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

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ABSTRACT

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

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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

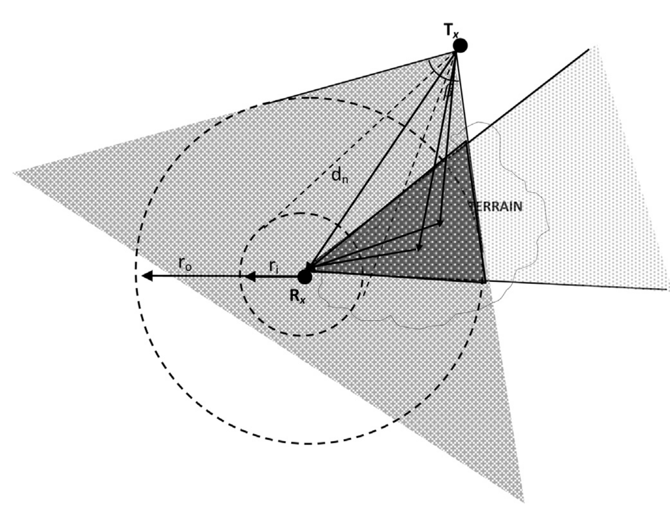


Fig. 1. Problem geometry.

center from the receiver is obtained, and larger the region in which the scattering center is searched.

Based on the description of the problem on Fig. 1, the position of the transmitter and the receiver can be represented (x_t, y_t, z_t) and(x_r, y_r, z_r), respectively. The distance between the transmitter and the receiver is denoted byd_n (it is much greater than the radius of the circles in practice). As can be seen from the figure, some part of the terrain, and the receiver has a line of sight to the transmitter; hence, both direct and multipath scattered signals arrive at the receiver. As it is a pulsed system considered, the multipath signals arrives right after the direct signal, and this places a constraint on the minimum distance for the scattering center of the multipath signal. Then, two circles can be considered in searching the scattering center. The calculation of the outer circle radius, r_o, is related to the distance between the transmitter and the receiver along with the transmitter antenna beamwidth. On the other hand, inner circle radius, r_i, is related to the pulse width of the radar system (non-overlapping pulses condition is met). In order to detect the multipath signals, pulse width of the radar system is smaller and equal to the time difference of arrival measured in between the multipath signal and the direct signal.

Henceforth, as shown in figure and region of limitations, scattering points or center can be determined, as follows, by using GO and Fresnel Zone concept. The scattering center of the multipath should be sought over the area where both the beam of the transmitter illuminates and multipath arrives from (widened area). This could be illustrated by a triangular area as shown in Fig. 1. Furthermore, there may be some other parameters (pulse width, operating frequency etc.) in practical scenarios, that might be important for determining the scattering center of the multipath. Furthermore, digital terrain data has to be considered to have information about terrain profile. In order to employ GO and Fresnel zone concept, 3D digital terrain data is required. However, as mentioned before 3D terrain is not appropriate to minimize the computation time for this problem; therefore, 2D digital terrain profile is reconstructed from 3D using Durkin's model [15]. It is likely that the reflection points, whose number and composition will determine the scattering center, could be the highest points over the terrain according to GO (ray propagation over homogenous media). The model is then applied to all terrain profiles, between the transmitter to the highest points on the terrain and the same highest points to the receiver. It is a searching process of the reflection/scattering points by considering the Fresnel zones on vertical cross sections from different angles on the terrain. This process may start from the highest point with which the transmitter and the receiver intersects over the terrain, and continues until all points are completed.

3. Background and proposed method

3.1. Geometric optics (GO)

In order to solve the problem at sufficiently high frequencies, high frequency asymptotic techniques such as geometric optic (GO), geometrical theory of diffraction (GTD) and Uniform Theory of Diffraction (UTD) can be applied [3]. In literature, GO is the simplest and the basic high frequency technique [4], and its applicability is based on ray-tracing. The ray in GO is an abstraction which can be used to approximately model how wave propagates (incorporated from optical energy propagation). Rays are defined to propagate a rectilinear path as far as they travel in homogenous medium. However, it provides some limitations that are dependent on the frequency and the media in which they travel.

