Suchang GUO
Hu WAN
Gui-Bao WANG
Min XIE

ANALIZA REKOMPENSATY ZA ZASOBY GRIDOWE W ŚRODOWISKU PRORYNKOWYM

ANALYSIS OF GRID RESOURCE COMPENSATION IN MARKET-ORIENTED ENVIRONMENT

Ostatnio ideę prorynkowego zarządzania zasobami gridowymi proponuje się jako sposób na uporanie się z niedostatkiem zasobów gridowych w systemach sieci typu grid. W środowisku prorynkowym, użytkownicy sieci grid powinni płacić właścicielom zasobów pewną sumę pieniędzy za wykorzystane zasoby. Jednakże, należy pamiętać, że właściciele zasobów nie tylko oferują zasoby dla aplikacji gridowych, ale również muszą rezygnować z wykonania lokalnych zadań na rzecz terminowego dostarczenia zasobów do wykonania zadania gridowego. Istnieje niewiele badań zajmujących się problemem rekompensaty za utratę korzyści z zadania lokalnego na zasobach gridowych. W związku z istnieniem tego problemu posiadacze zasobów mogą nie chcieć przyłączać się do sieci gridowej, o ile nie otrzymają pewnej rekompensaty. W niniejszym artykule wyznaczono minimalną rekompensatę, jaką użytkownicy sieci gridowej winni płacić posiadaczom zasobów. Obliczeń dokonano w oparciu o analizę oczekiwanego dochodu w odniesieniu do dwóch strategii szeregowania zadań w zasobach gridowych oraz wykorzystując pojęcie kosztu alternatywnego (opportunity cost). Aby zagwarantować uczciwe warunki rynkowe, przedstawiono również model zmiennej ceny (variable price model). Do obliczenia rekompensaty minimalnej wykorzystano podejście oparte na symulacji Monte Carlo. Rekompensatę minimalną wyznacza się kierując się charakterystykami zasobu gridowego i terminem wykonania zadania gridowego. W oparciu o wyniki symulacji, przeanalizowano czynniki wpływające na rekompensatę minimalną wykorzystując przykład numeryczny. Proponowany model cenowy może stać się motywacją dla posiadaczy zasobów przyciągając coraz więcej zasobów internetowych do uczestnictwa w sieciach gridowych.

Słowa kluczowe: *Rekompensata za zasoby gridowe, koszt alternatywny, prorynkowy, symulacja Monte Carlo.*

Recently, market-oriented grid resource management has been proposed to cope with the scarceness of grid resources in grid systems. In the market-oriented environment, grid users should pay resource owners a sum of money for resources consumed. However, the contribution of resources owners is not only offering resources for grid applications, but also for the loss of local task execution for the sake of grid task complement punctually. There is little research to address the problem of compensation for opportunities lose of local task in grid resources. As a result, resource owners may be reluctant to join the grid unless some compensation is paid. In this paper, based on the analysis of the expected income of two priority strategies in grid resources, the minimal compensation which grid users should pay to resources owners is determined using the concept of opportunity cost and a variable price model is presented to ensure a fair market environment. To calculate minimal compensation, an evaluation approach based on Monte Carlo simulation is given and the minimal compensation can be determined according to the characteristics of the grid resource and the deadline of the grid task. Based on the simulation results, the influence factors of minimal compensation are studied using a numerical example. The proposed price model can provide an incentive for resource owners and attract more and more resources in the Internet to participate in the grid.

Keywords: *Grid resource compensation, opportunity cost, market-oriented, Monte Carlo Simulation.*

1. Introduction

Grid computing provides a service-oriented infrastructure that leverages standardized protocols and services to enable pervasive access to and coordinated sharing of geographically distributed resources [6-8]. Large numbers of unoccupied resources in the Internet can be collected in the grid framework to tackle large-scale and difficult problems [10-13, 21] that would be impossible to feasibly solve using the computing resources of a single organization, such as climate modeling [5] and bioinformatics [16]. Recently, many researchers endeavor to extend grid technology from scientific computing into the commercial world so as to provide necessary impetus for grid growth and funding.

However, there are still a lot of problems to be resolved in the process of grid commercialization. With increasing popularity and usage of grid applications, it has been observed frequently in some grid projects that the demand for available grid resources exceeds their supply [9, 17]. In such a situation, simply aiming to minimize the waiting time and maximizing the grid service reliability for users may make it worse [3, 15]. Furthermore, it may be free for resource owners to contribute their computing resources to execute grid tasks. As a result, resource owners are reluctant to participant in grid sharing and computing resources in the grid become less and less as a result. To address this problem, the idea of market-oriented resource management was proposed by researchers to ensure a fair environment for both grid users and resource owners [3].

