Comparison between two original methods including scattering in 3D channel simulations

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***Abstract* — Two original methods to characterize the channel behavior in indoor environments composed of rough surfaces are presented and compared between themselves. They are based on algorithms developed for the image rendering field using Monte-Carlo methods to simulate the scattering phenomenon from rough surfaces. A previous study has shown which statistical parameters of real rough surfaces such as wall roughcasts have to be considered in order to have the more realistic scattering simulation as possible. Firstly, this paper presents in details the two studied methods. Secondly, we compare their performance and accuracy by simulating the radio channel for different rough indoor environments at 60 GHz**

***Index Terms* — 3D ray tracing, indoor environments, Monte Carlo, rough surfaces, scattering.**

I. INTRODUCTION

Nowadays, an increasing interest is devoted to wide-band applications like wireless local area networks (WLANs). Since the present multimedia services are more and more demanding in terms of high bit rate and thus large bandwidth, the working frequency increases. In order to deploy such wireless systems we have to study the radio channel.

Ray tracing (RT) techniques [1] are widely used in radio communications to predict the channel behavior. Indeed, they are very fast and applicable as long as the wavelength is smaller than the dimensions of objects which interact during the wave propagation. RT is based on the geometrical optics (GO) [2] extended with the (geometrical) uniform theory of diffraction (GTD/UTD) [3,4]. RT techniques take into account several physical mechanisms such as transmission, reflection, and diffraction with a great accuracy.

For example, the single direction of a reflected wave from a smooth surface is given by Snell-Descartes's reflection law, and its power is computed by Fresnel reflection coefficients [2]. However, if we consider millimetric systems, a surface can be considered slightly rough (wavelength measures 5 mm at 60 GHz). From such a surface, the reflection direction is not only the specular one. Indeed, some fraction of the energy is scattered in others directions, due to the roughness of the surface [5-8].

Actual ray tracing techniques are not able to take into account these new reflected directions around specular one in radio channel simulations. To eliminate this drawback, we present in this paper two different methods related to computer graphics [12]. They were developed at the origin to solve the global illumination problem for image rendering and we have adapted them to our problem. Then, to simulate the radio channel with scattering in rough environments, we have integrated these two methods in a full 3D ray tracing software [11]. In Section II, we briefly describe the rough surfaces and the scattering principle (see [10] for details) we use in the two original methods presented in Section III. Their goal is to simulate the wave propagation in environments composed of rough surfaces. Section IV presents three different studied environments. In order to evaluate the contribution of the scattering phenomenon in a radio channel simulation and the performances of these two original methods, channel parameters are compared in Section V.

II. ROUGH SURFACES

A. Definition

The Rayleigh criterion (1) is widely used to know whether a surface is rough or not. It respects the following principle: a surface can be considered smooth if the phase difference between two rays reflected by two different heights on the surface is smaller than $\pi/2$ in the far field [7].

$$\sigma_h < \frac{\lambda}{8\sin\theta_i} \quad (1)$$

Two techniques exist to describe a rough surface. Thanks to a sensor, we can store from a real rough surface all its heights in a structure called height map (also called height field). The second technique consists of describing real or not rough surfaces using statistical parameters according to statistical laws. This latter is more simple and does not suffer from a long acquisition time and a huge storage space for large rough surfaces.

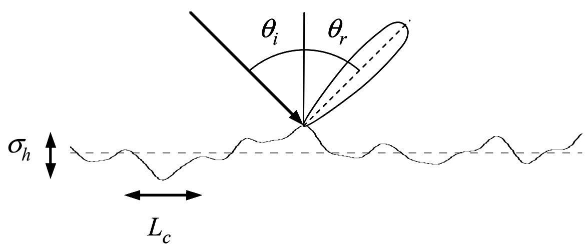
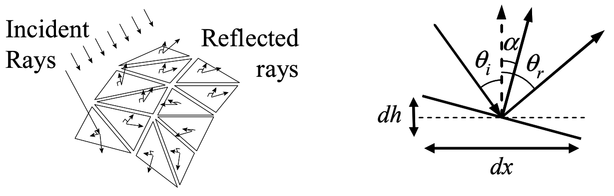


Fig. 1. Profile of a rough surface with σ_h (height standard deviation) and L_c (correlation length) parameters.



