Research of radio wave propagation in forest based on Non-uniform mesh Parabolic Equation

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***Abstract*- Non-uniform mesh technology of parabolic equation method is introduced to solve the radio wave propagation problems in forest more efficiently. The simulation errors of radio wave propagation in forest with different uniform grids are analyzed first. The results indicate that fine grid in forest area is necessary to ensure the simulation accuracy. As typical scenes for simulation are usually forest region within a large area, using uniform fine grids requires large computation memory. Hence, the non-uniform mesh technology is employed. The performance of non-uniform mesh technology in the application of local forest scene is analyzed. The result obtained by non-uniform meshes is in good agreement with that obtained by uniform fine grids. Besides, it makes nearly three times reduction of computation time compared with the one with uniform fine grids in this example. This demonstrates that the employment of non-uniform mesh parabolic equation method for forest scenes simulation can improve the computational efficiency greatly.**

***Key words*- Parabolic equation, Forest, Non-uniform mesh, Radio wave propagation**

I. INTRODUCTION

The research of radio wave propagation in complex electromagnetic environment is an important project in modern electromagnetic field [1, 2]. In the rural and suburban areas, forest is an important factor of affecting the radio wave propagation over a long distance [3, 4]. For the scattering and absorption of trees, the attenuation and phase shift of signal will happen, which affects the target identification, remote sensing and wireless communication greatly. Therefore, it has very important practical application value to study the forest effect on wave propagation.

The parabolic equation (PE) method, introduced by Leontovich and Fock in 1946 [5], is applied to the underwater acoustics problems at the earliest and has been used extensively in electromagnetic field since the mid-1980s. PE can deal with the inhomogeneous medium and complex boundary conditions and has been widely used to simulate the radio wave propagation characteristics in complex electromagnetic environment [6, 7].

Comparing with experimental results, Tamir obtained that forest can be viewed as a dissipative dielectric slab in solving the radio wave propagation problems in range 2-200 MHz, and the effective dielectric constant approached 1 [8]. As effective dielectric constant satisfies the PE approximation conditions, the radio wave propagation characteristics can be easily solved through PE.

In recent years, scholars at home and abroad have done some research about the radio wave propagation problems in forest using PE. The radio wave propagation characteristics are simulated by Palud [9], including the source located inside and outside forest. Through the finite-difference algorithms of PE, the radio wave propagation problems over Irregular Terrain partly covered by forest are solved by Holo and the results are compared with experiments [10]. Besides, the radio wave propagation characteristics in areas covered by forest entirely and partly respectively are analyzed by Jianyan Guo based on the split-step Fourier transform algorithm [4, 11]. At present, the uniform grid is used in all PE simulations for forest. The computing resources and calculating time will increase when using the uniform fine mesh, and the computational accuracy will reduce when using the uniform coarse grid. To this end, the non-uniform mesh technology of PE is introduced in this paper and from the simulation result it is found that the computational efficiency is improved greatly for wave propagation problems in large scale forest environment.

II. OVERVIEW OF PARABOLIC EQUATION

In rectangular coordinate system, we assume that $e^{-i\omega t}$ is the time-dependence of fields, where ω is the angular frequency. The field component ψ satisfies the two-dimensional scalar wave equation [12]

$$\frac{\partial^2\psi(x,z)}{\partial x^2}+\frac{\partial^2\psi(x,z)}{\partial z^2}+k_0^2 n^2\psi(x,z)=0 \qquad (1)$$

Where ψ is the electric field for horizontal polarization or magnetic field for vertical polarization. n is the refraction index. k_0 is the wave number in vacuum. Introduce the reduced function associated with the paraxial direction x

$$u(x,z)=e^{-ik_0x}\psi(x,z) \qquad (2)$$

Now plugging (2) into (1) and factoring(1), we can get the forward parabolic equation

$$\frac{\partial u}{\partial x} = -\mathrm{i}k_0(1-Q)u$$

(3)

Where Q is the pseudo-differential operator and is defined by

$$Q = \sqrt{\frac{1}{k_0^2}\frac{\partial^2}{\partial z^2} + n^2}$$

(4)

By using the Feit-Fleck approximation [13] of Q, the wide angle parabolic equation(WAPE) is obtained

$$\frac{\partial u(x,z)}{\partial x} = \mathrm{i}k_0\left[\sqrt{1+\frac{1}{k_0^2}\frac{\partial^2}{\partial z^2}} - 1\right]u(x,z) + \mathrm{i}k_0\left(n-1\right)u(x,z) \qquad (5)$$

The WAPE can be solved using the split-step Fourier transform algorithm(SSFT), which is represented as

$$u(x_0+\Delta x, z) = e^{\mathrm{i}k_0\Delta x(n-1)}F^{-1}\left\{e^{\mathrm{i}\Delta x\left(\sqrt{k_0^2-p^2}-k_0\right)}F\left[u(x_0,z)\right]\right\} \qquad (6)$$

Where $u(x_0,z)$ is the initial field. Δx is the range step. F and F^{-1} indicate the Fourier transformation and inverse Fourier transformation respectively. $p=k_0\sin\alpha$ is the variant of z, α is the grazing angle. SSFT is a algorithm marching over range steps and its range step is almost not limited by wavelength, so it can be easily applied to solve the radio wave problem in large scale complex environment.

III. NON-UNIFORM MESH TECHNOLOGY FOR PARABOLIC EQUATION

A. Analysis of range step in forest

The influence of range step on simulation results is analyzed for 100 MHz and 200 MHz. We assume that the antenna height is 16 m, the receiving height is 10 m, atmosphere is ideal uniform air, the relative dielectric constant and the conductivity of the earth surface are 20 and 0.01 S/m respectively. the forest condition: height 19 m, equivalent complex permittivity 1.064+0.037i.

