Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Comments on channel modeling**
Date Submitted	**2007-05-09**
Source(s)	Dean Kitchener, Kelvin Au, Robert Novak, Mo-Han Fong, Sophie Vrzic, Jun Yuan, Peiying Zhu, Wen Tong, Jianglei Ma Nortel Voice: +44-1279-403118 Fax: +44-1279-402100 mail to:deank@nortel.com mhfong@nortel.com
Re:	This is a response to a call for contributions http://www.ieee802.org/16/tgm/docs/80216m-07_014r1.pdf
Abstract	Recommendations for user speed distribution and wideband channels (>5MHz)
Purpose	For consideration when specifying channel models for the evaluation methodology
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	The contributor is familiar with the IEEE 802.16 Patent Policy and Procedures <http://ieee802.org/16/ipr/patents/policy.html>, including the statement "IEEE standards may include the known use of patent(s), including patent applications, provided the IEEE receives assurance from the patent holder or applicant with respect to patents essential for compliance with both mandatory and optional portions of 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:chair@wirelessman.org> as early as possible, in written or electronic form, if patented technology (or technology under patent application) might be incorporated into a draft standard being developed within the IEEE 802.16 Working Group. The Chair will disclose this notification via the IEEE 802.16 web site <http://ieee802.org/16/ipr/patents/notices>.

Comments on channel modelling

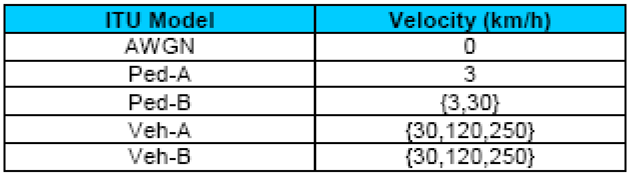
Dean Kitchener, Kelvin Au, Robert Novak, Mo-Han Fong, Sophie Vrzic, Jun Yuan, Peiying Zhu, Wen Tong, Jianglei Ma

Nortel

1 Introduction

2 User Speed Distribution and Doppler Spectrum

In the draft evaluation methodology [1] for 802.16m the user speed distribution is discussed in the context of both link and system simulations. For link level simulations, Table 4.2.1-3 in [1] proposes different velocities for the different (5MHz) ITU models. This table is repeated below in table 1.



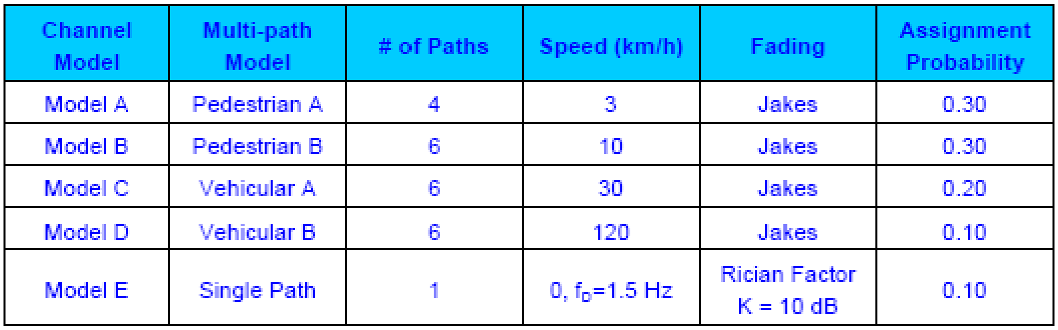
ITU Model	Velocity (km/h)
AWGN	0
Ped-A	3
Ped-B	{3,30}
Veh-A	{30,120,250}
Veh-B	{30,120,250}

Table 1

However, on page 30 of [1] the ITU channel models are again proposed for link level simulations, but with a slightly different set of velocities:-

Case-I: Pedestrian A: NLOS, speed: 3, 30, 120 km/h; 4 paths
Case-II: Vehicular A: Speed: 30, 120, 250 km/h; 6 paths
Case-III: Pedestrian B: Speed: 3, km/h; 6 paths
Case-IV: Vehicular B: Speed: 30, 120, 250 km/h; 6 paths

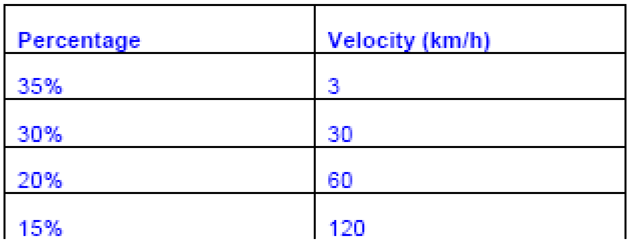
For system simulations, different proposals are given, where these are again based on the ITU models. In table 4.3.1-1 of [1] the following speeds are recommended:-



Channel Model	Multi-path Model	# of Paths	Speed (km/h)	Fading	Assignment Probability
Model A	Pedestrian A	4	3	Jakes	0.30
Model B	Pedestrian B	6	10	Jakes	0.30
Model C	Vehicular A	6	30	Jakes	0.20
Model D	Vehicular B	6	120	Jakes	0.10
Model E	Single Path	1	0, f_D=1.5 Hz	Rician Factor K = 10 dB	0.10

Table 2

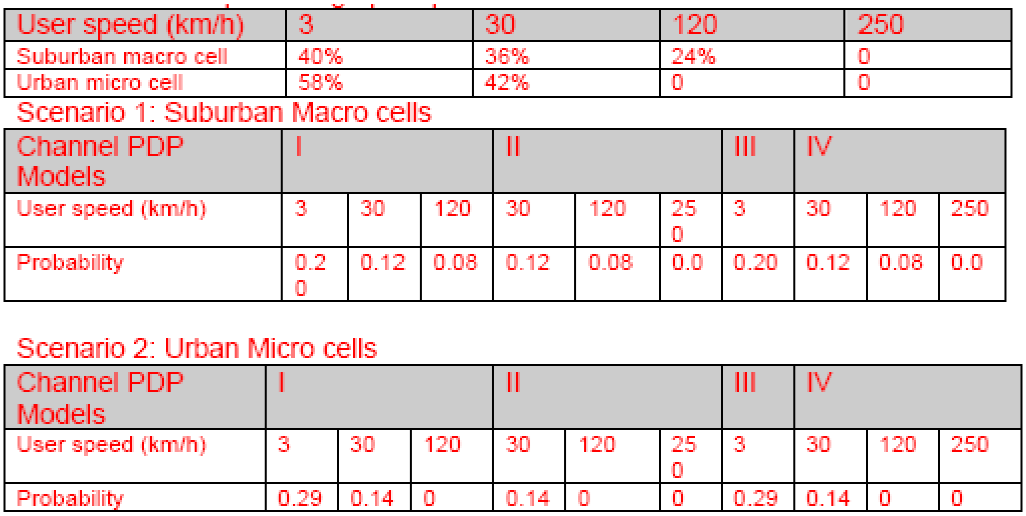
where the speed distribution for the system simulation is as given in table 3:-