Although GO is the simplest yet oldest techniques that has been used in radio propagation, it fails when diffraction parameters are taken into account. However, diffraction parameter is critical when the signal power at the receiving point is predicted, and it is not the case here. In this study, therefore, the proposed method uses the fact that electromagnetic energy propagation can be modeled as GO rays, and then Fresnel concept, described in the following, can be employed over propagation links whether any significant disturbance due to objects over and around the link exists or not.

3.2. Fresnel zones

Fresnel zones concept has been widely used in radio wave propagation. It is used to calculate propagation losses due to diffraction and reflection, between transmitter and receiver [12]. In theory, infinite number of Fresnel zones can be generated; however, in practice first three Fresnel zones may represent adequately the effects of objects in radio wave propagation. As shown in Fig. 2, Fresnel zones are homocentric 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.

The radius of the nth Fresnel zone circle at a distance d_k that is represented as F_n. On the other hand, F_n can be a way of thinking on a cross section radius of the ellipsoid at distance d_k. Distance between transmitter and receiver is denoted as d. Then, d_k and $d - d_k$ are distance from receiver to point and point to transmitter, respectively.

In Fresnel zone concept, highest radius of the Fresnel zone circle can be observed at the midpoint between transmitter and receiver, $d_k = d/2$. It follows that, when the point d_k is close to the transmitter

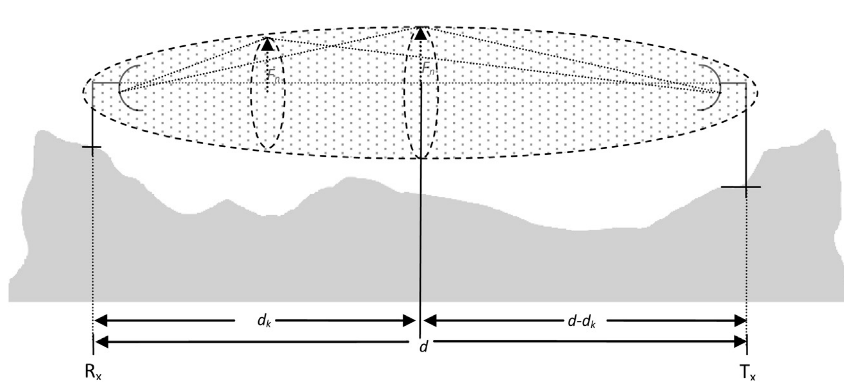


Fig. 2. Fresnel zone of the transmitted signal.

or receiver, radius of the Fresnel zone decreases, and the density of the electromagnetic wave increases proportionally. In addition, radius of the Fresnel zone at a distance d_k can be calculated as

$$F_n = \sqrt{\frac{n\lambda d_k(d-d_k)}{d}}$$

where λ is the wavelength and n is the number of the Fresnel zone. Radius of Fresnel zone is dependent on the wavelength and distance between transmitter and receiver. When operational wavelength is decreased, the radius of the Fresnel zone decreases accordingly.

When there are objects in the Fresnel zones, received signal cannot be differentiated as to be direct or reflected/indirect due to scattering effects. The signal variation at the receiving point is dependent on the phases of direct and scattered fields, as total signal level consists of not only the direct signal component but also the reflected or scattered signal components from the objects in the Fresnel Zones. Material and geometrical properties of these objects are critical. Then, Fresnel Zone concept provides a way of estimation how these objects may cause path loss for a particular link and terrain profile. However, this study looks at Fresnel Zones only for making sure that the path is clear, and then the point may be candidate in determining the scattering center.

3.3. Profile reconstructions

In order to obtain digital terrain data, maps are obtained from some free tools. Terrain data has been obtained manually from the tool for a particular region. While collecting this data imaginary cells are generated on the maps of the tool and position of the each cell is recorded. Then, a 3D terrain has been recreated from the recorded data using a software package, and then the receiver and the transmitter have been placed on the 3D terrain data for a particular scenario. Afterward, as mentioned before in order to reduce the computational complexity in Fresnel zone clearance calculations, 2D data is reconstructed from the 3D as in Durkin's Model [15]. The following sections describe how these 2D reconstructions were implemented in this study.

Considering the positions of the transmitter and receiver, radial line has been drawn as shown in Fig. 3. A sub-terrain profile is represented in Fig. 3 (For example, consider the whole terrain profile as a 200 × 200 matrix then sub terrain can be as a 5 × 5 matrix). a represents the cell resolution and $A(x, y)$ stores the altitude (relative height) value. So that, $A(m, n)$ represents the actual height value at the center of (m, n) point as z. The transmitter and receiver have been placed in the center of cells, and the positions are shown as (x_t, y_t) and (x_r, y_r).

