss at 5.2 GHz. This information was used in evaluating the potential interference from WLANs to satellite-based receivers, prior to the decision of the ITU to allow WLANs in the 5.15–5.35 GHz band.

Work is underway within Study Group 3 to extend Recommendation P.1411 to cover more frequency bands and a more comprehensive set of environments. Measurements are needed to evaluate and refine the prediction methods.

2.2 Broadband Wireless Access

Recommendation ITU-R P.1410 provides advice and prediction methods for millimetre-wave BWA systems, in the frequency range 20 – 50 GHz; however, work is underway to extend this to 3 – 60 GHz. It particularly addresses area-coverage issues, including blockage by buildings and vegetation effects, and provides a calculation for improvement when using two or more base stations. As rain causes significant attenuation above about 10 GHz, the Recommendation extends the point-to-point rain calculation to an area-coverage model and allows the calculation of the improvement in using route diversity. Advice about the distortion due to frequency-selective vegetation attenuation and multipath effects is also provided.

More work is needed on this Recommendation to extend the frequency range and to consider mesh networks and other emerging BWA technologies.

2.3 Ultrawideband

With the growing interest in ultrawideband (UWB) systems, both from potential developers who need to understand the performance of UWB and from regulators who need to estimate the interference to other services, Study Group 3 has recently developed a new Recommendation on ultrawideband propagation. It represents an initial step to characterise the basic transmission loss for typical indoor and outdoor systems up to a range of 20 metres. This is useful for establishing a link budget or planning system coverage. For interference analysis, the Recommendation indicates that other models should be used, depending on the narrowband system (mobile, satellite, WLAN, radar, etc) that may receive interference from UWB transmitters.

Study Group 3 plans to extend this Recommendation to cover distance beyond 20 metres, indoor-to-outdoor losses, and to extend the path loss parameters to more specific environments.

2.4 Land mobile and broadcasting systems

In the past, Study Group 3 maintained separate Recommendations to predict coverage for land-mobile systems (including mobile phones) and for broadcasting, but as the geometries and frequencies involved are similar, these have been merged into a single Recommendation

ITU-R P.1546. It covers the frequency range 30 MHz to 3 GHz. In contrast to other Recommendations which provide step-by-step equations, the core of Recommendation P.1546 is a series of curves, developed for the broadcasting and mobile industry on the basis of very extensive measurement campaigns. The curves provide the field strength exceeded for 50%, 10% and 1% time, within an area of 500 m by 500 m, for a 1 kW ERP (equivalent radiated power) transmission at 100 MHz, 600 MHz or 2 GHz, for a range of transmitter antenna heights and a fixed receiver height. Procedures are then provided to extrapolate or interpolate to other time percentages, other frequencies, other antenna heights, and to take account of local terrain variations.

This Recommendation is currently being used by the ITU in replanning the allocation of broadcasting frequencies across Europe, North Africa and the Middle East.

2.5 Fixed terrestrial and satellite services

Two well-known Study Group 3 Recommendations provide prediction methods for fixed terrestrial point-to-point links (Recommendation ITU-R P.530) and for satellite services (Recommendation ITU-R P.618). Both Recommendations address atmospheric attenuation, rain attenuation, cross-polarisation effects due to clear-air or rain effects, and improvement in availability through the use of various diversity systems. Rain attenuation is covered in particular detail, and step-by-step methods allow the calculation of long-term (annual or worst-month) statistics. In addition, there is advice on the short-term statistics of rain fades, that is, fade duration, inter-fade duration, and fade slope. Both Recommendations also provide a method to calculate the statistics of outages due to the combination of clear-air and rain effects. These Recommendations make extensive use of the global maps of climatic parameters discussed in Section IV below.

Recommendation P.530 for terrestrial links also gives prediction methods for diffraction loss, with a procedure for planning path clearance over terrain obstructions, and for fading or enhancement due to multipath effects, including a calculation of the occurrence of simultaneous fading on multi-hop links. Information is provided on the variation in the angle of arrival, prediction of BER (Bit Error Ratio) for digital links and a new section on techniques to reduce multipath.

Work is proceeding to add a prediction method for attenuation by snow or wet snow, to provide more advice on fade dynamics for fades due to multipath and rain, and to further test the rain attenuation predictions against a wide range of climate types. There is also a growing interest in predicting the joint statistics of rain attenuation on two paths with a common endpoint for the purposes of interference analysis.

In addition to the issues listed above, Recommendation P.618 for satellite systems provides calculation methods for scintillation and multipath at low elevation angles, noise temperature, angle of arrival variability and extends the attenuation methods to account for non-geostationary satellites.

Three further Recommendations, P.680, P.681 and P.682, give additional information relevant to maritime mobile-satellite, land-mobile satellite, and aeronautical mobile-satellite systems, respectively.

