

Agenda item: 6.2.6.2

Source: Broadcom Corporation

Title: Path Loss for 3D Channel Modeling

Document for: Discussion and Decision

1 Introduction

At RAN1 #72bis, the following study directions [1] and working assumptions [2] for 3D channel modeling were provided, including two highlighted topics for further discussions [3]:

- Models should be studied for
 - User equipment (UE) height dependent line-of-sight (LOS)/non-line-of-sight (NLOS) probability
 - Clutter height could be considered as part of modeling
 - UE height dependent path loss (PL)
 - HE height dependent elevation angles of departure
 - Including studying the height and/or distance dependence of angular spread
 - Which models to introduce is for further study (FFS)
- For LOS/NLOS urban micro-cell (UMi)/urban macro-cell (UMa) PL calculations, the 2D distance shall be replaced with 3D distance.
- For outdoor UE, reuse ITU UMi LOS/NLOS and ITU UMa LOS/NLOS PL equations at $h_{UT} = 1.5$ m in TR 36.814.
- For indoor UE, UMi/UMa outdoor-to-indoor (O-to-I) PL modeling is according to:

$$PL = PL_b + PL_{tw} + PL_{in}$$

Loss through wall $PL_{tw} = 20$ dB

Loss inside $PL_{in} = 0.5 d_{in}$

where $d_{in} = \text{Uniform}(0, \min(25, d))$

Basic path loss PL_b is determined according to the following:

– ***PL_b* for LOS**

For both UMi and UMa, reuse the ITU LOS PL formula (with the new UE height)

– ***PL_b* for NLOS**

The baseline understanding is that the following formula is considering collectively all paths seen by the UE. Meanwhile, the application of this formula separately to the above-rooftop paths can be further investigated.

▪ 3D UMa PL is determined according to:

$$PL_{UMa-NLOS-3D}(d, h_{UT}) = \max(PL_{UMa-NLOS}(d, h_{UT}), PL_{ITU-UMa-LOS}(d, h_{UT}))$$

where

$$PL_{UMa-NLOS}(d, h_{UT}) = PL_{ITU-UMa-NLOS}(d, h_{UT} = 1.5) - \alpha(h_{UT} - 1.5)$$

Height gain α is FFS, and to be chosen from 0.6, 0.9, 1.1, and 1.5

▪ ***3D UMi PL***

- Study introduction of additional term to the ITU UMi NLOS PL, capturing a linear decrement of PL with h_{UT}
- Study impact of the clutter height

This contribution provides an update of the UE-height-dependent PL models.

2 Distance in 3D Channel Modeling

The antenna height at BS is $h_{BS} = 10$ m for UMi and 25 m for UMa. The antenna height at UE is $h_{UT} = 3(n_f - 1) + 1.5$ m depending on its floor number n_f in $\{1, 2, \dots, N\}$ with the maximal floor number N in $\{4, 5, 6, 7, 8\}$. The UMi BS is right below the fourth floor, whereas the UMa BS is above the eighth floor.

Figure 1 shows the 3D BS-to-UE distance $d_{3D} = (d^2 + (h_{BS} - h_{UT})^2)^{0.5}$ as a function of 2D distance d between BS and UE for various UE antenna heights in $\{1.5$ m, 10.5 m, 22.5m $\}$ corresponding to $n_f = 1, 4$, and 8, respectively. The increase of d_{3D} over d at 10 m is 60% for UMi and 155% for UMa. These increases become less than 1% for $d \geq 87$ m in UMi and $d \geq 162$ m in UMa.

Figure 1. UMi and UMa BS-to-UE distance for various UE heights.

3 UE-Height-Dependent LOS Probability

Table 1 provides the LOS probability P_{LOS} as functions of BS-to-UE 2D distance d for UMi and UMa from Table B.1.2.1-2 of TR 36.814 [4]. The P_{LOS} for UMa was modified by [5] to include dependency on UE height h_{UT} as shown in Table 2.

Table 1. LOS probability functions for UMi and UMa.

Model	Scenario
$P_{LOS} = \min(18/d, 1) \times (1 - \exp(-d/36)) + \exp(-d/36)$	UMi
$P_{LOS} = \min(18/d, 1) \times (1 - \exp(-d/63)) + \exp(-d/63)$	UMa

Table 2. UE-height-dependent LOS probability function for UMa.

