Millimeter-Wave Line-of-Sight Probability Modeling for Inside Metro Carriages Scenarios

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***Abstract*—This paper proposes a new Line of Sight (LoS) probability model for metro carriage scenarios to evaluate radio propagation for the future Fifth Generation (5G) Wireless Communications Systems in the Millimeter Wave (mmW) bands. The new model has been defined after 36 measurement campaigns. For each campaign a high precision 3D scenario with a random distribution of passengers and different positions of TX has been used. A comparison between the proposed model and ITU, WINNER A1 and WINNER B3 LoS probability models has been made. As a result, it is shown that the proposed model is the most suitable for this scenario and considerably minimizes the Mean Square Error (MSE) compared to the other models.**

***Index Terms*—5G, LoS probability, millimeter-wave, propagation.**

I. Introduction

Most of 5G mobile communications improvements comes from increasing spectral efficiency of wireless channels, therefore they need to be properly characterized [1]. Among the main 5G characteristics, there is a wide range of possible propagation scenarios and network topology that should be included in channel modelling. Another characteristic is related to the use of the electromagnetic spectrum, such as the total bandwidth used, which must be at least 100 MHz, as well as the central operating frequency where the trends are clearly for millimeter wave mmW range between 30 and 300GHz.

Existing wireless channel modelling has to adapt and update to these new requirements and scenarios. In the near future, various types of links (eg, traditional cellular, Device to Device (D2D), mobile base stations, etc.) have to coexist in the same area, and the model should support engineers consistently. Most of the current channel modelling present particular problems such as: limitation of 2D models, incomplete frequency coverage, bandwidth, limited number of scenarios, inconsistency of correlation in D2D, inconsistent small-scale parameters, dual mobility, non-existent long-scale array support and LoS probability models [1], which are the motivation for this paper.

In fact, LoS probability models plays an essential role in channel modeling, especially for complex and dense scenarios where blocking and shadowing terms are adverse to signal transmission. In that sense, for a correct characterization of the operating modes to obtain the comparative advantages that 5G will offer, it is necessary to study separately each scenario in which the technology will operate. In this paper, the train carriage scenario has been chosen because the High Speed Rails or metropolitan trains are a special case that combines both high density on users and, in some cases, high speeds. Channel characterization in this scenario and considering high density on users has been more focused on the large scale characteristics such as path loss, shadow fading, or the correlation properties [2]–[4].

The main objective of this study is to evaluate the current LoS probability models that are used for the mmW bands and to propose a new model that fits properly to this particular scenario. To this end, a 3D model of the train carriages has been created and a massive measurement campaign has been carried out for multiple Transmitter (TX) and Receiver (RX) locations.

The paper is organized in five sections. An introductory section presents the context of this work. Section II introduces the LoS probability models used by the ITU, WINNER A1 and B3, Section III presents LoS probability measurements and it scenario. A new LoS probability model is presented in Section IV. Results of the new model are presented in Section V. Finally, the conclusions of the assessment are discussed at the end of the document.

II. LoS probability models

The probability that a wave propagating between a TX and RX will not be blocked along its path is called the line-of-sight probability [5], [6]. Among the several LoS probability models, we will focus on the ones that are closer to the indoor metro carriage scenario, since to the best of our knowledge there is none.

Two LoS probability models of WINNER II are selected [7], the first one called WINNER B3 that considers a non-grid based level of detail, wich only depends on distance between TX and RX. The second one, which is called WINNER A1 indoor office , considers a grid based level of detail, which means it depends on the Cartesian coordinates. Another model to be explored is the one from ITU applied for indoor scenarios [8]. All the described models were developed for general scenarios. They are not efficient for calculation in a specific case such as a metro carriage indoor scenario. Therefore the

