Comparison and Analyzing of Propagation Models with Respect to Material, Environmental and Wave Properties

M. B. Tabakcioglu [1], D. Ayberkin [2], and A. Cansiz [3]

[1] Department of Electrical and Electronics Engineering
Bayburt University, Bayburt 69000, Turkey
mbtabakcioglu@bayburt.edu.tr

[2] Department of Computer Programming
Bayburt University, Bayburt 69000, Turkey
doruk@bayburt.edu.tr

[3] Department of Electrical Engineering
Istanbul Technical University, Istanbul 34469, Turkey
acansiz@itu.edu.tr

Abstract **─** This paper presents a study on a class of algorithms based on Uniform Theory of Diffraction (UTD) for multiple diffractions. Within this context Slope UTD with Convex Hull (S-UTD-CH) model based on Slope UTD and Fresnel zone concept was reviewed. S-UTD-CH model can be used for fast and more accurate field prediction for multiple diffractions in transition zone. An extensive simulation results for comparison of UTD based algorithms with respect to the computation time and accuracy was provided. Furthermore, the study shows how relative permittivity constant, conductivity and inner angle of wedge and polarization type affect the relative path loss.

Index Terms **─** Convex hull, Fresnel zone, material properties, multiple wedge diffraction, radio propagation, slope diffraction and Uniform Theory of Diffraction (UTD).

I. INTRODUCTION

In order to construct more reliable and efficient digital communication networks and broadcasting systems, accurate and time efficient theoretical models being capable of generating field predictions are necessary. Along with the literature, many models have been proposed to meet required demand of accuracy. Propagation models have traditionally treated irregularities in the terrain as knife edge, wedge or cylinder for UHF. For example, while mountains and hills can be modeled as wedge, buildings can be modeled as knife-edge.

Multiple diffraction problems have widely been investigated for a long time; UTD based and numerical solutions have been proposed to predict the field strength in the urban, rural, suburban and indoor environments. In asymptotic high-frequency electromagnetic wave propagation methods, the total electric field at a receiving point is the sum of the field associated with all the rays that reach this point. These reached rays can be direct, reflected, refracted or diffracted rays [1, 2].

Although, previously proposed UTD method by [3] is time efficient method, it fails to predict the field strength accurately when, even if one obstacle is placed in the transition zone of the frontal obstacle. UTD method is high frequency asymptotic method used in electromagnetic wave propagation [4]. A more accurate solution is called S-UTD, has been proposed by [5, 6] by including slope diffraction terms to predict the field strength accurately. In S-UTD method, it is claimed that the phase continuity should be ensured in calculating the distance parameters appearing in the amplitude and the slope diffraction coefficients. S-UTD method gives acceptable

Submitted On: March 25, 2013
Accepted On: July 14, 2014

results when compared with [7]. Vogler's method is based on numerical solution of Fresnel–like integrals and it is known to be ultimate in accuracy. However, S-UTD method still exhibits an error when number of diffraction increases. Although, S-UTD method has shown to deal with multiple transition diffraction problems, its validity has been reported to be limited in the number of diffractions. It is reported in various studies [8-10] that after a total of 10 diffractions, S-UTD method loses the accuracy, causing unreliable and inefficient digital communication networks and broadcasting systems.

Relative path loss is a measure of the average RF attenuation experienced by a transmitted signal when it arrives at the receiver, after traversing a path of several wavelengths [11]. In other words, relative path loss is a path loss divided by free space loss. In order to overcome the path loss problem, a UTD based method called as the Slope UTD with Convex Hull (S-UTD-CH) is proposed in [9, 10]. S-UTD-CH method combines S-UTD and Convex Hull methods. Convex hull method reduces the diffracting wedges and then Slope UTD algorithm runs. By reducing wedge number, computation time is reduced. UTD based solutions are known with small computation time in urban radio propagation modeling, with respect to numerical methods. There is a trade-off between computation time and accuracy. Methods having higher accuracy require large computation time as in numerical methods [7, 12-15]. These methods seem to be infeasible in many cases. In this paper, the UTD based model proposed in [9, 10] is reviewed. The simulation results for comparison of UTD solutions are presented and discussed. Hard polarization is considered in simulations. Accuracy of predicted relative path loss and computation time is compared in UTD models. Moreover, how material properties like wedge angle, conductivity and relative permittivity constant of wedge affects the path loss is analyzed.

