Comparison of Ray Theoretical Propagation Models with High Performance Computing

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Abstract**—**How electromagnetic wave propagates in the environment including obstructions that can be buildings, trees or hills? Electromagnetic waves are reflected or diffracted from these obstructions. To predict the coverage, field strength, relative path loss of electromagnetic waves at the receiving position, superabundant electromagnetic wave propagation models, which are classified to some classes such as ray tracing based models and numerical integration based models, are proposed. In this study some ray theoretical based propagation models are explained shortly. Uniform theory of diffraction (UTD), slope diffraction (S-UTD) and Slope diffraction with convex hull (SUTD-CH) models are compared in accordance with accuracy of predicting field and computation time. Furthermore comparison results of high performance parallel computing are given.

Keywords**—** Electromagnetic wave diffraction, High performance computing, parallel programming, S-UTD-CH model.

I. Introduction

To make trustable, time-efficient terrestrial digital radio broadcasting systems superabundant electromagnetic wave propagation models have been introduced in order to predict the relative path loss at the receiving point. Some electromagnetic wave propagation models are based on ray tracing technique and computation time and accuracy of model are less than numerical integration based models. On the contrary computation time and accuracy of integral based models are higher. In literature, so many ray theoretical models introduced [1-3]. Uniform theory of diffraction (UTD) model is introduced by Kouyoumjian and Pathak [4]. This model gives erroneous results in transition region. That is; in the case of that obstruction heights are close to each other, UTD model fails to predict the relative path loss accurately. Slope UTD model is introduced to remove the discontinuity of UTD model in transition region and shadow boundary points [5-7]. Slope UTD model loses the accuracy and compels so much computation time in multiple diffraction scenarios including more than 10 obstructions. To decrease the computation time, without compromising from accuracy, Slope UTD with convex hull (S-UTD-CH) model is introduced [8, 9]. In the case of that there are so many obstructions in the scenario; computation time of S-UTD-CH is high. In that case high performance computing has to be appealed to reduce the computation time. High performance computing based on parallel programming and there are a lot of CPUs in work station. In this study HP Z830 work station is used with 64 GB RAM, Intel Xeon 2670 processor 40 CPUs. Parallel programming software is coded in MATLAB media. “Parfor” command in MATLAB enables parallel computing and distributes the work into CPUs. In this study, after giving some brief information about models, models are compared with respect to computation time and accuracy. Moreover high performance computing results are given.

II. Propagation models

UTD model, proposed by Kouyoumjian and Pathak, applied into multiple diffraction scenarios. UTD model is the fastest propagation model. However accuracy of predicted field of UTD is relatively less than the other propagation models. If there is only one obstruction between transmitting and receiving antennas, UTD model gives accurate results in predicting the relative path loss. In the case of multiple obstructions, UTD fails to predict the relative path loss in the transition region exactly. To remove the transition zone diffraction problem of UTD model, slope UTD and improved slope UTD models are introduced. S-UTD model [5] shows singularities at the shadow boundary points caused by calculating the distance parameters wrongly. Distance parameter calculated by means of solving continuity equations. Due to not using phase continuity in Andersen’s model, there are singularities in relative path loss at the shadow boundary points. Improved slope UTD model [6, 7] removes the singularities by ensuring phase continuity. In the case of that there are more than 10 obstructions in scenario; improved slope UTD model loses the accuracy and need more computation time. To solve accuracy and computation time problems of improved S-UTD model, S-UTD-CH model is introduced [8, 9]. S-UTD-CH model based on fresnel zone concept and combination of improved slope UTD and convex hull [10] models. Most of the field emanates from the transmitter propagates in an ellipsoid region is called fresnel zone [11]. Obstructions are outside of this zone can be excluded from diffraction scenario due to less contributing to relative path loss at the receiver. Excluding the obstructions causes relatively less computation time without conceding accuracy. In the next section previously mentioned models are compared with each other with respect to computation time and accuracy. Moreover another comparison is made by using a work station to reduce the computation time with using high performance computing.

III. COMPARISON OF MODELS

In this section Slope UTD model is used as a reference model [12]. UTD and S-UTD-CH models are compared with S-UTD model according to accuracy and computation time respectively. Simulation scenario is taken from [13] as depicted in Fig.1.