Compared with the Tamir model, Propagation loss(PF) on the receiving height for 100MHz and 200MHz are simulated, which are showed in figure 1 and figure 2.

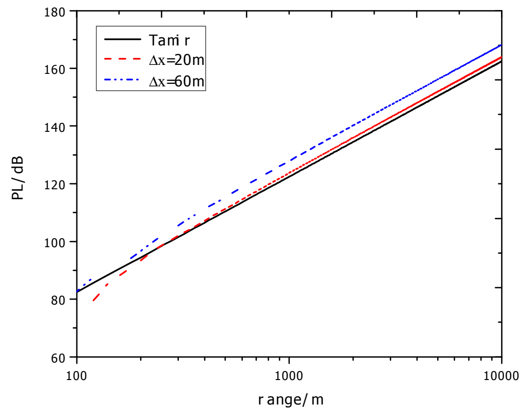

Figure 1 Propagation Loss for frequency 100MHz

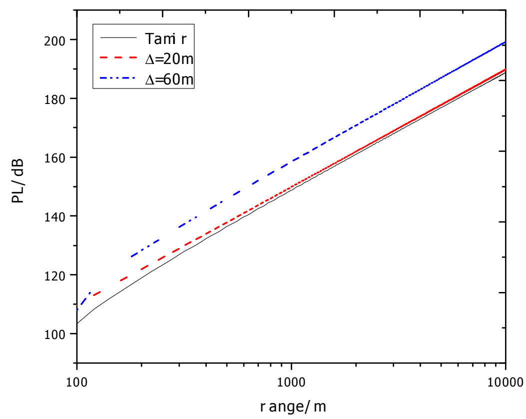

Figure 2 Propagation Loss for frequency 200MHz

Figure 1 and Figure 2 indicate that the error of PE increases with the increasing of range step. Compared with the Tamir model, the max error is 6dB and 12dB respectively for 100 MHz and 200MHz when the range step is 60m. Thus, we should reduce the range step to improve the simulation efficiency for forest scene.

B. Non-uniform mesh technology

From the previous analysis, we get that the range step should be reduced to improve the computational efficiency for solving the radio wave propagation problems in forest. In large scale areas, if the space is divided by the uniform fine mesh, the computing time will be added greatly, which is bad for rapidly solving the radio wave propagation problems. Therefore, the paper introduces the non-uniform mesh technology of PE. The general idea: the uniform fine mesh is adopted in areas covered by forest where the electromagnetic field changes quickly and the uniform coarse grid is used in the open areas where the electromagnetic field changes slowly to reach the equilibrium between calculation accuracy and computation time.

IV. NUMERICAL EXAMPLES

The radio wave propagation characteristics in partly forested area are simulated based on the non-uniform mesh technology and the results are compared with the uniform fine mesh and the uniform coarse grid.

In this example, the forest exists in range from 10 km to 20 km, the max range is 32 km, source frequency is 0.1 GHz. Other parameters are set the same as the previous example. The range step of uniform fine mesh is set to 10 m and the uniform coarse grid is set to 100 m and 150 m respectively. the minimal range step of non-uniform mesh is 10 m and the maximal range step is 200 m. The contour of propagation factor on the receiving height is plotted in Figure 3.

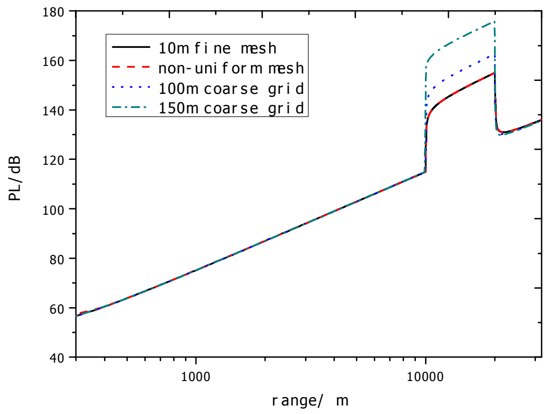

Figure 3 Propagation Loss

The figure 3 shows that there is excellent agreement for different grids in the area without forest. The uniform coarse grid will bring large error in the forest area and the error increases with the increasing of grid size. The good agreement between the non-uniform mesh and the uniform fine mesh validates the correctness of non-uniform mesh technology in forest.

The calculating time of uniform fine mesh and non-uniform mesh is showed in Table I.

TABLE I
CALCULATING TIME

mesh type	time / s
uniform fine mesh	29.028
non-uniform mesh	9.656

Table 1 shows us that the calculating time of uniform fine mesh and non-uniform mesh are 9.656 s and 29.028 s respectively. Compared with the uniform fine mesh, the computing speed of PE is improved by nearly three times with the uniform fine mesh, which is very important in simulating the electromagnetic characteristics rapidly in large scale areas, especially in the three-dimensional space. From the previous analysis we can see that PE with non-uniform mesh has good precision, this demonstrates that the non-uniform mesh technology can improve the computational efficiency greatly when solving the wave propagation problems in forest.

V. Conclusion

In this paper, the non-uniform mesh technology is employed to improve the computation efficiency when the simulation scenes are local forest within a large area. The numerical results show the advantages of non-uniform mesh technology. Comparing with the result using uniform fine grids, the one using non-uniform meshes can reduce the computation time while keeping the simulation accuracy.

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