<table>
<thead>
<tr>
<th><strong>Project</strong></th>
<th><strong>IEEE 802.16 Broadband Wireless Access Working Group</strong> <a href="http://ieee802.org/16">http://ieee802.org/16</a></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Title</strong></td>
<td>Amendments to the Multi-hop Relay System Evaluation Methodology Document</td>
</tr>
<tr>
<td><strong>Date</strong></td>
<td>2006-11-16</td>
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<td><strong>Submitted</strong></td>
<td>2006-11-16</td>
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<tr>
<td><strong>Source(s)</strong></td>
<td>Gamini Senarath, Mark Naden, Dean Kitchener, G.Q. Wang, Wen Tong, Peiying Zhu Hang Zhang, David Steer, Derek Yu</td>
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<tr>
<td></td>
<td>Voice: 1-613-763-1315 [<a href="mailto:wentong@nortel.com">mailto:wentong@nortel.com</a>]</td>
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<tr>
<td></td>
<td>Nortel 3500 Carling Avenue Ottawa, Ontario K2H 8E9</td>
</tr>
<tr>
<td><strong>Re:</strong></td>
<td>Call for Technical Proposals regarding IEEE Project P802.16j (IEEE 802.16j-06/027)</td>
</tr>
<tr>
<td><strong>Abstract</strong></td>
<td>Correction to the path loss models in 802.16j-06/.013r1</td>
</tr>
<tr>
<td><strong>Purpose</strong></td>
<td>Address a missing path loss models and some editorial corrections to make the applicability of the models clear in P802.16j-06/13r1 document.</td>
</tr>
<tr>
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</tr>
</tbody>
</table>
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Amendments to the Multi-hop Relay System Evaluation Methodology Document
Gamini Senarath, Mark Naden, Dean Kitchener, G.Q. Wang, Wen Tong, Peiying Zhu, Hang Zhang, David Steer, Derek Yu

1. Introduction

The purpose of this document is to propose the following text amendments to the current 802.16j-06/013r1 document to address some of the missing propagation models and editorial comments. They are listed below:

a) Current document does not cover the ART to ART model for urban environment. Since the current ART to ART model (Type D, LOS) is valid only for antenna heights lower than 10 m, it would not be valid for the urban case where average roof top height is larger than 10 m. The new model is described in the document 802.16j-06_271.pdf.

   Proposed Text Change: The text included in Section 2.1.2.6 below should be inserted as Type H model into the 802.16j-06/013r1 document for the urban ART-ART case, with the same section number. The changes to the current section numbers are proposed in (e) below.

b) Current document has no reference on how to model outdoor to indoor, outdoor to inside a tunnel, outdoor to inside a vehicle, and outdoor to underground subways. For that purpose, we propose to include several penetration losses which can be used on top of all the other models, and include them as Type J outdoor to indoor models.

   Proposed Text Change: The Text included in Section 2.1.2.7 below should be inserted into the 802.16j-06/013r1 document for the outdoor-indoor case, with the same section number. The changes to the current section numbers are proposed in (e) below.

c) The type E model does not have adequate parameters to be used for the simulations. In order to have alignment across different simulations we propose to have some parameters specified.

   Proposed Text Change: Proposed Text Change: The Text marked in Blue color included in Section 2.1.2.3 below should be inserted into Type E model description in the 802.16j-06/013r1 document.

d) The above modifications to the models means several changes are required to Table 3 in Section 2.1.1 and Table 4 in Section 2.1.1.1 of 802.16j-06/013r1.

   Proposed Text Change: Replace Table 3 in Section 2.1.1 of 802.16j-06/013r1 by the Table 1 provided in Section 2.1.1 of this document and change Table 4 in Section 2.1.1.1. of 802.16j-06/013r1 as indicated by blue in Table 2, Section 2.1.1.1 of this document.
Several headings of the subsections to be changed to reflect the above changes and Type F LOS and NLOS be covered under the same Type F Section as two subsections.

Proposed Text Changes: We propose to use the titles and section numbers used in this document below as the New section numbers of 802.16j-06/013r1.

Legend for the type of changes:
ABC: Complete changes to a Section or to a Table are marked in BLUE color. These sections should be replaced by the new sections marked in blue. In addition, the other paragraphs marked in blue are new insertions. Some section headings are changed to reflect the model it represents closely which are marked in blue as well.

ABC: The existing unchanged text is in BLACK color.
ABC: The deleted text is marked as STRIKETHROUGH in RED color.
ABC+: New editorial comments are in Pink.

