Project	**IEEE 802.16j Mobile Multihop Relay Task Group**	
Title	**Proposal for additional pathloss models for 802.16 links with relay stations**	
Date	**2007-01-18**	
Source(s)	**Andreas F. Molisch, Jinyun Zhang** Mitsubishi Electric Research Lab 201 Broadway Cambridge, MA 02139 USA	Voice: Fax: 617-621-7550 {molisch, jzhang}@merl.com
	Toshiyuki Kuze Mitsubishi Electric Corp 5-1-1 Ofuna Kamakura, Kanagawa 2478501, Japan	Voice: +81-467-41-2885 Fax: +81-467-41-2486 Kuze.Toshiyuki@ah.MitsubishiElectric.co.jp
	Dean Kitchener Nortel London Road, Harlow, Essex CM17 9NA, UK	Voice: +44 1279 403118 Fax: +44 1279 402100 deank@nortel.com
	Gamini Senarath Nortel 3500 Carling Avenue Ottawa, Ontario K2H 8E9 **Jun Bae Ahn** SOLiD Technologies, Inc. 78 Garak-Dong, Songpa-Gu, Seoul, 138-803 Korea **I-Kang Fu** NCTU/ITRI ED922, 1001 Ta Hsueh Road, Hsinchu City, Taiwan, R.O.C.	
Re:	*Response to the call for technical proposal regarding IEEE Project 802.16j (i.e., IEEE 802.16j-06/034, "Call for Technical Proposals regarding IEEE Project P802.16j", December 12, 2006).*	
Abstract	*This contribution describes a proposal for additional channel models for the evaluation of IEEE 802.16j system proposals. Those channel models particularly take into account the presence of a relay station, which either leads to a different channel model, or allows to extend the range to environments that cannot be covered by other 802.16 systems. Each model is based on an extensive literature study.*	
Purpose	*To adopt the solution to **the channel modeling problem** proposed herein into IEEE 802.16j.*	
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>.*

Proposal for additional pathloss models for 802.16 links with relay stations

Andreas F. Molisch, Jinyun Zhang
Mitsubishi Electric Research Lab
201 Broadway
Cambridge, MA 02139 USA

Toshiyuki Kuze
Mitsubishi Electric Corp
5-1-1 Ofuna Kamakura, Kanagawa
2478501, Japan

Dean Kitchener
Nortel
London Road, Harlow, Essex CM17 9NA, UK

Gamini Senarath
Nortel
3500 Carling Avenue
Ottawa, Ontario K2H 8E9

Jun Bae Ahn
SOLiD Technologies, Inc.
78 Garak-Dong, Songpa-Gu,
Seoul, 138-803 Korea

I-Kang Fu
NCTU/ITRI
ED922, 1001 Ta Hsueh Road,
Hsinchu City, Taiwan, R.O.C.

1. Introduction

The 802.16j group is in the process of establishing a standard for wireless MANs that use (fixed) relay stations. Propagation channel models are required, so that the performance of various system proposals can be evaluated quantitatively. This submission recommends some path loss models for some cases which are missing from the current Evaluation Methodology Document text (80216j-06_013r2.pdf), and it also addresses some typographical errors present in the document.

While there are some good channel models from the 802.16e group [1], those models do not take into account the particular environments that arise when stations with relaying capability are taken into account. In particular, the 16j standard requires the following scenarios:

- propagation from a BS antenna to a relay antenna that is at, or above, rooftop height. It is obvious that an efficient relay needs a strong (low attenuation) channel to the BS; otherwise, the BS might just as well transmit directly to the MS.

- propagation to MSs that under normal circumstances would not receive sufficient power. In particular, MSs located inside of buildings, inside cars, and in tunnels, are to be considered.

The proposed models are all based on results from the literature; time constraints did not allow to perform new measurements. the subsequent sections therefore first start out with a literature review of each scenario, then discuss the results, and finally propose a specific model.

We make the following comments about the remainder of this document:

- We discuss both the average pathloss (as a function of distance), and the variance of the pathloss (shadowing). To simplify the discussion, we assume that the shadowing is lognormally distributed, even though this specific pdf does not always follow from the data provided in the literature (in most cases, the number of available data points does not allow to make any conclusions about the form of the pdf).

- In most cases, there are large variations in the values of the pathloss obtained in different papers. We try to fit the shadowing variance in such a way that the *10%* and *90%* percentiles are achieved at

the extreme values observed in the literature. This is done so that "best" and "worst" case estimates occur with reasonable frequency in simulations.

- In many cases (outdoor-to-indoor; outdoor-to-car), the model we describe is just the *excess* attenuation. When the variance of the "normal" (outdoor-to-outdoor) shadowing is combined with the shadowing of the excess pathloss, we assume that the composite distribution again has a lognormal distribution. Mean and variance of such a composite lognormal distribution can be obtained, e.g., via the method of [2].

- The models do not include a frequency dependence in most cases. The reason for this is that many of the measurements were performed only at 900 and 1800 MHz. The 1800 MHz measurements are close enough to at least some of the envisioned 802.16 bands, so that the values can be taken over; many of the measurements also confirmed that the behavior at 1800 and 900 MHz are relatively similar. While it is not appropriate to extrapolate a frequency-dependence from the 900/1800 range to the 2500/3500/5000 frequency range, such a frequency dependence was neglected for want of a better available model.

