Coverage Prediction for Triple Diffraction Scenarios

Mehmet B. Tabakcioglu

Electrical and Electronics Engineering Department
Bursa Technical University, Bursa, 16330, Turkey
mehmet.tabakcioglu@btu.edu.tr

Abstract **─** Electromagnetic waves emanating from the transmitter can reach to the receiver by reflection, direct or diffraction mechanism. In urban areas, dominant mechanism is diffraction. Thanks to using of high frequency, the obstructions can be modeled as a knife-edge. Coverage prediction is vital to install reliable and high-quality communication systems. In this study, a triple diffraction coefficient is derived for Uniform Theory of Diffraction (UTD) model and used for coverage problem. Coverage problems could be solved by the developed program in MATLAB computationally. Simulation results obtained in developed program are compared with FEKO electromagnetic wave propagation simulation software.

Index Terms **─** Coverage mapping, diffraction coefficient, FEKO, radio wave propagation, ray-tracing.

I. INTRODUCTION

Predicting the electric field strength and extracting the coverage maps are very important in order to install more efficient and reliable digital communication system in urban or rural areas including multiple obstructions. Ray-tracing based electromagnetic wave propagation models are introduced to predict the field strength accurately at the receiving point [1-9] and to extract the coverage map [10].

Geometrical optic (GO) model had used for some physical events like reflection and refraction before Geometrical theory of diffraction was introduced [11]. Geometrical optic model fails to calculate the electric field behind an obstruction. Keller introduced Geometrical theory of diffraction (GTD) model in 1962 [12]. The GTD model is an extension to the GO model with including diffracted wave terms [13]. If a source, diffraction and observation points are close to the same line, the GTD model is not succeeded in calculating the field strength accurately [14,15]. In order to remove the discontinuity problem of GTD model in the vicinity of the shadow, another high frequency asymptotic technique, called Uniform theory of diffraction (UTD) model, introduced [1].

In the rest of paper, firstly UTD model is explained briefly for single, double and triple diffraction, respectively. Then simulation results for the scenario including single, double and triple obstructions are given and compared with FEKO. FEKO, developed by Altair, is a comprehensive computational electromagnetics code used widely in the telecommunications, space and defense industries [16].

II. UTD MODEL

Buildings, hills, trees and cars etc. are obstructions and can cause reflection, refraction and/or diffraction. Due to ultra-high frequency (UHF), these obstructions are modeled as a knife edge or wedge. Electric field can be calculated behind an obstruction [14] by:

$$E = [E_i D] A(s) e^{-jks}, \tag{1}$$

where E_i is incident electric field, *A(s)* represents spreading factor, *D* stands for amplitude diffraction coefficient, k and *s* refers to wave number and travelling distance, respectively. The simplest case in outdoor or indoor propagation in the real environment is single diffraction case. The diffraction coefficient for single obstruction case is given by:

$$D = \frac{e^{-j\frac{\pi}{4}} F(L_{123})}{2\sqrt{2\pi k}\sqrt{\cos(\alpha_{123})/2}}, \tag{2}$$

where, *F* is transition function given in [17], k is the wave number, *L* is distance parameter and α is diffraction angle as shown in Fig. 1. The spreading factor for a single diffraction case is given by:

$$A(s) = \sqrt{\frac{s_1}{s_2(s_1+s_2)}}, \tag{3}$$

where, s_1 and s_2 are distance before and after diffraction point as illustrated in Fig. 1.

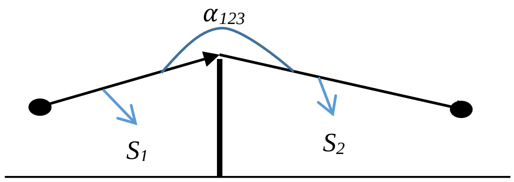

Fig. 1. Single diffraction case.

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The diffraction coefficient for double obstruction case is given by:

$$DD = \frac{e^{-j\frac{\pi}{2}} F(L_{123}) F(L_{1234})}{8\pi k \sqrt{\cos(\alpha_{123})/2} \sqrt{\cos(\alpha_{1234})/2}}, \quad (4)$$

where, F is the transition function, k is the wave number, L_{123} and L_{1234} are the distance parameters and α_{123} and α_{1234} are the diffraction angles as shown in Fig. 2. The spreading factor for double diffraction case is given by:

$$AA(s) = \sqrt{\frac{s_1}{s_2 s_3 (s_1 + s_2 + s_3)}}, \quad (5)$$

where, s_1 is the distance between the transmitter and first obstruction, s_2 is the distance between obstructions, and s_3 is the distance between second obstruction and the receiver as depicted in Fig. 2.