Model	Scenario and applicable range	
$P_{LOS} = (\min(18/d, 1) \times (1 - \exp(-d/63)) + \exp(-d/63)) \times (1 + C(d, h_{UT}))$	UMa	
$C(d, h_{UT}) = 0$	$h_{UT} < 13$ m	n_f in $\{1, 2, 3, 4\}$
$C(d, h_{UT}) = ((h_{UT} - 13)/10)^{1.5} \times g(d)$	$13 \leq h_{UT} \leq 23$ m	n_f in $\{5, 6, 7, 8\}$
$C(d, h_{UT}) = g(d)$	$23 < h_{UT}$	
$g(d) = 1.25 \times 10^{-6} \times d^3 \times \exp(-d/150)$		

Figure 2 shows that the LOS probability P_{LOS} for both UMi and UMa decreases as UE located farther away from BS. For UMa, P_{LOS} is the same for UE height h_{UT} in {1.5 m, 4.5 m, 7.5 m, 10.5 m} or floor number n_f in {1, 2, 3, 4}, and increases with UE height h_{UT} in {10.5 m, 16.5 m, 22.5 m} or floor number n_f in {4, 6, 8}.

Observation 1: The UE-height-dependent increase in the UMa LOS probability is mainly from LOS over the rooftop.

Proposal 1: For UMa, use the UE-height-dependent incremental probability for LOS over the rooftop.

Figure 2. LOS probability for UMi and UE-height-dependent LOS Probability for UMa.

4 Path Loss for Outdoor UE

By replacing 2D distance d with 3D distance d_{3D} , Table 3 provides the UMi/UMa LOS/NLOS path loss models undated from TR 36.814 for outdoor UE with $h_{UT} = 1.5$ m and effective environment height (or average clutter height) $h_{Env} = 1$ m.

Table 3. UMi/UMa LOS/NLOS path loss models for outdoor UE.

Type	Path loss [dB] Note: f_c value in GHz	Applicability range and default values Note: f_c value in Hz
LOS	$PL_{LOS} = 22 \log_{10}(d_{3D}) + 28 + 20 \log_{10}(f_c)$	$10 \text{ m} < d_{3D} < d'_{BP}$ $d'_{BP} = 4 h'_{BS} h'_{UT} f_c / c$ $h'_{BS} = h_{BS} - h_{Env}$ $h'_{UT} = h_{UT} - h_{Env}$ $h_{Env} = 1 \text{ m}$ $c = 3 \times 10^8 \text{ m/s}$
	$PL_{LOS} = 40 \log_{10}(d_{3D}) + 7.8 - 18 \log_{10}(h'_{BS}) - 18 \log_{10}(h'_{UT}) + 2 \log_{10}(f_c)$	$d'_{BP} < d_{3D} < 5000 \text{ m}$
NLOS	UMi	$PL_{NLOS-UMi} = 36.7 \log_{10}(d_{3D}) + 22.7 + 26 \log_{10}(f_c)$
	UMa	$PL_{NLOS-UMa} = 161.04 - 7.1 \log_{10}(W) + 7.5 \log_{10}(h) - (24.37 - 3.7(h/h_{BS})^2) \log_{10}(h_{BS}) + (43.42 - 3.1 \log_{10}(h_{BS})) (\log_{10}(d_{3D}) - 3) + 20 \log_{10}(f_c) - (3.2 (\log_{10}(11.75 h_{UT}))^2 - 4.97)$ $10 \text{ m} < d_{3D} < 5000 \text{ m}$ $h_{BS} = 25 \text{ m}$ $h_{UT} = 1.5 \text{ m}$ Street width $W = 20 \text{ m}$ Average building height $h = 20 \text{ m}$

Figure 3 shows the PL values for outdoor UE. The LOS PL break point distance d'_{BP} is **120 m** at $f_c = 2 \times 10^9$ Hz (**210 m** at $f_c = 3.5 \times 10^9$ Hz) for UMi and **320 m** at $f_c = 2 \times 10^9$ Hz for UMa — the inter-site distance (ISD) is 200 m for UMi and 500 m for UMa [6]. Using 3D distance increases PL values from using 2D distance. These increases become less than 1% beyond 23 m, 26 m, 58 m, and 70 m for UMi-LOS/NLOS and UMa-LOS/NLOS, respectively.

