ANALYSIS OF FLUCTUATIONS PHENOMENA IN COMPLEX MICROCELLULAR STRUCTURES

Reuven Mazar[(1)], Alexander Bronshtein[(1)], I-Tai Lu [(2)]

[(1)]*Department of Electrical and Computer Engineering, Ben Gurion University of the Negev, P.O.Box 653 Beer Sheva 84105, Israel, Email: mazar@ee.bgu.ac.il*

[(2)]*Department of Electrical Engineering and Computer Science, Polytechnic University, Route 110, Farmingdale, New York, NY 11735, U.S.A., Email: itailu@rama.poly.edu*

ABSTRACT

Modeling of wave propagation for modern radio links must take into account the fluctuations phenomena caused by random changes of medium parameters. There are two factors that cause signal arrival from transmitter to receiver via multiple random paths. The first is a result of scattering by boundaries and various obstacles, while the second is related to random changes in the refractive index of the medium. In this work the influence of both factors is demonstrated when the propagation takes place above a perfectly reflecting surface in presence of randomly fluctuating medium.

1. INTRODUCTION

Attempts to increase the capabilities of cellular mobile radio telephones and/or other local radio communication services, together with the expanding demands for more communication channels lead to increasing exploitation of higher and higher frequencies, extending well into the millimeter-wave regions of the spectrum. At such high frequencies, radio waves start to interact with the propagation environment, for example through absorption and dispersion by atmospheric gases, with scattering and absorption induced by the prevailing meteorological conditions, especially precipitation, and with the effects of fluctuations in the refractivity of the atmosphere. Random refractive index variations result in multipath arrival even for the line of sight links and can cause appreciable fluctuations of high-frequency signals. From the other side, planning of modern radio links must take into account the interaction of the propagating electromagnetic waves with the complexities prescribed by the medium. These include the topography in the vicinity of the propagation path, vegetation and structures of densely populated areas. As is well known, the presence of boundaries and various obstacles results to the signal arrival from transmitter to receiver via multiple paths. Therefore in addition to the signal arriving along a line-of-sight path, signals may also be received via one or more delayed paths as a result of reflection from the ground, hills, building walls, and/ or scattering by trees, merging traffic and other obstacles. This factors giving raise to additional multipath arrival can result in increased fading and fluctuations phenomena. Modeling of the propagation phenomena under complex wave - medium interactions exposes a challenge for the designers of the wireless-communication networks. The diversity of propagation structures and a great number of factors affecting the signal - medium interaction in complex propagation environments requires the application of methods developed in the theory of scattering and diffraction of deterministic fields combined with phenomena which can be described only by the statistical approach.

Determining the interaction of interfering electromagnetic waves with natural and artificial obstacles, involves taking into account of reflection, refraction and diffraction of radio waves from straight and curved edges, scatter of EM waves from plane and curved surfaces of varying electromagnetic properties and scatter from irregularly shaped and oriented obstacles such as moving traffic, trees and vegetation areas. Quantitative foundations for the analysis of such problems have been established in the Stochastic Geometrical Theory of Diffraction (SGTD) [1] formulated for analyzing high-frequency wave phenomena in complicated random media. This theory is based on the localization of the high-frequency random fields and their statistical measures around the geometrical ray trajectories in the deterministic background medium and their consequent transport along these trajectories. The solution strategy of this work is based on the methods prescribed by the SGTD and is demonstrated when the propagation takes place above a flat reflective surface. In this situation the observer is accessible to two rays.

