

A Scheduling Strategy on Load Balancing of Virtual Machine Resources in Cloud Computing Environment

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Abstract—The current virtual machine (VM) resources scheduling in cloud computing environment mainly considers the current state of the system but seldom considers system variation and historical data, which always leads to load imbalance of the system. In view of the load balancing problem in VM resources scheduling, this paper presents a scheduling strategy on load balancing of VM resources based on genetic algorithm. According to historical data and current state of the system and through genetic algorithm, this strategy computes ahead the influence it will have on the system after the deployment of the needed VM resources and then chooses the least-affective solution, through which it achieves the best load balancing and reduces or avoids dynamic migration. This strategy solves the problem of load imbalance and high migration cost by traditional algorithms after scheduling. Experimental results prove that this method is able to realize load balancing and reasonable resources utilization both when system load is stable and variant.

Keywords—cloud computing; virtual machine resources; load balancing; genetic algorithm; scheduling strategy

I. INTRODUCTION

Cloud computing is a new technology in academic world [1]. On cloud computing platform, resources are provided as service and by needs, and it guarantees to the subscribers that it sticks to the Service Level Agreement (SLA). However, due to the situation that the resources are shared, and the needs of the subscribers have big dynamic heterogeneity and platform irrelevance, it will definitely lead to resource waste if the resources cannot be distributed properly [2]. Besides, the cloud computing platform also needs to dynamically balance the load among the servers in order to avoid hotspot and improve resource utility. Therefore, how to dynamically and efficiently manage resources and to meet the needs of subscribers become the problems to be solved.

Virtualization technology provides an effective solution to the management of dynamic resources on cloud computing platform. Through sealing the service in virtual machines and mapping it to every physical server, the problem of the heterogeneity and platform irrelevance of subscribers' needs can be better solved and at the same time the SLA is guaranteed. What is more, virtualization technology is able to carry out remapping between virtual machine (VM) and physical resources according to the load change so as to achieve the load balance of the whole

system in a dynamic manner [3]. Therefore, virtualization technology is being comprehensively used in cloud computing. However, due to the highly dynamic heterogeneity of resources on cloud computing platform, virtual machines must adapt to the cloud computing environment dynamically so as to achieve its best performance by fully using its service and resources. But in order to improve resource utility, resources must be properly allocated and load balancing must be guaranteed [4]. Therefore, how to schedule VM resources to realize load balancing in cloud computing and to improve resource utility becomes an important research point.

Currently in cloud computing, it mainly considers the current system condition in VM resources scheduling but seldom considers the previous condition before scheduling and the influence on system load after scheduling which usually leads to load imbalance. Most of the load balancing exists in VM migration [5]. Yet, when the entire VM resources are migrated, due to the large granularity of VM resources and the great amount of data transferred in migration and the suspension of VM service, the migration cost becomes a problem. This paper presents a scheduling strategy to realize load balancing. According to historical data and current state and through genetic algorithm, this method computes in advance the influence it will have when the current VM service resources that need deploying are arranged to every physical node, then it chooses the deployment that will have the least influence on the system. In this way, the method realizes the best load balancing and reduces or avoids dynamic migration.

II. RELATED WORK

Load balancing has always been a research subject whose objective is to ensure that every computing resource is distributed efficiently and fairly and in the end improves resource utility. In traditional computing environments of distributed computing, parallel computing and grid computing, researchers in and abroad have proposed a series of static and dynamic and mixed scheduling strategies [6]. In static scheduling algorithm, ISH [7], MCP [8] and ETF [9] algorithms based on BNP are suitable for small distributed environments with high internet speed and ignorable communication delay while MH [10] and DSL [11] algorithm based on APN take into consideration of the

communication delay and execution time so they are suitable for larger distributed environments. In dynamic scheduling algorithm, some algorithms guarantee the load balancing and load sharing in task distribution through self-adapting distribution and intelligent distribution. In mixed scheduling algorithm, it mainly emphasizes equal distribution of assigned computing task and reduction of communication cost of distributed computing nodes and at the same time it realizes balanced scheduling according to the computing volume of every node. Researchers have also conducted studies on algorithms of autonomic scheduling, central scheduling, intelligent scheduling and agent negotiated scheduling. There are many similarities and also differences between traditional scheduling algorithms and the scheduling of VM resources in cloud computing environment. First, the biggest difference between cloud computing environment and traditional computing environment is the target of scheduling. In traditional computing environment, it mainly schedules process or task so the granularity is small and the transferred data is small; whereas in cloud computing environment the scheduled target is VM resources so the granularity is large and the transferred data is large as well. Second, in cloud computing environment, compared with the deployment time of VMs, the time of scheduling algorithm can almost be neglected. This paper sees to the equal distribution of hardware resources of VMs in cloud computing environment so that the VM can improve its running efficiency while meeting the QoS needs of subscribers.

