Project	**IEEE 802.16 Broadband Wireless Access Working Group** **<http://ieee802.org/16>**	
Title	Propagation models for coexistence studies	
Date Submitted	2001-9-6	
Source(s)	Avi Freedman Hexagon System Engineering Ltd. 2 Kaufman st. Tel-Aviv, 68012, Israel	Voice:+972-3-5101128 Fax: +972-3-5103331 mailto:avif@hexagonltd.com
	Ofer Kelman Marconi Communications Israel 11 Hamelacha st. Lod, 71293, Israel	Voice: +972-8-977 7026 Fax: +972-8-977 7080 mailto: Ofer.Kelman@marconi.com
Re:		
Abstract	This document suggests propagation models to use in coexistence studies	
Purpose	Select an agreed set of models for the studies to be performed by TG2a	
Notice	This document has been prepared to assist IEEE 802.16. It is offered as a basis for discussion and is not binding on the contributing individual(s) or organization(s). The material in this document is subject to change in form and content after further study. The contributor(s) reserve(s) the right to add, amend or withdraw material contained herein.	
Release	The contributor grants a free, irrevocable license to the IEEE to incorporate text contained in this contribution, and any modifications thereof, in the creation of an IEEE Standards publication; to copyright in the IEEE's name any IEEE Standards publication even though it may include portions of this contribution; and at the IEEE's sole discretion to permit others to reproduce in whole or in part the resulting IEEE Standards publication. The contributor also acknowledges and accepts that this contribution may be made public by IEEE 802.16.	
Patent Policy and Procedures	The contributor is familiar with the IEEE 802.16 Patent Policy and Procedures (Version 1.0) <http://ieee802.org/16/ipr/patents/policy.html>, including the statement "IEEE standards may include the known use of patent(s),	

Propagation models for coexistence studies

Avi Freedman
Hexagon System Engineering Ltd.

1. Introduction

A PAR, [1], has been recently approved in which 802.16 is to study and write recommended practice for coexistence between 802.16 system in the licensed band between 2-11 GHz. The project is to be performed by the TG2a task group. TG3 has developed a channel model document [2], to be used for link simulations, and it includes a propagation loss model. For the purpose of interference calculation, this model is not adequate. Its prediction is too optimistic for interference. Other models are suggested here for the purpose of coexistence studies.

2. The TG3 Channel Model

The path loss propagation model, in [2], is an experimental model, developed to fit a set of measurements taken in suburban environment in non-line of sight conditions. As stated in [2], this model is found to fit quite well with models used for urban areas (COST 231-WI) and to test drives done in urban environment. While this model is perfectly adequate for worst case link simulations, it is not adequate for coexistence studies, as it gives quite high estimates for the propagation path loss, and it may underestimate the interference.
[2] shows some models propagation loss as a function of range, predicting about 120dB path loss for 1km range and about 140dB loss for $10^{0.8}$ = 6.3km. These values are much larger than expected path loss in very common cases of rooftop installations, where the propagation conditions are closer to LOS and the receivers are exposed to a much higher interference.

3. Alternative models

3.1 "Official" Models

The FCC, [3] and the ITU [4], have recommended models, which are designed to assess the path loss for interference to MMDS systems or point-to-point links respectively. The main features of those models are:

3.1.1 FCC Model

The FCC methodology is based upon the basic calculation described in [5]. The propagation model has three basic elements that affect the predicted field strength at the receiver:
1) Line-of-Sight (LOS) mode, using basic free-space path loss
2) Non-line-of-sight (NLOS) mode, using multiple wedge diffraction
3) Partial first Fresnel zone obstruction losses applicable to either mode

The excess loss component, calculated according to the Epstein Peterson method (see [6] and [7])

3.1.2 ITU-R Models

The ITU-R, SG3 has published several recommendations for path loss calculations. [4] is a recommendation for path loss calculation of microwave interference and is quite relevant to our case. The main points in that recommendation:

1. It takes into account various physical phenomena such as Line-of-Sight, diffraction, tropospheric scatter, surface ducting, elevated layer reflection and refraction and hydrometeor scatter.
2. For multiple diffraction it uses the Deygout method, as desribed in [7] and [8].
3. Path loss is calculated for clear line-of-sight, line-of-sight with sub-path obstruction and trans-horizon cases.

While the FCC model is focused on the MMDS interference calculation, the ITU-R recommendation is more general in nature and applies for longer range and more diverse cases.

3.2 Other possible models

The main drawback from the co-existence study point of view is that the above-mentioned models require the ability to calculate the profile between the interferer and the victim, and hence require a digital terrain map of the analysis area. If such a map is not available, or for more general analyses, a simpler model, which do not take terrain into account, has to be selected. Possible such models are:

1. Free space propagation
2. Free space models with variable propagation exponent, clutter constant values etc.
3. Two- Ray, or dual slope models
4. FCC or ITU-R rec. plus a statistical model for profile information
5. HATA, COST-231, WI, TG3 etc.
6. Parametric model

3.2.3 Free Space

The free space model is the simplest model, but does not model the terrestrial environment reliably. One may heuristically change the coefficient factor, add a constant value according to clutter etc. However, more theoretical or experimental data are need to support that.

