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An Optimal Method about Resource Scheduling for Economizing Energy in Extended Virtual Machine System

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Abstract

With the growth of system scale, it has become a key problem that how to economize energy when the system resources are scheduled in extended virtual machine system. In order to resolve the problem, we first propose an optimal method about resource scheduling, which fully consider the factor of energy consumption. Then, we do a series of experiment. At last, we give out the results of experiment and analyze these results. Based on the steps, we draw some conclusions.

Keywords: *System Resource, Scheduling mechanism, Energy Consumption, Virtual Machine*

1. Introduction

Today, more systems owners are realizing their hardware is being under-utilized, and virtualization is becoming a common solution. By using the virtualization technology, a computer system can aggregate all kinds of data resources, software resources and hardware resources and make these resources to provide service for different tasks. Moreover, the virtualization technology can separate hardware and software management and provide useful features including performance isolation [1], server consolidation and live migration [2]. In addition, the virtualization technology can also provide secure and portable environments for these modern computing systems [3]. Therefore, the computing theorem and model that these virtual technology embodies are applied widely.

Because the virtualization technology can carve some individual physical machine into multiple virtual containers, people begin to build some extended virtual machine systems for various applications [4, 5]. In these extended machine systems, their architectures are same and divide into four layers, namely the multiple computers layer, the multiple virtual machine monitors layer, the single image management layer and the application system layer. In the multiple computers layer, there is a lot of hardware, which include CPU, storage, network card and so on. In the multiple virtual machine monitors layer, there are some virtual machine monitors. Each virtual machine monitor is managed and scheduled by the single image management layer. The main function of each virtual machine monitor includes: managing its local physical machine safely, providing isolation between the virtual machine monitors and executing the commands that the single image management layer sends to it. In the single image management layer, there is a single image management module. Its function includes: enabling each virtual machine to share the corresponding physical machine safely, providing isolation between the different virtual machines, providing some different strategies for virtual machine to access hardware resources, controlling all virtual machine monitors and managing the central datum. In the application system layer, there are some different applications which can be run on the corresponding virtual machines.

Because there are a lot of advantages by using extended virtual machine system, the scale that people need to use virtual machine system is becoming larger. However, with the rapid growth of virtual machine system, the scheduling of all kinds of hardware and software resources is becoming more and more difficult. Moreover, the power consumption is becoming more serious. In fact, a mass of power consumption will generate a lot of heat and affect the utilization ration and the service performance of system resource in an extended virtual machine system. Thus, there are two inconsistent factors between how to expand the scale of the computer system and how to schedule system resource and economize the power consumption of system. Therefore, it is urgent to design and deploy the energy economizing technology for resource scheduling

In order to resolve this problem, we propose an optimal method about resource scheduling for economizing energy in extended virtual machine system. In the optimal method about resource scheduling, the factor of energy consumption is fully considered. Then, we do a series of experiment. At last, we give out the results of experiment and analyze these results.

2. Related Works

With the development of virtual machine system, the power consumption of system and the scheduling management of resource begin to be widely concerned. In order to ensure the quality of service of system resource, people presented a lot of methods to reduce the power consumption when the system resources are scheduled. A lot of great processes have been made in the aspect. These great processes can be simply shown as follows.

Deng et al. propose to divide these workloads into buckets which are equal in time length, and predict the number of the forthcoming requests in each bucket instead of the length of the idle periods [6]. By doing so, the bucket method makes the converted workload more predictable. The method also squeezes the executing time of each request to the end of its respective bucket, thus extending the idle length. By deliberately reshaping the workloads such that these crests and troughs of each workload become aligned, the peaks and the idle periods of these workloads can be aggregated. Thus, energy can be conserved.

In order to save energy in a cluster with virtual machines, Liao et al. design a novel scheme, called Magnet [7]. In the scheme, the migration of virtual machines is used to transfer load among the nodes on a multi-layer ring-based overlay. By using the scheme, the power consumption can greatly be reduced.