(a) Global (b) Local (2D)

Fig. 2. Reflection process on a rough surface.

B. Scattering Phenomenon

To compute the scattering field from a rough surface, we use a method similar to Kirchhoff Approximation (KA) [5], [7]. We decompose the deterministic rough surface in micro-facets [15] (Fig. 2.a). Each one receives a part of the emitted power and reflects it in its own specular direction. Thus, the heights distribution (σ_h) gives the phase variations in the far-field, while slopes and thus local normals ones ($\sigma_{x,y}$) give the reflected directions. In a particular direction, the scattering power is weighted by the probability to have a well directed micro-facet (Fig. 2.b).

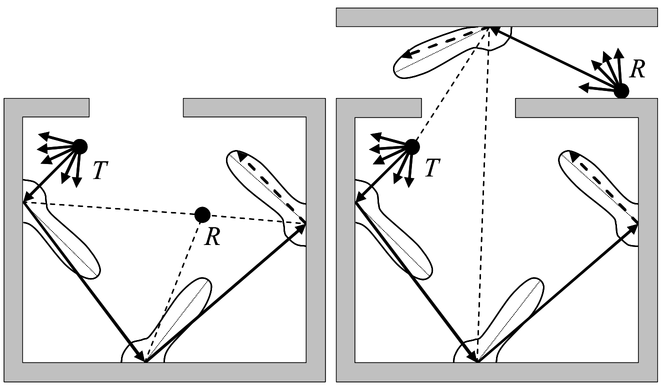
A previous study [10] has shown the link between statistical roughness parameters and distributions of reflected directions for Gaussian and non-Gaussian rough surfaces. In order to reproduce scattering phenomenon, a solution is to sample these distributions with Monte Carlo methods [12]. Thus, others directions around the specular one in a channel simulation may exist.

III. Principle of Two Original Methods

To simulate the wave propagation in environments composed with rough surfaces, we have to use other methods than classical ray tracing techniques. In the following, we describe the principle of the two original methods respectively called Path Tracing (PT) and Bi-Directional Path Tracing (BDPT).

A. Path Tracing (PT)

This method is similar to ray launching [13]. Many rays are sent from the transmitter T in the studied environment and interact with it. For example, when a ray interacts with a smooth surface, a ray is reflected from the hit point according to the Snell-Descartes's relationship. However, when a ray interacts with a rough surface, the treatment is different: a reflected direction is randomly chosen according to the statistical properties of the hit rough surface (solid vectors in Fig. 3.a). Moreover, a part of the reflected power can be received by the receiver if a line-of-sight (LOS) exists between this latter and the hit point on the rough surface. In the positive case, a second ray is reflected toward the receiver with a magnitude weighted by the probability to have a reflected ray in this particular direction (dotted segment in Fig. 3.a).



(a) Path Tracing (PT) (b) Bi-Directional PT

Fig. 3. Principle of Path Tracing for three allowed reflections.

B. Bi-Directional Path Tracing (BDPT)

The principle of Bi-Directional Path Tracing (BDPT) [14] consists of generating two paths independently from the transmitter and the receiver in same time. All hit points on a transmitter path are connected to the receiver if it is possible (a LOS must exist between them). For example, for a particular hit point (as in the previous PT algorithm), a part of the reflected power can be reflected toward the receiver. The novelty of the BDPT algorithm lies in the fact that a part of the reflected power from a hit point on the transmitter path can be reflected toward each hit point on the receiver path (dotted segment in Fig. 3.b). The magnitude of each new ray is computed with their existence probability (according to the rough surfaces statistical parameters).

IV. Test Configurations

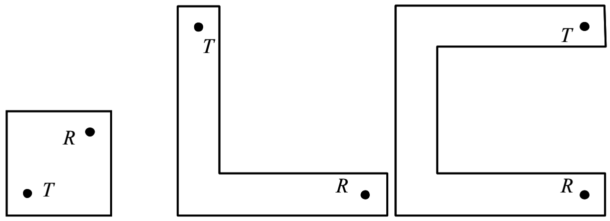
After describing the two original methods, we have to test them in particular environments. The aim is to determine which method is better to use according to the complexity of the environment.