Therefore, we stress that all of the models presented in this document are only approximate, and are partly based on measurements in frequency ranges that are not envisioned 802.16 bands. The models are therefore not recommended for scientific purposes or absolute performance prediction, but only for an estimate of the relative merits of different systems within 16j.

2. Pathloss Model between Base Station and Relay Station on a Roof

2.1 Literature overview and simulation results

If the relay station is at rooftop height, then the model of Walfish and Bertoni (for a summary, see [3]) can be used with very small modifications. This model was originally intended for the coverage predictions in urban areas; it describes the total pathloss as the sum of three terms: the free-space pathloss, the "over-the-rooftop" pathloss, and the diffraction pathloss from the building into the street. If the communication is between a device above rooftop, and a device at rooftop height, then the last attenuation term (roofedge-to-street) is not present; no other modifications of the model are necessary (this conclusion was confirmed by H. Bertoni, private communications). In order to retain consistence with other widely used models, we recommend that the COST 231 version of the Walfish-Bertoni-Ikegami model (often known as COST231-WI model) be used (see [4])

$$L_{\text{msd}} = L_{\text{bsh}} + k_{\text{a}} + k_{\text{d}} \log d + k_{\text{f}} \log f_{\text{c}} - 9 \log b \tag{1}$$

where b is the distance between two buildings (in meters). Furthermore,

$$L_{\text{bsh}} = \begin{cases} -18\log(1+\Delta h_{\text{b}}) & \text{for } h_{\text{b}} > h_{\text{Roof}} \\ 0 & \text{for } h_{\text{b}} \leq h_{\text{Roof}} \end{cases} \tag{2}$$

$$k_{\text{a}} = \begin{cases} 54 & \text{for } h_{\text{b}} > h_{\text{Roof}} \\ 54 - 0.8\Delta h_{\text{b}} & \text{for } d \geq 0.5 \text{ km and } h_{\text{b}} \leq h_{\text{Roof}} \\ 54 - 0.8\Delta h_{\text{b}} \dfrac{d}{0.5} & \text{for } d < 0.5 \text{ km and } h_{\text{b}} \leq h_{\text{Roof}} \end{cases} \tag{3}$$

where

$$\Delta h_{\text{b}} = h_{\text{b}} - h_{\text{Roof}} \tag{4}$$

and h_{b} is the height of the BS. The dependence of the pathloss on the frequency and distance is given via the parameters k_{d} and k_{f} in Eq. (1):

$$k_{\text{d}} = \begin{cases} 18 & \text{for } h_{\text{b}} > h_{\text{Roof}} \\ 18 - 15\dfrac{\Delta h_{\text{b}}}{h_{\text{Roof}}} & \text{for } h_{\text{b}} \leq h_{\text{Roof}} \end{cases} \tag{5}$$

$$k_{\text{f}} = -4 + \begin{cases} 0.7(\dfrac{f_c}{925} - 1) & \begin{array}{l} \text{for medium} - \text{size cities} \\ \text{suburban areas with average vegetation density} \end{array} \\ 1.5(\dfrac{f_c}{925} - 1) & \text{for metropolitan areas} \end{cases} . \tag{6}$$

Table 1 gives the validity range for this model; note that the range of validity for the MS assumes the presence of a rooftop-to-street diffraction loss. In our case, where the MS (or rather, RS) is at rooftop height, the strict validity region is the RS height equals the rooftop height. A more extensive discussion will be given in the following.

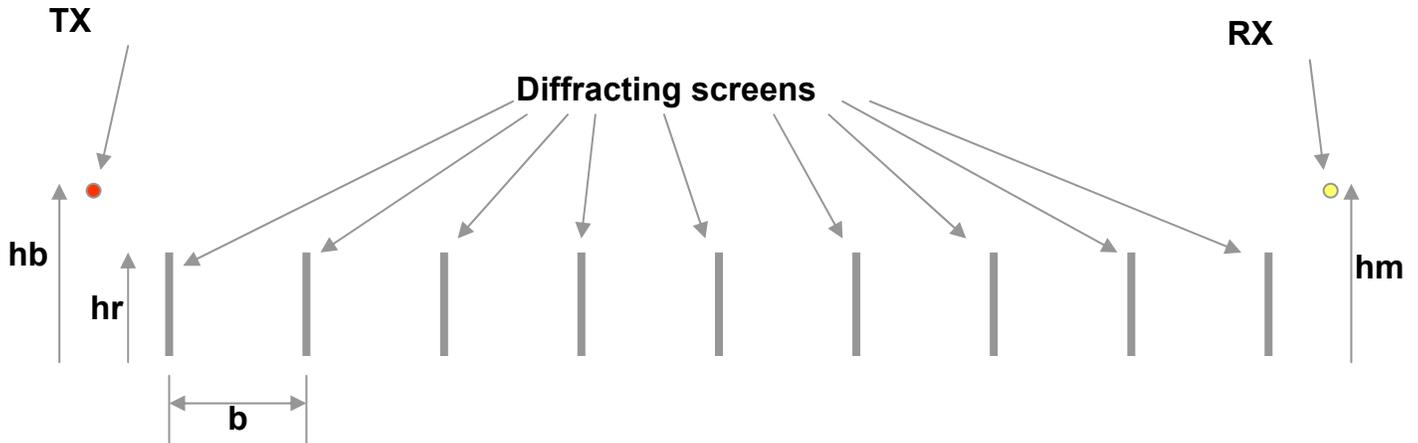|			
Carrier frequency	f_c	800...2000	MHz
height of the BS antenna	h_{b}	4...50	m
height of the MS antenna	h_{m}	1...3	m
distance	d	0.02...5	km

