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Re:	This is a response to the chairman of the coexistence task group's oral call for contributions at the July 99 meeting for input to the document outline in paper 80216cc-99/11.
Abstract	This document provides baseline text for section 5 (propagation model).
Purpose	802.16.2 is asked to consider this text for adoption in the coexistence practice.
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Release	

Propagation Model for Coexistence Modelling

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Introduction

This contribution provides text for section 5 of the coexistence practice outline (reference paper 802.16cc-99/11).

Propagation Model

Basic Relations

As this coexistence practice is based on consideration of power spectral density, rather than power, the familiar radio link quantities of power and power flux density are replaced by power spectral density and power spectral density flux density respectively.

Transmitter antenna gain and radiated power spectral density are lumped together and expressed as an equivalent isotropic radiated power spectral density given by:

$$EIRPSD = PSD_t + G_t \qquad [5.1]$$

where:

EIRPSD is equivalent isotropic radiated power spectral density in dB(W/MHz);

PSD_t is the transmitted power spectral density in dB(W/MHz) at the transmitter antenna flange; and

G_t is the transmitter antenna gain in dBi in the direction of the receiver

Note that for a given antenna, EIRPSD varies with direction. The maximum occurs in the direction of maximal antenna gain, but an EIRPSD for every direction can also be defined, and is often required for sidelobe interference calculations.

BWA systems generally employ elevated antennas with line-of-sight paths free of obstructions. As such, an appropriate propagation model for interference paths assumes free space propagation and only atmospheric and rain losses. Thus, the power spectral density flux density produced at a given distance from the transmitter is given by:

$$PSDFD = EIRPSD - 10\log 4\pi - 20\log d - L_a - L_r - 60$$

This simplifies to:

$$PSDFD = EIRPSD - 20\log d - L_a - L_r - 71 \qquad [5.2]$$

where:

PSDFD is power spectral density flux density in dB(W/MHz/m^2);

d is distance from the transmitter in km;

L_a is atmospheric gaseous loss in dB, described in a section below; and

L_r is rain loss in dB, described in a section below; and all logarithms are to the base 10.

PSDFD is the basic parameter that is calculated to determine the potential for interference to be caused at any given distance from an interfering transmitter.

The relationship between PSDFD and received power spectral density at a victim receiver is given by:

$$PSD_r = PSDFD + A_e - L_{xp} \qquad [5.3]$$

where:

PSD_r is the power spectral density received at the receiver antenna flange in dB(W/MHz);

A_e is the receiving antenna effective aperture in the direction of the transmitter in dB(m^2); and

L_{xp} is cross-polarization loss if transmitter and receiver are not co-polar

The effective aperture of any antenna is related to its gain by:

$$A_e = G_r + 10\log(\lambda^2/4\pi)$$

which simplifies to:

$$A_e = G_r + 20\log\lambda - 11 \qquad [5.4]$$

where:

G_r is receiver antenna gain in the direction of the transmitter in dBi; and

λ is the wavelength in meters.

Thus,

$$PSD_r = PSDFD + G_r + 20\log\lambda - L_{xp} - 11 \qquad [5.5]$$

Equation 5.2 is used to express the interference potential of a given transmitter at any given distance and direction. Equation 5.5 is used to determine the susceptibility of a given receiver to that emission.

Combining equations 5.1, 5.2 and 5.5 we obtain another equation which is sometimes useful to express the relationship between transmitted and received power spectral density for a specific transmitter-receiver pair:

$$PSD_r = PSD_t + G_t + G_r + 20\log\lambda - 20\log d - L_a - L_r - L_{xp} - 82 \qquad [5.6]$$

Atmospheric Gaseous Loss

Equations expressing losses due to oxygen and water vapour can be found in [REF5.1], and supporting information about water vapour density distributions by region are found in [REF5.2]. Gaseous losses increase linearly in dB with distance.