In the satellite area, work within Study Group 3 is underway to extend the prediction methods to frequencies above 50 GHz, to better characterise fade dynamics, and to extend the range of applicability for the mobile-satellite prediction methods.

2.6 Free Space Optical (FSO) systems

There is a growing interest worldwide in wireless communication systems using near-infrared or optical wavelengths. Study Group 3 has developed Recommendation ITU-R P.1622 for predicting propagation impairments for satellite path FSO systems, and is currently writing a new Recommendation on terrestrial FSO systems.

3. Prediction methods for interference

A key component of spectrum management is setting conditions on some services to minimise the potential for interference to others. These conditions may take the form of power limitations, or they may consist of a requirement to assess interference on a case-by-case basis. In either situation, an analysis of the power received by one service by a transmitter in another service is necessary.

Typically, an interfering signal must not exceed a given threshold for a specified percentage of time. Over long distances (tens of kilometres), the interfering signal may be enhanced by climatic changes for small periods of time. Therefore the prediction methods must consider these anomalous conditions, and provide a prediction of the minimum signal level (or equivalently, the maximum loss) which may occur for small time percentages.

3.1 Interference between systems

Recommendation ITU-R P.452 gives comprehensive prediction methods to calculate the interference between a transmitter and a receiver which are both on the surface of the Earth. It is applicable at frequencies above 700 MHz, and covers all types of interference paths.

Prediction methods for system design typically concentrate on losses due to propagation phenomena, in order to establish a link margin, but as the emphasis in these methods is on signal levels that potentially cause interference, it is necessary to consider propagation effects which enhance the average signal level. The Recommendation starts with interference mechanisms which can occur for large percentages of time: line-of-sight, diffraction over terrain or buildings, and tropospheric scatter (see Figure 1).

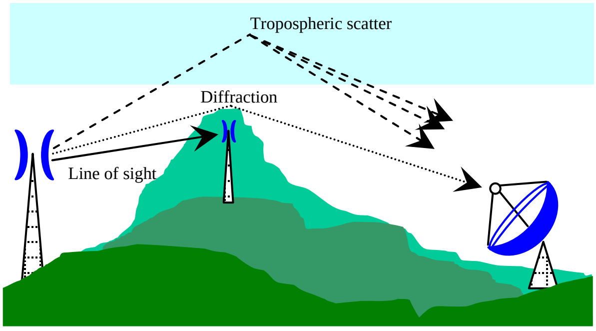

Figure 1. Long-term interference mechanisms

But it also considers those mechanisms which can occur for short periods of time: multipath enhancements of the line-of-sight signal, ducting from surface or elevated atmospheric layers, reflection and refraction from atmospheric layers, and scattering by raindrops or other hydrometeors (see Figure 2).

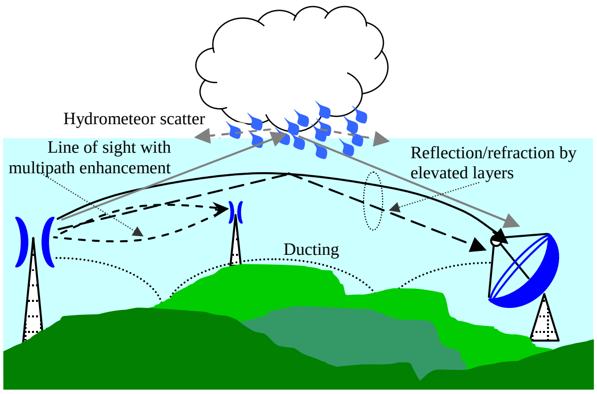

Figure 2. Short-term interference mechanisms

The prediction method requires information about the transmitter and receiver: frequency, geographic location and height of the antennas above local ground and above mean sea level. A terrain profile between the transmitter and receiver is needed, as well as an estimate of what proportion of the path is over water. It also requires radiometeorological data, particularly statistics of the refractive index variation with height, as well as rain statistics for the rain scatter calculations.

World-wide radiometeorological data is available in other Study Group 3 Recommendations, described in Section IV below.

With the information described above, the step-by-step procedures in Recommendation P.452 calculate the loss due to each mechanism, then combines the statistics to estimate the maximum transmission loss for a given percentage of a year or of the worst month.

Figures 3 and 4 shows contours produced by the method of Recommendation P.452 around a possible radioastronomy site in Western Australia. It has been assumed that the interfering signal arises from a typical fixed point-to-point link, and three thresholds for the interference level, corresponding to different radioastronomy requirements, have been used. In Figure 3, the contours represent the area where the thresholds are exceeded for 50% time (median signal level), while Figure 4 shows where the threshold would be exceeded for the worst 2% of a year. The effect of anomalous propagation can be clearly seen in the difference between the two Figures.

