60-GHz Indoor Propagation with Time-Domain Geometric-Optics

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Compared with 2.4 GHz and 5GHz, 60 GHz has the potential of high speed communication. In this paper, 60 GHz indoor propagation is studied with the Time-Domain Geometric-Optics (TDGO) method. Compared with full wave numerical methods of electromagnetic simulation such as the finite difference time domain (FDTD), the TDGO takes less operating time. For the wide band communication, the TDGO is more accurate than geometric optics (GO) in frequency domain.

***Index Terms*—60 GHz wireless communication, indoor channel model, Time-Domain Geometric-Optics**

I. Introduction

THE high speed wireless communication is attracting much attention because of the wide application, such as military, entertainment and health care. The existed frequency spectrum, such as 2.4 GHz and 5GHz, is becoming crowdy. As one of the candidates of frequency spectrum, 60 GHz is a potential candidate based on its high frequency and about 5 GHz bandwidth. The same as other frequency spectrum, channel model is one of the critical problem in coding or modulating in 60 GHz. Up to now, the 60 GHz channel model has not been well studied and well established.

Most of the studies are based on experiments. The most used numerical simulation methods are full wave such as the finite difference time domain (FDTD) and high frequency asymptotic numerical electromagnetic method such as the geometric optics (GO) in frequency domain. For electrically large objects, full wave methods need more computational resources and operating time because of spatial meshing. Without meshing, the GO in frequency need more time in frequency sweeping compared with the method in time domain. The Time-Domain Geometric-Optics (TDGO) has been implemented on the Ultra-Wideband (UWB) channel [1], offering reasonable speed and accurate of simulation. To the author's knowledge, there is no study on 60GHz wideband wireless channel with the TDGO. In this paper, the TDGO will be implemented in the modeling of 60 GHz channel and compared with the FDTD.

II. TDGO Method for Wireless Communication Channel

The channel of wireless communication is an impulse response of a linear system which is physically constructed by a set of scatters in space. In an empty room, the impulse response is a sum of field components as [1]

$$h(t) = \sum_{n=1}^{N_{1GO}} A_n \delta(t-\tau_n) + \sum_{n=1}^{N_{2GO}} B_n r_n \otimes \delta(t-\tau_n) \qquad (1)$$

where A_n and B_n are real values. $r_n(\tau)$ is the impulse response of rays arising from multiple reflections. τ_n is the delay of the rays and $\otimes$ is the operator of convolution.

The aforementioned coefficients are physically described by the mechanism of electromagnetic propagation. The two terms in (1) denote the direct impulses and reflected impulses respectively, and the corresponding physic process is the propagation of wave in far field free space and reflection at the surface of scatterers. When the wave length is much smaller than the scale of the scatter, the process can be described by geometric optic theory. The energy propagates along straight lines and the reflecting field is denoted with Fresnel's reflecting coefficients.

The trajectory of optic ray can be found by Fermat's principle and the law of reflection. For reflection, the Fresnel's reflecting coefficients in frequency domain is transformed to time domain response $r_n(t)$ [1]

$$r(t) = \pm\left[K\delta(t) + \frac{4\kappa}{1-\kappa^2}\frac{e^{-at}}{t}\sum_{n=1}^{\infty}(-1)^{n+1} n K^n I_n(at)\right] \qquad (2)$$

where $K = (1-\kappa)/(1+\kappa)$ and $a = 120\pi\sigma c/2/\varepsilon_r$. Here, ε_r is relative permittivity and σ is electric conductivity of the reflecting surface. $\kappa = \sqrt{\varepsilon_r - cos^2\psi}/(\varepsilon_r sin\psi)$ and the leading plus sign and are used for vertical polarization, whereas $\kappa = sin\psi/\sqrt{\varepsilon_r - cos^2\psi}$ and the leading minus sign are used for horizontal polarization, in which ψ is the incident angle. I_n is the modified Bessel function. The coefficients in (1), A_n and B_n, are spatial spreading factors in free space as

$$A = \sqrt{\frac{\rho_1\rho_2}{(\rho_1+s)(\rho_2+s)}} \qquad (3)$$

where ρ_1 and ρ_2 are the principal radii of curvature of the corresponding wave front at the reference point O, which is shown in figure 1.

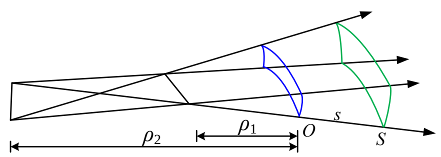

Fig. 1. A tube of incident geometric optics ray

Once the coefficients in (1) are determined by (2) and (3), the impulse response of the wireless communication system $h(t)$ is obtained and the received electric field $E^{rec}(t)$ can be computed by the convolution

$$E^{rec}(t) = E^{inc}(t) \otimes h(t) \qquad (4)$$

where E^{inc} is the incident electric field.