Oxygen loss is negligible for frequencies up to about 50 GHz and will be neglected in this coexistence practice. Water vapour absorption can be significant for long interference paths (more than 10 km). Loss has a local maximum at 22 GHz and a local minimum at about 31 GHz. For interference analysis in the range 20 - 40 GHz, we will use the value at 30 GHz to be conservative. The loss due to water vapour varies with the absolute humidity level. To be conservative in interference analysis, one could calculate assuming dry air. On the other hand, interference analysis is usually concerned with scenarios in which rain is present which fades the desired signal. In this case, we can assume that the air is generally humid. [REF5.1] gives a loss coefficient of 0.1 dB/km at 30 GHz for air containing 7.5 g/m^3 of moisture, which corresponds to 50% relative humidity at 16°C. [REF5.2] lists February and August mean moisture content by region. In most of the world, the moisture content tends to be between 10 and 20 g/m^3 in the hotter season. We can therefore take the 0.1 dB/km value as relatively conservative.

Thus,

$L_a = 0.1d$ [5.7]

As the dependence on d complicates the solution of equation 5.2 for the value of d which produces a specific PSDFD, the modelling of gaseous loss can be simplified as follows:

$L_a = 0$, $d < 10$km (i.e. neglected for generally intra-city scenarios) [5.8]

$L_a = 1.5$, $10 < d < 20$ km (i.e. quasi-constant for inter-city scenarios)

$L_a = 2.5$, $20 < d < 30$ km

etc.

Rain Loss

Equations expressing loss due to rain can be found in [REF5.3], and supporting information about rain rate statistics by region are found in [REF5.4]. Rain loss increases linearly in dB with distance, and the specific attenuation coefficient γ in dB/km is a function of frequency, polarization and rain rate. Attenuation for vertical polarization is slightly lower than for horizontal polarization.

The specific attenuation is given by:

$\gamma = \kappa R^{\alpha}$ [5.9]

where

γ is specific attenuation in dB/km;

κ is a constant, dependent on polarization and frequency;

α is a constant, dependent on polarization and frequency; and

R is the rain rate in mm/hr

At 30 GHz, for vertical polarization, the relationship simplifies to:

$\gamma = 0.167R$ [5.10]

In BWA systems, we are concerned with the worst-case rain fade of the desired signal; i.e. the scenario which occurs when the desired signal travels through a rain cell having the highest rain rate that the system is designed to cope with. For a given availability target, e.g. 99.99%, the rain rate that is not exceeded that percentage of the year can be found from regional meteorological data, such as [REF5.4]. For example, in global rain region K, the rain rate which is not exceeded 99.99% of the time is 42 mm/hr, resulting in an attenuation of 7 dB/km for vertical polarization, using equation [5.9] above.

Correlated Rain Fading of Desired and Interfering Signals

In the interference scenario in which the desired signal has faded to the receiver threshold, we are concerned with modelling the degree of rain fading that the interfering path experiences. As

BWA hub stations employ relatively wide sector beamwidths, compared to point-to-point systems, it is possible that the interfering signal travels through a path relatively unaffected by rain compared to the path travelled by the desired signal. A model is required for correlation of desired and undesired signals converging to the same point, as a function of angular separation. The most conservative model assumes no correlation of desired and undesired signal paths. In this case, the worst case that must be modelled has the desired signal faded to threshold, whereas the interfering signal has a clear-sky path from transmitter to victim receiver. The most optimistic model assumes perfect correlation (uniform rain fading of the entire region including victim receiver, desired transmitter and interfering transmitter). In this case, if the desired signal has experienced the maximum fade, the undesired signal will also experience a deep fade.

Data on the spatial correlation of rain events is scant; however, a rudimentary model can be based on work published by Crane in [REF5.5]. A rain event consists of small "volume cells" of intense rain rate within much larger "debris regions" with a lower rain rate. The dimensions of these areas are inversely related to rain rate.