At present, a number of studies on the balanced scheduling of VM resources are based on dynamic migration of VMs. Sandpiper [12] system carries out dynamic monitoring and hotspot probing on the utility of system's CPU, Memory resources and network bandwidth. It also puts up with the resource monitoring methods based on black-box and white-box. The focus of this system is how to define hotspot memory and how to dispose hotspots through the remapping of resources in VM migration. VMware Distributed Resource Scheduler (DRS)[13] is a tool to distribute and balance computing volume by using the available resources in virtualized environment. VMware DRS continuously monitors resource utility over the resources pool then conducts intelligent distribution of available resources among several VMs according to the predefined rule which reflects business needs and the changing priority. If there is dramatic change of workload in one or more VMs, VMware DRS will redistribute VMs among physical servers and migrate VMs to different physical servers through VMware VMotion. All of the above systems achieve system load balance through dynamic migration, but frequent dynamic migration will employ a large number of resources which finally leads to performance degrading of the whole system.

Genetic algorithm [14] is a random searching method developed from the evolution rule in ecological world (the genetic mechanism of survival of the fittest). It has internal implicit parallelism and better optimization ability. By the optimization method of probability, it can automatically obtain and instruct the optimized searching space and adjust

the searching direction by itself. Considering the VM resources scheduling in cloud computing environment and with the advantage of genetic algorithm, this paper presents a balanced scheduling strategy of VM resources based on genetic algorithm[15][16][17]. According to historical data and current states, this method computes in advance the influence it will have when the current VM service resources that need deploying are arranged to every physical node, based on which the method achieves the best load balancing. In the first part of this paper, it introduces the current situation of VM resources scheduling in cloud computing environment; in the second part, it designs the VM scheduling model; in the third part, it raises the VM resources scheduling method based on genetic algorithm; at the end, an analysis of the method is made and an experiment and summary is also conducted.

III. THE MODEL DESIGN OF VM SCHEDULING

A. VM Model

Figure 1 shows the mapping relationship between VMs and physical machines. The set of all the physical machines in the system here is $P = \{P_1, P_2, \dots, P_N\}$, N is the number of physical machines, $P_i (1 \leq i \leq N)$ stands for physical machine No.i. We name the VMs set on physical machine P_i $V_i = \{V_{i1}, V_{i2}, \dots, V_{im_i}\}$ in which m_i is the number of VMs on physical machine No.i. Suppose we need to deploy VM V at present, and we use $S = \{S_1, S_2, \dots, S_N\}$ to represent the mapping solution set after V is arranged to every physical machine. S_i here refers to the mapping solution when VM V is arranged to physical machine P_i .

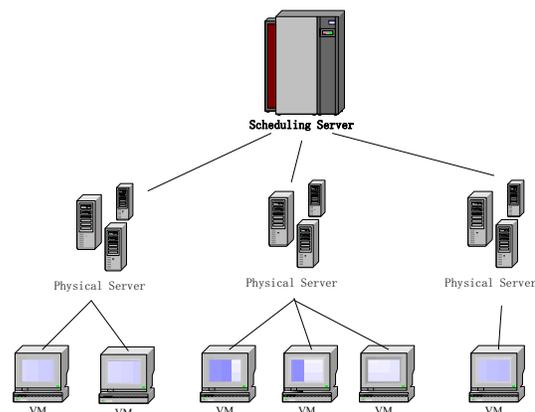


Figure 1. System Structure

B. The Expression of Load

The load of a physical machine usually can be obtained by adding the loads of the VMs running on it. We suppose the best time span monitored by historical data is T . That is, the time zone of T from the current time is the monitoring zone by historical data. According to the varying law of physical machine load, we can divide time T into n time periods. Thus we hereby define $T = [(t_1 - t_0), (t_2 - t_1), \dots, (t_n - t_{n-1})]$.

