Research on Economic Grid Resource Scheduling for Utility Optimization

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***Abstract*—As Grid technologies evolve quickly on Internet, research related to resource scheduling faces new opportunities and challenges. These new technologies, ideas and approaches provide a new environment for researching and developing the economy-based resource scheduling system. Aiming at the hierarchical Grid model, following utility optimization thinking, while an universal flexible utility function is provided for addressing the Grid users' QoS requirements of deadline and budget, this paper proposes a new Grid resource scheduling algorithm, which can not only increase the utilization of resources and system throughput, but also realize cost-time optimization between resource providers and users within Grid systems. On the basis of having described the different functional parts of the proposed algorithm, two kinds of simulative experiments about completion time and cost of tasks are conducted. Finally, the experiment results show that the proposed algorithm is effective.**

***Index Terms*—economic grid, resource scheduling, utility optimization, universal logics, QoS**

I. INTRODUCTION

Grid computing has emerged as a promising distributed computing paradigm, which can support efficient executing of computational intensive and data intensive applications with different computing needs, and it has strong vitality, good prospects for development. However, Grid resource management and scheduling is a complex undertaking. This is due to the geographic distribution of resources that are often owned by different organizations having different usage policies and cost models, and varying loads and availability patterns.

The goals of a resource management system in the Computational Grid are to manage and provide resources to satisfy users' requests, which may require different types and levels of quality of service (QoS), such as response time, cost and so on. It is heterogeneity and dynamics of the Grid that make QoS problems challenging. Grid resource management must deal with various demands from users. So, QoS is directly related to the performance of a Grid.

To address these issues, the economy-based Grid resource management and scheduling has become a hot point of research for domestic and foreign scholars, and there is a great deal of research results. Reference [1] applied an optimal multi-reservation technique to achieve a fault tolerant scheduling in economic-based grid with respect to optimized cost price, and minimum latency by applying rough set theory. In [2], Fard developed a new list heuristic algorithm for workflow applications modeled as Directed Acyclic Graphs (DAGs) to solve the scheduling problem, considering time and cost parameters. Tao Yang proposed a classified optimization scheduling algorithm for a set of independent tasks under the limitation of time and cost, which could satisfy the multi-QoS attributes effectively in [3]. Chard presented a novel architecture for a Virtual Organization (VO) based distributed economic meta-scheduler in which members of the VO collaboratively allocated Grid resources in [4]. Sonmez proposed a novel economy driven job scheduling heuristic, which was effective both in terms of parameter sweep and sequential workflow type of applications in [5].

It must be pointed out that in the heterogeneous Grid and distributed parallel computing environment the majority of resource scheduling problems are very hard problems, although the current study has made certain achievements, it is still limited, and further research is necessary.

Based on the hierarchical Grid structure model, this paper focuses on the economy-based Grid resource allocation and task scheduling. Firstly, based on the principle of universal logics in [6], an universal flexible utility function is provided for addressing the Grid users' QoS requirements of deadline and budget. Secondly, following utility optimization thinking, this paper proposes a new Grid resource scheduling algorithm which can not only increase the utilization of resources and system throughput, but also realize cost-time optimization between resource providers and users within Grid systems. In the organization of content, this paper exposes the structure of hierarchical model firstly, and then carries detailed analysis of the universal flexible utility function and the economic Grid resource scheduling strategy. Finally, we use the GridSim simulation tool to simulate experiments, and results shows that the algorithm is effective.

II. HIERARCHICAL GRID SYSTEM MODEL

In a hierarchical structure model of resource management, resource management and scheduling are of

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multi-levels, each resource has its own scheduling system, and users only need to submit the assignment to the Grid resource manager (GRM), but the number of resources after GRM and to which resources the assignment will be allocated is transparent for users. Resources provider can be a single PC, a single or multiple clusters, also can be a small and medium-sized LAN of a certain organization. They have one thing in common, that is, there is a same manager, domain resources manager. A single PC itself is a manager; but normally there is a full-time server to manage the various nodes in cluster / LAN for clusters and local area networks. The first level scheduling of users' assignment is carried out in GRM, the second level scheduling of users' assignment is carried out in the domain resource managers (DRM), if there were more following clusters or LANs, there would be the third level, the forth level scheduling and so on.