2. Channel Models

2.1 Path-Loss Model

2.1.1 Path-loss Types
The path loss for the IEEE802.16j system contains the basic models for the IEEE802.16-2004 and additional path-loss associated with RS nodes. The path-loss types are listed in

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A</td>
<td>Macro-cell suburban, ART to BRT for Hilly terrain with moderate-to-heavy tree densities</td>
<td>LOS/NLOS</td>
</tr>
<tr>
<td>Type B</td>
<td>Macro-cell suburban, ART to BRT for Intermediate path-loss condition</td>
<td>LOS/NLOS</td>
</tr>
<tr>
<td>Type C</td>
<td>Macro-cell suburban, ART to BRT for Flat terrain with light tree densities</td>
<td>LOS/NLOS</td>
</tr>
<tr>
<td>Type D</td>
<td>Macro-cell suburban, ART to ART</td>
<td>LOS</td>
</tr>
<tr>
<td>Type E</td>
<td>Macro-cell, urban, ART to BRT</td>
<td>NLOS</td>
</tr>
<tr>
<td>Type F</td>
<td>Urban or suburban, BRT to BRT</td>
<td>LOS</td>
</tr>
</tbody>
</table>

NLOS | Section 2.1.2.4.2 |
Note: LOS (Line Of Sight), NLOS (Non Line Of Sight), ART (Above Roof Top), BRT (Below Roof Top)

### 2.1.1.1 The relationship path-loss models with the relay system usage models

#### Table 2. Relationship between path-loss and usage models.

<table>
<thead>
<tr>
<th>Links</th>
<th>Path-loss Type</th>
<th>Applicable Usage Model</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS-RS</td>
<td>Type A/B/C</td>
<td>I, III, IV</td>
<td>Suburban, RS antenna is BRT</td>
</tr>
<tr>
<td></td>
<td>Type D</td>
<td>I, III</td>
<td>Suburban, BS antenna is ART and RS antenna is ART</td>
</tr>
<tr>
<td></td>
<td>Type H</td>
<td>I, III</td>
<td>Urban, BS antenna is ART and RS antenna is ART</td>
</tr>
<tr>
<td></td>
<td>Type E</td>
<td>I, III, IV</td>
<td>Urban, BS antenna is ART and RS antenna is BRT</td>
</tr>
<tr>
<td></td>
<td>TYPE J</td>
<td>II</td>
<td>BS is outdoor and RS is indoor/tunnel</td>
</tr>
<tr>
<td>BS-MS</td>
<td>Type A/B/C</td>
<td>I, III, IV</td>
<td>Suburban, BS antenna is ART</td>
</tr>
<tr>
<td></td>
<td>Type E</td>
<td>I, III, IV</td>
<td>BS antenna is ART</td>
</tr>
<tr>
<td></td>
<td>Type J</td>
<td>II</td>
<td>BS is outdoor and MS is indoor/tunnel</td>
</tr>
<tr>
<td>RS-RS</td>
<td>Type A/B/C</td>
<td>I, III, IV</td>
<td>Suburban, one RS antenna is ART</td>
</tr>
<tr>
<td>-------</td>
<td>------------</td>
<td>------------</td>
<td>--------------------------------</td>
</tr>
<tr>
<td>Type D</td>
<td>I, III</td>
<td></td>
<td>Suburban, both RS antennas are BRT</td>
</tr>
<tr>
<td>Type H</td>
<td>I, III</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type E</td>
<td>I, III, IV</td>
<td></td>
<td>Urban, One RS antenna is ART and another one is BRT</td>
</tr>
<tr>
<td>Type F</td>
<td>I, III, IV</td>
<td></td>
<td>Both RS antennas are BRT</td>
</tr>
<tr>
<td>Type G</td>
<td>II</td>
<td></td>
<td>Both RS antennas are inside building</td>
</tr>
<tr>
<td>Type J</td>
<td>II</td>
<td></td>
<td>One RS is outside the other inside a building/ tunnel</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RS-MS</th>
<th>Type A/B/C</th>
<th>I, III</th>
<th>Suburban, RS antenna is ART</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type E</td>
<td>I, III</td>
<td></td>
<td>RS antenna is ART</td>
</tr>
<tr>
<td>Type F</td>
<td>I, III, IV</td>
<td></td>
<td>RS antenna is BRT</td>
</tr>
<tr>
<td>Type G</td>
<td>II</td>
<td></td>
<td>Both RS and MS antennas are inside building</td>
</tr>
<tr>
<td>Type J</td>
<td>II</td>
<td></td>
<td>RS is outside and MS is inside or RS is inside and MS is outside</td>
</tr>
</tbody>
</table>