Table 1: Validity region of the COST 231 WI-model

Fig. 1 Scenario for over-the-rooftop diffraction

It is interesting to treat the situation where the relay station is above rooftop height. In this case, the distribution of the field can be computed from the solution of the diffraction equation as described in [3], Sec. 6.5. In the following, we give one example (Fig. 2): distance between screens $d = 50$ m. carrier frequency $f = 2$ GHz. As the distance from the BS increases, the normalized field above the screens soon reaches a steady state - in other words, the "height gain" if the RS antenna is higher than rooftop becomes constant. On the other hand, the "BS-to-rooftop" attenuation follows Eq. (1).

However, the solution of these equations for arbitrary heights of the relay station above the rooftops requires numerical solution that are quite CPU-time intensive. Another problem lies in the fact that all the above equations are purely theoretical, and have not been verified by measurements (the exception are measurements of the MIND project of the European Union, see Fig. 3). Building structures in urban and even suburban environments are not completely regular - this is in contrast to the assumption of the model above that all rooftops have the same height. In this light, it seems doubtful whether a highly accurate curvefitting procedure (based on extensive simulations) is useful.

For these reasons, we suggest as an extremely simple, though suboptimum, solution to use the COST 231 WI-model, with the rooftop-to-street diffraction loss removed. This neglects the gain that we can obtain from raising the RS antenna above rooftop. In view of the above discussion (model not fulfilled exactly; little experimental verification), this inaccuracy seems tolerable.
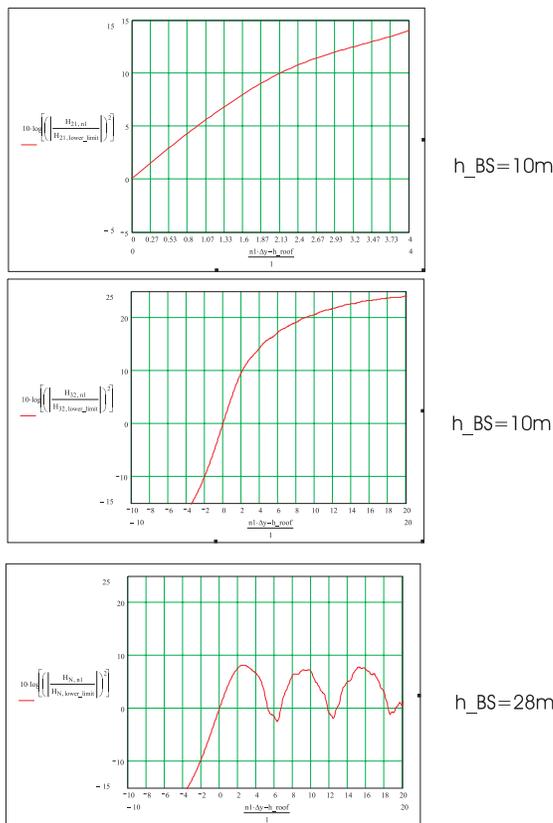

Figure 2 "Elevation gain" of a relay station above rooftop from numerical simulations according to the method of Bertoni. Simulation assumptions: Number of screens: 31, screen spacing: 50 m, frequency: 2 GHz, screen height: 8m.