Percentage	Velocity (km/h)
35%	3
30%	30
20%	60
15%	120

Table 3

Then in Table 4.3.1-3 of [1] the following recommendations are made for the mobile user speed distribution for two different environments:-



User speed (km/h)	3	30	120	250
Suburban macro cell	40%	36%	24%	0
Urban micro cell	58%	42%	0	0

Scenario 1: Suburban Macro cells

Channel PDP Models	I			II			III	IV		
User speed (km/h)	3	30	120	30	120	250	3	30	120	250
Probability	0.20	0.12	0.08	0.12	0.08	0.0	0.20	0.12	0.08	0.0

Scenario 2: Urban Micro cells

Channel PDP Models	I			II			III	IV		
User speed (km/h)	3	30	120	30	120	250	3	30	120	250
Probability	0.29	0.14	0	0.14	0	0	0.29	0.14	0	0

Table 4

The key thing to note for all of the above recommendations is that there are no stationary users. For IMT-Advanced, delivering high data rate multimedia services, it is expected that many users will be stationary, since the user will need to look at the information being received. This has been taken into account in the specification of parameters for HSDPA simulations where the user speed distribution given in Figure 1 is used [2] (see also Table 5). In this case it can be seen that 14% of users are stationary and 51% of users have speeds ≤ 1kph. It is recommended that this distribution also be used for macrocellular system simulations for IEEE 802.16m. For the hotspot layer this distribution will be different again, where in this case all users are likely to be walking or stationary (all ≤ 3kph).

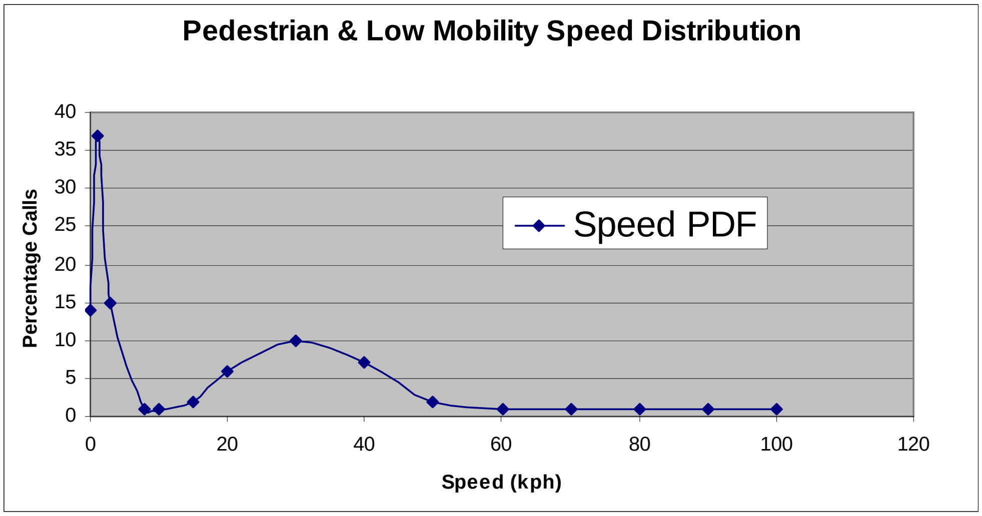


Figure 1 – HSDPA user speed distribution

Speed (kph)	0	1	3	8	10	15	20	30	40	50	60	70	80	90	100
Percentage	14	37	15	1	1	2	6	10	7	2	1	1	1	1	1

Table 5 – HSDPA user speed distribution

For stationary users the Doppler spectrum will not be anything like the ‘Classic’ or ‘Jakes’ spectrum. One possible model for the Doppler spectrum is the model specified for IEEE 802.16d [3], which is a model for fixed links. The model is repeated below:-

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

In [3] it states that this function is parameterized by a maximum Doppler frequency f_m. Alternatively, the -3dB point can be used as a parameter where f_{-3dB} can be related to f_m using the above equation. According to [3], measurements at a 2.5GHz centre frequency show maximum f_{-3dB} values of about 2Hz.

For system simulations, the user speed will be completely independent of the actual channel characteristic (TDL model) at each location. It is therefore recommended that the TDL model assignment probability be decoupled from the user speed probability. It is also recommended that for stationary users the Doppler spectrum for the taps should be modified to that used in [3] for fixed links.

The HSDPA speed distribution contains a large number of user speeds. To simplify the system simulation these can be reduced to a smaller set, but with a similar probability distribution:-

Speed (km/h)	0	3	30	120
Percentage	51	17	25	7

Table 6 – Modified HSDPA speed distribution

For channels with a greater bandwidth than 5MHz, the speed distribution used for HSDPA will still be valid, but a modified TDL model should be used. This is discussed in the next section. Following section 3, a recommended channel mix for system simulations is then given.

3 Wideband (>5MHz) Tapped Delay Line Models

In [4] it is shown that the frequency correlation functions for the ITU TDL models are periodic functions, which is contrary to the behaviour of real channels. The oscillatory behaviour is essentially due to the fact that the channel is represented by a number of discrete paths, whereas in reality it is more like a continuum of paths. The discrete representation is used for ease of simulation, and has proved adequate for bandwidths up to 5MHz.

The spaced-frequency correlation function , as given in [4] is:-

$$\phi_C(\Delta f;0)=\sum_{i=1}^{L} p_i e^{-j2\pi\Delta f\tau}$$

where,

p_i = Power of the i^th^ tap
τ_i = Delay of the i^th^ tap

The function is shown plotted for the ITU Ped B channel in figure 2, for bandwidths up to 20MHz. It can be seen that it has a period of 10MHz, but even at 5MHz the correlation is high. This clearly shows the need for improved models for bandwidths greater than 5MHz.

