

Project	IEEE 802.16 Broadband Wireless Access Working Group < http://ieee802.org/16 >	
Title	TG3 Channel Model – Protested Status and Voting	
Date Submitted	2001-07-02	
Source(s)	David Trinkwon Transcomm Inc PO Box 2886, Fairfax Virginia, 22031	Voice: 650 245 5650 Fax: 650 649 2728 trinkwon@compuserve.com
Re:	Status of Document 802.16.3c-01/29r1 and subsequent Motions / Voting at Meeting #13 (Orlando)	
Abstract	This document records the misunderstandings that were revealed at Meeting #13 (Orlando) regarding the status and disposition of the TG3 Channel Model document 802.16.3c-01/29r1 at Meetings #11 (Ottawa) and #12 (Hilton Head) and its relevance for subsequent voting at Meeting #13 (Orlando). Conclusions are made which would alter certain decisions of the Chair on these matters at Meeting #13. Some commentary is also provided as to why the resolution of these misunderstandings is important to the integrity of the proposed 802.16a Standard.	
Purpose	To correct / complete the record on the status of the Channel Model documents and voting.	
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 material 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	<p>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), including patent applications, if there is technical justification in the opinion of the standards-developing committee and provided the IEEE receives assurance from the patent holder that it will license applicants under reasonable terms and conditions for the purpose of implementing the standard."</p> <p>Early disclosure to the Working Group of patent information that might be relevant to the standard is essential to reduce the possibility for delays in the development process and increase the likelihood that the draft publication will be approved for publication. Please notify the Chair <mailto:r.b.marks@ieee.org> as early as possible, in written or electronic form, of any patents (granted or under application) that may cover technology that is under consideration by or has been approved by IEEE 802.16. The Chair will disclose this notification via the IEEE 802.16 web site <http://ieee802.org/16/ipr/patents/notices>.</p>	

TG3 Channel Model – Protested Status and Voting

David Trinkwon

1. Introduction

At Meeting #13 (Orlando), following some comments by the TG3 Chairman, this Member stated his view that the Chairman was mistaken in declaring that Doc [802.16.3c-01/29r1](#) had been adopted by the Task Group as a baseline Channel Model and therefore a subsequent motion to change the number of taps from 3 to 6 (as recommended by the Channel Model ad hoc group) required a 75% (rather than 50%) vote to pass. This Member was over-ruled by the Chairman and the 6-tap motion failed because of the 75% ruling. The Chairman's decisions on these matters during Meeting #13 was based on his recollection of the previous proceedings, plus a brief review and discussion of the appropriate Minutes etc during Meeting #13.

This current contribution is a more specific review of the previous proceedings and reveals the basis for the Chairman's misunderstanding. The Conclusions address the implications of these findings for the ongoing work of the Task Group and makes recommendations for remedial action. A final section addresses the question of "Why does it matter ..."

This contribution protests the decisions taken by the TG3 Chairman during Meeting #13 in respect of the status of Doc 29r1 and the decisions on Motions 4 and 5 during the Meeting. The TG3 Chairman is hereby requested to rescind his earlier declarations and let Doc 29r1 stand as a Working Document pending the release / approval of 29r2 (or later) and that the channel Model should include a mandatory six taps, as voted at Meeting #13 with a simple majority.

2. Meeting #11 (Ottawa)

Reference: [802.16.3-01/04](#) IEEE 802.16.3 Session #11 Minutes

“ In this session, the following contribution was presented by Vinko Erceg as a result of the channel model ad hoc group.

Contribution [802.16.3c-01/29](#) Channel Models for Fixed Wireless Applications (V.Erceg,et al.,01/01/22)

In addition, the following contribution was presented by Amir Sarajendini regarding some comments on the above channel model proposal.

Contribution [802.16c-01/26](#) Issues with previously proposed channel models for Broadband Fixed Wireless Applications (Amir Sarajendini,Phil Kelly,Dale Branlund,Randall Schwartz,01/01/19) “

[DBT Comment : The Channel Model ad hoc group was asked to address the differences between the two contributions and reported back later in the week, as below]

“ Vinko Erceg presented the results of the channel model ad hoc group. Here are a few of the changes that will be provided in detail in contribution 802.16.3c-01/29r1:

- Doppler frequency 0.4 and 2 Hz
- Tap delays (0-20 microseconds)and powers
- Proposed changes
 - Base Station Antenna Height 30m (vs 20m)
 - CPE Antenna Height 6.5m (3m before)
 - K-factors changes

Motion 7 David Trinkwon to accept the changes discussed in Vinko 's presentation as it stands.

Motion 7 Passes by unanimous voice vote.

There will be an updated version of this document with numbers by mid February.”

[DBT Comment :

- a) The Minutes do not capture all the proposed changes and details which were presented by Vinko.*
- b) There is no copy currently on record of Vinko's presentation of the ad hoc Group's conclusions*
- c) Vinko's verbal presentation included the fact that it would be necessary for Vinko, Amir and Stanford to meet (in California) to refine the proposed changes for inclusion in the proposed revision*
- d) The vote to accept the proposed changes was therefore contingent upon the satisfactory resolution of details at the proposed (California) follow-up meeting and document revision*
- e) There was no vote on the actual 29r1 document at the meeting, because it hadn't yet been created.]*

Reference : [802.16.3-01/03](#) IEEE 802.16.3 Session #11 Closing Report

“ Adopted 802.16.3c-01/29r1 as a baseline channel model for purposes of evaluating future PHY candidates/options “

[DBT Comment : This conclusion assumed that the details would be completely / correctly resolved at the follow-up meeting and correctly incorporated into the proposed document revision, to be available in mid-February. Document 29r2 was never actually presented or reviewed by TG3 during Meeting #11]

3. Meeting #12 (Hilton Head Island)

Reference : [802.16.3-01/10](#) IEEE 802.16 TG3 Session #12 Minutes

“ Channel Model

An update was made to the channel model by Vinko Erceg in document 29r1 ”

[DBT Comment : Although not captured in the Minutes, Vinko was not available at Meeting #12 to present / discuss the 29r2 document. This Member plus Amir Sarajedini informed the TG3 Meeting that the 29r2 document had NOT fully or accurately incorporated all the changes approved at the previous Meeting, and that it would be necessary for the Channel Model ad hoc to meet again during Meeting #12 (and by phone/e-mail with Vinko) to finalize the matters. The TG3Chair agreed and asked this Member to lead the ad hoc discussions during Meeting #12 and report back later in the week (see below). This means that document 29r2 was never handed over to the Task Group by the Channel Model ad hoc, and no vote was taken to adopt it in its published form (as opposed to the vote in Meeting #11 to adopt it In its proposed / intended form)].

“ Channel Model Adhoc Update

David Trinkwon gave an update on the channel model adhoc meeting. There were a number of comments that are still under review of the Adhoc group.”

[DBT Comment : In my update, I presented / described a draft 29r2 document which included proposed changes (to 29r1) which I had e-mailed to Vinko and discussed with him by phone. This included additional items requested by the ad hoc during the week, including the need to include more than three taps to adequately cover the nature of non-LOS deployments seen as critical to the TG3 markets.

The draft 29r2 document was NOT distributed at (or after) the meeting, anticipating that Vinko would finalize it and publish it “in a week or two” in the normal way. A copy of the draft 29r2 presented at Meeting #12 is attached to this Contribution.

This means that at the end of Meeting #12, there was NO Channel Model document (29 or 29r1) which had been formally / actually adopted by the Task Group. The work was still in progress within the Channel Model ad hoc, as noted in the draft 29r2 document.]

Reference : [802.16.3-01/11](#) IEEE 802.16 TG3 Session #12 Closing Report

“ The 802.16.3c-01/29r1 baseline RF channel model was updated to Rev 2. Some parameter tweaking is still needed. Conference call to be held next week and document completed. Source code of the tap model will be made available by Stanford ”

[DBT Comment : With hindsight, this Closing Report by the TG3 Chairman reveals that he believed that document 29r1 had been adopted / approved as a “baseline RF channel model” whereas this Member believes (as noted above) that the document was still with the ad hoc group as work in progress, anticipating the finalization of 29r2 in “a week or two”]

4. Meeting #13 (Orlando)

Reference : [802.16.3-01/19](#) IEEE 802.16 TG3 Session #13 Minutes

“ Channel Model

Channel Model group will meet at 3:00pm on Tuesday May 15, 2001

The following contribution was presented to the group.

