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Channel Bounding modeling for THz Communication

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Summary

This paper presents a statistical channel bounding model based on the ray tracing model for the THz frequency. The proposed model investigates the sub-channel bandwidth limitation for indoor and outdoor scenarios based on the delay spread function.

1. Introduction

The THz frequency bands are promising for addressing spectrum and capacity limitations in wireless systems and enabling new applications. However, THz communication systems still face challenges, such as limited transmitter output power and higher noise levels in received signals. As a result, THz communication systems are primarily suited for short distances and/or high-gain antennas. The literature discusses the requirements and challenges for designing and analyzing THz channels for various scenarios and applications. In THz communication, a multi-channel system with high spectral efficiency is the best way to achieve high data rates due to power limitations and fast/deep fading. Accurate analysis of the channel's delay spread function is essential for implementing a multi-channel system, as it determines important system-level parameters. The delay spread function depends on various factors, including link distances, antenna gain, operating frequency, and transmitter/receiver location. Channel modeling is considered in different research works [1,2], but the limited sub-channel bandwidth and efficient strategy to bounding the multi-channel together is less considered in the literature. So, this paper presents a channel bounding model for use in the THz frequency, where it can determine the bandwidth of each sub-channel based on the simulated coherence bandwidth. The proposed model and simulation results are provided for indoor and outdoor THz communication with 140GHz center frequency and 10% fractional overall bandwidth.

2. Channel Model

The channel model uses ray-tracing techniques to create a multi-ray channel model for THz communication. These techniques trace the propagation of different propagating rays, including line-of-sight (LOS), reflected, diffracted, and diffusely scattered waves [3,4]. Despite the small wavelengths of THz bands, ray-tracing techniques allow for precise simulation. The resulting channel model includes a combination of LOS, reflection, diffraction, and scattering as follows:

$$h_i(\tau) = \alpha_{LoS}^{(i)}\delta(\tau - \tau_{LoS}) + \sum_{R=1}^{N_{\mathrm{Re}}^{(i)}} \alpha_{\mathrm{Re}}^{(i,R)}\delta(\tau - \tau_{\mathrm{Re}}^{(R)}) + \sum_{S=1}^{N_{sc}^{(i)}} \alpha_{sc}^{(i,S)}\delta(\tau - \tau_{sc}^{(S)}) + \sum_{D=1}^{N_{Dif}^{(i)}} \alpha_{Dif}^{(i,D)}\delta(\tau - \tau_{Dif}^{(D)}) \quad (1)$$

Where the $\left[\alpha_{LoS}^{(i)}, \alpha_{\mathrm{Re}}^{(i,R)}, \alpha_{sc}^{(i,S)}, \alpha_{Dif}^{(i,D)}\right], \left[\tau_{LoS}, \tau_{\mathrm{Re}}^{(R)}, \tau_{sc}^{(S)}, \tau_{Dif}^{(D)}\right], \left[1.N_{\mathrm{Re}}^{(i)}, N_{sc}^{(i)}, N_{Dif}^{(i)}\right]$ are the attenuation, delay, and number of rays for the LOS, reflected, scattered, and diffracted rays.

3. Performance Analysis

The delay spread function, which determines key parameters such as the minimum channel number, lowest symbol rate, and coherence bandwidth, is critical for accurately modeling a multi-channel system. Its evaluation depends on several factors, such as distance, frequency, location, and antenna gains. The statistical measure of the channel temporal dispersion, as determined by the root means square of delay spread (RMS-DS), can be numerically simulated using Eq (1). To ensure the validity of the model's results, it is important to investigate a wide range of different transmitter and receiver configurations. Thus, for each indoor and outdoor scenario (office, street canyon), 1000 random link distances are considered. Comparing the RMS-DS for different scenarios leads to finding the probability of each value RMS-DS and coherence bandwidth. The coherence bandwidth is equal to 0.1/RM, and if we consider the highest value of RMS-DS as a criterion for system design, the lowest coherence bandwidth and lowest sub-channel bandwidth can be determined. Considering the channel bounding strategy and bounding two adjacent channels with a guard band is described in Fig. 1, where the definition and relation between different terms are mentioned.