In the definition, $(t_k - t_{k-1})$ refers to time period k . Suppose the load of VMs is relatively stable in every period, then we can define the load of VM No. i in period k is $V(i, k)$. Therefore, we can conclude that in cycle T , the average load of VM V_i on physical machine P_i is

$$\overline{V_i(i, T)} = \frac{1}{T} \sum_{k=1}^n V(i, k) \times (t_k - t_{k-1}) \quad (1)$$

According to the system structure, the load of a physical machine usually can be obtained by adding the loads of the VMs running on it. Therefore we can conclude the load of physical machine P_i is

$$P(i, T) = \sum_{j=1}^{m_i} \overline{V_i(j, T)} \quad (2)$$

The current virtual machine needs deploying is V . Since the resources information needed by the current deployment VM has already been defined, we can estimate the load of the VM is V' based on relevant information. So when VM V is arranged to physical machine, the load of every physical machine should be

$$P(i, T)' = \begin{cases} P(i, T) + V' & \text{After Deploy } V \\ P(i, T) & \text{Others} \end{cases} \quad (3)$$

Usually, when VM V is arranged to physical machine P_i , there will be a certain change in system load. Thus we need to carry out load adjustment to achieve load balancing. The load variation of mapping solution S_i in time period T after VM V is arranged to physical machine P_i is

$$\sigma_i(T) = \sqrt{\frac{1}{N} \sum_{i=1}^N (\overline{P(T)}' - P(i, T)')^2} \quad (4)$$

where

$$\overline{P(T)}' = \frac{1}{N} \sum_{i=1}^N P(i, T)' \quad (5)$$

C. Mathematical Model

Through the previous analysis, we define the following mathematical model:

Definition 1: Under system mapping solution S_i , the load of every physical machine is $P(i, T)'$, and the total load variation (mean square deviation to the average load) in time period T is defined as

$$\sigma_i(S_i, T) = \sqrt{\frac{1}{N} \sum_{i=1}^N (\overline{P(T)}' - P(i, T)')^2} \quad (6)$$

where

$$\overline{P(T)}' = \frac{1}{N} \sum_{i=1}^N P(i, T)' \quad (7)$$

Definition 2: the balanced mapping solution of system

mapping solution S_i is S_i' , and then the set of mapping solution S should correspond to the set of balanced mapping solution $S' = \{S_1', S_2', \dots, S_N'\}$. S_i' is the best mapping solution to make $\sigma_i(S_i, T)$ meet the predefined load constraints.

Definition 3: we define the ratio of VM number M' need migrating to achieve load balancing in a certain mapping solution to the total VM number M as cost divisor. Then for every mapping solution S_i , the cost divisor $\rho(S_i)$ to reach load balancing S_i' is defined as

$$\rho(S_i) = \frac{M'}{M} \quad (8)$$

The objective of this paper is to find the best mapping solution S_i so as to achieve the best system load balancing or rather, to minimize the cost divisor $\rho(S_i)$ in load balancing. We can obtain the best mapping solution S_i' from mapping solution S_i though genetic algorithm.

IV. REALIZATION OF BALANCED SCHEDULING THROUGH GENETIC ALGORITHM

Genetic algorithm is a random searching method developed from the evolution law in the ecological world. After the first population is produced, it evolves better and better approximate solutions based on the law of survival of the fittest and from generation to generation. In every generation, the individual is chosen based on the fitness of different individuals in a certain problem domain. Then the individuals combine and cross and vary by the genetic operators in natural genetics and then a new population representing a new solution set is produced. Based on the real situation of cloud computing, this paper presents a scheduling strategy through genetic algorithm.

A. Population Coding

To tackle problems by genetic algorithm, it is not to function on the solution pool but to produce a certain coding denotation. So first we need to do the coding for the problem to be tackled. The selection of the coding method to a great extent depends on the property of the problem and the design of genetic operators. The classic genetic algorithm marks the chromosome structure of genes by binary codes. Judged from the data model in this paper, it can be found that it is a one-to-many mapping relationship between physical machines and VMs. Therefore, this paper chooses tree structure to mark the chromosome of genes [18]. That is to say, every mapping solution is marked as one tree; the scheduling and managing node of the system on the first level are the root nodes while all of the N nodes on the second level stand for physical machines and the M nodes on the third level stand for the VMs on a certain physical machines.