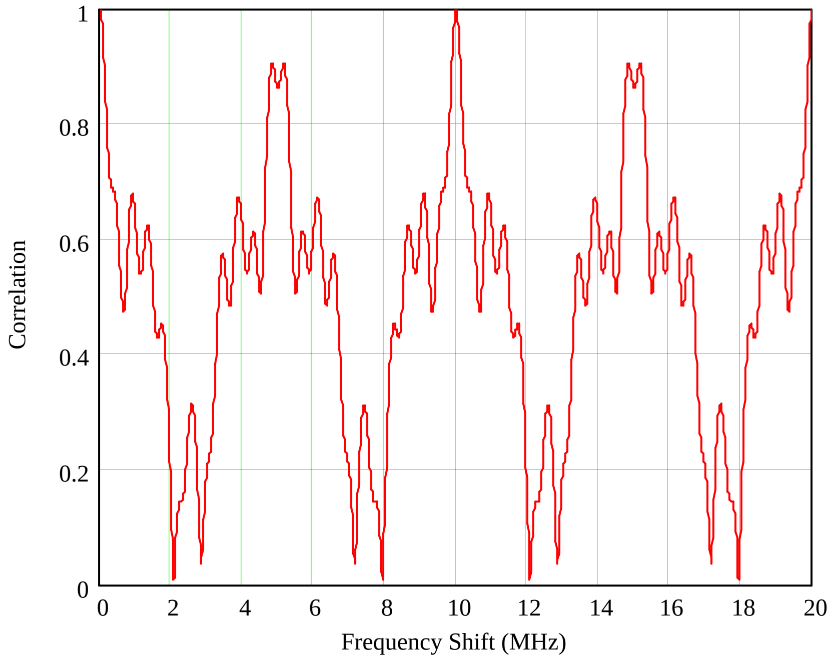


Figure 2 – Magnitude of the spaced-frequency correlation function for ITU Ped B

.

It is noted that the spaced-frequency correlation function can only be periodic if the combined phase of the multipaths repeats periodically. This can be shown to be the case.

The multipath phase variations with frequency are governed by the path delays such that;

$$\phi_i = 2\pi f \tau_i$$

Therefore, we can find the period in frequency for each multipath by solving;

$$\phi_i = 2\pi n$$
$$2\pi n = 2\pi f_n \tau_i$$
$$f_n = \frac{n}{\tau_i}$$

We can list the f_n for the various taps of the ITU Ped B model and look for instances where the tap periods coincide. We note that the smallest tap delay will give the largest period in frequency;

$$\frac{1}{200 \cdot 10^{-9}} = 5MHz$$

The phase for this tap will therefore repeat every 5MHz. We therefore look to find the smallest multiple of 5MHz where the phases of the other taps repeat;

Tap delay, ns	n for f_n=5MHz	N for f_n=10MHz
800	4	8
1200	6	12
2300	11.5 (non-integer)	23
3700	18.5 (non-integer)	37

Table 7 – Phase alignment in the frequency domain for the ITU Ped B channel

Clearly from the table the taps all have integer values for *n* at 10MHz, and so we expect, and get, a periodic function in the frequency domain with a period of 10MHz.

We also note that if the tap powers for taps 5 and 6 (longest delayed components) are set to zero we would expect a period of 5MHz, since taps 2-4 all have integer values for *n* at 5MHz. This is shown to be true in figure 3.

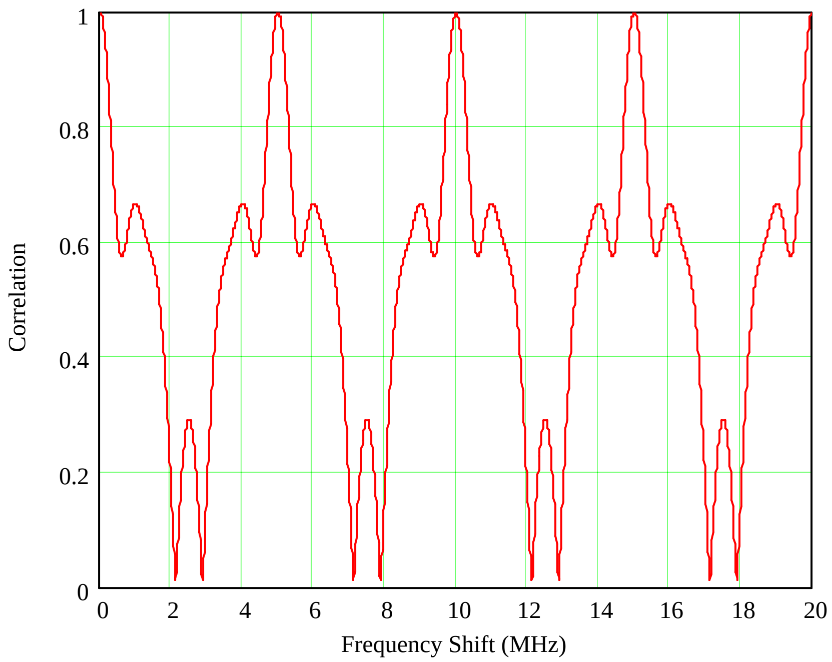


Figure 3 – Spaced-frequency correlation function for ITU Ped B with the powers of taps 5 and 6 set to zero

In [4], the approach taken to remove the periodicity of the spaced-frequency correlation function is to replace each original path by a cluster of N number of paths, such that the time delays are within ε of the time delay of the original path and the total average power of the cluster is the same as that of the original path. In order to calculate the new paths, a desired spaced-frequency correlation function is derived, based on an exponentially decaying power delay profile. The 'best fit' exponentially decaying power delay profile to the given ITU model is used. In addition, a symmetry constraint can be applied, whereby the set of offsets, δ's, from the original path delays should be symmetric about 0, and any pair of paths in a cluster that are symmetrically placed around the path in the original profile should have the same average powers. This is to ensure that the additional paths do not change the mean delays of the profile.

Using this approach it was found that the behaviour of the spaced-frequency correlation function improves as the cluster size increases, and better performance is achieved without imposing the symmetry constraint. Cluster sizes of N=2, 3, and 4 were tried with ε=100ns.The modified channel models for different cluster sizes are given in [4], and repeated in tables 7, 8, 9, 10, 11, and 12. Note that in some cases, the delays of more than one path are the same. In these instances, one could make a single path out of the taps with the same delay by adding their powers (since the paths are uncorrelated their powers will add up).