Volume cells are quite small, generally less than 5 km^2. [REF5.5, figure 2.32 shows average volume cell area of about 3 km^2 over the range of rain rates 20 - 40 mm/hr, often of interest as design targets for BWA systems. This could be represented as a rectangle of about 1.6 x 3 km diameter (rain cells are usually not circular). Thus, when the worst-case fade of the desired signal occurs, it is likely that a volume cell is positioned exactly in between the hub and subscriber, with the long side along the path.

For hub sector angles greater than 15 - 30 degrees, there will often be cases where the interfering signal does not pass substantially through the rain cell, only through the debris region. An example is depicted in figure 5.1.

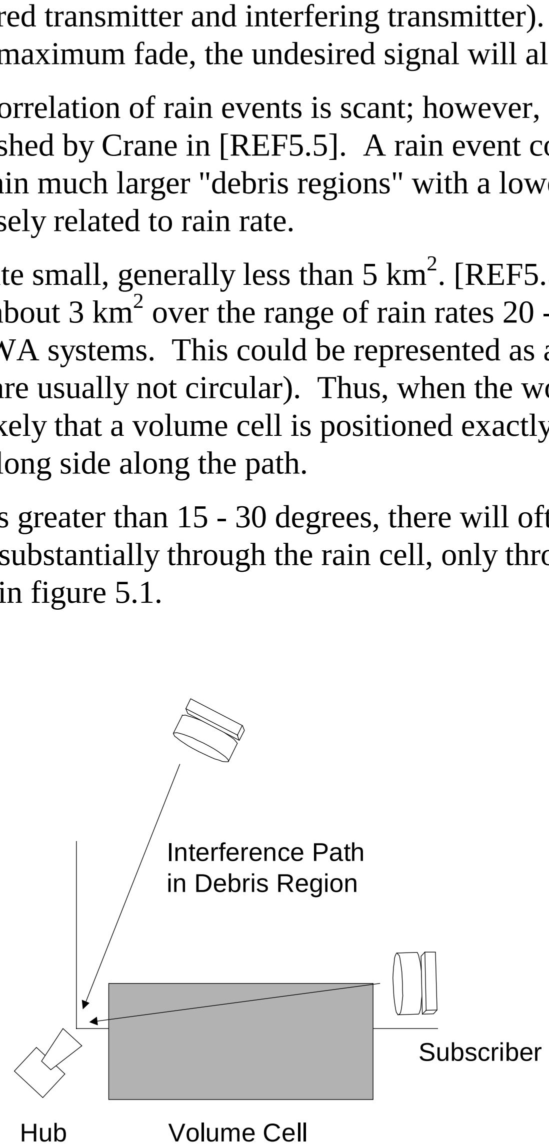

Figure 5.1: Rain Correlated Fading Scenario

In the debris region, rain rate tends to be approximately log-normally distributed with a low median [REF5.5, figure 2.22]. In one example, the median rate was only 0.7 mm/hr, whereas volume cells within the region had rates as high as 32 mm/hr. The size of the debris region can be much larger than a volume cell. A model for the dimension of the debris region as a function of rain rate is found in [REF5.5, section 4.4.1.2]. At 0.7 mm/hr, the debris region would be 30 km across. Unlike the volume cell, it would tend to encompass the entire path of most interfering signals.

Thus, a conservative model for interference assumes that when the worst-case rain fade of the desired signal occurs, any interfering travels only through the debris region and experiences a rain rate of 0.7 mm/hr uniformly along its path. Using equation [5.10], this is equivalent to attenuating the interfering signal by 0.12 dB/km.

References

[REF5.1] ITU-R Recommendation P.676-1 (1992)

[REF5.2] ITU-R Recommendation P.836 (1992)

[REF5.3] ITU-R Recommendation P.838 (1992)

[REF5.4] ITU-R Recommendation P.837-1 (1994)

[REF5.5] Crane, Robert K., "Electromagnetic Wave Propagation Through Rain", Wiley-Interscience, 1996.