STUDY ON HIGH EFFECTIVE SIMULATION OF COMPLEX ELECTROMAGNETIC ENVIRONMENT

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Abstract

The simulation of Complex Electromagnetic environment (CEME) is very helpful and can provide much information for communication systems design and the testing of electronic equipment. In order to simulate CEME in a computer, the commutating time and capacity of the computer memory must be considered, especially for large-scale areas. In this paper, a hierarchy and structure of high efficiency simulation for CEME is proposed, as well as the performance index in the simulation. A new performance index is given out to deal with the use of computer memory, communication time, and power consumption. In order to calculate the matrix equation for CEME simulation, we can use computer clusters, and solve the matrix equation which is the derivation using the finite-difference (FD) method by parallel computing. This method requires much higher arithmetic speed, timeliness handling accuracy, and fleetness of the computers. The energy consumption of the entire system is considered in the performance index. The conservation of energy concept in high efficiency simulation for CEME is investigated, and the optimal method used to obtain the optimal performance in the simulation system is studied. In order to get good performance and high efficiency, multi-object optimization method (MOOM) is employed to minimizing the communication time, power consumption, computer memory.

Keywords: CEME simulation, high effective simulation, parallel computation, optimal method

Presenting Author's biography

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1 Introduction

Complex Electromagnetic environment (CEME) is very important in both civil and military wireless communication systems. The simulation of CEME is very helpful and can provide much information for communication systems design and the testing of electronic equipment.

CEME itself is a complex system; its main characteristics are as follows:

In order to simulate the electromagnetic wave propagation in the real environment, the atmosphere, terrain, ocean model, and so on, must be considered during the modeling of CEME, which is a huge and complex system.

Simulation of CEME is a large-scale areas simulation, and it a huge amount data and computation has to be deal with.

The methods and models proposed for CEME simulation, such as the numerical solution of Maxwell's equations, is very time consuming and requires large capacity of memory.

Based on the above characteristics of CEME simulation, in order to simulate CEME in a computer, the commutating time and capacity of the computer memory must be considered. In this paper, a hierarchy and structure of high efficiency simulation for CEME is proposed, as well as the performance index in the simulation. The energy consumption of the entire system is considered in the performance index. The conservation of energy concept in high efficiency simulation for CEME is investigated, and the optimal method used to obtain the optimal performance in the simulation system is studied. After optimization the energy consumption, computation time and computation node communication time will be optimized.

This paper is organized as follows. The CEME simulation model, and the modeling assumptions and methods considering less computing time and memory are described in Section 2. In addition, the method to calculate the modeling equation, which can make computation much faster, is discussed in section 2. The high efficiency simulation scheme and the optimal method for CEME is presented in Section 3. Section 4 concludes the whole paper.

2 Simulation model of CEME

The simulation model of electromagnetic environment model consists of the atmosphere, terrain model, etc. Maxwell's equations are the basic rule of electromagnetic, and a lot of methods have been used to address them for object scattering and propagation problems. There are many methods such as the method of moments (MoM) and finite-difference time-domain (FDTD), which can solve Maxwell's equations exactly. However, because of the large-scale computation areas involved in radio wave propagation modeling in CEME, it is usually impossible to solve Maxwell’s equations directly. Alternative approaches must be utilized to obtain the solution in a reasonable time and limited computer memory.

There are approximate methods based on ray-tracing (RT), physical optics (PO) or parabolic differential equation (PE) solutions. Despite the fact that FDTD can only solve electrically small-scale problems, approximate methods like PE can be used for solving large-scale areas easily and is a good and efficient method for solving propagation problems.

In order to simulate CEME in a computer with the PE method, we have the following assumptions：

The earth is an ideal and symmetrical sphere, and the atmosphere architecture refractive index n of its surface is hierarchical obviously in the r direction.

The field in propagation path is symmetrical about the azimuth angle ϕ .

The field in both directions has nothing to do with the azimuth angle ϕ , and the dielectric constant ε changes very little along with it.

In a propagation path, there is no affect to path wasting with the landscape orientation variable of the terrain.

Based on the above assumptions, the scalar wave equation can be obtained, and it can be simplified into a two dimensional equation.

2.1 Standard parabolic equation modeling

Based on the assumptions, in the following formulation, the atmosphere is assumed to vary in range and height only, which makes the field equations are independent of azimuth. At the same time, it is assumed that the time dependence of $\mathrm{e}^{-i\omega t}$ in the field components. We begin with the parabolic wave equation for a flat earth [4-5] ,

$$\frac{\partial^2\psi}{\partial x^2}+\frac{\partial^2\psi}{\partial z^2}+k_0^2n^2\psi=0 \tag{1}$$

Where k_0 is the solution propagation constant and n is refractive index. The field ψ that represents a scalar component of the electric field is considered y independent, x and z are the spatial Cartesian coordinates corresponding to range and height, respectively.