II. SLOPE UTD WITH CONVEX HULL METHOD

S-UTD-CH method combines S-UTD and Convex Hull methods. Convex hull method uses the Fresnel zone concept [16]. Fresnel zone concept is not new and has widely been used in UTD based radio propagation modeling in urban/suburban, rural and indoor applications. Fresnel zones are ellipsoid of revolution about the direct line from a transmitter to a receiving end, with the transmitter and receiving ends serving as foci of the ellipse, as shown in Fig. 1.

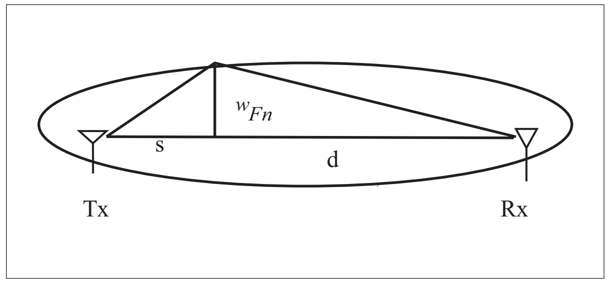

Fig. 1. Fresnel zone configuration.

In this figure, w_{Fn} is radius of Fresnel zone at a given distance given by:

$$w_{F_n} = \sqrt{\frac{\lambda s d}{s+d}}, \quad (1)$$

where λ is wavelength of the incoming wave. s and d is distance from transmitter and receiver. Fresnel zone radius is the maximum at the midpoint between the transmitter and receiver. Although, the obstacles which are placed outside the first Fresnel zone may introduce reflected, diffracted or scattered contributions to the total field strength, they cause only a small distortion in the original wave and can mostly be ignored [9, 10].

In order to reduce the computation complexity of diffraction problem, convex hull model is introduced [16]. By means of convex hull model, unsuccessive diffracting obstacles are excluded from the scenery. Convex hull is described as a polygon formed by some selected wedges between the transmitter and receiver positions [12].

S-UTD-CH based on Fresnel zone concept along with S-UTD, provides an improvement to S-UTD implementation both for computation time and accuracy when the number of the diffracting obstacles is greater than 10. S-UTD-CH model compared numerical model proposed in [13] and relatively small computation time obtained [9, 17]. The detailed sequence of S-UTD-CH algorithm is given in reference [9-10].

According to this sequence for a given height distribution, the main Fresnel zone is constructed between the transmitter and the receiver and the obstacles outside the main Fresnel Zone are eliminated. Following, the secondary Fresnel zones are constructed between the transmitter and the highest obstacle and then the highest obstacle and the receiver. The obstacles outside these secondary Fresnel zones are eliminated. The process is repeated successively for smaller Fresnel zone to be constructed under the secondary Fresnel zones until no obstacles are remained for elimination. In this way, the convex hull is constructed by the obstacles remained as a results of the elimination process. From the theoretical point of view, the diffraction from the obstacle placed outside the first Fresnel zone does not contribute much to the received field and can be ignored for most cases. After forming the convex hull, 2D ray tracing algorithm is run to find all the rays originated from the transmitter to the receiver point. Finally, S-UTD algorithm runs for calculating the total field at the receiver. For the wedge case, the process is illustrated in Fig. 2.

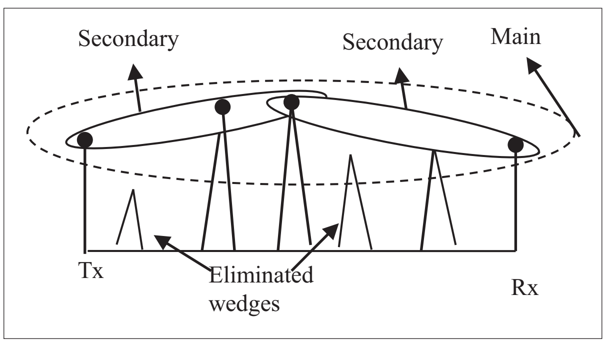

Fig. 2. Construction of the convex hull.

The motivation for the above approach of eliminating less important obstacles, which are outside of the Fresnel zones, is to reduce both computation time and make a compromise between computation time and error when the number of diffractions is large.

