3GPP TSG RAN WG1 #74 **R1-132904**
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Title: Remaining Details of Path Loss for 3D Channel Modeling

Document for: Discussion and Decision

1 Introduction

The agreement at RAN1 #73 on path loss (PL) for 3D channel modeling includes the remaining details for further study (FFS) as follows:

- For line-of-sight (LOS) probability calculation and environment height calculation, 2D distance is used.
- LOS probability for 3D urban micro-cell (3D-UMi):
  $\Pr_{3D\text{-}UMi\text{-}LOS}(d) = \Pr_{ITU\text{-}UMi\text{-}LOS}(d)$
- LOS probability for 3D urban macro-cell (3D-UMa) is a function of d and h_{UT}.
  - Details **FFS**.
- 3D-UMi
  - Environment height is 1m, independently of h_{UT}.
- 3D-UMa
  - A LOS user equipment's (UE's) environment height is 1m with probability $p(d, h_{UT})$.
  - Otherwise the environment height is $h_E(h_{UT})$.
  - Details of $p(d, h_{UT})$ and $h_E(h_{UT})$ **FFS**, *e.g.*, if $h_E(h_{UT})$ is a deterministic or stochastic function.
- 3D-UMa
  - Height gain α = [0.6][0.9].
- 3D-UMi
  - Alternative 1:
    $PL_{3D\text{-}UMi\text{-}NLOS}(d, h_{UT}) = PL_{ITU\text{-}UMi\text{-}NLOS}(d) - \alpha\,(h_{UT} - 1.5)$
    - **FFS** height gain α
  - Alternative 2:
    - Decrement of PL is a nonlinear function of height and/or distance
  - Alternative 3:
    - Proposal as in R1-132100
  - **FFS**, to decide in the next meeting, companies are encouraged to bring additional measurement or simulation results.

This contribution discusses the remaining details of the UE-height-dependent path loss models, including

- LOS probability for 3D-UMa
- Environment height for 3D-UMa
- Non-line-of-sight (NLOS) path loss for 3D-UMi

2 LOS Probability for 3D-UMa

Table 1 provides LOS probability as functions of 2D distance d between base station (BS) and UE for ITU-UMi and ITU-UMa from Table B.1.2.1-2 of TR 36.814 [1]. The same LOS probability for 3D-UMi and a modification for 3D-UMa with a height compensation term $C(d, h_{UT})$ were proposed in [2][3]. **Appropriate applicability ranges for $C(d, h_{UT})$ such as $d \leq$ 18 m and $d >$ 18 m are required so that LOS probability is not greater than one.** For indoor UEs, the distance d was proposed to be replaced by the outdoor distance d_{out} [3].

Table 1. LOS probability functions for ITU-UMi, ITU-UMa, 3D-UMi, and 3D-UMa.

Source	Model	Applicability range
[1]	$Pr_{ITU\text{-}UMi\text{-}LOS}(d) = \min(18/d, 1) \cdot (1-\exp(-d/36)) + \exp(-d/36)$	
	$Pr_{ITU\text{-}UMa\text{-}LOS}(d) = \min(18/d, 1) \cdot (1-\exp(-d/63)) + \exp(-d/63)$	
[2][3]	$Pr_{3D\text{-}UMi\text{-}LOS}(d) = Pr_{ITU\text{-}UMi\text{-}LOS}(d)$	
	$Pr_{3D\text{-}UMa\text{-}LOS}(d, h_{UT}) = Pr_{ITU\text{-}UMa\text{-}LOS}(d) \cdot (1+C(d, h_{UT}))$	
	$C(d, h_{UT}) = 0$	$d \leq 18$ m, $h_{UT} < 13$ m
[2]	$C(d, h_{UT}) = ((h_{UT} - 13)/10)^{1.5} \cdot g(d)$	13 m $\leq h_{UT} \leq$ 23 m
	$C(d, h_{UT}) = g(d)$	$h_{UT} >$ 23 m
	$g(d) = 1.25 \cdot 10^{-6} \cdot d^3 \cdot \exp(-d/150)$	$d >$ 18 m

Figure 1 shows that, at fixed d, the 3D-UMa LOS probability increases with the 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} where $C(d, h_{UT}) > 0$. The incremental probability for UEs on floor numbers five to eight with LOS above rooftops is $Pr_{3D\text{-}UMa\text{-}LOS}(d, h_{UT}) - Pr_{ITU\text{-}UMa\text{-}LOS}(d)$ as noted in [2].

Proposal 1: For 3D-UMa, adopt the modified LOS probability with a height compensation term and appropriate applicability ranges of BS-to-UE 2D distance.

