An Improved Shooting and Bouncing Ray Method for Outdoor Wave Propagation Prediction

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Abstract **─** An improved algorithm for shooting and bouncing ray tracing (SBR) is proposed in this paper. The conventional SBR method has to launch a large number of rays or ray tubes to guarantee the accuracy, which increases the calculation time significantly. This paper presents a novel adaptive ray launching (ARL) method based on the pattern of transmitting antenna, which reduces the launched rays greatly while maintaining the computation accuracy. Some examples of applying the proposed method to calculate the outdoor radio wave propagation are presented, and the results are compared with the measurements and simulations. The good agreements between them validate the proposed approach. The method has a high gain in terms of computational efficiency (about 480% speedup compared with 1^0 uniform ray launching).

Index Terms **─** Acceleration, pattern, ray tracing, receiver ball, shooting and bouncing ray, transmitting angle.

I. INTRODUCTION

With the growing demands of electromagnetic environment management (EEM) and wireless communication network design (WCND), the radio wave propagation prediction in outdoor environment attracts more and more attentions recently. Owing to the complexity and large size of the outdoor environment, the ray tracing method rather than other numerical methods such as finite difference time domain method (FDTD) and finite element method (FEM), is often applied in the computation. There are basically two types of ray tracing, namely image method [1] and shooting and bouncing ray (SBR) method [2-3]. Although the image method can find the exact propagation paths from the transmitters to the receivers, however, the computational burden grows exponentially with the number of the facets or the walls in the environment [4]. Thus, its application is limited to very simple environment. The SBR method, on the other hand, is computationally efficient for the complex environment, and can well model the refraction phenomenon. However, generally the SBR method is less accurate than the image method for it launches a limited number of rays to save the computational time. Therefore, a large number of rays have to be launched to increase the accuracy, which greatly increases the simulation time simultaneously. Thus, a lot of research has been done to save the computational time of the SBR method in the published literatures [5-13]. A group of acceleration techniques incorporate bounding volumes, which reduce the simulation time mainly by decreasing the intersection test calculations [5-7]. In other research activities, the concept of spatial super-sampling is used [8-9]. Nevertheless, the intelligent reduction of the number of the rays is an efficient way to reduce the computational burden [10-13], by using wave-front decomposition method and line search theory.

In this paper, a new method to reduce the number of the rays is proposed. The method focuses on reducing the chance to trace these rays which cannot reach the receivers. The rays with strong possibility to reach the receiver are refined to enhance the accuracy of the simulation. This is achieved by dynamical iterations of transmitting angle and the receiver ball radius. Moreover, the ray assignment is combined with the pattern of the transmitter, leading to more rays are sent out in the direction of the main lobe, which enhances the computational accuracy and efficiency at the same time.

The organization of this paper is as follows. In Section II, the proposed method is introduced. In Section III, some examples of applying the method for studying the outdoor radio wave propagation are presented, and the results are compared with other methods and measurements. The conclusion is drawn in Section IV.

II. METHOD DESCRIPTION

In traditional SBR method, the source is often modeled with a limited number of rays, which are uniformly generated in all directions of the three-dimensional space with identical angular separation [14-16]. However, the transmitting angles that transport electromagnetic power to the receivers constitute only a

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small fraction of the total space. If these transmitting angles are specified prior to the start of the high-resolution ray tracing, the refinement rays are launched only through them, and the computational burden decreases significantly. In this paper, it is proposed to find the transmitting angles around the transmitter that transport electromagnetic power to the receivers firstly and then trace the rays in those angles with a high resolution. Some iterative algorithms are applied, which include adaptive receiver ball radius and changeable transmitting angles. As the method used in the commercial software Wireless Insite (WI) [16], the transmitting sphere is often divided by 1^0 angles, and every angle sends out a ray. Thus, there are 64800 rays sent out from the source initially and the number would increase dramatically for modeling scattering and diffraction effects, which depends on the terrain and geometry environment. Thus, the number of rays is increased significantly in complex environment if all the rays from the source should be traced. In our model, however, the transmitting angles are not uniform and are iterated step by step. Moreover, the angles are dependent on the pattern of the transmitter. The angles in the main lobe of the transmitter are assigned much smaller while the angles in other directions are roughly assigned. For example, a diploe has 60^0 beam-width in E plane and is omni-directional in H plane. If 3^0 transmitting angle is applied in the main lobe and 10^0 transmitting angle is applied in other directions, there are only 2832 rays sent out from the source. So, the rays launched initially are less than the traditional method with 1^0 uniform ray launching.

