Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Interim Channel Models for G2 MMDS Fixed Wireless Applications**
Date Submitted	**2000-11-15**
Source(s)	K. V. S. Hari Stanford University Department of EE Packard #223 Stanford University Stanford, CA 94305-9510 Voice: 650-724-3640 Fax: 650 723 8473 mailto: hari@rascals.stanford.edu Carl Bushue Sprint 2330 Shawnee Mission Pkwy. Westwood, KS 66205 Voice: 913-624-3090 Fax: 913-624-7890 mailto: carl.bushue@mail.sprint.com
Re:	Call for Contributions: Session #10 Topic: Traffic, Deployment, and Channel Models, dated September 15, 2000 (IEEE 802163-00/13) This responds to the second item: Channel propagation model
Abstract	This document provides a proposed channel model
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	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." 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>.

Interim Channel Models for G2 MMDS Fixed Wireless Applications

K. V. S. Hari, Stanford University

Carl Bushue, SPRINT

Background

An important requirement for assessing technology for Broadband Fixed Wireless Applications is to have an accurate description of the wireless channel. Unlike the copper 'wire', the wireless channel has many impairments. This document provides the interim channel model for the scenario relevant to G2 MMDS.

Scenario

The channel model is heavily dependent upon the radio architecture (for example, in G1 MMDS, a super-cell architecture is used where the BTS and the CPE are in LOS condition and the system uses a single cell with no co-channel interference). For G2 MMDS, a scalable multi-cell architecture with NLOS conditions becomes necessary. Typically,

- Cells are around 4 miles in radius, reuse not poorer than 3.
- Under-the-eave/window directional antennas (8-15ft) at the CPE.
- 50-120ft BTS antennas.

The radio link in such a scenario would have the following impairments

- Higher Path Loss (as compared to super cell architecture)
- Fading: Macroscopic (due to shadowing) and Microscopic (due to multipath).
- Co-channel and Adjacent channel Interference
- More severe multipath delay spread
- Doppler spread

The wireless channel is characterized by

- Path Loss Model (including shadow margin)
- Multipath Delay Spread
- Temporal Fading characteristics (K-factor, Average duration of fade, Level-Crossing rates)

- Spatial Fading characteristics (K-factor, coherence distance)

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: The terrain categories encountered in suburban environments are [1]
    - Type A: Hilly/moderate-to-heavy tree density
    - Type B: Hilly/Light tree density or flat/moderate-to-heavy density
    - Type C: Flat/Light tree density

  For light to moderate urban areas, Type A can be used.
- Wind speed
- Season /Time of the year
- Traffic density and proximity
- Height and beamwidth of CPE and BTS antennas

Path Loss Model

Earlier cellular mobile path loss models (Hata, COST 231 Hata) are valid for base station heights greater than 100 ft and for distances more than 1 km and are not suitable for G2 MMDS deployment. The path loss model relevant to G2 MMDS, based on an extensive measurement campaign for fixed wireless applications is given in [1]. For a given close-in distance d_0, the median path loss (PL in dB) is given by

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

where $A = 20\log_{10}(4\,\pi\,d_0/\lambda)$ (λ being the wavelength in m), γ, the path-loss exponent with $\gamma = (a - b\,h_b + c / h_b)$ for h_b between 10m and 80m (h_b is the height of the base station in m), d_0 is chosen as 100m and a,b,c are constants dependent on the terrain category given in [1] and reproduced below.

Model parameter	Terrain Type A	Terrain Type B	Terrain Type B
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 has been found to be lognormal in distribution [1]. The typical value of the standard deviation for s is between **8** and **10 dB** [1].

Correction terms

The above path loss model is based on published literature for frequencies close to 2 GHz and for CPE antenna heights close to 2 m. In order to use the model for the MMDS band and for CPE antenna heights between 2m and 8m, correction terms have to be included. The path loss model (in dB) with the correction terms would be

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

where PL is the path loss given in [1], $\Delta\,PL_f$ (in dB) is the frequency correction term [2] given by

$$\Delta\,PL_f = 6\log(f / 2000),$$ f being the frequency in MHz,

and $\Delta\,PL_h$ (in dB) is the CPE height correction term given by

$$\Delta\,PL_h = -10.8\log(h / 2),$$ h being the CPE height between 2m and 8m.

For example, for f = 2500 MHz, $\Delta\,PL_f = 0.55$ dB and for a CPE height of 4m,

$\Delta\,PL_h = -3.25$ dB.

Multipath Delay Spread

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 [3]. It is characterized by τ_{rms} (RMS delay spread of the entire delay profile which is defined as

$$\tau^2_{rms} = \Sigma_j \; P_j \, \tau^2_j - (\tau_{avg})^2$$

where $\tau_{avg} = \Sigma_j P_j \tau_j$,

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

P_j = (power in the j th delay component) / (total power in all components).