We assume that the average permeability of the medium is unity, and present its refractive index as

$$n(\boldsymbol{R}) = 1 + \tilde{n}(\boldsymbol{R}), \tag{1}$$

where $\tilde{n}(\boldsymbol{R})$ is the randomly fluctuating part. We consider propagation of a high-frequency radiation created by an isotropic infinitesimal source radiating TE wave over a perfectly reflecting flat surface (see Fig.1). The field observed at the observation point by an isotropic antenna is comprised then from two components:

$$U(\boldsymbol{R}) = U_1(\boldsymbol{R}) + U_2(\boldsymbol{R}), \tag{2}$$

where $U_1(\boldsymbol{R})$ represents the field arriving along a direct ray AO, while $U_2(\boldsymbol{R})$ represents the field arriving to the observation point via the ray ACO which undergoes a reflection from the flat surface (see Fig.1).

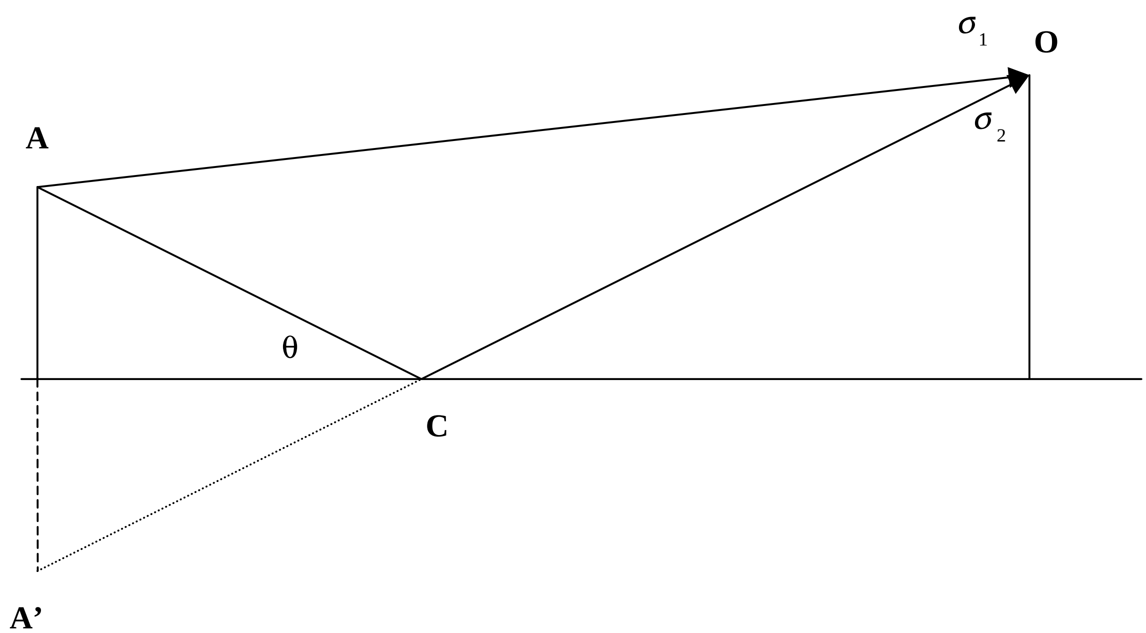

Fig.1

2. INTENSITY FLUCTUATIONS

First we assume a situation when the direct ray AO and the reflected ray ACO are well separated. This means that their spatial separation is much grater than the correlation scale of medium fluctuations, and also much greater than the Fresnel dimension of each ray. In such situations propagations along each of these rays can be considered as statistically independent. This assumption allows to replace the reflected ray ACO by a ray A’CO emanating from the image source at A’. Employing the parabolic extension along each separate ray, the propagating field can be presented in the following form: $U(\boldsymbol{r}_i, \sigma_i) = u(\boldsymbol{r}_i, \sigma_i) exp(ik\sigma_i)$, i=1,2, where each of the parabolic wave amplitudes $u(\boldsymbol{r}_i, \sigma_i)$ is a solution of a parabolic-type wave equation [1-3]. In the case of the above source-observer configuration, the power received by the isotropic antenna is proportional to the square of the absolute value of the field:

$$I(\boldsymbol{R}) = \left| u(\boldsymbol{r}_1, \sigma_1) exp(ik\sigma_1) + u(\boldsymbol{r}_2, \sigma_2) exp(ik\sigma_2) \right|^2 . \tag{3}$$

