A NOVEL VM MIGRATION ALGORITHM BASED ON MARKOV MODEL UNDER THE CLOUD ENVIRONMENT

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The development of cloud computing satisfies the requirement of the computing force in the data center, and also brought the "high energy consumption" problem. It has already been the research hotspot at home and abroad to optimize the data center by using effective energy-saving algorithms. The VM (Virtual Machine) migration strategy is one of the effective methods to decrease the energy consumption of the data center. The existing methods consider the VM migration as the bin packing issue, and don't take the fluctuation of the load into consideration, which causes the inappropriate VM deployment and leads to the excessive energy consumption. In this paper, a novel VM migration algorithm based on the Markov model is proposed. The main idea of this algorithm is to predict the future load of the host by the use of the Markov model, and then the VM migration algorithm with the energy consumption perception is proposed based on this idea. The cloud simulation software CloudSim is used to do the simulation experiment to evaluate the availability of the algorithm. The result shows that, as compared with other algorithms, the proposed algorithm has advantages in terms of the numbers of active hosts, the migration times of the VMs, and the energy consumption.

Keyword: Cloud computing; Markov model; Energy efficiency; VM migration

1. Introduction

With the fast development of internet technology, the traditional application program has become more and more complicated. The enterprise needed to purchase various hardware and software to meet this demand, and needed to carry out a series of installation, configuration, test and maintenance for these facilities, which made the cost increase continuously with the adding of the application scope. Cloud computing came out under this background [1,2].

The generation of cloud computing has got lots of attention from industry circles and the academic world. Cloud computing is a pay-as-you-go model based on the internet. It changed the ways people used IT sources. The users can obtain the needed sources and services at any time anywhere only via the internet, which

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also had the advantages of low price, high reliability, high expandability, and shielding the bottomed technical details for the users. The cloud computing provided three services to the users: Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS) [3,4].

Since the cloud system has been more and more complicated, the scale of the data center is becoming larger constantly, and the "high energy consumption" of the data center was generated, which not only adds the operating costs of the cloud service supplier and cause the unsteadiness of the system, but increase the emission of the CO2 and intensify the greenhouse effect [5,6]. Therefore, it was extremely necessary to decrease the energy consumption of the data center and optimize the energy efficiency of the data center.

It is the key for the cloud service supplier to choose a suitable VM migration strategy to optimize energy efficiency [7,8]. In IaaS, the user request is often allocated to a series of VM resources, changing with time per the user's demand, which caused the dynamic change of the working load in the cloud environment. The load fluctuation was not considered in the previous VM migration algorithm, which caused the inappropriate VM deployment and thus caused the excessive energy consumption. In this paper, the VM migration algorithm based on the Markov model is proposed. The main idea of this algorithm is to predict the future load of the host by the use of the Markov model. And on this basis, the VM migration algorithm with the energy consumption perception is proposed to decrease the energy consumption of the data center and increase the energy efficiency of the data center. To be specific, the contributions of this paper are as follows:

(1) The future load of the host is predicted by using the Markov Model. It is beneficial for the reasonable migration of the VM by predicting the future load of hosts correctly.

(2) The VM migration algorithm with the energy consumption perception is proposed to decrease the energy consumption of the data center and increase the energy efficiency of the data center.

(3) The validity and effectiveness of the proposed algorithm is verified by lots of experiments.

The rest of the paper is organized as follows: In Section 2, we present the related work. Energy-aware VM Migration Algorithm (EVMA) is proposed in Section 3. The experimental results and analysis are presented in Section 4. Section 5 is the summary and prospect.

2. Related Work

The scholars at home and abroad carried out research and obtained some fruits for the VM migration to decrease the energy consumption of the data center. Many researchers modeled the VM migration issue as the bin packing problem. This is an NP hard problem, which is mainly solved by the heuristic algorithm. The traditional heuristic algorithms include First Fit (FF), Best Fit Decreasing (BFD), and First-Come First-Served (FCFS) and other algorithms [9,10]. Shi et al. [11] believed that different strategies would generate different deployment schemes, and they proposed six algorithms based on FFD. Mastafa et al. [12] evaluated the performance of the current BFD algorithm based on different working loads and migration technologies. Under consideration of the importance of the service level agreement (SLA), the SLA factor was introduced in the traditional BFD algorithm to minimize the default rate of the SLA.

