

Implementing Distributed Simulation in Grid Computing Environment: Application to Electromagnetic Field

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Abstract - Grid Infrastructure and popular Grid computing toolkit Globus Toolkit 3.0(GT3) are introduced in this paper. A distributed simulation system based on Grid computing is developed, working mechanism and architecture model of this system are also discussed in this paper. Simultaneously, a distributed simulation experimentation about lightning electromagnetic field is implemented in Grid computing environment. The result indicates that computing capacity can be greatly improved by using Grid computing in advanced distributed simulation system.

Keywords: Grid, Grid Computing, Advanced Distributed Simulation, Electromagnetic Field, Globus.

1 Introduction

Using supercomputing to solve some problems such as advanced distributed simulation applications can pose unique and difficult problems. For example, consider the simulation of the high capacity data systems. Such a system may have the data storage nodes at different geographical locations to address local area needs of data access. However, to be cost effective input/output devices may be centrally located. By Grid computing, various resources in network, such as supercomputers, great capacity of store facility, personal computers and all kinds of outer devices, are organized in a uniform framework. So Grid computing is a convenient approach to solve a distributed application problem. With the evolvement of network technology, many supercomputers can communicate on Internet, users can access their hardware resources by network. Because of rapid development of Internet, Grid computing has become to the third Internet tidal wave after traditional Internet and Web. Traditional Internet realizes communication with computer hardware, Web realizes link of web pages, Grid attempts to implement full connection to all resources on Internet. Grid computing means that high dependable and consistent hardware and software resources are available to different geographical users and resources. In this environment, many scientific research and engineering calculation will be promoted greatly. Grid computing has become a crucial technology in information technology area [1].

Advanced distributed simulation system(ADS) is just a kind of system that can utilize Grid fully. ADS's essential is that simulation system's main nodes distributed in a widespread area are connected by LAN or WAN, ADS assigns computing tasks needed by large scale simulation environment to these main nodes. Grid computing applied in ADS aims to enable researchers to leave laboratories to visit, monitor or administrate distributed experimentation platforms, and undertake collaborative examinations and remote computing by distributed Grid system [2].

2 Background

2.1 Architecture of Grid

Grid computing system is seamless, integrated computing and collaboration environment. In general, Grid architecture has some features as the followings: heterogeneous, extensible, adaptable, non-predictable. Grid system can be divided into four basic layers: (1) resource layer, (2) middleware layer, (3) toolkit layer, (4) application layer(see Fig.1) [3].

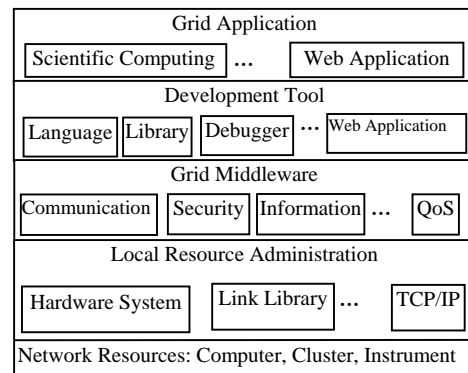


Fig. 1 Architecture of Grid

2.2 Globus Toolkit

The open source project Globus Toolkit 3.0 (GT3) is the most famous Grid system nowadays, it is a fundamental enabling technology for the "Grid", letting people share computing power, databases, and other tools securely online across corporate, institutional, and geographic boundaries without sacrificing local autonomy. The toolkit