In a market-oriented grid environment, a competitive price-setting mechanism is provided. It can offer an incentive to resource owners for contributing resources and motivate grid users to think about tradeoffs between grid service deadline and computational cost according to their quality of service (QoS) requirements [3] [20]. Recently, price-setting of grid resources has attracted substantial attention from researchers. A simple pricing scheme is a fixed price model. The Libra RMS [14] makes a simple minimum cost computation for a submitted job. In other Market-inspired systems such as Bellagio [1] and Mirage [4], the fixed price model is still used for resources auctions. Although it is much simpler, fixed price model does not work when the users place QoS demands that vary with applications and time [15]. Consequently, variable price models were proposed to address those limitations. Zheng et al. [22] used a varying price model to balance load among heavily-loaded and lightly-loaded computers in grid computing. Stuer et al. [19] presented a pricing scheme that responds to the dynamics of demand and supply in the grid market. AuYoung et al. [2] used aggregate utility functions in conjunction with individual utility functions for sets of jobs. However, most variable price models pay great attention to user's utility, but neglect the characteristics of grid resources, especially the opportunity loss of local tasks in grid resources.

In the grid, when a grid user asks for a grid application, a deadline of the application is often specified. If the application can not be completed in the given deadline, this grid application will be claimed to be failed and the user will not pay the grid at all. Thus, it demands grid resources to spend more time on grid task execution so as to ensure grid task completed on schedule. However, for grid resources, they engage in tasks coming not only from the grid system but also from the local administrative domain. Taking on too many grid tasks will lead to the opportunity loss of local tasks. Therefore, it is necessary for grid users to pay a sum of money not only for the resource consumed by the user applications, but also for the compensation of the opportunity loss of local tasks. However, most price models fail to take into consideration the compensation part of grid resources. As a result, resource owners will be unwilling to spend more time and resource on grid task execution if the grid task has a time limit. Therefore, the additional compensation is necessary.

In this paper, we focus on determining how much compensation grid users should pay resource owners at least if grid users' task can be completed in a given deadline. The concept of opportunity cost in microeconomics [18] is used. Opportunity cost plays an important part in decision-making of resource usages where more than two uses for a resource exist and the resource can be devoted to only one use at a time. Through the comparison of opportunity costs, the resource use with the minimal opportunity cost will be chosen by resource owners. Thus, if one use of resource with higher opportunity cost is desired to be chosen, the additional compensation should be paid, i.e., the minimal compensation of resource use with non-minimum opportunity cost is the difference between opportunity costs of this resource use and its best alternative use.

To determine the minimal compensation, two resource usages are modeled and the minimal compensation is expressed. However, it is difficult to compute an exact result with a deterministic mathematical expression. Thus, a calculation approach based on Monte Carlo simulation is proposed. Based on the analysis, a fair price model is presented. A numerical example is given to show that the resource price determined by the proposed model can be variable with the deadline of grid tasks and the attributes of grid resources. It can provide an incentive to resource owners and attract more and more resources in the Internet to participate in the grid.

This paper is organized as follows. The expected income of two alternative resource usages, Local Task Priority (LTP) and Local Task Priority under Grid Task Deadline (LTPD), are analyzed and a price model is presented in Section 2. Section 3 presents a calculation approach to the determination of minimum compensation based on Monte Carlo Simulation. Section 4 uses a numerical example to show the superiority of the proposed price model. Section 5 concludes this paper and indicates some directions for future study.

2. Compensation determination based on cost opportunity

For the sake of grid task complement in a given deadline, the resource has to reject some arriving local tasks. It is necessary to pay a sum of money to resource owners for the compensation of opportunity lose of local tasks. To determine the minimal compensation, the opportunity costs of the resource usage considering grid task deadline and its best alternative one has to be determined. In this section, we will firstly discuss the strategy of Local Task Priority, which can bring the maximal income for resource owners.