2.2 Suggested model

For BS-to-relay transmission, the pathloss (additively) consists of the free-space pathloss and the multi-screen diffraction loss, as given by equations (1)-(6). The model is to be used for RS heights between 0 and 2 m above rooftop height.
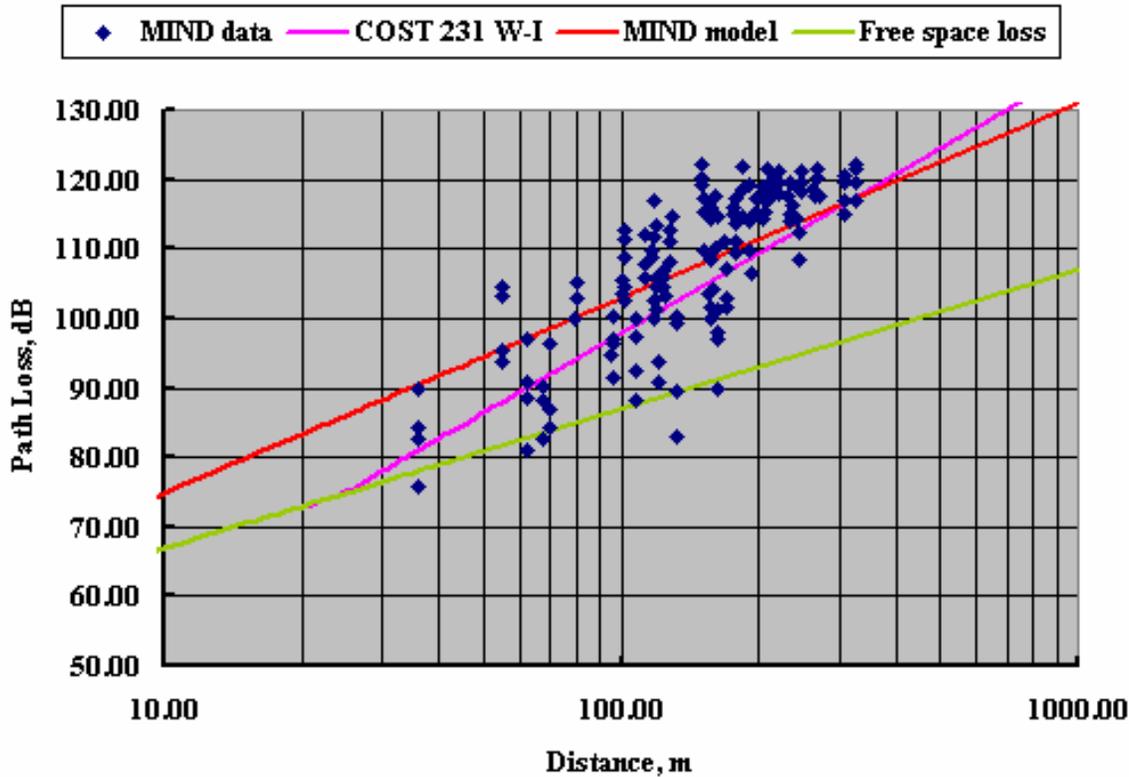

Fig. 3 comparison of the modified COST 231 W-I model with the measured data from IST MIND, and the IST MIND empirical path loss model b = 50m; w = 30m; hr = 6.5m; hb = hm = 8m; f = 5.3GHz

3. Pathloss Model for Receivers inside a Building

3.1. Literature Overview

Most of the literature for outdoor-to-indoor propagation models the pathloss as the sum of a pathloss from the BS to a point right outside the considered building, plus an extra penetration loss:

$$L_{\text{total}} = L_{\text{outdoor}-\text{outdoor}} + L_{\text{penetration}} \qquad (7)$$

When studying the literature, it is useful to keep in mind that some papers include an extra "floor gain" in the pathloss equations, i.e., they explicitly take into account the fact that the pathloss decreases as the height of the MS above (absolute) ground increases. Typically, floor gains of 1.5 - 2 dB per floor have been observed [5], [6], [7], [8], while up to 7 dB were measured in [9]. However, we consider only the worst-case scenarios, i.e., mobile stations on the ground floor, so that the height gain will not be considered further here.

Following the work of [5], the penetration loss $L_{\text{penetration}}$ can be modeled as

$$L_{\text{penetration}} = L_e + L_g' + n_{\text{walls}}L_i \qquad (8)$$

where L_e is the attenuation of waves at normal incidence onto an outer wall, L_g' is an extra attenuation that occurs when the wave is incident at oblique incidence, n_{walls} is the number of walls, and L_i is the attenuation by an interior wall. It must be emphasized that in principle, the quantity L_g' depends on the angle of incidence of the wave. However, since typically (especially in NLOS) *several* significant waves are incident, we can take an average value.[1]

Ref. [5] then provides the following values for the parameters for the penetration loss at 2.5 GHz

Parameter	Wood	Stucco	Mixed
L_e	6.6	6.7	5.2
L_i	2.4	3.5	NA
L_g'	5.7	6.4	6.4

The relative standard deviation of wall-penetration attenuations was measured, both for normal and oblique incidence. The relative rms deviation varies between 0.28 and 0.82 .

Similar parameters had also been established by the COST 231 action ([4], cited in [5]) at 1800 MHz

Parameter	material	approximate value [dB]
L_e (or L_i) for	wooden walls	4
L_e (or L_i) for	concrete walls with non-metallized windows	7
L_e (or L_i) for	concrete walls without windows	10-20
L_g'	unspecified	6

---

[1]A somewhat more detailed model is described by COST 231 in [4]. However, in order to simplify the discussion, we do not elaborate on this model in the present document.

We also note that according to [10], the attenuation of concrete, and of metallized windows, is rather similar. For this reason, the above results for concrete walls without windows can also be applied to concrete walls with metallized windows, which are often encountered in modern office buildings. For the internal walls made of brick or double softboard, [9] give the values of 5.8 and 6.7 dB, respectively.

From the model of [5], when calculating the total penetration losses, we then obtain (for the typical case of $n_{walls} = 1$, a total loss of $13 - 16$ dB. This is somewhat lower than the penetration loss determined by [6], which was between 19 and 22 dB, as well as that of [9], who measured $16 - 22$ dB for the outer walls. On the other hand, [7] measured penetration losses of 12 dB; [8] measured a mean of 17 dB.

[8] also measured the frequency dependence, and showed a slight decrease of the attenuation with increasing frequency: e.g., from 14.2 dB at 900 MHz to 12.8 dB at 2300 MHz. The standard deviation within one building is approximately 4 dB in NLOS situations, and $6 - 9$ dB in LOS situations.