In order to decrease the power consumption and cooling overheads, Nathuji et al. propose a set of management components and abstractions for use by software power budgeting policies [8]. The key idea is to manage power from a VM-centric point of view, where the goal is to be aware of global utility tradeoffs between different virtual machines (and their applications) when maintaining power constraints for the physical hardware on which they run. By using the set of management components and abstractions, the efficiency of datacenter can be improved.

In order to coordinate and tradeoff the power and performance of virtual machine, a power aware resource allocation algorithm, named PaRA, is proposed [9]. In the power aware resource allocation algorithm, the virtual machine monitor is responsible for allocating basic resources such as CPU slices, memory capacities, and disk and network I/O bandwidths. In runtime, resource allocation is automated based on the workload characterization and the real time power consumption is measured.

In order to reduce power consumption in a computer cluster, a novel power-aware scheduling algorithm is presented, which can allocate virtual machines in a DVFS-enabled cluster by dynamically scaling these supplied voltages [10]. By using the algorithm, the power consumption of a DVFS-enabled cluster can be reduced.

In order to research the energy efficiency cloud computing, a virtual machine based energy-efficient data center architecture for cloud computing is presented [11], which includes the consolidation and migration mechanism. By using the consolidation and migration mechanism, the data center can maintain energy efficiency automatically.

In order to reduce the memory energy consumption in multicore system, several heuristic scheduling algorithms by using a memory power simulator are designed and implemented [12]. By using these algorithms, the memory-aware virtual machine can save memory energy. Therefore, these algorithms are essential to reduce the memory energy consumption in power-aware memory management

In order to reduce energy consumption in computer clusters, a new power-aware scheduling policy for heterogeneous clusters is proposed [13]. In the new power-aware scheduling policy, the power consumption information of each machine is used to find an allocation of the machine, which results in the maximum energy saving.

Though above these methods are very useful for correspondingly application, they will still confront a lot of difficulties in scheduling system resources and economizing energy because the scheduling mechanism of resource in the extended virtual machine system is different from these virtual machine systems. In order to overcome these disadvantages and economizing power consumption, we present an optimal method about resource scheduling in extended virtual machine system.

3. Optimal Method about Resource Scheduling

In an extended virtual machine system, the total number of physical resources that all virtual machines can schedule in any time is less than the total number of system resources. If we use PM_i to denote the i^{th} physical resource, m to denote the total number of physical resources and PM to denote the set of physical resources, we can get $PM=\{PM_1, PM_2, PM_3, \ldots, PM_m\}$. Similarly, if we use vm_i to denote the i^{th} virtual machine, n to denote the total number virtual machine and VM to denote the set of virtual machine in the extended virtual machine system, we can get $VM=\{vm_1, vm_2, vm_3, \ldots, vm_n\}$.

In an extended virtual machine system, physical resources need to be managed by the single image management module and the corresponding virtual machine monitor. When some tasks are submitted to different virtual machines, these virtual machines need to schedule corresponding physical resource for these different virtual machines. Moreover, when the number of tasks that a virtual machine is submitted is too much, the virtual machine may be migrated. Therefore, a resource scheduling model is needed for different tasks in the extended virtual machine system.

In order to conveniently describe the resource scheduling model in extended virtual machine system, some notation and definitions are used in the rest of this paper and these notation and definitions are summarized here.

M the total number of physical machines in the extended virtual machine system

PM_i the physical resource of the i^{th} physical machine
$vm_i \rightarrow PM_j$ the i^{th} virtual machine schedule physical resource PM_j

t_0 the beginning time that tasks are processed

t_i the i-th time that tasks are processed

$q_i(t_0)$ the number that tasks begin to be processed in the i-th virtual machine

$\lambda_i(t)$ the rate that the i-th virtual machine submits tasks to the single image management layer and the corresponding virtual machine monitor at the time t

$u_i(t)$ the rate that the i-th virtual machine gets services, which is managed and controlled by the single image management layer and the corresponding virtual machine monitor at the time t

x+ a non-negative, which is an abbreviation for max(x; 0).