2.1. Local Task Priority

With the aim to obtain the maximal income from computing resources, resource owners strive for high resource utilization rate, which corresponds to higher income. Therefore, when the resources are not occupied by local tasks, a resource owner may share his resource in grid system and additional income can be obtained from grid task execution. When a local task arrives, grid task execution is suspended and waits for the completion of the local task, and then the grid task continues to be executed from the point of suspension until the next local task comes or the grid task is completed. This strategy of resource utilization, referred to as *Local Task Priority* (LTP), does not care about the time limit of grid task complement and can obtain the highest resource utilization rate and bring the maximal income for resource owners. Fig.1 gives an example of LTP given the required execution time of grid task in the resource $\tau = 600$ min. In Fig. 1, during the execution of grid task, there are three local tasks arriving at $t_1 = 200$ min, $t_2 = 500$ min, $t_3 = 800$ min. The total income of the resource will be divided into two parts: the income from 600 min grid task execution and the income from 400 min local task execution.

From Fig. 1, it can be seen that LTP can bring the maximal income for resource owners. Therefore, LTP will be the first choice of a resource owner. To achieve the expected income of LTP, some basic assumptions are as follows:

(a) When a grid task is assigned to a resource, which is idle at the initial time, the resource will execute the task immediately.

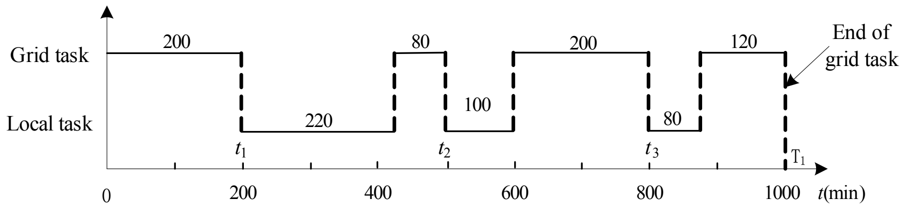

Fig. 1. An example of LTP given τ = 800 min

(b) There is no failure occurrence during the execution of the grid task or the local task.
(c) The arrival process of local tasks can be modeled by a homogeneous Poisson process.
(d) The execution time series of local tasks are i.i.d. random variables, each following the exponential distribution with the same parameter μ.

Denote by $N(t)$ the number of local tasks that have arrived in the interval $(0, t)$ and t the cumulative time of grid task execution. According to the assumption (c), $\{N(t), t \geq 0\}$ is a homogeneous Poisson process whose intensity can be represented by λ. For local task execution, based on assumption (d), the execution time series of local tasks $\{Y_i, i = 1,2,\cdots\}$ are i.i.d. random variables, each following the exponential distribution with parameter μ. Therefore, due to the independence of local task arrivals and the execution of local tasks, the total execution time of local tasks $Y(t)$ during the time t is a compound Poisson process with rate λ, which can be written as

$$Y(t) = \sum_{i=1}^{N(t)} Y_i \quad (1)$$

where $\{N(t), t \geq 0\}$ is a Poisson process with rate λ, and $\{Y_i, i = 1,2,\cdots\}$ are i.i.d. random variables, each following the exponential distribution with parameter μ, which are also independent of $\{N(t), t \geq 0\}$.

Given the required time of grid task τ, which is the execution time of grid task without any interruption in grid resource and can be estimated according to the processing capability of the grid resource and the computational complexity of the grid task, $Y(\tau)$ can be expressed by

$$Y(\tau) = \sum_{i=1}^{N(\tau)} Y_i \quad (2)$$

Thus, the life time of grid task in the grid resource is

$$T(\tau) = \tau + Y(\tau) = \tau + \sum_{n=1}^{N(\tau)} Y_n \quad (3)$$

According to the property of a compound Poisson process, the mean value of $T(\tau)$ can be obtained by

$$m_1(\tau) = \tau + m_2(\tau) = \tau + E[N(\tau)]E[Y] = \tau + \lambda\tau/\mu \quad (4)$$

where $m_1(\tau)$ and $m_2(\tau)$ are the mean values of $T(\tau)$ and $Y(\tau)$, respectively.

Denote by ρ the fixed cost of the resource per unit time, according to equation (4), given the required execution time of grid task τ using the resource, the expected income of LTP, $L(\tau)$, is

$$L(\tau) = G(\tau) + C_1(\tau) = \rho\tau + \rho\lambda\tau/\mu \quad (5)$$

where $G(\tau)$ and $C_1(\tau)$ are the obtained income from the grid task and the local task, respectively.

