DELAY SPREAD ESTIMATION USING A GAME ENGINE RAY BASED MODEL IN INDOOR SCENARIO AT 5 GHZ

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ABSTRACT

In this paper we show the results of a simulation of channel parameters using a Game Engine Ray based tool, developed by our group, which has been evolving during last few years. We show simulation results and compare it with a set of measurements for an indoor scenario, in the band of 5.4 GHz. We found a good match between the rays based tool and measurements for Delay Spread. Also, we show the use of an Open Source 3D modelling tool for the scenario building, showing the flexibility of the XML description language for this kind of scenarios.

Keywords: ray launching, game engine, channel estimation, delay spread.

INTRODUCTION

The use of 5.4 GHz band in office environments to WLAN is a good alternative to traditional solution of 2.4 GHz. Overall, the 5 GHz band is a better choice for to achieve high data rate transmission and reliable wireless communication in the wireless network or device [1]. Besides, the use of access point (AP) equipped with multiple input- multiple-out (MIMO) antenna arrays have attracted great attention worldwide [2], but for a realistic office environment, the wireless system performance is very much dependent of the power-delay profile characteristic and the derived parameters of mean delay and delay spread [3]. Besides, the delay spread is one of the parameters that contribute to avoid a decrease of the channel bandwidth and inter symbol interference (ISI). Additionally, Delay spread at future wireless technology devices will reduce power consumption through feedback information to the Steerable Beam transmitters [4]. Therefore, the development of MIMO to indoor wireless communication system requires extensive knowledge on channel characteristics. This makes it necessary to have a channel experimentally characterized or an accurate propagation model to predict propagation channel characteristics in indoor environment.

The radio channel characterization employs extensive measurement campaigns or deterministic models estimation. In the case of measurement campaigns, intensive and time consuming activities are required and it is also expensive. For deterministic models estimation, the use of ray tracing (RT) models is required in order to simulate multipath propagation.

RT is a deterministic technique and it is currently employed to predict wireless channel parameters such as delay spread, Doppler spread and angular spread in a variety of environments and a wide range of frequency. The multipath channel model is the representation of complex phenomena involving several mechanisms of interaction between the radio wave and the environment [3]. Accordingly, through spatial and time characterization is possible to design and theoretically evaluate the wireless communication systems.

One of the important aspects in modeling 3D indoor scenarios for Ray Tracing is the precision used to represent the realistic scenario with high geometric resolution. Also, the representation of electromagnetic characteristics of the materials present in the scenario, are the base for accurate results using RT techniques. Because of the diversity and quantity of objects typically found in indoor environments, such as lamps, tables, structures, windows, etc., the difficult to characterize all possible indoor environment increases and may reduce the accuracy of delay spread estimated in a real indoor situation.

Game engines are powerful software packages that efficiently use data-structures and speed-up techniques to render 3D worlds in real-time and high-fidelity physical simulations [5]. In recent years, some authors have used GPU power in order to improve the computation capacity for propagation calculations and channel modeling [6]. The authors of this paper have proposed the use of Game Engines to improve computation time and to use the efficient ray tracing techniques implemented in such engines [7].

We developed an accuracy 3D realistic office environment using Blender 3D tools and exported to XML (eXtensible Markup Language) format or OBJ format. This process allows generating 3D scenarios with more details and higher geometric resolution [8].

The idea behind this paper is to compare a ray-tracing model with a set of measurements in the 5.4 GHz band in a complex office environments, with a set of measurements. In this case, we use delay spread measurements, using a VNA. Because of the complexity of the environment, we have found that some materials do not behave as dielectrics and is necessary to adjust ray-tracing model parameters (i.e. constitutive parameters).

The organization of this paper is as follows: In section II we describe the channel model; in section III we explain the indoor scenario and measurement campaign; in the section IV simulations and results; in section V conclusions.