Figure 3. UMi and UMa LOS/NLOS path loss for outdoor UE.

5 Path Loss Models for Indoor UE

For indoor UE, the BS-to-UE 2D distance is $d = d_{out} + d_{in}$ where d_{out} is the 2D distance from BS to wall, and d_{in} is from wall to UE and uniformly distributed in $(0, \min(25, d))$. Table 4 provides the O-to-I path loss models undated from TR 36.814 for indoor UE by replacing 2D distance $d = d_{out} + d_{in}$ with 3D distance $d_{3D} = ((d_{out} + d_{in})^2 + (h_{BS} - h_{UT})^2)^{0.5}$. The antenna height at BS is $h_{BS} = 10$ m for UMi and 25 m for UMa. The UE height is $h_{UT} = 3(n_f - 1) + 1.5$ m depending on its floor number n_f in $\{1, 2, \dots, N\}$ with the maximal floor number N in $\{4, 5, 6, 7, 8\}$. For indoor UE with $h_{UT} = 1.5$ m and effective environment height (or average clutter height) $h_{Env} = 1$ m, the models in Table 3 can be used to derive the basic path loss PL_b . For the floor number n_f in $\{2, 3, \dots, 8\}$, the path loss models in Table 3 require modifications as discussed below.

Table 4. Path loss models for indoor UE.

Type	Path loss [dB] Note: f_c value in GHz	Applicability range and default values
O-to-I	$PL_{O-to-I} = PL_b + PL_{tw} + PL_{in}$	
Basic	$PL_b = PL(d_{3D})$	$10 \text{ m} < d_{3D} < 1000 \text{ m}$
Through wall	$PL_{tw} = 20$	
Inside building	$PL_{in} = 0.5d_{in}$	$0 \text{ m} < d_{in} < \min(25, d) \text{ m}$

5.1 LOS Break Point Distance

Given that $h_{BS} = 10$ m for UMi and 25 m for UMa, $f_c = 2 \times 10^9$ Hz, and $c = 3 \times 10^8$ m/s, the LOS PL break point distance $d'_{BP} = 4(h_{BS} - h_{Env})(h_{UT} - h_{Env})f_c / c$ varies with both the UE height h_{UT} and effective environment height (or average clutter height) h_{Env} . Table 5 compares the UE-height-dependent d'_{BP} values based on different h_{Env} assumptions:

- $h_{Env} = 1$ m for LOS over the street
- h_{Env} in $\{12, 15, 18, 21, 24\}$ m for LOS over the rooftop
- $h_{Env} = (2/3) \times \min(h_{BS}, h_{UT})$

Only LOS over the street is assumed for UMi since its BS antenna height is 10 m that is below all the building heights in $\{12, 15, 18, 21, 24\}$ m. In contrast, LOS can be over the street or over the rooftop for UMa since its BS antenna height at 25 m is above all buildings. The probability for LOS over the rooftop is determined according to Proposal 1.

Observation 2: Two modified UMa LOS break point distances ($d'_{BP} = 280$ m and 160 m with $h_{Env} = 18$ m and 21 m for $h_{UT} = 19.5$ m and 22.5 m, respectively) are less than 320 m for $h_{UT} = 1.5$ m with $h_{Env} = 1$ m.

Proposal 2: For UMa LOS over the rooftop, assume the effective environment height at 12 m.

Table 5. LOS PL break point distance based on specific UE height and effective environment height in meters.