2.2. Local Task Priority under Grid Task Deadline

The basic assumption of LTP is that there is no limitation of deadline for grid task execution. In reality, when a grid user asks for a grid application, a deadline of the application is specified. If the application can not be completed in a given time, this grid application will be claimed to be failed and the user will not pay the grid at all. Thus it is advisable for a resource owner to balance the execution of local tasks and grid tasks, i.e., if the execution of a coming local task will cause the failure of the grid task, the gridresource will reject this local task and continue executing the grid task. This strategy of resource utilization, referred to as *Local Task Priority under Grid Task Deadline* (LTPD), can ensure the completion of the grid task on schedule, as well as obtain comparative resource utilization. The diagram of grid task execution in grid resource is shown in Fig.2. Fig.3 gives an example of LTPD given the same situation of Fig.1 and the deadline of grid task D = 800 min. In Fig.3, when the first local task arrives at t_1 = 200 min, the estimated execution time of the local task is 220 min. If the resource executes this local task, the grid task will not be completed before D = 1000 min for 220 + 600 > 800 min. Therefore, the resource will reject this local task and continue executing the grid task. However, the second local task will be executed for it has no impact on grid task complement.

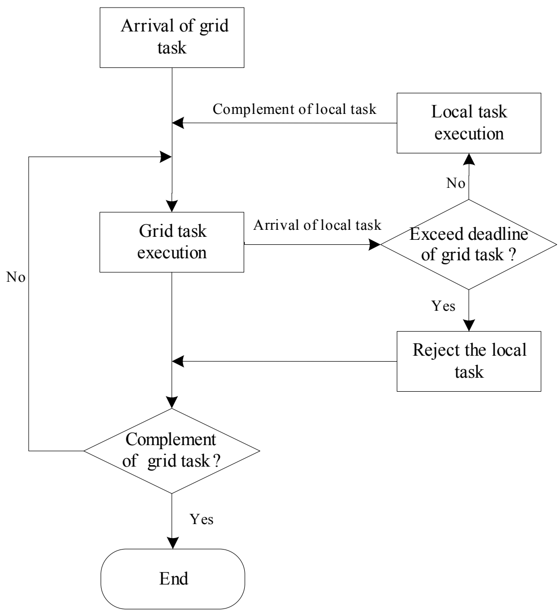

Fig. 2. The process of grid task execution in LTPD

From Fig. 3, it can be seen that LTPD can obtain the maximal income under the constraint of grid task deadline. Compared with LTP, it is known that the income of LTPD can be divided into three parts. The first part is the income from grid task execu-

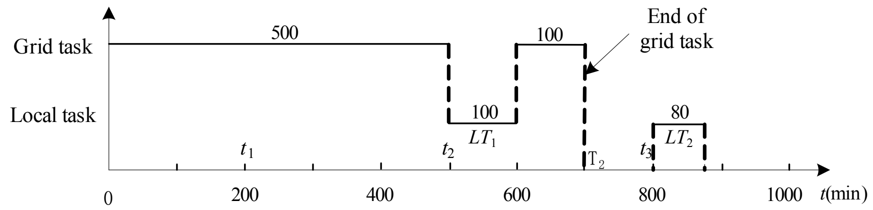

Fig. 3. An example of LTPD given τ = 600 min and D = 800 min

tion $G(\tau)$, which is the same as LTP with the assumption that the income of resource is only related to execution time. The second part is the income from the local task during the grid task execution, represented by $C_2(\tau)$, e.g., the execution of local task LT_1 as shown in Fig. 3. With the deadline of grid task, it is obvious that the lifetime of the grid task in LTPD, e.g., T_2 in Fig. 3, is smaller than that in LTP, e.g., T_1 in Fig. 1.

Moreover, during the time interval $[T_2, T_1]$, some other local tasks may arrive. Thus, the third part is the income from local task execution in time interval $[T_2, T_1]$, represented by $C_3(\tau)$, e.g., the execution of local task LT_2 as shown in Fig. 3. Consequently, given the required execution time τ and the deadline D of the grid task, the income of the resource in LTPD, $D(\tau)$, is

$$D(\tau) = G(\tau) + C_2(\tau) + C_3(\tau) \quad (6)$$

From Fig. 1 and Fig. 3, it can be seen that $L(\tau) > D(\tau)$ for any τ. If we assume that there is no difference between the prices of local tasks and grid tasks, the opportunity cost of LTPD is higher than that of LTP. Thus, the resource owner will choose LTP with no doubt and is not willing to execute grid tasks with a deadline unless additional compensation will be paid. Thus it is reasonable for the grid user to compensate the resource owner. In the next subsection, the minimal compensation will be given and a price model of grid resource is presented.