Contribution 802.16.3c-01/53 Simulating the SUI Channel Models (Daniel S. Baum, 01/04/11) ”

“ Channel Model

There was a discussion in the meeting as to whether or not the channel model was accepted as a baseline document within the task group. After further review, Brian Kiernan decided that the document 802.16.3c-01/29r1 is the baseline for the channel model. The adhoc group made some updates to the document. It will be issued next week as 802.16.3c-01/29r2.

Motion 4 Walt Roehr - To approve the change to 6 taps from 3 taps in the channel model 802.16.3c-01/29r1 2nd Rick Baugh

Call the question Anader, 2nd Zion Hadad. Question is called 33-1.

Motion 4 fails 23-14. The baseline remains 3 taps.

Motion 5 Marianne Goldhammer To provide 6 taps as an option to the channel model contribution. 2nd David Trinkwon. Chairman directed that this motion is unnecessary because the adhoc could include this in the document at its own volition.”

[DBT Comment : Motion 4 failed because of the Chairman’s declaration of the 75% rule, based on his belief that Doc 29r1 had previously been approved / adopted by TG3 as a baseline channel model. The vote was 23/37= 62% in favor of the Motion and therefore would have passed under a 50% “working document” rule.]

Reference : [802.16.3-01/20](#) IEEE 802.16 TG3 Session #13 Closing Report

“ The 802.16.3c-01/29r1 baseline RF channel model was revised by the AD Hoc. Rev 2 of the document is to be issued next week. The Task Group decided that the mandatory model would consist of the 3 taps already specified in 29r1. The Rev 2 document will include 6 taps as an option.”

[DBT Comment : This statement in the TG3 Final Report of Meeting #13 continues to reflect the Chairman’s (mis)understanding of the status of Doc 29r1.]

5. Conclusions & Recommendations

- 1) Doc 802.16.3-01/29 was never adopted by TG3 as a baseline channel model
- 2) Doc 802.16.3-01/29r1 was never adopted by TG3 as a baseline channel model ***in its published form.*** Arguably, it was adopted at Meeting #11 (Ottawa) in ***its proposed / intended form*** but this proposal / intention was never completed, as advised when the document was submitted (without further vote and without prior consideration by the Channel Model ad hoc group) at Meeting #12 (Hilton Head). The changes intended to be included in 29r1 are not currently on record within 802.16
- 3) Based on Conclusions (1) and (2) there is currently NO baseline channel model (document) reviewed / adopted / approved by TG3. Doc 29r1 is still a working document, being updated by the ad hoc group.
- 4) We are currently awaiting a new document 802.16.3-01/29r2 (or later) to be published by the Channel Model ad hoc group for consideration by TG3. Under current directions, this would include more than three taps.
- 5) Based on Conclusions (3) and (4), the Motion at Meeting #13 (Orlando) to include more than three taps should have ***passed*** under the 50% rule (as a working document), and became binding on the TG3 channel model.
- 6) Notwithstanding Conclusion (5) (and noting the Chairman's direction at Meeting#13 that the Channel Model ad hoc group should include more than three taps as an option within the proposed 29r2 document) the intent of the ad hoc (at Hilton Head) was that this "option" should be obligatory for NLOS evaluations. The three tap model might suffice for LOS evaluations, but on the other hand, the Functional Requirements Document (FRD) makes NLOS operation a Mandatory Requirement for the TG3 Standard.
- 7) Based on Conclusions (5) and (6) above, the TG3 Channel Model ***must*** include more than three taps, at least for NLOS evaluations (which are themselves mandatory under the FRD). Vinko has proposed (verbally) three main taps (at non-regular spacings) with three additional taps "alongside" the main taps to represent the local clutter near the receiver (e.g. foliage) which acts on each of the main or reflected paths.

6. Why Does It Matter ...

- a) The integrity of the IEEE-SA and IEEE 802 Standards development process, and the careful / correct traceability of significant decisions is a valuable and essential requirement of the TG3 activity.
- b) An approved Channel Model (along with Traffic Model, Functional Requirements and certain other Key Characteristics) is an essential technical element for the evaluation of PHY and MAC proposals, options and techniques, and ultimately for the characterization of the performance of the air interface when incorporated into systems and deployed networks further along in the finalization or adoption of the Standard
- c) NLOS operation is an essential Requirement of the TG3 Air Interface, and needs to be properly addressed within the Channel Model if the Standard is to be relevant to the BWA Vendor and Service Provider industry.

ATTACHMENT

DRAFT 802.16.3/29r2 PRESENTED AT MEETING #12 (Hilton Head)

Project	IEEE 802.16 Broadband Wireless Access Working Group < http://ieee802.org/16 >	
Title	Channel Models for Fixed Wireless Applications (final 802.16.3 ad hoc version)	
Date	2001-02-23	
Submitted		
Source(s)	V. Erceg, Iospan Wireless Inc., USA Voice: 408-232-7551, verceg@iospanwireless.com K.V. S. Hari, S USA M.S. Smith, N D.S. Baum, Sta K.P. Sheikh, S C. Tappenden, J.M. Costa, No C. Bushue, Spr A. Sarajedini, R. Schwartz, I D. Branlund, B	<p style="text-align: center;">Draft IEEE802.16.3c-01/29r2</p> <p style="text-align: center;">From ad hoc meeting (HHI)</p> <p style="text-align: center;">14th March 2001</p> <p style="text-align: center;">Amir Sarajedini Tal Kaitz Sean Sonander David Trinkwon Dale Branlund Avi Freedman Bob Heise</p>
Re:	Call for Contrib September 15, This responds t	casals@stanford.edu erceg@stanford.edu smith@stanford.edu sheikh@stanford.edu tappenden@stanford.edu costa@stanford.edu bushue@stanford.edu sarajedini@stanford.edu rschwartz@stanford.edu branlund@stanford.edu
Abstract	This document fixed wireless applications.	channel Models, dated nel models suitable for
Purpose	This is for use by the Task Group to evaluate air interface performance	
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	<p>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), including patent applications, if there is technical justification in the opinion of the standards-developing committee and provided the IEEE receives assurance from the patent holder that it will license applicants under reasonable terms and conditions for the purpose of implementing the standard."</p> <p>Early disclosure to the Working Group of patent information that might be relevant to the standard is essential to reduce the possibility for delays in the development process and increase the likelihood that the draft publication will be approved for publication. Please notify the Chair <mailto:r.b.marks@ieee.org> as early as possible, in written or electronic form, of any patents (granted or under application) that may cover technology that is under consideration by or has been approved by IEEE 802.16. The Chair will disclose this notification via the IEEE 802.16 web site <http://ieee802.org/16/ipr/patents/notices>.</p>	

Channel Models for Fixed Wireless Applications

Note : Need to add an appendix with Stanford Source Code listings etc for the model.

Background

An important requirement for assessing technology for Broadband Fixed Wireless Applications is to have an accurate description of the wireless channel. Channel models are heavily dependent upon the radio architecture. For example, in first generation systems, a super-cell or “single-stick” architecture is used where the Base Station (BTS) and the subscriber station are in Line-of-Sight (LOS) condition and the system uses a single cell with no co-channel interference. For second generation systems a scalable multi-cell architecture with Non-Line-of-Sight (NLOS) conditions becomes necessary. In this document a set of propagation models applicable to the multi-cell architecture is presented. Typically, the scenario is as follows:

- Cells are < 10 km in radius, variety of terrain and tree density types
- Under-the-eave/window or rooftop installed directional antennas (2 – 10 m) at the receiver
- 15 - 40 m BTS antennas
- High cell coverage requirement (80-90%)

The wireless channel is characterized by:

- Path loss (including shadowing)
- Multipath delay spread
- Fading characteristics
- Doppler spread
- Co-channel and adjacent channel interference

It is to be noted that these parameters are random and only a statistical characterization is possible. Typically, the mean and variance of parameters are specified.

