Optimization of 3D Ray Tracing for MIMO Indoor Channel

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Abstract

In this paper, an optimization of 3D ray tracing for wideband multiple-input multiple-output (MIMO) indoor channel is presented. First, the evolution of the predicted wideband parameters with the number and type of interactions of the simulated channel is analyzed and the relevant phenomena to take into account during simulations are specified. Then, and for a better performance of 3D ray tracing, an efficient approach to consider the diffuse scattering is presented. It extends 3D ray tracing by associating a scattering cluster with each interaction point of the ray. Scattering clusters are defined by analyzing the simulated responses of each object while taking into account its surfaces roughness or small details. They vary with the type of interaction point and the kind of object where the interaction occurs. Comparisons with measurements performed in a residential area show that adding scattering into simulations substantially improves the accuracy of the prediction of spatio-temporal channel parameters.

1. Introduction

The capacity of wireless communicating systems is a constant goal in the mobile communication research area and many advanced radio techniques promising in terms of capacity, like MIMO and ultra wideband (UWB), are being deployed. The potential capacity of these systems is directly related to the space-time characteristics of the propagation channel [1]. So, a precise space-time channel characterization is required in order to evaluate the awaited profits of these techniques. 3D ray tracing based models can provide the required spatio-temporal channel characterization. However, conventional 3D ray tracing normally underestimate wideband channel parameters [2]. This may be due to the absence of scattered signals in simulations and of details in the environment model. In this paper, we present first an analysis of the relevant phenomena to take into account during simulations. Then, an efficient approach to model the scattering in the indoor channel is presented. It extends 3D ray tracing by associating a scattering cluster with each interaction point of a ray. The parameters of the scattering cluster vary with the type of the interaction point (reflection, transmission) and the kind of the object where the interaction occurs (wall, closet). Section 2 presents the channel simulation tool and an analysis of the relevant phenomena. Section 3 describes the scattering model. Measurements are presented in section 4 and the results in section 5. The conclusion is drawn in section 6.

2. 3D Ray Tracing

2.1. 3D Channel Simulation Tool

MATRIX is a 3D ray tracing software that calculates the ray paths between a given transmitter (Tx) and receiver (Rx). It is based on geometrical optics (GO) and the uniform geometrical theory of diffraction (UTD). The propagation phenomena taken into account are combinations of multiple transmissions, reflections and diffractions.
Since a detailed description of the 3D indoor environment is essential for a proper wave propagation modelling, we need to account for walls, floor, ceiling, windows and doors as well as some details such as furnitures. Plane facets with 3D dimensions describe indoor environment. Each facet is affected to a material which is characterized by its permittivity, conductivity and thickness. The electromagnetic properties of various building materials have been estimated in a previous study over the 2-16 GHz frequency band [3]. Consequently, MATRIX can operate over a large frequency range. In addition, it takes into account the UWB antenna including polarization and radiation pattern.

2.2. Analysis of the Relevant Phenomena

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It is known that ray tracing computation time increases rapidly with the number of reflection or diffraction phenomena. In order to reduce computation time, we have to compute useful paths only and ignore those without significant contribution to energy or any influence on the spatio-temporal channel parameters. For this purpose, we investigated on the evolution of both delay and angular spreads as a function of the number and type of phenomena taken into account. Also, different transmitter positions were considered in order to characterise the propagation channel in a residential environment. Figure 1 represents the evolution of the delay spread and the azimuth and elevation angular spreads versus the type of added paths for 4 different transmitter positions. Each step on the horizontal scale corresponds to the addition of a new type of path in the simulation. Paths containing reflexions were added first, then paths containing diffractions. Finally, paths containing a mix of reflexions and diffractions were considered. Note that a maximum of 6 transmissions have been allowed for every path. For most Tx positions, paths with six reflections or 2 diffractions or one diffraction and more than 3 reflections do not have any significant influence on the channel characteristics. For instance, they do not have any significant contribution to energy as their dynamic energy is 30 dB below the main path energy. From the above observations, one can make some compromise between performance and computation time by only considering paths containing a maximum of 5 reflections or 2 diffractions, or one diffraction and maximum 3 reflections.