Let u be the electric field, and

$$u(x,z) = e^{-ik_0 x}\psi(x,z) \quad (2)$$

By substituting (2) in (1) and with some approximation, a partial differential equation for u can be extracted as follows.

$$\frac{\partial^2 u}{\partial x^2} + 2ik_0\frac{\partial u}{\partial x} + \frac{\partial^2 u}{\partial z^2} + k_0^2(n^2-1) = 0 \quad (3)$$

Based on assumption (1), $\partial(n^2)/\partial x \approx 0$, this can be formally factored as

$$\left[\frac{\partial}{\partial x} + ik_0(1-Q)\right]\left[\frac{\partial}{\partial x} + ik_0(1+Q)\right]u = 0 \quad (4)$$

Forward propagation corresponds to rays propagating with increasing x, and backward propagation to rays propagating with decreasing x. By using the forward propagation wave equation，we can get the PE as follows

$$\frac{\partial u}{\partial x} = -ik_0(1-Q)u$$

Different approximate expressions of Q can generate different PE, and different PE has different computation precision.

By using a first-order Taylor expansion of the exponential term and the square-root, Q is defined as follow:

$$Q = \sqrt{1+q} \cong 1 + 0.5q$$

Where $q = \frac{1}{k_0^2}\frac{\partial^2}{\partial z^2} + n^2(x,z) - 1$. Hence, a standard parabolic equation (SPE) can be obtained as follows:

$$\frac{\partial u(x,z)}{\partial z} = \frac{ik_0}{2}\left[\frac{1}{k_0^2}\frac{\partial^2}{\partial z^2} + n^2(x,z) - 1\right]u(x,z)$$

This SPE is suitable for large scale wave propagation problems. It has good computation precision for small angles, which is up to 15°.

By using different approximate expressions of Q, the better computation precision for larger angles can be achieved. The following key problem is to improve the emission angles suitable for a numerical solution by computer.

2.2 Problems in CEME simulation with PE

Numerical solutions of the PE are primarily classified into two categories, the Fourier/split-step (FSS) and finite-difference (FD) method approaches [1-2, 5-7]. The FSS methods allow for a relatively large range step. However, some complex boundary conditions cannot be dealt with by FSS. In the FD method, implementation of the appropriate boundary condition is usually straightforward. A disadvantage FD, however, is a requirement for fine sampling on the horizontal or range grid, which makes the calculations computationally intensive, especially for large-scale areas.

For the FD method [2, 4-5], it is assumed that the lower boundary is horizontal, and located at $z = 0$. We start by defining the integration grid, which is fixed in the vertical direction, but not in a range, so the terrain shape can be adapted. Set

$$z_j = j\Delta z, j = 0,\ldots,N$$

$$x_m = m\Delta x, m = 0,\ldots,N$$

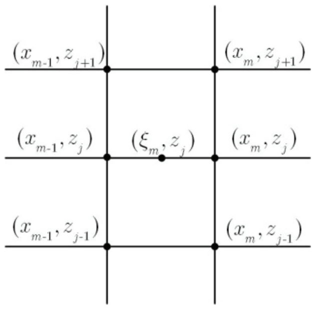

Fig. 1 FD grid in a Crank-Nicolson scheme

In order to advance the solution from range x_{m-1} to range x_m, the midpoint is considered:

$$\xi_m = \frac{x_{m-1} + x_m}{2}$$

The basic idea is to write FD expressions for the partial derivatives at point (ξ_m, z_j), as shown in Fig. 1.

Based on the derivation in [5], the matrix form of the scheme can be given as follows:

$$A_m U_m = B_m U_{m-1}$$

Where U_m is the vector giving the field at range x_m

$$U_m = \begin{bmatrix} u_0^m \\ \vdots \\ u_N^m \end{bmatrix}$$

Computation time and capacity of the computer memory are the key problems in the simulation of CEME.

Fig. 2 is the CEME computing time related to simulation distance and height. Simulation of CEME is a large-scale areas simulation, the larger distance and height is simulated, the longer computing time will be used. For one PC, because of the limit of memory and computing time, it is difficult to deal with large-scale areas and huge amount data.

