Channel Modelling based on Game Engines Light Physics for mmW in Indoor Scenarios

Saúl Inca, Danaisy Prado, David Martín-Sacristán, Jose F. Monserrat
iTEAM Research Institute, Universitat Politècnica de València, Camino de Vera s/n, 46022 Valencia, Spain
{*sauin,dapraal,damargan,jomondel*}*@iteam.upv.es*

***Abstract*—The importance of Millimeter Waves (mmW) band for the Fifth Generation (5G) of mobile and wireless communications has motivated a lot of work in mmW channel modelling. In this paper, we assess the use of the light physics modelling of a game engine to calculate the propagation losses at mmW band in an indoor scenario. With that aim, we propose a model that we refer to as Light Intensity Model (LIM), in which a detailed 3D scenario is created in a game engine, radio transmitters and receivers are replaced by light sources and detectors, and the received light intensities are translated to received radio signal power through a translation function which is the key of the model. The results obtained corroborate the validity of the assessed approach to model propagation losses in indoor scenarios.**

***Index Terms*—millimeter waves, mmW, propagation, channel modelling, path loss, game engine.**

I. Introduction

The Fifth Generation (5G) of mobile and wireless communications promises to be a technological revolution which requires new enabling technologies to meet its challenging goals. One of these enablers is the use of Millimeter Wave (mmW) bands in which a large amount of spectrum is available.

Channel models are required to predict radio channel characteristics and reliably evaluate 5G performance in the mmW bands. Specifically, a first need is the correct modelling of path losses. One accurate approach is the use of Ray Tracing (RT), a deterministic modelling based on a reliable knowledge of the geometric and electromagnetic features of the scenario [1]. RT can be very accurate in realistic environments but this accuracy comes with a high computational cost. A simpler option to estimate the path loss in realistic environments is to first determine the type of sight between a transmitter and a receiver, either Line of Sight (LoS) or Non Line of Sight (NLoS), based on the real obstructions present in the environment, and then calculate the losses as a function of the type of sight, the frequency used, and the distance between transmitter and receiver. These kind of formulas are provided by stochastic channel models such as those of the Third Generation Partnership Project (3GPP) [2] or the New York University (NYU) [3].

On the other hand, in recent years, video game technology has developed powerful tools to model the propagation of light in super realistic scenarios. Game engines, i.e. the platforms used to develop video games, include complex and efficient ray tracing implementations to model the light propagation. Some authors, including the authors of the present paper, have used part of these capabilities to implement electromagnetic ray tracing on game engines [4], [5], [6].

The approach followed in this study is different and novel, as far as we know. Given the spectral closeness between the visible spectrum and the mmW waves, the present assessment has studied the direct application of the light propagation modelling tools of game engines for the radio channel modelling in mmW. The main idea is to replace the radio transmitters by light sources and translate the light intensity received at a point into radio signal power in mmW through a simple polynomial function. We refer to this model as the Light Intensity Model (LIM).

In this paper, we apply this novel approach to estimate the path loss in a well-known indoor scenario of the NYU where measurements and path loss models at 28 GHz and 73 GHz are available in the literature [3]. The game engine used is Unity 3D [7] which is a multi-platform game engine previously used for ray-tracing by the authors of this paper in [5].

The remainder of the paper is as follows. Section II introduces the path loss models used by the 3GPP and NYU channel models. Then, Section III describes the new modelling proposed in this paper. Section IV details the characteristics of the indoor scenario of the NYU used in the assessment, and explains how we have modelled it in the Three Dimensions (3D) game engine. Section V analyzes the accuracy of our model based on the comparison with real measurements, and the predictions of stochastic models. Finally, the conclusions of the assessment are discussed in Section VI.

II. Stochastic Channel Models for mmW in 5G

The mmW band comprises the spectrum band from 30 GHz to 300 GHz, although the industry has typically considered a lower edge of 10 GHz [8]. This band has been selected as a 5G enabler, due to the huge amount of available bandwidth at these frequencies. Nevertheless, the high path loss and severe fading due to obstructions inherent to this spectrum region are challenging. In this context, an accurate channel modelling becomes crucial.