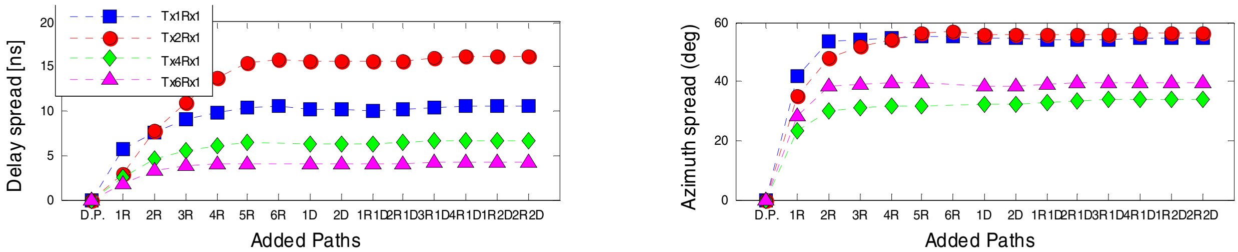

Fig. 1 Evolution of delay spread and azimuth and elevation angular spread vs. type of added paths: D.P. = Direct Path, R = Reflection, D = Diffraction

3. Scattering Cluster

In order to define the backward and forward scattering clusters associated respectively with a reflection on an object or a transmission through it, the simulated responses of the concerned object were analyzed. For this purpose, a diffuse effective roughness (ER) model has been integrated into ray tracing in the case of a wall, and all the closet details have been taken into account in the case of a closet.

The simulated responses of the wall were analysed after having integrated a diffuse ER model into ray tracing. It is shown in [4] that the directive model is the best ER model to describe the scattering behavior of a wall. It assumes that the wave impinging on a wall element is scattered according to a single lobe scattering pattern oriented toward the reflection direction. In [5] the directive ER model has been extended to include through-wall diffuse scattering with a single lobe scattering pattern oriented toward the transmitted signal.

Simulated responses of a 5 $\times$ 2.54 m^2 single wall to this ER directive model were analyzed in order to define a simplified scattering function of the wall. Figure 2 illustrates an example of a wall response, when the transmitter and receiver are in front of it. It shows the power delay profile and the azimuth and elevation power angular profiles. The power of the rays is summed every 1 nanosecond in time scale and every 2 degrees in space scale. The strongest ray (time = t) corresponds to the reflected one and the others correspond to the backward scattered rays. Five parameters were extracted from the simulations, the slope *s* of the straight line tendency of the power delay profile, the ratio *r*, the delay spread (*DS*) and the elevation and azimuth angular spread (*ES* and *AS*, respectively). These parameters are illustrated in Fig. 2. Values of these 3 parameters vary slightly over the different positions. They depend only on the type of the interaction (transmission, reflexion) and the wall characteristics. Concerning the arrival azimuth and elevation angular spreads, they decrease with the distance between the wall and the receiver. This decrease of angular spreads versus the distance is approximated with straight lines tendencies. None of the parameters shows any significant variation when varying frequency between 3 and 10 GHz.

To study the characteristics of the scattering cluster corresponding to a closet, a detailed closet model with a set of objects distributed inside it is built and the simulated responses are analyzed. As for the wall, the parameters *r*, *s*, *DS*, *AS* and *ES* were extracted from the simulations for both cases: Tx and Rx are in front of the closet for backward

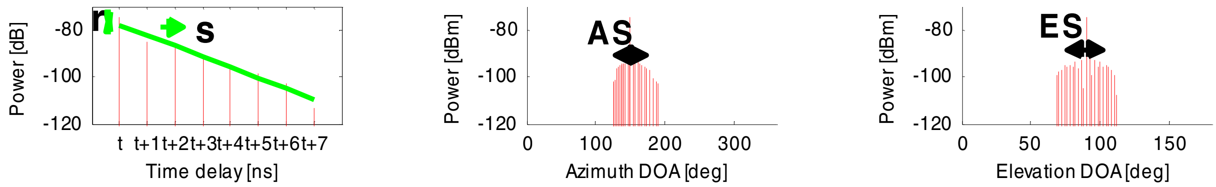

Fig. 2. Illustration of a response of the wall when the transmitter and receiver are in the same side of it. Extracted simulated parameters are indicated.

scattering and Tx is in front of the closet while Rx is behind it for forward scattering. For both cases, s, r and DS vary slightly over the different positions; they depend only on the type of the interaction.