The above propagation model parameters depend upon terrain, tree density, antenna height and beamwidth, wind speed, and season (time of the year).

This submission combines and elaborates on contributions [7], [8], and [16] which were presented at the IEEE 802.16.3 meeting in Tampa, FL, on November 7, 2000.

Suburban Path Loss Model

The most widely used path loss model for signal strength prediction and simulation in macrocellular environments is the Hata-Okumura model [1,2]. This model is valid for the 500-1500 MHz frequency range, receiver distances greater than 1 km from the base station, and base station antenna heights greater than 30 m. There exists an elaboration on the Hata-Okumura model that extends the frequency range up to 2000 MHz [3]. It was found that these models are not suitable for lower base station antenna heights, and hilly or moderate-to-heavy wooded terrain. To correct for these limitations, we propose a model presented in [4]. The model covers three most common terrain categories found across the United States. However, other sub-categories and different terrain types can be found around the world.

The maximum path loss category is hilly terrain with moderate-to-heavy tree densities (Category A). The minimum path loss category is mostly flat terrain with light tree densities (Category C). Intermediate path loss condition is captured in Category B. The extensive experimental data was collected by AT&T Wireless Services across the United States in 95 existing macrocells at 1.9 GHz. For a given close-in distance d_0 , the median path loss (PL in dB) is given by

$$PL = A + 10 \gamma \log_{10} (d/d_0) + s \text{ for } d > d_0,$$

where $A = 20 \log_{10}(4 \pi d_0 / \lambda)$ (λ being the wavelength in m), γ is the path-loss exponent with $\gamma = (a - b h_b + c / h_b)$ for h_b between 10 m and 80 m (h_b is the height of the base station in m), $d_0 = 100\text{m}$ and a, b, c are constants dependent on the terrain category given in [4] and reproduced below.

Proposed Change : Gamma values below are too optimistic. More appropriate values are approx. 4.0, 3.5 and 3.0 for Terrain types A,B,C respectively. Need to revisit Greenstein's source data to determine better coefficients.

Model parameter	Terrain Type A	Terrain Type B	Terrain Type C
a	4.6	4	3.6
b	0.0075	0.0065	0.005
c	12.6	17.1	20

The shadowing effect is represented by s , which follows lognormal distribution. The typical value of the standard deviation for s is between 8.2 and 10.6 dB, depending on the terrain/tree density type [4].

Receive Antenna Height and Frequency Correction Terms

The above path loss model is based on published literature for frequencies close to 2 GHz and for receive antenna heights close to 2 m. In order to use the model for other frequencies and for receive antenna heights between 2 m and 10 m, correction terms have to be included. The path loss model (in dB) with the correction terms would be

$$PL_{\text{modified}} = PL + \Delta PL_f + \Delta PL_h$$

where PL is the path loss given in [4], ΔPL_f (in dB) is the frequency correction term [5,6] given by

$$\Delta PL_f = 6 \log (f / 2000)$$

where f is the frequency in MHz, and ΔPL_h (in dB) is the receive antenna height correction term given by

$$\Delta PL_h = - 10.8 \log (h / 2); \quad \text{for Categories A and B [7]}$$

$$\Delta PL_h = - 20 \log (h / 2); \quad \text{for Category C [1]}$$

where h is the receive antenna height between 2 m and 10 m.

Urban (Alternative Flat Suburban) Path Loss Model

In [8], it was shown that the Cost 231 Walfish-Ikegami (W-I) model [9] matches extensive experimental data for flat suburban and urban areas with uniform building height. It has been also found that the model presented in the previous section for the Category C (flat terrain, light tree density) is in a good agreement with the Cost 231 W-I model for suburban areas, providing continuity between the two proposed models.

Figure 1. compares a number of published path loss models for suburban morphology with an empirical model based on drive tests in the Dallas-Fort Worth area [9]. The Cost 231 Walfisch-Ikegami model (see Appendix A) was used with the following parameter settings

Frequency = 1.9 GHz

Mobile Height = 2 m

Base Height = 30 m

Building spacing = 50 m

Street width = 30 m

Street orientation = 90°

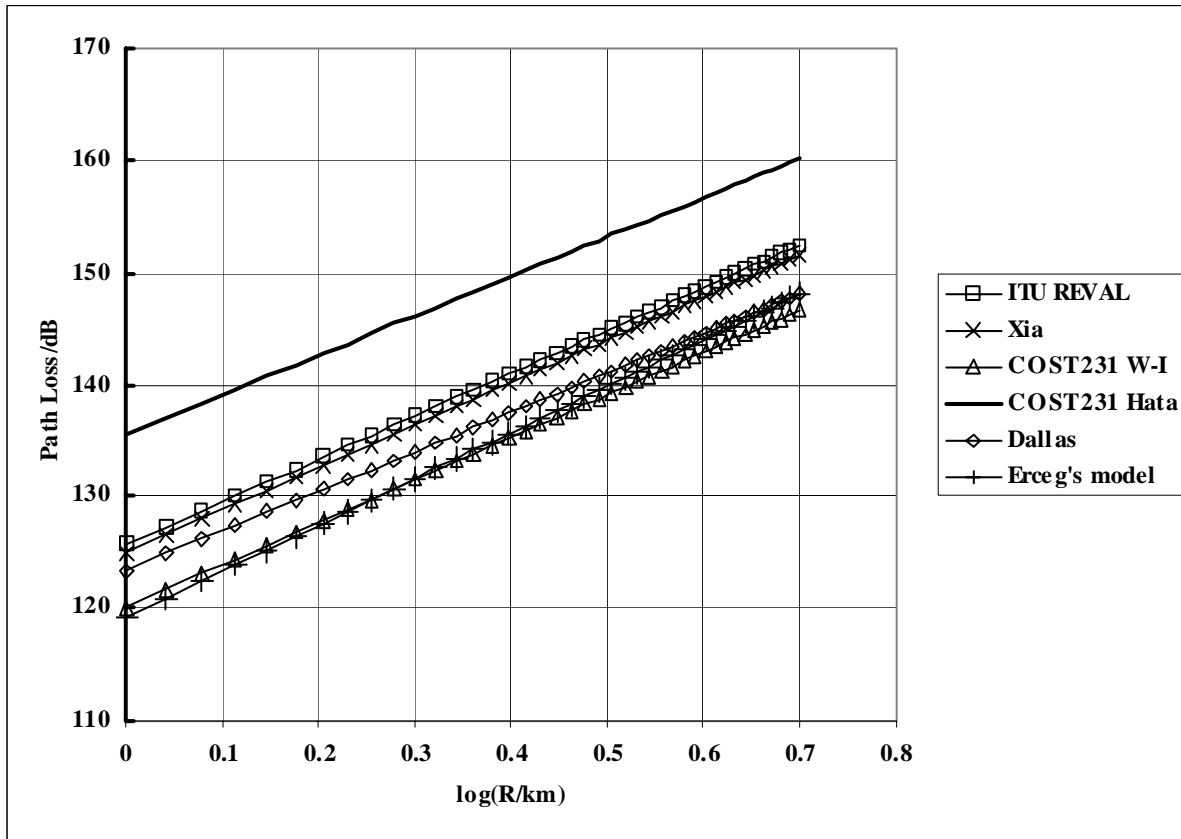


Figure 1. Comparison of suburban path loss models.

Note: COST 231 W-I, ITU Reval and Xia models all have a Hata correction term added for modeling the path loss variation with mobile height (see Appendix A).

It has also been found that the Cost 231 W-I model agrees well with measured results for urban areas, provided the appropriate building spacing and rooftop heights are used. It can therefore be used for both suburban and urban areas, and can allow for variations of these general categories between and within different countries.

Flat terrain models in conjunction with terrain diffraction modeling for hilly areas can be used in computer based propagation tools that use digital terrain databases. In [9] it was found that the weighting term for knife-edge diffraction should be set to 0.5 to minimize the lognormal standard deviation of the path loss.