2.3. The minimal compensation

Opportunity cost plays an important part in the resource owner's decision-making processes. Based on the analysis presented earlier, the opportunity costs of LTP and LTPD are different and resource owner will choose LTP which has a smaller opportunity cost. To ensure grid task completion in a given time, the grid owner should pay a sum of money as compensation to the resource owner. According to equations (5) and (6), the minimal compensation $U(\tau)$ can be expressed as

$$U(\tau) = L(\tau) - D(\tau) = C_1(\tau) - C_2(\tau) - C_3(\tau) \quad (7)$$

where $U(\tau)$ is the minimal compensation which can make the opportunity costs of the two strategies equal and subsequently ensure a fair environment in the grid resource market. Based on the value of $U(\tau)$, for a grid task with a required processing time τ, the price of grid resource will not be fixed and is determined by the initial price ρ and the minimal compensation $U(\tau)$, which can be written as

$$\rho' = [G(\tau) + U(\tau)]/\tau = \rho(1 + \lambda/\mu) - [C_2(\tau) + C_3(\tau)]/\tau \quad (8)$$

The above price model not only takes care of the deadline demand of the grid task, but also gives compensation to the resource owner for opportunity loss of local tasks. Thus it is more meaningful than other price models. However, to obtain the accurate price of a grid resource is not easy. From equation (8), it can be seen that $U(\tau)$ is related to several random variables, e.g., the arrival rate λ and the execution rate μ. It is difficult to compute an exact result with a deterministic mathematical expression. Thus, a calculation approach based on Monte Carlo Simulation is given in the following section.

3. Compensation Calculation Based on Monte Carlo Simulation

To simplify the expression, denote by T_1 and T_2 the life times of the grid task in LTP and LTPD, X_1 and X_2 the interval times of the grid task execution in LTP and LTPD, Y_1 and Y_2 the execution times of local tasks during the grid task execution, respectively. Denote by i and k the numbers of local tasks which have been completed during grid task execution in LTP and LTPD. Denote by T_out the total execution time of local tasks in the interval $[T_2, T_1]$. Moreover, in LTPD, some local tasks have to be rejected in favor of grid task completion in a given time. Thus, an index α is defined. α has two possible values (1, 0): If $\alpha = 1$, it means that the coming local tasks will be rejected. If $\alpha = 0$, it means that grid task execution will be suspended and local tasks will be executed.

Furthermore, since $T_1 \geq T_2$, LTPD can be embedded in the process of LTP and an index β is defined to describe whether the grid task is completed in LTPD or not, i.e., if $\beta = 1$, it means that the grid task has been completed in LTPD and LTPD is finished. If $\beta = 0$, it means that the grid task has not been completed. When $sum(X_1) \geq \tau$, it means that the grid task in LTP has been completed and the simulation process ends. The detailed steps are given below:

Step 1: Initialization

Fix the required time of grid task τ, grid task deadline D, arrival rate of local task λ, execution rate of local task μ, and the initial price of resource ρ. Initialize T_1, X_1, Y_1, T_2, X_2, Y_2, i, k, α, β, T_out and set all of them zero. Go to Step 2.

Step 2: Random number generation

Generate XF randomly using the exponential distribution with parameter λ and IL randomly using the exponential distribution with parameter μ. Judge the value of β, if $\beta = 0$, go to Step 3 otherwise go to Step 4.

Step 3: Execution process of LTP and LTPD

Compare $sum(X_2) + XF$ with τ. If $sum(X_2) + XF \geq \tau$, which means that the grid task in LTPD has been completed before arrival of the local task, set $\beta = 1$, and update T_2 and X_2 according to α. If $sum(X_2) + XF < \tau$, update T_2 and X_2 according to α. Compare $\tau + sum(Y_2) + IL$ with D, if $\tau + sum(L_2) + IL > D$, which means the coming local task will be rejected in LTPD, set $\alpha = 1$. However, all of local tasks arriving during the execution of the grid task will be executed in LTP. If $sum(X_2) + IL < \tau$, which means that LTPD will not be finished when the local task execution is completed in LTP, otherwise set $\beta = 1$. Update T_2 and X_2 in the above two situations and go to Step 4. If $\tau + sum(L_2) + IL < D$, which means that local tasks will be executed in LTPD, set $\alpha = 0$. Update Y_2 and set $k = k + 1$, and then go to Step 4.

Step 4: Calculation of *T_out*

Compare $sum(X_1) + XF$ with τ. If $sum(X_1) + XF < \tau$, the coming local task will be executed in LTP. Update T_1, X_1, Y_1 and set $i = i + 1$. Meanwhile, decide whether LTPD has been finished when the local task arrives. If it is true, record the execution time of this local task and update T_out, and then go to Step 2. If $sum(X_1) + XF \geq \tau$, update T_1, G_1 and go to Step 5.