The steps are as follows:

1) Firstly, the radius of the receiver ball is set as half of the distance between the transmitter and the receiver. Such large radius is to guarantee receiving as many rays as possible and thus avoid leaving out the rays that contribute to the total electromagnetic field at the receivers. In other words, this process is to roughly determine the fraction of the sphere around the transmitter from which the rays are needed to be refined.

2) Then, according to the received rays in last step, the iterations of the receiver ball and transmitting angles are implemented. If the ray from the transmitting angle is received, the transmitting angle should be refined, and more rays are emitted from this transmitting angle. During the iteration, the radius of receiver ball is reduced by half until it reaches the threshold, which is 1/10 of the distance between the transmitter and the receiver. This threshold is obtained on the basis of thousands of experiments. The process and flow chart are displayed in Fig. 1 and Fig. 2, respectively.

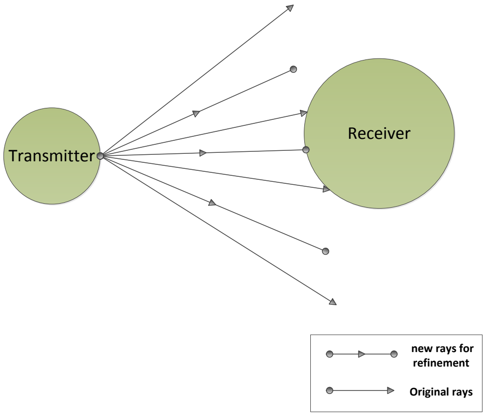

Fig. 1. The iteration of rays.

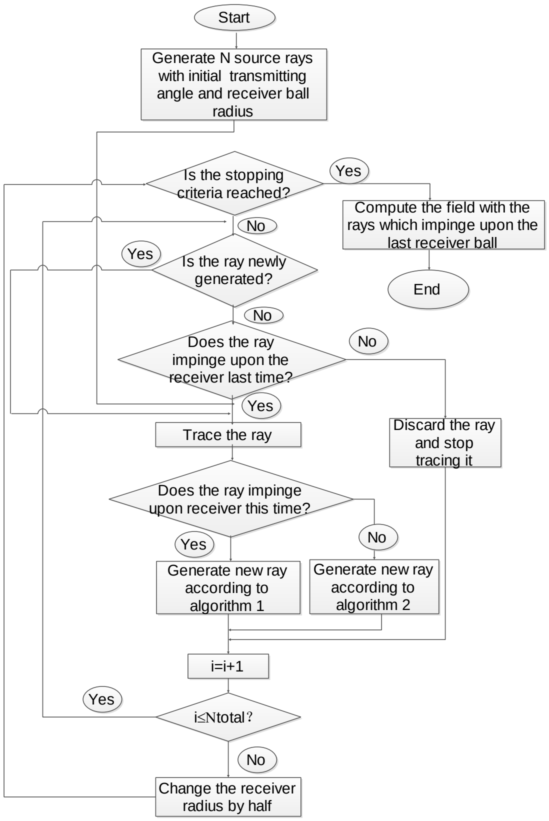

Fig. 2. Flowchart of the proposed method.