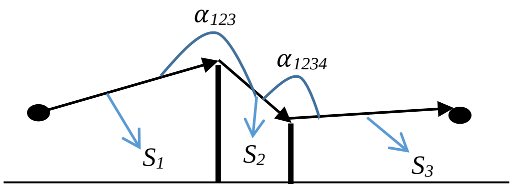

Fig. 2. Double diffraction case.

The diffraction coefficient for triple obstruction case is given by:

$$DDD = \frac{e^{-j\frac{3\pi}{4}} F(L_{123}) F(L_{1234}) F(L_{12345})}{2^3 (\sqrt{2\pi k})^3 \sqrt{\cos(\alpha_{123})/2} \sqrt{\cos(\alpha_{1234})/2} \sqrt{\cos(\alpha_{12345})/2}}, \quad (6)$$

where, F is the transition function, k is the wave number, L_{123}, L_{1234} and L_{12345} are the distance parameters and α_{123}, α_{1234}, α_{12345} are the diffraction angles as shown in Fig. 3. The spreading factor for triple diffraction case is given by:

$$AAA(s) = \sqrt{\frac{s_1}{s_2 s_3 s_4 (s_1 + s_2 + s_3 + s_4)}}, \quad (7)$$

where, s_1 is the distance between the transmitter and the first obstruction, s_2 is the distance between first and second obstructions, s_3 is the distance between the second and third obstructions, and s_4 is the distance between the third obstruction and the receiver as demonstrated in Fig. 3.

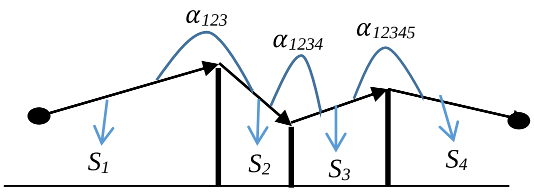

Fig. 3. Triple diffraction case.

III. SIMULATION RESULTS

UTD model can be used in coverage prediction before base station installation. Optimization of base station location is so important to increase the QoS. For a test case following scenario is considered. Operation frequency is 900 MHz. The distance between the antennas is 35 m. At 10, 20 and 30 m from the origin there are 3 knife-edge type obstructions. The transmitter is 5 m away from the origin and has an altitude of 6 m. The receiver height changes between 0 and 30 m. In the developed program, firstly all the data is entered and then ray paths are determined as follow.

- 1-4-5: In that case there is only single diffraction (the ray emanates from the transmitter, diffracts from the third obstruction and reaches to receiver).
- 1-2-4-5: In that case there is double diffraction (the ray emanates from the transmitter, diffracts from the first and then the third obstruction and reaches to receiver).
- 1-2-3-4-5: In that case there is triple diffraction (the ray emanates from the transmitter, diffracts from the first, then the second and then the third obstruction and reaches to receiver).

There will be 4 different cases for simulations. In the first case there is only single knife edge, whose height is 10 m, and 15 m away from the receiver in the scenario as mentioned previously. As both direct and reflected waves are considered, coverage map of single diffraction is depicted in Fig. 4.

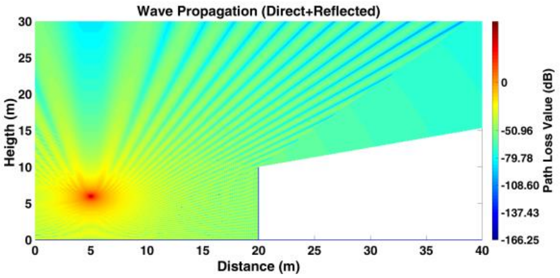

Fig. 4. Single diffraction (direct and reflected waves).

As can be seen in Fig. 4, there are two regions, which are lit and dark regions, separated with shadow boundary line in the coverage map of the single diffraction case. Due to not considering diffraction, there is no twilight region. Path loss decreases to -166.25 dB on the receiver side. If only diffraction phenomena is considered coverage map is demonstrated in Fig. 5.

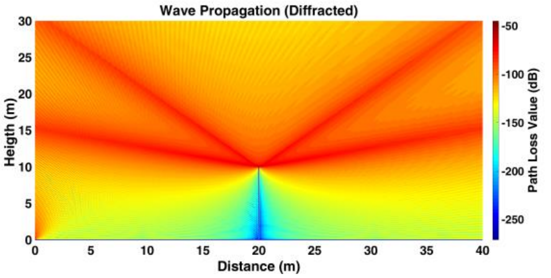

Fig. 5. Single diffraction (diffracted waves).