Further measurements were made by Shafi et al. (private communication), indicating mean pathlosses between 18 and 22 B in urban environments (with somewhat lower values in suburban environments), and a standard deviation of 8 dB.

3.2. Discussion

It is of interest to discuss the various possible reasons for the different penetration-loss values that have been measured in the above-cited papers.

The main reason is probably the different building materials that have been used for the outside walls. Some of the papers explicitly measured penetration losses for different materials, while other papers just picked some specific buildings (partly describing their wall structure). The measurements of [8] are especially interesting, because they show a wide variety of building structures (e.g., some buildings with a glass front, others with reinforced concrete), and observe penetration losses between 5 dB and more than 20 dB, while [11] measured between 0 and 23 dB, with an average of 16 dB, and a standard deviation within each site of about 4 dB (as read from Fig. 2 of that paper). This makes reinforces the (intuitively pleasing) notion that the building material and building structure has a major influence on the received signal power.

Furthermore, the materials of the windows also plays a significant role. In most residential buildings in the USA, normal single-glass pane windows are used, which provide a good propagation path into a building. The fact that this is a dominant propagation path is also confirmed by the fact that the height of the mobile station above the floor (e.g., 0.5 m, 1 m, etc.), has a significant impact on the measured field strength. Receivers that are at window height see higher receive power than those below or above the window opening [5]. The situation is different when windows are metal-coated, e.g., for energy savings. As mentioned above, such windows have about 20 dB penetration loss, and are thus similar to the attenuation created by reinforced concrete [10].

Yet another major factor is the angle of incidence of the radiation. In a line-of-sight scenario, the penetration loss can strongly depend on the angle of the LOS component. However, in an NLOS scenario, the results of [9] show that the most effective waves are incident almost perpendicularly onto the building, so that the penetration loss is similar to the "excess loss" (due to grazing incidence) $L_g^{'}$ is *smaller* in NLOS scenarios than in LOS scenarios. Thus, a possible channel model would distinguish between LOS and NLOS. In that case, the LOS model should explicitly take into account the angle under which the LOS component is incident on the building. This (probably more accurate) approach is not pursued here for the sake of simplicity.

While the available measurements mostly cover a frequency range of 900-2000 MHz, we use them (without justification) also for higher frequencies.

We finally notice that the presence of a building increases the shadowing variance.

3.3 Suggested Model

We propose to use a simple "excess attenuation" to the attenuation of the outdoor-to-outdoor model

$$L_{\text{total}} = L_{\text{outdoor-outdoor}} + 18 \text{ dB} + 3n_{\text{walls}} \tag{9}$$

and a standard deviation of 8 dB. The model is to be used for carrier frequencies between 2 and 6 GHz, and mobile station heights between 0 and 2 m.

4. Pathloss Model for Receivers inside a Car

4.1. Literature Overview

A number of measurements and models have been developed for the excess penetration loss that occurs when a user is inside a car. The impact of the elevation angle of the radiation on the attenuation was investigated in [12], at a frequency of 1600 MHz. The measurements in this paper were done with different antenna types, and with different types of cars. The results for the mean excess loss and the 90% percentile of the excess loss are given in the following table.

Elevation	Patch mean	Patch 90%	helix mean	helix 90%
8	4.8	19.9	4.3	11.5
15	7.9	17.9	1.6	6.9
27	7.8	16.9	1.5	5.1
46	4.5	14.6	0.4	4
73	5 (est.)	12 (est.)	0 (est.)	3 (est.)
90	5 (est.)	12 (est.)	0 (est.)	3 (est.)

Note that 0 degree elevation angle here means horizontal propagation. The considerable difference between mean and 90% percentile indicates the strong increase in the variance of the pathloss. Overall, the excess median pathloss is 5.5 dB, with a 3.1 dB standard deviation. It was confirmed that the statistics of the excess loss follow a lognormal distribution

[13] analyzes the car penetration loss at different frequencies - up to 900 MHz. They also tested different arrangements of the antennas on the tester, i.e., next to head, as well as hip position. They found that the excess loss decreases with frequency, and that the mean is 3.2 dB near the head, while it is almost 10 dB for a belt case. No statements were made about the shadowing.

We finally note that quasi-deterministic models have been created by [14], and [15].

4.2. Suggested model

We suggest that the case "terminal inside a car" only be considered if the terminal is moving - in the case of a stationary terminal, the "outdoor-to-indoor" case provides higher attenuation, and thus a more strict "worst-case" estimate. In the case that the terminal is moving, the following simple pathloss model is suggested

$$L_{\text{total}} = L_{\text{outdoor}-\text{outdoor}} + 5.5 \text{ dB} \tag{10}$$

This reflects a worst-case scenario where the user "sees" mostly radiation coming in from 20 degrees elevation, and has a belt-mounted antenna. The standard deviation of the shadowing is proposed to be 3 dB. With this choice, the 90 % reliability requires aboutadditional 10 dB power; in line with the maximum excess attenuation measure for a beltcase-born device in [13].

5. Pathloss Model for Receivers in Tunnels

5.1. Literature Overview

The attenuation of a narrowband signal in a tunnel consists of two components: the loss experienced by the signal when coupling into the tunnel, and the attenuation in the tunnel itself. It is noteworthy that the distance dependence of the signal in the tunnel is different from the usual power law; it is given as

$$L_{\text{tunnel}-\text{distance}} = \alpha d \text{ [dB]} \tag{11}$$

where α is the attenuation in dB/unit length.