A simple modelling is provided by the stochastic channel models. They are based on probability density functions to characterize some parameters of the channel, being this functions different for each environment. Stochastic models can take into account the geometry of the scenario, mainly the relative position and orientation of the transmitters an receivers. Concerning the propagation losses modelling, they usually have probability functions to determine if the receiver and the transmitter are in line of sight or not, and for each kind of sight, they provide simple functions to calculate the losses. The models of the WINNER II project [9], the IMT-2020 models [10] and the 3GPP models [2] are relevant examples.

Particularly, focusing on indoor scenarios, the 3GPP model is described mathematically as follows:

$$PL_{LoS}[dB] = 32.4 + 17.3\log_{10}(d_{3D}) + 20\log_{10}(f_c), \quad (1)$$

$$PL'_{NLoS}[dB] = 38.3\log_{10}(d_{3D}) + 17.3 + 24.9\log_{10}(f_c), \quad (2)$$

$$PL_{NLoS}[dB] = \max(PL_{LoS}, PL'_{NLoS}), \quad (3)$$

where $PL_{LoS}[dB]$ is the path loss in case of LoS, $PL_{NLoS}[dB]$ is the path loss in case of NLoS, f_c is the frequency in GHz, and d_{3D} is the 3D distance between the transmitter and the receiver.

In this paper, a quasi-deterministic path loss model based on 3GPP model will be evaluated. For the path loss computation, the equations 1, 2 and 3 provided by the 3GPP will be used. However, whether the receivers are in LoS or not, will be determined by using deterministic methods.

NYU Wireless research group has been very active in the field of channel modelling for 5G and millimeter waves. In this context, NYU has carried out measurement campaigns for both indoor and outdoor scenarios. In [3], the authors propose single frequency and multi-frequency path loss models based on measurements from an indoor environment at mmW. Directional and omnidirectional path loss models are obtained considering 3D distance between transmitters and receivers. Measurements derived from co-polarized and cross-polarized path loss model are provided. This dataset encourages a comparative study, serving as a stochastic model reference. Concretely, the single-frequency omnidirectional close-in free space reference distance (CI) path loss model provided by [3] has been selected for the purpose of this work. Regarding polarization, it is also worth to mention that only vertical-vertical co-polarized transmissions are in the scope of this study.

For the large-scale propagation loss estimation it proposes an equation for both LoS and NLoS, as shown in (4). Where $FSPL$ is the free space path loss, d_0 is the reference distance, n is the Path Loss Exponent (PLE) and, X_σ^{CI} is the scattering factor that represents large-scale signal fluctuations as a result of shadows due to wireless channel obstructions and is defined as a zero-Gaussian random variable σ in dB. However, in our case, X_σ^{CI} has been disregarded since the propagation conditions are known.

$$PL^{CI}(f,d)[dB] = FSPL(f,d_0) + 10n\log_{10}\left(\frac{d}{d_0}\right) + X_\sigma^{CI}$$
$$\text{for } d \geq d_0, \text{ where } d_0 = 1 \text{ m} \quad (4)$$

In this paper, both 3GPP based quasi-deterministic model and CI model from [3] will be compared to LIM.

III. Light Intensity Channel Model

Given the spectral closeness between the visible spectrum and the mmW bands, it seems appropriate to propose the use of light propagation modelling tools for radio channel modelling. Considering this, LIM comes up as a model for estimating large-scale propagation losses in mmW based on the light modelling of game engines. LIM replaces the signal transmitters with light sources, then light propagates through the scenario and finally the received light intensity at each specific point is translated into propagation losses via a simple polynomial function.

LIM exploits the two most important resources of game engines: the first one, a great capacity and friendly developer interface that facilitate the creation process of super realistic scenarios. And the second, the advanced ray tracing algorithms of the lighting processes performed by the game engines.

The ability to create realistic scenarios is of paramount importance to emulate in detail the physical phenomena as they happen in reality due to the specific geometry of the real scenarios.

Concerning the lighting processes, games engines have specific tools for those tasks. For example, Unity has the Global Illumination (GI) advanced lighting tool. The GI is a group of algorithms and mathematical models that attempts to simulate the complex behavior of light, i.e. specular reflections, diffuse reflections, refractions and each one of the phenomena associated with the propagation of light.