B. Initialization of Population

For the initialization of population, this paper

mainly uses the method of spanning tree. We have the following definitions for the tree:

- This tree is a spanning tree constructed by the elements in the physical machine set and VM set.
- The root node of this tree is the predefined management source node.
- All of the physical machine nodes and VM nodes are included in this tree.
- All of the leaf nodes are VM nodes.

The principle of the spanning tree is that it should meet the given load balancing conditions or it should produce relatively fine descendents through inheritance. This means the tree itself should also be a comparatively fine individual. Therefore we can get the mapping relationship between physical machines and VMs through the following procedures. First, we compute the selection probability p (p is the ratio of a single VM load to the load sum of all the VMs) of every VM according to the VM load in the VM set; then based on the probability p all of the logic disks are allocated to the smallest-loaded node in the physical machine set to produce the leaf node of the initial spanning tree. In this way, the possibility of those VM with more heat being selected is raised and those VM with low heat can also be selected.

C. Fitness Function

In the natural world, an individual's fitness is its productivity which directly relates to the number of its descendents. In genetic algorithm, fitness function is the criterion for the quality of the individuals in the population. It directly reflects the performance of the individuals – the better the performance, the bigger the fitness, vice versa. The individuals are decided to multiply or to extinct by the value of the fitness function. Therefore, fitness function is the driving force of genetic algorithm. The fitness function in this paper is

$$f(S, T) = \frac{1}{A + B \times f_H} \quad (9)$$

$$f_H = \Phi(\sigma_i(S, T) - \sigma_0), \Phi(X) = \begin{cases} 1, & X \leq 0 \\ r, & X > 0 \end{cases} \quad (10)$$

Where, A and B are weighted coefficients which are defined in concrete application. σ_0 stands for the heat variation constraints permitted in system load balancing and can be predefined. $\Phi(X)$ is penalty function in which the value is 1 when the individual meets the correspondent constraints; otherwise the value is r which can also be defined according to concrete situations.

D. Selection Strategy

Selection strategy means to select the individual of next generation according to the principle of survival of the fitness. Selection strategy is the guiding factor for genetic performance. Different selection strategies will lead to different selection pressure or rather, the different

distribution relationship of parental individuals of next generation. The algorithm in this paper mainly uses the selection strategy based on fitness ratio.

First we work out the fitness of the individuals in current population by fitness function, and we keep the individual with the highest fitness into the child population; then we compute the selection probability of the individuals according to their fitness values.

$$p_i(S) = \frac{f_i(S, T)}{\sum_{i=1}^D f_i(S, T)} \quad (11)$$

Where, $f_i(S, T)$ stands for the fitness of member No. i in the population; D stands for the scale of the population.

Lastly, we conduct election of the individuals by the rotating selection strategy so that the individual with the high fitness has higher probability being selected and those with low fitness also have the chance to be chosen.

E. Crossover Operation

Hybridizing operation is to produce new individuals by substituting and reforming parts of the two subsequently selected parental individuals. Through hybridization the searching ability of genetic algorithm gets tremendous improvement. Since genetic algorithm uses tree coding, so in order to ensure the validity of the chromosome of the descendents, the algorithm here cannot do the hybridization like the genetic algorithm using binary coding which simply exchanges parts of the genes[18]. This paper simulates the hybridizing process of life-beings to ensure the descendents intake the same gene from the parental chromosome and also to guarantee the validity of the trees of the descendents. The hybridization operators are as follow.

- Choose two parental individuals T_1 and T_2 according to the rotating selection algorithm;
- Combine the two parental individuals to form a new individual tree T_0 which keeps the individuals with the same leaf nodes in the two parental individuals and disposes the different ones;
- For the different leaf nodes in the two parental individuals, first compute their selection probability p according to the load of every VM, then based on p distribute them as leaf nodes to the smallest-loaded nodes in the physical machine set until the distribution is completed;
- Repeat the above procedures until the produced individuals reach the number required.

F. Mutation Operation

In order to get bigger variation operators in the beginning of genetic operation to maintain the variety of the population and avoid prematurity, the variation operator is reduced to ensure the regional searching ability when the algorithm gets close to the best solution vicinity. This paper uses the following self-adaptive variation probability.

$$P_m = \exp(-1.5 \times 0.5t) / D \times \sqrt{M} \quad (12)$$

Where, t is the number of generations; D is the scale of the population; and M is the number of VMs.