In the extended virtual machine system, we assume that each virtual machine can schedule the system resources in term of the corresponding request order. Using a combination of online measurement, prediction and adaption, we can dynamically determine the resource share that each virtual machine can schedule, which is based on the response time and the task number that each virtual machine submits.

Considering multiple virtual machines can submit tasks to the extended virtual machine system and the system can provide service for the corresponding tasks, we can assume that the mode that different virtual machines submit tasks may be parallel and the service mode that different virtual machine may also be parallel. Moreover, the service mode that each virtual machine gets is First Input First Output mode for the same type tasks.

In general, each task that a virtual machine submits is serviced by multiple hardware and software resources, such as the CPU, NIC, disk, etc. But there are a single image management layer and multiple virtual machine monitors, all these resources may be regarded as a coordinate entirety. These resources that each virtual machine schedule will be a part of whole system resources.

In the extended virtual machine system, if these tasks that a virtual machine system submits are heavy, the virtual machine may be migrated. Therefore, there are two main factors, which decide a virtual machine should be migrated or not. One is the rate that the virtual machine submits tasks and the other is the rate that the virtual machine gets services. If the values of $\lambda_i(t)$ and $u_i(t)$ are constant, the amount of tasks at time *t* is given by

$$q_i(t) = [q_i(t_0) + (\lambda_i(t) - u_i(t)) * (t - t_0)]^+ \tag{1}$$

Intuitively, in each virtual machine, the amount of tasks at the time t is the sum of the initial number and the amount of tasks arriving in this interval minus the amount of tasks serviced in this duration. Since the queue length is non-negative, we use $q_i(t)$ to denote the amount of tasks at any time *t* in the *i-th* virtual machine.

Let *C(PM)* to denote the total of physical resources. Thus, we can get the following equation

$$C(PM) = PM_1 + PM_2 + PM_3, \ldots, + PM_m \tag{2}$$

If we use $E(vm_i)$, $E_{dynamic}(vm_i)$, $E_{static}(vm_i)$ to denote the whole energy consumption, the dynamic energy consumption and the static energy consumption of the *i-th* virtual machine, respectively, then we can get the following equation

$$E(vm_i) = E_{dynamic}(vm_i) + E_{static}(vm_i) \tag{3}$$

Because the processing procedure of each virtual machine involves the processing of task and the migrating of task, we can get the following equation

$$E_{dynamic}(vm_i)= E_{processing}(vm_i)+ E_{migrating}(vm_i) \tag{4}$$

If we use $s_{processing}(i)$ to denote the processing frequency of task in the *i-th* virtual machine, $s_{migrating}$ *(i)* to denote the migrating frequency of task from the *i-th* virtual machine, *C* is the total capacitance load, *v(i)* is the supply voltage of the *i-th* virtual machine, then we can get

$$E_{dynamic}(vm_i)=\sum_{t} \zeta_i *C*v(i)^2*(s_{processing}(i)+ s_{migrating} (i)) *(t-t_0) \tag{5}$$

Because the set of virtual machines is $VM=\{vm_1, vm_2, vm_3, \ldots, vm_n\}$, we need to find an optimal schedule *f*, which minimizes the power consumption of the extended virtual machine system, namely

$$E_{min}=\min\sum_{i=1}^{n} E(vm_i) \tag{6}$$

Where, $E(vm_k)$ is the power consumption of the k-th virtual machine in the extended virtual machine system.

In the extended virtual machine system, the supply voltages that different physical machines use have two states. One is: the supply voltages that different physical machines use are inequality each other. The other is: the supply voltages that different physical machines use are equality each other. In the extended virtual machine system, if the supply voltages that different physical machines use are the same, then we can get a few rules of thumb which are based on the equation (5). The main principle of those rules is to minimize the processing frequency of each virtual machine. By using these rules, we can build a theoretical model of resource scheduling about energy optimization in the extended virtual machine system. These rules can be described as follows.

