Human Influence on 60 GHz communication in close to user Scenario

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Abstract

This paper presents a new human influence model for 60 GHz close-to-user communications. The model is based on both Geometrical Optics results and a modified creeping wave formulation. It is applied in an indoor environment and the mean attenuation of the channel with the human body presence is calculated. As expected, it is shown that the attenuation is highly affected by the user orientation with respect to the transmitter. In this paper, only a normally incident plane wave with TM polarization is studied.

1. Introduction

The recent advance in miniaturization of electronic devices and the bandwidth availability in the millimeter band have allowed the development of 60 GHz communications. This technology provides high data rate communications and new services to the users. However, millimeter wavelengths introduce high path losses and shadowing effects. One of the most important interactions to deal with is the human body influence on the communication channel. Recent works have studied the path loss around the human body for both on- [1] and off-body [2] communications at 60 GHz. However, one of the most probable scenarios would be the presence of the human body next to the receiver and it has not already been studied to the best knowledge of the authors. In this paper, a simple diffraction model is proposed for a receiver located from 5 to 30 cm away from the body.

The paper is organized as follow: firstly, section 2 presents the diffraction model. Then, in section 3, the mean channel attenuation is studied and discussed. Finally, section 4 concludes the paper.

2. Close-to-user Propagation Model

In [2], an off-body channel model has been derived by modeling the human body with a circular cylinder. It is experimentally shown that this assumption is assessed with a maximum 3 dB error. However, in that paper, the antenna is always assumed to be at maximum 5 mm from the human body. In this section, using the same methodology, a modified model is derived for larger distances from 5 to 30 cm. This will allow modelling the channel between an external base station and a user using a device close to his body such as a cellphone, a tablet or a computer.
The geometry of the propagation model is presented in Fig. 1. The model is divided into two parts: lit and shadow regions.

The cylinder modeling the body is immersed in free-space. It has a radius a , a principal axis $\bar{z}$, relative complex permittivity ε_r depending on the conductivity σ by $\varepsilon_r = \varepsilon_r' + \sigma / j\varpi\varepsilon_0$ with ε_r' defined as the real part of the relative permittivity, ε_0 is the free-space permittivity and $\varpi = 2\pi f$ is the angular frequency and f is the frequency. Cylindrical coordinates (ρ, ϕ, z) are adopted where $-\pi < \phi \le \pi$ and $\rho \ge a$. The incident electric field E^{inc} is assumed to be TM polarized and with normal incidence such as it can be written:

$$E^{inc} = E_0 e^{jkx} \bar{z}$$

where k is the wavenumber in free-space, x is the coordinate along the propagation path and E_0 is the plane wave magnitude.

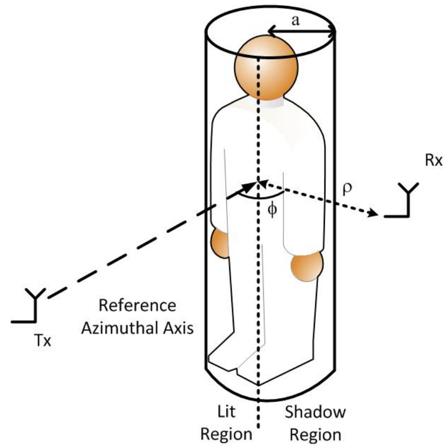

Fig. 1 Problem Geometry. The cylinder is assumed to be filled with the electric properties of the human skin.

2.1 Lit Region

The lit region model is based on Geometrical Optics (GO) formulations. The total electric field is then given by the incident plane wave and the reflected one. The equations relative to this region can be found in [2].

2.2 Shadow Region

To solve the electric field in the shadow region, it proposed to use Watson's transform. This allows writing the electric field as a sum of creeping waves. In [3], due to the close to cylinder assumption, the sum has been approximated to the first creeping wave mode. For distances between 5 cm and 30 cm, this approximation is not accurate enough. Numerically, it can be shown by comparing the creeping wave modes formulation to the Eigenmode solution [4] that the two first modes are sufficient to reach a 3 dB maximal error between the two solutions. This error corresponds to the accuracy of the circular cylinder model found in [3]. The creeping wave modes formulation is given by:

$$E_z = 2\pi \sum_s j^{v_s} a_s H_{v_s}^{(2)}(k\rho)\Phi_{v_s}(\phi) \tag{1}$$

where $v_s = ka + m\tau_s$, $m = (ka/2)^{1/3}$, $\Phi_{v_s} = \dfrac{\cos(v_s(\varphi - \pi))}{\sin(v_s \pi)}$ and $a_s = \dfrac{1}{m}\dfrac{A'(\tau_s) - qA(\tau_s)}{\tau_s W_2(\tau_s) - qW'_2(\tau_s)}$. In the previous equations, $H_{v_s}^{(2)}$ is the Hankel function and A, W_2 are the classic and modified Airy functions [2]. The τ_s are obtained by solving:

$$W'_2(\tau_s) - qW_2(\tau_s) = 0 \tag{2}$$

where $q = jm\sqrt{\varepsilon_r}$. By keeping the only two first creeping wave modes, the path gain in [dB] with $P = 20\log_{10}|E|$ can be derived:

$$P = P_0 - n(\phi - \pi/2) + 20\log_{10}\left|1 + j^{v_2 - v_1}\frac{a_2 H_{v_2}^{(2)}(k\rho)}{a_1 H_{v_1}^{(2)}(k\rho)}\frac{\Phi_{v_2}(\phi)}{\Phi_{v_1}(\phi)}\right| \tag{3}$$

with $n = 20\log_{10}(e) m \,\mathrm{Im}(\tau_1)$ and P_0 the path gain at $\phi = \pi/2$. This solution is similar to the one obtained in [3].