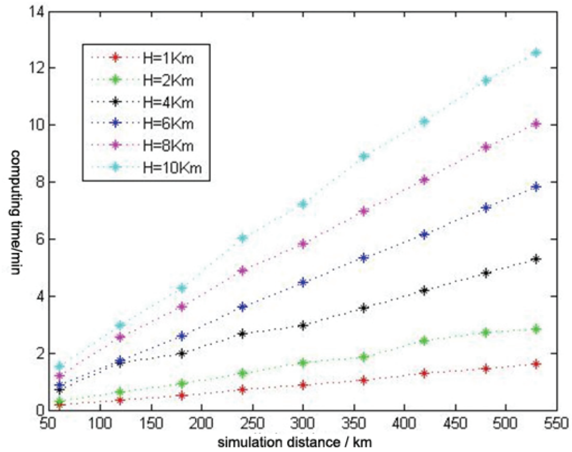

Fig. 2 CEME computing time related to distance

We can compute a serial 2DPE in *y* direction to simulate a 3DPE model which called Quasi-3DPE. Base on Quasi-3DPE, we simulation the space about 60km*64km*2km in PC:

Software environment:

Operation System: Windows XP

Hardware environment:

CPU: AMD Opteron™ Processor 2.2GHz

Memory: 2GB

The computing time is 141.5667 minutes.

In order to take advantage of FD, computer clusters can be used to improve the computational level. Then we can both deal with complex boundary conditions and get high computation speed in CEME simulation.

3 High effective simulation for CEME

In order to calculate the matrix equation for CEME simulation, we can use computer clusters, and solve the matrix equation which is the derivation using the FD method by parallel computing. A parallel cluster is built under the Linux environment, and a MPI is combined base on the parallel cluster environment.

This method requires much higher arithmetic speed, timeliness handling accuracy, and fleetness of the computers. Therefore, a PC cluster system based on fleet technology and distributed store technology becomes an effective approach satisfying the high-performance data handling requirements. How to make better use of PC clusters, design high-effect and stable parallel algorithms for a CEME simulation, is one of the hot spots in the computer simulation field at present, it also has a broad application background and practical value.

The parallel scheme for the CEME simulation:

A. Use parallel algorithms to solve the 2DPE matrix equation: $A_m U_m = B_m U_{m-1}$.

B. Use parallel algorithms to compute every equation group of the Quasi-3DPE.

C. Combine scheme A and scheme B.

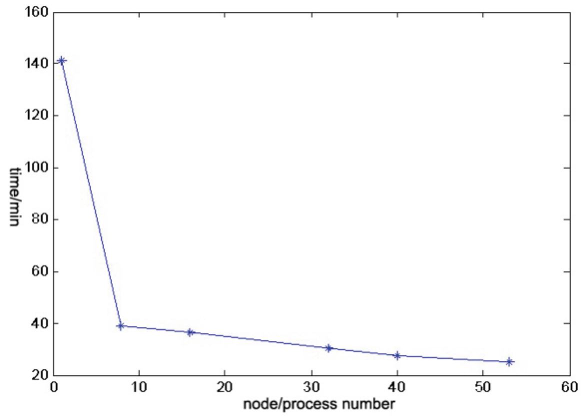

Fig. 3 CEME computing time related to node/process number

Fig. 3 is the simulation result of scheme B. The simulation space is about 60km*64km*2km.

There is no parameter and algorithm optimal in the scheme. If the simulation space is much larger than above, it will take more computing time.

In this paper, a new performance index is given out to deal with the use of computer memory, communication time, and power consumption. The performance index is as follow:

$$J = C + P + M = \sum Comm_{ij} + \sum Power_i + \sum Mem_i$$

Where $Comm_{ij}$ is the communication time from Node *i* to Node *j* in the computer clusters, $Power_i$ is the power consumption of Node *i*, and Mem_i is the computer memory of Node *i*.

The key problem is how to express the *C*, *P*, *M* in the parallel algorithm structure. We will either get expressions of them or functions of them.

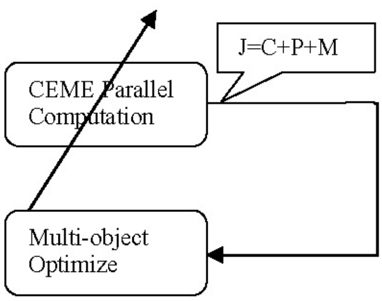

Fig. 4 High efficiency simulation structure

In order to get good performance and high efficiency, multi-object optimization method (MOOM) is employed to minimizing the *C*, *P*, *M*.

We can use a novel quantum multi-agent evolutionary algorithm (QMAEA) for MOOM algorithm [8]. QMAEA is combining agents and quantum-bit.

In QMAEA, each agent represented by a quantum-bit is defined as a candidate solution, and agents can reproduce, perish, compete for survival, observe and communicate with the environment. Operators such as energy evaluation, competition, crossover, mutation, and trimming are designed to specify the evolvement of QMAEA. Three evolutionary strategies are designed to balance the exploration and exploitation of QMAEA.