In order to calculate the height values under the radial line, any interpolation technique can be used. Three different interpolation techniques are employed to increase the number of samples under the radial line since the number of samples is directly related to the resolution of terrain profiles. The interpolation techniques employed are diagonal, vertical (row), and horizontal (column) interpolations, and to store interpolation data the form of $(n+1)x^2$ matrix is defined in the followings

$$R = [D \quad H] \tag{1}$$

where D and H are the distance and altitude vectors, respectively.

$$R = \begin{bmatrix} d_0 & h_0 \\ d_1 & h_1 \\ d_2 & h_2 \\ \vdots & \vdots \\ d_n & h_n \end{bmatrix} \tag{2}$$

Calculated distance between transmitter and receiver has been presented in first column and corresponding calculated heights of the ground profile have been listed in the second column. Therefore, first column of the matrix is arranged as in the following

$$d_0 < d_1 < \ldots < d_{k-1} < d_k < d_{k+1} < \ldots < d_n \tag{3}$$

$$d_0 = 0 \tag{4}$$

$$d_n = d \tag{5}$$

where d_n can be defined as a radial line distance between transmitter and receiver, and d_0 is the distance between receiver and receiver (zero). In the following step, h_0 and h_n heights of the ground at the receiver and the height of the ground at the transmitter, respectively, are determined. The choice of the distances d_k and the calculation of the corresponding height h_k is determined from the results of diagonal, vertical, and horizontal interpolation routines.

The distances can be formulated for interpolation techniques as

$$d_k = \begin{cases} \dfrac{ka}{\sqrt{2}\cos|\theta - \pi/4|} & \text{for} \quad \text{diagonal} \\ \dfrac{ka}{\sin(\theta+\gamma)} & \text{for} \quad \text{vertical and horizontal} \end{cases} \tag{6}$$

where $k = 1, 2, \ldots, |x_r - x_t| + |y_r - y_t| - 1$ for diagonal interpolation, $k = 1, 2, \ldots, |x_r - x_t| - 1$ for horizontal interpolation, and for vertical interpolation $k = 1, 2, \ldots, |y_r - y_t| - 1$. In addition, γ is 0 and $\pi/2$ for vertical and horizontal interpolations, respectively. θ is an angle between $-y$ axis and radial line, and this angle can be calculated from

$$\theta = \tan^{-1}\frac{|x_r - x_t|}{|y_r - y_t|} \tag{7}$$

For calculating corresponding height values h_k at a distance d_k the following equation is used.

$$h_k = \begin{cases} \dfrac{|K-S||A(p,q)-A(i,j)|}{a\sqrt{2}} + A\left(i,j\right) & \text{for} \quad \text{diagonal} \\ \dfrac{|K-S||A(p,q)-A(i,j)|}{a} + A\left(i,j\right) & \text{for} \quad \text{vertical and horizontal} \end{cases} \tag{8}$$

where $A(p,q)$ and $A(i,j)$ represent the actual height value at the points (p,q) and (i,j). This equation is based on similarity of triangles that shown in Fig. 4.

Here, K represents the position of the obstruction. F and S represent the locations with $A(p,q)$ and $A(i,j)$ altitude values, respectively. In order to calculate h_k value, similarity of triangles in Fig. 5 can be used.

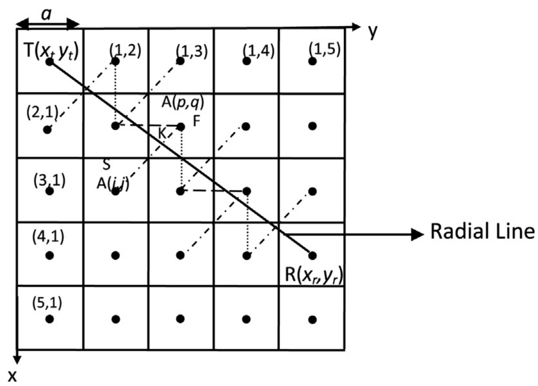


Fig. 3. Interpolation techniques for a radial (— —: diagonal, ·······: vertical, - - -: horizontal).