Averaging it, we obtain the average intensity at the receiving antenna:

$$< I(\boldsymbol{R}) > = < I(\boldsymbol{r}_1, \sigma_1) > + < I(\boldsymbol{r}_2, \sigma_2) >$$

$$+ < u(\boldsymbol{r}_1, \sigma_1) >< u^*(\boldsymbol{r}_2, \sigma_2) > exp(ik\Delta\sigma) + < u^*(\boldsymbol{r}_1, \sigma_1) >< u(\boldsymbol{r}_2, \sigma_2) > exp(-ik\Delta\sigma). \tag{4}$$

Because of the random refractive index fluctuations, the received power also will be a fluctuating function. Adopting the measures defined in the analysis of laser beam propagation, the behavior of such fluctuations can be derived from the normalized intensity variance or the intensity scintillation index defined as [2,3]:

$$\beta_I(\boldsymbol{R}) = \frac{< I^2(\boldsymbol{R}) > - < I(\boldsymbol{R}) >^2}{< I(\boldsymbol{R}) >^2} , \tag{5}$$

with

$$< I^2(\boldsymbol{R}) > = < I^2(\boldsymbol{r}_1, \sigma_1) > + < I^2(\boldsymbol{r}_2, \sigma_2) > + 4 < I(\boldsymbol{r}_1, \sigma_1) >< I(\boldsymbol{r}_1, \sigma_1) >$$

$$+ < u^2(\boldsymbol{r}_1, \sigma_1) >< u^{*2}(\boldsymbol{r}_2, \sigma_2) > exp(2ik\Delta\sigma) + < u^{*2}(\boldsymbol{r}_1, \sigma_1) >< u^2(\boldsymbol{r}_2, \sigma_2) > exp(-2ik\Delta\sigma)$$

$$+ 2 < I(\boldsymbol{r}_1, \sigma_1) u(\boldsymbol{r}_1, \sigma_1) >< u^*(\boldsymbol{r}_2, \sigma_2) > exp(ik\Delta\sigma) + 2 < I(\boldsymbol{r}_1, \sigma_1) u^*(\boldsymbol{r}_1, \sigma_1) >< u(\boldsymbol{r}_2, \sigma_2) > exp(-ik\Delta\sigma)$$

$$+ 2 < I(\boldsymbol{r}_2, \sigma_2) u(\boldsymbol{r}_2, \sigma_2) >< u^*(\boldsymbol{r}_1, \sigma_1) > exp(ik\Delta\sigma) + 2 < I(\boldsymbol{r}_2, \sigma_2) u^*(\boldsymbol{r}_2, \sigma_2) >< u(\boldsymbol{r}_1, \sigma_1) > exp(-ik\Delta\sigma), \tag{6}$$

Since the coherent cross-terms are rapidly decaying functions with range, in the saturation regime the scintillation index can be approximated as:

$$\beta_I^2(\boldsymbol{R}) = \frac{\beta_I^2(\boldsymbol{r}_1, \sigma_1) j_{12}^2 + \beta_I^2(\boldsymbol{r}_2, \sigma_2) + 2 j_{12}}{(1 + j_{12})^2} , \qquad j_{12} = \frac{< I(\boldsymbol{r}_1, \sigma_1) >}{< I(\boldsymbol{r}_2, \sigma_2))} . \tag{7}$$

When the source is located close to the surface, the direct and the reflected rays traverse the same random inhomogeneities, and cannot be treated separately. In this case, we consider a dipole source:

$$u(\boldsymbol{r}, \sigma_0) = [\delta(x - a) exp(-ik\chi) - \delta(x + a) exp(ik\chi)] \delta(y), \tag{8}$$

with $AS = A'S = h$, $BS = B'S = a = h\cos\vartheta$, and $AB = A'B = \chi = h\sin\vartheta$. The propagation takes place along a single ray connecting the center S of the dipole with the observer at O, (see Fig.2).