From these observations, a cluster of scattered rays can be attributed to each interaction point (reflection, transmission). This can be seen as if each reflected or transmitted ray arrives within a cluster of scattered rays resulting from the interactions with rough surfaces and small details that might be present in the environment around the interaction point. Each cluster of rays is defined by a power delay profile P and azimuth and elevation angle distributions:

$$\begin{aligned} P &= \sum_{n=1}^{N} r P_0 \, e^{-s(t_0 + (10^{-9})n)} \\ AoA^{Azimuth} &= U(\mu = AoA_0^{Azimuth}, \, \sigma = AS) \\ AoA^{Elevation} &= U(\mu = AoA_0^{Elevation}, \, \sigma = ES) \end{aligned} \tag{1}$$

where P_0, t_0 and AOA_0 represent the power, time delay and angles of arrival of the reflected or transmitted ray. The number of the cluster rays is n and U is a uniform distribution with μ and σ its mean and standard deviation, respectively. Parameters r, s, n, AS and ES depend on the type of the interaction (transmission, reflection) and the kind of the object where the interaction occurs (wall, closet).

4. Measurement

The measurement equipment relies on two UWB circular arrays at both sides of the transmission link. The UWB array structure was described in [6]. It combines a virtual uniform circular array (UCA) and a 5-axes monocone UWB antenna. Propagation channel measurements were performed in frequency domain. The transmission channel was estimated with a VNA (Vector Network Analyser). To reduce the experiment duration, only 3 antennas were measured at each side of the link. The radius of the UCA is 8 cm and the virtual location number was set to 60 to comply with Shannon sampling theory. The propagation channel was sampled over 4000 equally spaced frequencies between 2.5 and 12.5 GHz. It covers the FCC-defined frequency band for indoor UWB applications. The schematic diagram of the measurement equipment is depicted in Fig. 3. An extensive UWB MIMO channel measurement campaign was carried out in a residential flat built inside the Orange labs premise [7]. This flat (see Fig. 4) is furnished and consists of 2 bedrooms, a kitchen, a desk room and a large living room. Thirteen different transmitter locations were investigated.

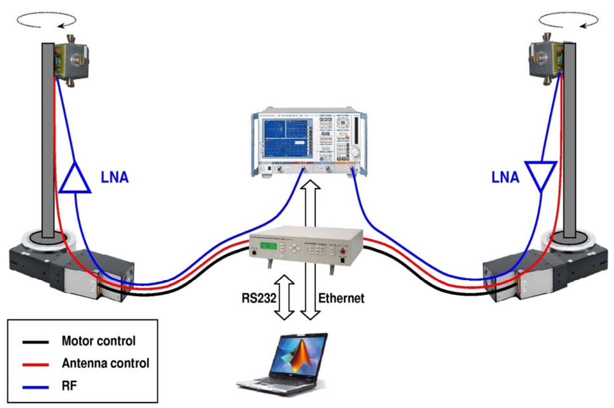

Fig. 3 Schematic diagram of the measurement equipment

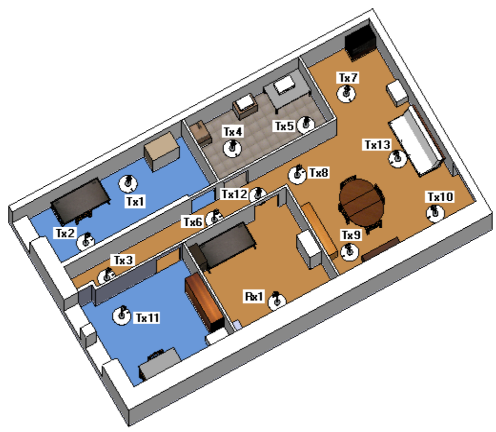

Fig. 4 A representation of the residential flat

5. Results

To allow a fair comparison between measurements and simulations, we accounted for the influence of antennas and MIMO configuration in our simulations. For this purpose, we generated the channel transfer functions of the sets of rays simulated with MATRIX, according to the MIMO circular array configuration and antenna characteristics. Then PDP and azimuth and elevation PAP as well as the delay spread and the azimuth and elevation angular spreads were computed over 8 sub-bands of 1 GHz each. The central frequencies of the selected bands extend from 3 to 10 GHz with 1 GHz step.