n_{fl} h_{UT} [m]		1 1.5	2 4.5	3 7.5	4 10.5	5 13.5	6 16.5	7 19.5	8 22.5
UMi	h_{Env} [m] d'_{BP} [m]	1 120	1 840	1 1560	1 2280	1 3000	1 3720	1 4440	1 5160
	$h_{Env} = (2/3) \times \min(h_{BS}, h_{UT})$ [m] d'_{BP} [m]	1 120	3 280	5 333	6.7 341	6.7 607	6.7 874	6.7 1141	6.7 1407
UMa	h_{Env} [m] d'_{BP} [m]	1 320	1 2240	1 4160	1 6080	1 8000	1 9920	1 11840	1 13760
	$h_{Env} = (2/3) \times \min(h_{BS}, h_{UT})$ [m] d'_{BP} [m]	1 320	3 880	5 1333	7 1680	9 1920	11 2053	13 2080	15 2000
	h_{Env} [m] d'_{BP} [m]					12 520	12 1560	12 2600	12 3640
	h_{Env} [m] d'_{BP} [m]						15 400	15 1200	15 2000
	h_{Env} [m] d'_{BP} [m]							18 280	18 840
	h_{Env} [m] d'_{BP} [m]								21 160

Figure 4 shows the LOS path loss $PL_{O\text{-to-}I}$ for indoor UE assuming $d_{in} = 5$ m. In UMi, $h_{Env} = 1$ m for h_{UT} in $\{1.5 \text{ m}, 10.5 \text{ m}, 22.5 \text{ m}\}$ and $d'_{BP} = 120$ m for UE at $h_{UT} = 1.5$ m. In UMa, $h_{Env} = 1$ m for h_{UT} in $\{1.5 \text{ m}, 10.5 \text{ m}\}$ and $d'_{BP} = 320$ m for UE at $h_{UT} = 1.5$ m, and $h_{Env} = 12$ m ($d'_{BP} = 3640$ m) for UE at $h_{UT} = 22.5$ m.

Figure 4. UMi and UMa LOS path loss for indoor UE with specific height and break point distance.

5.2 NLOS Antenna-Height-Dependent Gain

Although Table 3 shows h_{UT} as a parameter in the UMa NLOS path loss model, its applicability range is $1 \text{ m} < h_{UT} < 10 \text{ m}$ [4]. The following basic path loss model was proposed by [5] [7] to include the antenna-height-dependent gain:

$$PL_b = \max(PL_{UMa-NLOS}(d_{3D}, h_{UT} = 1.5) - \alpha(h_{UT} - 1.5), PL_{LOS}(d_{3D}, h_{UT})) \quad (1)$$

Several contributions proposed the height gain slope α to be chosen from 0.6, 0.9, 1.1, or 1.5 dB/m [8] [9] [10] [5]. An alternative to (1) was proposed by [10] for not only UMa but also UMi to limit the height gain with the effective environment height (or average clutter height) h_{Env} as follows:

$$PL_b = PL_{NLOS}(d_{3D}, h_{UT} = 1.5) - \alpha \min((h_{UT} - 1.5), h_{Env}) \quad (2)$$

Using $d_{in} = 5$ m, $\alpha = 9$ dB/m, $h_{Env} = 1$ m for $h_{UT} = 1.5$ m and 10.5 m, and $h_{Env} = 12$ m for $h_{UT} = 22.5$ m, Figure 5 shows the UMa NLOS path loss $PL_{O\text{-to-}I}$ for indoor UE based on the PL_b Models (1) and (2). Figure 6 shows similar results for UMi.

Observation 3: Model (1) generates height gains more evenly over elevation than Model (2), whereas Model (2) does not reach the LOS path loss limit as Model (1) does.

Proposal 3: Use the height gain and effective environment height to generate NLOS path loss for indoor UE in both UMi and UMa.

Figure 5. UMa NLOS path loss for indoor UE based on the PL_b Models (1) and (2).

Figure 6. UMi NLOS path loss for indoor UE based on the PL_b Models (1) and (2).

6 Conclusion

This contribution has presented the following proposals for discussion and decision.

Proposal 1: For UMa, use the UE-height-dependent incremental probability for LOS over the rooftop.

Proposal 2: For UMa LOS over the rooftop, assume the effective environment height at 12 m.

Proposal 3: Use the height gain and effective environment height to generate NLOS path loss for indoor UE in both UMi and UMa.

7 References

- [1] R1-131760, Ericsson, ST-Ericsson, *et al.*, “Way forward on 3D channel modeling.”
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- [3] Email discussion [72bis-19], “Height-dependent 3D path loss modeling.”
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- [6] R1-131756, Nokia Siemens Networks, *et al.*, “Way forward on scenarios for 3D channel modeling.”
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