Modified ITU Ped A		Modified ITU Ped B		Modified ITU Veh A	
Delay/ns	Power	Delay/ns	Power	Delay/ns	Power
0	0.44465	0	0.20285	0	0.2425
40	0.44465	40	0.20285	40	0.2425
130	0.04765	130	0.1649	290	0.19265
130	0.04765	310	0.1649	370	0.19265
130	0.00535	800	0.06565	680	0.03055
290	0.00535	840	0.06565	780	0.03055
380	0.00235	1200	0.03215	1070	0.02425
480	0.00235	1240	0.03215	1150	0.02425
		2270	0.03365	1680	0.00765
		2370	0.03365	1820	0.00765
		3700	0.00085	2510	0.00245
		3740	0.00085	2550	0.00245

Table 8 - Modified ITU models with N=2 and with the symmetry constraint

Modified ITU Ped A		Modified ITU Ped B		Modified ITU Veh A	
Delay/ns	Power	Delay/ns	Power	Delay/ns	Power
0	0.28209	0	0.12913	0	0.15777
30	0.32511	40	0.14745	40	0.16947
60	0.28209	80	0.12913	80	0.15777
140	0.04623	200	0.10975	310	0.12521
140	0.00285	240	0.11031	350	0.13489
140	0.04623	280	0.10975	390	0.12521
220	0.00351	800	0.0433	730	0.02332
220	0.00368	840	0.0447	750	0.01446
220	0.00351	880	0.0433	770	0.02332
370	0.00067	1190	0.02681	1050	0.00994
440	0.00336	1240	0.01068	1130	0.02862
510	0.00067	1290	0.02681	1210	0.00994
		2310	0.01758	1730	0.00561
		2340	0.03214	1770	0.00407
		2370	0.01758	1810	0.00561
		3730	0.00052	2480	0.00157
		3740	0.00067	2550	0.00177
		3750	0.00052	2620	0.00157

Table 9 – Modified ITU models with N=3 and with the symmetry constraint

Modified ITU Ped A		Modified ITU Ped B		Modified ITU Veh A	
Delay/ns	Power	Delay/ns	Power	Delay/ns	Power
0	0.13758	0	0.09985	0	0.10022
30	0.30707	40	0.103	40	0.14228
50	0.30707	80	0.103	80	0.14228
80	0.13758	120	0.09985	120	0.10022
120	0.02562	170	0.07172	280	0.10295
120	0.02203	210	0.09318	320	0.0897
180	0.02203	310	0.09318	420	0.0897
180	0.02562	350	0.07172	460	0.10295
190	0.00285	770	0.03463	750	0.00804
220	0.0025	800	0.03102	750	0.02251
240	0.0025	920	0.03102	790	0.02251
270	0.00285	950	0.03463	790	0.00804
390	0.00109	1230	0.01311	1060	0.01168
410	0.00126	1250	0.01904	1150	0.01257
490	0.00126	1270	0.01904	1150	0.01257
510	0.00109	1290	0.01311	1240	0.01168
		2300	0.01941	1700	0.00259
		2330	0.01424	1710	0.00506
		2390	0.01424	1870	0.00506
		2420	0.01941	1880	0.00259
		3690	0.00064	2510	0.0013
		3740	0.00021	2530	0.00115
		3780	0.00021	2610	0.00115
		3830	0.00064	2630	0.0013

Table 10 – Modified ITU models with N=4 and with the symmetry constraint

Modified ITU Ped A		Modified ITU Ped B		Modified ITU Veh A	
Delay/ns	Power	Delay/ns	Power	Delay/ns	Power
0	0.04971	0	0.20404	0	0.24343
40	0.41094	40	0.20166	40	0.24157
70	0.47836	80	0.18905	180	0.17677
120	0.04559	120	0.14075	220	0.20853
150	0.00596	760	0.03758	600	0.05368
170	0.00474	840	0.09372	730	0.00742
320	0.00029	1100	0.04509	1000	0.02632
420	0.00441	1160	0.01921	1060	0.02218
		2250	0.042	1610	0.00792
		2370	0.0253	1690	0.00738
		3650	0.00115	2470	0.00295
		3760	0.00055	2510	0.00195

Table 11 - Modified ITU models with N=2 and with no symmetry constraint

Modified ITU Ped A		Modified ITU Ped B		Modified ITU Veh A	
Delay/ns	Power	Delay/ns	Power	Delay/ns	Power
0	0.19731	0	0.13258	0	0.11267
40	0.38581	50	0.12033	40	0.17034
70	0.30618	90	0.1528	80	0.202
130	0.04261	130	0.1456	330	0.1262
150	0.02166	170	0.09301	370	0.13494
160	0.03103	280	0.09119	410	0.12416
250	0.00130	770	0.00562	770	0.05366
250	0.00479	790	0.07694	790	0.00471
300	0.00461	840	0.04874	820	0.00273
470	0.00122	1170	0.02727	1040	0.01628
480	0.00218	1230	0.01972	1130	0.01618
520	0.00131	1290	0.01731	1210	0.01604
		2280	0.01854	1790	0.00046
		2290	0.03151	1790	0.00773
		2360	0.01725	1870	0.00712
		3630	0.0006	2600	0.00098
		3630	0.00087	2600	0.002
		3630	0.00023	2630	0.00191

Table 12 - Modified ITU models with N=3 and with no symmetry constraint

Modified ITU Ped A		Modified ITU Ped B		Modified ITU Veh A	
Delay/ns	Power	Delay/ns	Power	Delay/ns	Power
0	0.09413	0	0.08419	0	0.07439
70	0.23742	40	0.11035	50	0.13808
90	0.30251	70	0.10604	90	0.15198
120	0.00116	120	0.10511	130	0.12055
120	0.25524	210	0.10379	270	0.10989
150	0.0466	250	0.10073	300	0.109
160	0.02443	290	0.04081	390	0.1065
180	0.02312	350	0.08447	420	0.0599
220	0.00284	780	0.01001	670	0.0033
220	0.00136	830	0.02957	750	0.00552
280	0.0038	880	0.04952	770	0.04889
330	0.0027	920	0.0422	800	0.00339
420	0.00098	1200	0.01076	1040	0.01818
480	0.00134	1250	0.03007	1060	0.0098
540	0.00061	1310	0.01083	1070	0.01472
560	0.00176	1350	0.01264	1190	0.0058
		2290	0.00445	1670	0.00304
		2350	0.01331	1710	0.00719
		2380	0.03056	1820	0.00493
		2400	0.01898	1840	0.00014
		3700	0.00002	2480	0.0017
		3730	0.00065	2500	0.0019
		3730	0.00027	2540	0.00002
		3870	0.00076	2620	0.00128

Table 13 - Modified ITU models with N=4 and with no symmetry constraint

As an example, the spaced-frequency correlation function for the modified ITU Ped B model is shown in figure 4, where N=2 and the symmetry constraint is imposed. It can be seen that this is no longer periodic, and the correlation generally decreases with increasing frequency offset. Clearly, this is a good result even with the symmetry constraint imposed.