Another relevant feature of Unity is that it is possible to modify the configuration of the materials of the 3D objects to have an interaction with the light closer to the interaction of those materials with the radio waves. In the case of our LIM implementation, the texture of the materials is adjusted with that aim. Specifically, we use extremely smooth materials to emulate high reflective materials such as metal while different levels of roughness are assigned to materials originating diffuse scattering.

A. Acquisition of Light Intensity Values

As explained, LIM associates a light intensity value received at a certain point of an scenario with a propagation loss. For the acquisition of light intensity, cameras are located at the point of interest. In order to capture light from all directions of the scene, not a single camera is used. Instead, a 0.05 m side cube is placed at the Rx position, and the intensity of the light is obtained by assigning and focusing a camera to each and every one of the 6 faces of the cube to capture the light intensity at each plane. The total light intensity of the Rx is the sum of the light intensity of the 6 faces of the cube. The position of the cameras is not a problem because the cameras are completely transparent and do not create shadows by themselves. The light intensity for each cube side is normalized to be in the range $[0, 1]$ by dividing the intensity measured by the maximum value achievable if the source was co-located with the cube side. As a result, the total intensity at the RX point, which is the sum of the intensity captured in the six faces of the cube, is in the range $[0, 6]$.

B. Global Illumination and Light Rendering Process

The two main components of GI are light sources and High Definition Render Pipeline (HDRP). The four main parameters of the light sources are the Light Source Intensity (LSI), the Light Bounce (LB), the Shadow Strength (SS) and the Shadow Bias (SB) [11]. These four characteristics determine the light intensity values in the scenario. Briefly, LSI sets the brightness of diffuse ambient light in the scene. LB is used to set how many reflection bounces are allowed. SS and SB determine how dark the shadows are and adjust the position and definition of the shadows, respectively. Concerning to HDRP, it is an advanced shader capable of modelling the response of direct and indirect light in real time, with multiple Bidirectional Reflectance Distribution Functions (BRDFs) [11]. The BRDFs available in Unity for specular reflection are the Ward model and the Phong model. Both models add a specular component, the first as a function of the normal of the reflection point and the second as a function of the normal of the surface of the object. For diffuse scattering, the Oren Nayar model and the Lambertian model are available. The Oren Nayar model is designed to model scattering on rough surfaces. For smooth surfaces, the Lambertian model is sufficient according to [12]. For the Unity calibration, all possible combinations between the diffuse and reflective functions that best match the electromagnetic behavior of the materials have been evaluated.

C. Light Intensity Model Calibration

Transmitters and receivers were placed in the synthetic scenario strictly following the location coordinates and the height and orientation specifications in the actual measurement campaign as shown in Fig. 1. Omnidirectional light sources were placed one by one at transmitter locations and light intensity values were collected at receiving points.

For the calibration process, a sweep of each of the five Unity lighting variables mentioned above was performed with a step of 0.01 units. For each combination of values, a light intensity is obtained at each measurement point. Then, it is find the polynomial function that returns path loss values from the light intensities such as the mean absolute error between the predicted path loss and the measured path loss is minimized. Once the polynomials and their mean absolute errors are available for all the lighting variables combinations, it is selected the polynomial and combination which produces the lowest error.

IV. Evaluation Scenario and Unity Configuration

Using Unity we have modelled the real indoor scenario of NYU Wireless research center as shown in Fig. 1. This scenario comprises spaces such as common cubicle offices, lecture rooms and corridors, in which different propagation characteristics are manifested. TX and RX positions are marked in Fig. 1. It is necessary to indicate that since in this work neither transmission nor diffraction have been considered, some Tx-Rx measurements in [3] have been discarded.

In Unity 3D, it is possible to characterize the interaction of each material with the light in a different way. Specifically, through the GI process, specular and diffuse reflection models of BRDF that best fit the reflective behavior of each material have been set for each and every one of them. Since metal, chipboard, drywall and glass have smooth surfaces, the Ward and Lambertian models have been used for them, while for concrete, which has a somewhat rough surface, the Ward and Oren Nayar models were selected. Furthermore, each one of the materials has been configured with a height map that emulates its roughness. Regarding the lighting rendering of Unity, it has been considered 32 direct samples, 512 indirect samples, 4 bounces, lightmap resolution is set in 40 texels per unit and the light map size set in 1024×1024 pixels. Lightmap is set in high resolution. This setting are adequate to calculate direct and indirect illumination in scenarios with complex geometries according to [11].