4. Results

The simulated value for the cumulative distribution function of RMS-DS for the indoor and outdoor scenarios is presented in Fig.2. The operating frequency is 140GHz, and the FOBW is 0.1 for all simulations. The number of sub-channels equals 24 and 8 for indoor and outdoor scenarios. It can be concluded that the multi-path effect for a directive link in the THz frequency depends on the indoor and outdoor conditions. For instance, a multiple narrow band sub-channel with around 0.41% FSBW is required to overcome multipath fading for the indoor scenario. At the same time, for the outdoor conditions, FSBW is about 1.25% works as well.

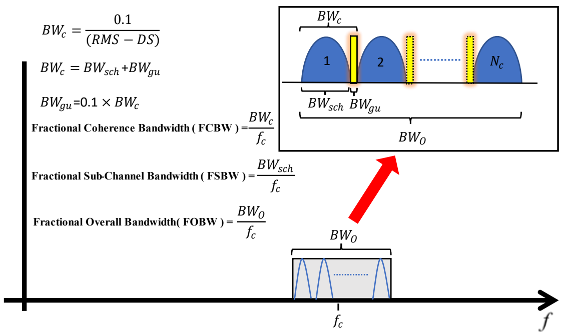

Figure 1. Channel bounding strategy for Multi-channel THz communication

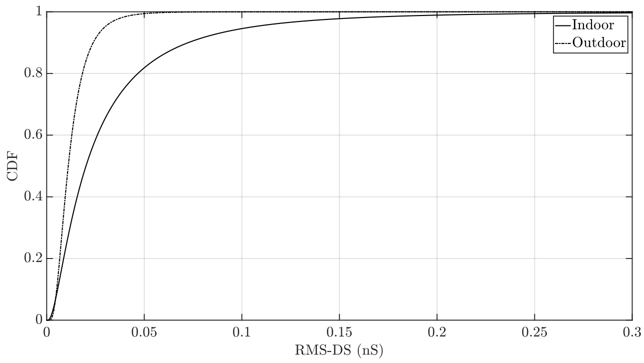

Figure 2. CDF of RMS DS for different link conditions, with 140GHz center frequency and 10% FOBW

5. Conclusion

This paper has developed a theoretical model for indoor and outdoor THz communication coherence bandwidth channel bounding limitation, considering LOS, multi-path reflections, scattering, and diffraction. The model has been evaluated for directive antenna configurations, 140GHz operation-frequency bands, and a large range of indoor and outdoor transmitter/receiver positions and link distances. The numerical results show the RMS-DS and, thus, the recommended sub-channel bandwidth for optimum channel bounding strategy. The findings in this paper are influential for system-level design when designing multi-channel THz communication systems.

References

[1]. C. Han, A. O. Bicen and I. F. Akyildiz," Multi-Ray Channel Modeling and Wideband Characterization for Wireless Communications in the Terahertz Band," in IEEE Transactions on Wireless Communications, vol. 14, no. 5, pp. 2402-2412, May 2015.

[2]. Y. Xing and T. S. Rappaport," Millimeter Wave and Terahertz Urban Microcell Propagation Measurements and Models," in IEEE Communications Letters, vol. 25, no. 12, pp. 3755-3759, Dec. 2021.

[3]. R. Piesiewicz, C. Jansen, D. Mittleman, T. Kleine-Ostmann, M. Koch and T. Kurner," Scattering Analysis for the Modeling of THz Communication Systems," in IEEE Transactions on Antennas and Propagation, vol. 55, no. 11, pp. 3002-3009, Nov. 2007.

[4]. M. Jacob, S. Priebe, R. Dickhoff, T. Kleine-Ostmann, T. Schrader and T. Kurner," Diffraction in mm and Sub-mm Wave Indoor Propagation Channels," in IEEE Transactions on Microwave Theory and Techniques, vol. 60, no. 3, pp. 833-844, March 2012.