When the wedges outside Fresnel zone can be determined and eliminated before running slope UTD, the computation time can be substantially reduced with minimum error. Eliminating one obstacle approximately decreases the computational time by one-fifth and the lesser obstacles are in the Fresnel zone, means lesser computational time.

III. COMPARISON OF MODELS

In order to investigate the ray theoretical methods, simulation results are compared in this section. Computer configuration is as followed. Processor is Intel (R) Core (TM) 2 Quad CPU Q8300 2.5 GHz and RAM is 3GB. Within this context, to compare the UTD, S-UTD and S-UTD-CH methods, following test case is considered for GSM with hard polarization. The transmitter height is taken as 60 m, the operational frequency as 900 MHz and receiver height changes between 0 and 120 m. There is 25 km between transmitting and receiving antennas. There are 4 hills as wedges with 30º inner angle. At 6, 12, 16 and 22 km there are four wedges of 65, 70, 65 and 30 m heights, respectively. Relative permittivity of constant of the hills is taken as 15 and conductivity of the hills as 0.0012 S/m. Relative path losses of the three methods for the considered terrain profile are given in Fig. 3.

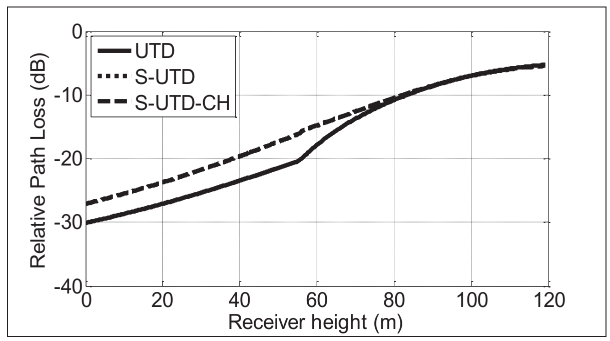

Fig. 3. Comparison of the results for hard polarization.

This figure illustrates relative path losses of the methods for given scenario. Solid line presents UTD method. Dotted and dashed lines show S-UTD and S-UTD-CH methods. As can be seen from Fig. 3, S-UTD and S-UTD-CH gives almost same results. However, UTD model gives relatively higher error, resulted from wedges that are in the transition zone of the previous wedges. As illustrated in Fig. 3, there is 5 dB errors in prediction of field strength. Table 1 shows the computation time for the ray theoretical methods. As can be seen from Table 1, UTD is the fastest method with lower accuracy (5 dB error). S-UTD-CH model is a faster method than S-UTD method, with almost the same accuracy.

Table 1: Computation time for the simulation

UTD (s)	S-UTD (s)	S-UTD-CH (s)
8.3	73.7	59.4

Material properties like conductivity and relative permittivity constant and inner angle of wedges, affect the relative path loss at the receiver. To validate this fact, a simple test case is considered. In the considered case, the inner angle of wedge is 160° with a height of 50 m, placed at 5 km of a propagation path of 10 km, at an operational frequency of 100 MHz. The transmitter height is 50 m, while the receiver height changes from -100 to 200 m. Figure 4 shows the analysis of the relative permittivity constant of the wedge with varying cases. As can be seen from this figure, relative path loss decreases with increasing of relative permittivity constant.

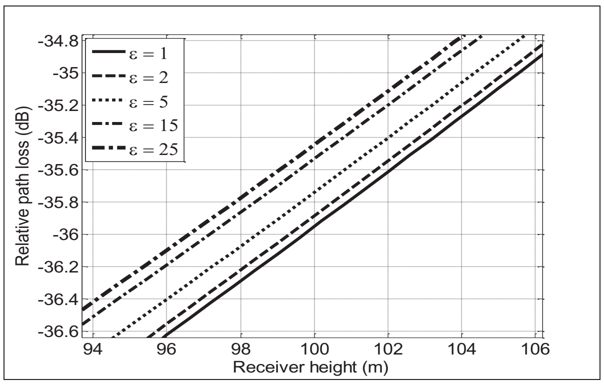

Fig. 4. Analysis of the relative permittivity constant of the wedge.

Figure 5 shows the effect of inner angle of the wedge on relative path loss. As it is illustrated in the figure, relative path loss decreases with increasing the inner angle. When the inner angle tends to zero, it gives the same results with the knife-edge case.