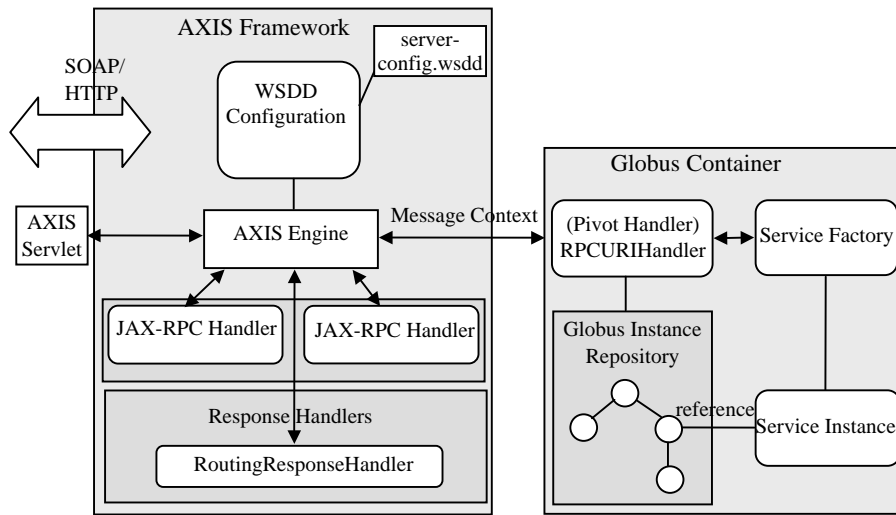


Fig. 2. GT3 software framework: server-side architecture components

contains software services and libraries for resource monitoring, discovery, and management, plus security and file management. It is packaged as a set of components that can be used either independently or together to develop applications. The Globus Toolkit was conceived to remove obstacles that prevent seamless collaboration. Its core services, interfaces and protocols allow users to access remote resources as if they were located within their own machine[4]. Fig.2 illustrates the components on the server side.

In Fig.2, the major architecture components of the server side frameworks include the following:

(1)Web services engine. This engine is provided by Apache AXIS framework software and is used to deal with normal web services behaviors, SOAP message processing, JAX-RPC handlers processing, and web services configuration.

(2)Globus container framework. GT3 provides a container to manage the stateful web service through a unique instance handle and repository.

Currently GT3 uses Apache AXIS as its web services engine, which runs in a J2EE Web container and provides a SOAP message listener (AXIS servlet). It is responsible for SOAP request/response serialization and deserialization, JAX-RPC handler invocation, and Grid service configuration. As shown in Fig. 2, GT3 container provides a pivot handler to the AXIS framework to pass the request messages to the Globus container.

Fig. 3 illustrates the components of the client side. In

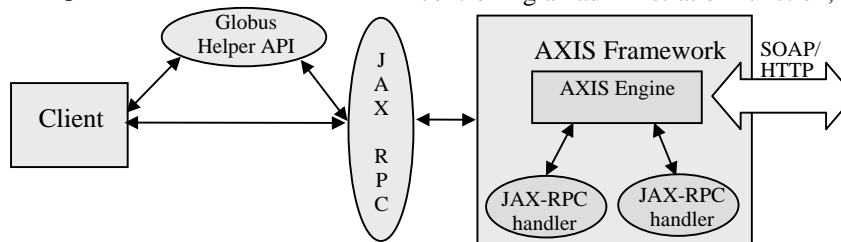


Fig.3 GT3 software framework: client-side architecture components

Fig.3, Globus uses the normal JAX-RPC client-side programming model and AXIS client-side framework on Grid service clients. In addition to the normal JAX-RPC programming model, Globus provides a number of helper classes at the client side to hide the details of the OGSi client-side programming model[5].

3 Simulation Experiment Based on Grid Computing

3.1 System Model

We have developed a numerical value calculating and simulation program (GEMS) for electromagnetic field of lightning based on Grid computing, its model is shown as Fig. 4. Web pages shown as uniform interface are provided to users as services in this system, so ensuring the system can run on many different kinds of platform. So long as you can browse web pages, you will be able to use all resources provided by GEMS. Our design prevents users from accessing computing system directly. Because of this feature, we avoid both malicious and unconscious user actions that might adversely affect our system resources or attack this system, and it is helpful to building uniform validated authorization mechanism. It is easy to use for most users, operation method based on web is easy to be mastered, and it is helpful to spread high performance computing. Software system implements various controlling an administration function, downwards controls

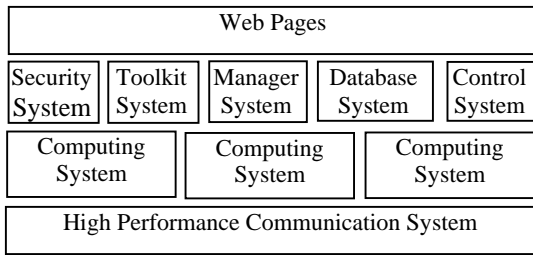


Fig.4 Model of GEMS

and managers various computing systems, and upwards provides various services and realizes various computing tasks submitted by users. Computing system is a provider of computing capability in GEMS, it contains various hetero-architecture, homo-architecture and different capability of computing systems which consist of clusters, massively parallel processor systems, or high performance servers. GEMS is different from other computing system, it provides a uniform web interface and middleware over computing system, it is just middleware that transforms computing resource into web's computing capability, users can use computing facility in different geographical area and mask different computing system by web pages. So computing capability is "link and play" as electric power [6].

