Indoor Propagation Using a Game Engine Ray-Based Model in Indoor Scenario at 5.4GHz

Jorge Gomez
Universidad del Magdalena
Santa Marta, Colombia
jgomez@unimagdalena.edu.co

Dinael Guevara, Diego A. Parada and José O. Vargas
Universidad Francisco de Paula Santander
Cucuta, Colombia
dinaelgi@ufps.edu.co

Andres Navarro C
I2T Research Group
Universidad Icesi
Cali, Colombia
anavarro@icesi.edu.co

Jordi Joan Giménez and Narcis Cardona
ITEAM
Universitat Politècnica de Valencia
Valencia, Spain
ncardona@iteam.upv.es

***Abstract*—The results of a simulation of signal propagation strength in indoor environment using a game engine ray-based tool and use of an open source 3D modeling tool for scenario building are presented in this paper, showing the flexibility of the XML description language for this kind of scenario. We show simulation results and compare them with an extensive set of measurements for an indoor scenario with multiple materials in the 5.4GHz band, obtaining a good match between the ray-based tool and measurements of received power. We found also that constitutive parameters have an important effect on the simulation results and made some small adjustments to improve results.**

***Index Terms*—Channel estimation game engine, indoor estimation channel, power received, ray launching,.**

I. Introduction

Currently, development of wireless communication uses multiple-input multiple-output (MIMO) technology to achieve maximum capacities. In the indoor environment case, in addition to exploiting MIMO, a goal is to integrate mobile wireless communications [1]; this ensemble of multiple radio access technologies (RAT) is the basis for the operation of next-generation mobile communications (5G) [2].

In an indoor scenario the signal suffers multiple reflections and diffractions before reaching the receiver. Therefore, the average received power depends on the signal losses and delay for each signal component arriving at the receiver [3], [4]. These effects on the reception point are modeled by the square of channel impulse response and used to estimate the power received.

WiFi networks entered the 5GHz band in 1999 with 802.11a as standard [5]. Potential development and performance evaluation for WiFi of 5.4GHz in version 2.0 of 802.11ac are based on simulations and development is ongoing although some devices are now available in the market [6].

A characteristic of WiFi networks is that capacity depends on the strength of the signal received [7]. The signal received depends on the environment and the objects in it. To estimate channel characteristics, reflections and refractions caused by ceiling, floor, windows, different kinds of walls and office furniture should be considered. Because of these factors, signal distortion and propagation loss that occur during transmission from transmitter to receiver point affect the reception. The diversity is such that it is very difficult to characterize all possible environments and constitutive parameters change frequently.

In addition, all objects implicated cause multipath affecting channel parameters. Recent studies have verified the applicability and accuracy of ray tracing (RT) techniques in conjunction with UTD (uniform theory of diffraction)[8], [3], [9]–[11].

The representation of complex phenomena between the radio wave and the environment is known as the multipath channel model [12]. The characteristics of the materials present in the scenario play an important role, allowing accurate results by using RT techniques in the spatial and temporal characterization. By means of RT and a multipath channel model it is possible to design and theoretically evaluate modern wireless communication systems.

Given the level of detail necessary for the indoor scenario, the use of a graphics processing unit (GPU) and efficient algorithms developed using a game engine allow adequate computational cost [3]. Game engines are defined as a software suite designed for the creation and development of video games. They include a physics engine for collision detection, and an efficient memory management system. They are a potential tool for optimally implementing the effects of optical physics such as reflections, refractions and diffraction.

Furthermore, the use of free software tools like Blender allows us to obtain very real representations of the environment in great detail. Blender is a multi-platform open source GNU license, especially dedicated to the modeling and creation of three-dimensional graphics [13]. It uses Python as an internal

978-1-5090-1698-3/16/$31.00 ©2016 IEEE

programming language and comprises two types: *internal Blender*, present since the first versions of the program, and *Cycles* since version 2.6, which allows more realistic results.

The aim of this paper is to compare a simulation of received power using an RT model based on a game engine with a set of measurements in the 5.4 GHz band in a complex indoor environment, a conference room.

The rest of this paper is organized as follows. In Section II we describe the simulation tool and measurement setup used, the relevant equipment and software and the measurement environment. Then, in Section III we present and discuss the results of our simulation. We conclude with Section IV.