As can be seen in Fig. 5, there is diffracted wave behind the obstruction. The diffracted field effect is at the utmost along the shadow boundary line. Diffracted field contribution is at most -50 dB and decreases to -250 dB as far away from the shadow boundary line. In order to approve the results, the same scenario is run with FEKO software and obtained results are given in Fig. 6.

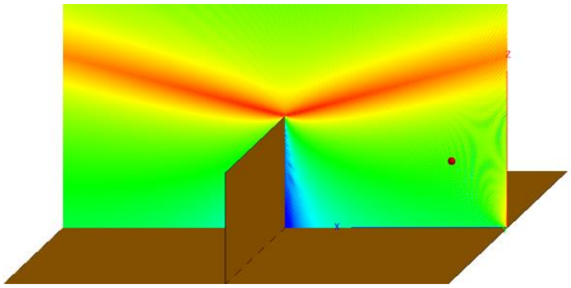

Fig. 6. Single diffraction (diffracted waves, FEKO).

As can be seen in Fig. 6, FEKO software gives almost the same diffraction pattern with developed program. Full coverage map for single obstruction case is obtained by using direct, reflected and diffracted waves as it is shown in Fig. 7.

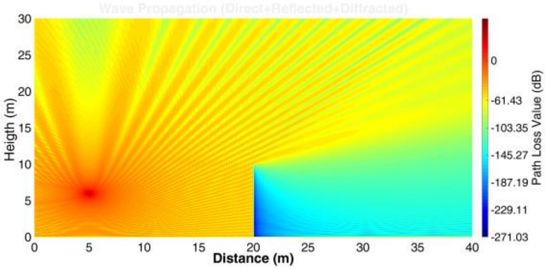

Fig. 7. Single diffraction (full coverage).

As it is shown in Fig. 7, there is a shadow line and diffracted field below and above this line. Also it is seen, there is a deep shadow region just behind the obstruction and diffracted field reduces to -271.03 dB in this region. Moreover, there is an interference pattern due to phase difference of direct, reflected and diffracted fields. Comparison results with FEKO software are demonstrated in in Fig. 8.

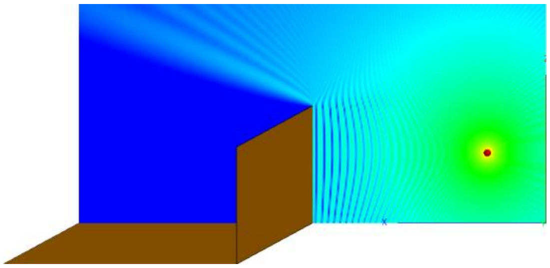

Fig. 8. Single diffraction (full coverage, FEKO).

As can be seen in Fig.8, FEKO software gives approximately the same diffraction and reflection pattern with developed program.

In the second case, an extra knife-edge, whose height is 6 m, is appeared at a distance of 25 m from the transmitter in the scenario. Both direct and reflected waves are considered, and coverage map is depicted in Fig. 9.

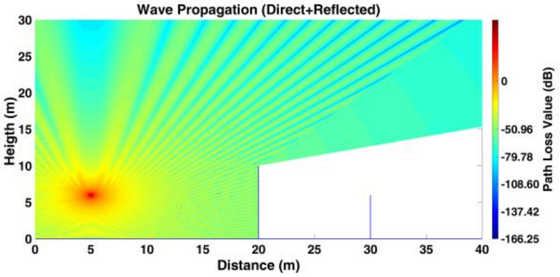

Fig. 9. Double diffraction (direct and reflected waves).

As can be seen in Fig. 9, there is a shadow region below the shadow boundary line of the first obstruction. There is no electromagnetic wave behind the first obstruction thanks to that geometrical optic model cannot explain the diffraction phenomena. Due to that there is no contribution of diffracted field from the first and second obstruction; coverage prediction is the same with first case as it is shown in Fig. 4. As only diffracted waves are considered, the coverage map is plotted in Fig. 10.

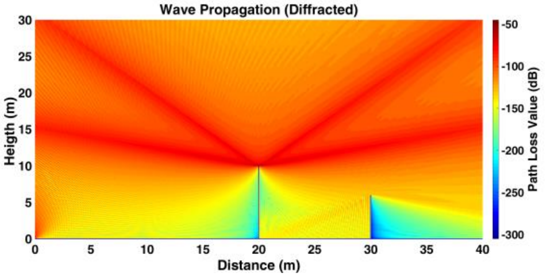

Fig. 10. Double diffraction (diffracted waves).