Multipath Delay Profile

Due to the scattering environment, the channel has a multipath delay profile. For directive antennas, the delay profile can be represented by a spike-plus-exponential shape [10]. It is characterized by τ_{rms} (RMS delay spread of the entire delay profile) which is defined as

$$\tau_{\text{rms}}^2 = \sum_j P_j \tau_j^2 - (\tau_{\text{avg}})^2$$

where

$$\tau_{\text{avg}} = \sum_j P_j \tau_j,$$

τ_j is the delay of the j th delay component of the profile and P_j is given by

$$P_j = (\text{power in the } j \text{ th delay component}) / (\text{total power in all components}).$$

The delay profile has been modeled using a spike-plus-exponential shape given by

$$P(\tau) = A \delta(\tau) + B \sum_{i=0}^{\infty} \exp(-i\Delta\tau/\tau_0) \delta(\tau-i\Delta\tau),$$

where A , B and $\Delta\tau$ are experimentally determined.

RMS Delay Spread

A delay spread model was proposed in [11] based on a large body of published reports. It was found that the rms delay spread follows lognormal distribution and that the median of this distribution grows as some power of distance. The model was developed for rural, suburban, urban, and mountainous environments. The model is of the following form

$$\tau_{\text{rms}} = T_1 d^\epsilon y$$

where τ_{rms} is the rms delay spread, d is the distance in km, T_1 is the median value of τ_{rms} at $d = 1$ km, ϵ is an exponent that lies between 0.5-1.0, and y is a lognormal variate. The model parameters and their values can be found in Table III of [11]. However, these results are valid only for omnidirectional antennas. To account for antenna directivity, results reported in [10,12] can be used. It was shown that 32° and 10° directive antennas reduce the median τ_{rms} values for omnidirectional antennas by factors of 2.3 and 2.6, respectively.

Depending on the terrain, distances, antenna directivity and other factors, the rms delay spread values can span from very small values (tens of nanoseconds) to large values (microseconds).

Fading Characteristics

Fade Distribution, K-Factor

The narrow band received signal fading can be characterized by a Ricean distribution. The key parameter of this distribution is the K-factor, defined as the ratio of the “fixed” component power and the “scatter” component power. In [13], an empirical model was derived from a 1.9 GHz experimental data set collected in typical suburban environments for transmitter antenna heights of approximately 20 m. In [14], an excellent agreement with the model was reported using an independent set of experimental data collected in San Francisco Bay Area at 2.4 GHz and similar antenna heights. The K-factor distribution was found to be lognormal, with the median as a simple function of season, antenna height, antenna beamwidth, and distance. The standard deviation was found to be approximately 8 dB.

The model presented in [13] is as follows

$$K = F_s F_h F_b K_o d^y u$$

where

F_s is a seasonal factor, $F_s = 1.0$ in summer (leaves); 2.5 in winter (no leaves)

F_h is the receive antenna height factor, $F_h = (h/3)^{0.46}$; (h is the receive antenna height in meters)

F_b is the beamwidth factor, $F_b = (b/17)^{-0.62}$; (b in degrees)

K_o and γ are regression coefficients, $K_o = 10$; $\gamma = -0.5$

u is a lognormal variable which has zero mean and a std. deviation of 8.0 dB.

Using this model, one can observe that the K-factor decreases as the distance increases and as antenna beamwidth increases. We would like to determine K-factors that meet the requirement that 90% of all locations within a cell have to be services with 99.9% reliability. The calculation of K-factors for this scenario is rather complex since it also involves path loss, delay spread, antenna correlation (if applicable), specific modem characteristics, and other parameters that influence system performance. However, we can obtain an approximate value as follows: First we select 90% of the users with the highest K-factors over the cell area. Then we obtain the approximate value by selecting the minimum K-factor within the set. For a typical deployment scenario (see later section on SUI channel models) this value of K-factor can be close or equal to 0.

Proposed Change : For representative demodulator performance analysis purposes the K-factor should be modeled over a range of values (e.g. Monte Carlo using the formula above) rather than single spot values currently shown in the Stanford SUI tables.

Figure 2 shows fading cumulative distribution functions (CDFs) for various K factors. For example, for K = 0 dB (linear K = 1) a 30 dB fade occurs 10^{-3} of the time, very similar to a Rayleigh fading case (linear K = 0). For a K factor of 6 dB, the probability of a 30 dB fade drops to 10^{-4} . The significance of these fade probabilities depends on the system design, for example whether diversity or retransmission (ARQ) is provided, and the quality of service (QoS) being offered.