Both previous algorithms have been implemented in a full 3D ray tracing software [11]. They permit to compute impulse responses and corresponding mean delay τ_m and delay spread σ_τ (2) in rough indoor environments. For an impulse response composed of n delayed paths with a magnitude A_k, $k=1..n$, we have:

$$\tau_m = \sqrt{\frac{\sum_{k=1}^{n} \tau_k |A_k|^2}{\sum_{k=1}^{n} |A_k|^2}}, \quad \sigma_\tau = \sqrt{\frac{\sum_{k=1}^{n} (\tau_k - \tau_m)^2 |A_k|^2}{\sum_{k=1}^{n} |A_k|^2}} \quad (2)$$

The parametric study is completed on three environments (Fig. 4): cubic, L, and U rooms. Channel parameters can be computed according to various simulation properties such as:

1) N_I, the number of iterations for each simulation.
   $N_I = \{10, 25, 50, 75, 100, 200, 300, 400, 500\}$
2) N, the number of emitted or launched rays.
   $N = \{1000, 5000, 10000, 50000, 100000\}$
3) N_R, the number of interactions for each simulation.
   $N_R = \{2, 5, 10\}$



(a) cube (b) L (c) U

Fig. 4. Floor plans of tested indoor environments. Cube measures 5m x 5m x 2.5m, while other ones measure 10m x 10m x 2.5m.

4) L_R, the roughness level.
$L_R = \{0, 1, 2, 3\}$, with:
0 means $\sigma_h = 0\ \mu m$, and $\sigma_{x,y} = 0.0°$
1 means $\sigma_h = 111\ \mu m$, and $\sigma_{x,y} = 16.0°$
2 means $\sigma_h = 219\ \mu m$, and $\sigma_{x,y} = 19.7°$
3 means $\sigma_h = 292\ \mu m$, and $\sigma_{x,y} = 25.2°$

5) t_c, the computational time obtained with a computer powered by a processor at 1.2 GHz and 256 MB of RAM.

IV. Results

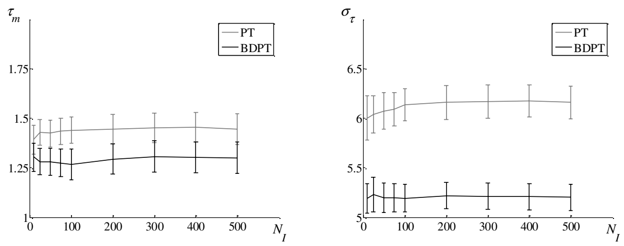
In order to compare both algorithms, we have simulated the propagation channel corresponding to the three environments defined in Section III (Fig. 4). We compute results of mean delay τ_m, delay spread σ_τ and computation time t_c varying simulation parameters N_I, N, N_R and L_R.

A. Number of iterations: N_I

Since emitted rays in both methods are sent randomly, we have to make an average of channel parameters on a great realizations or iterations number N_I. We do not present detailed results according to this parameter due to the identical observations on all tested environments with our two methods. For example, we present results obtained with cube 1 scene (Fig. 5). As the number of realizations increases, the standard deviation decreases and the mean value becomes constant. In the following, we use 200 iterations that it is a good compromise between computation time and accuracy.

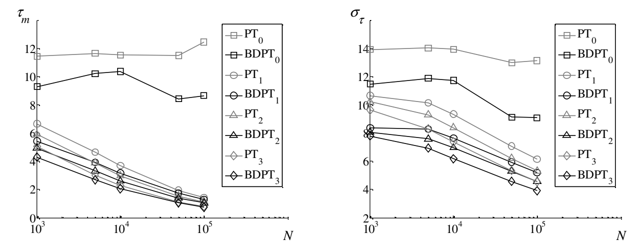
B. Number of launched rays: N

The goal of these two original methods is to sample hit surfaces with a great number of rays in order to have a great accuracy on the scattering phenomenon. So we study the influence of N on channel parameters (Fig. 6). N_I is fixed to 200 realizations and N_R is fixed to 5 reflections.

