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Atmospheric Attenuation Analysis in Indoor THz Communication Channels

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***Abstract*—In this paper, we study the terahertz (THz) transmission channels from 100 GHz (0.1 THz) to 1000 GHz (1 THz) by including the effects of frequency-dependent atmospheric attenuation and diffuse reflection (non-specular scattering) due to surface roughness for short-range indoor wireless communications. First and foremost, the ITU-R Rec. P. 676-8 model has been used for this study to compute the effects of water-vapor content in the atmosphere by demonstrating the multipath channel transfer function (CTF) dynamics for line-of-sight (LoS) and non-line-of-sight (NLoS) scenarios in a simple realistic office environment. Then, the indoor multipath propagation and its impact considering rough surfaces has been investigated employing the classical Beckmann-Kirchhoff (B-K) model by using our self-developed ray tracing algorithm (RTA). Finally, the relative received power and contribution of the diffusely scattered power at 300 GHz has been illustrated at each scenario point with different surface roughness to predict the achievable signal-to-noise ratio.**

***Keywords*—THz communication, atmospheric attenuation, diffuse reflection, ray-tracing, Beckmann-Kirchhoff theory.**

I. INTRODUCTION

The new "Tera-Era" visions extreme high speed wireless data transfer of 100 Gb/s, machines computing at rates of teraflops, and electronic devices performing operations on the picosecond time scale. In fact, to achieve 100 Gb/s wireless links, a bandwidth of several gigahertz (GHz) is enforced, best sheltered in the THz range. However, the atmospheric attenuation is still not out of picture. Perhaps, the attenuation also in atmosphere at frequencies above 100 GHz is much larger than that in the microwave frequency band. It is worth mentioning that the resonances for frequencies below 100 GHz occur at 24 GHz for water molecules and 60 GHz for oxygen, whilst the frequency range from 100 GHz to 1 THz is dominated by water molecules only. Next, the diffuse reflection from typical indoor building materials (e.g., granular wallpaper and plaster walls) becomes more prominent with increasing frequencies, and additionally contributes to multipath propagation due to diffuse paths in non-specular directions, impairing the quality of the THz links [1]. In the end, simplifying approximations commonly used in conventional channel models below 100 GHz cannot be applied at THz frequencies.

Despite the atmospheric attenuation, there are certain spectral windows available for THz communication. For instance, a spectral window centered at 300 GHz offers 47 GHz of bandwidth with atmospheric impact amounts to no more than 2.8 dB/km, which allows a 100 Gb/s high throughput even with a simple modulation scheme for short-range wireless communications [2]. Thus, a reliable wireless terabit-per-second (Tbps) link up to few meters can be achieved and maintained indoor [3] as well as outdoor [4] by utilizing reflected paths.

In our previous work [5], the simulated line-of-sight channel has already been presented by analyzing the impact of atmospheric attenuation (or molecular absorption) on the path loss. However, in this paper the illustrated frequency-domain channel transfer function (CTF) at 1801 frequency points for f = 100...1000 GHz are obtained for both LoS and NLoS conditions for a dry/clear environment. In this paper, we dedicate our attention in addition to diffuse reflection mechanism by investigating it's impact on the relative received power upon increasing surface roughness (i.e., by varying the standard deviation height σ_h and keeping the correlation length ℓ_{cr} fixed). We use the Kirchhoff Approximation to model diffuse reflection at angles near the surface normal for random rough surfaces by using our self-developed ray tracing algorithm [6]. This is considered to be some of the earliest activity undertaken in this area by Beckmann and Spizzichino [7] briefly discussed in Section II.

II. CHARACTERIZATION OF DIFFUSE REFLECTION

A. Beckmann-Kirchhoff (B-K) Model

The Beckmann-Kirchhoff (B-K) model accounts for the diffuse reflection in both specular and non-specular directions from random rough surfaces under some assumptions for slightly and very rough surfaces. According to B-K model, the mean scattered power is given by

$$\left\langle R_{power} \right\rangle_{non-specular} = \frac{4A^2 \cos^2(\Theta_i)}{\lambda^2 {r_2}^2} \langle \rho\rho^* \rangle_{\text{finite}} \tag{1}$$

Likewise, for the direction of specular reflection it is

$$\left\langle R_{power} \right\rangle_{specular} = \langle \rho\rho^* \rangle_{\text{finite}} = \langle \Gamma\Gamma^* \rangle \, e^{-g} \tag{2}$$

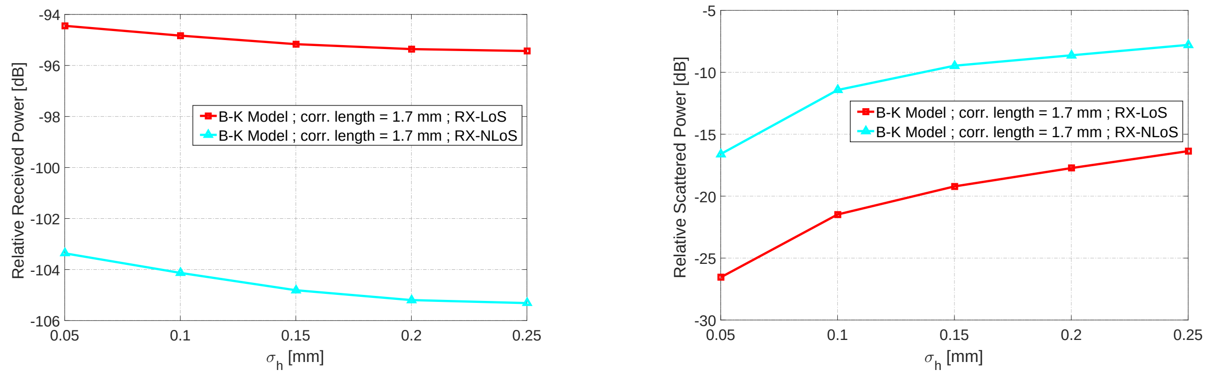
As in, the total received power P_{tot} can be summarized with the following expression

$$P_{tot}(RX) = \left\langle R_{power} \right\rangle_{specular} + \left\langle R_{power} \right\rangle_{non-specular} \tag{3}$$

The details about the expressions A, Θ_i, λ, r_2, ρ, Γ, and g are given at [7, p. 88].

