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Investigating Correlation of Rough Surface Diffuse Scattering in Frequency Domain

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***Abstract*—This paper investigates numerically the correlation function in the frequency domain due to diffuse scattering originated from rough surfaces. The scattered fields are computed by means of physical optics methods. The irregularities of the rough surface are modeled as a correlated Gaussian process. The correlation of the channel transfer function comprising only diffuse scattering components is analyzed. In the analysis, radio propagation channels comprising orthogonally oriented dipoles at the link ends are considered while assuming different Gaussian roughness profiles. This study offers a useful characterization of the channel behavior in a multipath-rich environment due to diffuse scattering. The presented results are of particular interest to wireless systems based on orthogonal frequency-division multiplexing.**

***Index Terms*—radio propagation, physical optics, diffuse scattering**

I. Introduction

The study of radio wave propagation provides the physical fundamentals for channel modeling, which in turn offers guidance on system design. Diffuse scattering (DS) is one of the fundamental propagation mechanisms that dictate the behavior of radio channels in indoor and outdoor scenarios. The DS we consider in this study is caused by macroscopically rough surfaces and can significantly contribute to the receive power [1], [2]. In wideband wireless systems, the frequency selective properties of radio channel need to be investigated so that wireless systems can be designed accordingly. The accurate prediction of frequency domain correlation due to DS may impact the prediction of the coherence bandwidth of the whole radio channel, particularly in a DS-rich environment.

The DS is usually considered as a non-correlated random process over the spatial, the temporal and the frequency domains. In [3]–[6], different studies show that assigning correlated phases to rough surface tiles according to the spatial variations of link terminals [3], [4], or assigning constant phases to tile fields in wide sense stationary region [5], [6], leads to a better prediction of the spatial channel properties. Those have displayed the DS correlation in spatial or temporal domains. However, the frequency domain coherence of DS has not yet been investigated, to the best of the authors' knowledge.

The objective of this paper is to fill the gap and explores the DS correlation over frequency domain by using simulation approach. To simulate the DS component of channel originated from rough surface, the physical optics approach is applied. The irregularities of surface roughness can be acquired deterministically by point cloud data [7] obtained from laser scanning where diverse types of roughness can be recorded from real environments, and can also be described stochastically by a roughness profile extracted from macroscopically irregularity measurements. With the information of surface roughness, macroscopic electromagnetic parameters, as well as link terminals, the radio channel due to the DS component is computed and investigated in frequency domain.

The rest of this paper is organized as follows. Section II introduces the simulation methodology, Section III investigates the DS correlation in frequency domain numerically, and Section IV summaries this paper.

II. Simulation Methodology

The PO is an approximation can be used to determine surface currents. When dealing with a rough surface, it is divided into meshes that are small enough compared to the wavelength and each mesh is considered as locally planar where reflection occurs according to geometrical optics [8],

[9]. Instead of using Maxwell's equations that gives us the solution at any point in space, PO approach is used where it only gives solution in the lit region. The lit region is the region that is illuminated by the waves impinging on the surface. It is in this region where we look for the diffuse scattered waves. The advantage of using PO is that it has wide applicability for differently shaped scatters, and it costs less computation time when compared with other rigorous numerical approaches for which the induced currents are determined by a large set of linear equation hence may be extremely time-consuming. PO gives a good approximation of the electromagnetic field when applying to high frequency and low curvature scenarios. A high frequency approximation method indicates that the surface of an object is much larger than the wavelength of the impinging wave.

Originally, PO was developed for analyzing scattering from a perfect electric conductor (PEC) material, but the concept of approximating currents is quite general and applicable for magnetic conductors, dielectric materials, and bodies with surface impedance, etc. The major source of errors in the PO method is at the edge of surface, or when the surface curvature of surface is large and multiple reflections exists. In this study, a triangular mesh is applied to the rough surface, and the edge effects are neglected. The PO-based computation algorithm used in this paper is the same as the one presented in [4] and therefore omitted here. The surface roughness profiles of the correlated Gaussian process, including the rms height and the correlation length, are used to describe the macroscopic irregularity of the surface of a scatterer. The rms height is used to determine whether a surface is rough or not, according to Rayleigh criterion [10].

III. DS Correlation in Frequency Domain

The simulation scenario is shown in Fig. 1. The considered frequencies range from $f_{\min} = 4.2$ GHz to $f_{\max} = 4.71$ GHz. The corresponding maximum and minimum wavelengths are $\lambda_{\max} = \frac{c}{f_{\min}}$ and $\lambda_{\min} = \frac{c}{f_{\max}}$, respectively, where c is the speed of light. The antennas at the link ends are the collocated orthogonal incremental dipoles (same phase center), i.e. one x-polarized and one z-polarized dipoles both with length of $\frac{\lambda_{\max}}{2}$. The positions of transmit (Tx) and receive (Rx) antennas are fixed and set to $[x, y, z] = [0, 1.5, 0]$ and $[0.65, 0.65, 0.75]$, respectively. The rough surface has dimension 20×20 m^2 laying on the xz-plane. The center of the scattering surface plate coincides with the coordinate origin of the scattering geometry. We assume that the scattering surface models a brick wall with permittivity (4.44), permeability (1.0) and conductivity (0.01) across the target frequencies [4]. This assumption is reasonable since the frequency span considered here is not so large. Different roughness profiles, as is shown in Table I, are applied to investigate the diffuse scattering correlation in frequency domain. The PO simulation employs a the mesh size of 0.005 m, which is less than $\frac{1}{10}\lambda_{\min}$. Note that the antennas are in the near-field of the rough surface but in the far-field of each mesh.