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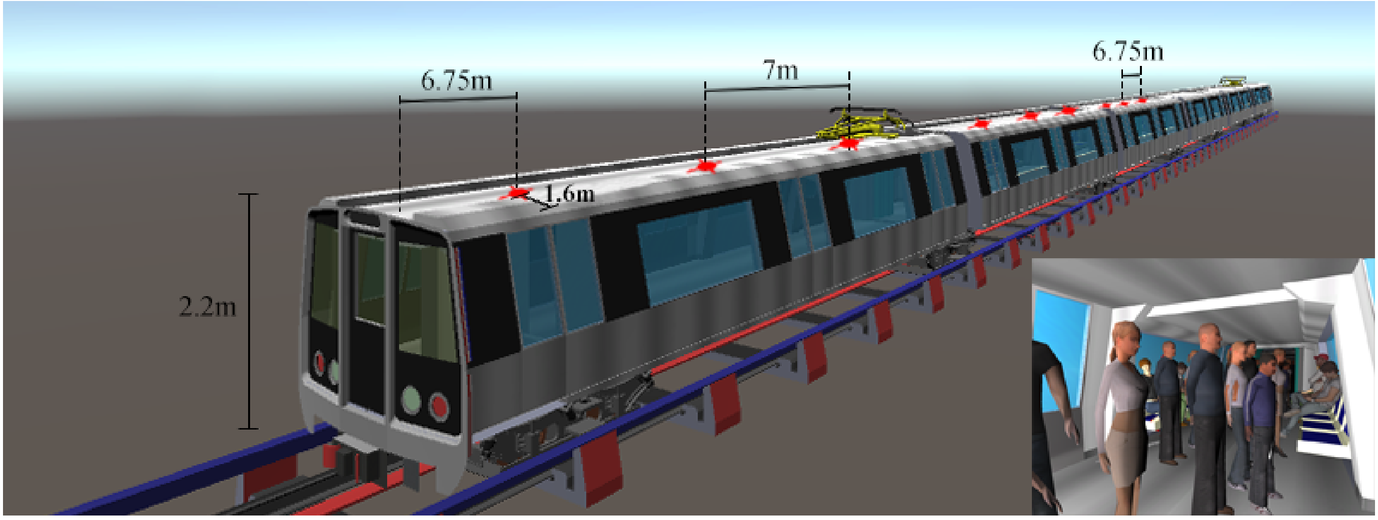

Fig. 1: 3D scenario overall view and carriage indoor view with a random distribution of passengers.

importance of comparing the efficiency of these models and to propose a new model for this scenario. Table I describes the four models. Based on its equations it is possible to notice that the WINNER A1 model is the most optimistic of the four, since its break-point distance is larger and the probability remains 1 until 2.6m. And, the most pessimistic is WINNER B3.

TABLE I: LoS probability models for the indoor environment

Model	Description
(1)ITU Model	$P_{LOS} = \begin{cases} 1 & , d \leq 1.1m \\ exp(-(d-1)/4.9 & , 1.1m < d < 9.8m \\ 0.17 & , d \geq 9.8m \end{cases}$
(2)WINNER B3	$P_{LOS} = \begin{cases} 1 & , d \leq 1m \\ exp(-(d-1)/9.4 & , d > 1m \end{cases}$
(3)WINNER A1	$P_{LOS} = \begin{cases} 1 & , d \leq 2.6m \\ 1\text{-}0.9(1\text{-}(1.16\text{-}0.4\log_{10}(d))^3)^{\frac{1}{3}} & , d > 2.6m \end{cases}$
(4)New Model	$P_{LOS} = \begin{cases} 1 & , d \leq 0.7m \\ exp(-(d-0.7)/6.7), & 0.7m < d < 7m \\ exp(-(d-7)/2.4) \cdot 0.36 & , d \geq 7m. \end{cases}$

III. Metro-Carriage LoS Probability Measurements

In this study, 36 measurement campaigns were carried out. Each campaign's setup involves three parts: A) the scenario modelling, B) a random distribution of users to replicate realistic blocking conditions inside train carriages and C) LoS probability estimation for different TX positions with a high grid resolution of 0.10 meter side. In each measurement campaign, 237402 LoS probability estimations have been obtained. These results were then used to propose a new LoS probability model.

A. Scenario

The scenario has been designed in a multi-platform of 3D and 2D video games called Unity3D. This software allows the creation of realistic and complex environments and can be used in wireless network simulations as in [9], [10]. Indeed, we exploit Unity's graphic engine to determine the incident ray collisions of the mobile link.

A 3D scale model of Lima's metro train carriages has been implemented in Unity with the help of the free Scketchup models available at [11]. It has a high level of detail because it contains the geometry and various obstacles typical of the scenario such as chairs, railings and an average density of people on rush hours.

The metro train has a total length of 134m and is made up of 6 carriages 2.2m high, 3.2m wide. It has a capacity of 1200 people and considers a total of 36 seats where each seat can be occupied by 4 people. On a weekday and in rush hour, it is possible to see 200 people per carriage, made up of 24 people sitting and 176 people standing.

For this research, the first three carriages have been considered as a reference. Three TX antennas per carriage have been placed at a height of 2.2m. They are evenly distributed with a distance of 7m between them and are represented by red circles in Fig. 1. About the RX, two heights at 0.6m and 1.5m above ground level have been considered.