(1) Minimize the frequency that each virtual machine processes task

(2) Minimize the frequency that each virtual machine migrate task

Base on the above two rules, two conditions should be taken into account in the extended virtual machine system in order to reduce power consumption. One is that the load of each physical machine keep balance as much as possible and the other is the total number of virtual machine migration keep the minimum as much as possible. Based on the two conditions, we use the optimal theory to present a theoretical model of resource scheduling about energy optimization in the extended virtual machine system. The theoretical model can be described as follows:

$$f(\zeta) = \max(C(PM) - \sum_{i=1}^{n} \zeta_i * C(PM)),\ st$$

$$q_i(t) \le q_i(t_0) \tag{7}$$

$$0 \le \zeta_i \le 1 \tag{8}$$

$$0 \le \sum_{i=1}^{n} \zeta_i \le 1 \tag{9}$$

Here, Equation (7) denotes that the amount of tasks at time t is no more than that of tasks at the initiate state, which need to be processed by the i-th virtual machine. This equation indicates that the i-th virtual machine doesn't need to be migrated. Equation (8) denotes that the amount of physical resources that the i-th virtual machine can schedule is no more than the total of the extended virtual machine system. Equation (9) denotes that the total of physical resources that all virtual machines can schedule is no more than the total of the extended virtual machine system.

In fact, the above theoretical model is an objective function. It is also a multi-objective optimization question. The aim that the objective function is presented here includes two factors. One is to keep the minimum of physical resources that all virtual machine can schedule and the other is to keep the minimum that virtual machine need to be migrated. Because the total of virtual machine and physical machine are limited, it is a NP-hard problem that how to achieve the optimal result.

4. The Solution of Optimal Method

In order to resolve the optimal solution of the resource scheduling model, we propose an algorithm. In the algorithm, we first randomly choose a group initial solution, namely a group initial value. Then, we begin to search the optimal solution in the global scope of domain. At last, we repeated execute the search process till the results are satisfied with the termination conditions. By using some selecting methods, we ensure the optimal result. The algorithm can be described as follows:

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Step 1: Make sure $VM=\{ vm_1, vm_2, ..., vm_n\}$ and $PM=\{PM_1, PM_2, ..., PM_m\}$
Step 2: Make sure $q_i(t_0)$, (i=1,2,3,…,n)
Step 3: Make sure the rate $\lambda_i(t)$ and $u_i(t)$ at the time $t$ $(i=1,2,3,...,n)$
Step 4: Randomly choose a group initial value $\zeta$ ={ $\zeta_1,\zeta_2,\zeta_3,..\zeta_n$ }
Step 5: Calculate $q_i(t)$ at the time $t$ $(i=1,2,3,...,n)$, which is based on Equation (1)
Step 6: If $q_i(t) \le q_i(t_0)$, then { go to Step 9} Else {go to Step 7}
Step 7: Randomly choose an initial value $\rho_0$, an infinitely small number $\varepsilon$, and $k=0$
Step 8: If $k \le n$ Then { $\alpha \leftarrow 1-k/n$ ; $\rho_{k+1} \leftarrow \rho_k * \alpha$ ; $\Delta\zeta_k \leftarrow \zeta_k - \rho_k$ ;
    If $0 \le \Delta\zeta_k \le 1$ Then { $\zeta_k^* \leftarrow \Delta\zeta_k$ } Else { $\zeta_k^* \leftarrow \zeta_k$ };
        $\zeta^* \leftarrow \{\zeta_1^*,...\zeta_k^*,\zeta_{k+1},...\zeta_n\}$; $\Delta f(\zeta) \leftarrow f(\zeta) - f(\zeta^*)$;
        If $\Delta f(\zeta) > 0$ Then { $\zeta \leftarrow \zeta^*$;
        If $|\rho_{k+1} - \rho_k| < \varepsilon$ Then { go to Step 9 } Else { $k \leftarrow k+1$, go to Step 7} }
        Else { $\zeta \leftarrow \zeta^*$, go to Step 9 } } }
Step 9: Output $\zeta$ ={ $\zeta_1,\zeta_2,\zeta_3,...\zeta_n$ }
Step 11: End
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5. Experiments and Results Analysis

In order to validate the efficiency of our proposed optimal method about resource scheduling for economizing energy in extended virtual machine system, we do a series of experiments. In these experiments, we first use the open source of Xen and the corresponding virtualization technology to construct a extended virtual machine system. Then, we use different scheduling methods to schedule system resource and monitor the state of resource scheduling. At last, we will analyze these results of experiments. The whole process can be described as follows.