The individuals are randomly chosen to vary according to the variation probability. Besides, to avoid the reoccurrence of the same gene on the same one chromosome, when the gene on one locus varies in this chromosome, the gene on the correspondent locus of the varied gene code should consequently change into the original gene code of the varied locus. That is to say, the leaf nodes should be changed after variation.

G. Scheduling Strategy

The objective of this paper is to find the best mapping solution to meet the system load balance to the greatest extent or to make the cost gene of load balancing the lowest. We want to find the best scheduling solution for the current scheduling through genetic algorithm. And the terminating condition of this hunting for the best scheduling solution is the existence of a tree that meets the heat restriction requirement. We first compute the cost gene through the ratio of the current scheduling solution to the best scheduling solution, and then we decide the scheduling strategy according to the cost gene. We choose the scheduling solution with the lowest cost as the final scheduling solution so that it has the least influence on the load of the system after scheduling and it has the lowest cost to reach load balancing. In this way, the best strategy is formed.

V. ALGORITHM ANALYSIS

A. Global Scheduling Algorithm

Considering the VM resource scheduling in cloud computing environment and with the advantage of genetic algorithm, this paper presents a balanced scheduling strategy of VM resources based on genetic algorithm. Starting from the initialization in cloud computing environment, we look for the best scheduling solution by genetic algorithm in every scheduling. When there are no VM resources in the whole system, we use the algorithm to choose the scheduling solution according to the computed probability; with the increase of VM resources and the increase of running time, according to historical data and the current state we compute in advance the influence it will have when the current VM service resources that need deploying are arranged to every physic node, and then choose the best solution. The main procedures are as follow.

Step 1: In initialization, there are not any VM resources in the system so there is no historical information. When there are VM resources to be scheduled, based on the computed probability, the algorithm randomly chooses the free physical machine and starts scheduling;

Step 2: With the increase of VM resources in the system and the increase of running time, according to historical information and the current state, the algorithm computes the load and variance of every physical machine in every solution from the scheduling solution set S .

Step 3: The algorithm uses genetic algorithm to compute the best mapping solution for every solution in S . The best

solution refers to the one in which the variance meets the predefined load constraints;

Step 4: The algorithm computes respectively the costs or cost divisors of every solution in S to achieve the best mapping solution;

Step 5: According to the cost divisor of every solution, the algorithm chooses the one with the lowest cost as the scheduling solution and completes the scheduling;

Step 6: Should there be new VM resources need scheduling, then go back to step 2.

In every scheduling, we use genetic algorithm to find the best scheduling solution; and in the next scheduling, because of the accumulation of the best solutions by the original scheduling solutions, the best scheduling solution can always be found to achieve load balancing. Even though there is big load variation in the system due to special reasons and one time scheduling cannot achieve system load balance, the method can still find a scheduling solution with the lowest cost to achieve load balancing of the system.

B. Astringency Analysis of the Genetic Algorithm

To test the astringency of the genetic algorithm, we carry out the following experiment. We suppose the number of physical machines is 5 and the number of started VMs is 15. The mapping relationship between physical machines and VMs is shown in figure 3. The average load of every VM in period T is shown in Table 1. Meanwhile according to the whole system condition, we make the following supposition. The scale of the population $D=50$, replication probability $P_r=0.1$, hybridization probability $P_c=0.9$, variation probability is self-adaptive probability. Besides, according to the theory, we conclude that hybridization probability $P_c \in [0,1]$, variation probability $P_m \in (0,1)$. When the system load variation constrain $\sigma=0.5$, through the experiment we finally attain a new mapping solution shown in figure 2.

