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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:

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

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

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

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

  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:

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

      where

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

      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 $h_{UT} = 3(n_{fl} - 1) + 1.5$ m depending on its floor number n_{fl} in {1, 2, …, N} with the maximal floor number N in {4, 5, 6, 7, 8}.

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_{fl} = 1, 4, and 8, respectively. The increase of d_{3D} over d at 10 m is up to 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 applicability 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_{fl} in {1, 2, 3, 4}
$C(d, h_{UT}) = ((h_{UT} - 13)/10)^{1.5} \times g(d)$	13 m $\leq h_{UT} \leq$ 23 m	n_{fl} in {5, 6, 7, 8}
$C(d, h_{UT}) = g(d)$	23 m $< h_{UT}$	
$g(d) = 1.25 \times 10^{-6} \times d^3 \times \exp(-d/150)$		

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_{fl} in {1, 2, 3, 4}, and increases with UE height h_{UT} in {13.5 m, 16.5 m, 19.5 m, 22.5 m}or floor number n_{fl} in {5, 6, 7, 8}.

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

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

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.

<table>
<tr><th colspan="2">Type</th><th>Path loss [dB]
Note: f_c value in GHz</th><th>Applicability range in 2D and default values
Note: f_c value in Hz</th></tr>
<tr><td colspan="2" rowspan="2">LOS</td><td>$PL_{LOS} = 22 \log_{10}(d_{3D}) + 28 + 20 \log_{10}(f_c)$</td><td>$10 \text{ m} < d < d'_{BP}$
$d'_{BP} = 4\, h'_{BS}\, h'_{UT}\, f_c / c$
$h'_{BS} = h_{BS} - h_{env}$
$h'_{UT} = h_{UT} - h_{env}$
$h_{env} = 1$ m
$c = 3 \times 10^8$ m/s</td></tr>
<tr><td>$PL_{LOS} = 40 \log_{10}(d_{3D}) + 7.8 - 18 \log_{10}(h'_{BS}) - 18 \log_{10}(h'_{UT}) + 2 \log_{10}(f_c)$</td><td>$d'_{BP} < d < 5000$ m</td></tr>
<tr><td rowspan="2">NLOS</td><td>UMi</td><td>$PL_{NLOS\text{-}UMi} = 36.7 \log_{10}(d_{3D}) + 22.7 + 26 \log_{10}(f_c)$</td><td>$10 \text{ m} < d < 2000$ m</td></tr>
<tr><td>UMa</td><td>$PL_{NLOS\text{-}UMa} = 161.04 - 7.1 \log_{10}(W) + 7.5 \log_{10}(h) - (24.37 - 3.7 (h / h_{BS})^2) \log_{10}(h_{BS}) + (43.42 - 3.1 \log_{10}(h_{BS}))(\log_{10}(d_{3D}) - 3) + 20 \log_{10}(f_c) - (3.2 (\log_{10}(11.75\, h_{UT}))^2 - 4.97)$</td><td>$10 \text{ m} < d < 5000$ m
$h_{BS} = 25$ m
$h_{UT} = 1.5$ m
Street width $W = 20$ m
Average building height
$h = 20$ m</td></tr>
</table>

Figure 3 shows the PL values for outdoor UE. The LOS break point 2D 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 $h_{UT} = 3(n_{fl} - 1) + 1.5$ m depending on its floor number n_{fl} in {1, 2, …, 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_{fl} in {2, 3, …, 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 in 2D and default values
O-to-I	$PL_{O\text{-}to\text{-}I} = PL_b + PL_{tw} + PL_{in}$	
Basic	$PL_b = PL\ (d_{3D})$	10 m < d < 1000 m
Through wall	$PL_{tw} = 20$	
Inside building	$PL_{in} = 0.5d_{in}$	0 m < d_{in} < min (25, d) m

5.1 LOS Break Point Distance and Effective Environment Height

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 break point 2D 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:

a) h_{env} = 1 m
b) h_{env} = (2/3) × min (h_{BS}, h_{UT})
c) h_{env} = (12 + 3(n_{fl} – 1))/2 for UMa UE on n_{fl} = 5, 6, 7, 8 with LOS above rooftops

Only LOS above streets is assumed for UMi since its BS antenna height at 10 m is less than all the building heights in {12 m, 15 m, 18 m, 21 m, 24 m}. In contrast, LOS can be above streets or above rooftops for UMa since its BS antenna height (25 m) is greater than all the building heights. The probability for UMa LOS above rooftops is determined according to Proposal 1.

Observation 2: Under assumption a) with h_{env} = 1 m, several break point distances exceed the 5000 m applicability range in Table 3. Assumption b) with h_{env} as two-thirds of min (h_{BS}, h_{UT}) provides break point distances within the 5000 m applicability range. It also considers the clutters significantly taller than 1 m such as *buses*, *trucks*, *poles*, *trees*, etc. that may have impact on elevated indoor UE. On the other hand, it does not distinguish LOS above rooftops from LOS above streets. For UMa UE on n_{fl} = 5, 6, 7, 8 with LOS above rooftops and h_{env} values in {12 m, …, 3(n_{fl} – 1) m}, two 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. Assumption c) takes the average of the h_{env} values in {12 m, …, 3(n_{fl} – 1) m} for UMa UE on n_{fl} = 5, 6, 7, 8 with LOS above rooftops.