5.1 A Series of Experiments

In our constructed extended virtual machine system, there are some resource scheduling mechanisms and methods. These resource scheduling mechanisms and methods include our proposed resource scheduling mechanism for reducing energy consumption, the load balancing mechanism, and the credit scheduling algorithm. The image management system can respectively use these algorithms and mechanisms to schedule the physical machine and provide service for tasks.

In our experiments, there are six physical machines (PM_1, PM_2, PM_3, PM_4, PM_5 *and* PM_6) and each physical machine only has two same processors. The supply voltage that each physical machine uses is 220 volt. Moreover, the hardware and the software configurations of each physical machine are the same. And the operation system that each physical machine used is windows XP. In addition, we use the extended virtual machine system to built eight virtual machines and three virtual machine monitors. The eight virtual machines are named vm_1, vm_2, vm_3, vm_4, vm_5, vm_6, vm_7 and vm_8, respectively. Similarly, the three virtual machine monitors are respectively named VMM_1, VMM_2 and VMM_3.

In our experiments, the task that each virtual machine submits is to resolve the inverse matrix for an invertible matrix. The invertible matrix is a 5 order matrix. In these experiments, the rate that each virtual machine submits task to the single image management layer may be different each other and the rate that each virtual machine submits task will be equality in different time phase. The rate that each virtual machine submits tasks to the single image management layer is shown 32(Time/S), 24(Time/S), 29(Time/S), 30(Time/S), 21(Time/S), 19(Time/S), 29(Time/S), 19(Time/S), separately. In addition, the percent that each virtual machine can schedule the physical resources of the system in the initiate state is shown as 16%, 10%, 9%, 18%, 12%, 13%, 10%, 12%, separately.

Moreover, the process that each virtual machine submits task keep the same in order to study the service state of physical machines in different resource scheduling algorithms and mechanisms. By using the statistical method, we can get the rate that each physical machine provides service for these tasks in the three resource scheduling algorithms and mechanisms, respectively. The results are shown as Figure 1, Figure 2, Figure 3, Figure 4, Figure 5, Figure 6, respectively.

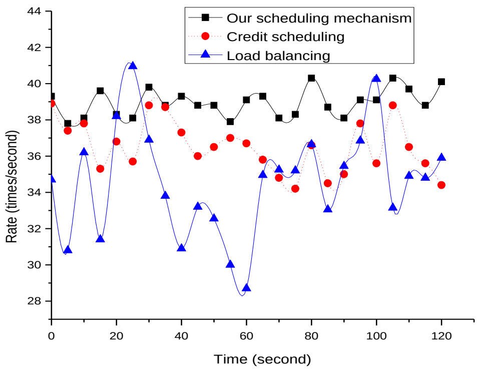

Figure 1. The Rate that the PM_1 physical machine provide Services in Different Scheduling Algorithms and Mechanisms

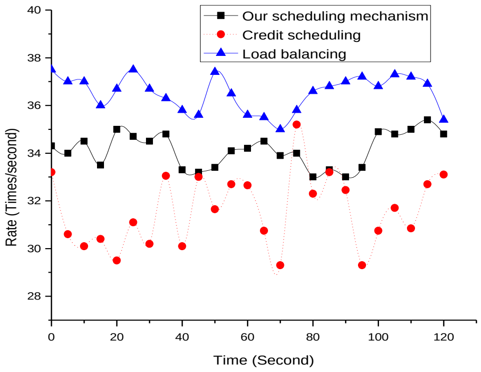

Figure 2. The Rate that the PM_2 Physical Machine Provide Services in Different Scheduling Algorithms and Mechanisms