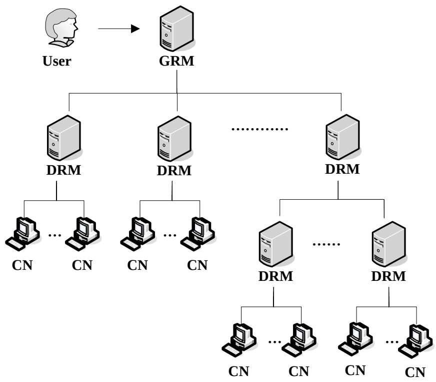

Figure 1. Structure of hierarchical Grid model.

Fig. 1 describes the structure of the model. It shows the various parts of the model and relations between them.

III. ECONOMIC GRID RESOURCE SCHEDULING

Here, we will mainly discuss about economy-based Grid resource allocation and task scheduling strategy. Considering the performance and the task number of the DRM and the computing node (CN), following the cost-time optimization strategy, the corresponding algorithm is realized.

A. Analysis of the Common Utility Functions

The integration of computational economy as part of a scheduling system greatly influences the way resources are selected to meet the user requirements. The users should be able to submit their application along with their requirements to a scheduling system, which can process the Grid applications on the user's behalf and try to complete the assigned work within a given deadline and budget. So, a utility model is needed to represent the users' resource demand and preferences, which has the following common form:

$$U(T_i, R_j) = \alpha\times U_t(T_i, R_j) + \beta\times U_c(T_i, R_j). \tag{1}$$

While the task T_i is assigned to the resource R_j, U_t denotes the utility value about completion time, U_c the utility value about cost, and U represents the total utility value by combining U_t and U_c. The α, β are two coefficients, $\alpha + \beta = 1$.

From (1), we can notice that U is the weighted average of U_t and U_c, which is between the minimum and the maximum of U_t and U_c. There transformation ranges are limited. Besides, if we make compromise by average operation, the results that offend common sense can be obtained. As $\min(U_t, U_c) \le U \le \max(U_t, U_c)$, when U_t, $U_c > 0$, the U might be smaller than the maximum, which indicates that the total utility value decreases in despite of the appearance of the same agreement. Therefore, they are the deficiencies of the above common utility functions.

The correct integration method about time and cost is: if both sides are for it, the result is not less than the maximum; if one side gives up, the result should be the result of other side. In the next section, a reasonable utility function will be presented.

B. Definition of the Universal Utility Function

To avoid the shortages in common utility functions, we will discuss the construction of utility function mainly used in economy-based Grid resource allocation and task scheduling strategy, and provide an universal flexible utility function by applying zero-level universal OR operators (*ZUOR*), which are the parameterized families of operators called Universal Logics operators stated in [6].

The universal flexible utility function is mapping:

$$\begin{aligned} &U: [0,1]\times[0,1] \rightarrow [0,1],\\ &U(T_i, R_j, h) = 1 - \Gamma^1[((1-U_t(T_i, R_j))^m + (1-U_c(T_i, R_j))^m - 1))^{1/m}]. \end{aligned} \tag{2}$$

Where, $\Gamma^1[x]$ is the limit function denoted ite{1| x>1; 0|x<0 or imaginary number; x}. The ite{ β| α; γ} is the conditional expression indicated that if α is true, then β, otherwise γ. The m has relation with generalized correlation coefficient h as $m = (3 - 4h) / 4h\,(1 - h)$, $h\in[0, 1]$, $m\in R$.

Four special utility functions can be obtained by specifying the parameter h:

$U(T_i, R_j, 1)=\mathbf{U_3}= \max(U_t(T_i, R_j), U_c(T_i, R_j))$.

$U(T_i, R_j, 0.75)=\mathbf{U_2}= 1 - (1 - U_t(T_i, R_j))(1 - U_c(T_i, R_j))$.

$U(T_i, R_j, 0.5)=\mathbf{U_1}=\min(1, U_t(T_i, R_j) + U_c(T_i, R_j))$.

