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Determination of scattering center of multipath signals using geometric optics and Fresnel zone concepts

Kamil Yavuz Kapusuz, Ali Kara*

Department of Electrical and Electronics Engineering, Atilim University, Ankara 06836, Turkey

A R T I C L E I N F O

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In this study, a method for determining scattering center (or center of scattering points) of a multipath is proposed, provided that the direction of arrival of the multipath is known by the receiver. The method is based on classical electromagnetic wave principles in order to determine scattering center over irregular terrain. Geometrical optics (GO) along with Fresnel zone concept is employed, as the receiver, the transmitter positions and irregular terrain data are assumed to be provided. The proposed method could be used at UHF bands, especially, operations of radars and electronic warfare applications.

1. Introduction

The first studies on the understanding of physical wave propagation in urban areas started in the middle of 1980s. Generally, physical models of radio wave propagation are proposed to study effects of buildings in residential areas on wireless communication systems. Later on, these applications are extended to cover irregular terrains for the path loss prediction in different applications. Moreover, understanding of electromagnetic wave propagation in three-dimensional realistic environment is needed from the communication systems' design [1]. However, usage of the three-dimensional realistic environment may require much more computational complexity. Therefore, in order to simplify these realistic models techniques on equivalent two dimensional models of environments have been used. In literature, many methods such as analytic, numerical and asymptotic are presented.

For studying radio channels, analytic solutions can be based on ray approaches, mode approaches or wide band approaches. Besides, numerical methods provide high accuracy in wave propagation problems for complex geometries and different material properties; nonetheless, long computation times can be required [2] to solve these problems. Electrical length could be an important metric in choosing the most appropriate method and scales. According to the electrical length of the terrain, different methods can be applied to minimize computation time, or even to scale the problem. If the electrical length of the terrain is not large, numerical methods can be used to get accurate results with short computational times (for example studying short range indoor links at some unlicensed bands). Moreover, numerical methods can be essentially based on either frequency domain or time domain methods [1]. Parabolic Equation (PE) and Method of Moments (MoMs) can be given as examples of the frequency domain methods. PE as in Ref. [1] is employed as it is the most attractive ground wave propagator because of its robustness, low memory requirements and fast execution. MoM as in Ref. [1] is again discussed to understand the ground wave propagation and modeling of scattering from terrains. On the other hand, Transmission Line Matrix (TLM) and Finite-Difference Time Domain (FDTD) methods are the Time-Domain (TD) solution methods. In addition, these studies are based on the sliding window approach, and they are capable of handling atmospheric refractivity and irregular terrain effects as well as boundary conditions [1]. However, they can be applicable for short ranges, and they may not be appropriate owing to environment and wavelength dimensions since these methods need much more computational time. In literature, in order to obtain greater performance and higher accuracy at sufficiently high frequencies, asymptotic techniques have been proposed. The oldest as wells as simplest asymptotic method is Geometric Optics (GO) [3,4]. GO implies that ray travels toward a straight line as a path and it did not includes some scattering mechanisms; therefore, it is not valid everywhere [5]. GO is not applicable in two types of transition

* Corresponding author.
E-mail address: akara@atilim.edu.tr (A. Kara).
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regions: surfaces of irradiated bodies and free space far from the bodies, say near caustic [3]. In literature in order to reduce these limitations, its expansion form is proposed by Keller [4], Geometrical Theory of Diffraction (GTD). However, Keller's GTD has still some discontinuities; therefore in order to reduce this discontinuities, by Kouyoumjian and Pathak [5] GTD's expansion form, Uniform Theory of Diffraction (UTD), is proposed. In literature in order to understand effectiveness of UTD many studies are presented [6]. Therefore, Incremental Theory of Diffraction is recommended by Tiberio [7] to remove singularities close to and at caustics in the UTD formulation. Moreover, ITD experimentally proved by Erricolo et. al. [8].

To achieve greater accuracy with minimum computational time at sufficiently high frequencies for electrically large problems, GTD/UTD may be more appropriate. GTD/UTD have widely been applied to predict the path loss for urban and suburban areas in Refs. [9,10]. With some constraints, numerical methods may also be studied to predict the path loss. However, it has been shown that GTD and/or its variants [11] provides efficient and time effective results compared with the other methods in literature. Specifically, in some path prediction problems; however, GTD could not work well when number of the obstacles between transmitter and receiver are greater, or the obstacle is in the transition region [11]; otherwise it works accurately. As GTD is an extension to GO, it requires much more computation time and more parameters when compared with the GO, and this may make it inappropriate in some applications. Therefore, in order to reduce the computational time and burden, GO is preferred in this study although it does not include scattering mechanisms. On the other hand, GO can be applied in practice, if the link between transmitter and receiver is clear. However, the problem at hand may not be simple free space link as there may be many obstructions in and over the link. As the objective of the study is not to predict the path loss GO along with Fresnel Zone concept can be employed in order to obtain simple but accurate results. Fresnel zones concept is necessary in this study as electromagnetic energy radiates in ellipsoid that is concentrically ellipsoids of revolution about the direct line from a transmitter to a receiving point, with the transmitter and receiving points serving as foci of the ellipse [12].