In our future work, we will give the parallel algorithms and the optimal methods used for the performance index.

We have developed a CEME simulation system, which can compute the propagation of electromagnetic wave in irregular terrain. The terrain data is converted from the DEM data. The simulation area and terrain material can be set in the system.

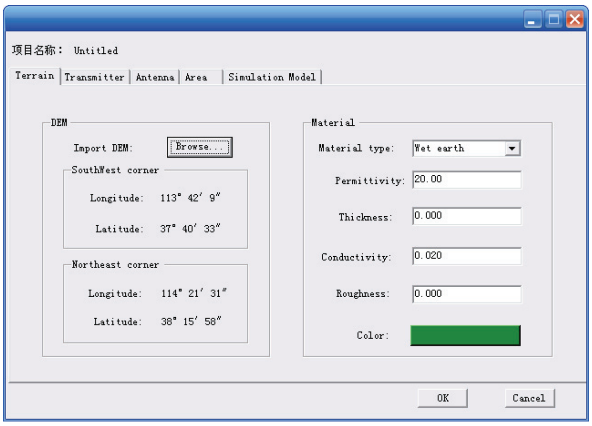

Fig. 5 CEME simulation system configure interface

The Electromagnetic environment is invisible to us, but in a war and communication test, people intercommunicate with the environment mainly from visual information. It is important for us to make the invisible electromagnetic field visible. Fig. 6 is the propagation power display in 2D in our CEME visualization system, and different colors means different power strength.

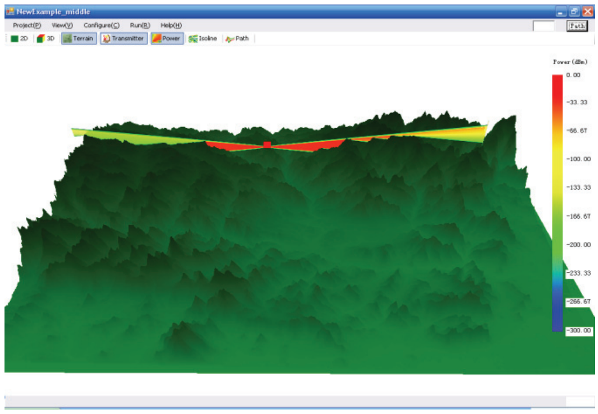

Fig. 6 CEME simulation visualization

The characterization of CEME data is massive and should be displayed in real-time for visualization. And for 3D or 4D visualization, real-time is the key index for the visualization effect. Real-time methods to directly convey the data of large volumetric scalar or vector fields are still a challenge to the computer graphics community. Based on the observation that the capability of a single general-purpose CPU is not sufficient to achieve interactivity or even real-time for large data sets in general, considerable effort must be spent on the development of acceleration techniques for GPU-based volume rendering and on the design and exploitation of parallel visualization method and hardware.

This consists of all kinds of the electromagnetic signal types, properties and distribution information in the CEME visualization. It should show not only the CEME visualization situation but the terrain, forest and atmosphere, etc.. CEME visualization mainly consists of 2D and 3D forms at present, and we think that a 4D display (Add the Time Axis) will be used in the future for CEME visualization. And high performance visualization technology will be used to a large-scale CEME simulation region. In addition to the visualization of the EME, terrain and atmosphere must be displayed simultaneously.

4 Conclusion

Complex electromagnetic environment simulation has been mentioned in recent years. In the past years, the electromagnetic modeling was mainly done by the people from the Department of Applied Physics. Their research interest is the physics method and the process, the key is not on whether the algorithm is proper for the computer solution and how to make the algorithm actually work in a computer or a computer cluster. The computer’s speed and memory capacity is the bottleneck of the CEME simulation.

We have given some ideas in CEME modeling and discussed the parallel computing scheme with it, and provide the idea of transforming the equation solving algorithm to a parallel algorithm.

Saving energy and environmental protection is the main topic of development. A new performance index is given out to deal with the use of computer memory, communication time, and power consumption. The optimal scheme and MOOM method is discussed.

The CEME simulation high performance visualization is mentioned and discussed. It is a key issue on how to deal with massive data and parallel display them in 3D or even in 4D, using a high performance Graphics Process Unit (GPU) and developing new computer graphics rendering parallel methods.

With more and more requirements for CEME simulation; high performance computer, parallel modeling methods, parallel solving algorithms, feedback optimal computing scheme, should all be considered together as a single entity. The latest computer Computing Technology and Optimal parallel computing algorithm should be used in CEME.

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