II. SIMULATIONS AND MEASUREMENT

We now describe the simulation software and its components, the 3D ray-optical propagation model, followed by a description of the measurement campaign and equipment employed to validate the results. Finally, we describe the channel model.

A. Simulation Tools

We used the Java programming language and Java monkey engine (JME) version 2.0. JME is a powerful tool designed as a high-speed real-time graphics engine. Likewise, we used JME physics V.2.0 as a physics engine and as an interface between JME and the open dynamics engine (ODE).

The indoor scenario was created in a free and open source creation suite called Blender 3D. Use of Blender 3D tools and exporting to XML (eXtensible Markup Language) format or OBJ format generates a realistic indoor office environment in detail[13]. We employed planar geometries to depict each object, obtaining excellent 3D resolution in the model. After its rendering, was exported from Blender format to an XML format. Once imported to JME, RT techniques were applied using the graphic card.

B. 3D Ray-Optical Propagation Model

Radio waves are modeled as an optic ray that follows a straight path from transmitter to receiver. During this process, the wave interacts with flat objects, corners and edges. Initially, we only processed reflections, diffractions, free space attenuation and multiple combinations of these effects. In order to model walls, floor and ceils reflections, we applied Fresnel coefficients.

We used a shooting and bouncing algorithm, which is based on launching a ray from the transmitter to the antenna and verifying if the ray impacts on a wall or ceiling. The rays were launched with a mean angular separation between neighboring rays in 3D space $\alpha_e \approx 0.27°$.

The RT algorithm implemented was limited to 10 events, an event being defined as a reflection, diffraction or transmission and a maximum of two diffractions at vertical or horizontal building edges, which is appropriate for indoor environments. We used the computational capacity of a graphic card to estimate the impact on receiving spheres, flat polygons and in-edge cylinders, as well as for the election or discarding of relevant rays.

In our model, if the ray hit an edge, the rays of the diffraction cone were computed with a given angle increment. It was assumed that diffracted rays were generated with an angular resolution fixed in 3D space α_e for the first diffraction and $2\alpha_e$ for the second diffraction.

C. Measurement Campaign

We made a measurement campaign at the Institute of Telecommunications and Multimedia Applications (iTEAM), Valencia, Spain. We employed an Agilent E5072A ENA Series vector network analyzer, two UWB patch antennas which was designed and made in the same institute with operation frequency of 5.4 GHz [14].

The dimensions of the scenario were 7.16x7.62x2.64m. The transmitter was located in the center of the scenario at a height of 1.93 m. The reception point was located in the scenario, forming a grid of 60cm x 60 cm at a height of 1.23m. The grid is comprised of 89 receiving points. It was developed using the Blender 3D tool and is shown in Fig.1. In both cases, for transmission and reception points, a tripod was employed to maintain the positions.

We stored and manipulated the constitutive parameters as an attribute within the 3D model (i.e. permittivity) and their electromagnetic material properties, the structures of the walls, floor, desk, desk legs, electronics devices (i.e. video beam, VNA), windows and chairs were classified into different classes with dielectric material parameters as shown in Table I[18], [19], and the location within the scenario is shown in Fig. 2.

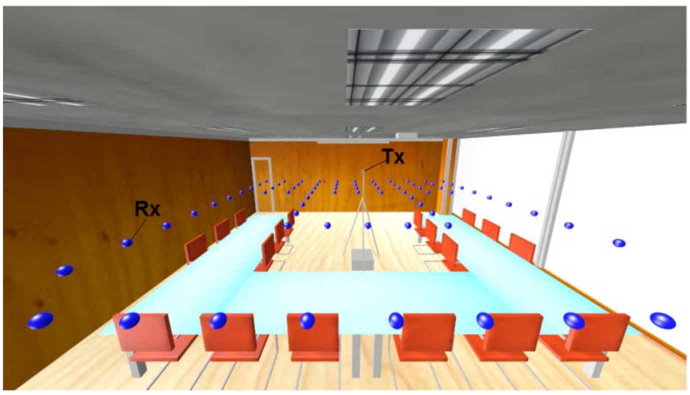

Fig. 1. Measurement receiver points (Rx) and transmitter position (Tx) located in the indoor scenario.