TABLE I. VM AVERAGE LOAD

Virtual Machine	CPU Utility	Virtual Machine	CPU Utility
V1	28.8	V9	18.0
V2	23.4	V10	9.2
V3	17.9	V11	8.8
V4	16.8	V12	7.3
V5	12.6	V13	8.1
V6	22.3	V14	28.8
V7	13.9	V15	24.0
V8	40.2	V16	26.9

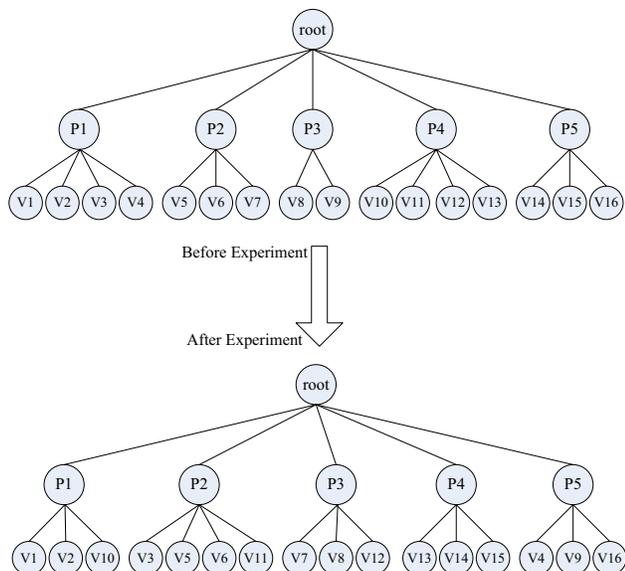


Figure 2. Mapping relationship before and after using the algorithm

Through the experiment, we get the mapping relationships before and after using the algorithm respectively. The results are shown in figure 2. It can be seen in the figure that after using the algorithm, the loads of every node basically tend to be balanced and the system load variation is smaller than σ . Therefore we can conclude that the algorithm has fairly good global astringency and can converge to the best solution in a very short time.

VI. EXPERIMENT AND RESULTS ANALYSIS

After the above verification of the astringency of the genetic algorithm, in order to further assess the performance of the global algorithm, we carried out the experiment on the Platform ISF® and open-source VM management platform OpenNebula [19]. We chose a physical machine as the host machine in which we installed OpenNebula front-end to manage and schedule VM; and its operation system is RHEL5.4, the CPU is Intel® Core™ 2 Duo 3.0GHz, and the Memory is 2.0GB. Meanwhile, we chose 5 physical machines as client machines in which we installed OpenNebula Agent client and KVM VM; and the operation system is Ubuntu 10.04, CPU is Intel® Core™ 2 Duo 3.0GHz and Memory is 2.0GB, and the disk capacity is 320GB. The whole network was connected by LAN (Local Area Network). In the experiment, the host machine was the root node; the client physical machines were the second level nodes and the VM client operation systems on the physical machines were child nodes. The whole algorithm was realized by C++.

The experiment mainly analyzes the load balancing effect of the algorithm and the migration cost to realize the system load balancing after scheduling by the algorithm, and makes relevant comparisons between this algorithm and the current VM balancing scheduling methods including the least-loaded scheduling method and the rotating scheduling method.

A. Algorithm Effect Analysis

This experiment mainly analyzes the load balancing effect of the algorithm, and compares this method with the least-loaded scheduling method and the rotating scheduling method in two different situations. One is in a certain period of time the system load variation is small; the other one is when the system load variation is evident. From Figure 3 and Figure 4, it can be seen that when the system load is comparatively stable, all of the three methods are able to ensure the system load balancing to a certain extent; while when the system load variation is evident, the method of this paper better guarantees the system load balancing because of its consideration of historical factors. The least-loaded scheduling method works worse and the rotating scheduling method works the worst. The experiment shows that the method of this paper has certain superiority in achieving system load balancing.