III. VALIDATION OF TDGO METHOD

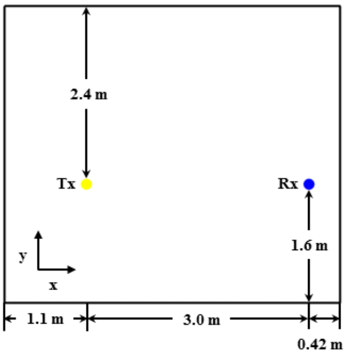

Fig. 2. Empty room area in which is simulated

TDGO method is validated by 2D FDTD. The validation is made in an empty room as shown in figure 2 [2]. The transmitting and receiving antennas are both dipole in z direction. The material parameters of the wall are $\varepsilon_r = 10$ and $\sigma = 0.1$. The transmitted signal and its received signal are shown in figure 3. The agreement between TDGO and FDTD is very good.

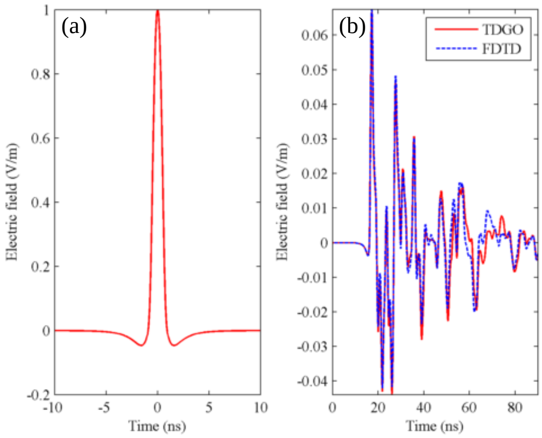

Fig. 3. (a) Transmitted signal for validation and (b) the received signals compared between FDTD and TDGO

IV. PROPAGATION OF 60-GHZ WAVE WITH TDGO

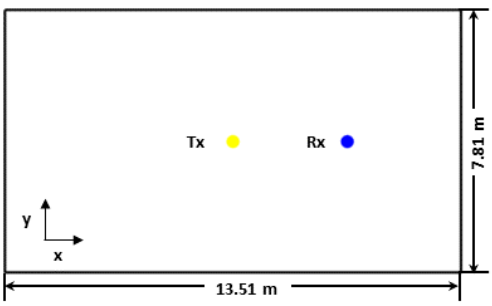

Fig. 4. The scene of simulation

The simulation is implement in the scene as figure 4 [3]. The walls were covered with a layer of plasterboard of which the complex refractive index is 1.76-0.014j. The transmitted signal is a Gaussian-modulated cosine with 1 GHz band centered around 57.5 GHz as shown in figure 5. The delay profiles of the received signal is shown in figure 6. The ordinate is normalized to the peak level corresponding to the direct wave from the transmitter to the receiver. Compared to the transformation from frequency domain in reference [3], the result in time domain directly is more accurate compared to the experiment. However, calculating on a 2.6GHz CPU, the TDGO operated only 12 min, much faster than 60 hours by using the FDTD.

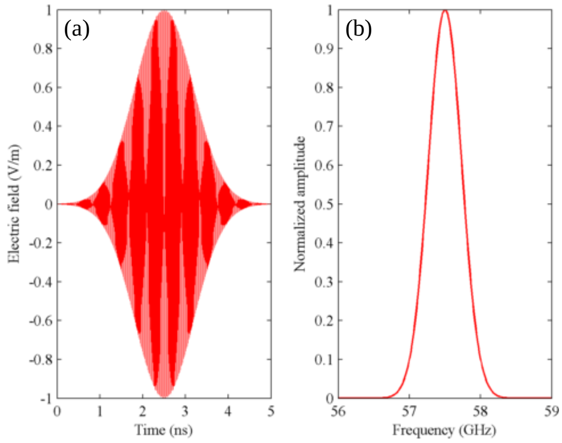

Fig. 5. (a) 57.5 GHz Gaussian-modulated cosine signal and (b) Frequency spectrum of transmitted signal

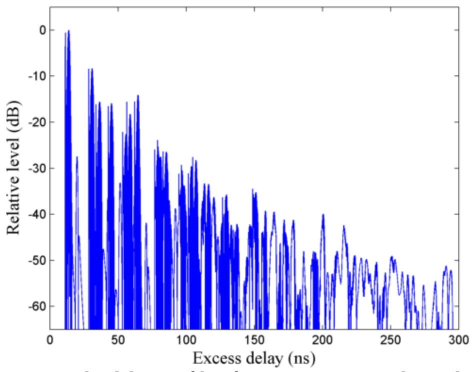

Fig. 6. The delay profile of 60 GHz transmitted signal

V. CONCLUSION

The Time Domain Geometric Optics has been validated by an impulse and used to simulate the indoor channel of 60 GHz wireless communication. Compared with a full wave method such as the FDTD, the TDGO is much faster, meanwhile, the method in time domain is more accurate than the GO method in frequency domain. The TDTO is reasonable to modeling the 60 GHz wireless channel.

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