3.2 System Architecture

Based on the above GEMS system, we take a simulation experimentation regarding lightning electromagnetic field. Fig. 5 illustrates the system architecture [7]. The executing process is as below:

- (1) Start up data server: Oracle;
- (2) Event: data available;
- (3) Start up electromagnetic field calculating: *CaLEM*
- (4) *CaLEM* reads data;
- (5) *CaLEM* writes data;
- (6) Event: *CaLEM* done;
- (7) Start up visualization;
- (8) Visualization reads data;

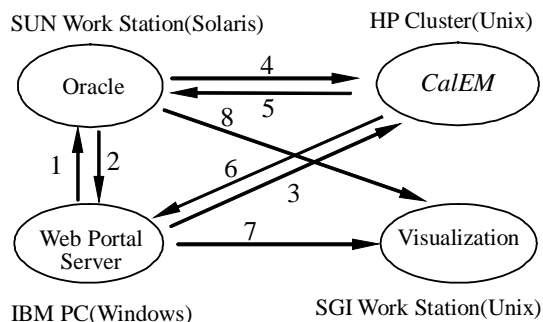


Fig. 5 System Architecture of GEMS

In this system, HP Cluster is the main node of Grid computing, it is the calculating center on which the program codes *CaLEM* for electromagnetic field of lightning run. By web portal server, client can submit many calculating tasks to the main node at the same time, forming

a calculating queue, Grid operating system can schedule the queue in an optimum means. This main node is acted by a super computer. In this system, we use HP cluster computers, their calculating speed can achieve 7×10^8 times per second.

By web portal server, client can submit calculating tasks, configure parameters for numerical value calculating of electromagnetic field of lightning, display and simulate calculating result, executing security authentication and so on. Web portal site is the main interface displayed to clients, it is a security barrier as well. SOAP protocol is used when messages are posted between web port server and Grid main node. Clients visit web portal server by HTTP protocol. HTTP and SOAP are the standard Internet protocol, so the system can be deployed on Internet.

Thin client are computers that users can operate directly. By using web browser to visit the web pages on the portal server, users can invoke Grid computing program to implement calculating tasks for electromagnetic field.

3.3 Developing Grid Computing Application

In order to use GT3 to develop Grid application, the following toolkits must be installed:

- (1) Java Development Kit: Sun J2SE1.4.2 (<http://java.sun.com/j2se>);
- (2) Java compiling tool: Jakarta ant1.5 (<http://ant.apache.org/>);
- (3) GT3 core source code: *gt3-core-src.tar* (<http://www.globus.org/>) or binary code;
- (4) web server: Apache Tomcat 5.0 (<http://jakarta.apache.org/tomcat>) or other J2EE containers;

GT3 programming is consistent with distributed computing programming model, namely proxy-stub model which includes server side programming and client side programming, they are loose coupling and associated with each other by web service description language(WSDL). When the service provider develops services, he must provide a corresponding WSDL file to describe service interface, method invocation and communication protocol. Only after getting the WSDL file, Clients can produce a client stub to call Grid services.

Programming on server side includes four steps[8]:

- (1) Provide a service interface. There are two means to provide a service interface, the first is writing a interface in Java and using *generateWSDL* tool in GT3 to generate a WSDL document about *poteType* to clients to use. This means is easy and convenient, but it is difficult to generate some complicate WSDL files. Another means is writing a WSDL file directly by developers themselves, thus descriptions about Grid service interface can be controlled entirely. This means is appropriate to some complicate Grid services, but it is more difficult for developers to master than the first.

(2) Generate Grid service codes. GT3 provides three ways to generate Grid service, they are bottom up, top down and multi-service. Fig. 6 illuminates these ways.

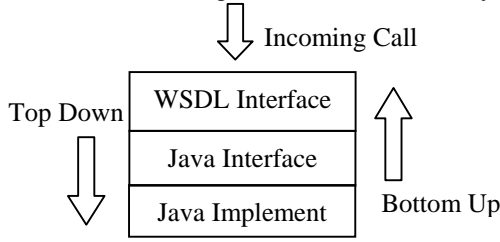


Fig. 6 Model for Generating Grid Service

Bottom Up: this way is appropriate to transform a legacy system into Grid service. By using this way, Java source code should be compiled and packaged into a *jar* file, then using a GT3 tool named *createBottomUpGridService* to generate stub, service locators and WSDL documents.

Top Down: this way is appropriate to a new Grid service. It can generate some documents about binding, stubs, service locators, WSDL, operation provider and service implementation class by using a tool named *createTopDownGridService*. You can add some logical codes in the implementation class.