CHANNEL MODEL

Channel characteristics can be estimated obtaining the path parameters based on the frequency response $H(f,t)$ and the time-variant channel-impulse response of the channel $h(t,\tau)$.

Path parameters for the propagation between the transmitter and the receiver is defined by $n=1,\ldots,N(t)$ propagation paths [9]. The identified propagation path parameters between the transmitter and the receiver are:

$\tau_n(t)$: Time delay of arrival (TDA) of path;

$\bar{\mathrm{T}}_n(t)$: Full polarimetric transmission matrix of path;

$\Omega_{\mathrm{T},n}(t)$: Direction of departure (DoD) of path;

$\Omega_{R,n}(t)$: Direction of arrival (DoA) of path.

At each interaction of the ray with an obstacle, the field strength is multiplied with a dyadic propagation transfer factor, which accounts for the actual propagation effect and for a change in divergence due to the interaction. Cascading all transfer factors (and therefore all occurring propagation phenomena) leads to the full polarimetric transmission matrix $\bar{\mathrm{T}}_n(t)$, which together with path length (time delay $\tau_n(t)$) characterize the field strength of the ray. $\Omega_{T,n}(t)$ And $\Omega_{R,n}(t)$ are represented in colatitude and longitude (spherical coordinates). Introducing the gains of the transmitting and receiving antenna G_R and G_T and their complex directional pattern $\vec{C}_R$ and $\vec{C}_T$.

The frequency response of the channel is:

$$\begin{aligned} H(f,t) &= \sqrt{\left(\frac{C_o}{4\pi f_c}\right)^2 G_R G_T}\cdot\sum_{n=1}^{N(t)}\vec{C}_R(\Omega_{R,n}(t)) \\ &\quad \cdot\bar{T}(t)\vec{C}_T(\Omega_{T,n}(t))e^{-j2\pi f\tau_n(t)} \qquad (1) \\ &= \sum_{n=1}^{N(t)} A_n(t)e^{-j2\pi f\tau_n(t)} \end{aligned}$$

Where C_0 is the vacuum speed of light and f_c is the center frequency of the system. $A_n(t)$ Represents the complex amplitude of the n^{th} multipath component and incorporates the properties of the transmitter and receiver antenna.

The low-pass impulse response of the channel $h(t,\tau)$ is obtained by the inverse Fourier transform of (4). Thus, the channel model could be represented as a power delay profile (PDP) expressed by:

$$h(\tau,t)=\sum_{n=1}^{N(t)} A_n(t)e^{-j2\pi f_c\tau_n(t)}\delta(\tau-\tau_n(t)) \qquad (2)$$

We used the parameter values TDA, full polarimetric transmission matrix, DoD and DoA for simulated delay spread and elevation spread. Our previous work has shown that these techniques are appropriate for obtaining multipath parameters with high accuracy and fast processing [10, 11, 12].

The characterization of wideband radio channel in time domain is obtained from the PDP and first and second order moments, the mean excess delay and RMS delay spread.

The mean excess delay and RMS delay spread quantify the multipath channel scattering properties and these parameters determine the dispersion of the channel, making it a better indicator of the system performance about the ISI [13].

The mean excess delay is the "center of gravity" of the profile; defined by:

$$\bar{\tau}=\frac{\sum_k P(\tau_k)\tau_k}{\sum_k P(\tau_k)} \qquad (3)$$

Where $P(\tau_k)$, is the individual power and τ_k is the delay according to each tap. The RMS is the second moment or spread of the taps; defined by:

$$\sigma_t=\sqrt{\tau^2-(\bar{\tau})^2} \qquad (4)$$

and,

$$\overline{\tau^2}=\frac{\sum_k P(\tau_k)\tau_k^{\,2}}{\sum_k P(\tau_k)} \qquad (5)$$

INDOOR SCENARIO AND MEASUREMENT CAMPAIGN

This section we describe the building 3D of the scenario and the measurements campaign carried out in the indoor environment.

a) 3D indoor scenario model

The Figure-1 show the 3D model of scenario development using 3D tool Blender. This included all elements presents in the realistic scenario. We used planar geometries for represent each object achieving great 3D resolution in the model. This was exported from Blender to an XML format [8], then the archives were imported in the game engine Jmonkey, in order to apply RT techniques using the Game Engine and GPU.