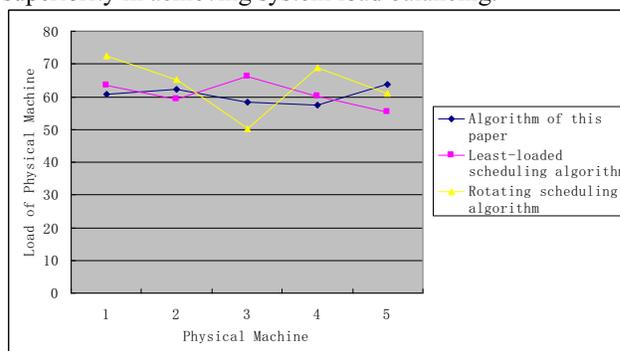


Figure 3. Comparison of three algorithms when system load stable

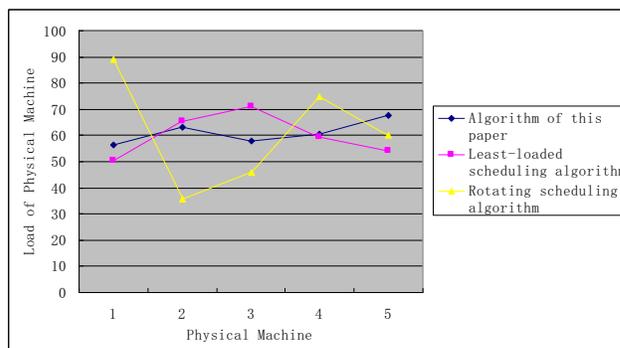


Figure 4. Comparison of three algorithms when system load variant

B. Migration Cost Analysis

On some special occasions, there is a big increase of the load of some nodes in the system due to frequent access thus leads to the load imbalance of the whole system. Under this situation, usually the system cannot realize the system load balancing through only one-time scheduling so it must do it through VM migration. However, the cost of VM migration cannot be neglected. Thus where the VM should be migrated and how to migrate the least number of VM are also the problems that need consideration during VM scheduling. The algorithm of this paper takes historical factors into consideration. It computes the situation of the

whole system after scheduling in advance through genetic algorithm and then chooses the scheduling solution with the lowest cost. Figure 5 and Figure 6 show respectively the number of VMs needed migrating to achieve complete load balancing after scheduling when different number of VM are started while the system load is stable and the system load variation is evident. When the system load is relatively stable, there is little performance difference among different methods; whereas when the system load variation is evident, the method of this paper shows conspicuous advantage. The experiment shows that the method of this paper can greatly brings down the migration cost.

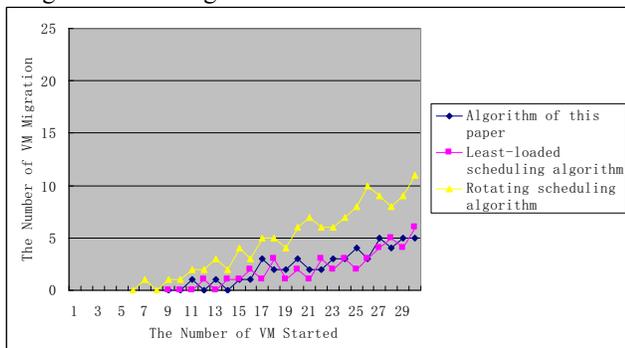


Figure 5. The migration number of VM when system load is stable

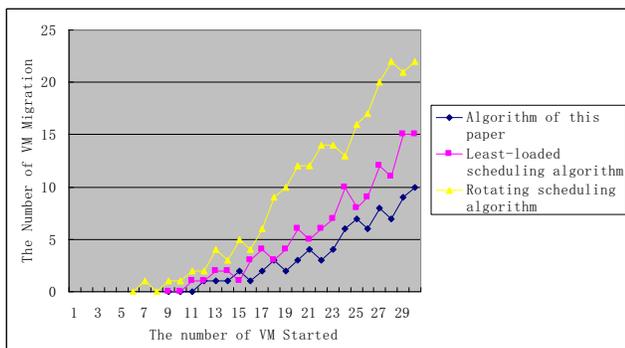


Figure 6. The migration number of VM when system load variation is evident

VII. CONCLUSIONS

In view of the current load balancing in VM resources scheduling, this paper presents a scheduling strategy on VM load balancing based on genetic algorithm. Considering the VM resources scheduling in cloud computing environment and with the advantage of genetic algorithm, this method according to historical data and current states computes in advance the influence it will have on the whole system when the current VM service resources that need deploying are arranged to every physical node, and then it chooses the solution which will have the least influence on the system after arrangement. In this way, the method achieves the best load balancing and reduces or avoids dynamic migration thus resolves the problem of load imbalancing and high migration cost caused by traditional scheduling algorithms. The experimental results show that this method can better realize load balancing and proper resource utilization.

This paper builds a model based on the concrete situations of cloud computing. It considers the historical data and current states of VM, uses tree structure to do the coding in genetic algorithm, proposes the correspondent strategies of selection, hybridization and variation also puts some control on the method so that it has better astringency. However in real cloud computing environment, there might be dynamic change in VMs, and there also might be an increase of computing cost of virtualization software and some unpredicted load wastage with the increase of VM number started on every physical machine. Therefore, a monitoring and analyzing mechanism is needed to better solve the problem of load balancing. This is also a further research subject.

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