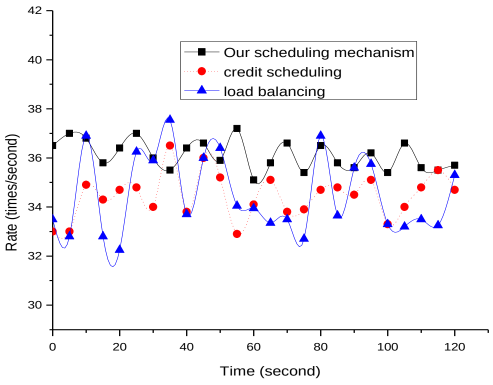

Figure 3. The Rate that the PM_3 Physical Machine Provide Services in Different Scheduling Algorithms and Mechanisms

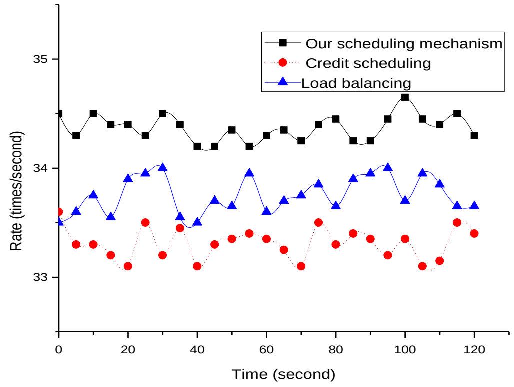

Figure 4. The Rate that the PM_4 Physical Machine Provide Services in Different Scheduling Algorithms and Mechanisms

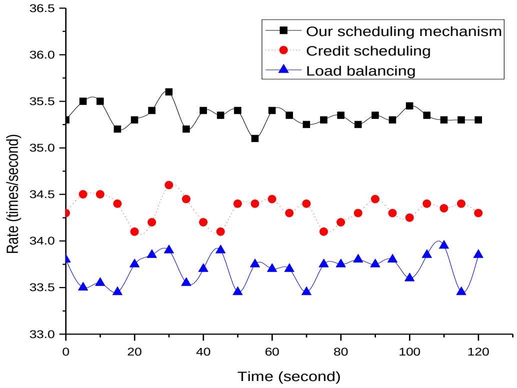

Figure 5. The Rate that the PM_5 Physical Machine Provide Services in Different Scheduling Algorithms and Mechanisms

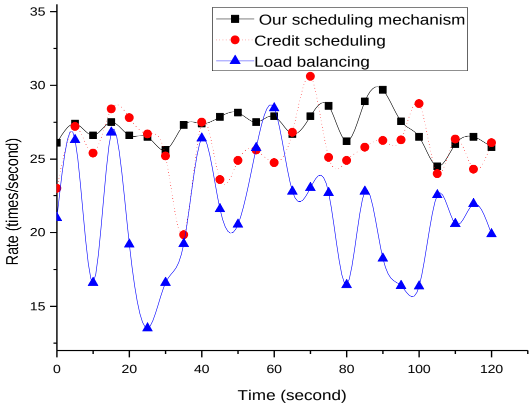

Figure 6. The Rate that the PM_6 Physical Machine Provide Services in Different Scheduling Algorithms and Mechanisms

In addition, by using the power consumption monitor function of our resource scheduling module, we can get the average consumption of power that each physical machine respectively uses these three different scheduling algorithms in time interval [0, 120s]. The results are shown as Figure 7.