3.2.4. Two- Ray or dual slope model

This model takes into account the effect of ground reflection, and the antenna heights above it. Basically the model take free space path loss of 20dB/decade up to a range $R_b = 4h_{T_X} h_{R_x} / \lambda$, where h_{Tx} and h_{Rx} are the transmitter and receiver antenna heights respectively, and 40dB/decade there after. This model, although simplistic, can be very well suited for analyses involving line-of-sight scenarios.

3.2.5 ITU-R or FCC recommendations

Without profile information, the recommendations described above can be used, provided there is a good estimate of the profile parameters. A model can be used to simulate the profiles (Rayleigh distribution for building heights, or similar model for terrain heights). The question is how accurate and how representative are those models.

3.2.6 HATA, COST-231, WI, TG3 etc

All those models are results of test and experiments performed mainly in conditions (frequency, environment, etc.) suitable for mobile cellular systems. See above for discussion.

3.2.7 Parametric models

Some new models, described in [7]. Those models use statistics based on area parameters (building density, size, area height, material and more) to develop a theoretically based estimation of the average path loss. Being based on theoretical grounds, those models can be more readily extended in frequency and range. Appendix A gives a description for such a model. [9]-[11] describe it in a much deeper detail.

4. Conclusions

We recommend the following rules for choosing the appropriate propagation model for co-existence studies:

a. In analyses, which include terrain information, the FCC or ITU-R models are recommended.
b. In analyses, which do not include terrain information, the FCC or ITU-R models can be used provided that the model for the terrain profiles can be justified.
c. The “two ray” model is recommended for simple analyses, in which the propagation conditions are clearly line-of sight.
d. The parametric model could be a good candidate for analysis, but still needs further discussion.

We should keep it simple, and adopt one or two models that will be the most conclusive and will cover most common cases. The scheme suggested may be too complicated and involve too many models. The parametric model could be such an model.

References

[1] IEEE 802.16.2-01/06r1, IEEE SA Project Authorization Form – P802.16.2a
[2] IEEE 802.16.3c-01/29r3, Channel Models for Fixed Wireless Applications
[3] FCC: methods for predicting interference from response station transmitters and to response station hubs and for supplying data on response station systems. MM docket 97-217
[4] Rec. ITU-R P.452-10: Prediction procedure for the evaluation of microwave interference between stations on the surface of the Earth at frequencies above about 0.7 GHz
[5] Transmission Loss Prediction for Tropospheric Communication Circuits," Technical Note 101, NTIS Access Number AD 687-820, National Technical Information Service, US Department of Commerce, Springfield, VA.
[6] J. Epstein and D.W. Peterson. "An experimental study of wave propagation at 850 Mc.," Proc. IRE, vol. 41, no. 5, pp. 595-611, May, 1953.
[7] Blaunstein, N. "Radio Propagation in Cellular Networks", Artech House, MA, 2000.
[8] Rec. ITU-R P.526: Propagation by diffraction
[9] Blaunstein, N. "Prediction of cellular characteristics for various urban environments", *IEEE Antennas Propagat. Magazine,* vol. 41, No. 6, 1999, pp. 135-145.
[10] N. Blaunstein, A. Freedman, I Matityahu, "Prediction of Loss Characteristics for mixed Residential Areas with Vegetation", submitted to *IEEE Trans. On Ant. And Prop.,* July 2000.
[11] N. Blaunstein, D. Katz, D. Censor, A. Freedman, I. Gur-Arie, "Propagation in Built-up areas with various terrain and buildings' overlay profiles", submitted to *IEEE Trans. on Vehicular Technology,* Aug. 2000.

Appendix A

The Parametric Model

A.1. The area parameters

To develop the parametric model, buildings are modeled as reflecting screens randomly distributed and randomly oriented in the deployment area. Trees are modeled as phase-amplitude cylinders, which are also distributed randomly. These approximations are valid for a large range of frequencies, between UHF and X band (0.5-10 GHz), a band which covers most of the bands used by mobile and FWA cellular systems. The following parameters are needed to describe the environment:

1. The density of obstructions (buildings, trees) - ν objects/km^2.
2. The average length of building walls, size of trees: L meters.
3. The reflection coefficient of the obstruction material: Γ. (For typical building this value is between 0.5-0.8, no need for a more accurate knowledge)
4. The correlation length of the obstructions in the vertical direction l_v meters and in the horizontal direction l_h. This value describes the average height of floors in the buildings and the distance between branches in trees etc.
5. The statistics of the obstacles absolute height (above sea level). We use $P_h(z)$, the probability that a building is above a given level z. This complementary cumulative distribution takes into account both building height and the topographical nature of the terrain in the area investigated. Details are elaborated in Appendix A.
6. In addition we need the lower z_1 and higher z_2 antenna height and minimum h_1 and maximum h_2 of the built-up layer height.
7. Antennas' absolute heights.