TABLE I. INITIAL VALUES OF RELATIVE PERMITTIVITY AND CONDUCTIVITY.

Material	Element	Relative Permittivity	Conductivity (S/m)
Concrete	Floor	2.22	0.0138
	Ceiling		
Glass	Desk	6.4	0.0325
	Windows		
Fiberboard	chairs	60.0	0.02
	Wallboard		
Wood	Column	2.08	0.007
Metal	Structure (windows, desk and chair), VNA, video beam, lamps and tripod		

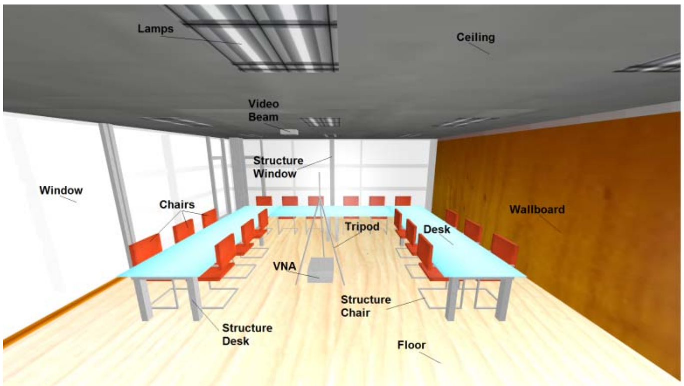

Fig.2. Measurement scenario.

D. *Channel Model*

The most important channel characteristics can be estimated by obtaining the path parameters based on the time-variant channel-impulse response of the channel $h(t,\tau)$.

We used ray launching as it provides information for multipath reception conditions, allowing us to estimate the propagation model and received power through a power delay profile (PDP). The path parameters for the propagation between the transmitter and the receiver are defined by *n = 1,…,N(t)* propagation paths [15]. Thus, it is possible to represent a PDP by:

$$h(\tau,t)=\sum_{n=1}^{N(t)} A_n(t)e^{-j2\pi f_c \tau_n(t)}\delta(\tau-\tau_n(t)) \qquad (1)$$

where

$A_n(t)$ represents the complex amplitude of the n^{th} multipath component and incorporates the properties of the transmitter and receiver antenna

f_C is the center frequency of the system

$\tau_n(t)$ is the time delay of arrival (TDA) of path.

Implementation (1) using the game engine and GPU techniques are appropriate and checked for obtaining multipath parameters with high accuracy and fast processing time [3], [16], [17].

III. ANALYSIS AND RESULTS

With the final purpose of verifying our 3D RT model, we compared the simulation results of power received with measurements for the case of vertical polarization. Initial values used for the permittivity and conductivity of the materials present in the scenario were found in the literature [18], [19].

A. *Initial Simulation*

Once we obtained the scenario, it was imported from Blender to JME. Initial simulation was performed using constitutive parameters according to Table I for each material composing the scene and the results are shown in Fig. 3 by a green line. We obtained the PDP value and adjusted the constitutive parameters in order to minimize the PDP error against measurements. Once the PDP was adjusted, we estimated the received signal as shown in Fig. 3.

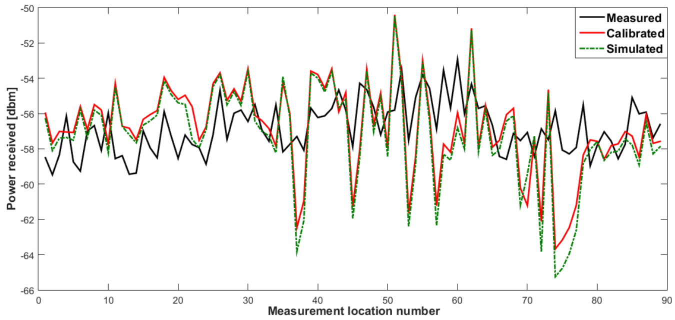

Fig. 3. Power received comparison of the ray tracing output (green line) and adjusted (red line) with measurement (black line).