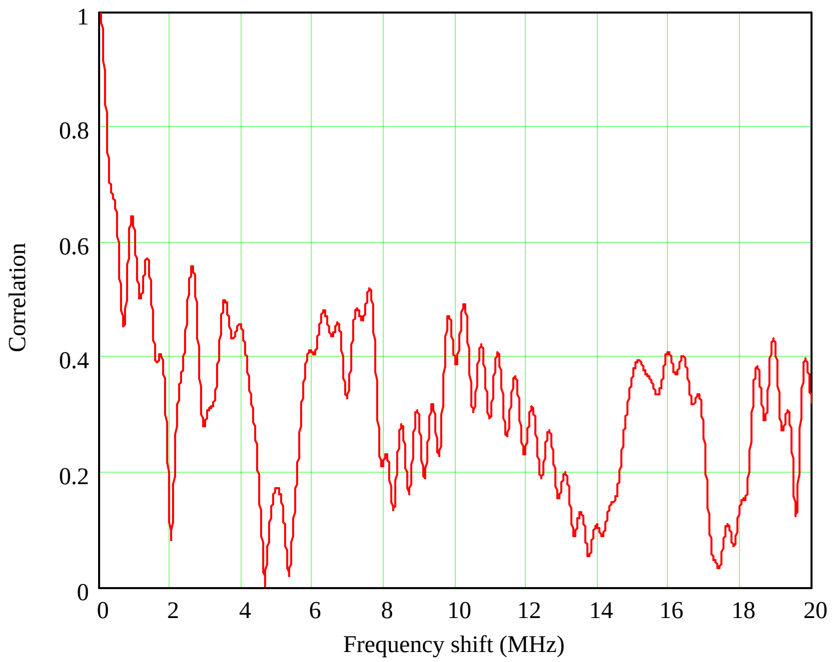


Figure 4 – Space-frequency correlation function for modified ITU Ped B TDL model

In [5], a similar approach is taken to modeling the channel for wide bandwidths. In this case a modification to the 3GPP/3GPP2 Spatial Channel Model (SCM) is proposed. The SCM is a statistical model, but nevertheless, is still restricted to 6 taps in the delay domain. Each of these 6 taps is represented by 20 sub-paths, but the sub-paths all have the same delay. They are used to specify the A0D's and the AoA's for the multipath. In [5] it is suggested that for wideband channels (i.e. >5MHz) each tap should have its own delay spread (eg. 10ns) so that the 20 subpaths within each tap now have different delays. This is equivalent to the approach taken in [4], but with N=20. The effect will be to eliminate the periodicities observed in the frequency domain for 6-tap TDL models. Thus [4] and [5] give methods for modifying the basic ITU TDL models, or the more complex 3Gpp/3GPP2 SCM.

It is recommended that the modified ITU models be used for wideband channels (i.e. for bandwidths greater than 5MHz and up to 20MHz). It is recommended that the modified models with N=2 be used, without the symmetry constraint.

4 Channel Mix

For bandwidths ≤5MHz the recommended channel mix for system simulations is as follows:-

Model	TDL model	# of paths	Assignment Probability
A	Ped A	4	0.3
B	Ped B	6	0.4
C	Veh A	6	0.3

Table 14 – TDL model mix for bandwidth ≤5MHz

For bandwidths where 5MHz < bandwidth ≤ 20MHz the recommended channel mix for system simulations is as follows:-

Model	TDL model	# of paths	Assignment Probability
D	Modified Ped A	8	0.3
E	Modified Ped B	12	0.4
F	Modified Veh A	12	0.3

Table 15 – TDL model mix for 5MHz < bandwidth ≤ 20MHz

For all cases, the user speed distribution should be as given in table 16.

Speed km/h	Fading model	Percentage
0	IEEE 802.16d	51
3	Jakes	17
30	Jakes	25
120	Jakes	7

Table 16 – User speed distribution for system simulations

Note that the ITU Veh B model has not been included. This is to be consistent with the models presented in [4].

5 Proposed Text Change

[Add a reference to page 11, after line 35]

+++++++++++++++ Start Text ++++++++++++++++++++++++++

[49] A.G.Kogiantis et al, 'Extension of the Strawman-ITU channel models and the SCM to wide-band channel models with desired spaced-frequency correlation', 3GPP2 TSG-C WG3, C30-20050718-028

+++++++++++++++ End Text ++++++++++++++++++++++++++

[Modify sections 4.2.1, 4.2.2, 4.3, 4.3.1 as shown below]

+++++++++++++++ Start Text ++++++++++++++++++++++++++

4.2. Link Model Definition

A baseline link level channel model should be a tapped-delayed-line (TDL) with a multi-antenna correlation properly defined. An example of the baseline TDL model, in a macro-cell outdoor terrain, is the ITU channel models for the 5MHz bandwidth case. The antenna correlation could be derived from a certain antenna configuration assumption and a certain "typical" spatial parameters. The following sections describe the suggested TDL model and the derivation of antenna correlations.

4.2.1. TDL Models

A link-level channel model defines a specific number of paths, path delay and power profile, and Doppler frequencies for the paths. The tapped-delay line model defined by the ITU is suggested as the baseline TDL model for the 5MHz case. It defines the number of taps (or the number of paths), time delay relative to first tap, average power relative to the strongest tap, and Doppler spectrum of each tap.

The tapped delay line model can be represented in the time-domain as

$$h(t) = \sum_{l=1}^{n} p_l h_l(t)\delta(t - \tau_l) \qquad (4.2.1\text{-}1)$$

Where p_l and τ_l are amplitude and delay of path l, and $h_l(t)$ represents the time varying channel coefficient. All simulations assume that $h_l(t)$ is a temporally correlated random variable with classical (Jakes) Doppler spectrum

$$S(f) = \begin{cases} \frac{1}{\pi f_d} \frac{1}{\sqrt{1-(f/f_d)^2}} & |f| < f_d \\ 0 & \text{otherwise} \end{cases} \qquad (4.2.1\text{-}2)$$

Where f_d is the appropriate Doppler rate for the subscriber speed and the carrier frequency.

The tapped-delay line parameters of suggested ITU channel models for bandwidth up to 5MHz are further summarized in

Table 4.2.1-1 and Table 4.2.1-2. Note that the power values in the tables need to be normalized so that they sum to unit power (0 dB).