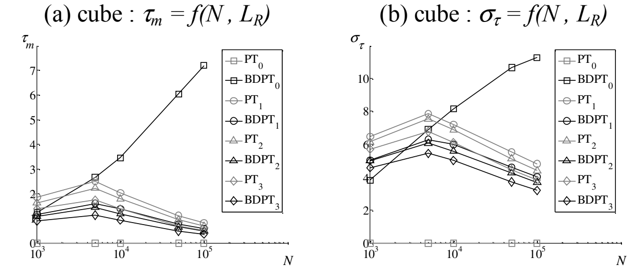


Mean delay: $\tau_m = f(N_I)$ Delay spread: $\sigma_\tau = f(N_I)$

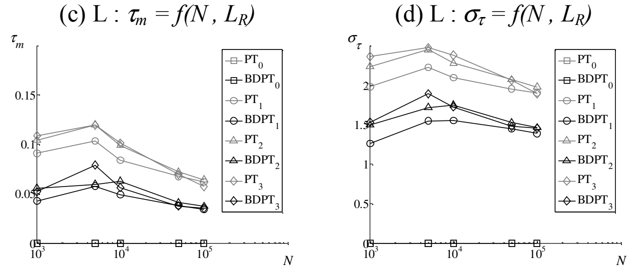
Fig. 5. Means and corresponding standard deviations of τ_m and σ_τ for both methods according to N_I in the cube 1 environment.



(a) cube : $\tau_m = f(N, L_R)$ (b) cube : $\sigma_\tau = f(N, L_R)$



(c) L : $\tau_m = f(N, L_R)$ (d) L : $\sigma_\tau = f(N, L_R)$



(e) U : $\tau_m = f(N, L_R)$ (f) U : $\sigma_\tau = f(N, L_R)$

Fig. 6. Means values of τ_m and σ_τ for our two methods (PT, BDPT) according to N and L_R (indices *0, 1, 2, 3* in legends).

When N increases channel parameters converge. This phenomenon is faster for the BDPT. Nevertheless, it is more time consuming and thus the computational time increases (Fig. 7). Notice that some values are equal to zero (scenes L0 and U0). It means that these scenes are too complex and that no rays are received with 5 reflections. In this case, a classical ray tracing taking into account only reflection phenomena give same null results. When the roughness increases, the randomly reflected rays do not pass uniquely through the deterministic paths between the transmitter and the receiver but by others which may be received. Hence channel parameters values become different from zero.

C. Number of interactions: N_R

Channel parameters are directly related to the number of interactions chosen to simulate the wave propagation. Since we do not have channel measurements or references for these environments we cannot interpret our simulated channel parameters results. Nevertheless, we study in Section IV.E the influence of N_R on t_c (Fig. 7).

D. Level of roughness: L_R

Fig. 6 shows that the channel parameters are dependant on the level roughness. When this latter increases, channel parameters values decrease independently of the method, the number of emitted rays, the complexity of tested scenes.

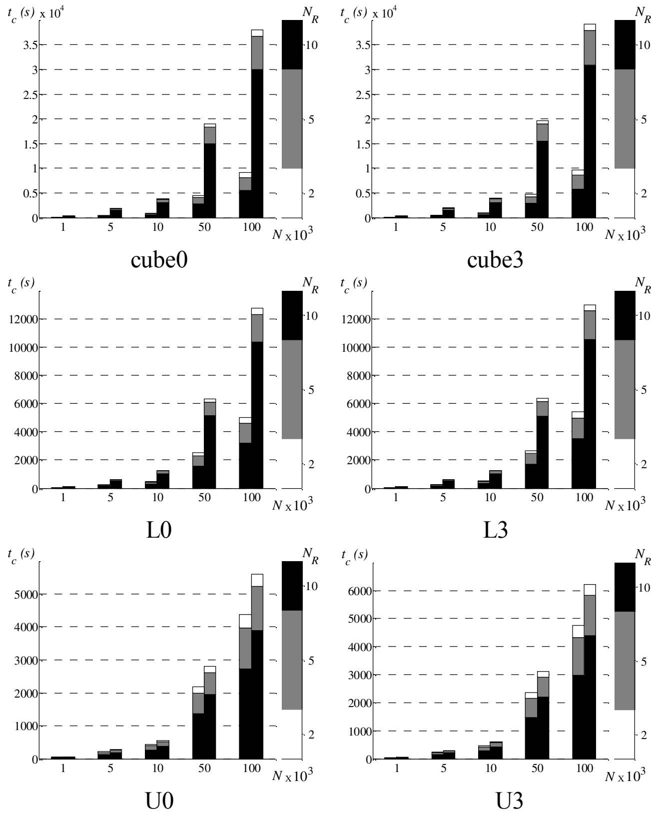


Fig. 7. Computational time for cube, L and U environments with and without roughness. Results for PT and BDPT methods are represented on each graph (respectively left and right bars for a *N*).