As can be seen in Fig. 10, unlike to geometrical optic model there is diffracted wave behind the obstructions. Also, the diffracted field effect is maxima (-50 dB) in vicinity of the shadow boundary lines of obstruction. Owing to double diffraction, electric field strength reduced -300 dB in deep shadow region behind the second obstruction. In order to validate the results of UTD model, the same scenario has been run with FEKO software and images of result is given in Fig. 11.

As can be seen in Fig. 11, FEKO software gives approximately the same electromagnetic field pattern and shadow boundary lines with developed program. Besides, electric field strength is reduced with far away from the transmitting antenna. Moreover, after two diffraction electric field strength decrease radically. Full coverage map for double obstruction case is got by using direct, reflected and diffracted waves as it is indicated in Fig. 12.

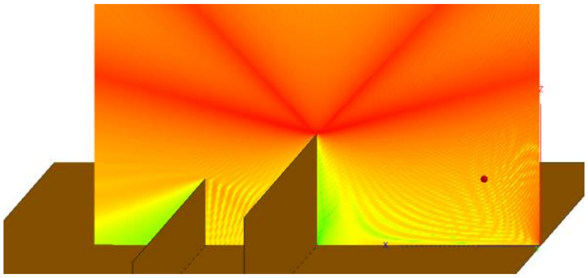

Fig. 11. Double diffraction (diffracted waves, FEKO).

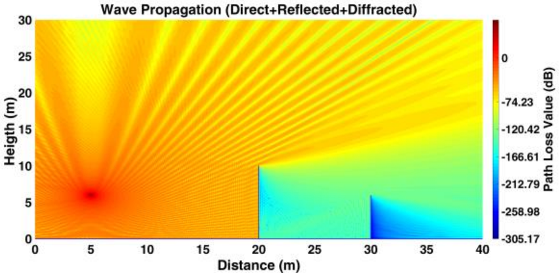

Fig. 12. Double diffraction (full coverage).

As it is indicated in Fig. 12, there are diffracted waves below and above the shadow boundary lines of first and second obstruction. Also it is seen, there is a shadow (-166 dB) and deep shadow (-305 dB) region just behind the first and second obstruction, respectively. Moreover, a diffraction and interference pattern has been composed by diffracted, reflected and direct fields due to phase difference of fields. In order to confirm the results of UTD model for double diffraction case, FEKO software has been run for the same scenario and images of the results are given in Fig. 13.

As can be seen in Fig. 13, FEKO software gives almost the same interference pattern with developed program.

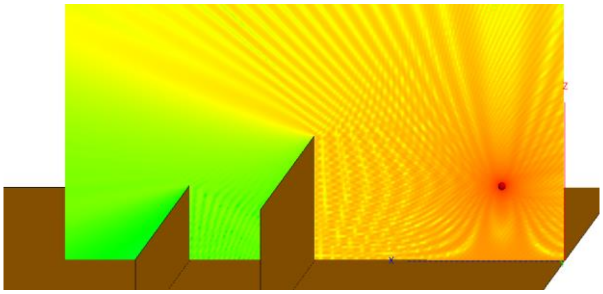

Fig. 13. Double diffraction (full coverage, FEKO).

In the third case, an extra knife-edge, whose height is 10 m, is appeared at a distance of 5 m from the transmitter in the second scenario. Both direct and reflected waves are considered, and coverage map is demonstrated in Fig. 14.

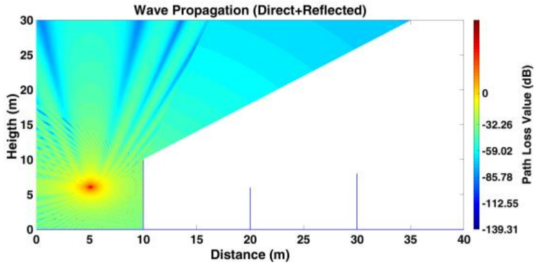

Fig. 14. Triple diffraction (direct and reflected waves).

As it is demonstrated in Fig. 14, there is a shadow region below the shadow boundary line of the first obstruction. There is no electromagnetic field behind the first obstruction owing to that there is no diffracted field in geometrical optic model.

As only diffracted waves are considered, the coverage map is plotted in Fig. 15.