Tap	**Channel Ped-A** $\tau_{rms} = 45ns$		**Channel Ped-B** $\tau_{rms} = 750ns$		**Doppler** $v = 3km/h$ and 10 km/h
	Delay (ns)	Power (dB)	Delay (ns)	Power (dB)	Jakes
1	0	0	0	0	Jakes
2	110	-9.7	200	-0.9	Jakes
3	190	-19.2	800	-4.9	Jakes
4	410	-22.8	1200	-8.0	Jakes
5	-	-	2300	-7.8	Jakes
6	-	-	3700	-23.9	Jakes

Table 4.2.1-1: Outdoor to indoor and pedestrian test environment channel impulse response

Tap	**Channel Veh-A** ($\tau_{rms} = 370ns$)		~~**Channel Veh-B**~~ ~~($\tau_{rms} = 4000ns$)~~		**Doppler** ($v = 30,120\ km/h$)
	Delay (ns)	Power (dB)	~~Delay (ns)~~	~~Power (dB)~~	Jakes
1	0	0	~~0~~	~~0~~	Jakes
2	310	-1.0	~~300~~	~~-2.5~~	Jakes
3	710	-9.0	~~8900~~	~~-12.8~~	Jakes
4	1090	-10.0	~~12900~~	~~-10.0~~	Jakes
5	1730	-15.0	~~17100~~	~~-25.2~~	Jakes
6	2510	-20.0	~~20000~~	~~-16.0~~	Jakes

Table 4.2.1-2: Vehicular test environment channel impulse response

~~One example for SISO link-level channel model is given below based on ITU models at different velocities. The table is to be finalized to include stationary channel model. Note also that the stationary AWGN channel included could be used mainly for modeling a wired test condition only, not necessary reflecting the realistic stationary channel condition.~~

~~**ITU Model**~~	~~**Velocity (km/h)**~~
~~AWGN~~	~~0~~
~~Ped-A~~	~~3~~
~~Ped-B~~	~~{3,30}~~
~~Veh-A~~	~~{30,120,250}~~
~~Veh-B~~	~~{30,120,250}~~

~~Table 4.2.1-3: ITU Profiles for Link Level Simulations~~

4.2.2. TDL Models for Bandwidth Greater than 5MHz

In [49] it is shown that the frequency correlation functions for the ITU TDL models are periodic functions, which is contrary to the behaviour of real channels. The oscillatory behaviour is essentially due to the fact that the channel is represented by a number of discrete paths, whereas in reality it is more like a continuum of paths. The discrete representation is used for ease of simulation, and has proved adequate for bandwidths up to 5MHz.

The approach taken in [49] to remove the periodicity of the spaced-frequency correlation function should be used for bandwidths greater than 5MHz and up to 20MHz. In this approach, each original path is replaced by a cluster of N number of paths, such that the time delays are within ε of the time delay of the original path and the total average power of the cluster is the same as that of the original path. In order to calculate the new paths, a desired spaced-frequency correlation function is derived, based on an exponentially decaying power delay profile. The ‘best fit’ exponentially decaying power delay profile to the given ITU model is used. In addition, a symmetry constraint can be applied, whereby the set of offsets, δ’s, from the original path delays should be symmetric about 0, and any pair of paths in a cluster that are symmetrically placed around the path in the original profile should have the same average powers. This is to ensure that the additional paths do not change the mean delays of the profile.

It is recommended that the modified models with N=2 be used, without the symmetry constraint. The corresponding modified ITU channel models are shown in Table 4.2.2-1.

Modified ITU Ped A		Modified ITU Ped B		Modified ITU Veh A	
Delay/ns	Power	Delay/ns	Power	Delay/ns	Power
0	0.04971	0	0.20404	0	0.24343
40	0.41094	40	0.20166	40	0.24157
70	0.47836	80	0.18905	180	0.17677
120	0.04559	120	0.14075	220	0.20853
150	0.00596	760	0.03758	600	0.05368
170	0.00474	840	0.09372	730	0.00742
320	0.00029	1100	0.04509	1000	0.02632
420	0.00441	1160	0.01921	1060	0.02218
		2250	0.042	1610	0.00792
		2370	0.0253	1690	0.00738
		3650	0.00115	2470	0.00295
		3760	0.00055	2510	0.00195

Table 4.2.2-1 - Modified ITU models with N=2 and with no symmetry constraint

4.2.3. TDL Models with Antenna Correlation

The MIMO link-level channel model is defined based on the SISO power delay profile, but a pre-defined antenna correlation should be specified on a per-tap basis.

The MIMO channel model is a stochastic channel model for MIMO systems that extends the SISO channel model to the MIMO case by utilizing transmit and receive spatial correlation matrices. Let M and N be the number of TX and RX antennas, respectively, and let $\mathbf{R}_{TX}$, of dimensions MxM, and $\mathbf{R}_{RX}$, of dimensions NxN, be the correlation matrices at the transmit and receive side, respectively. If **H** denotes the NXM discrete-time MIMO channel impulse response matrix between the transmitter and the receiver with entries $H_{n,m}$ expressing the channel impulse response between transmit antenna m, m=1..M, and receive antenna n, n=1..N, then the elements $[R_{\mathrm{Tx}}]_{i,j}$, i,j=1..M, of the MxM spatial correlation matrix $\mathbf{R}_{TX}$ are defined according to

$$[R_{\mathrm{Tx}}]_{i,j} = \left\langle H_{l,i}, H_{l,j} \right\rangle \qquad (4.2.3\text{-}1)$$

where $\left\langle H_{l,i}, H_{l,j} \right\rangle$ calculates the correlation coefficient between $H_{l,i}$ and $H_{l,j}$ and is independent of l, l=1..N, i.e., of the receive antennas at the MS. The elements of the NxN correlation matrix $\mathbf{R}_{\mathrm{Rx}}$ are defined similarly.