Step 5: Compensation calculation

Calculate $\rho[sum(Y_1) - sum(Y_2) - T\_out]$ and the compensation of one realization S_1 is obtained and then go to Step 6.

Step 6: Sample aggregation

Repeat the above process n times and n samples are obtained, which is $\mathbf{S} = S_1, S_2, \cdots, S_n$. Using $U(\tau) = sum(\mathbf{S})/n$, the expected compensation of grid users is obtained.

4. Numerical Example

Suppose that $\tau = 800$ min, $D = 1000$ min, $\lambda = 0.004$, $\mu = 0.01$ and the initial price of grid resource is 1, i.e., $\rho = 1$ \$/min. The size of samples is 10000, i.e., $n = 10000$. Based on the Monte Carlo simulation introduced in Section 3, the expected compensation is obtained as 159.2077 \$, which means that the grid user should pay at least \$(800+159.2077) to the resource owner for a grid task completed in a given time $D = 1000$ min. According to equation (8), the price of grid resource should be 1.1990 \$/min.

Furthermore, according to equation (7), grid compensation is a random variable, which is related to some certain factors. Thus, it is reasonable to study the influence of those factors on the minimal compensation. Firstly, the influence analysis of the required time of grid task τ on the minimal compensation is given. A variable M, referred to as *time margin*, is defined first, which describes the demanded margin of grid task completion. M can be obtained by $M = (D-\tau)/\tau$. Given $\lambda = 0.004$ and $\mu = 0.01$, the curve of the minimal compensation with respect to the required time of grid task τ is shown in Fig. 4, in which $M = 0.3$ and the number of samples $n = 10000$. It can be seen that the minimal compensation increases roughly linearly with the increase of the required time of grid task τ when it is greater than 800 minutes.

Deadline is the main measurement of QoS of a grid task and it is obvious that the bigger the time margin is, the larger the minimal compensation is. Given $\lambda = 0.004$, $\mu = 0.01$, and $\tau = 800$ min, the curve of minimal compensation with respect to deadline D is shown in Fig. 5, in which the range of D is [800, 2000]. In Fig. 5, the minimal compensation decreases as the deadline D increases. Especially, when $D > 3\tau$, the minimal compensation tends to 0. It should be noted that when $D = \tau$, the resource will reject all the arrival local tasks so that the grid task can be completed in time. Thus, the strategy of LTP becomes the grid task priority strategy and $C_2(\tau) = 0$ in this case.

The arrival rate of local task λ describes the degree of busyness of the grid resource. Given $\tau = 800$ min, $D = 1000$ min and $\mu = 0.01$, the curve of the minimal compensation with respect to the arrival rate λ of local task is shown in Fig. 6, in which the range of λ is [0.001, 0.2]. It can be seen that with the increase of local tasks' arrival rate, if grid tasks must be completed in a given time, the resource will reject more local tasks and $U(\tau)$ will increase with respect to λ. When λ is large enough, the influence degree of λ on $U(\tau)$ becomes weak and $U(\tau)$ tends to be a fixed value, as shown in Fig. 6.