Obviously, the coupling losses depend on the angular distribution of the radiation at the tunnel entrance. Unfortunately, there seems to be no results in the literature about either this distribution, or the effective coupling losses incurred when the base station antenna is far away from the tunnel entrance (a number of results exist in the below-cited papers when the BS antenna is directly at the tunnel entrance.

[16] presents extensive measurement results in several subway tunnels at 900 MHz. Attenuations range from 15 dB/100 m in a two-track tunnel to 25 dB/100 m in a one-track tunnel. In a two-track tunnel, the presence of a second (masking) train leads to an extra attenuation of 15 dB, while in a two-track tunnel, a second train does not have an impact on the total attenuation. [17] found $10-15$ dB/km at 900 MHz in rectangular railway tunnels, while he found 35 to 40 dB for tunnels with semi-circular cross section. [18] found 20 dB/km in a standard two-way street tunnel with smooth walls, while they found 50 dB /km in a tunnel with rough (untreated rock) walls. [19] did not provide curve-fitting results for their measurements in subway tunnels, but from the graphs in this reference, approximately 20 dB/km are to be anticipated at 1800 MHz.

[20] measured the attenuation in the tunnel at various frequencies, finding that it decreases with frequency. The measured values of the attenuation constant are extremely low, namely 0.7 dB/km at 4 GHz. This is in contrast to the results of [16], who found that the attenuation is independent of frequency. The reason for this discrepancy lies in the fact that the results of [16] were obtained in a heavily over-moded tunnel (i.e., at all observed frequencies, multiple modes were significantly above the cutoff frequency, while this was not the case in [20]. However, the huge difference in attenuation constants (0.7 dB / km vs. 150 dB/km) is still somewhat of a mystery.

The above-mentioned papers do not contain statements about distance-dependent shadowing. [18] give a 12 dB fading margin for 95% reliability, which is consistent with pure Rayleigh fading. Extra attenuation is introduced due to the presence of other vehicles, e.g., a masking train (see above), or due to trucks entering the

2007-01-08 IEEE C802.16j-07/105

tunnel, and blocking the transmission path of the waves into the tunnel. For the latter case, [18] identify an average loss between -1.5 and +1 dB (depending in the type of car), with a standard deviation of about 3.5 dB (5 dB for 90% reliability).

5.2 Suggested Model

We suggest the following model for the pathloss in a tunnel:

$$L_{\text{total}} = \begin{cases} L_{\text{entrance}}(f) + 6 + qd + k & \text{if BS or relay far away from tunnel entrance} \\ L_0(f) + qd + k & \text{if BS or relay at tunnel entrance} \end{cases} \tag{12}$$

where L_{entrance} is the attenuation from the base station (or relay) to the tunnel entrance, 6 dB coupling loss of the rays into the tunnel was assumed (this number is pure guesswork). If the BS is located at the tunnel entrance, then we assume a standard free-space law up to a distance of 1 m (the term $L_0(f)$; for larger distances, the exponential pathloss model is again valid.

The parameter q is the attenuation per meter; the parameter k is an extra attenuation arising from obstacles (e.g., a train) present in the tunnel. For the typical case (tunnel model A), we set $q=0.02$ dB/m, and $k=0$. For the worst case (tunnel model B), we set $q=0.1$ dB/m, and $k=15$.

6. Summary and Conclusions

We have presented a number of additional channel models for the evaluation of IEEE 802.16j systems. In particular, we propose simple models for propagation from BS to relay over rooftops, and propagation from (elevated) relay station into buildings, cars, and tunnels. For propagation into buildings and cars, a simple excess loss value was taken as an average (or worst-case) from measurements in the literature; we also recommend that the shadowing variance of a possible pathloss model is increased. For tunnels, an exponential pathloss model is recommended.

7. Proposed text changes

We propose to change the current text in the Evaluation Methodology Document 80216j-06_013r2.pdf as indicated below.

A. Typographical Errors (Corrections to tapped delay line models)

We propose to replace the following text in Section 2.2.3.1 from the text indicated below.

Table 5. 802.16 - SUI channel models

Terrain Type A: Hilly terrain with moderate-to-heavy tree densities: SUI 1				
	Tap1	Tap2	Tap3	Unit
Delay	0	0.4	0.9	μs
Power	0	-15	-20	dB
K factor	4	0	0	
Doppler	0.4	0.3	0.5	Hz
Terrain Type A: Hilly terrain with moderate-to-heavy tree densities: SUI 2				
	Tap1	Tap2	Tap3	Unit
Delay	0	0.4	1.1	μs
Power	0	-12	-15	dB
K factor	2	0	0	
Doppler	0.2	0.15	0.25	Hz
Terrain Type B: Intermediate path-loss condition: SUI 3				
	Tap1	Tap2	Tap3	Unit
Delay	0	0.4	0.9	μs
Power	0	-5	-10	dB
K factor	1	0	0	
Doppler	0.4	0.3	0.5	Hz
Terrain Type B: Intermediate path-loss condition: SUI 4				
	Tap1	Tap2	Tap3	Unit