According to Fig. 2, N rays are launched initially, and the receiver ball radius is assigned according to the distance between the transmitter and the receiver. Then these rays are traced one by one and recorded according to this radius. After all these rays are traced, the receiver ball radius is reduced by half. And then these rays are traced according to the new receiver ball radius. The rays which are not received in the last iteration would be discarded in this iteration. After determining whether the ray illuminates the receiver or not in this iteration, two branches appear: one is "Generate new rays according to algorithm 1" and the other is "Generate new rays according to algorithm 2". In algorithm 1, if the neighboring ray is also received, one more ray is launched between them for refinement. On the other hand, if the neighboring ray is not received, one more ray is launched between them for narrowing the range of the ray generation. In algorithm 2, if the neighboring ray is received, one more ray is launched between them for narrowing the range of the ray generation. If the neighboring ray is not received, no more rays are launched between them. After all the rays are traced and recorded once, the receiver ball radius is reduced by half. The procedure is repeated until the stopping criteria is reached, which is the minimal receiver ball radius.

To provide an efficient way for data storage and path searching, the data structure is designed as shown in Fig. 3. The information of every ray is comprised of four parts, which are starting point, direction vector, flag to mark whether the ray is received or not, and the path information.

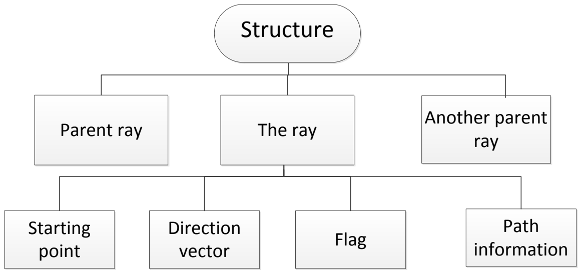

Fig. 3. Data structure for rays.

III. NUMERICAL RESULTS

Two examples in the outdoor scenarios are investigated with the proposed algorithm in this part.

The first scenario is shown in Fig. 4. The transmitter is a planar antenna consisted of a dipole antenna array with a reflector of a base station, whose input power is about 43 dBm, and the gain is about 13 dBi. The center frequency is 935 MHz. Its location in the electric map is x = 207 m, y = 528 m and z = 20 m. It is located on the roof of a building, which is marked with a red triangle. There are three receivers, which are all half wave dipole antennas and marked with the red circles. The receiver 1 is located at the position where x = 382 m, y = 199 m, and z = 2 m. The receiver 2 is located at x = 94 m, y = 0, z = 2 m. The receiver 3 is at x = 1046 m, y = 134 m, z = 2 m. The distances between the transmitter and the three receivers are 373 m, 540 m and 927 m, respectively. The terrain is loaded from the electric map directly. The conductivity and permittivity of different materials are listed in Table 1.

Fig. 4. The transmitter and receivers in an outdoor scenario.

Table 1: Material properties

Material	Conductivity (S/m)	Relative Permittivity
Concrete wall	0.015	15
Brick wall	0.014	4
Wood	0	5
Asphalt	0.0005	5.72
Ground	0.001	4
River	0	81
Grass	0.085	40
Leaf	0.39	26
Branch	0.39	20

The calculation area is several square kilometers. In such site - specific environment, numerous reflections and diffractions occur. If the transmitting angle is uniformly set as 1^0 according to the traditional method, it takes 8 hours and 13 minutes to complete the calculation. However, if the transmitting angle is uniformly set as 10^0 firstly, and then is refined on the basis of the received rays, the computation time is only 33 minutes. As an improved method for the accuracy, if the transmitting angle is assigned by the pattern of the transmitter, in which the transmitting angle is set as 3^0 in the main lobe direction and 10^0 in other directions firstly, and then is iterated based on the received rays, the computation time is 1 hour and 25 minutes. In this model, the smallest transmitting angle is only 0.0625^0 finally. The eventually received rays and computation accuracy are compared in Table 2.

From Table 2 and Fig. 5, it can be found that the method with adaptive transmitting angle improves the accuracy comparing with the traditional method. Moreover, the accuracy is highest when the transmitting angles are assigned on the basis of the pattern of the transmitter. The results obtained with this improved method are very close to the measurements. The proposed method not only improves the computational accuracy, but also saves a lot of the computational time. The computational efficiency is enhanced by a factor of 4.8 compared with 1^0 uniform ray launching.