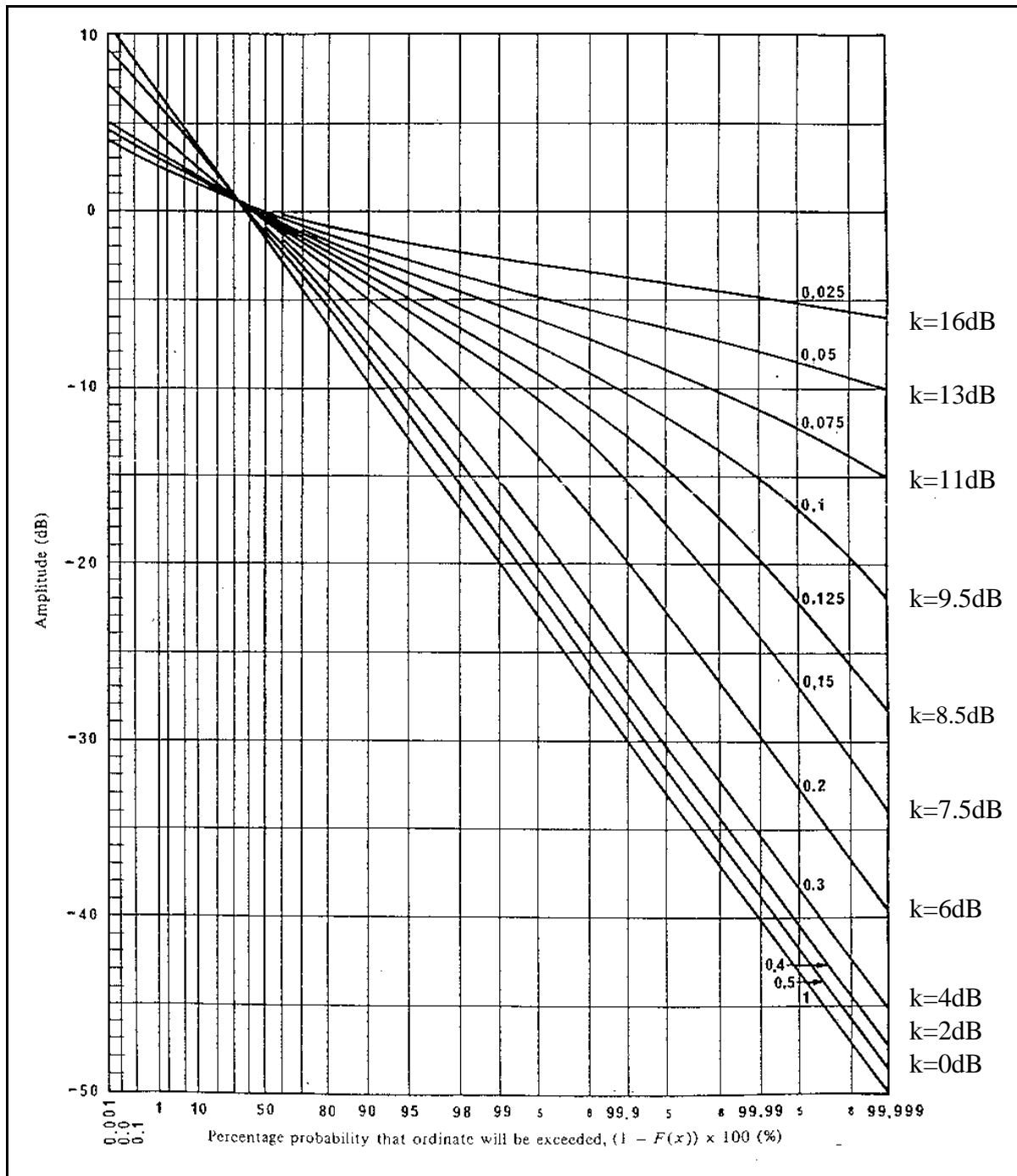


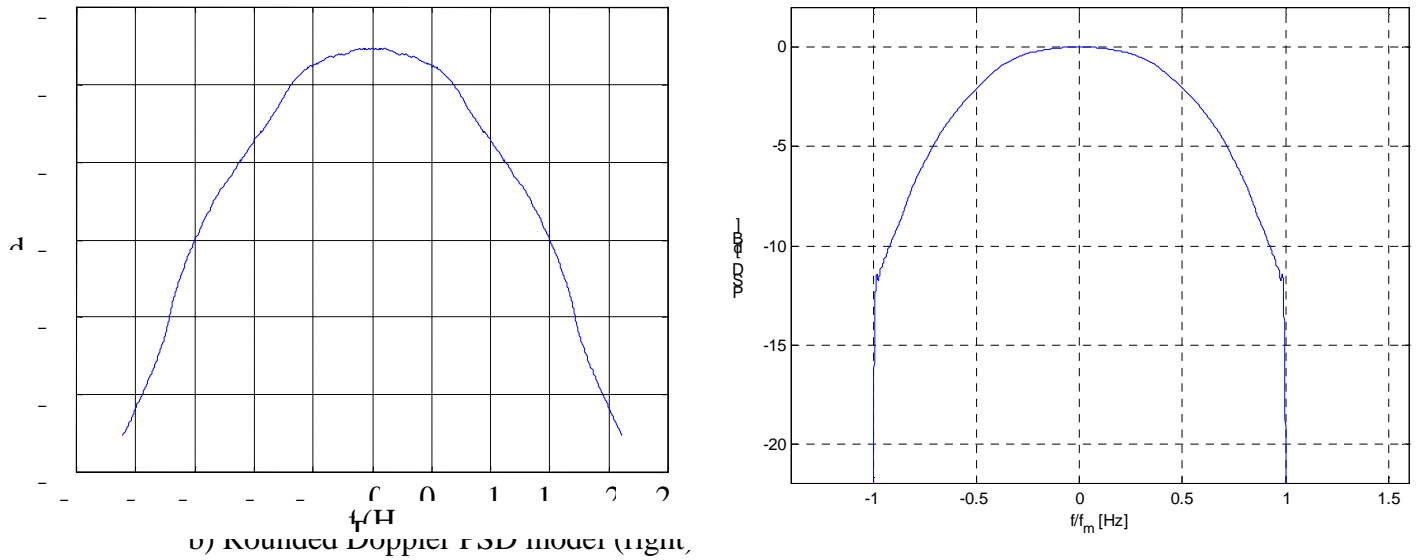
Figure 2. Ricean fading distributions.

Doppler Spectrum

Following the Ricean power spectral density (PSD) model in COST 207 [18], we define scatter and fixed Doppler spectrum components. In fixed wireless channels the Doppler PSD of the scatter (variable) component is mainly distributed around $f = 0$ Hz (Fig. 3a). The shape of the spectrum is therefore different than the classical Jake's spectrum for mobile channels. A rounded shape as shown in Fig. 3b can be used as a rough approximation to the Doppler PSD which has the advantage that it is readily available in most existing radio frequency (RF) channel simulators [17]. It can be approximated by:

$$S(f) = \begin{cases} 1 - 1.72f_0^2 + 0.785f_0^4 & |f_0| \leq 1 \\ 0 & |f_0| > 1 \end{cases} \quad \text{where } f_0 = \frac{f}{f_m}$$

The function is parameterized by a maximum Doppler frequency f_m . Alternatively, the -3dB point can be used as a parameter, where $f_{-3\text{dB}}$ can be related to f_m using the above equation. Measurements at 2.5 GHz center frequency show maximum $f_{-3\text{dB}}$ values of about 2 Hz. A better approximation of fixed wireless PSD shapes are close to exponential functions [14], however further research is needed in this area. Wind speed combined with foliage (trees), carrier frequency, and traffic influence the Doppler spectrum. The PSD function of the fixed component is a Dirac impulse at $f = 0$ Hz.



Spatial Characteristics, Coherence Distance

Coherence distance is the minimum distance between points in space for which the signals are mostly uncorrelated. This distance is > 0.5 wavelengths, depending on antenna beamwidth and angle of arrival distribution. At the BTS, it is common practice to use spacing of about 10 and 20 wavelengths for low-medium and high antenna heights, respectively (120° sector antennas).

Co-Channel Interference

C/I calculations use a path loss model that accounts for median path loss and lognormal fading, but not for ‘fast’ temporal fading. In the example shown in Fig. 4, a particular reuse pattern has been simulated with r^2 or r^3 signal strength distance dependency, with apparently better C/I for the latter. However, for non-LOS cases, temporal fading requires us to allow for a fade margin. The value of this margin depends on the Ricean K-factor of the fading, the QoS required and the use of any fade mitigation measures in the system. Two ways of allowing for the fade margin then arise; either the C/I cdf is shifted left as shown below or the C/I required for a non-fading channel is increased by the fade margin. For example, if QPSK requires a C/I of 14 dB without fading, this becomes 24 dB with a fade margin of 10 dB.

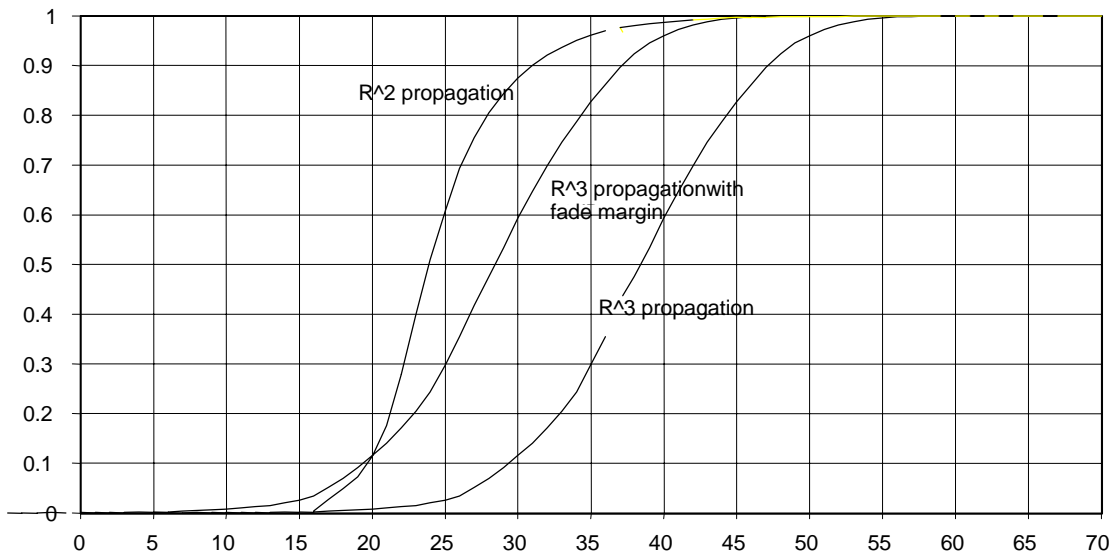


Figure 4. Effects of fade margin on C/I distributions.

Antenna Gain Reduction Factor

Proposed Change :

GRF rationale is not fully accepted as described. We propose to limit the GRF to the values mentioned in the Nortel contribution (e.g. 1-2 dB max). Also, as the antenna beamwidth reduces, the corresponding K-factor should improve to compensate.

The use of directional antennas needs to be considered carefully. The gain due to the directivity can be reduced because of the scattering. The effective gain is less than the actual gain. This has been characterized in [15] as *Antenna Gain Reduction Factor* (GRF). This factor should be considered in the link budget of a specific receiver antenna configuration.