V. Evaluation Results

The calibration process indicated in Section III has been applied to the indoor scenario, leading to the values of the lighting parameters shown in Table I and the polynomials for light intensity to path-loss translation for LoS and NLoS shown in (5) and (6) respectively, where i is the normalized light intensity value.

TABLE I
Calibration variable values for LIM

Lighting variables	Range	28 GHz
Light source intensity (LSI)	$[0, 6]$	2.75
Light bounce (LB)	$[0, 1]$	0.35
Shadow strength (SS)	$[0, 1]$	0.55
Shadow bias (SB)	$[0, 1]$	0.90

$$PL_{LoS}[dB] = -10.44i + 128.8 \tag{5}$$

$$PL_{NLoS}[dB] = -0.45i^2 - 3.23i + 109.9 \tag{6}$$

Fig. 2 shows a scatter plot that for each one of the 24 measurement points indicates its measured path loss and its simulated normalized intensity. The measurements points in LoS are represented by blue circles while the measurement points in NLoS are represented by red squares. The figure also shows the polynomial functions obtained after LIM calibration for LoS and NLoS. The R^2 of the polynomial regressions are 0.93 and 0.83 for LoS and NLoS respectively, and the mean absolute error between the measured path loss and the path loss estimated by the LIM for all the measurement points is 2.20 dB, which confirms the high accuracy of LIM in this case. The scatter plot also shows that points in LoS have high light intensity values and low large scale losses and are then concentrated on the right side of the graph. On the other hand, the points in NLoS are more dispersed over the entire light intensity range. Analyzing the estimation error in LoS and NLoS separately, we obtained that the mean absolute error in LoS is 0.94 dB and in NLoS is 2.83 dB.

Also, LIM has been compared with the NYU and 3GPP path loss models presented in Section II. For the sake of a fair comparison, the values of the parameter n for the NYU model have been recalculated compared to the values reported in [3]

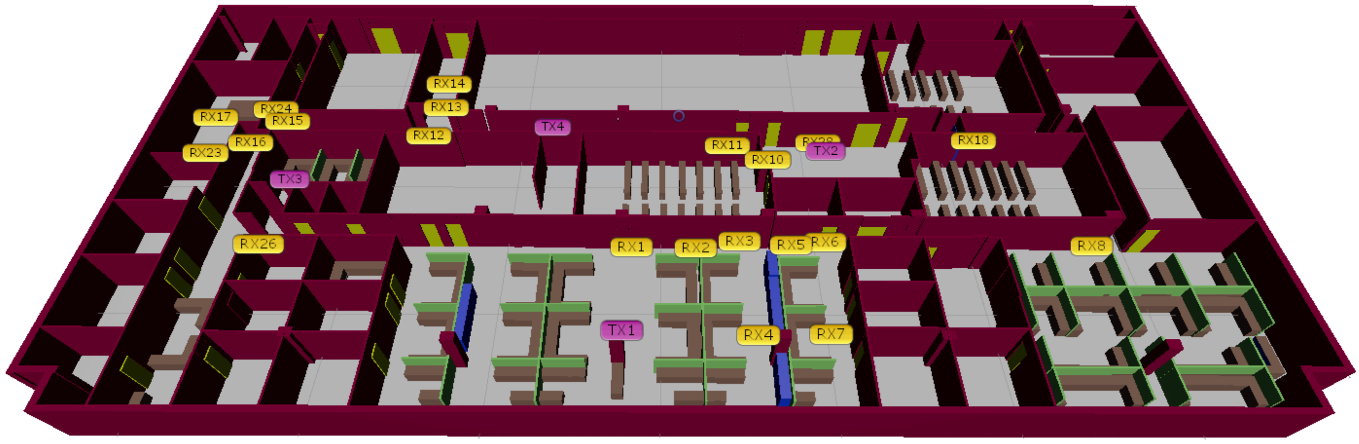

Fig. 1. 3D scenario developed in Unity3D and Tx-Rx location. The materials characterized are concrete (red), drywall (green), metal (blue) and chipboard (brown).