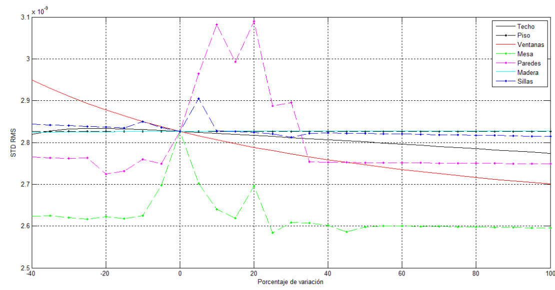

Fig. 4. Comparison of RMS error versus change in constitutive parameters expressed in percentage terms.

B. *Simulation Results After Calibration*

Although results with the initial parameters were quite good, it is well known that ray-based models are affected by the values of constitutive parameters and, also, published values can be different from real values, because of the specificities of the scenarios. For this reason, and in order to evaluate the effect of the constitutive parameters in our model and to improve obtained results and reach more realistic values for the particular scenario, we implemented an adjustment algorithm oriented to reduce the mean square error between simulation and measurements.

The mentioned algorithm allowed us to adjust the constitutive parameters (i.e. permittivity values). With the aim of analyzing how the predictions were affected by simulated objects, we used the values given by the literature for each of the materials and, by changing each one of these values at a time, evaluated the model's sensitivity to that parameter. The first value modified was for windows; once we obtained an improvement, then we modified the value for tables, and finally for walls.

Initially, power received results were tested for the varying values of permittivity for a class from -10% to 10%, in single steps at one processing time. Then, using this method reiteratively, we obtained the global minimum standard deviation for best values of PDP for each class for all the above predictions with respect to the measurements. We adjusted the parameters, obtaining the simulation results shown in Fig. 3 by a red line. In Fig. 4 we show the standard error versus the percentage of variation of constitutive parameters to illustrate the effect of the modification on the simulation.

Simulation with the calibration result improved the accuracy with respect to measurement data represented by a mean error of 0dB and standard deviation of 2.6 dB. After adjustments, the mean error of received power improved on 100% and standard deviation improved on 10.3%. In Table II we summarize the values for the initial simulation and after the adjustment of relative permittivity and in Table III we show the mean error. For the permittivity, only the modification of values of table glass and window glass had a representative impact on the results and these are shown in red.

This type of strategy solved a typical problem found with ray-based models, as is the variability of information about constitutive parameter values for different materials, because the intrinsic differences between materials in different environments. Relative permittivity values for the global minimum standard deviation were adjusted by using the measurement results.

TABLE II. RELATIVE PERMITTIVITY VALUES FOR THE GLOBAL MINIMUM STANDARD DEVIATION

Material	Element	Relative Permittivity Initial	Relative Permittivity Adjusted
Concrete	Floor	2.22	2.22
	Ceiling		
Glass	Table	6.4	**6.9**
Glass	Windows	6.4	**12.6**
Fiberboard	Chairs	60	60
Fiberboard	Wallboard	60	**59**
Wood	Column	2.08	2.08

TABLE III. STATISTICAL SUMMARY FOR POWER RECEIVED PREDICTION FOR PERMITTIVITY VALUES BEFORE AND AFTER ADJUSTMENT.

Condition	Mean error (dBm)	Std. Deviation error (dBm)
Initial	-0.4	2.9
Adjusted	0.0	2.6

IV. CONCLUSIONS

We have shown the results of our ray-based propagation model in the 5.4GHz band, obtaining a very good agreement with measurements, even before adjustment of the permittivity values.

For this scenario, the main element that affects results are the windows of the wall. As seen in Table II, the modification of the initial value was near 100%. This variation between the initial value and the final value could be related to the film used to cover the glass. These results indicate that even with accurate initial information about constitutive parameters, particular scenarios may have different values.

Initial values for constitutive parameters were very accurate and the required adjustments were minimal. However, this indicates that good information about constitutive parameters of materials is still an open issue regarding the 5G.

REFERENCES

[1] N. Himayat, S. Yeh, and A. Panah, "Multi-radio heterogeneous networks: Architectures and performance," in *International Conference on Computing, Networking and Communications (ICNC)*, 2014, February, pp. 252–258.

[2] A. H. Ali, "Investigation of Indoor Wireless-N Radio Frequency Signal Strength," in *IEEE Symposium on Industrial Electronics and Applications (ISIEA)*, 2011, pp. 200–203.