The usage models referenced from IEEE 802.16j-06/015 are:

I. Fixed Infrastructure Usage Model
II. In-Building Coverage Usage Model
III. Temporary Coverage Usage Model
IV. Coverage on Mobile Vehicle Usage Model

2.1.2 Detailed Path-loss Models

2.1.2.1 Type-A/B/C (Suburban, ART-to-BRT, LOS/NLOS)
The modified IEEE 802.16 path-loss model is recommended for these links which are provided in [9].

Basic IEEE802.16 model is provided below for reference.

\[
PL = A + 10 \cdot \gamma \cdot \log_{10}(d/d_0) + \Delta PL_f + \Delta PL_h
\] (0)

where \(d_0=100\)m and \(d>d_0\). \(A=20\log_{10}(4\pi d_0/\lambda)\) and \(\gamma=(a - b \cdot h_b + c/ h_b)\). \(\lambda\) is the wavelength in meter and \(h_b\) is the BS antenna height, which is between 10m and 80m.

Three propagation scenarios are categorized as
- Terrain Type A: Hilly terrain with moderate-to-heavy tree densities
- Terrain Type B: Intermediate path-loss condition
- Terrain Type C: Flat terrain with light tree densities

The corresponding parameters for each propagation scenario are

<table>
<thead>
<tr>
<th>Model Parameter</th>
<th>Terrain Type A</th>
<th>Terrain Type B</th>
<th>Terrain Type C</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>4.6</td>
<td>4</td>
<td>3.6</td>
</tr>
<tr>
<td>b</td>
<td>0.0075</td>
<td>0.0065</td>
<td>0.005</td>
</tr>
<tr>
<td>c</td>
<td>12.6</td>
<td>17.1</td>
<td>20</td>
</tr>
</tbody>
</table>

Moreover, the correction factors for carrier frequency (\(\Delta PL_f\)) and receive antenna height (\(\Delta PL_h\)) are:

\(\Delta PL_f = 6 \cdot \log_{10}( f / 2000)\) dB (0)

where \(f\) is the carrier frequency in MHz.

\(\Delta PL_h = -10.8 \cdot \log_{10}(h/2)\) dB; for Terrain Type A and B (0)
\(\Delta PL_h = -20 \cdot \log_{10}(h/2)\) dB; for Terrain Type C

where \(h\) is the MS/RS receive antenna height between 2m and 10m.

**Extended Modified IEEE802.16 model**
where, 
\[ A = 20 \log_{10} \left( \frac{pd}{l} \right) \]

\[ d_0 = 100m \]

\[ d'_0 = d_0 \times 10^{0.005} \]

\[ g = a - bh_b + \frac{c}{h_b} \]

\[ DPL_f = 6 \log_{10} \left( \frac{f \text{ (MHz)}}{2000} \right) \]

\[ DPL_{ht} = -10 \log_{10} \left( \frac{DPL_f}{d} \right) \]

\[ -20 \log_{10} \left( \frac{DPL_{ht}}{d} \right) \]

The parameters for Types A, B and C are same as those of basic model provided in Table 3.
[Editor’s note: The above parameter values of a, b and c, provided with the modified equation should be deleted].
2.1.2.2 Type-D: (Suburban, ART-to-ART. LOS)

This scenario is shown in Figure 1 and Figure 2, where both node antennas are mounted above the rooftops (ART) and they have a LOS between them.
For this link the modified IEEE 802.16d channel model is recommended as presented in this section. There are three categories for this model, as shown in the previous section, where each category represents a different environment. The most benign category (category C) is chosen for this scenario to allow for the fact that the relays in this case are assumed to have been deployed with a good LOS back to the BS. The model is equal to the free space path loss up to a breakpoint, which is determined by the transmission frequency and the relay antenna height. Beyond the breakpoint, the path loss exponent increases, and this is to account for the fact that LOS probability will decrease with distance from the BS. This factor is also important for multi-cell simulations for interference calculations.
\[
\begin{align*}
\text{PL (dB)} &= 10 \log \left( \frac{\rho d}{l} \right) \\
&= A + 10 \log \left( \frac{d}{d_0} \right) + DPL_f + DPL_{ht} \quad \text{for } d > d_0'
\end{align*}
\]