The delay profile has been modeled [3] 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 [3].

The typical value of the RMS delay spread in the wireless channel based on [3,4] and preliminary measurements at Stanford University, is in the range of **0.1** to **5 µs.**

K-factor

The K-factor is defined as

K = (power in the fixed component) / (power in the variable component)

The NLOS component is typically Rayleigh. For example, a K-factor of 0 implies that the channel is Rayleigh. For larger values of K, the channel is said to be Ricean.

The model for the K-factor [5] is given as

$$K = F_s F_h F_b K_o d^{\gamma} u$$

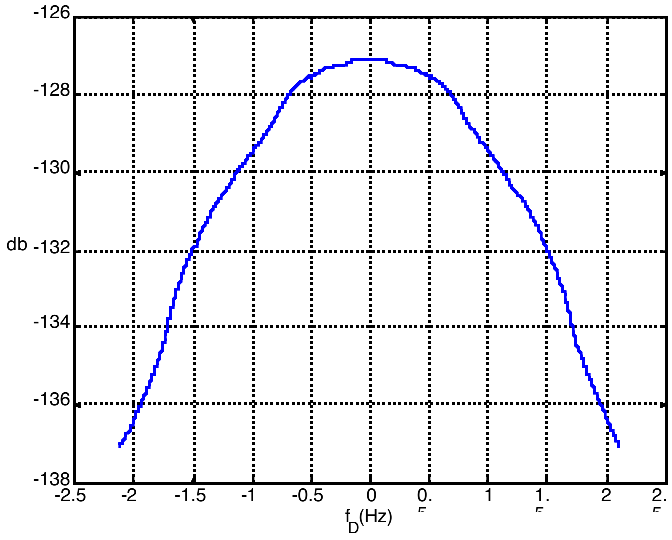
where F_s is a seasonal factor, F_s =1.0; summer (leaves), 2.5; winter (no leaves))
F_h is the CPE height factor, $F_h = (h/3)^{0.46}$ (h is the CPE height in meters)
F_b is the beamwidth factor, $F_b = (b/17)^{-0.62}$; (b in degrees)
K_o and γ are regression coefficients, $K_o = 10; \gamma = -0.5$
u is a lognormal variable which has zero mean and a std. deviation of 8.0 dB.
Using this model, it is very clear that the K-factor decreases as the distance increases and as antenna beamwidth increases. Using the value of the standard deviation it is easy to determine that a K-factor of 0 must be assumed for a 99.9% link reliability.

Average duration of fade (ADF): The average duration of fade is the total duration of the signal below a level divided by the number of times the signal crosses the level. The level is usually chosen with respect to the mean signal power level. Values could be as high as **0.1 s** for a level which is 10 dB below the mean signal power level.

Level Crossing Rates(LCR): LCR is the number of times the signal crosses a given level per second. Values could be as high as **2 per sec** for a level, which is 10 dB below the mean signal power level.

Doppler Spectrum

A related parameter to ADF and LCR is the **Doppler Spectrum.** The maximum Doppler frequency observed is about **2 Hz**. The shape of the spectrum is different than the classical Jakes' spectrum. Measurements have indicated a 'rounded' shape as shown below. Wind speed and traffic density influence the maximum doppler frequency.



Spatial Fading Characteristics

Coherence distance: The minimum distance between points in space where the signals received in time are uncorrelated. This distance is about 0.5 wavelength for CPE antennas and about 10 to 20 wavelengths for medium and high BTS antenna heights.

Co-Channel Interference

This depends on the frequency reuse plan. Typically, for a path loss exponent of 4, a reuse factor of 3 and 2 interferers, for 90% coverage reliability, the C/I is close to **10 dB.**

Antenna Gain Reduction Factor

The use of directional antennas in the G2 MMDS deployment scenario 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 [6] as *Antenna Gain Reduction Factor*. This factor should be considered in the link budget of a specific BTS, CPE configuration.

Denote ΔG_{BW} as the Gain Reduction Factor. This parameter is a random quantity which is Gaussian distributed with a mean (μ) and standard deviation (σ) given by

$\mu = -(0.53 + 0.1\ I) \ln(\beta/360) + (0.5 + 0.04\ I)(\ln(\beta/360))^2$

$\sigma = -(0.93 + 0.02\ I) \ln(\beta/360)$,

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.

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 model will then be characterized by a matrix.

Stanford University Interim (SUI) Channel Models

The channel model described above provides 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. We picked 6 typical channels for the three terrain types that are typical of the continental US. The SUI channels can be used for design, development and testing of technologies suitable for fixed broadband wireless applications in the MMDS band.