Figure 5 presents the measured and simulated delay spread and azimuth and elevation angular spreads at the receiver side for all Tx positions and frequencies. The predicted values tend to be equal to the measured ones when scattering was taken into account. Whereas simulations without diffuse scattering underestimate the values of the delay and angular spreads, these values are relatively better estimated when diffuse scattering is added and this for different frequencies.

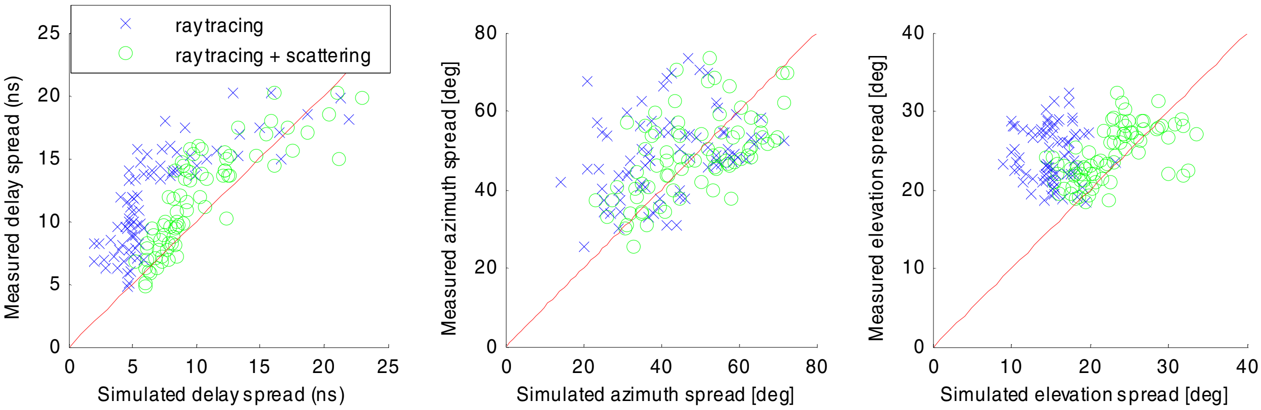

Fig. 5: Measured and simulated delay spread, azimuth and elevation angular spread for all Tx positions and frequencies.

6. Conclusion

In this paper, an optimization of 3D ray tracing for wideband MIMO indoor channel was presented. First, the relevant phenomena to take into account during simulations were analysed. Then, an efficient approach to model the scattering was presented. It extends 3D ray tracing by associating a scattering cluster with each interaction point of a ray. The cluster characteristics depend on the type of the interaction point (reflection, transmission) and the kind of the object where the interaction occurs (wall, closet). Comparisons with measurements performed in a residential area validate our approach. They show that adding scattering into simulations substantially improves the accuracy of the prediction of wideband channel parameters.

7. References

1. G. J. Foschini and M. J. Gans, "On limits of wireless communications in a fading environment when using multiple antennas," *Wireless Personnal Communications*, vol. 6, pp. 311-335, 1998.
2. Y. Lostanlen, G. Gougeon, S. Bories, and A. Sibille, "A deterministic indoor UWB space-variant multipath radio channel modelling compared to measurements on basic configurations," presented at Antennas and Propagation, 2006. EuCAP 2006. First European Conference on, 2006.
3. G. Tesserault, N. Malhouroux, and P. Pajusco, "Multi-frequencies characterization of building materials: Angular and polarization analysis," presented at European Conference on Antennas and Propagation, 2007. EuCAP 2007., 2007.
4. V. Degli-Esposti, F. Fuschini, E. M. Vitucci, and G. Falciasecca, "Measurement and Modelling of Scattering From Buildings," *Antennas and Propagation, IEEE Transactions on*, vol. 55, pp. 143, 2007.
5. F. Fuschini, V. Degli-Esposti, and E. M. Vitucci, "A model for forward-diffuse scattering through a wall," presented at Antennas and Propagation (EuCAP), 2010 Proceedings of the Fourth European Conference on.
6. P. Pajusco, G. Tesserault, N. Malhouroux, and C. Sabatier, "Novel array structure for space-time characterization of the UWB channel," presented at Personal, Indoor and Mobile Radio Communications, 2008. PIMRC 2008.
7. P. Pajusco, N. Malhouroux, and Y. Chartois, "Techniques de caractérisation ULB doublement directionnelle," presented at JNM 2009, Grenoble 2009.