Meta-heuristic methods such as the genetic algorithm, ant colony optimization algorithm, and the particle swarm optimization algorithm can also be used for the VM migration [13] to achieve the goal of minimizing the energy consumption of the data center and the SLA violation. For example, Towfeek et al. [14] regarded the VM migration problem as the multi-objective optimization problem and proposed one ant colony optimization algorithm, with the aim of optimizing the CPU and the memory resources at the same time. Sun et al. [15] proposed one improved ant colony optimization algorithm, which took the resource wastes and energy consumption as the optimization target. The simulation result showed that this algorithm could decrease the resource wastes and the energy consumption of the VM deployment efficiently. Liu et al. [16] analyzed the impact of the multi-dimensional resources on energy consumption and proposed the improved algorithm. They initialized the particle position by the improved FF algorithm and measured the relationship between the deployed cloud system and the idle energy consumption, thus increasing the resource utilization rate and decreasing the SLA violation.

The heuristic method required the fixed number of the VMs, which violated the elastic characteristics of the cloud computing obviously. While the fluctuation of the working load at the physical node also exposed the defects of the heuristic method [17]. In terms of this issue, some scholars proposed the dynamic migration strategy of the VM. For example, Gondhi et al. [18] considered the future load characteristics before the migration of the VM, and decreased the energy consumption by the application of the improved best-fit algorithm, to improve the overall service quality and the performance. Verma et al. [19] proposed a dynamic resource demand forecasting and the allocation framework and deployed the VMs with the best-fit algorithm, which increased the resource utilization rate of the host effectively. Khoshkholghi et al. [20] proposed one migration algorithm of the dynamic adaptive energy-saving VM and detected the overloaded host by the weighted linear regression method, and minimized the number of the host by the suitable migration to decrease the energy consumption of the data center.

3. Energy-aware VM Migration Algorithm (EVMA)

The VM migration algorithm can decrease the energy consumption of data centers in an efficient way. In this paper, a VM migration algorithm named EVMA (Energy-aware VM Migration Algorithm) is proposed, which mainly included the working load prediction, the migration overhead of the VM, the state determination of the host and the VM migration algorithm. These four parts will be introduced as below.

3.1 Working load prediction

In this paper, the working load of the physical host is predicted by using the Markov model to determine whether the VM should be migrated. The EVMA used the history data of the host to analyze the next possible loading state, and the prediction will be carried out when there are at least 10 observed values of the historical data. There were three load states of the active host: underload (marked as "U"), normal (marked as "N"), and overload (marked as "O"), which will be described as $\{S_1 = U, S_2 = N, S_3 = O\}$ in the Markov model. The observational variable W is discrete, which was described by the discrete observation sequence $\{w_1, w_2, \cdots, w_n\}$, where each variable w_i is in three different status: S_1, S_2 or S_3. The random variable χ obtained one discrete random variable from these three values.

Eq. (1) describes the dynamic process of the first order Markov chain. The conditional probability of the observed value w_n only depended on w_{n-1}. In addition, the joint probability $P(w_1, w_2, \cdots, w_n)$ of the n observed values that used the first order Markov chain could be obtained by the Eq. (2).

$$P(w_n | w_{n-1}, w_{n-2}, \cdots, w_1) \approx P(w_n | w_{n-1}) \tag{1}$$

$$P(w_1, w_2, \cdots, w_n) = \prod_{i=1}^{n} P(w_i | w_{i-1}) \tag{2}$$

The conditional probability $P(w_n = S_j | w_{n-1} = S_i)$ is called the state transition probability. It describes the condition that the system is in the state of S_i at the moment n-1, the probability is in the state of S_j at the moment n.

Assume that the transition probability is homogeneous and it will not change with the time, i.e.,

$$p(w_n = S_j | w_{n-1} = S_i) = p(w_{n+T} = S_j | w_{n-1+T} = S_i) \tag{3}$$

Where variable T is the positive integer which is greater than or equal to 1.

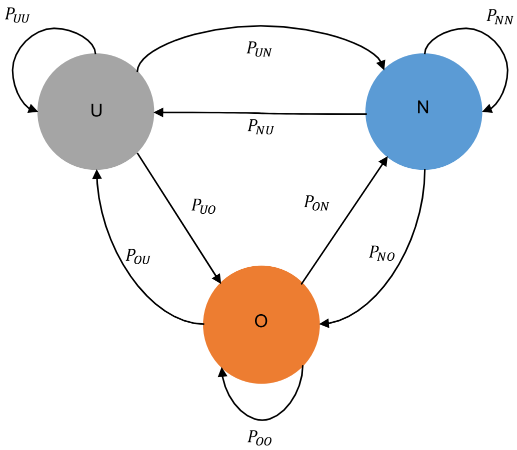

Fig. 1. Markov model used for host detection

The Markov model is shown in Figure 1. It describes the state and the transition probability of the Markov chain. It has three discrete states, namely, *O*, *U*, and *N*. Each periodic time is converted to the new state according to the probability of the Eq. (4). The system model started from one of these states and moved continuously from one state to another state.

$$P = \begin{pmatrix} p_{11} & p_{12} & p_{13} \\ p_{21} & p_{22} & p_{23} \\ p_{31} & p_{32} & p_{33} \end{pmatrix} = \begin{pmatrix} p_{UU} & p_{UN} & p_{UO} \\ p_{NU} & p_{NN} & p_{NO} \\ p_{OU} & p_{ON} & p_{OO} \end{pmatrix} \tag{4}$$

The probability p_{ij} indicates the possibility for the system model to move from the current state S_i to the next state S_j.