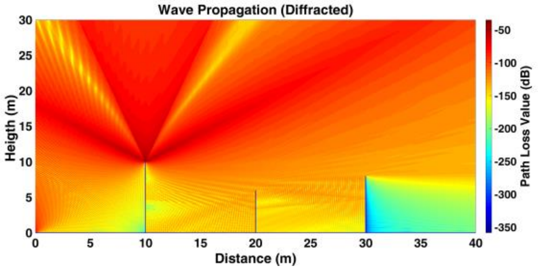

Fig. 15. Triple diffraction (diffracted waves).

As can be seen in Fig. 15, in contrast to geometrical optic model there is diffracted wave behind the obstructions. Also, the diffracted field effect is maxima (-50 dB) in the case of plane angle diffraction. Owing to triple diffraction, electric field strength reduced -350 dB in deep shadow region behind the third obstruction. In order to attest the results of UTD model, the same scenario has been run with FEKO software and plot of result is given in Fig. 16.

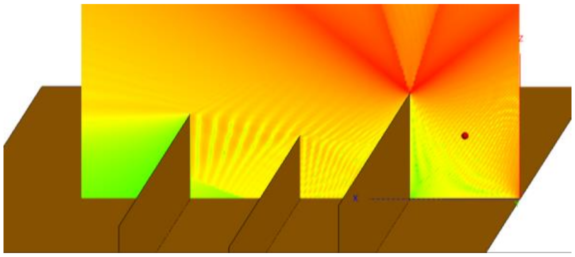

Fig. 16. Triple diffraction (diffracted waves, FEKO).

As can be seen in Fig. 16, FEKO software gives well-nigh the same diffraction pattern with developed program. Full coverage map is obtained by using direct, reflected and diffracted waves as it is indicated in Fig. 17.

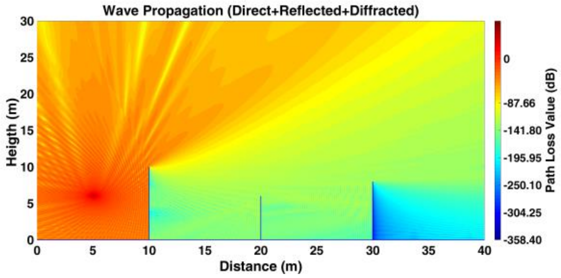

Fig. 17. Triple diffraction (full coverage).

As it is indicated in Fig. 17, there are diffracted waves below and above the shadow boundary lines of first, second and third obstruction. Also it is seen, there is a shadow (-87 dB), deep shadow (-195 dB) and the deepest shadow (-358 dB) region just behind the first, second and third obstruction, respectively. Moreover, an interference pattern has been generated by phase difference of diffracted, reflected and direct fields. In order to validate the results of UTD model for triple diffraction case, FEKO software has been run for the same scenario and images of the results are given in Fig. 18.

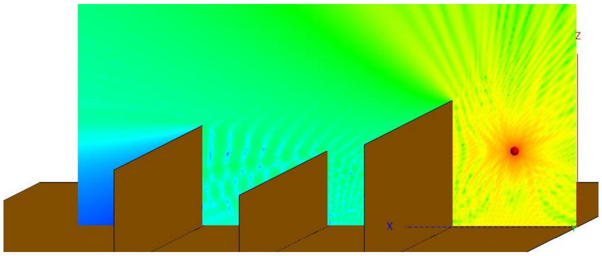

Fig. 18. Triple diffraction (full coverage, FEKO).

As can be seen in Fig. 18, FEKO software gives approximately the same diffraction and reflection and interference pattern with developed program.

IV. CONCLUSIONS

In real environment, there is almost no free space LOS and/or single diffraction in broadcasting systems. Geometrical optic model fails to calculate the field strength behind an obstruction because of diffraction. UTD model can be used in calculation of field strength and coverage prediction in multiple diffraction scenario including buildings, trees, hills, cars etc. In order to verify the results of developed program, detailed comparison results with FEKO software are represented. Coverage prediction should be made before base station installation in order to make more reliable broadcasting systems.

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Mehmet Baris Tabakcioglu He was born in 1981. He received B.S. degree in Physics from Middle East Technical University in 2005. Then he received the M.S. degree in Electrical and Electronics Engineering from Atılım University in 2009. After that he received the Ph.D. degree in Electrical and Electronics Engineering from Atatürk University in 2013. His currently research area is wave diffraction, reflection and propagation. He is currently working at Bursa Technical University in Electrical and Electronics Engineering department.