3.4. Clearance of Fresnel zones

As discussed previously, obstruction or clearance of the Fresnel zone would help determine how much the transmitted signal is perturbed, and the assessment of the signal power at the receiver. Specifically, for this study, if the Fresnel zone is clear or is obstructed slightly, then it is likely that the link could be a candidate for determining the reflection point, and vice versa.

Therefore, clearance of Fresnel zones is way of inspecting the links between the transmitter to the highest points, and the highest points to the receiver. Fig. 5 shows how Fresnel zones can be constructed for transmitter and receiver positions over a given terrain profile. In this figure h_0 and h_n represent the heights of the ground at the receiver and transmitter, respectively. Then, h_r and h_t are height of the receiver and the transmitter antennas masts (elevated antennas), and the distance between center of the Fresnel zone on x–z plane and ground can be symbolized as h_c. In addition, altitude of the terrain at a distance d_k is represented, based on previous section's convention, by h_k.

In order to understand the clearance of the nth Fresnel zone between transmitter and receiver points at point k, height difference between h_c and h_k has to be inspected. h_c can be calculated by

$$h_c = h_{line} + h_r + h_0 \tag{9}$$

where h_{line} is the height difference between center of the Fresnel zone and absolute difference of transmitter and receiver heights.

$$h_{line} = d_k \tan(\alpha) \tag{10}$$

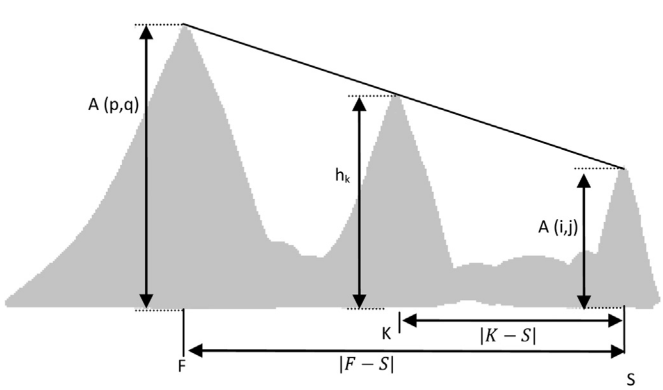


Fig. 4. Detail of altitude calculations.

$$\alpha = \tan^{-1}\left(\frac{h_t + h_n - (h_r + h_0)}{d}\right) \tag{11}$$

Sign of difference (positive or negative) determines the clearance of the first Fresnel zone. If a height difference between h_c and F'_n is greater than or equal to altitude of the obstacle, Fresnel zone is clear, and vice versa. This can be represented by a simple function;

$$F_n = \begin{cases} 1 & \text{if} \quad h_c - F'_n \geq h_k \\ 0 & \text{if} \quad h_c - F'_n < h_k \end{cases} \tag{12}$$

where unity value of this function represents the case that Fresnel zone is clear, and zero value presents the case that Fresnel zone is obstructed. It should be noted that only the first Fresnel zone is considered in this stud.

4. Simulation results

This chapter presents some simulation results regarding with the proposed method that has been described in previous chapters. As discussed previously, 3D terrain data for a particular region in western Turkey (cost of Aegean sea) was created manually from a free mapping tool, and processed in a software package for further analysis and illustrations. A 3D reconstruction of the terrain is provided in Fig. 6. In order to simplify problem, and make is easy for visual inspection of the result of the proposed method, an island was chosen. As setting up a measurement system for the validity of the proposed method is quite complicated and costly, it was believed that choosing an island and placing the transmitter and receiver over sea would make the proposed method's results interpret easy, and it can be used to validate the results by visual inspection.

In Fig. 6, x and y axes represent cell number, corresponding to the distance in a plane. Each cell has size of 0.5 km, and overall a 100 km × 100 km region is represented by 200 × 200 cells. Moreover, the peak altitude of the terrain is 1800 m (in z axis). Moreover, Fig. 6 also represents 3D version of the problem geometry given in Fig. 1. It is assumed that the transmitter and the receiver's positions are known, and they can be arbitrarily placed. Then, clearance of the Fresnel zone may vary with the positions of the transmitter and the receiver, and moreover it depends on the operating frequency, terrain profile, and distance between the transmitter and the receiver.