E. Computational time: t_c

The computational time t_c is related to all previous parameters N_I, N, N_R, and L_R. We can summarize them in Fig. 7. According to N, PT is faster than BDPT. This advantage is reduced when the complexity of the environment increases. Indeed, in complex environments, there is a small number of LOS between hit points on transmitter and receiver paths. Thus, the number of tests in BDPT algorithm decreases significantly. The tests number in both algorithms explains also the fact that t_c decreases when N_R decreases too.

Moreover, we can observe that the computational time is strongly dependant on the number of emitted rays. Notice that the computational time increases smoothly with L_R. The computational time can be simply computed for different values of N_I since it is proportional to this latter.

Notice that a channel simulation in scene U for 10 reflections using a classical ray tracing lasts more than 1day.

V. Conclusion

In theory, BDPT is more costly in terms of computation time, but it brings to a faster convergence of canal simulation results in complex environments (when the transmitter and the receiver are not in direct visibility).

This principle is well verified in practice. Indeed, channel parameters converge faster and the computational time difference between both methods is strongly reduced when the complexity increases. The conclusion of this work is that bi-directional method (BDPT) gives an improvement of propagation channel simulations at lower cost in term of computational time in complex indoor environments.

In future works, we will have to make this parametric study in parallel with channel measurements to study the influence of N_R.

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References

[1] G. A. Deschamps, “Ray techniques in electromagnetics,” *Proc. IEEE,* vol. 60, no 9, pp. 1022–1035, Sept. 1972.

[2] C. A. Balanis, *Advanced Engineering Electromagnetics.* New York: John Wiley and Sons, 1989.

[3] J. B. Keller, “Geometrical theory of Diffraction,” *J. Opt. Soc. Amer.*, vol. 52, no. 2, pp. 116–130, Feb. 1962.

[4] R. G. Kouyoumjian and P. H. Pathak, “A uniform geometrical theory of diffraction for an edge in a perfectly conducting surface,” *Proc. IEEE*, vol. 62, no 11, pp. 1448–1461, Nov. 1974.

[5] J. A. Oglivy, *Theory of wave scattering from random rough surfaces*, Hilger, 1991.

[6] F. T. Ulaby, R. K. Moore and A. K. Fung, *Microwave remote sensing: active and passive*, vol. 2, Addison-Wesley, 1982.

[7] P. Beckmann and A. Spizzichino, *The scattering of electromagnetic waves from rough surfaces*, Pergamon, 1963.

[8] A. G. Voronovich, *Wave scattering from rough surfaces*, 2nd ed., Germany: Springer series on Wave Phenomena, 1999.

[9] D. Didascalou, M. Döttling, N. Geng and W. Wiesbeck, “An approach to include stochastic rough surface scattering into a deterministic ray-optical wave propagation modelling,” *IEEE Trans. Antennas Propagat.*, vol. 51, no. 7, pp. 1508–1515, Jul. 2003.

[10] Y. Cocheril, R. Vauzelle, L. Aveneau, “3D channel simulations including scattering from non-gaussian rough surfaces,” *IEEE VTC’2006 Fall*, Montréal, Canada, Sept. 2006.

[11] F. Escarieu, Y. Pousset, R. Vauzelle and L. Aveneau, “Outdoor and indoor characterization by a 3D simulation software,” *IEEE PIRMC’2001,* San Diego, Oct. 2001.

[12] P. Shirley, “Physically based lighting calculations for computer graphics,” Ph.D Thesis, University of Illinois, Nov. 1990.

[13] E. P. Lafortune, “Mathematical models and Monte Carlo algorithms for physically based rendering,” Ph.D Thesis, University of Leuven, Feb. 1996.

[14] E. P. Lafortune and Y. D. Willems, “Bi-Directional path tracing,” *Compugraphics’93*, Alvor, Portugual, pp. 145–153, Dec. 1993.

[15] D.T. Lee and B. J. Schacter, “Two algorithms for constructing a Delaunay triangulation,” Int. J. Conput. Inf. Sci., vol. 3, no. 9, pp. 219-242.