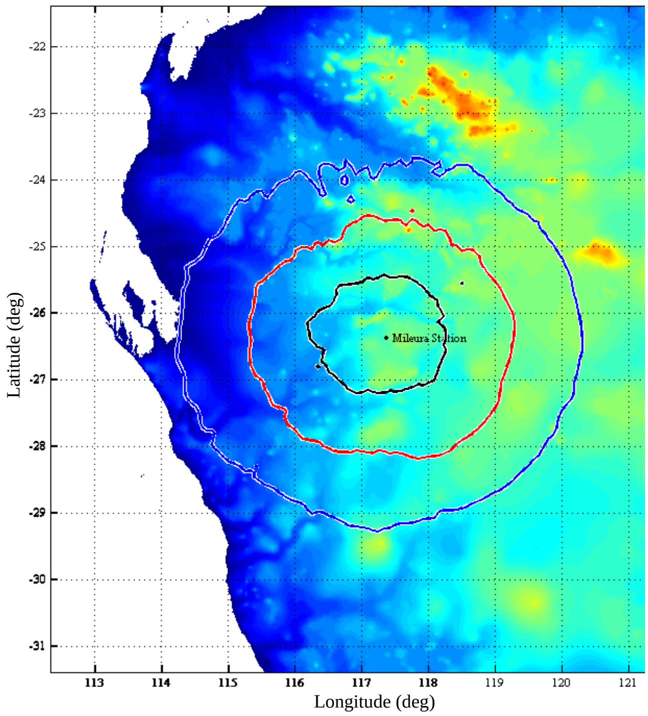

Figure 3. Interference contours for 50% time

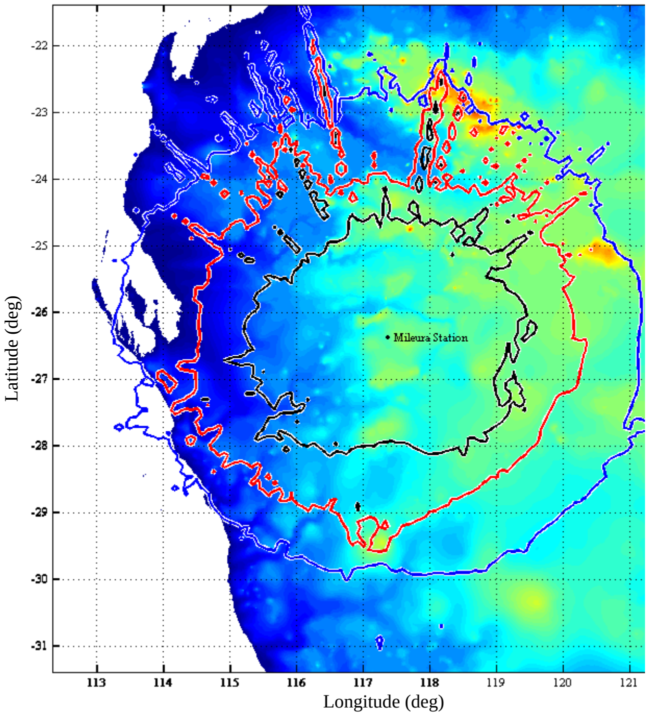

Figure 4. Interference contours for 2% time

3.2 Satellite coordination distance

Key frequency bands used by fixed satellite services are also allocated to terrestrial services. Without proper planning, transmissions from an earth station can interfere with terrestrial systems, or terrestrial systems can cause interference to earth station receivers. Before the installation of a new earth station, a detailed analysis is carried out to ensure that no harmful interference will occur. It should be noted that in many parts of the world, the earth station may be in one country and potentially affected terrestrial systems in a different country, so international procedures approved by all nations are required.

Recommendation ITU-R P.620 is used to calculate the coordination area around a fixed earth station, that is, a geographic area surrounding the station within which the possibility of interference between the earth station and terrestrial systems exceeds a certain threshold. Once this zone is defined, more specific interference calculations are then carried out for the actual radio services within the zone, using Recommendation P.452 described above. For economic and technical reasons, it is important that the zone be accurately estimated; if the zone is too small, potential interference sites may be overlooked, but if the zone is too large, an excessive number of detailed analyses must be performed.

There are two components to the coordination area calculation in Recommendation P.620. The first considers terrain shielding, the earth station antenna pattern and clear-air effects: line-of-sight propagation, diffraction, ducting and troposcatter. For each azimuth angle around the earth station, a distance is calculated at which the total clear-air loss exceeds a threshold value, and a contour is drawn. The second component is rain scatter, which produces a circular contour around a point offset from the earth station location along the direction of the main beam. The complete coordination zone is then defined by taking the larger distance at each azimuth.