3.2 The migration overhead of the VM

This section introduces the migration overhead of the VM. The VM migration refers to the process where the VM is migrated from the source host to the destination host. The energy consumption during the VM migration not only depends on the time of the migration process, but the energy consumption of the network devices during the migration of the VMs. As indicated in the literature

[21], The Eq. (5) illustrates the energy consumption generated by the data center during the process of the VM migration.

$$E_M = t_m \times \sum_{i=1}^{k_{migrate}} (c_m + 0.17 x_i) \tag{5}$$

where t_m indicates the time of the VM migrated, $k_{migrate}$ means the number of hosts that carry out the VM migration, c_m is the energy consumption for the VM migration process, and x_i indicates the number of the VM that is migrated.

Because the network devices are used to transfer the VM among the different hosts during the migration process, and the energy consumption is also generated, the energy consumption of the network devices should also be considered, which is called the network energy consumptions. According to the research of Shirayanagi [22], the network energy consumption is based on the distance between the source host and the destination host. The distance is defined as the cluster number between the source host and the destination host. The Eq. (6) displays the definition.

$$E_N = t_m \times \sum_{i=1}^{k_{migrate}} (c_n + N_i) \tag{6}$$

where variable c_n represents the constant quantity of the power consumption generated by the network devices during VMs migration, the N_i is the calculated energy consumption migrated from the host h_i to the destination host based on the network distance.

The total energy consumption for the VM migration included the energy consumed in the migration of the VM and the energy consumed by the network devices during the transmission process, as shown in the Eq. (7).

$$E_{migrate} = E_M + E_N \tag{7}$$

3.3 The determination of the host state

The determination of the host state is the premise of migrating the VM. It is beneficial for the high efficiency of VM migration, for the purpose of decreasing the number of VM migration, lowering the energy consumption of the data center, and increasing the energy efficiency of the data center. How to determine the state of the host? One detecting algorithm of the host state is proposed in this paper to solve this issue, as shown below.

Algorithm 1: detection of the host state

Input: the CPU utilization $u_{cpu,i}$ of the host h_i, the upper threshold T_{upper} and the lower threshold T_{lower}

Output: the current host state x

1. Begin
2. if $u_{cpu,i} \le T_{lower}$ then
3. $x \leftarrow U$
4. else if $T_{lower} < u_{cpu,i} < T_{upper}$ then
5. $x \leftarrow N$
6. else if $u_{cpu,i} \ge T_{upper}$ then
7. $x \leftarrow 0$
8. end if
9. return x
10. End

Algorithm 1 shows the pseudo-code for the detection of the host state. The input of this algorithm includes three parameters: the CPU utilization of the host, the lower threshold, and the upper threshold. Each host has a state of underload (*U*), overload (*O*), or normal load (*N*). By comparing the CPU utilization of the current host with the lower threshold and the upper threshold, the load state of this host can be determined, and the output can be carried out. How to determine the lower threshold and the upper threshold in Algorithm 1?

The lower threshold and the upper threshold for the adaptive CPU utilization can be obtained based on the statistical approach. In this paper, the Inter Quartile Range (IQR), which is the difference value between the third and the first quartile, can be defined as follows:

$$IQR = Q_3 - Q_1 \tag{8}$$

Then, the IQR method is used to set a lower threshold:

$$T_{lower} = 0.4 \times (1 - s \times IQR) \tag{9}$$

An upper threshold is set by the same method.

$$T_{high} = 0.8 \times (1 - s \times IQR) \tag{10}$$

Where variable *s* is the safety parameter for the VM migration, the higher *s* is, the lower the default degree of SLA is, but the higher the energy consumption is. Vice versa.

3.4 Energy-aware VM Migration Algorithm (EVMA)

Energy-aware VM Migration Algorithm (EVMA) is proposed in this paper. Firstly, the future load of the host is predicted by the Markov model to determine whether the migration should be carried out. Then, the suitable destination host is chosen to place the migrated VM. At last, these idle hosts are switched to the sleep mode to decrease the energy consumption of the data center.