Since the correlation coefficients between any two channel impulse responses connecting two different sets of antennas can be expressed as the product of the correlation coefficients at the transmit and the receive antennas, the spatial correlation matrix of the MIMO channel matrix **H** can be expressed as the Kronecker product of the spatial correlation matrices at the transmit and receive side:

$$\mathbf{R}_{\mathrm{MIMO}} = \mathbf{R}_{\mathrm{Tx}} \otimes \mathbf{R}_{\mathbf{Rx}} = \mathbf{C}_{\mathrm{Tx}}^{*\mathrm{T}} \mathbf{C}_{\mathrm{Tx}} \otimes \mathbf{C}_{\mathrm{Rx}}^{*\mathrm{T}} \mathbf{C}_{\mathrm{Rx}} \qquad \mathbf{(4.2.3\text{-}2)}$$

where $\mathbf{C}_{\mathrm{Tx}}$ and $\mathbf{C}_{\mathrm{Rx}}$ represent the Cholesky decomposition of $\mathbf{R}_{\mathrm{Tx}}$ and $\mathbf{R}_{\mathrm{Rx}}$, respectively.

This property of the MIMO channel matrix **H** means that the effects of multipath propagation and mobility can be modeled by generating MxN uncorrelated channel impulse responses, each according to the SISO power delay profile (PDP) and the desired model for including the impact of mobility, e.g., use of the Doppler spectrum, and then for each multipath component w, w=1..W, determine the MIMO channel matrix according to

$$\mathbf{H}_w = \mathbf{C}_{\mathrm{Rx}}^{*\mathrm{T}} \mathbf{H}_{\mathrm{un},w} \mathbf{C}_{\mathrm{Tx}}^{*}, \quad w = 1...W, \qquad \mathbf{(4.2.3\text{-}3)}$$

where $\mathbf{H}_{\mathrm{un,w}}$, w=1..W, denotes the NxM MIMO channel matrix created by the N·M uncorrelated channel impulse responses at delay w, w=1..W.

A per-tap antenna correlation matrix should be defined in the MIMO link level model. Such a correlation may be derived based on the per-tap mean angle of arrival (AOA), mean angle of departure (AOD), and a per-tap angular spread (AS) at both BS and MS. For example, using the per-tap AS parameters defined in SCM for urban macro-cell, one can realize a set of per-tap mean AOA and AOD so that the overall AS at BS and AS at MS achieve the values defined in SCM under different power delay profiles. Such an example is given below. The table defines a particular realization of the AOA and AOD for the sake of generating the antenna correlation for link level simulation. For system level simulation, the AOA and AOD certainly vary with locations. For link level simulation, other sets of values could be defined corresponding to different cell environments such as suburban macro, urban macro, and so on.

The antenna correlation can be further computed after assuming a certain antenna configuration. Other modifications are needed for polarized antenna, antenna imbalance, or high K-factor conditions.

Channel Scenario	**Urban Macro-Cellular**
AS at BS	$\sigma_{AS} = 15^0$
Per-path AS at BS (Fixed)	2 deg
AS at MS	$\sigma_{AS, MS} = 68^0$
Per-path AS at MS (fixed)	35^0
AoDs	As specified in Table 4.2.3-2
AoAs	As specified in Table 4.2.3-2

Table 4.2.3-1 ITU Profiles Spatial Extension Parameters

	Path Power	**Path AOD (rad)**	**Path AoA (rad)**
Ped-	0.889345301	0.346314033	1.737577272
	0.095295066	-0.05257642	-1.55645
	0.010692282	-1.817837659	-1.049078459
	0.00466735	-0.836999548	0.345571431
Ped-	0.405688403	-0.13638548	1.319340881
	0.329755914	0.302249557	-0.119072067
	0.131278194	0.496051618	0.901442565
	0.064297279	0.544719913	-1.424448314
	0.067327516	0.212670549	-3.062670939
	0.001652695	-0.604134536	-1.202289294
Veh-	0.48500285	-0.46084874	-0.780118399
	0.385251458	-0.897480352	-1.729577654
	0.061058241	-0.525726742	1.792547973
	0.048500285	0.00282531	1.776985779
	0.015337137	-1.016095677	1.386034573
	0.004850029	0.245512493	3.50389557
Veh-			

Table 4.2.3-2 Path Power, AoD, AoA

4.3. System Model Definition

For system level simulation, certain deployment related parameters need to be defined first that could relates to the channel modeling. For example in macro-cell environment, the cellular system contains three sectors. Antenna pattern and orientation are part of the deployment related parameters that will not be included here. The following sections describe the procedures to simulate MIMO channels in a wireless system and define propagation-related parameters, in sufficient details so that system level simulation can be performed.

A few environments should be considered for IEEE 802.16m system-level simulations:

1. **Suburban macro-cellular**: This scenario is characterized by large cell radius (approximately 1-6 km BS to BS distance), high BS antenna positions (above rooftop heights, between 10-80 m, typically 32 m), moderate to high delay spreads and low angle spreads and high range of mobility (0 – 350 km/h).
2. **Urban macro-cellular**: This scenario is characterized by large cell radius (approximately 1-6 km BS to BS distance), high BS antenna positions (above rooftop heights, between 10-80 m, typically 32 m), moderate to high delay and angle spread and high range of mobility (0 – 350 km/h).
3. **Urban micro-cellular**: This scenario is characterized by small cell radius (approximately 0.3 – 0.5 km BS to BS distance) BS antenna positions at rooftop heights or lower (typically 12.5m), high angle spread and moderate delay spread, and medium range of mobility (0 – 120 km/h). This model is sensitive to antenna height and scattering environment (such as street layout, LOS)]

4.3.1. Channel Mix

A TDL channel model as defined in 4.2.1 and 4.2.2 shall be used for system level simulation. In system level simulation, users may be associated with a set of different channel types and velocities should such a case of mixed user speed is evaluated. ~~A few examples are given below.~~

~~[If a TDL-based (e.g., ITU) channel with pre-defined antenna correlation is used as the baseline for also system level simulation,~~ For bandwidths ≤5MHz the channel models are randomly assigned to the various users according to the probabilities of Table 4.3.1-1 at the beginning of each drop and are not changed for the duration of that drop. The assignment probabilities given in Table 4.3.1-1 are interpreted as the percentage of users with that channel model in each sector. For bandwidths where 5MHz < bandwidth ≤ 20MHz the channel models are randomly assigned according to the probabilities of Table 4.3.1-2. For all bandwidths, users are assigned a speed according to the probabilities given in Table 4.3.1-3.

For bandwidths ≤5MHz the recommended channel mix for system simulations is as follows:-

Model	TDL model	# of paths	Assignment Probability
A	Ped A	4	0.3
B	Ped B	6	0.4
C	Veh A	6	0.3

Table 4.3.1-1 – TDL model mix for bandwidth ≤5MHz

For bandwidths where 5MHz < bandwidth ≤ 20MHz the recommended channel mix for system simulations is as follows:-

Model	TDL model	# of paths	Assignment Probability
D	Modified Ped A	8	0.3

E	Modified Ped B	12	0.4
F	Modified Veh A	12	0.3

Table 4.3.1-2 – TDL model mix for 5MHz < bandwidth ≤ 20MHz

For all cases, the user speed distribution should be as given in Table 4.3.1-3. JTC method shall be used to generate the fading values for the Jakes spectrum of the mobility cases. The exact method to generate fading values for the stationary spectrum shall be defined in the methodology [TBD].