The intensity fluctuations measures can be computed using the above source condition and the solutions for the high-frequency propagators derived in the SGTD [4].

The above procedure can be extended to more complicated structures where the field at the observer is a superposition of the species arriving along multiple ray trajectories. As example we mention propagation along a city street which can be approximated as a plane-parallel multislit waveguide [5].

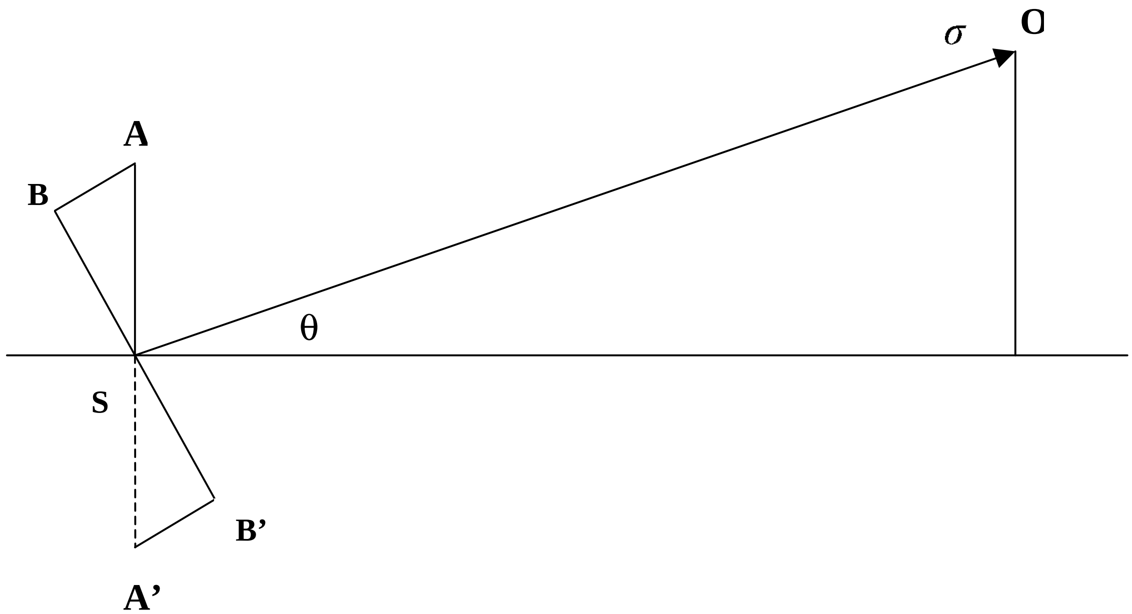

Fig.2

ACKNOWLEDGEMENT

This research was supported by The Israel Science Foundation founded by the Israel Academy of Sciences and Humanities.

REFERENCES

[1] R. Mazar and L. B. Felsen, "Stochastic geometrical theory of diffraction.", J. Acoust. Soc. Am., **86**(6), pp.2292-2308, (1989).

[2] A. Ishimaru, *Wave Propagation and Scattering in Random Media*, vols. 1 and 2, (Academic Press, New York 1978).

[3] S. M. Rytov, Y. A. Kravtsov, and V. I. Tatarskii, *Introduction to Statistical Radiophysics*, vols. 3, 4, (Springer Series in Electrophysics, Springer, 1988).

[4] R.Mazar and A.Bronshtein, "Multiscale solutions for the high-frequency propagators ininhomogeneous background random medium", J. Acoust. Soc. Am., **91**, pp.802-812 (1992).

[5] R. Mazar, A. Bronshtein, and I-Tai Lu, "Theoretical analysis of UHF propagation in a city street modeled as a random multislit waveguide", IEEE Trans. **AP-46**(6), 864-871, (1998).