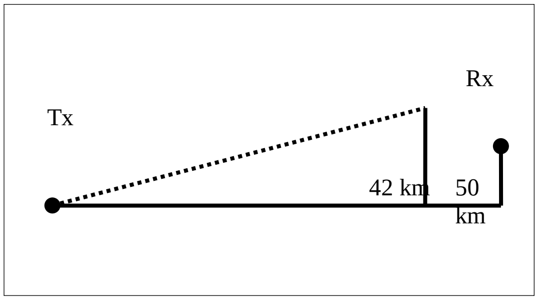

Fig.1. Diffraction geometry

As can be seen in Fig. 1, propagation path is 50 km, the operational frequency is 500 MHz and transmitter height is zero. Receiver height changes from 300 to 650 m. A single fixed knife edge type of obstruction with a height of 420 m is at a distance of 42 km from the transmitter. There are 4 different conditions of the path.

i) two additional knife edges types of obstruction, evenly spaced between 0 and 42 km, for a total of three obstructions,

ii) four additional knife edge type of obstruction, evenly spaced between 0 and 42 km, for a total of five obstructions,

iii) six additional knife edge type of obstruction, evenly spaced between 0 and 42 km, for a total of seven obstructions.

iv) eight additional knife edge type of obstruction, evenly spaced between 0 and 42 km, for a total of nine obstructions.

In all cases the heights of the additional obstructions are such that the tops just graze the direct line between the transmitter and the obstruction at 42 km.

Firstly, all three models are applied to scenario given in (iv) case that there are 9 knife-edges between the transmitter and receiver. Comparison results are shown in Fig.2.

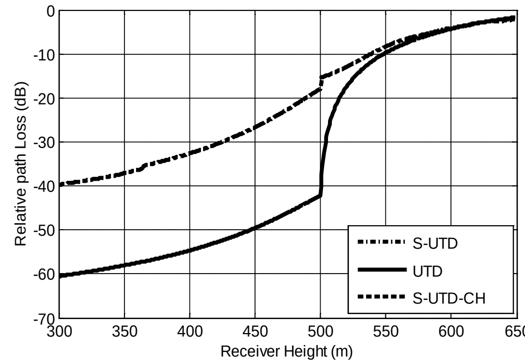

Fig.2. 9 Knife-edge scenario results

As can be seen in Fig. 2, solid, dashed and dotted lines represents the UTD, S-UTD and S-UTD-CH models respectively. Moreover, more than 20 dB differences between UTD and S-UTD model results from contribution of derivative terms. Furthermore S-UTD and S-UTD-CH models give almost the same results thanks to that ineffective knife-edges are excluded from the diffraction scenario. All models are run twice for normal and high performance computing. Computation times (s) of models are given in Table 1.

Table 1. Computation times for 9 knife edges

CPU	UTD	S-UTD	S-UTD-CH
2	462	13990	11342
40	154	3273	2468

As can be read from Table 1, First column gives the CPU numbers. Next columns show computation time of propagation models. Also it is seen in Table 1, UTD is the fastest model with relatively high error. Computation time of S-UTD-CH model is less than S-UTD model due to that effective obstruction number is less. Furthermore HP work station (40 CPU, 64 GB Ram, Intel Xenon 2670 Processor) reduces the computation time.

Secondly, all three models are applied to scenario given in (iii) case that there are 7 knife-edges between the transmitter and receiver. Comparison results are shown in Fig.3.

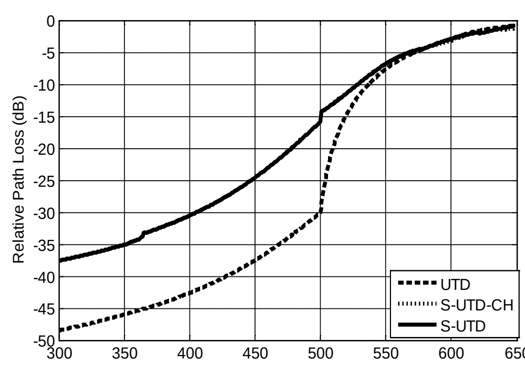

Fig.3. 7 Knife-edge scenario results

As can be seen in Fig.3, dashed, solid and dotted lines represents the UTD, S-UTD and S-UTD-CH models respectively. Moreover, approximately 13 dB differences between UTD and S-UTD model results from contribution of derivative terms. Furthermore S-UTD and S-UTD-CH models give almost the same results thanks to that ineffective knife-edges are excluded from the scenario. Computation times (s) of models are given in Table 2.

Table 2. Computation times for 7 knife edges

CPU	UTD	S-UTD	S-UTD-CH
40	49	489	402

As it is demonstrated in Table 2, First column gives the CPU number. Next columns illustrate computation time of propagation models with 40 CPUs. Moreover UTD is the fastest model (49 s) with relatively high error. Computation time of S-UTD-CH model (402 s) is less than S-UTD model (489 s) due to that effective obstruction number is less.

Finally, UTD and S-UTD models are applied scenarios given in (i-iv) cases. Simulation results are shown in Fig.4 and Fig. 5.