An algorithm has been developed to take pre-determined number of highest points over the terrain, location of the transmitter and the receiver and the terrain data of Fig. 6 as inputs. First, for the digital terrain data of the portion of the earth and sea level, a normalization process is carried out according to the lowest altitude value (the tools provide altitude values of the terrain under the sea level along the coastal of the sea). Then, the highest points are taken in order of levels as candidate reflection/scattering points, and the transmitter and the first highest point is taken the first link and its terrain profile is reconstructed. Then, this is repeated for the other highest points to the receiver. The process continues for all reflection/scattering points according to their altitude values. Then, Fresnel zones are created over every terrain profile, for both the transmitter and the candidate reflection/scattering point (the highest points), and the candidate reflection/scattering point (the highest points) to the receiver. Finally, clearance of the Fresnel zones are inspected, and they are listed in the order of their level of clearance, by taking the link with highest clearance as the first. Every scattering point that has clearance is candidate, and every scattering point has obstruction (no clearance) is ignored. The scattering center is then calculated as the average of all candidate reflection/scattering points.

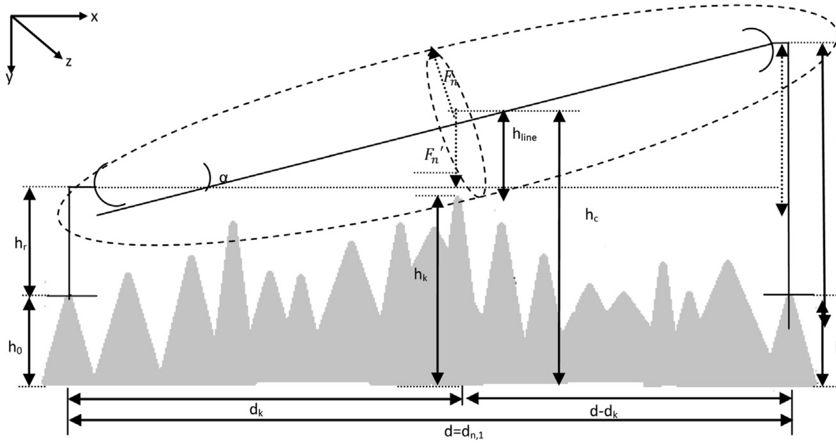


Fig. 5. Clearance of Fresnel zone.

Fig. 7 shows one of those terrain profiles, constructed between the transmitter to the highest point (a), and then the receiver and the highest point (b). In this particular case, it seems that the highest point is placed at (148,104) cells. Terrain profile between transmitter and highest point is plotted Fig. 7a and between highest point and receiver is represented in Fig. 7b.

In Fig. 7, blue lines represents the altitude values between the transmitter and the highest points while red lines represents how much intervention in the Fresnel zone is measured over the same link. According to Fig. 7, it is evident that both links have Fresnel zone clearance, and it is one of the candidate reflection/scattering points.

The first ten highest points on the terrain are used in the simulations as the candidate scattering points, and starting from the peak altitude of the island. Although candidate scattering points would greatly dependent on the orientation of the receiver and the transmitter, but not only their altitude values, the terrain profile and the transmitter and the receiver positions are chosen such that the altitude values become dominant factor in estimating the candidate scattering points. In practice, there should be a pre-processing on estimating candidate scattering points, and altitude would be only one of the parameters to be considered in calculations. This will be a further study.

By testing the profiles over which whether Fresnel zone is clear or not, the scattering points (so clear profiles) are evaluated and identified. The identified profiles are ordered starting from the highest altitude value to lowest altitude value. Results are represented in Table 1. In the simulation, the transmitter and the receiver are located at (105,113) and (162,132) at 20 m, respectively.

Although there may be many parameters in determining the scattering points, the positions of the transmitter and receiver are chosen in this simulation such that almost every highest point could be a candidate scattering point. It is evident that only one of the links is obstructed (5th link between the highest point to the receiver). On the contrary, if all Fresnel zones are obstructed, and no link is found to be clear, then, the diffraction loss of each link has to be taken into consideration. Then, there may be two alternatives for the next stage: diffraction loss of each link can be calculated by using either GTD, or simply the parameter given as diffraction loss in Fresnel zone technique. In order to decide the scattering center, all candidate scattering points have to be taken into considerations. Therefore, simply geometrical center of the ten points could be used by taking the average of the points as follows

$$SC = \frac{\sum_{i=1}^{m}(x_i, y_i)}{m} \tag{17}$$

where m is the number of the highest points that is clearly seen (with Fresnel Concept not only optical visibility) from both the transmitter and the receiver. SC and (x_i, y_i) are the scattering center and position of the scattering points, respectively.