[3] A. Navarro, D. Guevara, N. Cardona, and J. Gimenez, "Using 3D game engines and GPU for ray launching based channel modeling in indoor," in *General Assembly and Scientific Symposium (URSI GASS), 2014 XXXIth URSI*, 2014, pp. 14–17.

[4] R. Knopp and P. A. Humblet, "Information capacity and power control in single-cell multiuser communications," *IEEE Int. Conf.*, vol. 1, pp. 331–335, 1995.

[5] L. Deek, E. Garcia-Villegas, E. Belding, S. J. Lee, and K. Almeroth, "Intelligent channel bonding in 802.11n WLANs," *IEEE Trans. Mob. Comput.*, vol. 13, no. 6, pp. 1242–1255, 2014.

[6] M. Dianu, J. Riihij, and M. Petrova, "Measurement-based study of the performance of IEEE 802 . 11ac in an indoor environment," *Ieee Icc 2014*, pp. 5771–5776, 2014.

[7] E. Bonek, "Measurement and modeling of wireless propagation channels for MIMO," *Jt. IST Work. Mob. Futur. 2006 Symp. Trends Commun. SympoTIC '06.*, p. 4244, 2006.

[8] M. El-Absi, S. Galih, M. Hoffmann, M. El-Hadidy, and T. Kaiser, "Antenna selection for reliable MIMO-OFDM Interference

alignment systems: Measurement based evaluation," *IEEE Trans. Veh. Technol.*, vol. 9545, no. c, pp. 1–1, 2015.

[9] N. Navarro, A., Guevara, D., & Cardona, "Game engines ray-tracing models for indoor channel modeling," *Antennas Propag. Soc. Int. Symp. (APSURSI), 2014 IEEE*, pp. 1163–1164, 2014.

[10] A. Sun, S., Rappaport, T. S., Thomas, T., & Ghosh, "A preliminary 3D mmWave indoor office channel model," in *International Conference on Computing, Networking and Communications (ICNC), 2015 I*, 2015, pp. 26–31.

[11] Y. Dama, R. Abd-Alhameed, F. Salazar-Quinonez, D. Zhou, S. Jones, and S. Gao, "MIMO indoor propagation prediction using 3D shoot-and-bounce ray (SBR) tracing technique for 2.4 GHz and 5 GHz," *Proc. 5th Eur. Conf. Antennas Propag.*, pp. 1655–1658, 2011.

[12] T. S. Rappaport, *Wireless communications principle and practice*. New York:Prentice Hall, 2002.

[13] A. Navarro, D. Guevara, and S. Londono, "Using 3-D video game technology in channel modeling," in *Access, IEEE*, pp. 1652–1659, 2014.

[14] E. Tarín, C., Martí, P., Traver, L., Cardona, N., Díaz, J., & Antonino, "UWB channel measurements for hand-portable devices: a comparative study.," in *IEEE 18th International Symposium on Personal, Indoor and Mobile Radio Communications, 2007,* pp. 1–5.

[15] R. S. T. M. Narandžić, W. Kotterman, M. Käske, C. Schneider, G. Sommerkorn, and A. Hong, "On a characterisation of large-scale channel parameters for distributed (multi-link) MIMO—the impact of power level differences," *Antennas Propag. (EuCAP), 2010 Proc. Fourth Eur. Conf.*, pp. 3–7, 2010.

[16] A. Navarro Cadavid and D. Guevara Ibarra, "Using game engines in ray tracing physics," in *2010 IEEE Latin-American Conference on Communications*, pp. 1–5.

[17] A. Navarro, D. Guevara, N. Cardona, and J. J. Gimenez, "DVB coverage prediction using game engine based ray-tracing techniques," *IEEE Veh. Technol. Conf.*, no. 122, pp. 1–6, 2011.

[18] C. M. Pereira, C. Blanchard, L. M. Carvalho, and C. A. Costa, "High frequency heating of medium density fiberboard (MDF): theory and experiment," *Chem. Eng. Sci.*, vol. 59, no 4, pp. 735–745, 2004.

[19] A. Safaai-Jazi, S. M. Riad, A. Muqaibel, and A. Bayram, "Ultra-wideband propagation measurements and channel modeling," *DARPA NETEX Time Domain RF Meas. Lab.*,Virginia, 2002.