B. Scenario, Ray-Tracing Algorithm, and Material Parameters

Fig. 2 shows the simulation setup. Due to the length constraint, we refer the reader to author's separate publication [6] for the detailed description of the scenario, the ray tracing algorithm and material parameters.



(a) (b)

Fig. 1: B-K model at 300 GHz for different roughness parameters for RX-LoS and RX-NLoS receiver locations (a) Total received power relative to input power and (b) Scattered power relative to total received power.

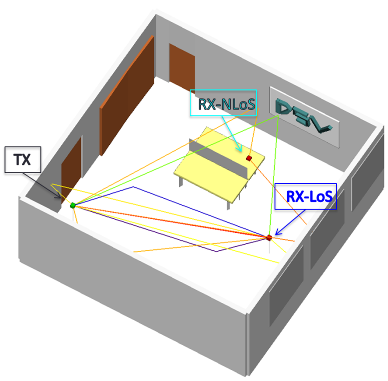


Fig. 2: 3D layout of the office room BB121 with examples of rays reaching receivers via complex paths.

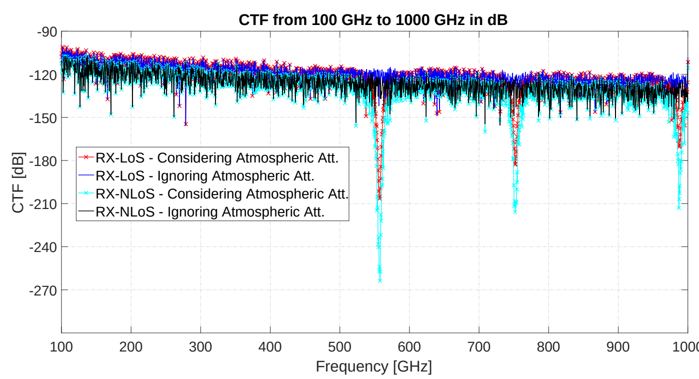


Fig. 3: Channel Transfer Function (CTF) with and without considering the atmospheric attenuation for RX-LoS and RX-NLoS receiver locations.

III. Results and Conclusions

In Fig. 3, the channel transfer functions are depicted by ignoring and considering the atmospheric attenuation for Fig. 2 scenarios. In order to show the impact of atmospheric attenuation only, the rough plaster walls and ceiling are modeled as ideally smooth surface ($\sigma_h = 0$). However, the impact of surface roughness on the THz propagation channel and its influence on the total received power is separately shown in Fig. 1a. As deduced the peak-to-peak frequency dependent variations of up to 87.5 dB and 138.5 dB at $f = 557.5$ GHz (water-vapor resonances) are well evident for LoS and NLoS in Fig. 3. Conversely, it is 0.1 dB at $f = 300$ GHz (spectral window) for both scenarios. The atmospheric attenuation for short-range indoor wireless communications can thus be neglected. As expected, in Fig. 1b the results show the fundamental behaviour that the relative scattered power depends on rough surfaces in the simulation environment and it increases with increasing σ_h especially for NLoS case. Moreover, in NLoS scenario most of the total received power contribution comes from diffuse reflections. For LoS scenario, however, the contribution of diffuse reflection is less poignant and the total received power depends highly on direct path.

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References

[1] S. Priebe et al., "Non-specular scattering modeling for THz propagation simulations," *Proceedings of the 5th EUCAP*, pp. 1–5, May 2011.

[2] H. J. Song and T. Nagatsuma, "Handbook of Terahertz Technologies: Devices and Applications," *Pan Standford Pub*, Singapore, 2015.

[3] C. Jansen et al., "Diffuse scattering from rough surfaces in THz communication channels," in *IEEE Transactions on Terahertz Science and Technology*, vol. 1, no. 2, pp. 462–472, Jun. 2011.

[4] J. Ma et al., "Channel performance for indoor and outdoor terahertz wireless links," *APL Photonics*, vol. 3, no. 5, pp. 1–12, Feb. 2018.

[5] F. Sheikh, M. El-Hadidy, and T. Kaiser, "Terahertz Band: Indoor ray-tracing channel model considering atmospheric attenuation," *IEEE AP-S/URSI*, pp. 1782–1783, Jul. 2015.

[6] F. Sheikh, D. Lessy, and T. Kaiser, "A novel ray-tracing algorithm for non-specular diffuse scattered rays at terahertz frequencies," *in 2018 First International Workshop on Mobile Terahertz Systems (IWMTS)*, pp. 1–6, Jul. 2018.

[7] P. Beckmann and A. Spizzichino, "The Scattering of Electromagnetic Waves from Rough Surfaces," *Artech House Radar Library*, USA, 1963.