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

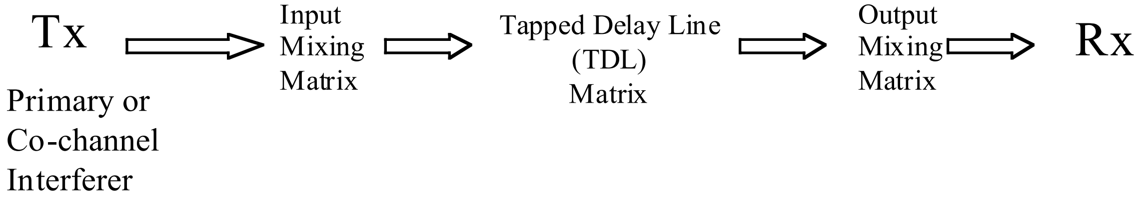
K-Factor: Low

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 that correlation between the input signals if multiple transmitting antennas are used.

Tapped Delay Line Matrix: This part models the multipath fading part 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 the 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 SUI channels:

- A cell size of 4 miles (6.4 km)
- BTS Antenna height: 50ft
- CPE antenna height: 10ft
- BTS Antenna beamwidth: 120 deg
- CPE Antenna Beamwidth: 50 deg
- Vertical Polarization only

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

SUI – 1 Channel				
	Tap 1	**Tap 2**	**Tap 3**	**Units**

Delay	**0**	**0.2**	**0.4**	μs
Power	**0**	**-3**	**-10**	**dB**
K Factor	**10**	**10**	**10**	
Doppler	**0.4**	**0.4**	**0.4**	**Hz**
Terrain Type: C, Antenna correlation: 0.7, RMS Delay Spread: 0.1 μs				

SUI –2 Channel				
	Tap 1	**Tap 2**	**Tap 3**	**Units**
Delay	**0**	**0.3**	**0.6**	μs
Power	**0**	**-3**	**-8**	**dB**
K Factor	**5**	**5**	**5**	
Doppler	**0.4**	**0.4**	**0.4**	**Hz**
Terrain Type: C, Antenna correlation: 0.5, RMS Delay Spread: 0.2 μs				

SUI – 3 Channel				
	Tap 1	**Tap 2**	**Tap 3**	**Units**

Delay	**0**	**0.5**	**1**	μs
Power	**0**	**-5**	**-10**	**dB**
K Factor	**0**	**0**	**0**	
Doppler	**0.4**	**0.4**	**0.4**	**Hz**
Terrain Type: B, Antenna correlation: 0.25, RMS Delay Spread: 0.3 μs				

SUI – 4 Channel				
	Tap 1	**Tap 2**	**Tap 3**	**Units**
Delay	**0**	**2**	**4**	μs
Power	**0**	**-4**	**-8**	**dB**
K Factor	**0**	**0**	**0**	
Doppler	**1**	**1**	**1**	**Hz**
Terrain Type: B, Antenna correlation: 0.25, RMS Delay Spread: 1.3 μs				

SUI – 5 Channel				
	Tap 1	**Tap 2**	**Tap 3**	**Units**

Delay	**0**	**4**	**11**	µs
Power	**0**	**-3**	**-5**	**dB**
K Factor	**0**	**0**	**0**	
Doppler	**2**	**2**	**2**	**Hz**
Terrain Type: A, Antenna correlation: 0.25, RMS Delay Spread: 3.1 µs				

SUI – 6 Channel				
	Tap 1	**Tap 2**	**Tap 3**	**Units**
Delay	**0**	**14**	**20**	µs
Power	**0**	**-10**	**-12**	**dB**
K Factor	**0**	**0**	**0**	
Doppler	**0.4**	**0.4**	**0.4**	**Hz**
Terrain Type: A, Antenna correlation: 0.25, RMS Delay Spread: 5.2 µs				

Conclusion:

The paper presents the channel model for fixed broadband wireless systems using macrocellular architecture. The path loss model and the multipath fading model are presented. Based on these models, for a given scenario, six interim channels (SUI channels) have been proposed which cover the diverse terrain types.

References

1. 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.
2. T.-S. Chu and L.J. Greenstein, "A Quantification of Link Budget Differences Between the Cellular and PCS Bands," IEEE Transactions on Vehicular Technology, vol. 48, no. 1, January 1999, pp. 60-65.
3. 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.
4. Larry J. Greenstein et.al, “A new path-gain/Delay-spread propagation Model for digital Cellular Channels,” *IEEE Trans. On Vehicular Technology*, vol. 46, no. 2, May 1997.
5. 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.
6. L. J. Greenstein and Vinko Erceg, Gain Reductions Due to Scatter on Wireless Paths with Directional Antennas, *IEEE Communications Letters*, Vol. 3, No. 6, June 1999.
7. David Parsons, “*The Mobile Radio Propagation Channel*,” John Wiley and Sons, 1992.