Proposal 2: For LOS above streets, assume the effective environment heights at two-thirds of min (h_{BS}, h_{UT}). For UMa LOS above rooftops for UE on floor numbers 5, 6, 7, and 8, assume the effective environment heights at 12 m, 13.5 m, 15 m, and 16.5 m, respectively.

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) × 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) × 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
	h_{env} = (12 + 3(n_{fl} – 1))/2 [m] d'_{BP} [m]					12 520	13.5 920	15 1200	16.5 1360

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

Table 3 shows h_{UT} as a parameter in the UMa NLOS path loss model with the applicability range 1 m < h_{UT} < 10 m, but not in the UMi NLOS path loss model with the applicability range 1 m < h_{UT} < 2.5 m [4]. The following NLOS path loss model was proposed by [5] to include the antenna-height-dependent gain and the path loss above rooftops and around buildings:

$$PL_{NLOS} = \min\left(PL_{NLOS}\,(\text{above rooftops}),\ PL_{NLOS}\,(\text{around buildings})\right) \quad (1)$$

where

$$PL_{UMi\text{-}NLOS}\,(\text{above rooftops}) = \max\left(PL_{UMa\text{-}NLOS}\,(d_{3D}, h_{UT} = 1.5) + 20 - \alpha\,(h_{UT} - 1.5),\ PL_{UMi\text{-}LOS}\,(d_{3D}, h_{UT})\right) \quad (2)$$

$$PL_{UMa\text{-}NLOS}\,(\text{above rooftops}) = \max\left(PL_{UMa\text{-}NLOS}\,(d_{3D}, h_{UT} = 1.5) - \alpha\,(h_{UT} - 1.5),\ PL_{UMa\text{-}LOS}\,(d_{3D}, h_{UT})\right) \quad (3)$$

$$PL_{NLOS}\,(\text{around buildings}) = PL_{UMi\text{-}NLOS}\,(d_{3D}) \quad (4)$$

The UMi NLOS above rooftops has a path loss increase of 20 dB for the additional diffraction edge due to the BS antenna height below the rooftop [5].

Several contributions proposed the height gain slope α to be chosen from 0.6, 0.9, 1.1, or 1.5 dB/m [7] [8] [9] [5]. Assuming d_{in} = 5 m, Figure 5 shows the NLOS path loss values for UMi and UMa indoor UE with α = 0.6, 0.9, 1.1, and 1.5 dB/m.

Observation 3: The UMi NLOS path loss above rooftops is greater than the one around buildings until the height gain becomes significant for elevated indoor UE. It does not reach the LOS path loss limit for indoor UE even with the height gain factor of 1.5 dB/m. In contrast, The UMa NLOS path loss around buildings is greater than the one above rooftops that reaches the LOS path loss limit for indoor UE on high floors and near the BS except for the height gain factor of 0.6 dB/m.

Proposal 3: To generate NLOS path loss values for indoor UE, use the height gain factor of 1.5 dB/m for UMi and 0.6 dB/m for UMa.

Figure 5. UMi and UMa NLOS path loss for indoor UE with height gain factor α = 0.6, 0.9, 1.1, and 1.5 dB/m.

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 above rooftops.

Proposal 2: For LOS above streets, assume the effective environment heights at two-thirds of min (h_{BS}, h_{UT}). For UMa LOS above rooftops for UE on floor numbers 5, 6, 7, and 8, assume the effective environment heights at 12 m, 13.5 m, 15 m, and 16.5 m, respectively.

Proposal 3: To generate NLOS path loss for indoor UE, use the height gain factor of 1.5 dB/m for UMi and 0.6 dB/m for UMa.

7 References

[1] R1-131760, Ericsson, ST-Ericsson, *et al.*, "Way forward on 3D channel modeling."

[2] R1-131752, Samsung, *et al.*, "Way forward on height dependent PL."

[3] Email discussion [72bis-19], "Height-dependent 3D path loss modeling."

[4] 3GPP TR 36.814, "Further advancements for E-UTRA physical layer aspects."

[5] R1-131335, Ericsson, ST-Ericsson, "3D-Channel Modeling Extensions."

[6] R1-131756, Nokia Siemens Networks, *et al.*, "Way forward on scenarios for 3D channel modeling."

[7] R1-131652, NTT DOCOMO, "Views on 3D-channel model for elevation beamforming and FD-MIMO."

[8] R1-131596, Orange, "Literature review on user antenna height correction factor for 3D-channel models."

[9] R1-131248, Nokia Siemens Networks, Nokia, "Path loss modeling for UE-specific elevation beamforming and FD-MIMO."