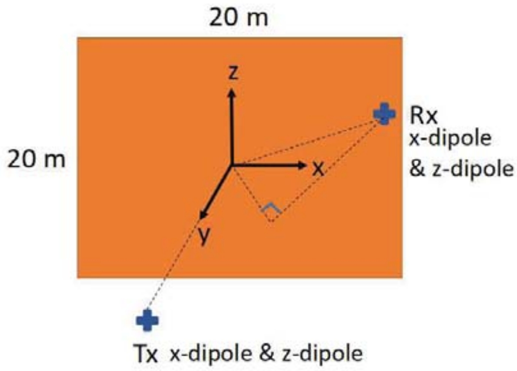

Fig. 1. Simulation scenario

TABLE I
Simulation parameters

Index	Rms height	Correlation length
1	$0.41\lambda_{\min} = 2.6$ cm	
2	$0.62\lambda_{\min} = 3.9$ cm	$6.61\lambda_{\min} = 42.1$ cm
3	$0.83\lambda_{\min} = 5.3$ cm	
4	$0.62\lambda_{\min} = 3.9$ cm	$4.96\lambda_{\min} = 31.6$ cm
5	$0.62\lambda_{\min} = 3.9$ cm	$8.26\lambda_{\min} = 52.6$ cm

From PO simulations, the channel transfer function (CTF) $\boldsymbol{H}_{\mathrm{DS}}^{n} \in \mathbb{C}^{2\times 2}$ is obtained for the n-th frequency point. A series of DS CTF matrices along all frequency points can be acquired. The diffuse scattering correlation in frequency domain is computed between one series and the same series lagged by one or more frequency units. For the m-th order autocorrelation, the lag is m frequency unit. The m-th order autocorrelation coefficient of the DS CTF is the correlation coefficient of the first $N_f - m$ observations $\boldsymbol{H}_{\mathrm{DS}}^{1:N_f-m}$ and the last $N_f - m$ observations $\boldsymbol{H}_{\mathrm{DS}}^{N_f-m+1:N_f}$, i.e.

$$\boldsymbol{\rho}_m = \frac{\sum_{n=1}^{N_f-m} \boldsymbol{H}_{\mathrm{DS}}^{n} \boldsymbol{H}_{\mathrm{DS}}^{n+m\,H}}{\sum_{n=1}^{N_f} \boldsymbol{H}_{\mathrm{DS}}^{n} \boldsymbol{H}_{\mathrm{DS}}^{n\,H}}. \tag{1}$$

The coherence bandwidth is defined as two times the frequency at which the correlation is decreased to a certain level from the maximum, e.g. $\frac{1}{e}$ [11], 0.5, 0.7, and 0.9 are commonly used [12].

Examples of results are shown in Fig. 2 where each roughness profile is generated once and the resulting DS correlations are compared. Following observations can be made.

- With the increase of rms height of the Gaussian process, the surface becomes rougher, the coherence bandwidth decreases.
- With the decrease of correlation length of the Gaussian process, the coherence bandwidth decreases.
- The coherence bandwidth of co-polarized channels connecting the z-polarized Tx and the z-polarized Rx is smaller than that connecting the x-polarized Tx and x-polarized Rx.
- Last but not the least, the coherence bandwidth of diffuse scattering component of the radio propagation channel can not be neglected.