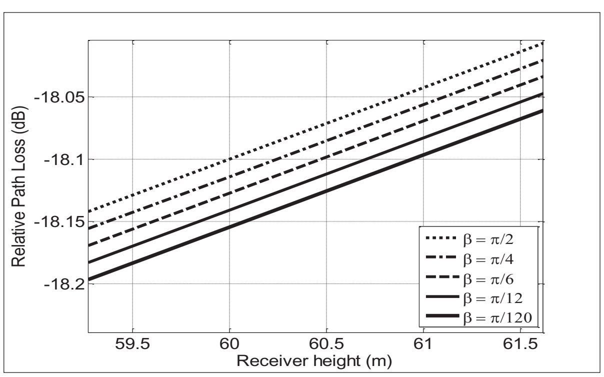

Fig. 5. Analysis of the inner angle of the wedge.

In addition, the conductivity of wedge is another parameter affecting the relative path loss at the receiver, as in Fig. 6. Relative path loss increases with decreasing of conductivity, as shown in this figure. Although, all parameters seem to have minor effect on the relative path loss, these effects tend to be important for total relative path loss in multiple diffraction case.

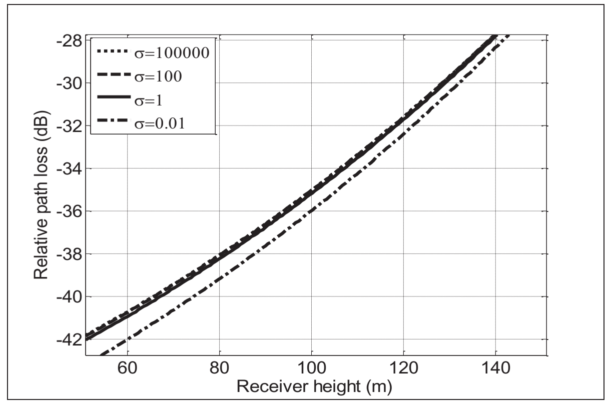

Fig. 6. Analysis of the conductivity of the wedge.

IV. CONCLUSION

In this paper, UTD based methods are reviewed. Study indicates that the Slope UTD contribution is shown in the transition zone diffraction. S-UTD has larger computation time with higher accuracy, while UTD has small computation time with lower accuracy for multiple-diffraction in transition zone. There is a tradeoff between the accuracy and the computation time, or the accuracy and the implementation complexity of methods. Moreover, an improved S-UTD method for multiple wedge diffraction is reviewed (called as S-UTD-CH). It is shown that S-UTD-CH that uses a selection algorithm of diffracting wedges based on Fresnel zone concept would be used for transition zone diffraction. S-UTD-CH provides not only very low computation time but also very accurate results for multiple transition zone diffractions, due to that after 10 diffractions S-UTD loses accuracy. Furthermore, increasing of relative permittivity constant, conductivity and inner angle of wedge, decreases the relative path loss at the receiver.

As a conclusion, S-UTD-CH model can be used for radio planning tools, due to the fact that they have relatively small computation time with high accuracy.

ACKNOWLEDGMENT

This work partially supported by Bayburt University Scientific Research Support Unit under grant 2013-1/14.

REFERENCES

[1] F. S. Adana, O. G. Blanco, I. G. Diego, J. P. Arriaga, and M. F. Cátedra, "Propagation model based on ray tracing for the design of personal communication systems in indoor environments," *IEEE Transactions on Vehicular Tech.*, vol. 49, no. 6, pp. 2105-2112, 2000.

[2] F. Weinmann, "UTD shooting-and-bouncing extension to a PO/PTD ray tracing algorithm," *ACES Journal*, vol. 24, no. 3, pp. 281-293, 2009.

[3] R. G. Kouyoumjian and P. H. Pathak, "Uniform geometrical theory of diffraction for an edge in a perfectly conducting surface," *Proc. IEEE*, vol. 62, pp. 1448-1461, 1974.

[4] O. Ozgun and L. Sevgi, "Comparative study of analytical and numerical techniques in modeling electromagnetic scattering from single and double knife-edge in 2D ground wave propagation problems," *ACES Journal*, vol. 27, no. 5, pp. 376-388, 2012.