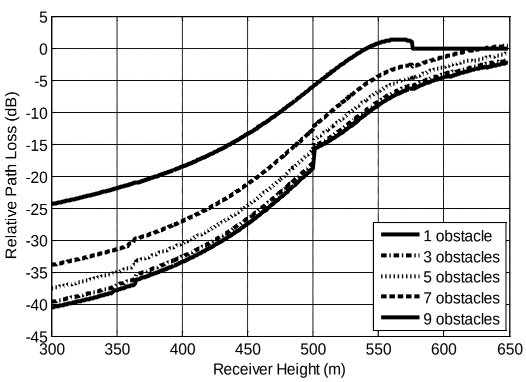

Fig.4. Simulation results of S-UTD model into Multiple diffraction geometry

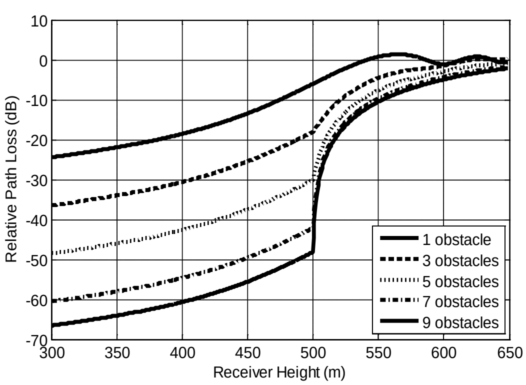

Fig.5. Simulation results of UTD model into Multiple diffraction geometry

As it is illustrated in Fig. 4 and Fig. 5, relative path loss decreases in the case of increasing obstructions number (>40 dB). Moreover slope term contribution for 9 knife-edges is approximately 26 dB. Also computation times for the cases are given in Table 3.

Table 3. Computation times of models

	1	3	5	7	9
S-UTD	32	51	177	3283	57855
UTD	32	42	64	149	535

As can be seen in Table 3, first row shows obstruction number in diffraction scenario. Second and third row demonstrates the computation time of S-UTD and UTD models respectively. Besides, computation time (for 40 CPU) increases with increase in obstruction number.

Another comparison is made among these three model into following scenario. There are 10 obstructions between transmitter and receiver position. The distance between the buildings and antennas is 25 m, building's heights are 20 m and operational frequency 100 MHz. Transmitter and receiver height are 10 and 1.5 m, respectively. In simulation HP Z820 64 GB RAM with 40 CPUs is used. Relative path loss and computation time of model is given Table 4.

As can be seen in Table 4, first column gives obstruction number in the diffraction scenario. Next three columns show relative path loss of the models S-UTD-CH, S-UTD and UTD, respectively. Following three column demonstrate the computation time of models. Last column gives eliminated building number. S-UTD model is reference model for relative path loss. As can be read from the Table 4, Although UTD model is the fastest model; it gives the most erroneous results in relative path loss. Also S-UTD and S-UTD-CH give almost the same results due to that obstruction number in the same height. Besides, eliminated building number is zero thanks to that Fresnel zone is wider and there is no excluded obstruction. Moreover, as the obstruction number decreases, computation time and relative path loss decreases, too. Furthermore, as the building number decreases, contribution of derivative terms of electric field decreases and finally contribution becomes zero.

IV. Conclusion

Ray theoretical propagation models are used in radio planning tool to predict the relative path loss and coverage. UTD model is fastest model; however give relatively large erroneous results in transition zone diffraction. Up to 10 diffractions, S-UTD model can be used as reference model with regard to accuracy. In the case of more obstructions, S-UTD loses accuracy and requires much more computation time. Also, S-UTD-CH model gives almost the same result with S-UTD model. Besides computation time of S-UTD-CH model is less than S-UTD model. Moreover, S-UTD-CH model would be used in scenario including great number of obstructions with high performance computing. Furthermore, as the diffraction number increases, relative path loss and contribution of S-UTD model increases, too.

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Table 4. Comparison Results of models

Building Number	S-UTD-CH RPL (dB)	S-UTD RPL dB)	UTD RPL dB)	S-UTD-CH Time (s)	S-UTD Time (s)	UTD Time (s)	Eliminated Building
10	-52,91	-52,91	-86,82	1355,95	1319,92	4,16	0
9	-52,12	-52,12	-80,71	208,52	206,09	1,93	0
8	-51,12	-51,12	-74,59	33,52	34,78	0,83	0
7	-50,17	-50,17	-68,44	5,93	5,79	0,47	0
6	-48,73	-48,73	-62,15	1,36	1,31	0,22	0
5	-46,57	-46,57	-56,05	0,48	0,4	0,16	0
4	-44,29	-44,29	-49,66	0,31	0,24	0,14	0
3	-40,99	-40,99	-42,99	0,25	0,14	0,15	0
2	-35,36	-35,36	-35,6	0,21	0,13	0,12	0
1	-23,72	-23,72	-23,72	0,22	0,11	0,1	0