Denote ΔG_{BW} as the Gain Reduction Factor. This parameter is a random quantity which dB value is Gaussian distributed (truncated at 0 dB) with a mean (μ_{grf}) and standard deviation (σ_{grf}) given by

$$\mu_{grf} = - (0.53 + 0.1 I) \ln (\beta/360) + (0.5 + 0.04 I) (\ln (\beta/360))^2$$

$$\sigma_{grf} = - (0.93 + 0.02 I) \ln (\beta/360),$$

β is the beamwidth in degrees

$I = 1$ for winter and $I = -1$ for summer

\ln is the natural logarithm.

In the link budget calculation, if G is the gain of the antenna (dB), the effective gain of the antenna equals $G - \Delta G_{BW}$. For example, if a 20-degree antenna is used, the mean value of ΔG_{BW} would be close to 7 dB.

In [12], a very good agreement was found with the model presented above, based on extensive measurements in a flat suburban area with base station antenna height of 43 m and receive antenna heights of 5.2, 10.4 and 16.5 m, and 10° receive antenna beamwidth. By comparing Figs. 5 and 6 in the paper, one can observe about 10 dB median GRF (difference between the directional and omnidirectional antenna median path loss) for the 5.2 m receive antenna height and distances 0.5-10 km. However, for the 10.4 and 16.5 receive antenna heights the difference (GRF) is smaller, about 7. More experimental data and analysis is desirable to describe more accurately the effects of different antenna heights and terrain types on the GRF values.

In system level simulations and link budget calculations for high cell coverage, the standard deviation of the GRF can also be accounted for. For a 20° antenna, the standard deviation σ_{grf} is approximately 3 dB. Furthermore, we can expect that the variable component of the GRF is correlated with the shadow fading lognormal random variable (more scattering, i.e. larger GRF, when shadow fading is present). In [8], a clear trend for the GRF to increase as the excess path loss over free space path loss increases was shown (see also Fig. 5 below). The correlation coefficient between GRF and excess path loss about median path loss (equivalent to shadow fading loss) was found to be 0.77. No significant distance dependency of the median GRF was found. (The correlation coefficient between GRF and distance was found to be 0.12.)

The combined shadow fading/GRF standard deviation σ_c can be calculated using the following formula

$$\sigma_c^2 = \sigma^2 + \sigma_{grf}^2 + 2 \rho \sigma \sigma_{grf}$$

where ρ is the correlation coefficient and σ is the standard deviation of the lognormal shadow fading random variable s . For $\sigma = 8$ dB and $\sigma_{grf} = 3$ dB the formula yields σ_c of 8.5 and 10.5 dB for $\rho = 0$ and $\rho = 0.77$, respectively. Larger standard deviation results in a larger path loss margin for the 90% cell coverage (approximately 0.3 dB for $\rho = 0$ and 1.5 dB for $\rho = 0.77$).

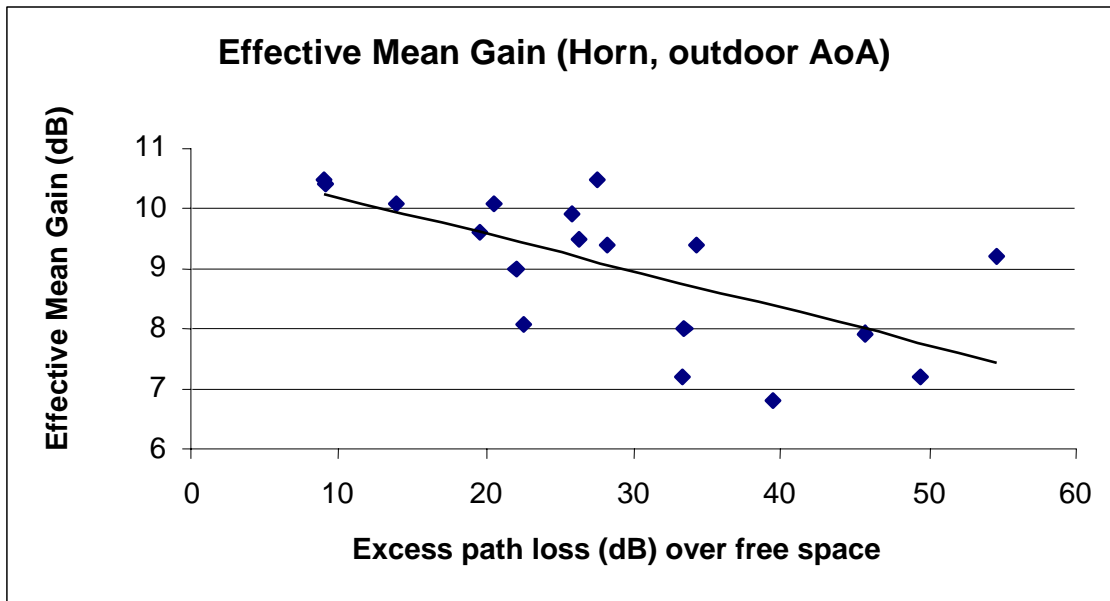


Figure 5. Effective mean (azimuth) gain for a 30-degree horn antenna.

For the results in Fig. 5, a BTS antenna height of 22 m was used, in a suburban area (Harlow, U.K.), in the summer. A 30° subscriber antenna was used, raised to gutter height as near as possible to houses being

examined. The antenna was rotated in 15 degree steps, and the effective gain calculated from the maximum signal compared to the average signal (signals averaged through any temporal fading). The peak gain was 10.4 dB (this only accounts for azimuthal directivity).

Multiple Antenna Channel Models (MIMO)

When multiple antennas are used at the transmitter and/or at the receiver, the relationships between transmitter and receiver antennas add further dimensions to the model. The channel can be characterized by a matrix.

Modified Stanford University Interim (SUI) Channel Models

Channel models described above provide the basis for specifying channels for a given scenario. It is obvious that there are many possible combinations of parameters to obtain such channel descriptions. A set of 6 typical channels were selected for the three terrain types that are typical of the continental US [4]. In this section we present SUI channel models that we modified to account for 30° directional antennas. These models can be used for simulations, design, development and testing of technologies suitable for fixed broadband wireless applications. The parameters were selected based upon statistical models described in previous sections.

Proposed Changes (Multipath Taps)

- a) Need to increase the number of multipath taps from 3 to 5,6 or 7 (without changing the delay spread)
- b) Replace scattering part of main (first) tap with exponential decay ($t_c=100-200\text{ns}$) to better model local reflections near the receiver
- c) Need Monte Carlo modeling for the placement of taps within the delay spread. Current taps are too regular.

The parametric view of the SUI channels is summarized in the following tables.

Terrain Type	SUI Channels
C	SUI-1, SUI-2
B	SUI-3, SUI-4
A	SUI-5, SUI-6

K-Factor: Low

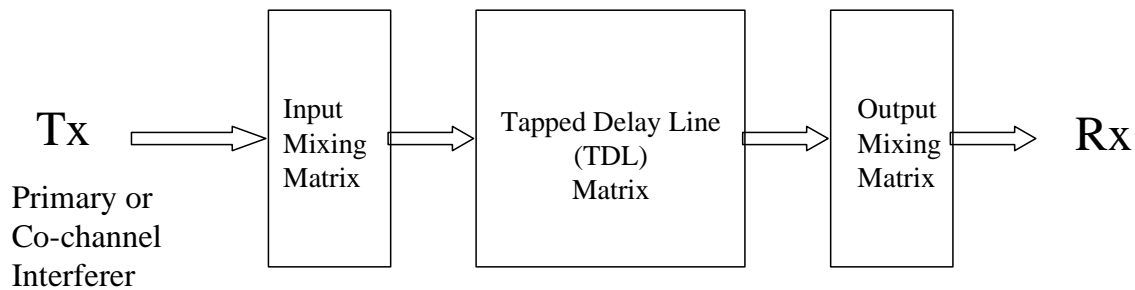
Doppler	Low delay spread	Moderate delay spread	High delay spread
Low	SUI-3		SUI-5
High		SUI-4	SUI-6

K-Factor: High

Doppler	Low delay spread	Moderate delay spread	High delay spread

Low	SUI-1,2		
High			

The generic structure for the SUI Channel model is given below



The above structure is general for Multiple Input Multiple Output (MIMO) channels and includes other configurations like Single Input Single Output (SISO) and Single Input Multiple Output (SIMO) as subsets. The SUI channel structure is the same for the primary and interfering signals.