B. Blocking and Shadowing terms

Users have been added to the scenario with a random location and density to model the blocking and shadowing terms. These users are 3D models that represent the users sitting and standing inside the metro carriage. This achieves a consistent scenario and makes the measurement campaigns more representative of the usual flow of passengers. As an example, Fig. 1 shows the passengers' 3D model and Fig. 2 shows the impact on the LoS condition for three random distributions of passengers with different densities and TX positions.

C. LoS probability estimation

To estimate the LoS probability, the LoS condition is modeled by a map-based approach assumes the TX and receiver RX positions. And, the blocking and shadowing terms are modeled separately [12]. The accuracy of the LoS probability models is directly related to the number of measurements made and the geometric accuracy of the scenario.

1) LoS Condition: To calculate the LoS condition we use a single-ray tracing method, which consists of launching a ray from the TX to the receiver RX and checking that no obstruction is in the way within the first Fresnel zone. This LoS condition can be defined as [13]:

$$C_{LoS} = \begin{cases} 1 & , l_p \leq d_{3D} + \frac{\lambda}{2} \\ 0 & , l_p > d_{3D} + \frac{\lambda}{2}, \end{cases} \tag{5}$$

where C_{LoS} can take the value of 1 or 0 and represents LoS and Non Line of Sight (NLoS) respectively. And, l_p is the ray-path length between the transmitter and the receiver, d_{3D} is the TX-RX distance in meters and λ is the wavelength of the transmitted signal. In this paper, the wavelength corresponds to the 28 GHz frequency band. As an example, Fig. 2 shows three maps of the condition computation for different TX positions, the red points correspond to $C_{LoS} = 1$ (LoS) and the blue points correspond to $C_{LoS} = 0$ (NLoS).

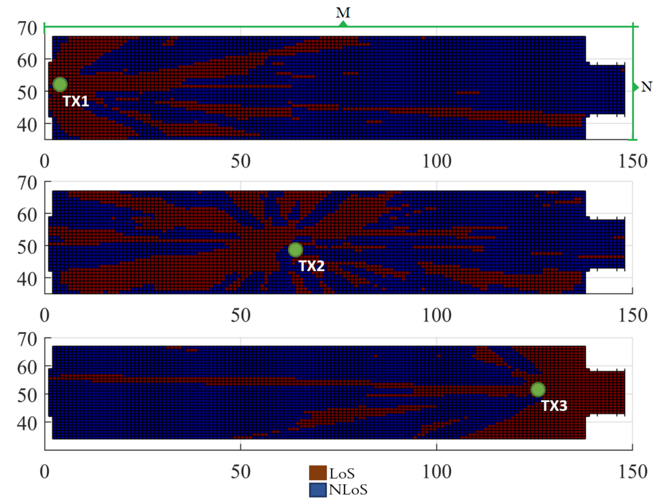

Fig. 2: Sample of LoS Condition Map for 3 TX positions

2) LoS Probability in Metro-Carriage Scenario: To consider all possible RX positions, the scenario has been divided into a grid of 0.10 meters on each side and with a height of 0.6m and 1.5m above the ground level, emulating the positions of the user equipment when passengers are seated or standing respectively. Fig. 2 shows the grid, which can be represented by an MxN matrix.

$$P_{LOS-MN} = \begin{pmatrix} a_{1,1} & a_{1,2} & \cdots & a_{1,N} \\ a_{2,1} & a_{2,2} & \cdots & a_{2,N} \\ \vdots & \vdots & \ddots & \vdots \\ a_{M,1} & a_{M,2} & \cdots & a_{M,N} \end{pmatrix}, \tag{6}$$

where M and N are the train length and width distances divided by the grid-resolution respectively. For each point (M,N) two variables have been calculated and stored: 1) the 3D distance between the transmitter and the point (M,N) and 2) the C_{LoS} condition which takes the value of 1 for LoS and 0 for NLoS. Once the LoS condition has been checked at all points of the MxN matrix, the LoS probability, p_d, is calculated by grouping the results by d3D distances by using the following equation:

$$p_d = \frac{NLoS, d}{N_d}, \tag{7}$$

where $NLoS, d$ is the total number of TX-RX combinations with a distance d from the MxN matrix that has LoS and N_d is the total number of elements of the MxN matrix. As a result of this iteration, we have MxN calculations of p_d for each measurement campaign.