[5] K. Rizk, R. Valenzuela, D. Chizhik, and F. Gardiol, "Application of the slope diffraction method for urban microwave propagation prediction," *IEEE Vehicular Tech. Conf.*, vol. 2, pp. 1150-1155, 1998.

[6] C. Tzaras and S. R. Saunders, "An improved heuristic UTD solution for multiple-edge transition zone diffraction," *IEEE Trans. Antennas Prop.*, vol. 49, no. 12, pp. 1678-1682, 2001.

[7] L. Vogler, "An attenuation function for multiple knife-edge diffraction," *Radio Science*, vol. 17, pp. 1541-1546, 1982.

[8] A. Kara, E. Yazgan, and H. L. Bertoni, "Limit and application range of slope diffraction for wireless communication," *IEEE Trans. Antennas and Prop.*, vol. 51, no. 9, 2005.

[9] M. B. Tabakcioglu and A. Kara, "Comparison of improved slope UTD method with UTD based methods and physical optic solution for multiple building diffractions," *Electromagnetics*, vol. 29, no. 4, pp. 303-320, 2009.

[10] M. B. Tabakcioglu and A. Kara, "Improvements on slope diffraction for multiple wedges," *Electromagnetics*, vol. 30, no. 3, pp. 285-296, 2010.

[11] T. K. Sarkar, "A survey of various propagation models for mobile communication," *IEEE Antennas and Propagation Magazine*, vol. 45, no. 3, pp. 51-82, 2003.

[12] H. K. Chung and H. L. Bertoni, "Application of isolated diffraction edge method for urban microwave path loss prediction," *Antennas and Propagation Symposium*, pp. 205-209, 2003.

[13] H. K. Chung and H. L. Bertoni, "Range-dependent path-loss model in residential areas for the VHF and UHF bands," *IEEE Transaction on Antennas and Propagation*, vol. 50, no. 1, pp. 1-11, 2002.

[14] J. Walfisch and H. L. Bertoni, "A theoretical model of UHF propagation in urban environments," *IEEE Transaction on Antennas and Propagation*, vol. 36, no. 12, pp. 1788-1796, 1988.

[15] H. H. Xia and H. L. Bertoni, "A theoretical model of UHF propagation in urban environments, diffraction of cylindrical and plane waves by an array of absorbing half-screens," *IEEE Transaction on Antennas and Propagation*, vol. 40, no. 2, pp. 170-177, 1992.

[16] O. M. Bucci, "The experimental validation of a technique to find the convex hull of scattering systems from field data," *IEEE Antennas and Propagation Symposium*, pp. 539-542, 2003.

[17] M. B. Tabakcioglu and A. Kara, "Discussions of various UTD and PO solutions for multiple-edge diffractions in urban radio propagation modeling," *Electromagnetic Wave Scattering Workshop*, section 11, pp. 1-6, 2008.

Mehmet Baris Tabakcioglu was born in 1981. He obtained his B.S. degree from Middle East Technical University in the department of Physics in 2005. Then he obtained his M.S. degree from Atilim University in the department of Electrical and Electronics Engineering in 2009. He then obtained his Ph.D. degree from Ataturk University in the department of Electrical and Electronics Engineering in 2013. His research area is electromagnetic wave propagation, diffraction and reflection. He is currently working at Bayburt University.

Doruk Ayberkin was born in 1981. He obtained his B.S. degree from Gazi University in the department of Physics in 2005. Then he obtained his M.S. degree from Ahmet Yesevi University in the department of Computer Engineering in 2012. His research area is electromagnetic wave propagation, diffraction and reflection and computer programming. He is currently working at Bayburt University.

Ahmet Cansiz is currently working in the Electrical Engineering Department at Istanbul Technical University, Turkey. He obtained his Ph.D. degree from the Illinois Institute of Technology, USA, in 1999. He has a wide experience in thermodynamics of the cryogenics systems regarding the superconductivity applications; superconducting levitation, superconducting bearing system and Superconducting MagLev. His research area also focuses on interdisciplinary subjects, such as heat transfer phenomena in heat exchangers and integration of renewable energy with smart grids. He has more than 30 journal publications in the subject of electromagnetics, electromechanics, thermodynamics and energy related topics.