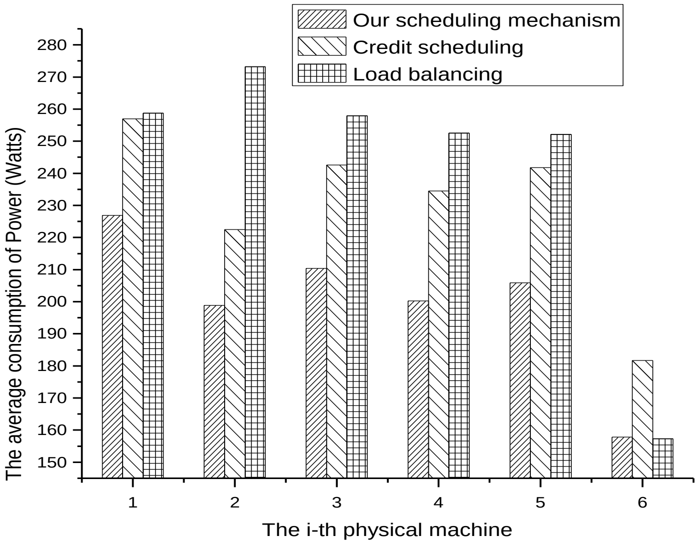

Figure 7. The Average Consumption of Power that each Physical Machine respectively uses these three different Scheduling Algorithms in Time Interval [0, 120s]

5.2 Results Analysis

In this section, we will analyze these results of our experiments. In order to describe the analyzing process conveniently, we use T_{Our}, T_{Credit} and T_{Load} to denote the even rate that the extended virtual machine system provides services for tasks in these three resource scheduling algorithms and mechanisms, respectively. Based on the results of above experiments, we can get T_{Our}, T_{Credit} and T_{Load}, respectively. The results are shown as fellows.

T_{Our} =214 (time/second), T_{Credit} =198.5 (time/second), T_{Load} =191.58 (time/second)

Because $T_{Our} > T_{Credit} > T_{Load}$, the even rate that the extended virtual machine system provides services for tasks in our proposed resource scheduling mechanism is faster than that in the other two scheduling algorithms. This indicates: the rate that the extended virtual machine system provides services for tasks in our proposed resource scheduling mechanism is faster than that in the other two scheduling algorithms.

If we use D_{Our}, D_{Credit} and D_{Load} to denote the mean square deviation of the rate that the extended virtual machine system provides service in the three resource scheduling algorithms and mechanisms, respectively. Then, we can get:

D_{Our}= 0.57, D_{Credit}= 1.04, D_{Load}=1.58

Because $D_{Load} > D_{Credit} > D_{Our}$, the mean square deviation of rate that the extended virtual machine system provides service in our proposed resource scheduling mechanism is smaller than that in the other two scheduling algorithms. This indicates:

the stability that the extended virtual machine system provides services for tasks in our proposed resource scheduling mechanism is better than that in the other two scheduling algorithms.

If we use P_{Our}, P_{Credit} and P_{Load} to denote the average power consumption of the extended virtual machine system in the three resource scheduling algorithms and mechanisms, respectively. Then, we can get:

P_{Our}=1200 (watts), P_{Credit}=1380 (watts), P_{Load}= 1452 (watts)

Because $P_{Load} > P_{Credit} > P_{Our}$, the average power consumption that the extended virtual machine system provides service in our proposed resource scheduling optimal method is smaller than that in the other two scheduling algorithms. This indicates: Our proposed resource scheduling optimal method can reduce energy consumption. Relative to the other two scheduling algorithms, the energy consumption can reduce 15% and 21% by using our proposed resource scheduling mechanism, respectively.

6. Conclusions

Based on the above analyses, we can find: (1) our proposed resource scheduling optimal method can economize energy in extended virtual machine system. (2) our proposed resource scheduling optimal method is efficient. (3) our proposed resource scheduling mechanism is better than the other two scheduling algorithms in extended virtual machine system. The main reasons that these situation can generate are: our proposed resource scheduling optimal method can minimize the frequency that each virtual machine processes task and minimize the frequency that each virtual machine migrates task. Based on the two reasons, energy consumption can be reduced by using our proposed resource scheduling optimal method.

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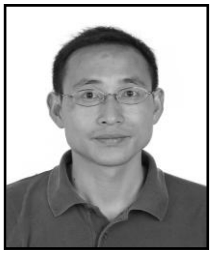

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