IV. New LoS Probability Model

To improve the accuracy of the probability of LoS in the millimeter bands inside the train carriages, a new LoS probability model is introduced in this paper. To model the LoS probability, 36 measurement campaigns have been carried out following the procedure in Section III. The positions of the transmitters in all campaigns are the same. In each measurement campaign, passengers are randomly distributed to emulate obstructions by emulating typical metro user flow conditions. First, matrix P_{LOS-MN} has been calculated for each TX. Then, the values of p_d at all points have been estimated. These values p_d represents the real LoS probability for our scenario. Fig. 3 shows the p_d estimation vs d.

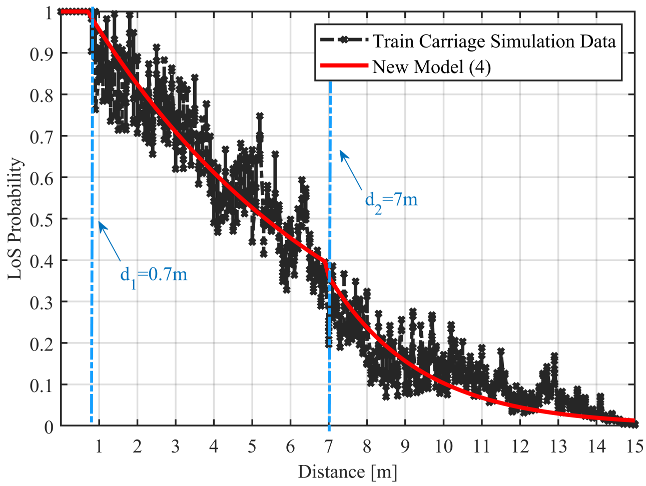

Fig. 3: LoS Probability (pd) vs distance results of the exhaustive measurement campaign in train-carriages and proposed New Model (4)

In Fig. 3, we can define two breakpoint distances, d_1 and d_2, where the LoS probability changes considerably. With that breakpoint distance, the new model can be defined as:

$$P_{LOS} = \begin{cases} 1 & , d \leq d_1 \\ exp(-(d-d_1)/A) & , d_1 < d < d_2 \\ exp(-(d-d_2)/B) \cdot C & , d \geq d_2. \end{cases} \tag{8}$$

To derive the parameters for the new LoS probability model in (8). The parameters A, B and C were calculated with the criteria of minimizing the MSE between the new model and the values of p_d obtained in the measurement campaign. As a result of this iteration, the optimal parameters values are A= 6.7, B= 2.4 and C= 0.36. Fig. 3 shows the model with the calibrated parameters.

V. Evaluation Results

The model proposed in this paper has been compared with the ITU, WINNER A1 and WINNER B3 LoS probability models. To be fair to the evaluation the following criteria have been used: 1) six new measurement campaigns have been carried out, 2) the users have been randomly distributed with different densities around the carriage, 3) the TXs have been placed in random positions on the top of the carriages and 4) the measurements have been carried out in 500 positions per campaign, the location of the RXs are random with a height of 0.6 or 1.5m.

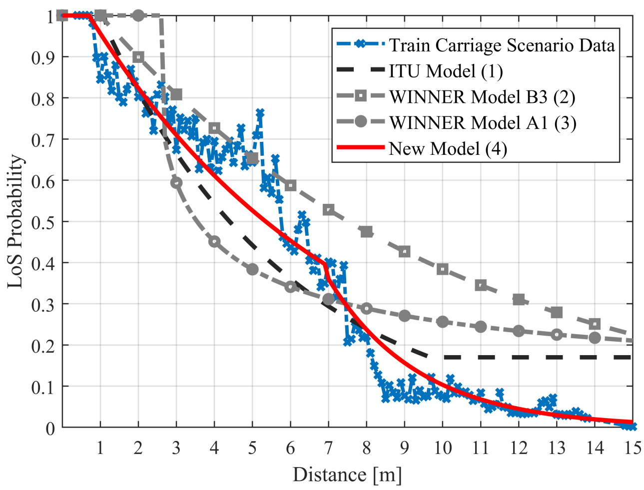

Fig. 4: LoS probability models evaluation on train carriages

Fig. 4 shows the results of the measurement campaigns and the estimation of the models. Analyzing the first zone from 0 to d_1 all models are similar except WINNER B3 which is more optimistic and extends its first breakpoint distance up to 2.6m. In the second segment from d_1 to d_2, it can be seen that the model proposed in this paper fits better and the ITU and WINNER A1 model are more pessimistic. We can point out that in this section the probability of LoS does not decrease so abruptly because the TX has a height that predominates over the users. In the last section, for distances greater than d_2, we can see that in the simulations the probability of LoS decreases substantially. For this case, the ITU, WINNER B3 and WINNER A1 models are very optimistic. In contrast, the model proposed in this paper has a better fit. The drop in the probability of LoS is caused by the fact that the TX height is no longer predominant and the users generate larger shadow areas on the scenario.