In Fig. 2, the comparison shows that for an antenna away from the cylinder, the proposed solution fits almost perfectly. In this figure, only the shadow region is presented. The shadow boundary is defined in [4].

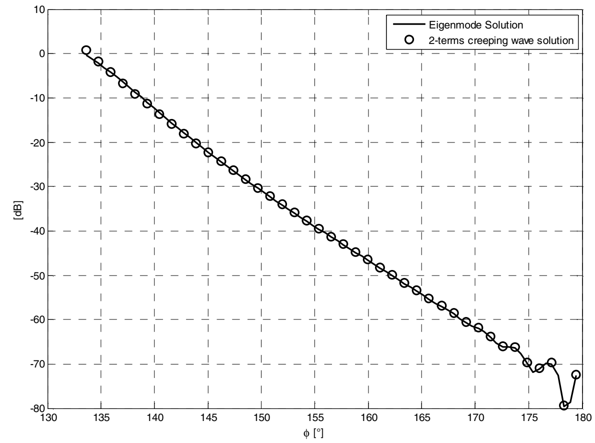

Fig. 2 Comparison between Eigenmode solution and 2-terms creeping wave formulation. The cylinder have a 20 cm radius and the receiving antenna is 10 cm away from the cylinder.

However, a correction term appears due to the second creeping wave mode. In order to simplify this correction term, Debye's expansion [4] and a simplification of $\Phi_{v_s} \cong je^{-jv_s\phi}$ are used. It allows writing:

$$Corr = 20\log_{10}\left|1 + j^{\Delta v}\frac{a_2}{a_1}e^{j\Delta v}e^{-j\Delta v\phi}\right| \cong \frac{20}{\ln 10}\left|\frac{a_2}{a_1}\right|e^{-\mathrm{Im}(\Delta v)(\phi-\frac{\pi}{2}-1)} \quad (4)$$

where a Taylor expansion has been used and $\Delta v = v_2 - v_1$. Finally, by noting $\tilde{n} = \frac{20}{\ln 10}\left|\frac{a_2}{a_1}\right|$, it can be inferred that:

$$P = P_0 - n(\phi - \pi/2) + \tilde{n}e^{-\mathrm{Im}(\Delta v)(\phi-\frac{\pi}{2}-1)}. \quad (5)$$

These solutions can be easily extended to take into account of the elevation angle of the plane wave as done in [3].

3. Channel Attenuation with user orientation

Using the methodology presented in [5], the previous results have been implemented in an indoor channel model to take into account numerically of the body presence. The diffraction model proposed in this paper is a ray description of the electric field and is well suited to be implemented in ray-based channel models. The chosen scenario is the *conference room* in the IEEE802.11ad indoor channel model.

The path loss can be calculated around the human body in a zone between 5 and 30 cm away from the body. To compute Fig. 3, the mean power of the frequency response has been calculated.

In the lit region, this figure shows fading because of the interaction between the incident and the reflected wave on the cylinder. In fact, the environment seems to have low impact on the mean channel attenuation. The channel has to be modeled by a two-waves distribution.

In the shadow region, high attenuation is created due to shadowing effect. This variation has to be taken into account for a communication with a device next to the body user. Also, it is important to notice in Fig.3 that the maximal variation between lit and shadow regions is about 40 dB. However, in Fig. 2, the creeping wave formulation has a maximal path loss of 80 dB. It can be inferred that the environment helps the budget link in the shadow region. In that region, the environment can not be neglected.

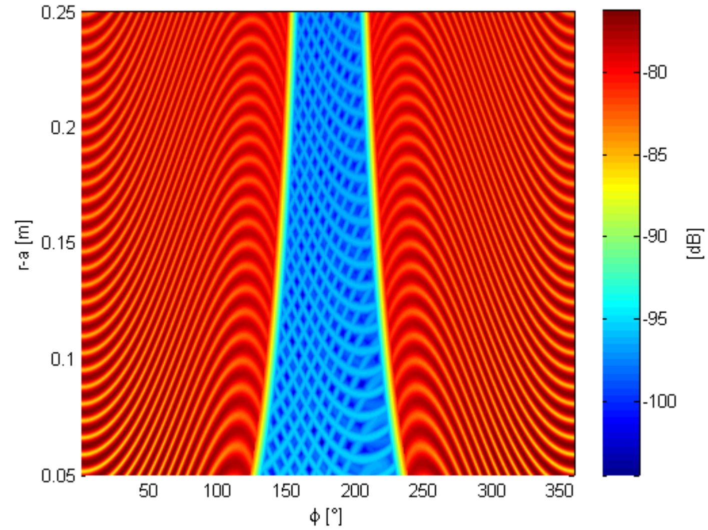

Fig. 3 Path Loss around the human body. The cylinder is assumed to have a 0.2 m radius and the transmitter is located 2 m away from the cylinder.

4. Conclusion

This paper presents a fast computing propagation model for 60 GHz communications close-to-user scenarios. The model is split up into two regions. The lit region is calculated using Geometrical Optics and the shadow region uses a two-terms creeping wave formulation. This formulation is compared to the Eigenmode solution and shows a maximum error of 3 dB.

In a second time, the propagation model has been implemented in an indoor scenario. This allows taking into account of both the environment and the user's body. It has been shown that the orientation of the user have a high influence on the received signal.

In the lit region, the environment does not influence the received signal. The power seems to be a "two-waves" distribution. In the shadow region, the human body creates a high shadowing due to the line-of-sight blockage. However, the environment has a strong influence. It is shown that in the deep shadow region, it allows to save 40 dB of power.

7. References

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