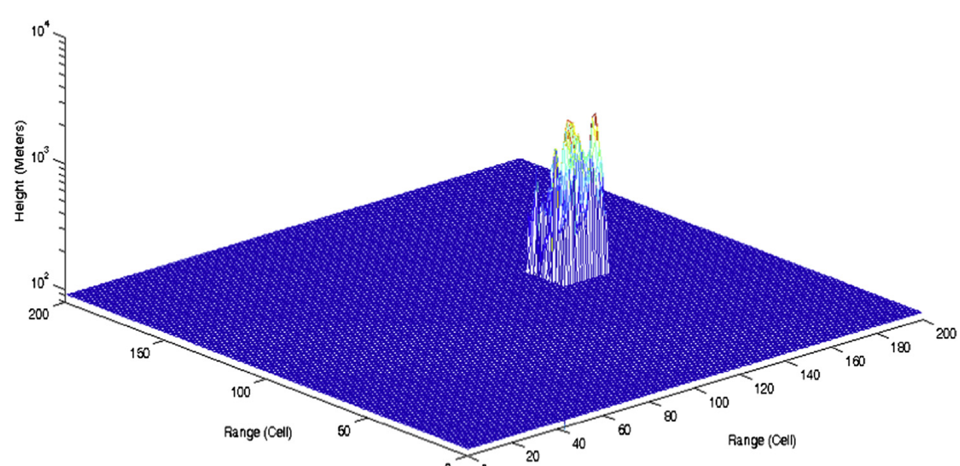
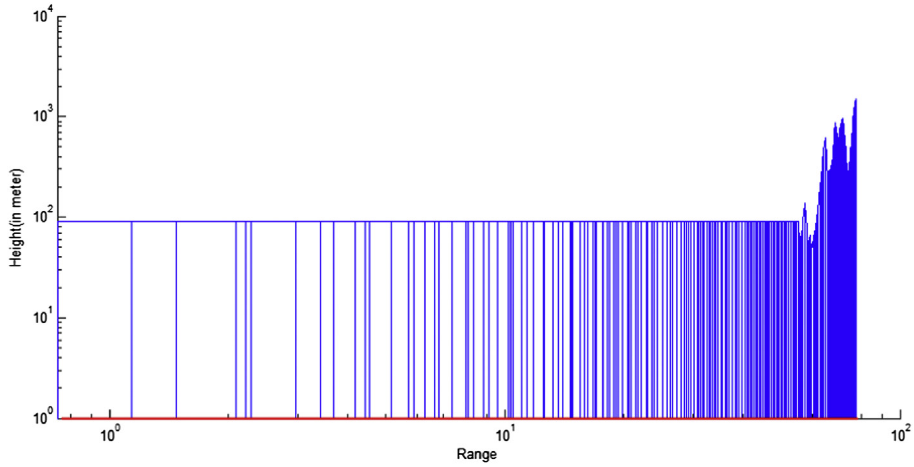
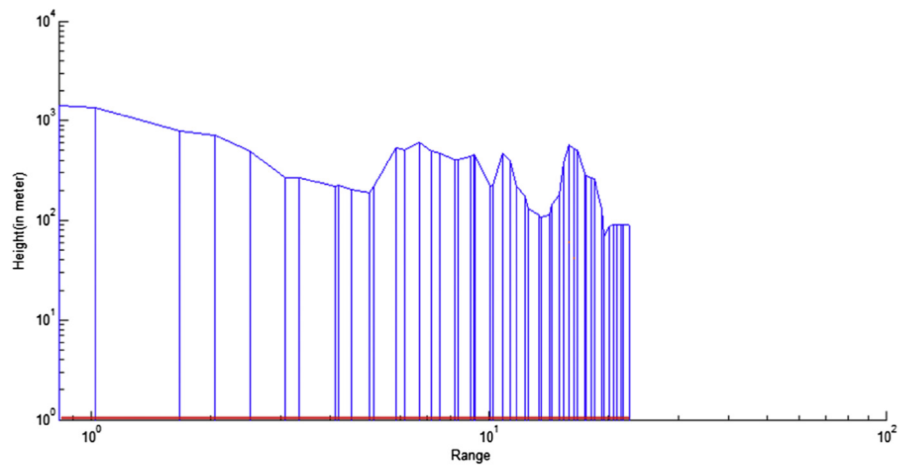


Fig. 6. Terrain in Aegean.



a. The transmitter and the highest point



b. The highest point and the receiver

Fig. 7. Terrain profiles between the transmitter and the highest point and between the highest point and the receiver.