Figure 1. LOS Probability for 3D-UMa.

3 Environment Height for 3D-UMa

For LOS path loss, the break point distance $d'_{BP} = 4\ (h_{BS} - h_E)\ (h_{UT} - h_E)\ f_c\ /\ c$ varies with both the UE height h_{UT} and environment height h_E assuming that $h_{BS} = 25$ m for 3D-UMa, $f_c = 2 \times 10^9$ Hz, $c = 3 \times 10^8$ m/s, $h_{UT} = 3(n_{fl} - 1) + 1.5$ m, and n_{fl} in $\{1,2,\ldots,8\}$. Similar to 3D-UMi, the 3D-UMa environment height is one meter for UEs with LOS above streets and probability $\Pr_{ITU\text{-}UMa\text{-}LOS}(d)$. In contrast, for UEs on floor numbers five to eight with LOS above rooftops and probability $\Pr_{3D\text{-}UMa\text{-}LOS}(d, h_{UT}) - \Pr_{ITU\text{-}UMa\text{-}LOS}(d)$, Table 2 compares d'_{BP} for $h_E = 1$ m and various h_E proposed as stochastic [2][3] or deterministic functions [4][5][6][7][8] of h_{UT}. **Like the one-meter average environment height for UEs with LOS above streets, the average heights of lower rooftops are recommended as environment heights for UEs with LOS above rooftops.**

Proposal 2: For 3D-UMa UEs with LOS above streets and probability $\Pr_{ITU\text{-}UMa\text{-}LOS}(d)$, assume $h_E = 1$ m, and for UEs on floor numbers five to eight with LOS above rooftops and probability $\Pr_{3D\text{-}UMa\text{-}LOS}(d, h_{UT}) - \Pr_{ITU\text{-}UMa\text{-}LOS}(d)$, assume $h_E = 12$, 13.5, 15, and 16.5 m, respectively.

Table 2. Environment height and LOS break point distance for 3D-UMa.

Source	Model		n_{fl} h_{UT}	1 1.5	2 4.5	3 7.5	4 10.5	5 13.5	6 16.5	7 19.5	8 22.5
[2][3]	LOS above streets, $1 \le n_{fl} \le 8$ $h_E = 1$		h_E d'_{BP}	1 320	1 2240	1 4160	1 6080	1 8000	1 9920	1 11840	1 13760
	LOS above rooftops, $5 \le n_{fl} \le 8$ $h_E = U(12, \lfloor h_{UT}/3 \rfloor \cdot 3)$ or $h_E = U(12, h_{UT} - 1.5)$		h_E d'_{BP}					12 520	12 1560	12 2600	12 3640
									15 400	15 1200	15 2000
										18 280	18 840
											21 160
[4][5]	$h_E = 1.5(n_{fl} + 3)$, $5 \le n_{fl} \le 8$ or $h_E = (12 + (h_{UT} - 1.5))/2$		h_E d'_{BP}					12 520	13.5 920	15 1200	16.5 1360
[6]	$h_E = 12$, $5 \le n_{fl} \le 8$		h_E d'_{BP}					12 520	12 1560	12 2600	12 3640
[7]	$h_E = (2/3) \times \min(h_{BS}, h_{UT})$		h_E d'_{BP}					9 1920	11 2053	13 2080	15 2000
[8]	$h_E = a(h_{UT} - 1.5) + 1.0$	$a = 0.4$	h_E d'_{BP}					5.8 3942	7 4560	8.2 5062	9.4 5450
		$a = 0.5$	h_E d'_{BP}					7 3120	8.5 3520	10 3800	11.5 2960
		$a = 0.6$	h_E d'_{BP}					8.2 2374	10 2600	11.8 2710	13.6 2706
		$a = 0.7$	h_E d'_{BP}					9.4 1706	11.5 1800	13.6 1794	15.7 1686
		$a = 0.8$	h_E d'_{BP}					10.6 1114	13 1120	15.4 1050	17.8 902
		$a = 0.9$	h_E d'_{BP}					11.8 598	14.5 560	17.2 478	19.9 354

4 NLOS Path Loss for 3D-UMi

The following NLOS path loss model has been agreed for 3D-UMa to include a height gain term with $\alpha = 0.6$ or 0.9 and a lower bound of LOS path loss:

$$PL_{3D\text{-}UMa\text{-}NLOS}\,(d, h_{UT}) = \max\,(PL_{ITU\text{-}UMa\text{-}NLOS}\,(d, h_{UT} = 1.5) - \alpha \cdot (h_{UT} - 1.5), PL_{ITU\text{-}UMa\text{-}LOS}\,(d, h_{UT}))$$

where d is the 3D distance between BS and UE as defined in Appendix. Table 3 lists three NLOS path loss models proposed for 3D-UMi:

Alternative 1 includes a height gain term and a lower bound of LOS path loss that is not required for $\alpha = 0.6$ dB/m [9][10] but is required for $\alpha \geq 7.4$ dB/m [11][12]. Although h_{UT} is not an explicit parameter of $PL_{ITU\text{-}UMi\text{-}NLOS}$, the 3D distance d varies with h_{UT}, and hence the specification of $h_{UT} = 1.5$.

Alternative 2 finds the dominant path with lower loss either above rooftops or around buildings [12][13]. The path loss above rooftops includes a lower bound of LOS path loss and ITU-UMa NLOS path loss with a height gain term of $\alpha = 1.5$ dB/m and a loss increase of $\gamma = 20$ dB for an additional diffraction edge due to the BS antenna height at 10 m instead of 25 m [13].

Alternative 3 uses ITU-UMi NLOS path loss for UEs on floor numbers one to four. For UEs on floor numbers five to eight, it takes a weighted sum of ITU-UMi path loss and reciprocal ITU-UMa NLOS path loss with swapped BS and UE antenna heights, a height gain term of $\alpha = 0.9$ dB/m, and the weight of $\beta = 0.5$ [3].

Table 3. NLOS path loss models for 3D-UMi.

Source	Model
[9][10] [11][12]	**Alternative 1**: $PL_{3D\text{-}UMi\text{-}NLOS}\,(d, h_{UT}) = \max\,(PL_{ITU\text{-}UMi\text{-}NLOS}\,(d, h_{UT} = 1.5) - \alpha \cdot (h_{UT} - 1.5), PL_{ITU\text{-}UMi\text{-}LOS}\,(d, h_{UT}))$ $\alpha = 0.6$
[12][13]	**Alternative 2**: $PL_{3D\text{-}UMi\text{-}NLOS}\,(d, h_{UT}) = \min\,(PL_{3D\text{-}UMi\text{-}NLOS}$ (above rooftops), $PL_{3D\text{-}UMi\text{-}NLOS}$ (around buildings)) $PL_{3D\text{-}UMi\text{-}NLOS}$ (above rooftops) $= \max\,(PL_{ITU\text{-}UMa\text{-}NLOS}\,(d, h_{UT} = 1.5) + \gamma - \alpha \cdot (h_{UT} - 1.5), PL_{ITU\text{-}UMi\text{-}LOS}\,(d, h_{UT}))$ $PL_{3D\text{-}UMi\text{-}NLOS}$ (around buildings) $= PL_{ITU\text{-}UMi\text{-}NLOS}\,(d)$ $\alpha = 1.5$, $\gamma = 20$
[3]	**Alternative 3**: $PL_{3D\text{-}UMi\text{-}NLOS}\,(d, h_{UT}) = PL_{ITU\text{-}UMi\text{-}NLOS}\,(d)$ $h_{UT} < 12$ m $PL_{3D\text{-}UMi\text{-}NLOS}\,(d, h'_{UT}) = \beta \cdot PL_{ITU\text{-}UMi\text{-}NLOS}\,(d) + (1 - \beta) \cdot (PL_{ITU\text{-}UMa\text{-}NLOS}\,(d, h_{BS} = h'_{UT}, h_{UT} = 1.5) - \alpha \cdot 8.5)$ $h'_{UT} \geq 12$ m, $\alpha = 0.9$, $\beta = 0.5$

Assuming $d_{in} = 5$ m, the charts on the left in Figure 2 compare the above NLOS path loss models for 3D-UMi indoor UEs. Alternative 2 tends to fit measurement results with larger decrements of path loss above rooftops for UEs on high floors than those on low floors as illustrated in [13]. Other models can be tuned to generate similar results as suggested in [12]. The charts on the right in Figure 2 compare the results from different parametric values, *e.g.*, Alternative 3' with $\beta = 0.1$. In particular, Alternative 1' provides results similar to those of Alternative 2 by using variable height gain factors $\alpha = 0.3$ for $h_{UT} \leq 13.5$ m, and $\alpha = 0.4$, 0.5, and 0.6 for $h_{UT} = 16.5$ m, 19.5 m, and 22.5 m, respectively. **In parallel with 3D-UMa NLOS path loss model, Alternative 1 with variable height gain factors is recommended for 3D-UMi.**

Proposal 3: For 3D-UMi NLOS path loss model, adopt Alternative 1 with variable height gain factors.