Replace "Terrain Type A: hilly terrain with moderate-to-heavy tree density: SUI 1" with "Terrain Type C: flat terrain with light tree densities: SUI 1"
Replace "Terrain Type A: hilly terrain with moderate-to-heavy tree density: SUI 2" with "Terrain Type C: flat terrain with light tree densities: SUI 2"

Delay	0	1.5	4.0	μ s
Power	0	-4	-8	dB
K factor	0	0	0	
Doppler	0.2	0.15	0.25	Hz
Terrain Type C: Flat terrain with light tree densities: SUI 5				
	Tap1	Tap2	Tap3	Unit
Delay	0	4	10	μ s
Power	0	-5	-10	dB
K factor	0	0	0	
Doppler	2.0	1.5	2.5	Hz
Terrain Type C: Flat terrain with light tree densities: SUI 6				
	Tap1	Tap2	Tap3	Unit
Delay	0	14	20	μ s
Power	0	-10	-14	dB
K factor	0	0	0	
Doppler	0.4	0.3	0.5	Hz

Replace "Terrain Type C: flat terrain with light tree densities: SUI 5" with "Terrain Type A: hilly terrain with moderate-to-heavy tree density: SUI 5"
Replace "Terrain Type C: flat terrain with light tree densities: SUI 6" with "Terrain Type A: hilly terrain with moderate-to-heavy tree density: SUI 6"

B. The new models to be included are to be included in the appropriate section numbers indicated below.

2.1.2.6 Type H Urban ART to ART model

The pathloss is determined by the COST 231 model (but excluding the rooftop-to-MS diffraction loss), and consists of the free-space pathloss plus the multiscreen diffraction loss L_{msd}

$$L_{\mathrm{msd}} = L_{\mathrm{bsh}} + k_a + k_d \log d + k_f \log f_c - 9 \log b \tag{1}$$

where b is the distance between two buildings (in meters). Furthermore,

$$L_{\mathrm{bsh}} = \begin{cases} -18 \log(1 + \Delta h_b) & \text{for } h_b > h_{\mathrm{Roof}} \\ 0 & \text{for } h_b \le h_{\mathrm{Roof}} \end{cases} \tag{2}$$

$$k_a = \begin{cases} 54 & \text{for } h_b > h_{Roof} \\ 54 - 0.8\Delta h_b & \text{for } d \geq 0.5 \text{ km and } h_b \leq h_{Roof} \\ 54 - 0.8\Delta h_b \dfrac{d}{0.5} & \text{for } d < 0.5 \text{ km and } h_b \leq h_{Roof} \end{cases} \tag{3}$$

where

$$\Delta h_b = h_b - h_{Roof} \tag{4}$$

and h_b is the height of the BS. The dependence of the pathloss on the frequency and distance is given via the parameters k_d and k_f in Eq. (1):

$$k_d = \begin{cases} 18 & \text{for } h_b > h_{Roof} \\ 18 - 15\dfrac{\Delta h_b}{h_{Roof}} & \text{for } h_b \leq h_{Roof} \end{cases} \tag{5}$$

$$k_f = -4 + \begin{cases} 0.7(\dfrac{f_c}{925} - 1) & \begin{array}{l} \text{for medium} - \text{size cities} \\ \text{suburban areas with average vegetation density} \end{array} \\ 1.5(\dfrac{f_c}{925} - 1) & \text{for metropolitan areas} \end{cases}. \tag{6}$$

A discussion about the scientific merits of that model for the application in rooftop-to-rooftop propagation, see document IEEE-C80216j-07_105r2.pdf.

The following parameters are to be used for the COST 231 WI model: h_b=30 m, r_{roof}=15 m, b=30m, and k_f chosen according to the specifications of metropolitan areas. Those parameters were chosen according to the specifications of COST 259 [22].

2.1.2.7 Type J Outdoor to Indoor, in-vehicle and tunnel model

For the outdoor-to-indoor case, the total pathloss (in dB) is

$$L_{total} = L_{outdoor-outdoor} + L_{excess} \tag{7}$$

where L_{excess} is a normally distributed variable with a mean of $18+3n_{walls}$ dB (with n_{walls}=1), and a standard deviation of 8 dB. For the term $L_{outdoor-outdoor}$, any channel model can be used, but for use in 16j simulations, channel model E as described above is recommended. The model should only be used for MSs being located on the ground floor.

For the outdoor-into-car propagation, the total pathloss (in dB) is

$$L_{total} = L_{outdoor-outdoor} + L_{excess} \tag{9}$$

15

where L_{excess} is a normally distributed variable with a mean of 5.5 and standard deviation of 3, For the term $L_{outdoor\text{-}outdoor}$, any channel model can be used, but for use in 16j simulations, channel model E as described above is recommended. The outdoor-into-car model is to be used only for the analysis of mobile scenarios.

We suggest the following model for the pathloss in a tunnel:

$$L_{\text{total}} = \begin{cases} L_{\text{entrance}}(f) + 6 + qd + k & \text{if BS or relay far away from tunnel entrance} \\ L_0(f) + qd + k & \text{if BS or relay at tunnel entrance} \end{cases} \qquad (12)$$

where L_{entrance} is the attenuation from the base station (or relay) to the tunnel entrance, 6 dB coupling loss of the rays into the tunnel was assumed (this number is pure guesswork). If the BS is located at the tunnel entrance, then we assume a standard free-space law up to a distance of 1 m (the term $L_0(f)$; for larger distances, the exponential pathloss model is again valid.