where,

\[A = 20 \log \left( \frac{\rho d_0}{l} \right)\]

\[d_0 = 100 \text{m}\]

\[d_0' = d_0 \times 10^{g/10}\]

\[g = a - bh_b + \frac{c}{h_b}\]

\[DPL_f = 6 \log \left( \frac{f}{\text{MHz}} \right) + 2000\]

\[DPL_{ht} = \begin{cases} 
-10 \log \left( \frac{h}{3} \right) & \text{for } h < 3 \text{m} \\
-20 \log \left( \frac{h}{3} \right) & \text{for } h > 3 \text{m}
\end{cases}\]

\[d = \text{distance between BS and RS}\]

\[h_b = \text{height of BS}\]

\[h_t = \text{height of RS}\]

\[a = 3.6\]

\[b = 0.005\]

\[c = 20\]

Note that the MS/RS height correction factor is Okumura’s correction factor.
2.1.2.3 Type-E: (Urban ART-to-BRT, NLOS)

For the urban NLOS case which is shown as the examples in Figure 4 and 5, the COST 231 Walfisch-Ikegami model is recommended and given in [14].

(Editor’s Note: The text of COST 231 Walfisch-Ikegami model is in the Appendix A of [14])
Parameter values to be used for this model are provided below. The use of these values is not mandatory.

- **Building spacing,** $b = 60m$  
  *(this is the spacing between building centers)*
- **Street width,** $w = 12m$  
  *(this is the spacing between building faces)*
- **Street orientation = 90 degrees**
- **Average rooftop height,** $h_{roof} = 25m$

An alternative is using WINNER model, which is given as:

$$PL(d) = 38.4 + 35\log_{10}(d) \text{ dB for } 50m < d < 5km$$

where $d$ is the distance in meter and the carrier frequency is 5GHz.

### 2.1.2.4 Type-F: (BRT-to-BRT)

Both LOS and NLOS models are provided separately below for this case.

[Editor’s note: Two subsections 2.1.2.4.1 and 2.1.2.4.2 are to replace 2.1.2.4 and 2.1.2.5 in the original document]

#### 2.1.2.4.1 LOS version:

For this scenario we assume that both node antennas are located below the rooftop, and that they are located on the same street.
For this case an advanced LOS model is recommended. This is a two-slope model, where the breakpoint is dependant on the relay and MS antenna heights. However, the effect of traffic is taken into account by defining an effective road height, which reduces the relay and MS heights. In addition, a visibility factor is included which reduces the path loss further as distance increases, and this factor accounts for the fact that LOS decreases with distance along a street. The model is given below:-

Figure 5. RS-MS LOS Scenario
\[ PL \ dB = 20 \log_e \left( 4 \frac{rD}{r} \right) \]

where,
- \( r \)  distance between Tx and Rx
- \( e^{sr} \)  Visibility factor  \( s \)  0.002
- \( Wavelength \)
  \[
  \frac{1}{r} \frac{r}{r_{bp}}
  \]
- \( D \)
  \[
  \frac{r}{r_{bp}} \frac{r}{r_{bp}}
  \]
- \( r_{bp} \)
  \[
  \frac{4}{h_i} \frac{h_0}{h_r} \frac{h_i}{h_0}
  \]

- \( h_t \)  Height of transmitter above ground
- \( h_r \)  Height of receiver above ground
- \( h_0 \)  Effective road height  1.0m

Note, for the distance between RS-RS or RS-MS less than 10m case, the free-space model is used.

For this scenario, the alternative WINNER path-loss model can be used:

\[ PL(d)=22.7 \log_{10}(d)+41.0 \ dB \quad \text{for} \ 10m < d < 650m \]

where \( d \) is the distance in meter and the carrier frequency is 5 GHz

\[2.1.2.4.2 \text{ NLOS version (Type-F: BRT-to-BRT)}\]

For this scenario both nodes antenna heights are below rooftop and they are located on different streets.
Figure 6. RS-MS NLOS scenario

For this case, the model takes the minimum of an over-the-rooftop component and a round-the-streets component. The round-the-streets component is based on a model by Berg, although this has been modified to be compatible with the advanced LOS model (see section 2.1.2.6), such that the visibility factor is included, and the effective road height to give the correct breakpoint in the first street section. The full model is shown below:
Figure 7. Geometry of street sections used for Berg model
PL_{Berg} dB \quad 20 \log \left( \frac{4}{n} \sum_{j=1}^{n} r_j \frac{d_j}{r_j} e^{\frac{r_j}{q_j}} \right)