Multi-Service: this way allows users to create Grid services from a XML document which must fit *CreateGridService.xsd* model in GT3.

(3) Generate GAR file to deploy by using GT3 tool named *gar*. This GAR file includes all Grid deploy files such as JAR, WSDL, WSDD files.

(4) Deploy service. Using deploy tool, you can deploy the above GAR file into a GT3 container.

4 Conclusions

4.1 Theory Analysis for Lightning Electromagnetic Field

In order to calculating electromagnetic field of lightning, we use Maxwell equations to solve electric field intensity and magnetic field intensity. In order to simplify research, assuming lightning channel is a line. Thus for linear, isotropic single medium, Maxwell equations are written as

$$\begin{aligned} \nabla \cdot \varepsilon E &= \rho; \\ \nabla \cdot \mu H &= 0; \\ \nabla \times E &= -\frac{\partial \mu H}{\partial t}; \\ \nabla \times H &= J + \frac{\partial \varepsilon E}{\partial t} \end{aligned} \quad (1)$$

where ε is permittivity; μ is permeability; J is current density; ρ is charge density.

For the known radiation source, we usually use scalar electric potential ϕ and scalar magnetic potential A as unknown parameters to substitute electric field intensity E and magnetic field intensity H in Eq.(1). E and H can be defined as below:

$$E = -\nabla \phi - \frac{\partial A}{\partial t} \quad (2)$$

$$H = \frac{1}{\mu} \nabla \times A \quad (3)$$

From Reference [9], we know the solutions to the above equations are:

$$A(r_s, t) = \frac{\mu}{4\pi} \int_{V'} \frac{J(r'_s, t - \frac{|r_s - r'_s|}{c})}{|r_s - r'_s|} dV' \quad (4)$$

$$\phi(r_s, t) = \frac{1}{4\pi\varepsilon} \int_{V'} \frac{\rho(r'_s, t - \frac{|r_s - r'_s|}{c})}{|r_s - r'_s|} dV' \quad (5)$$

where $c = 1/\sqrt{\mu\varepsilon}$ is spread velocity of electromagnetic wave. In air the wave velocity equals to light velocity $3 \times 10^8 m/s$; r_s and r'_s are shown in Fig. 7.

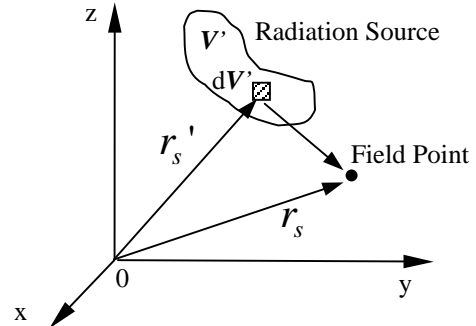


Fig. 7 Radiation Source and Field Point

For the radiation source which current is known, electric field E and magnetic field H can be solved according to Eq.(2) and Eq.(3). In spherical coordinate system (see Fig.8), when current unit $dl \ll \lambda$, $dl \ll r$ and the current equals to I , the component E_θ , E_r , and H_ϕ of electromagnetic field can be solved by Eq.(6)(7)(8)[10].

$$E_\theta = \frac{IdL\beta^3}{4\pi\omega\varepsilon_0} \left[\frac{-1}{j(\beta r)} + \frac{1}{(\beta r)^2} + \frac{1}{j(\beta r)^3} \right] \sin \theta \quad (6)$$

$$E_r = \frac{IdL\beta^3}{2\pi\omega\varepsilon_0} \left[\frac{1}{(\beta r)^2} + \frac{1}{j(\beta r)^3} \right] \cos \theta \quad (7)$$

$$H_\phi = \frac{IdL\beta^3}{4\pi} \left[\frac{-1}{j(\beta r)} + \frac{1}{(\beta r)^2} \right] \sin \theta \quad (8)$$

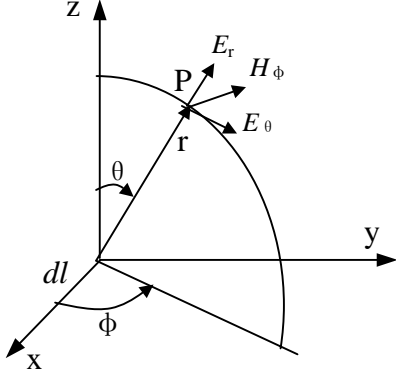


Fig.8 Electromagnetic Field in Spherical Coordinate

Because points in electromagnetic field lie in free space, they are axial symmetric for linear radiant source, we can use pillar coordinate system to analyze electromagnetic field. Assuming there is a conductor which is L long in pillar coordinate system (see Fig. 9), $-L$ is a equivalent mirror conductor.