Input Mixing Matrix: This part models correlation between input signals if multiple transmitting antennas are used.

Tapped Delay Line Matrix: This part models the multipath fading of the channel. The multipath fading is modeled as a tapped-delay line with 3 taps with non-uniform delays. The gain associated with each tap is characterized by a distribution (Ricean with a K-factor > 0 , or Rayleigh with K-factor = 0) and the maximum Doppler frequency.

Output Mixing Matrix: This part models the correlation between output signals if multiple receiving antennas are used.

Using the above general structure of the SUI Channel and assuming the following scenario, six SUI channels are constructed which are representative of the real channels.

Scenario for modified SUI channels:

- Cell size: 7 km
- BTS antenna height: 30 m
- Receive antenna height: 6 m
- BTS antenna beamwidth: 120°
- Receive Antenna Beamwidth: omnidirectional (360°) and 30° .
For a 30° antenna beamwidth, 2.3 times smaller RMS delay spread is used when compared to an omnidirectional antenna RMS delay spread [10]. Consequently, the 2nd tap power is attenuated additional 6 dB and the 3rd tap power is attenuated additional 12 dB (effect of antenna pattern, delays remain the same). For the omnidirectional receive antenna case, the tap delays and powers are consistent with the COST 207 delay profile models [18].
- Vertical Polarization only

- 90% cell coverage with 99.9% reliability at each location covered

For the above scenario, using the channel model, the following are the six specific SUI channels.

Notes:

- 1) The total channel gain is not normalized. Before using a SUI-X model, the specified normalization factors have to be added to each tap to arrive at 0dB total mean power (included in the tables).
- 2) The specified Doppler is the maximum frequency parameter (f_m) of the rounded spectrum, as described above.
- 3) The Gain Reduction Factor (GRF) is the total mean power reduction for a 30° antenna compared to an omni antenna. If 30° antennas are used the specified GRF should be added to the path loss. Note that this implies that all 3 taps are affected equally due to effects of local scattering.
- 4) K-factors have linear values, not dB values.

SUI – 1 Channel				
	Tap 1	Tap 2	Tap 3	Units
Delay	0	0.4	0.8	μs
Power (omni ant.)	0	-15	-20	dB
K Factor (omni ant.)	4	0	0	
Power (30° ant.)	0	-21	-32	dB
K Factor (30° ant.)	16	0	0	
Doppler	0.4	0.4	0.4	Hz
Antenna Correlation: $\rho_{ENV} = 0.7$		Terrain Type: C		
Gain Reduction Factor: GRF = 0 dB		Omni antenna: $\tau_{RMS} = 0.103 \mu s$, overall K = 3.3		
Normalization Factor: $F_{omni} = -0.1771$ dB, $F_{30^\circ} = -0.0371$ dB		30° antenna: $\tau_{RMS} = 0.041 \mu s$, overall K = 14.0		
SUI – 2 Channel				
	Tap 1	Tap 2	Tap 3	Units
Delay	0	0.5	1	μs
Power (omni ant.)	0	-12	-15	dB
K Factor (omni ant.)	2	0	0	
Power (30° ant.)	0	-18	-27	dB
K Factor (30° ant.)	8	0	0	
Doppler	0.2	0.2	0.2	Hz

Antenna Correlation: $\rho_{ENV} = 0.5$ Gain Reduction Factor: GRF = 2 dB Normalization Factor: $F_{omni} = -0.3930$ dB, $F_{30^\circ} = -0.0768$ dB	Terrain Type: C Omni antenna: $\tau_{RMS} = 0.200$ μ s, overall K = 1.6 30° antenna: $\tau_{RMS} = 0.076$ μ s, overall K = 6.9
--	---

SUI – 3 Channel				
	Tap 1	Tap 2	Tap 3	Units
Delay	0	0.5	1	μ s
Power (omni ant.)	0	-5	-10	dB
K Factor (omni ant.)	1	0	0	
Power (30° ant.)	0	-11	-22	dB
K Factor (30° ant.)	3	0	0	
Doppler	0.4	0.4	0.4	Hz
Antenna Correlation: $\rho_{ENV} = 0.4$ Gain Reduction Factor: GRF = 3 dB Normalization Factor: $F_{omni} = -1.5113$ dB, $F_{30^\circ} = -0.3573$ dB	Terrain Type: B Omni antenna: $\tau_{RMS} = 0.305$ μ s, overall K = 0.5 30° antenna: $\tau_{RMS} = 0.149$ μ s, overall K = 2.2			
SUI – 4 Channel				
	Tap 1	Tap 2	Tap 3	Units
Delay	0	2	4	μ s
Power (omni ant.)	0	-4	-8	dB
K Factor (omni ant.)	0	0	0	
Power (30° ant.)	0	-10	-20	dB
K Factor (30° ant.)	0	0	0	
Doppler	0.2	0.2	0.2	Hz
Antenna Correlation: $\rho_{ENV} = 0.3$ Gain Reduction Factor: GRF = 4 dB Normalization Factor: $F_{omni} = -1.9218$ dB, $F_{30^\circ} = -0.4532$ dB	Terrain Type: B Omni antenna: $\tau_{RMS} = 1.345$ μ s 30° antenna: $\tau_{RMS} = 0.677$ μ s			
SUI – 5 Channel				
	Tap 1	Tap 2	Tap 3	Units

Delay	0	5	10	μ s
Power (omni ant.)	0	-5	-10	dB
K Factor (omni ant.)	0	0	0	
Power (30° ant.)	0	-11	-22	dB
K Factor (30° ant.)	0	0	0	
Doppler	2	2	2	Hz
Antenna Correlation: $\rho_{ENV} = 0.3$		Terrain Type: A		
Gain Reduction Factor: GRF = 4 dB		Omni antenna: $\tau_{RMS} = 3.053 \mu$ s		
Normalization Factor: $F_{omni} = -1.5113$ dB, $F_{30^\circ} = -0.3573$ dB		30° antenna: $\tau_{RMS} = 1.493 \mu$ s		
SUI – 6 Channel				
	Tap 1	Tap 2	Tap 3	Units
Delay	0	14	20	μ s
Power (omni ant.)	0	-10	-14	dB
K Factor (omni ant.)	0	0	0	
Power (30° ant.)	0	-16	-26	dB
K Factor (30° ant.)	0	0	0	
Doppler	0.4	0.4	0.4	Hz
Antenna Correlation: $\rho_{ENV} = 0.3$		Terrain Type: A		
Gain Reduction Factor: GRF = 4 dB		Omni antenna: $\tau_{RMS} = 5.240 \mu$ s		
Normalization Factor: $F_{omni} = -0.5683$ dB, $F_{30^\circ} = -0.1184$ dB		30° antenna: $\tau_{RMS} = 2.370 \mu$ s		

Extension of Models to Other Frequencies

We expect that the proposed statistical models for delay spread, K-factor, and GRF can be “safely” used in the 1 – 4 GHz range (half and double frequency for which the models were derived). With appropriate frequency correction factors, path loss models can be also used in the extended frequency range [6]. However, the Doppler spectrum is a function of the center frequency and more work is required in this area.

Conclusion

The paper presents a set of channel models for fixed broadband wireless systems using macrocellular architecture. The path loss models and multipath fading models are presented. Based on these models six 3-tap channel models have been proposed which cover the diverse terrain types.