$U(T_i, R_j, 0)=\mathbf{U_0}=\text{ite}\{\max(U_t(T_i, R_j), U_c(T_i, R_j))|\min(U_t(T_i, R_j),U_c(T_i, R_j))=0;1\}$.

The utility value about completion time becomes larger while the time is nearer to deadline, so, the function of U_t can be defined in the following:

$$U_t(T_i, R_j) = (1-q)(t / Deadline)^p + q\ . \tag{3}$$

Where, p is user-defined exponent and required p>1, *Deadline* is the user required completion time, and t denotes the real completion time of task T_i assigned to the resource R_j, $t\in$ [0, *Deadline*]. In addition, it should be noticed that U_t is increasing monotonously and limited to [q, 1], that is:

$U_t = q$, if $t = 0$, where q represents the predefined utility value about time;

U_t = 1, if t = *Deadline*, which shows that it's the maximum utility value and can be obtained only if the completion time reaches *Deadline*.

However, the utility value about cost becomes smaller when the cost is nearer to budget, so, the function of U_c can be defined in the following:

$$U_c(T_i, R_j) = (c+1)^p . \qquad (4)$$

Where, p is user-defined exponent and required $p<0$, c denotes the real cost of task T_i assigned to the resource R_j, $c \in [0, Budget]$, and *Budget* is the user required cost. In addition, it should be noticed that U_c is decreasing monotonously and limited to (0, 1], that is:

U_c = 1, if c = 0, which shows that it's the maximum utility value and can be obtained only if no cost needs to be paid;

$U_c \to 0$, if c = *Budget*, which shows that the utility value is tend to zero when the cost reaches *Budget*.

C. Algorithm Analysis and Implementation

The GRM accepts the operating request of all the users at the same time. According to the nature of tasks, communication situation, and the state of resources load, it operates a coarse-grained scheduling. Based on the algorithm, GRM seeks the best allocation scheme and submits the operating task to the selected DRM. In order to achieve the algorithm, three tables are installed on the database server in GRM and DRM. The first table is stored with the every sub-DRM utility information. If there is no sub-DRM, that is the resource manager manages directly CNs, then not only the utility information of CN is stored in the table but also the details of computing resources, such as CPU speed, CPU utilization, the number of active process, the situation of used memory and I/O. The second table stores the number of tasks being operated by every DRM or CN. The content of the third table is the throughput and the average delayed response of every DRM or CN.

Firstly, one function of the algorithm is to get the utility information of DRM, monitor periodically the implementation state of operations and report it to the upper level for the overall management and scheduling. DRM reports its utility and completed assignment information as well as the state of all the running assignments on the DRM to GRM. When the task suffers a abnormal interruption during the implementation or the performance is not as good as expected, GRM can carry out a scheduling once again, and reschedule other resources; when the task is completed, GRM will ask DRM to return directly the operating results to users, and it will update the number of current assignments carried by every resource manager, and then, according to the utility information of the CN, data updating will be carried out for every DRM.

Secondly, the other one function of the algorithm is resource allocation and task scheduling. According to utility optimization, the GRM chooses a suitable DRM to carry out resource allocation and task scheduling. In the Grid system, the task is produced dynamically and scheduling. This is the most important function in the algorithm.

Supposed that U_i stands for the utility value of the i-th CN, which can be gotten according to the formula from (2) to (4) by assigning proper h. Then, the utility value of DRM can be calculated from the average of the sub-DRM's utility or CN's utility, that is:

$$U_{Dk} = \frac{1}{m}\sum_{i=1}^{m} U_i \ . \qquad (5)$$

Among them, U_{Dk} represents the utility value of the k-th DRM, m represents the number of sub-domain resources manager or CNs in this domain.

In addition, within the same level, in order to choose properly the deployment resources, when the DRM or the CN having the maximum utility is not unique, further judgment can be done by calculating the variance of utility:

$$Var_{Dk}(U) = E[(U_i - U_{Dk})^2] . \qquad (6)$$

Among them, Var_{Dk} stands for the variance of the k-th DRM's utility, E stands for the mathematical expectation of the operation.