In this work, a simple method is proposed to determine the scattering center of a multipath with a given angle of arrival (AoA) for known receiver and transmitter positions. Geometry of terrain and positions of transmitter and receiver are crucial for determining the scattering center. While applying the method in order to obtain accurate results with minimum computation time, profile reconstruction method presented in literature is employed. The second named author has already published extensively on the use of GTD/UTD and diffraction effects in various several propagation path loss problems [6,9,10]. As justified above, in order to obtain a more realistic but simple result, GO with Fresnel Zone concept is preferred in this study. The proposed method can be applied to any other problem where scattering center of signal path over irregular terrain is required. One of the free tools providing digital terrain data is used for a sample terrain. Digital terrain data is divided into cells (square), and altitude of the terrain at a particular cell is assigned center of the cell. Then for given positions of transmitter and receiver, terrain profile is reconstructed. Then, GO and Fresnel Zones concept are employed to search possible scattering points starting with the highest points on the terrain. Then, scattering points are used to determine the center of the multipath, or scattering center of the multipath.

2. Problem description

In wireless communication, the signal offered to the receiver includes both a direct line-of-sight radio wave and a large number of scattering waves, and this phenomenon is called multipath propagation [12]. Scattering mechanisms may include reflection, diffraction and diffuse scattering [13]. Reflection occurs when wavelength is much smaller than obstruction with dimensions. Besides, when radio path is obstructed by an impenetrable body, diffraction is observed and this mechanism explains how propagating electromagnetic energy can travels in irregular terrain without line-of-sight path. In addition scattering has the same physical principle of diffraction and it is observed when the dimension of the obstruction is smaller than the wavelength [13]. The scattering may typically occur due to objects in the terrain or sea. In sea, for example, islands may consist of mountains, forested areas, urban areas, and grassy lands. The energy, radiated from the transmitter or any source, can be reflected more than one point on the irregular terrain according to GO, and then many reflection points over the terrain are observed from the receiver part. Therefore, according to multiple reflection points, a scattering center of multipath signal that represents the center of reflection points can be attributed. Relationships between scattering center or multiple reflection (or scattering) points versus transmitter and receiver points are investigated in this study.

Geometry of the problem is illustrated in Fig. 1. In the figure; T_x and R_x represent the transmitter and the receiver positions, respectively, and it is assumed that the positions of the transmitter and receiver are known (Actually, the problem is a simplified version of the case where only the receiver position is known). Moreover, it is assumed that the transmitting antenna is a radar type antenna, rotating in horizontal plane with its narrow beamwidth in azimuth. The receiver is able to measure the direction of arrival (or angle of arrival-AOA) of both direct path to the receiver, and a dominant multipath from the terrain as illustrated in Fig. 1 (a sample of two reflected rays are indicated in here). However, it is assumed that measured AOA of each path may have error, and this is illustrated, in Fig. 1, by an area over the terrain where the multipath scattering center would be found. In radar and electronic warfare applications, a typical error could be between 0.5° and 3° [14]. Then, the area including the terrain would widen as the distance from the transmitter increases as illustrated in Fig. 1. However, it is also dependent on the distance to the transmitter and the beamwidth of the transmitting antenna. Greater the beamwidth and larger the distance to the transmitter, the greater the distance to the multipath scattering

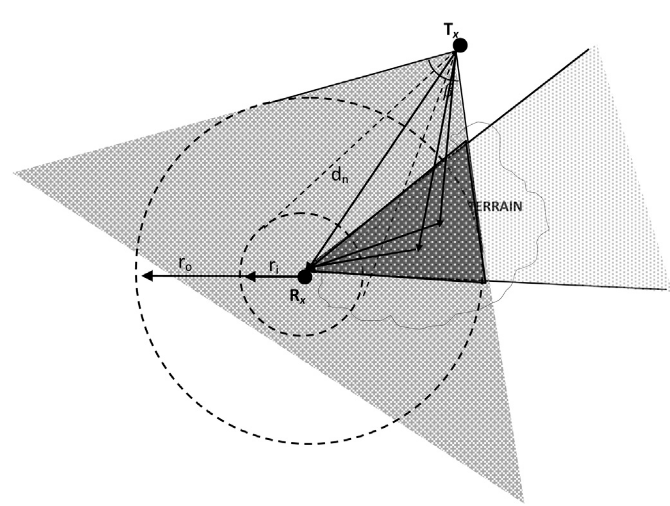

Fig. 1. Problem geometry.