Project	***IEEE 802.16j Mobile Multihop Relay Task Group***
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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 first version of proposals 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	
Release	
Patent Policy and Procedures	

Proposal for additional pathloss models for 802.16 links with relay stations

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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. 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 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 WiMax bands, so that the values can be taken over; many of the measurements also confirmed that the behavior at 1800 and 900 MHz are relativiely similar. In any case, it is not appropriate to extrapolate a frequency-dependence from the 900/1800 range to the 2500/3500 frequency range. Thus, frequency dependence was neglected for want of a

better available model.

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

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 be used (see [4])

$$L_{\mathrm{msd}} = L_{\mathrm{bsh}} + k_{\mathrm{a}} + k_{\mathrm{d}} \log d + k_{\mathrm{f}} \log f_{\mathrm{c}} - 9 \log b \qquad (1)$$

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

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

$$k_{\mathrm{a}} = \begin{cases} 54 & \text{for } h_{\mathrm{b}} > h_{\mathrm{Roof}} \\ 54-0.8\Delta h_{\mathrm{b}} & \text{for } d \ge 0.5 \text{ km and } h_{\mathrm{b}} \le h_{\mathrm{Roof}} \\ 54-0.8\Delta h_{\mathrm{b}}\dfrac{d}{0.5} & \text{for } d < 0.5 \text{ km and } h_{\mathrm{b}} \le h_{\mathrm{Roof}} \end{cases} \qquad (3)$$

where

$$\Delta h_{\mathrm{b}} = h_{\mathrm{b}} - h_{\mathrm{Roof}} \qquad (4)$$

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):

$$k_{\mathrm{d}} = \begin{cases} 18 & \text{for } h_{\mathrm{b}} > h_{\mathrm{Roof}} \\ 18-15\dfrac{\Delta h_{\mathrm{b}}}{h_{\mathrm{Roof}}} & \text{for } h_{\mathrm{b}} \le h_{\mathrm{Roof}} \end{cases} \qquad (5)$$

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

Table 1 gives the validity range for this model

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

The situation is somewhat more complicated when 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. 1): 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. It might be preferable to have fitting equations for the desired range of heights and wavelengths. Extensive simulations will be needed to find appropriate fitting factors. The fitting will depend on the spacing of the buildings, the frequency, and the BS height, RS height, and building height.

Another problem lies in the fact that all the above equations are purely theoretical, and have not been verified by measurements (the exception is a comparison by Kitchener of an extended COST 231 model with measurements of the MIND project of the European Union). Since 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 measurements) is useful.