Based on the above analysis, the economic Grid resource scheduling algorithm is described in the following:

Step 1: If there was information from DRMs or CNs, update the utility information of DRM or CNs according to the formula from (2) to (5), and calculate the rate of throughput and the average response delay.

Step 2: If there was information of completed assignment, deduct one assignment of corresponding DRM.

Step 3: If portal gives one assignment to GRM, implement gradually layer by layer as following steps.

Step 4: Calculate the maximum utility value of all DRMs in the next level:

$$U_{max} = \max_k U_k \ .$$

Step 5: If the node having the utility U_{max} is unique, make the node be the scheduling node, give it the assignment for scheduling, and update the number of assignment of DRM. Otherwise, identify the greatest variance node among nodes having U_{max} utility:

$$Var_{max} = \max_{U_{Dk}=U_{max}} Var_{Dk} \ .$$

Then, make the node whose variance is Var_{max} as the scheduling nodes, if still not unique, selecting the first node.

Step 6: For the scheduled DRM node, if the nodes on its next level are not CNs, but DRMs, go to step 4. Otherwise, find the maximum utility value:

$$U_{max} = \max_k U_k \ .$$

Then, make the node whose utility value is U_{max} be the final scheduling node, give it the assignment for scheduling, and update the number of assignment of CN.

IV. SIMULATIVE EXPERIMENTS

After having proposed the algorithm, we need to carry a simulative experiment in order to ensure the ability of the algorithm. In parallel and distributing systems, Gridsim simulation tool can carry modeling and simulation for users, applications, resource scheduling and other entities etc. It proposes the method of creating a user task and different types of heterogeneous resources. According to research purposes, it can simulate different resource allocation and task scheduling strategies, so here we use Gridsim to simulate this algorithm.

This paper compares the performance of the proposed economy-based resource scheduling method with the time optimization algorithm (TOA) and the cost optimization algorithm (COA) through experiments. Make 109 CNs in accordance with the structure of Fig. 1, and construct a simulated environment as Table 1:

TABLE I.

CONFIGURATION OF EXPERIMENT ENVIRONMENT

1st level	2nd level	3rd level	4th level
GRM	DRM1	DRM11	18
		DRM12	25
		DRM13	28
	DRM2	17	
	DRM3	21	

For these three scheduling algorithms, we conduct a great number of simulative experiments by adopting the different number of tasks, and compare the experiment results from the two aspects of time and cost. In Fig. 2, it is obvious that the TOA exceeds the other two algorithms in shortening the completion time of tasks. Similarly, comparing with the COA, the proposed algorithm in this paper shows good performance. In Fig. 3, it can be noticed that the COA exceeds the other two algorithms in reducing the cost of tasks, and the performance of the proposed algorithm is correspondence with the COA. Accordingly, it can be concluded that the behavior of this algorithm is due to the whole utility by considering time and cost together.

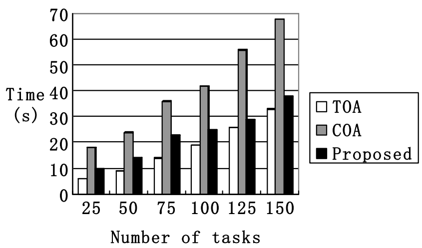

Figure 2. Comparison of time.

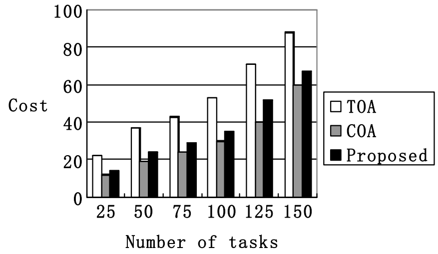

Figure 3. Comparison of cost.

V. CONCLUSIONS

Effective resource allocation and task scheduling program can play a crucial impact on enhancing the performance of the Grid system. This paper proposes an economy-based resource scheduling scheme, under the premise of a detailed analysis of an universal utility function, designs and implements a resource scheduling algorithm which considers the cost and time optimization of tasks. In the future research, we will introduce granular computing idea to improve this algorithm, and enhance further more the flexibility and efficiency of this algorithm.

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