When this simple method is applied to the points in Table 1, the resultant scattering center was found to be

$$SC = (144.3, 109.4) \quad (18)$$

It is not easy to prove that this point is the scattering center of the multipath but a visual inspection over the terrain and the transmitter and receiver positions clarify that it could be a scattering center. For full validation of the method would require simulations with complicated numerical algorithms.

5. Conclusion

In this work, a simple method to determine scattering center of a multipath has been proposed for known transmitter and receiver positions. Normally, multipaths are used to increase Signal to Noise ratio (SNR) at the receiver in wireless communications systems. On

Table 1
Clearance of the Fresnel zones for the transmitter to the highest ten points and, then, the highest ten points to the receiver for irregular terrain of Fig. 6.

Transmitter-highest points				Highest points-receiver			
Highest point	Position	Altitude (m)	Fresnel zone	Highest point	Position	Altitude (m)	Fresnel zone
1st	(148,104)	1526	1	1st	(148,104)	1526	1
2nd	(147, 104)	1465	1	2nd	(147, 104)	1465	1
3rd	(143, 110)	1259	1	3rd	(143, 110)	1259	1
4th	(144, 113)	1242	1	4th	(144, 113)	1242	1
5th	(148, 103)	1224	1	5th	(148, 103)	1224	0
6th	(145, 113)	1215	1	6th	(145, 113)	1215	1
7th	(139, 107)	1202	1	7th	(139, 107)	1202	1
8th	(147, 114)	1129	1	8th	(147, 114)	1129	1
9th	(143, 113)	1074	1	9th	(143, 113)	1074	1
10th	(143, 107)	1063	1	10th	(143, 107)	1063	1

the other hand, this work presents an attempt to develop a solution using to a geolocation problem using multipath propagation in radar and electronic warfare applications. The problem in this study is simplified version of the real problem in radar and electronic warfare applications. As the proposed method is based on simple ray theory (Geometric Optic) and Fresnel zone concept, a short discussion on higher frequency analytical and numerical techniques has also taken place in the beginning. This helps justify why GO and Fresnel zone concepts are chosen in the proposed method.

One of the objectives in the proposed method was simplicity, and minimization of computation time. Therefore, it has been decided that the GO and Fresnel Zone concept could be used initially, and they provide the simplest way in determining the scattering center. Later, additional scattering effects can be incorporated by considering how much computation can be tolerated for a particular problem. Once more, the proposed method is based on clearance of the first Fresnel zones between the transmitter to the highest points over the terrain, and the same highest points to the receiver. Clearance of first Fresnel zone may help determine whether the highest point could be candidate scattering point or not. Starting from the highest point, over the region in which the scattering center of the multipath could be placed, pre-determined numbers of points having higher altitudes are considered for Fresnel zone clearance. For this purpose, terrain profile of each link, made up from the highest point to the receiver or transmitter, should be reconstructed from equivalent 3D digital terrain data. When the candidate scattering points have no clearance, then diffraction loss should be incorporated.

As the objective of the work is to determine the scattering center with minimum computational load and parameters, the proposed method should be improved further. In many realistic situations, it might be critical to include diffraction effects in order to obtain more realistic results. Then, GTD, UTD or ITD techniques needs to be incorporated in future works regarding with the practical problem considered for the first time in this paper. These techniques may improve the proposed method but computational load should also be important for practicality of the proposed methods. Therefore, one way would be that every improvement to the proposed method should be evaluated from the computational load point of view along with accuracy. Moreover, after determining of candidate scattering points, there may be weighting of candidate points instead of simple averaging. The candidate points having higher Fresnel zone clearance should contribute greatly to the scattering center, and vice versa. Future works will help clarify all these issues.

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