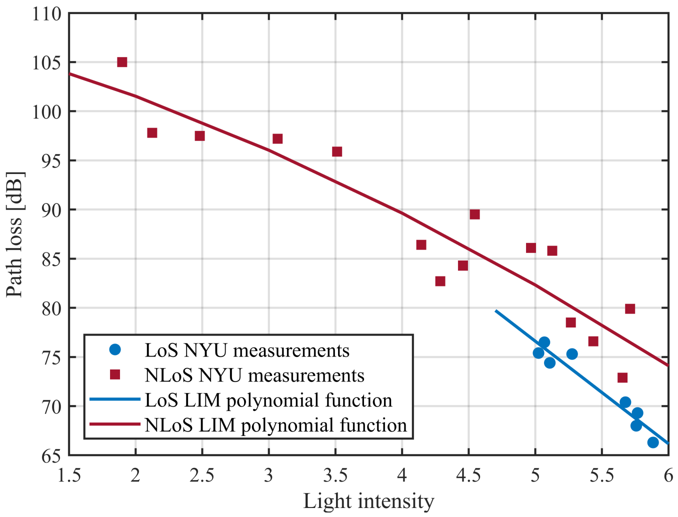

Fig. 2. Path loss vs light intensity for the NYU measurement points [3] and the LIM polynomial functions

since the set of receiver points used in this work is a subset of the points used in [3]. As a result, the n values used in this work are 1.15 for LoS and 2.42 for NLoS.

Fig. 3 shows a scatter plot of path loss versus Tx-Rx distance in which a diamond marker is used to represent each path loss measurement and a square marker is used for each LIM estimation. Also the path loss versus distance curves for the NYU and 3GPP stochastic models are represented in Fig. 3. It can be observed that the LIM estimation accuracy is independent of the distance and that its estimation is always close to the measured data. Concerning the stochastic models, the NYU is closer to the measured points.

For the sake of comparison between LIM and the NYU model, three points referred to as A, B, and C in the scatter plot of Fig. 3 have been selected because of the high error of the NYU model to predict their path loss. The points A, B, and C correspond to the TX-RX combinations TX4-RX13, TX4-RX14 and TX2-RX12, respectively (see Fig. 1). The distance between TX4 and A is 8.2 m, while it is 10.8 m between TX4 and B. It can be observed that, despite being relatively close to the transmitter, the NYU model presents a high error of 12.56 dB and 15.57 dB for A and B, respectively, while LIM has an error of 1.55 dB and 2.96 dB. The peculiarity of both points is that they are reached by a very small amount of rays from the transmitter due to its position after a corner where the rays have to traverse a narrow door space. Point C is located in a corridor, at a distance of 28.5 m from TX2. Despite the distance, the receiver is reached by a relatively high amount of reflected rays from the transmitter due to the reduced obstruction of the corner producing the NLoS condition and the location of RX12 in a narrow corridor which guides the reflections to the receiver. For this case, the NYU model error is 12.41 dB, while the LIM error is only 3.74 dB. All in all, the NYU model fails in special situations in which an abnormal amount of rays reach the measurement point due to an specific geometry of the obstacles and scatterers between the transmitter and the receiver.

Table II presents some statistics related to the error of the different models. The mean absolute error values obtained in the path loss estimation are 2.20 dB, 3.94 dB and 8.47 dB for LIM, NYU and 3GPP respectively. There are very slight differences between LIM and NYU model in LoS environments (0.93 dB and 1.69 dB, respectively) that are reasonably low. By contrast, the 3GPP model has a high absolute error of 5.47 dB. For NLoS environments, LIM is significantly better than 3GPP and NYU models. When it comes to the maximum absolute error, LIM outperform significantly the other two models. Its maximum absolute error is only 4.92 dB, compared to almost 20 dB for the other two models.