The simulated and analyzed scenario is a conference room in a University. The scenario has dimensions of 7.16 x 7.62 x 2.64 m.

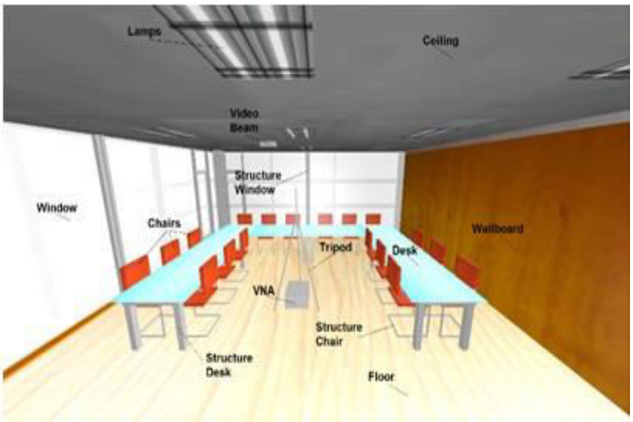

Figure-1. Measurement scenario.

We store and manipulate the constitutive parameters information as an attribute within the 3D Model (i.e. permittivity). According to their electromagnetic material properties, the floor, ceiling, desk, windows, chairs, wallboard, column, VNA, video beam, lamp and structures of windows, desk, and chairs, were classified into 5 different classes of dielectric material parameters. Nevertheless, all these materials are assumed to be homogenous and their material properties at 5.4 GHz band are summarized in Table-1.

The initials values used for the permittivity and conductivity of the materials present in the scenario were found of the literature [14-15]. We assume initially the same values for permittivity, assuming dielectric behavior and later we adjust parameters, according to simulation results.

Table-1. Relative permittivity values.

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		

b) Measurement campaign

Measurement campaign was carried out using the E5072A ENA Series Analyzer VNA. The transmitter was located in the center of the scenario at a height of 1.93 m; the operating frequency selected was 5.4 GHz, the transmitter uses an UWB antenna patch, designed and manufactured in the University [16]. The points measured are represented for blue spheres located in the scenario as shown in Figure-2; a total of 89 points at a height of 1.23 m, equidistant 60 cm each forming a grid constitutes the measurement set.

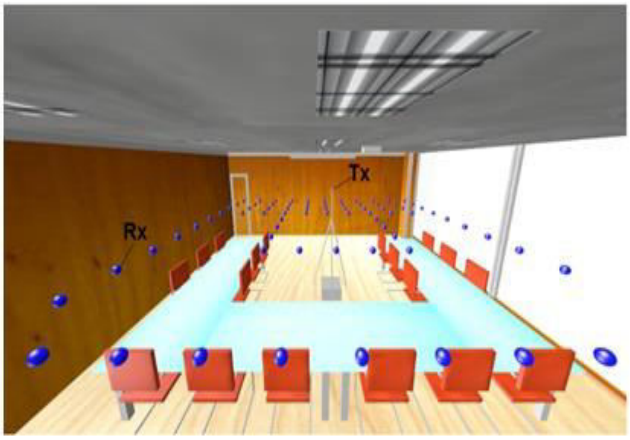

Figure-2. Measurement receiver points (Rx) and transmitter position (Tx) located in the indoor scenario.

SIMULATION RESULTS

a) Simulation results

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 process reflections, diffractions, transmission, free space attenuation and multiple combinations of these effects. In order to model reflections in planes, we apply Fresnel coefficients. In order to model diffractions in corners and edges we apply UTD and apply heuristic coefficients.