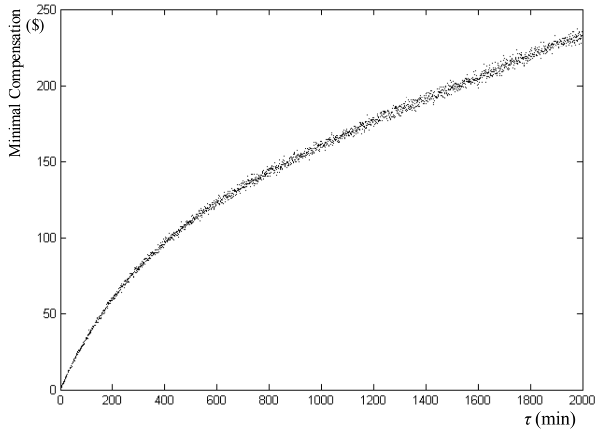

Fig. 4. The curve of the minimal compensation with respect to τ when M=0.3

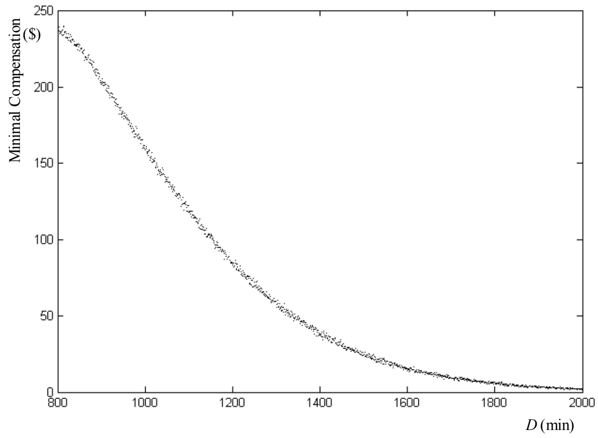

Fig. 5. The curve of the minimal compensation with respect to D

Finally, the influence of local task execution rate μ on the minimal compensation is studied. For a coming local task, whether to reject it or execute it depends on the required time of the local task. Thus, it is reasonable to study the influence of μ on the minimal compensation. Given $\tau = 800$, $D = 1000$, $\lambda = 0.004$, the curve of the minimal compensation with respect to local task execution rate μ is shown in Fig. 7, in which the range of μ is [0.0001, 0.1]. In Fig. 7, with respect to the increasing of μ, it can be seen that the minimal compensation decreases and tends to 0 finally.

5. Conclusion

Resource compensation is essential to the grid system to ensure a fair environment for both grid users and resource owners, especially in the trend of grid commercialization. According to the characteristics of resources and the demand of grid tasks, grid users give a sum of money as compensation for the grid resource,

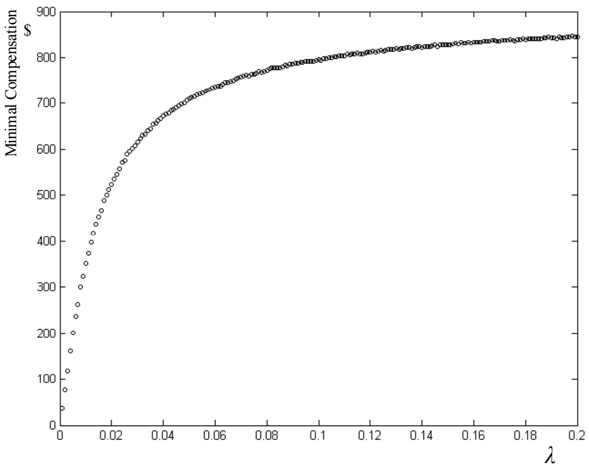

Fig. 6. The curve of the minimal compensation with respect to λ

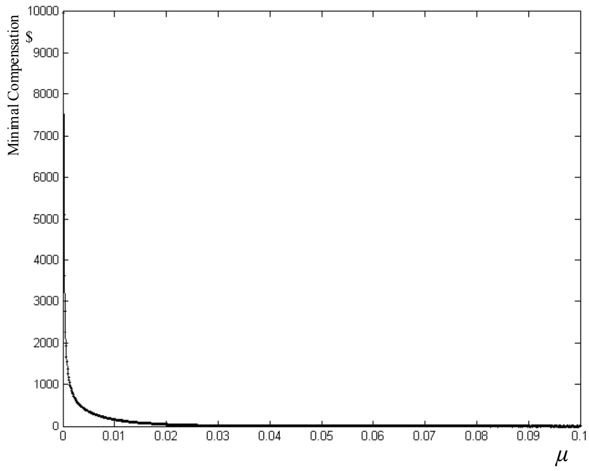

Fig. 7. The curve of the minimal compensation with respect to μ

which can provide resource owners an incentive to participate in grid sharing and help the grid system to make a reasonable price for grid resources. Meanwhile, it motivates grid users to think about tradeoffs between grid service deadline and computational cost according to their QoS requirements. In this paper, a calculation approach for minimal compensation based on Monte Carlo simulation is presented and the influence analysis of several factors on the minimal compensation is given. However, resource compensation is related to many random variables and it is difficult to be determined by an exact expression. The proposed calculation approach based on Monte Carlo simulation is still time-consuming. Furthermore, the exponential distribution is used in the paper. In reality, some other distributions may be more appropriate, which will make the process of grid task execution more complex. Thus, yet more in-depth research is needed and we shall address these issues in our future research.

****

This research was partially supported by the National Natural Science Foundation of China under the contract number 70828001 and the Open Project Program of the State Key Laboratory of Mechanical Transmission, Chongqing University, China under contract number 200802.