TABLE II
ABSOLUTE ERROR COMPARISON FOR LIM AND STOCHASTIC MODELS

Model	Absolute error [dB]			
	Global mean	LoS mean	NLoS mean	Max.
LIM	2.20	0.93	2.83	4.92
NYU	3.94	1.69	5.07	15.57
3GPP	8.47	5.47	9.97	19.55

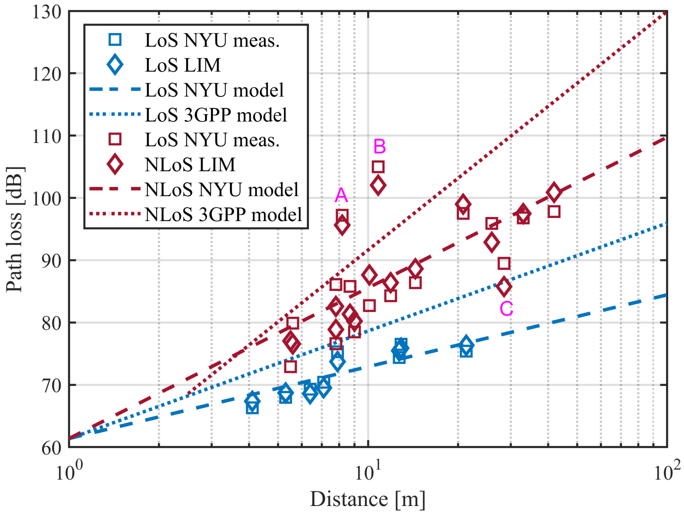

Fig. 3. Path loss versus TX-RX distance for stochastic models, NYU measurements [3] and LIM estimation

Fig. 4 shows the Probability Distribution Function (PDF) of the absolute error. It is noted that the LIM and NYU models estimate propagation losses better, which is expected since they are calibrated in the same scenario where the evaluation is conducted, while the 3GPP model shows a high error probability. LIM and NYU perform similarly but NYU shows a non-negligible probability of having high errors since it does not accurately captures some special situations of the realistic propagation.

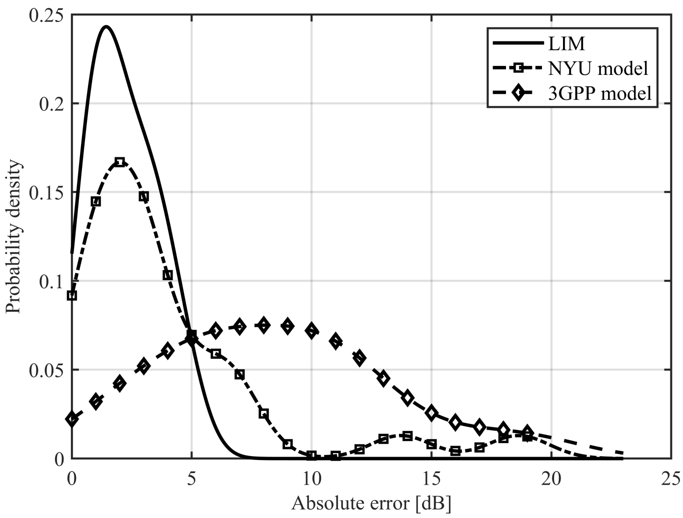

Fig. 4. Probability distribution of the absolute error in the path loss estimation

VI. Conclusion

In this paper, we have proposed a path loss model called LIM based on the use of light physics in game engines. We have compared our proposal with two stochastic path loss models for indoor environments. Concretely, a 3GPP based path loss model, and a path loss model obtained by the NYU. Simulation results show that LIM outperforms the other two models. Specifically for LoS, NYU model and LIM get very accurate path loss values, while the 3GPP model is overestimating the losses. Moreover, in NLoS the good results of LIM are accentuated both in terms of mean error and above all in the worst case, for the maximum error. From these outcomes, we can conclude that LIM is a valid and simple approach to obtain accurate estimates in indoor scenarios known with a high level of detail due to its capacity to correctly capture the peculiarities of the environment.

Future work will include the consideration of transmission and diffraction mechanisms by LIM. Transmission will be included modifying the transparency of the materials, while diffraction is planned to be emulated by adding secondary sources of light. In addition, we will work to generalize LIM so as to be accurate in different scenarios and with different hardware platforms.

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