R_j^{n} \quad \text{Distance along streets between Tx and Rx}

r_j \quad \text{Length of the street between nodes } j \text{ and } j+1 \text{ (there are } n \text{ nodes in total)}

r_0 \quad \text{if } r_0 \quad 4 \frac{h_i}{h_0} \frac{h_r}{h_0}

r_{bp} \quad 4 \frac{h_i}{h_0} \frac{h_r}{h_0} \quad \text{if } r_0 \quad 4 \frac{h_i}{h_0} \frac{h_r}{h_0}

1 \quad \text{if } R \quad r_{bp}

D \quad R \quad \text{if } R \quad r_{bp}

The distance } d_s \text{ is the illusory distance and is defined by the recursive expression,

\begin{align*}
&k_j \quad k_j \quad d_j \quad q_j \quad 1
\end{align*}

\begin{align*}
d_j \quad k_j r_j \quad d_j \quad 1
\end{align*}

\begin{align*}
&\text{with } k_0 \quad 1 \text{ and } d_0 \quad 0
\end{align*}

\begin{align*}
&\quad q_j \quad \frac{q_{90}}{90}
\end{align*}

\begin{align*}
&\quad j \quad \text{Angle between streets at junction } j
\end{align*}

\begin{align*}
&q_{90} \quad 0.5, \text{ and } 1.5
\end{align*}

\begin{align*}
&PL_{\text{over the rooftop}} dB \quad 24 \quad 45 \log r_{Eu}
\end{align*}

\begin{align*}
&r_{Eu} \quad \text{Euclidean distance between Tx and Rx}
\end{align*}

\begin{align*}
&PL dB \quad \min \left( PL_{Berg} dB , PL_{\text{over the rooftop}} dB \right)
\end{align*}

Note that the one-street turn corner modeling is recommended for the most of case.

For this scenario the alternative WINNER path-loss model (for 5GHz) can be used:
\[ PL = 65 + 0.096 \cdot d_1 + (28-0.024 \cdot d_1) \cdot \log_{10}(d_2) \ dB \text{ for } 10m < d_1 < 550m \text{ and } w/2 < d_2 < 450m \]

where \( d_1 \) is the distance along the main street in meters, \( d_2 \) is the distance for perpendicular street, \( w \) is the street width, and the carrier frequency is 5 GHz.

![Figure 8. The alternative model for RS-MS NLOS scenario](image)

### 2.1.2.5 Type-G Indoor Office Environment path-loss Model

The path-loss model for indoor environment is:

\[ PL = 37 + 30 \cdot \log_{10}(d) + 18.3 \cdot n^{(n+2)/(n+1)-0.46} dB \quad (0) \]

where \( d \) is the distance in meters and \( n \) is the number of floors in the path.

For Type-G Indoor Office Environment scenario the alternative WINNER path-loss model can be used:

For LOS case:

\[ PL(d)=18*\log_{10}(d)+46.8 \ dB \quad \text{for } 3m < d < 100m \]

For NLOS case:

\[ PL(d)=36.8*\log_{10}(d)+38.8 \ dB \quad \text{for } 3m < d < 100m \]

Where \( d \) is in meters and the carrier frequency is 5GHz.
2.1.2.6 Type H Urban ART to ART model

The model is based on the Type E model which is COST 231 Walfisch-Ikagami path loss model (given in [14]), modified by making the rooftop to street diffraction component \( L_{rts} \) to be zero. However, it is suggested that this may be used when at least one of the antennas (receive or transmit) is kept less than 2 m above the roof top level.

(Editor’s Note: The text of COST 231 Walfisch-Ikegami model is in the Appendix A of [14].)

{ TO editor: The text below is for information only. They are not intended to be included. }

Since this modification will not reflect the case when both nodes are reasonably above roof top, we recommend this to be used only for the case when one node is no higher than 2m above roof top.

The basic transmission loss is composed of two terms: free space loss \( L_0 \) and multiple screen diffraction loss \( L_{msd} \).

\[
L = \begin{cases} 
L_0 & \text{for } L_{msd} > 0 \\
L_0 & \text{for } L_{msd} = 0
\end{cases}
\]

The free space loss is given by:

\[
L_0 = 32.4 + 20 \log d / km + 20 \log f / MHz
\]

The multiple screen diffraction term represents the propagation over multiple rooftops and this is given by the following expression:

\[
L_{msd} = L_{bsh} + k_a \log \frac{d}{km} + k_f \log \frac{f}{MHz} + 9 \log \frac{b}{m}
\]

The term \( L_{bsh} \) describes the dependence of the loss on the height of the BS antenna
Here, hBase is the Base station antenna height, hRoof is the average rooftop height and b is the Building separation (building centre-to-building centre).