Figure 2. 3D-UMi NLOS path loss for indoor UEs.

5 Conclusion

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

Proposal 1: For 3D-UMa, adopt the modified LOS probability with a height compensation term and appropriate applicability ranges of BS-to-UE 2D distance.

Proposal 2: For 3D-UMa UEs with LOS above streets and probability $\mathrm{Pr}_{ITU\text{-}UMa\text{-}LOS}(d)$, assume h_E = 1 m, and for UEs on floor numbers five to eight with LOS above rooftops and probability $\mathrm{Pr}_{3D\text{-}UMa\text{-}LOS}(d, h_{UT}) - \mathrm{Pr}_{ITU\text{-}UMa\text{-}LOS}(d)$, assume h_E = 12, 13.5, 15, and 16.5 m, respectively.

Proposal 3: For 3D-UMi NLOS path loss model, adopt Alternative 1 with variable height gain factors.

6 References

[1] 3GPP TR 36.814, "Further advancements for E-UTRA physical layer aspects."

[2] R1-132123, RAN1 #73, Ericsson, ST-Ericsson, "LOS 3D-Channel Modeling."

[3] R1-132100, RAN1 #73, ZTE, "Discussion on 3D Channel Modeling."

[4] R1-132497, RAN1 #73, Qualcomm, "Initial calibration of channel models for elevation beamforming and FD-MIMO."

[5] R1-132642, RAN1 #73, Broadcom, "Path Loss for 3D Channel Modeling."

[6] R1-131988, RAN1 #73, Samsung, "Remaining details for PL for 3D channel modeling."

[7] R1-132242, RAN1 #73, LG Electronics, "Initial evaluation results based on height-dependent UE modeling."

[8] R1-131860, RAN1 #73, Huawei, HiSilicon, "Discussion on remaining large scale parameters."

[9] R1-132744, RAN1 #73, Samsung, *et al.*, "Way Forward on Height Dependent PL."

[10] R1-132369, RAN1 #73, NTT DOCOMO, "Views on 3D-Channel Model for Elevation Beamforming and FD-MIMO."

[11] R1-132062, RAN1 #73, Alcatel-Lucent Shanghai Bell, Alcatel-Lucent, "Initial Validation of 3D Channel Modeling."

[12] R1-132313, RAN1 #73, Nokia Siemens Networks, Nokia, "Remaining Details of Pathloss."

[13] R1-132124, RAN1 #73, Ericsson, ST-Ericsson, "NLOS 3D-Channel Modeling."

7 Appendix: Path Loss Models

The antenna height at BS is h_{BS} = 10 m for 3D-UMi and 25 m for 3D-UMa. The antenna height at UE is $h_{UT} = 3(n_{fl} - 1) + 1.5$ m depending on its floor number n_{fl} in $\{1, 2, \ldots, N\}$ with the maximal floor number N in $\{4, 5, 6, 7, 8\}$. By replacing 2D distance d with 3D distance $d_{3D} = (d^2 + (h_{BS} - h_{UT})^2)^{0.5}$, Table 4 provides the path loss models undated from TR 36.814 for outdoor UEs with h_{UT} = 1.5 m and environment height h_E = 1 m. The LOS break point 2D distance d'_{BP} is **120 m** for 3D-UMi and **320 m** for 3D-UMa at $f_c = 2 \times 10^9$ Hz— the inter-site distance (ISD) is 200 m for 3D-UMi and 500 m for 3D-UMa.

Table 4. Path loss models for outdoor UEs.

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

For indoor UEs, 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 5 provides the outdoor-to-indoor (O-to-I) path loss models undated from TR 36.814 by replacing 2D distance $d = d_{out} + d_{in}$ with 3D distance $d_{3D} = ((d_{out} + d_{in})^2 + (h_{BS} - h_{UT})^2)^{0.5}$. For indoor UEs with h_{UT} = 1.5 m and environment height h_E = 1 m, the models in Table 4 can be used to derive the basic path loss PL_b. For the floor number n_{fl} in $\{2, 3, \ldots, 8\}$, the path loss models in Table 4 require modifications as discussed to date.

Table 5. Path loss models for indoor UEs.

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	$PL_b = PL(d_{3D})$	$10\text{ m} < d < 1000$ m
Through wall	$PL_{tw} = 20$	
Inside building	$PL_{in} = 0.5 d_{in}$	$0\text{ m} < d_{in} < \min(25, d)$ m