We used a shooting and bouncing launching algorithm, which is based on launching a ray from transmitter to the antenna and verify if the ray impacts on a wall or an edge. The rays are launched with a mean angular separation between neighboring rays in 3D space. The Ray based algorithm implemented is limited to 10 events, defining an event as a reflection, diffraction or transmission and a maximum of two diffractions at vertical or horizontal building edges, which is appropriate for indoor environment. We use 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 will be computed with a given angle increment. It is considered that diffracted rays are generated with an angular resolution fixed in 3D space for the first diffraction and for the second. This assumption (resolution of diffracted ray decreases according to their order) dramatically reduces the memory and processor usage and does not substantially affect the prediction accuracy if it is adopted a high initial resolution of.

The predicted results agree quite well with the measurement data, with a mean error of -2.1 ns and standard deviation error of 3.1ns before adjustments, indicating differences of 12.5% in the mean values.

Besides this result, we decided to make some adjustments on the constitutive parameters, to improve results. After adjustments, we reduce the mean error of delay spread to 1.31 ns, indicating differences of 7.7%, and standard deviation error of 2.6 ns. In Table-2 we show the final values of relative permittivity for the minimum value of standard deviation obtained. For the permittivity, only the modification the values of glass desk and glass window affect the results.

Table-2. Relative permittivity values for the global minimum Standard Deviation.

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

In Table-2, we show the values for the initial simulation and after the adjustment of relative permittivity and conductivity.

b) Analysis and calibration of permittivity parameters

Table-3. Statistical summary delay spread prediction for permittivity values before and after adjustment.

Condition	Mean error (ns)	Std. Deviation error (ns)
Initial	-2.1	3.1
Adjusted	1.31	2.6

In order to analyze how the predictions are affected by the simulated objects characteristics, we assumed a set of values for each of the classes and by changing one of these values at a time, the model's sensitivity to that parameter is evaluated.

First, delay spread results are examined for the varying values of permittivity for one class within range from -10% to 10%, in steps of 1 at processing time. Second, using this method reiteratively, we obtain the global minimum standard deviation for best values of each class for all the above predictions, respect to the measurements

Table-2 shows the relative permittivity values obtained for the global minimum standard deviation error. The optimization results are shown in Figure-3 and summarized in Table-3.

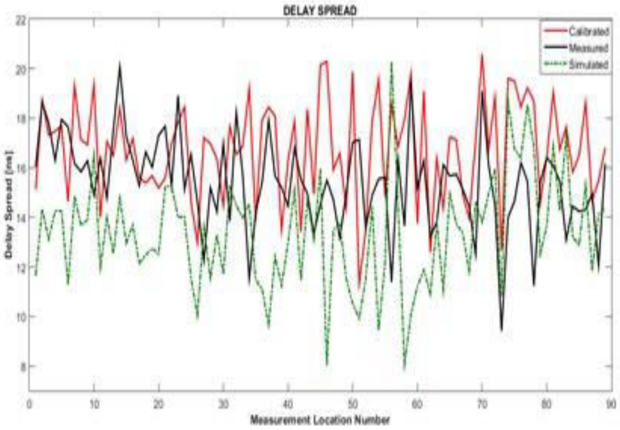

Figure-3. Delay spread prediction comparison of the ray tracing output (dotted green) and adjusted (red line) with measurement (black line).

CONCLUSIONS

We have shown results of channel simulation parameters using a Game Engine ray based tool and compared with measurements, obtaining a very good fit between simulation and measurements, in the 5.4 GHz band.

From initial simulations, we realize that for this frequency band, the details of the scenario, such as structure of chairs and table, measurement instrument, video beam and lamps details have important incidence in the results.

Constitutive parameters in this frequency band are quite accurate and the required adjustment between literature data and real scenario is small. The only important change was in the windows' glass, but we suppose that is because the foil used to shade the windows.

The number of required interactions (reflections, diffractions, etc) is also important. In this scenario, we have found 10 as an adequate number of interactions.

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