The term $k_a$ represents the increase of the path loss for base station antennas below the rooftops of the adjacent buildings.

$$L_{inh} = 18 \log \frac{h_{Base}}{m} \quad \text{for } h_{Base} \leq h_{Roof}$$

$$L_{inh} = 0 \quad \text{for } h_{Base} > h_{Roof}$$

The terms $k_d$ and $k_f$ control the dependence of the multi-screen diffraction loss on distance and radio frequency, respectively. They can be evaluated using the following expressions.

$$k_a = 54 \quad 0.8 \quad \frac{h_{Base}}{m} \quad \text{for } h_{Base} \leq h_{Roof}$$

$$k_a = 54 \quad 0.8 \quad \frac{h_{Base}}{m} \frac{d / \text{km}}{0.5} \quad \text{for } d \quad 0.5 \text{km and } h_{Base} > h_{Roof}$$

The terms $k_d$ and $k_f$ control the dependence of the multi-screen diffraction loss on distance and radio frequency, respectively. They can be evaluated using the following expressions.

$$k_d = 18 \quad 15 \quad \frac{h_{Base}}{m} \quad \text{for } h_{Base} \leq h_{Roof}$$

$$k_d = 18 \quad 15 \quad \frac{h_{Base}}{m} \quad \text{for } h_{Base} > h_{Roof}$$

$$k_d = 4 \quad 1.5 \quad \frac{f/\text{MHz}}{925} \quad 1$$
2.1.2.7 Type J: Outdoor to Indoor, tunnels, in-vehicle and subway model

This is modeled by incorporating a penetration loss factor to the previous base models (Type A, B, C, D, E, F, H). The following are the recommended penetration losses for various cases.

**Outdoor to indoor:** 12 dB mean, lognormal distribution with a standard variation of 8 dB. Ref [xx]
{Editor’s note: the following reference should be included under references.
Ref [xx]: Section 1.1.2., p.25 of Rec. ITU-R M.1225 }

**Outdoor to in-vehicle:** 6 dB mean value, a lognormal distribution having a standard deviation of 3 dB.

**Outdoor to tunnels:** Use of L dB attenuation on top of the outdoor to outdoor model as per the various path loss models defined in this document, where L is given by:

\[ L = L_{\text{couple}} + \alpha \cdot d_{l/2}, \]

where \( \alpha \) is the attenuation per unit length, and \( d \) is a uniformly distributed random variable between 0 and \( d_{l} \) m, where \( d_{l} \) is the tunnel length, and \( L_{\text{couple}} \) is the coupling loss of the incident waves into the tunnel. It is recommended to use these values which is not mandatory for the simulations.

\( d_{l} = 500 \text{ m}, \ L_{\text{couple}} = 6 \text{ dB}, \ \alpha = \text{TBD} \)

**Subway Stations:** Use a penetration loss of \( P_U \) as per the following equation similar to multi-floor indoor case, in Section 2.1.2.5. A lognormal variation of 6 dB is to be used.

\[ P_U = 18.3 \cdot n^{(n+2)/(n+1) - 0.46} \text{ dB} \]

where \( n \) is the number of floors below the ground. \( N = 1 \) for the ground floor. \( N=2 \) for the next level down etc.

2.1.2.8 LOS Probability

In path-loss Type-F and Type-G, the radio link may be either LOS (Line-Of-Sight) or NLOS (Non Line-Of-Sight).

For Type-F, both node-antennas are below rooftop. Therefore, the following equation for LOS probability [15] can be considered in simulation.
\[ P_{\text{LOS}}(d) = \begin{cases} 
1 & d \leq 15m \\
\left(1 - (1.56 - 0.48 \log g_{10}(d))^{3}\right)^{1/3} & d > 15m 
\end{cases} \]

where \( d \) is the distance, and \( d_1 \) and \( d_2 \) are like in Figure 9.

For Type-G, indoor office environment, the following equation for LOS probability [15] should be considered when simulation.

\[ P_{\text{LOS}}(d) = \begin{cases} 
1 & d \leq 2.5m \\
0.9 \left(1 - (1.24 - 0.61 \log g_{10}(d))^{3}\right)^{1/3} & d > 2.5m 
\end{cases} \]