The parameter q is the attenuation per meter; the parameter k is an extra attenuation arising from obstacles (e.g., a train) present in the tunnel. For the typical case (tunnel model A), we set q=0.02 dB/m, and k=0. For the worst case (tunnel model B), we set q=0.1 dB/m, and k=15.

8. References

[1] V. Erceg et al., "Channel models for fixed wireless applications," 802.16.3c-01/29r4, (2001).

[2]   J. Wu, N. B. Mehta, and J. Zhang, "Flexible lognormal sum approximation method," in *Proc. IEEE Globecom 2005*, pp. 3413–3417, 2005.

[3] H. L. Bertoni, *Radio Propagation for Modern Wireless Systems*. Prentice-Hall, 2000.

[4] E. Damosso and L. Correia, eds., *Digital mobile radio towards future generation systems*. Commission of the European Union, 1999.

[5]   C. Oestges and A. J. Paulraj, "Propagation into buildings for broad-band wireless access," *IEEE Trans. Vehicular Techn.*, pp. 521–526, 2004.

[6] T. Kuerner and A. Meier, "Prediction of outdoor and outdoor-to-indoor coverage in urban areas at 1.8 ghz," *IEEE J. Selected Areas Comm.*, pp. 496–506, 2002.

[7] E. Martijn and M. Herben, "Characterization of radio wave propagation into buildings at 1800 mhz," *IEEE Antennas and Wireless Propagation Letters*, vol. 2, pp. 122–125, 2003.

[8]   A. DeToledo, A. Turkmani, and J. Parsons, "Estimating coverage of radio transmission into and within buildings at 900, 1800, and 2300 mhz," *IEEE Personal Communications*, vol. 5, no. 2, pp. 40–47, 1998.

[9] R. Gahleitner and E. Bonek, "Radio wave penetration into urban buildings in small cells and microcells," in *Proc. 44th IEEE Vehicular Technology Conference*, pp. 887–891, 1994.

[10] S. Wyne, A. F. Molisch, P. Almers, G. Eriksson, J. Kåredal, and F. Tufvesson, "Statistical evaluation of outdoor-to-indoor office mimo measurements at 5.2 ghz," in *Proc. 61st IEEE Vehicular Techn. Conf.*, pp. 146–150, 2005.

[11] W. Tanis and G. Pilato, "Building penetration characteristics of 880 mhz and 1922 mhz radio waves," in *Proc. 43rd IEEE Vehicular Technology Conference*, 206-209.

[12] W. Vogel, G. Torrence, and K. N., "Measurement of propagation loss into cars on satellite paths at l-band," in *Proc. Second Europ. Workshop on Mobile and Personal Satellite Comm.*, pp. 129–138, 1996.

[13]   C. Hill and T. Kneisel, "Portable radio antenna performance in the 150, 450, 800, and 900 mhz bands 'outside' and in-vehicle," *IEEE Trans. Vehicular Techn.*, vol. 40, pp. 750–756, 1991.

[14] P. Wertz, D. Zimmermann, F. Landstorfer, G. Wolfle, and R. Hoppe, "Hybrid ray optical models for the penetration of radio waves into enclosed spaces," in *Proc. 58th IEEE Vehicular Technology Conference*, pp. 109–113, 2003.

[15] F. Harrysson, "A simple directional path loss model for a terminal inside a car," in *Proc. 58th IEEE Vehicular Technology Conference*, pp. 119–122, 2003.

[16] M. Lienard, P. Degauque, and P. Laly, "Communication and distance measurement in subway tunnels using natural propagation," in *Proceedings of the Fifth IEEE International Caracas Conference on Devices, Circuits and Systems*, pp. 240–243, 2004.

[17] R. Klingler, "Radio coverage for road and rail tunnels in the frequency range 75 to 1000 mhz," in *st Proc. IEEE Vehicular Technology Conference*, pp. 433–438, 1991.

[18] T. Klemenschits and E. Bonek, "Radio coverage of road tunnels at 900 and 1800 mhz by discrete antennas," in *Proc. 5th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*, pp. 411–415, 1994.

[19] D. Didascalou, J. Maurer, and W. Wiesbeck, "Subway tunnel guided electromagnetic wave propagation at mobile communications frequencies," *IEEE Trans. Antennas and Propagation*, vol. 49, pp. 1590–1596, 2001.

[20] J. Chiba, T. Inaba, Y. Kuwamoto, O. Banno, and R. Sato, "Radio communication in tunnels," *IEEE Trans. Microwave Theory and Techn.*, vol. 26, pp. 439–443, 1978.

[21] 'On the Propagation Characteristics of the 5GHz Roof-to-Rooftop Meshed Network', IST Mobile & Wireless Telecommunications Summit, 17-19 June 2002, Thessaloniki, Greece.

[22] M. Steinbauer and A. F. Molisch, "Directional channel modeling", Sec. 3.2 in L. Correia, "Wireless Flexible Personalized Communications", Wiley, 2001.