4. Climatic descriptions and other supporting material

To support the prediction methods described above, Study Group 3 maintains a number of Recommendations with descriptions of climatic parameters, terrain features, and fundamental physical phenomena.

4.1 Climatic maps and models

One major effort in the past few years has been the introduction of digital maps of climatic parameters. These maps cover the entire globe and have a resolution of 1.5° in both latitude and longitude. The data files are available for free in the software section of the Study Group 3 website [3], and the use of the files is described in various Recommendations. The radio refractive index of the atmosphere at the earth's surface, and refractive index gradient with altitude are described in Recommendation ITU-R P.453. Surface water vapour density and total water vapour content through the height of the atmosphere are given in Recommendation ITU-R P.836. Recommendation ITU-R P.840 provides a prediction method for attenuation by fog and cloud, along with maps of the total columnar cloud liquid water content.

Recommendation ITU-R P.837 has digital maps of rain rate, where the rain rate exceeded for a specified percentage of the year can be calculated. Recommendation ITU-R P.839 gives a map of the height of the rain layer, for use particularly in satellite applications.

Two climatic effects relevant to a large number of applications are attenuation by atmospheric gases, and rain attenuation. A comprehensive model for atmospheric attenuation is given in Recommendation ITU-R P.676. This provides both a calculation of specific attenuation as well as total attenuation on satellite paths, accounting for atmospheric variations in height. In addition to a rigorous calculation, a less computationally intensive method is provided for estimates for a limited range of meteorological conditions. Recommendation ITU-R P.838 provides a model for specific attenuation due to rain, over the frequency range 1 to 1000 GHz. The coefficients have recently been improved, and the frequency range extended, based on modelling work supplemented by extensive measurement data, and the revision corrects under-estimation of attenuation at higher frequencies.

4.2 Terrain maps and diffraction

Study Group 3 does not maintain detailed topographic terrain maps, as these are widely available from other sources. Recommendation ITU-R P.1058 provides advice about the use of commercially available digital terrain databases, including extraction of path profiles for propagation prediction, and information on categories of ground cover. Prediction methods for diffraction paths are given in Recommendation ITU-R P.526, which has a simple method assuming a smooth earth, more specific methods for single obstructions, and a comprehensive method using a path profile extracted from detailed terrain maps. This Recommendation has also been recently updated with more accurate but computationally-intensive methods supplementing the simpler approximation methods.

4.3 Other Recommendations of interest

Two other Recommendation of general interest should be mentioned. Recommendation ITU-R P.833 addresses attenuation by vegetation, modelling loss through a single tree as well as propagation through a forest. It has recently been expanded and further work is planned, due particularly to interest in outdoor wireless access systems, fixed or mobile, at a range of frequencies.

Finally, Recommendation ITU-R P.372 provides extensive advice on radio noise, including models for man-made radio noise across the frequencies of interest to radiocommunication services as well as naturally occurring noise from lightning, the ground, the atmosphere, and extraterrestrial sources. This Recommendation is in the process of being updated, on the basis of new measurements, to reflect the significant changes in man-made noise over recent decades. Further measurement data in relation to man-made noise would be useful to assist in this work.

4.4 Databanks and software

To test the prediction methods described above, Study Group 3 maintains an extensive data base of measurements, contributed by participants over many years. For climatic methods, it is desirable to have measurements from the full range of climatic regions, but there is generally less data available from tropical regions than from temperate. For other topics, a need for data has been identified and data base table established, but no measurements have been supplied. Information about the database and conditions for submitting data is available at [3].

Similarly, software to implement a number of the prediction methods is available at [3]. This software has been developed by individuals within Study Group 3 and is made available without charge but without any formal endorsement by Study Group 3 or the ITU.

5. Conclusions

ITU-R Study Group 3 continues to develop a large number of internationally approved propagation prediction methods and supporting material to assist system designers and to provide the technical basis for spectrum management decisions at the international, national, and local level. This paper has reviewed some of the Recommendations, particularly as they apply to new and growing wireless applications.

The continuing progress of these prediction methods relies on input from propagation researchers in the form of new measurement results, modelling, comments on potential improvements or extensions of the prediction methods, or results of testing against the database. The author is very willing to provide assistance for anyone wishing to contribute to Study Group 3 activities.

6. Acknowledgment

The author gratefully acknowledges the contribution of Dr Hajime Suzuki of the CSIRO ICT Centre in the calculation and mapping of Figures 3 and 4.

7. References

[1] International Telecommunication Union, *Radio Regulations.* Geneva, Switzerland, 2004.

[2] http://www.itu.int/ITU-R/

[3] http://www.itu.int/ITU-R/software/study-groups/rsg3/databanks/index.html