Speed km/h	Fading model	Assignment Probability
0	IEEE 802.16d	0.51
3	Jakes	0.17
30	Jakes	0.25
120	Jakes	0.07

Table 4.3.1-3 – User speed distribution for system simulations

~~Note the table could be further optimized, especially the model-E (LOS or quasi-LOS) channel definition.~~

~~Channel Model~~	**~~Multi-path Model~~**	**~~# of Paths~~**	**~~Speed (km/h)~~**	**~~Fading~~**	**~~Assignment Probability~~**
~~Model A~~	~~Pedestrian A~~	~~4~~	~~3~~	~~Jakes~~	~~0.30~~
~~Model B~~	~~Pedestrian B~~	~~6~~	~~10~~	~~Jakes~~	~~0.30~~
~~Model C~~	~~Vehicular A~~	~~6~~	~~30~~	~~Jakes~~	~~0.20~~
~~Model D~~	~~Vehicular B~~	~~6~~	~~120~~	~~Jakes~~	~~0.10~~
~~Model E~~	~~Single Path~~	~~1~~	~~0, f_D=1.5 Hz~~	~~Rician Factor K = 10 dB~~	~~0.10~~

~~Table 4.3.1-1 Channel Models~~

~~]~~

~~[If the SCM urban macro-cell channel model is used, the velocity profile is shown in Table 4.3.1-2 Because of the choice of urban macrocell, velocities are biased towards pedestrian speeds.~~

~~Percentage~~	**~~Velocity (km/h)~~**
~~35%~~	~~3~~
~~30%~~	~~30~~
~~20%~~	~~60~~
~~15%~~	~~120~~

~~Table 4.3.1-2: Quantized Velocity Profile~~

~~The RF carrier frequency for all link-level and system-level simulations shall be 2.5 GHz.~~

~~]~~

~~[~~

~~At the link level, the channel models shall include the following non-spatial-varying parameters:~~
~~Case-I: Pedestrian A: NLOS, speed: 3, 30, 120 km/h; 4 paths~~
~~Case-II: Vehicular A: Speed: 30, 120, 250 km/h; 6 paths~~
~~Case-III: Pedestrian B: Speed: 3, km/h; 6 paths~~
~~Case-IV: Vehicular B: Speed: 30, 120, 250 km/h; 6 paths~~

~~A channel mix, based on the link-level channel models with fixed path delays, should also be used.~~

~~The following channel mix, based on the link-level channel models with fixed path delays, is to be applied. Two scenarios are to be analyzed: suburban macro cell and urban micro cell which represent the two typical extremes of deployment environment. The assumptions on user speed distribution, quantized to 3, 30, 120 and 250 km/h, for each scenario are shown in Table 4.3.1-3~~
~~For each channel power delay profile corresponding to each of the above speeds, the probability of users is equally distributed.~~

~~Note that in the tables below, the percentage of users at 250 km/hr for the suburban macro cells and the percentage of users at 250 km/hr and 120 km/hr for the urban micro cell are set to zero. In a realistic scenario, this would be a very small percentage, but, in order to achieve statistically meaningful simulation results, they are set to zero in this table. However, in order to understand the system performance under these speeds, a separate set of link curves for the suburban macro cells at 250 km/hr and urban macro cells at 120 km/h should be provided.~~

~~User distribution percentage per speed~~

~~User speed (km/h)~~	~~3~~	~~30~~	~~120~~	~~250~~
~~Suburban macro cell~~	~~40%~~	~~36%~~	~~24%~~	~~0~~
~~Urban micro cell~~	~~58%~~	~~42%~~	~~0~~	~~0~~

~~Scenario 1: Suburban Macro cells~~

~~Channel PDP Models~~	~~I~~			~~II~~			~~III~~	~~IV~~		
~~User speed (km/h)~~	~~3~~	~~30~~	~~120~~	~~30~~	~~120~~	~~250~~	~~3~~	~~30~~	~~120~~	~~250~~
~~Probability~~	~~0.20~~	~~0.12~~	~~0.08~~	~~0.12~~	~~0.08~~	~~0.0~~	~~0.20~~	~~0.12~~	~~0.08~~	~~0.0~~

~~Scenario 2: Urban Micro cells~~

~~Channel PDP Models~~	~~I~~			~~II~~			~~III~~	~~IV~~		
~~User speed (km/h)~~	~~3~~	~~30~~	~~120~~	~~30~~	~~120~~	~~250~~	~~3~~	~~30~~	~~120~~	~~250~~
~~Probability~~	~~0.29~~	~~0.14~~	~~0~~	~~0.14~~	~~0~~	~~0~~	~~0.29~~	~~0.14~~	~~0~~	~~0~~

~~4.3.1-3: Assumptions on distribution of mobile user speed~~

~~]~~

+++++++++++++++ End Text ++++++++++++++++++++++++++

[Modify page 33, line 8 as follows]

+++++++++++++++ Start Text ++++++++++++++++++++++++++

The procedure is built upon any pre-selected conventional SISO TDL model. For system level simulation, the TDL model as defined in 4.2.1 and 4.2.2 shall be used to generate the spatial channel model. The per-tap …

+++++++++++++++ End Text ++++++++++++++++++++++++++

6 References

[1]. ‘Draft IEEE 802.16m Evaluation Methodology Document’, Editor Roshni Srinivasan, IEEE C802.16m-07/080r1, 17th April, 2007

[2]. ‘Physical layer aspects of UTRA High Speed Downlink Packet Access’, 3GPP TR 25.848, v4.0.0(2001-03)

[3]. ‘Channel Models for Fixed Wireless Applications’, IEEE 802.16.3c-01/29r4, 16th July, 2001

[4]. ‘Extension of the Strawman-ITU channel models and the SCM to wide-band channel models with desired spaced-frequency correlation’, A.G.Kogiantis et al, 3GPP2 TSG-C WG3, C30-20050718-028

[5]. ‘Wide Bandwidth Spatial Channel Model’, D.Reed et al, 3GPP2 TSG-C WG3, C30-20050718-017