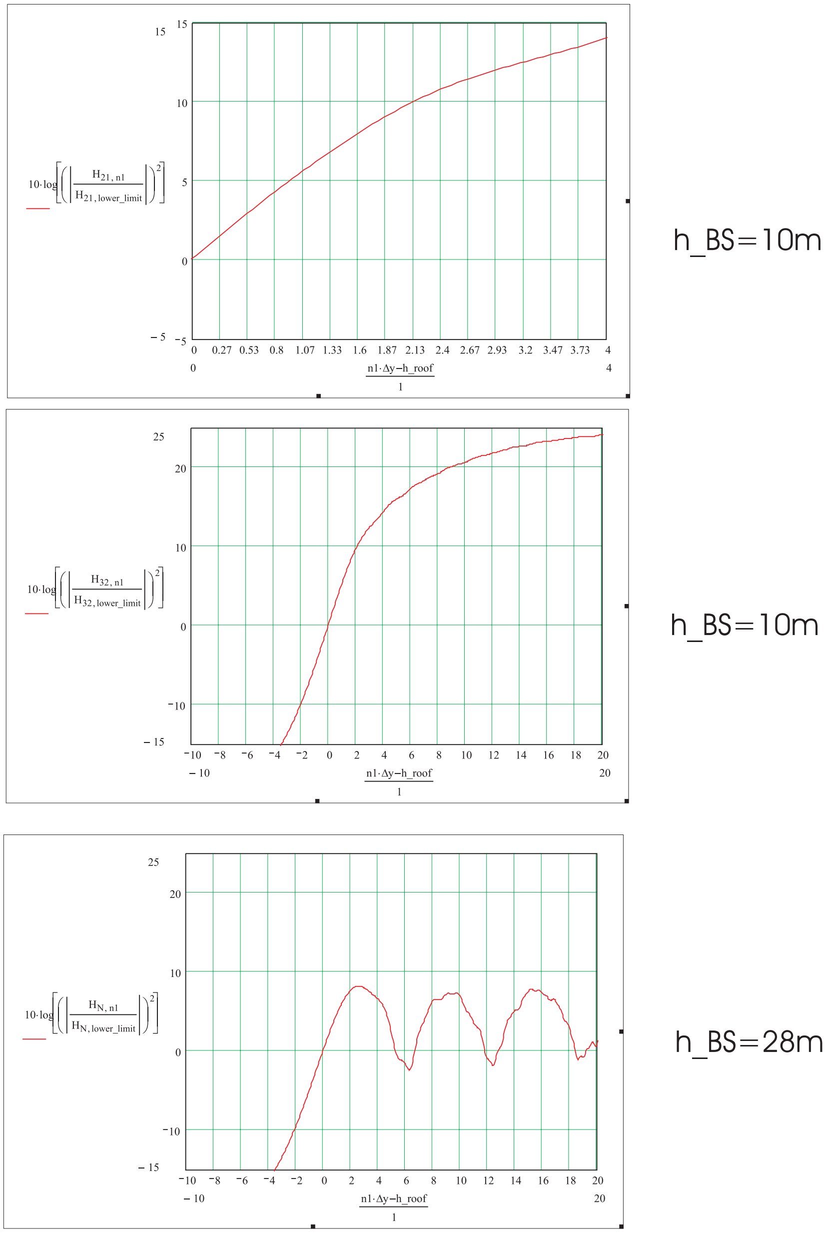

Figure 1 "Elevation gain" of a relay station above rooftop. Simulation assumptions: Number of screens: 31, screen spacing: 50 m, frequency: 2 GHz, screen height: 8m.

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. While the COST 231 Walfish Ikegami model is the most popular one, alternative models, including the existing 802.16e models, can be used. In order to achieve consistency with the existing 802.16 models, we suggest that those existing models be used as a basis for the outdoor-to-indoor propagation:

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

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, taking such a floor gain into account is not necessary when the equations for $L_{\text{outdoor-outdoor}}$ are height-dependent, and valid for MS heights between 0 and h_{rt}, i.e., the rooftop height. We note that the IEEE 802.16 channel models fulfill those conditions; therefore, an explicit consideration of the floor gain is henceforth not necessary.

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

$$L_{\text{penetration}} = L_{\text{e}} + L_{\text{g}}' + n_{\text{walls}} L_{\text{i}} \quad (8)$$

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 *several* 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

[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.

L_e (or L_i) for	concrete walls without windows	10-20
L'_g	unspecified	6

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.

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 penetation 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.

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

$$L_{\text{total}} = L_{\text{outdoor-outdoor}} + 15\ \text{dB} + 3n_{\text{walls}} \quad (9)$$

and a standard deviation of 6 dB, so that the 10 and 90 % reliability percentiles are at 5 and 25 dB.

An alternative 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. Further discussions about whether this is consistent with the 802.16 modeling approach are desirable.

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

$$L_{\text{total}} = L_{\text{outdoor-outdoor}} + 5.5 \text{ dB} \qquad (10)$$

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 additional 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 Wimax 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

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

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 strong constrast 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 any 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 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). Since variations of signal strength due to moving scatterers are not the main purview of the additional Wimax models, we suggest to ignore this effect.

5.2 Suggested Model

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

$$L_{\text{total}} = \begin{cases} L_{\text{entrance}}(f) + 6 + 0.02d & \text{if BS or relay far away from tunnel entrance} \\ L_0(f) + 0.02d & \text{if BS or relay at tunnel entrance} \end{cases} \quad (12)$$

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), and the 0.02 dB/m is an average value as taken from the above-mentioned papers. This value was chosen because it was the only one that occured in at least two papers. 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.

6. Summary and Conclusions

We have presented a number of additional channel models for 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.

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