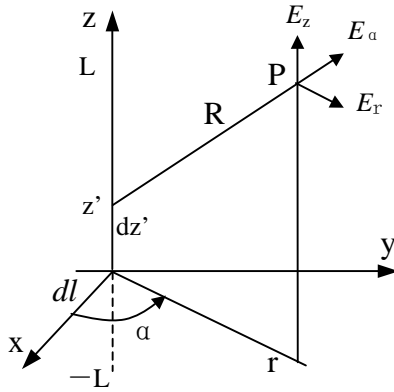


Fig.9 Electromagnetic Field in Pillar Coordinate

According to relations between pillar coordinate system and spherical coordinate system, the electromagnetic field of any point in space can be derived as below:

$$H_{\alpha} = \frac{I}{4\pi r} \left[\frac{L+z}{\sqrt{r^2 + (L+z)^2}} + \frac{L-z}{\sqrt{r^2 + (L-z)^2}} \right] \quad (9)$$

$$E_r = \frac{3I\beta r}{8\pi\omega\epsilon_0} \left[\frac{1}{r^2 + (L-z)^2} - \frac{1}{r^2 + (L+z)^2} \right] \quad (10)$$

$$E_z = \frac{I\beta}{4\pi\omega\epsilon_0} \left(2 + \frac{1}{2r^2} \right) \left[\frac{L-z}{r^2 + (L-z)^2} + \frac{L+z}{r^2 + (L+z)^2} \right] \quad (11)$$

where $\omega = 2\pi f$, f is current frequency(Hz); β is phase constant, $\beta = 2\pi/\lambda$; ϵ_0 is permittivity in free space, $\epsilon_0 = 1/36\pi \times 10^9$ (F/m).

4.2 Fourier Series Expansion of Lightning Wave

Based on the condition that excitation current is continuous sine wave, the above equations are derived by which electromagnetic fields of any point in free space can be calculated. But actually lightning current is a transient non-sine wave which needs to decompose into a standard sine wave. Standard Fourier series expansion requires a function is periodic, while lightning current $i(t)$ is a non-periodic pulse, its waveform needs expanding to satisfy the condition of Fourier [11].

Assuming the function $i(t)$ is defined at interval $[0, t_f]$, then it can be expanded into sine series as following:

$$i(t) = \frac{a_0}{2} + \sum_{i=1}^n b_n \sin i\omega t \quad (12)$$

where the coefficients of sine series are

$$a_0 = 0; \quad b_n = \frac{2}{t_f} \int_0^{t_f} i(t) \sin \frac{n\pi t}{t_f} dt \quad (n=1,2,3,\dots) \quad (13)$$

we use a bevel waveform to simulate lightning current, its expressions is written as

$$i(t) = \begin{cases} I_m \frac{t}{t_f} & 0 \leq t \leq t_f \\ I_m \left(1 - 0.5 \frac{t-t_f}{t_f} \right) & t_f < t < t_i \end{cases} \quad (14)$$

If the amplitude value of current $I_m=11$ kA, $t_f=1.2 \mu s$, $t_i=50 \mu s$, then the waveform is shown as Fig.10.

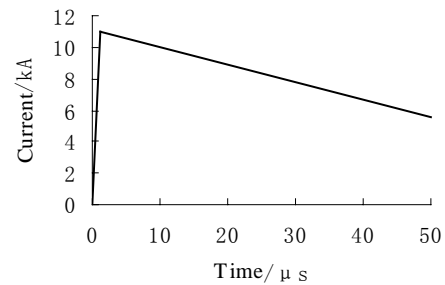


Fig.10 Approximate waveform for lightning current

By expanding the above waveform of lightning current according to sine series and calculating the value of b_n by Eq.(13), we obtain the coefficient of Fourier expansion item (see Tab.1). In Tab.1, $No.$ is every harmonic's ordinal number, I_m is harmonic's amplitude and the value of coefficient b_n of Fourier expansion item, percent (%) is the ratio of each harmonic's amplitude value to lightning

wave's. Fourier expansion is stopped when the ratio is less than 1%. Current after Fourier expansion can be written as

$$i(t) = \sum_{m=1}^n I_m \sin i\omega_1 t = I_1 \sin \omega_1 t + I_2 \sin 2\omega_1 t + I_3 \sin 3\omega_1 t + \dots \quad (15)$$

where ω_1 is the circle frequency of the basic wave and we assume $\omega_1 = 2\pi/(100 \times 10^{-6}) \text{ rad/s}$, I_m is the coefficient of Fourier expansion item which is listed in Tab.1. Substituting I_m into Eq.(15), lightning waveform after Fourier expansion can be obtained.