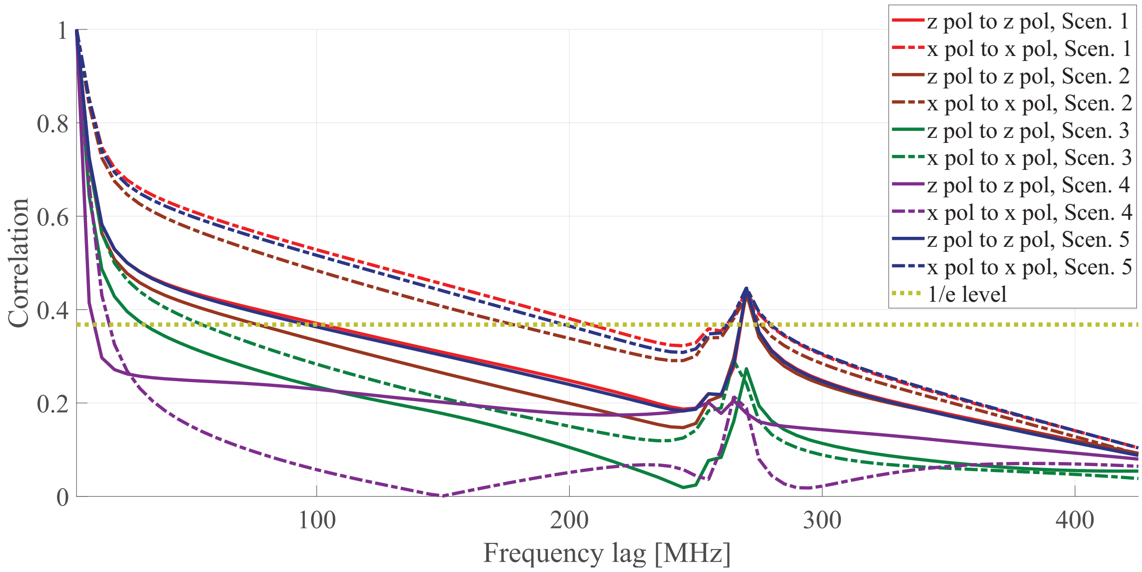

Fig. 2. DS correlation examples with different roughness profiles

IV. Summary

This paper presents the correlation of rough surface diffuse scattering component of the radio channel in frequency domain, based on the physical optics approximation. The coherence bandwidths of the diffuse scattering channel transfer functions were compared when fixed transmit and receive antennas with two orthogonal polarizations stand in front of a surface with different roughness profiles of correlated Gaussian processes. The coherence bandwidth is found to decrease with the increase of the rms height and with the decrease of the correlation length. In addition, the coherence bandwidth is found to be different for different polarization pairs.

In future study, the deterministic surface roughness featured by point cloud data for different materials at different frequency bands will be investigated.

References

[1] J. Poutanen, J. Salmi, K. Haneda, V. Kolmonen, and P. Vainikainen, "Angular and Shadowing Characteristics of Dense Multipath Components in Indoor Radio Channels," *IEEE Trans. Antennas Propag.*, vol. 59, no. 1, pp. 245253, Jan. 2011.

[2] E. Tanghe, D.P. Gaillot, M. Lienard, L. Martens, and W. Joseph, "Experimental Analysis of Dense Multipath Components in an Industrial Environment," *IEEE Trans. Antennas Propag.*, vol. 62, no. 7, pp. 37973805, Jul. 2014.

[3] Y. Miao, Q. Gueuning, M. Gan, C. Oestges, "Adding Diffuse Scattering Correlation to Effective Roughness Models in Ray Tracing," in *Proc. 2017 11th European Conference on Antennas and Propagation (EuCAP),* Paris, France, Mar. 2017.

[4] Y. Miao, Q. Gueuning, C. Oestges, "Modeling the Phase Correlation of Effective Diffuse Scattering from Surfaces for Radio Propagation Prediction with Antennas at Refined Separation," *IEEE Trans. Antennas Propag.*, vol. 66, no. 3, Mar. 2018.

[5] M. Gan, "Accurate and Low-Complexity Ray Tracing Channel Modeling," *M.S. thesis*, Technische Univ. Wien, Vienna, Austria, Nov. 2015.

[6] M. Gan, F. Mani, F. Kaltenberger, C. Oestges, and T. Zemen, "A Ray Tracing Algorithm Using the Discrete Prolate Spheroidal Subspace," in *Proc. IEEE Int. Conf. Commun. (ICC)*, Budapest, Hungary, Jun. 2013, pp. 57105714.

[7] J. Jarvelainen, "Measurement-based Millimeter-Wave Radio Channel Simulations and Modeling," *Aalto University publication series Doctoral Dissertations,* no. 164, 2016.

[8] M. Ando, *Physical Optics*, in E. Yamashita (Eds.), Analysis Methods for Electromagnetic Wave Problems, Volume Two, Chap. 4, Artech House, Inc. Norwood, MA., 1996.

[9] N. Lertsirisopon, G.S. Ching, M. Ghoraishi, J. Takada, I. Ida, and Y. Oishi, "Investigation of Non-Specular Scattering by Comparing Directional Channel Characteristics for Microcell Measurement and Simulation," *IET Microwaves, Antenna and Propagation,* vol. 2, no. 8, pp. 913-921, Dec. 2008.

[10] J.A. Ogilvy, *Theory of Wave Scattering from Random Rough Surfaces,* Bristol, U.K.: IOP Pub., 1991.

[11] N. Jalden, P. Zetterberg, B. Ottersten, and L. Garcia, "Inter- and Intrasite Correlations of Large-Scale Parameters from Macrocellular Measurements at 1800 MHz," *EURASIP J. Wireless Commun. Netw.*, vol. 2007, no. 25757, Jul. 2007.

[12] R.J.C. Bultitude, "Estimating Frequency Correlation Functions from Propagation Measurements on Fading Radio Channels: A Critical Review," *IEEE Journal on Selected Areas in Communications,* vol. 20, no. 6, Aug. 2002.