Finally, Table II compares maximum errors and MSE between all models. The results show that the proposed model reduces MSE more than 4.91 times with respect to the ITU model and that the maximum error is 3.85 times lower than the other models.

TABLE II: Maximum error and MSE of LoS Probability Models

LoS Probability Model	Max. Error	MSE
ITU Model	0.0682	0.0103
WINNER B3	0.1079	0.0224
WINNER A1	0.0907	0.0158
New Model	0.0177	0.0021

VI. Conclusion

In this paper the LoS probability for train's metro carriage has been studied. A new model has been proposed that fits better than the ITU, WINNER A1 and WINNER B3 models. The proposed model considerably minimizes the MSE compared to the other models. The results obtained from this study demonstrate that the proposed model is suitable for the evaluation of the train-carriage radio channel at mmW bands. This proposed model will allow a proper radio channel characterization. As future work, it is proposed to characterize new models for new massive transport scenarios.

References

[1] METIS Project, "Mobile and wireless communications Enablers for the Twenty-twenty Information Society (METIS)," ICT-317669-METIS, Deliverable Deliverable D1.4, Feb. 2015.

[2] K. Guan, Z. Zhong, B. Ai, and T. Kürner, "Propagation measurements and analysis for train stations of high-speed railway at 930 mhz," *IEEE Transactions on Vehicular Technology*, vol. 63, no. 8, pp. 3499–3516, 2014.

[3] K. Guan, Z. Zhong, B. Ai, and T. Kürner, "Empirical models for extra propagation loss of train stations on high-speed railway," *IEEE Transactions on Antennas and Propagation*, vol. 62, no. 3, pp. 1395–1408, 2013.

[4] R. He, Z. Zhong, B. Ai, and C. Oestges, "Shadow fading correlation in high-speed railway environments," *IEEE Transactions on Vehicular Technology*, vol. 64, no. 7, pp. 2762–2772, 2015.

[5] T. R. M. Samimi and G. MacCartney, "Probabilistic omnidirectional path loss models for millimeter-wave outdoor communications," *IEEE Wireless Commun. Lett*, vol. 4, no. 4, p. 357–360, Aug. 2015.

[6] J. Li, "Los probability modeling for 5g indoor scenario," in *2016 International Symposium on Antennas and Propagation (ISAP)*. IEEE, 2016, pp. 204–205.

[7] *WINNER II Channel Models, Part II, Radio Channel Measurement and Analysis Results*, WINNER II D 1.1.2 Std., September,2007.

[8] *Guidelines for evaluation of radio interface technologies for IMT-Advanced*, Report ITU-R M.2135-1 Std., Dec,2009.

[9] D. Garcia-Roger, D. Martín-Sacristán, S. Roger, J. F. Monserrat, A. Kousaridas, P. Spapis, S. Ayaz, and C. Zhou, "5G multi-antenna V2V channel modeling with a 3D game engine," in *2018 IEEE Wireless Communications and Networking Conference Workshops (WCNCW)*, Apr. 2018, pp. 284–289.

[10] E. Egea-Lopez, F. Losilla, J. Pascual-Garcia, and J. M. Molina-Garcia-Pardo, "Vehicular networks simulation with realistic physics," *IEEE Access*, vol. 7, pp. 44 021–44 036, 2019.

[11] Sketchup, "3dwarehouse of sketchup," 2020. [Online]. Available: URL https://3dwarehouse.sketchup.com/?

[12] K. Haneda, L. Tian, H. Asplund, J. Li, Y. Wang, D. Steer, C. Li, T. Balercia, S. Lee, Y. Kim *et al.*, "Indoor 5g 3gpp-like channel models for office and shopping mall environments," in *2016 IEEE International Conference on Communications Workshops (ICC)*. IEEE, 2016, pp. 694–699.

[13] J. Järveläinen, S. L. Nguyen, K. Haneda, R. Naderpour, and U. T. Virk, "Evaluation of millimeter-wave line-of-sight probability with point cloud data," *IEEE Wireless Communications Letters*, vol. 5, no. 3, pp. 228–231, 2016.