References

- [1] Y. Okumura, E. Ohmori, T. Kawano, and K. Fukua, "Field strength and its variability in UHF and VHF land-mobile radio service," *Rev. Elec. Commun. Lab.*, vol. 16, no. 9, 1968.
- [2] M. Hata, "Empirical formula for propagation loss in land mobile radio services," *IEEE Trans. Veh. Technol.*, vol. 29, pp. 317-325, Aug. 1980.
- [3] EURO-COST-231 Revision 2, "Urban transmission loss models for mobile radio in the 900 and 1800 MHz bands," Sept. 1991.
- [4] V. Erceg et. al, "An empirically based path loss model for wireless channels in suburban environments," *IEEE JSAC*, vol. 17, no. 7, July 1999, pp. 1205-1211.
- [5] T.-S. Chu and L.J. Greenstein, "A quantification of link budget differences between the cellular and PCS bands," *IEEE Trans. Veh. Technol.*, vol. 48, no. 1, January 1999, pp. 60-65.
- [6] W.C. Jakes and D.O. Reudink, "Comparison of mobile radio transmission at UHF and X-band," *IEEE Trans. Veh. Technol.*, vol. VT-16, pp. 10-13, Oct. 1967.
- [7] K.V. S. Hari, K.P. Sheikh, and C. Bushue, "Interim channel models for G2 MMDS fixed wireless applications," *IEEE 802.16.3c-00/49r2*
- [8] M.S. Smith and C. Tappenden, "Additional enhancements to interim channel models for G2 MMDS fixed wireless applications," *IEEE 802.16.3c-00/53*
- [9] M.S. Smith, J.E.J. Dalley, "A new methodology for deriving path loss models from cellular drive test data", *Proc. AP2000 Conference*, Davos, Switzerland, April 2000.
- [10] V. Erceg et.al, "A model for the multipath delay profile of fixed wireless channels," *IEEE JSAC*, vol. 17, no.3, March 1999, pp. 399-410.
- [11] L.J. Greenstein, V. Erceg, Y.S. Yeh, and M.V. Clark, "A new path-gain/delay-spread propagation model for digital cellular channels," *IEEE Trans. Veh. Technol.*, vol. 46, no. 2, May 1997.
- [12] J.W. Porter and J.A. Thweatt, "Microwave propagation characteristics in the MMDS frequency band," *ICC'2000 Conference Proceedings*, pp. 1578-1582.
- [13] L.J. Greenstein, S. Ghassemzadeh, V.Erceg, and D.G. Michelson, "Ricean K-factors in narrowband fixed wireless channels: Theory, experiments, and statistical models," *WPMC'99 Conference Proceedings*, Amsterdam, September 1999.
- [14] D.S. Baum et.al., "Measurements and characterization of broadband MIMO fixed wireless channels at 2.5 GHz", *Proceedings of ICPWC'2000*, Hyderabad, Dec. 2000.
- [15] L. J. Greenstein and V. Erceg, "Gain reductions due to scatter on wireless paths with directional antennas," *IEEE Communications Letters*, Vol. 3, No. 6, June 1999.
- [16] V. Erceg, "Channel models for broadband fixed wireless systems," *IEEE 802.16.3c-00/53*
- [17] TAS 4500 RF Channel Emulator, Operations Manual
- [18] "Digital Land Mobile Radio Communications - COST 207", Commission of the European Communities, Final Report, 14 March, 1984--13 September, 1988, Office for Official Publications of the European Communities, Luxembourg, 1989.

Appendix A
COST 231 WALFISCH-IKEGAMI MODEL

This model can be used for both urban and suburban environments. There are three terms which make up the model:

$$L_b = L_0 + L_{rts} + L_{msd}$$

L_0 = free space loss

L_{rts} = roof top to street diffraction

L_{msd} = multi - screen loss

free space loss :

$$L_0 = 32.4 + 20\log\left(\frac{R}{\text{km}}\right) + 20\log\left(\frac{f}{\text{MHz}}\right)$$

roof top to street diffraction

$$L_{rts} = -16.9 - 10\log\left(\frac{w}{m}\right) + 10\log\left(\frac{f}{\text{MHz}}\right) + 20\log\left(\frac{\Delta h_{\text{mobile}}}{m}\right) + L_{\text{ori}} \quad \text{for } h_{\text{roof}} > h_{\text{mobile}}$$

= 0

for $L_{rts} < 0$

where

$$L_{\text{ori}} = -10 + 0.354 \frac{\varphi}{\text{deg}} \quad \text{for } 0 \leq \varphi \leq 35 \text{ deg}$$

$$= 2.5 + 0.075 \left(\frac{\varphi}{\text{deg}} - 35 \right) \quad \text{for } 35 \leq \varphi \leq 55 \text{ deg}$$

$$= 4.0 - 0.114 \left(\frac{\varphi}{\text{deg}} - 55 \right) \quad \text{for } 55 \leq \varphi \leq 90 \text{ deg}$$

and $\Delta h_{\text{mobile}} = h_{\text{roof}} - h_{\text{mobile}}$

The multi-screen diffraction loss

$$L_{msd} = L_{beh} + k_a + k_d \log\left(\frac{R}{\text{km}}\right) + k_f \log\left(\frac{f}{\text{MHz}}\right) - 9 \log\left(\frac{b}{m}\right)$$

$$= 0 \quad \text{for } L_{msd} < 0$$

$$L_{beh} = -18 \text{Log}\left(1 + \frac{\Delta h_{base}}{m}\right) \quad \text{for } h_{base} > h_{roof}$$

$$= 0 \quad \text{for } h_{base} \leq h_{roof}$$

$$k_a = 54 \quad \text{for } h_{base} > h_{roof}$$

$$= 54 - 0.8 \frac{\Delta h_{base}}{m} \quad \text{for } R \geq 0.5 \text{km and } h_{base} \leq h_{roof}$$

$$= 54 - 0.8 \frac{\Delta h_{base}}{m} \frac{R/\text{km}}{0.5} \quad \text{for } R < 0.5 \text{km and } h_{base} \leq h_{roof}$$

$$k_d = 18 \quad \text{for } h_{base} > h_{roof}$$

$$= 18 - 15 \frac{\Delta h_{base}}{h_{roof}} \quad \text{for } h_{base} \leq h_{roof}$$

$$k_f = -4 + 0.7 \left(\frac{f/\text{MHz}}{925} - 1 \right) \quad \text{for medium sized cities and suburban centres with moderate tree density.}$$

$$= -4 + 1.5 \left(\frac{f/\text{MHz}}{925} - 1 \right) \quad \text{for metropolitan centres.}$$

Note that $\Delta h_{base} = h_{base} - h_{roof}$

This model is limited by the following parameter ranges:

f	:	800.....2,000MHz,
h base	:	4.....50m,
h mobile:		1....3m
R	:	0.02.....5km

Hata correction term in COST 231 W-I model to account for mobile height variation

Comparison with some measurements made by Nortel in 1996 for a base antenna deployed in Central London well above the average rooftop height revealed that the COST 231 W-I model did not correctly model the variation of path loss with mobile height. In contrast, the COST 231 Hata model did show the correct trend, which is not surprising, since it is an empirically derived model based on the very extensive measurement data of Okumura. Consequently, a Hata correction term has been added to the COST 231 W-I model to account for path loss variations with mobile height. However, the Hata correction term simply added to the COST 231 W-I model results in a path loss variation with mobile height that is greater than that of the Hata model. This is because it adds to the variation that exists already in the COST 231 W-I model. In the COST 231 W-I model the path loss variation due to mobile height is governed by the following term:

$$20\log(h_{roof} - h_{mobile})$$

Here the Hata correction term is made to be zero at a mobile height of 3.5m. Retaining this, a new correction term is proposed as follows :

$$a(h_m) = - \left[\left(1.1\log\left(\frac{f}{MHz}\right) - 0.7 \right) h_{mobile} - \left(1.56\log\left(\frac{f}{MHz}\right) - A \right) + 20\log(h_{roof} - h_{mobile}) - 20\log(h_{roof} - 3.5) \right] \text{ where}$$

$$A = 1.56\log\left(\frac{f}{MHz}\right) - \left(1.1\log\left(\frac{f}{MHz}\right) - 0.7 \right) 3.5$$

The term $a(h_m)$ is the correction factor and ensures that the COST 231 W-I model has the same path loss variation with mobile height as the COST 231 Hata model.