Tab.1 Fourier expansion coefficient of lightning current (kA)

No.	1	2	3	4	5	6	7	8
I_m	10.58	1.78	3.51	0.87	2.08	0.558	1.46	0.39
%	96.18	16.18	31.90	7.91	18.91	5.07	13.27	3.54
No.	9	10	11	12	13	14	15	16
I_m	1.12	0.29	0.891	0.229	0.738	0.167	0.611	0.124
%	10.18	2.64	8.1	0.221	0.731	1.52	5.55	1.13
No.	17	18	19	20	21	22	23	24
I_m	0.518	0.09	0.44	0.06	0.38	0.03	0.33	0.01
%	4.71	0.82	4.0	0.55	3.45	0.27	2.97	0.09
No.	25	26	27	28	29	30	31	32
I_m	0.28	-0.006	0.245	0.02	0.212	0.03	0.18	0.05
%	2.55	0.05	2.23	0.18	1.93	0.27	1.64	0.45
No.	33	34	35	36	37	38	39	
I_m	0.158	0.06	0.14	0.067	0.118	-0.07	0.102	
%	1.44	0.55	1.25	0.61	1.07	0.64	0.93	

4.3 Numerical Calculating of Electromagnetic Field

When calculating electromagnetic field, the value of every I_m in Tab.1 should be substituted into Eq.(9)-(11) to solve E and H . Then, electromagnetic field intensity of any point in space can be calculated according to the following expressions:

$$E_z = \sum_{i=1}^n E_{z_i} \sin i\omega_1 t = E_{z_1} \sin \omega_1 t + E_{z_2} \sin 2\omega_1 t + E_{z_3} \sin 3\omega_1 t + \dots \quad (16)$$

$$E_r = \sum_{i=1}^n E_{r_i} \sin i\omega_1 t = E_{r_1} \sin \omega_1 t + E_{r_2} \sin 2\omega_1 t + E_{r_3} \sin 3\omega_1 t + \dots \quad (17)$$

$$H_\alpha = \sum_{i=1}^n H_{\alpha_i} \sin i\omega_1 t = H_{\alpha_1} \sin \omega_1 t + H_{\alpha_2} \sin 2\omega_1 t + H_{\alpha_3} \sin 3\omega_1 t + \dots \quad (18)$$

According to Eq.(16)(17)(18), we can only calculate E and H of one point. When calculating actually, the space of electromagnetic field may be divided into some grids, E and H of every node on these grids should be solved, denser grids are, higher calculating precision is. Fig.11 illuminates these grids.

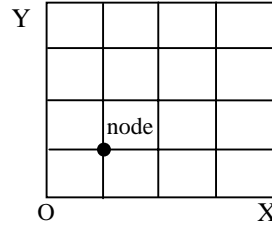


Fig.11 Grid Dividing of Electromagnetic Field

According to the above theory and method, we develop a calculating program named GEMS and deploy it into Grid computing environments. Executing codes get float point computing capacity of 6.6×10^8 times per second on HP minicom cluster. The codes compute and simulate electromagnetic wave radiated from lightning. Then data is handled and sent to a remote desktop for visualization by a high speed network. Users may select and set parameters of simulation and visualization remotely when the codes are running. Globus Toolkit plays a very important role in this system, which contains a web portal site on which users can configure and submit a calculating task by web browser. With the help of message sending interface in Globus Toolkit, this system can be deployed on different platform.

5 Conclusions

With the help of Globus Toolkit, we can easily create Grid applications for scientific computing and business application. Calculating and Simulating electromagnetic field is only a simple example which implements distributed computing and simulation successfully in Grid environment. For complicated calculating, such as nuclear fusion and black hole collision, high calculating capability of Grid computing will be exhibited sufficiently. Currently, Grid computing has been applied successfully in many domains, but Grid's structure needs still standardization to meet the need of various complicated computing. Even through Grid computing is beginning to be applied in actual distributed simulation systems, there are still many problems such as system architecture, frameworks, development tool and Grid security. It is predictable that applying Grid computing in system simulation technology will drastically improve and facilitate the evolution of advanced distributed simulation system.

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