This set of parameters is readily available, or at least can be estimated accurately enough. The model is based upon a stochastic approach namely the contributions of different paths, and various phenomena is calculated and estimated as well as the probability that such contribution does occur. All of those contributions are then averaged to provide the final result. For example, one starts with estimating the probability that a direct line of sight exists between the transmitter and receiver. Given that such a line of sight does exist, the received signal strength can be readily calculated, taking into account the reflection from the ground. Similarly, in order to estimate the contribution from reflection by a wall, one has to estimate the probability that a line of sight exist between the transmitter and that wall, the average size of the illuminated area, the average size visible by the receiver and the probability that this wall is visible by the receiver. A similar treatment is made for diffraction and scattering effects and, of course, to the direct LOS, or direct visibility.

A.2. The height profile function

The key to the model description is the height distribution of the obstacles in the investigated area. We mentioned above the function $P_h(z)$, which describes the probability to find an obstacle lower than z. If this function is not known precisely, we use the following approximation for it:

$$P_h(z) = \begin{cases} 1 & z < h_1 \\ \left(\dfrac{h_2 - z}{h_2 - h_1} \right)^n & h_1 < z < h_2 \\ 0 & z > h_2 \end{cases} \tag{A.1}$$

which states that we will find obstacles higher than the minimal value h_1 (the minimal value) with probability one, obstacles higher than the maximal value,h_2 , with probability zero, and in between by a function which depends on the parameter n, which is a function of the specific terrain. $n = 1$ means that the obstacles height is distributed uniformly between the maximum and minimum value. $n < 1$ means that the distribution is skewed towards the higher obstacles height. $n > 1$ means that the distribution is skewed towards the lower obstacles heights, e.g. a city with a lot of small buildings and few tall buildings. In fact the value of n can be easily estimated from the maximal, minimal and mean height of the obstacles.

We do not use the function $P_h(z)$ directly but rather its integral between the lower and higher antenna heights, z_1 and z_2 respectively. We call that function the height profile function, and denote it by $F(z_1,z_2)$.

A.3 Loss characteristics prediction

Following to the analysis presented in [5, 12], one can evaluate the total path loss in different environments, urban, suburban and rural mixed with vegetation. We do not present here the path loss directly, though, but rather its inverse- the normalized average field intensity. The electromagnetic wave is using different path and we have to average over the contributions of each of those paths to the field intensity. We partition the different paths to the coherent part, representing the waves arriving directly from the transmitter to the receiver, and the incoherent part, which is made of the contributions of reflection, diffraction and scattering effects on around and from the different obstacles.

The expression for the incoherent part of the total field intensity can be presented, taking into account single scattering and diffraction from buildings' corners and rooftops, as follows:

$$\langle I_{inc1}\rangle = \frac{\Gamma}{8\pi}\frac{\lambda l_v}{\left[\lambda^2 + (2\pi\lambda_v\gamma_0 F(z_1,z_2))^2\right]}\frac{\lambda l_h}{\lambda^2 + (2\pi l_h\gamma_0)^2}\frac{\left[(\lambda d/4\pi^3) + (z_2 - h)^2\right]^{1/2}}{d^3} \qquad \text{(A.2)}$$

where $\gamma_0 = \frac{2L\nu}{\pi}$ with L and ν as defined above and h is the average height of the area.

The corresponding formula for double scattering and diffraction is given by:

$$\langle I_{inc2}\rangle = \frac{\Gamma^2\lambda^3 l_v^2}{24\pi^2\left[\lambda^2 + (2\pi l_v\gamma_0 F(z_1,z_2))^2\right]^2 d^3} \qquad \text{(A.3)}$$

(the detailed definitions of these parameters one can find in [5, 12]). The coherent part of the total field intensity can be obtained in the same manner:

$$< I_{co} > = \exp\left\{-\gamma_0 d(z_2 - z_1)^{-1} F(z_1,z_2)\right\}\frac{\sin^2(2\pi z_1 z_2/\lambda d)}{4\pi^2 d^2} \qquad \text{(A.4)}$$

The total average field intensity now can be defined as:

$$\langle I_{total}\rangle = \langle I_{inc1}\rangle + \langle I_{inc2}\rangle + \langle I_{co}\rangle \qquad \text{(A.5)}$$

and the path loss is then given by:

$$PL = 20\log 10\left(\frac{1}{\langle I_{total}\rangle}\right) \tag{A.6}$$