Table 2: Comparisons with measurements

	Measurement	1^0 Fixed	10^0 Iterative	3^0+10^0 Iterative
Received rays at receiver 1		12	8	18
Power at receiver 1	-20.4 dBm	-36.3 dBm	-25.6 dBm	-21.4 dBm
Received rays at receiver 2		10	7	16
Power at receiver 2	-23.5 dBm	-38.1 dBm	-28.5 dBm	-23.8 dBm
Received rays at receiver 3		9	6	15
Power at receiver 3	-29.7 dBm	-46 dBm	-30.5 dBm	-29.8 dBm

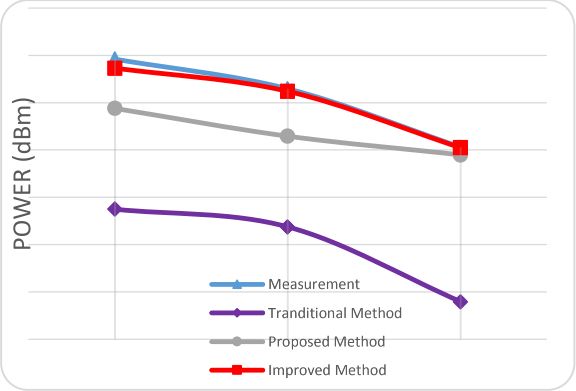

Fig. 5. Comparison between different methods and measurements.

To further verify the proposed method, the electric fields at 80 different points are calculated with the proposed method and Wireless Insite (WI) simulation. The results obtained by the proposed method are close with those by the WI simulation. In addition, the electric fields vs. distance and height are investigated in Fig. 6 and Fig. 7, respectively. In Fig. 6, the transmitter with a dipole antenna is located at the position where x = 49 m, y = 193 m, and z = 10 m, and 50 receivers are located at different positions with a 10 m interval with the neighboring one. It can be found that the electric field attenuates with the distance between the transmitter and the receiver. The reason why the electric fields at those points at the beginning are smaller is because that there are not line of sight paths between the receivers and the transmitter owing to the terrain.

In Fig. 7, the transmitter is same as that in Fig. 6, and 30 receivers are located the position where x = -73 m and y = 108 m. The height of these receivers varies from 10 m to 300 m with 10 m interval. From Fig. 7 we can see that the electric field attenuates with the height since the distance between the transmitter and the receiver increases as the height increases.

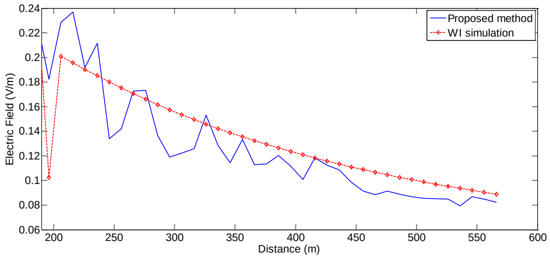

Fig. 6. Electric field vs. distance.

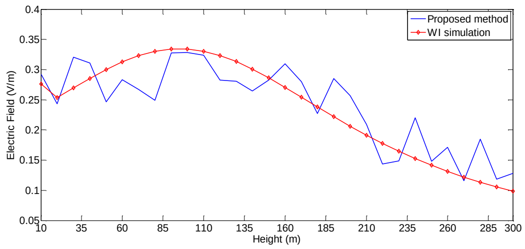

Fig. 7. Electric field vs. height.

IV. CONCLUSION

A new acceleration technique for the ray tracing method was presented. The proposed method is extremely suitable for the wave propagation prediction in the complex and electrically large environment. The results indicated the proposed approach had a speedup of 480% and a high accuracy compared with the measurements and the WI simulation. The proposed method can be applied in the EEM and WCND in practice.

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