****

6. References

1. AuYoung A, Chun B N, Snoeren A C, et al. Resource allocation in federated distributed computing infrastructures. Boston 2004; *Proceedings of the 1st Workshop on Operating System and Architectural Support for the Ondemand IT InfraStructure*.
2. AuYoung A, Grit L, Wiener J, et al. Service contracts and aggregate utility functions. Paris 2006; *Proceedings of the 15th IEEE International Symposium on High Performance Distributed Computing*.
3. Broberg J, Venugopal S, Buyya R. Market-oriented grids and utility computing: the state-of-the-art and future directions. Journal of Grid Computing 2008; 6: 255–276.
4. Chun B, Buonadonna P, Au Young A, et al. Mirage: a microeconomic resource allocation system for sensornet testbeds. Sydney 2005; *Proceedings of the 2nd IEEE Workshop on Embedded Networked Sensors*.
5. Fernández-Quiruelas V, Fernández1 J, Cofiño A S, et al. Climate modeling on the Grid experiences in the EU-project EELA. Catania 2007; *The 3rd EELA Conference*.
6. Foster I, Kesselman C. *The Grid 2: Blueprint for a New Computing Infrastructure*. Los Alios: Morgan-Kaufmann, 2003.
7. Foster I, Kesselman C, Tuecke S. The anatomy of the grid: enabling scalable virtual organizations. International Journal of High Performance Computing Applications 2001; 15: 200–222.
8. Foster I. The Grid: a new infrastructure for 21st century science. Physics Today 2002; 55: 42–47.
9. Grinstein S, Huth J, Schopf J M. Resource predictors in HEP applications. Interlaken 2004; *Proceedings of Computing in High Energy Physics*.
10. Huang H Z, Liu Z J, Murthy D N P. Optimal reliability, warranty and price for new products. IIE Transactions 2007; 39: 819-827.
11. Huang H Z, Qu J, Zuo M J. Genetic-algorithm-based optimal apportionment of reliability and redundancy under multiple objectives. IIE Transactions 2009; 41: 287-298.
12. Huang H Z, Tian Z, Zuo M J. Intelligent interactive multiobjective optimization method and its application to reliability optimization. IIE Transactions 2005; 37: 983-993.
13. Huang H Z, Zuo M J, Sun Z Q. Bayesian reliability analysis for fuzzy lifetime data. Fuzzy Sets and Systems 2006; 157: 1674-1686.
14. Jahanzeb S, Nosheen A, Nausheen L, et al. Libra: a computational economy-based job scheduling system for clusters. Software Practice and Experience 2004; 34: 573–590.

15. Rajkumar B. Economic-based distributed resource management and scheduling for grid computing. PhD thesis, Monash University, 2002.
16. Rungsarityotin W, Khiripet N, Tanpraset C, et al. Grid computing and bioinformatics development: A case study on the Oryza sativa (rice) genome. Pure and Applied Chemistry 2002; 74: 891–897.
17. Shneidman J, Ng C, Parkes D C, et al. Why markets could (but don't currently) solve resource allocation problems in systems. Berkeley 2005; *Proceedings of 10th Conference on Hot Topics in Operating Systems*.
18. Stiglitz J E. Principles of Microeconomics. WW: Norton & Company, 2002.
19. Stuer G, Vanmechelen K, Broeckhove J. A commodity market algorithm for pricing substitutable Grid resources. Future Generation Computer Systems 2007; 23: 688-701.
20. Wolski R, Plank J S, Brevik J, Bryan T. Analyzing market-based resource allocation strategies for the computational grid, International Journal of High-Performance Computing Applications 2001, 15: 258-281.
21. Zhang X L, Huang H Z, Liu Y. A hierarchical decomposition approach for large system reliability allocation. Eksploatacja i Niezawodnosc - Maintenance and Reliability 2009; 3: 32-37.
22. Zheng Q, Tham C K, Veeravalli B. Dynamic load balancing and pricing in grid computing with communication delay. Journal of Grid Computing 2008; 6: 239-253.

Suchang GUO, Ph.D. candidate
Hu WAN, Ph.D.
Gui-Bao WANG, Ph.D. candidate
School of Mechanical, Electronic, and Industrial Engineering
University of Electronic Science and Technology of China
Chengdu, Sichuan, 611731, P. R. China
The State Key Laboratory of Mechanical Transmission
Chongqing University
Chongqing, 400044, P. R. China
e-mail: schguo@uestc.edu.cn

Prof. M. XIE, Ph.D.
Department of Industrial and Systems Engineering
National University of Singapore
Kent Ridge Crescent, 119260, Singapore