The pseudo-code of the EVMA was shown as below:

Algorithm 2: EVMA
Input: all active hosts and their resource utilization rate.
Output: realization of the VM migration

1. Begin
2. call in the method in 3.1 and 3.3 to find all the underloaded hosts and the overloaded hosts, and add them in the list of $List_{lower}$ and $List_{heavy}$ separately;
3. for all host in $List_{lower}$ do
4. ascend sorting these hosts per the working load (marked as L_i);
5. end for
6. for each host in $List_{lower}$ do
7. for each VM in the host do
8. calculate the migration overhead $E_{migrate}$ for all the hosts as the candidate target host except for the host;
9. choose the host h_k with the minimum migration overhead $E_{migrate}$ as the destination host and carry out the migration;
10. end for
11. switch the idle hosts to sleep mode or shut down to save the energy consumption;
12. end for
13. for each host in $List_{heavy}$ do
14. randomly select a VM from the host and migrate it to target host with the least $E_{migrate}$;
15. repeat the above process until the host is not belonging to host with heavy load;
16. end for
17. end

The basic idea of the Algorithm 2 can be concluded as follows: to decrease the energy consumption and the default rate of the data center, EVMA algorithm firstly call in the method in Section 3.1 and 3.3 to find all the underloaded hosts and the overloaded hosts, and add them into the lists of $List_{lower}$ and $List_{heavy}$ (Line 1-Line 2) separately. Each host in the list $List_{lower}$ will be ascending sorted (Line

3-Line 5) per the working load (marked as L_i). Then for the VM of each host in this list, the migration overhead $E_{migrate}$ will be calculated for all the hosts as the candidate destination host except for the host. The host with the minimum migration overhead $E_{migrate}$ is chosen as the destination host and the migration is carried out. Then the idle hosts are switched to the sleep mode or shut down to save energy consumption (Line 6-Line 12). For each host in the list of $List_{heavy}$, a VM is randomly selected from the host and migrated it to the destination host with the minimum $E_{migrate}$. The above process is repeated until the host is not belonging to the state with heavy load. Finally, the whole VM migration is completed (Line 13-Line 17).

4. The Experimental Results and Analysis

To evaluate the performance of the EVMA algorithm, a series of experiments have been performed. The comparison algorithm EERACC [23] and the PMA [24] have been chosen to make a comparison in terms of the active host computer number, the migration number, and energy consumption.

The experimental platform chooses CloudSim 3.0 [25]. This software supports the energy consumption modeling of the data center and could also be used in the experiment of the VM migration strategy. The parameter lists for the hosts and the VM in the experiment are shown in Table 1 and Table 2.

Table 1

Parameter table for hosts

Host computer Type	CPU (MIPS)	Memory (GB)	Hard disk (GB)	Host computer number
1	1000	6	250	5
2	1200	8	500	10
3	1500	10	500	20
4	2000	15	750	30
5	4000	20	1000	35

Table 2

VM parameter table

CPU (MIPS)	Memory (GB)	Disk (GB)
100~300	1~5	5~50

4.1 Analysis of the active host computer number

The number of active host can be considered as the index for energy efficiency optimization. Because the energy consumption generated by the physical host in the active state accounts for a large percentage in the total energy consumption of the cloud data center, the number of active hosts reflects the energy consumption. The less the number of the active host is, the smaller the total energy consumption of the data center. Figure 2 shows the number comparison of the active hosts for the three algorithms at each moment with a time interval of 10 minutes.

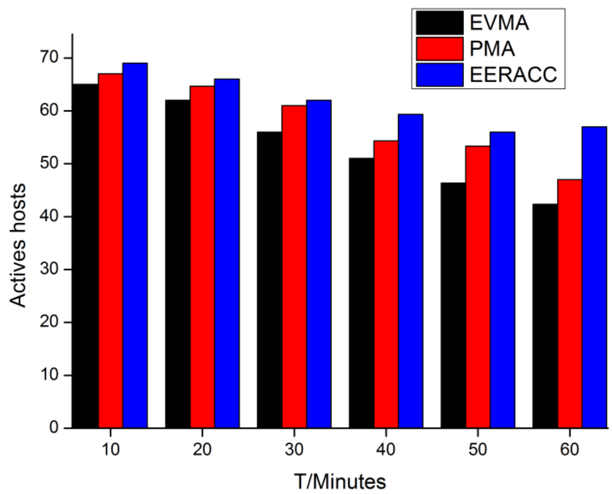

Fig. 2. Comparison of the number of active hosts

Figure 2 illustrates the number of active hosts for the EVMA algorithm at each moment. Compared with the EERACC and PMA algorithm, the EVMA algorithm has advantages. The reason is that the EVMA algorithm chooses a suitable VM to migrate to the correct destination hosts, and the idle hosts are switched to the standby mode or shut down to save the energy consumption of the system.

4.2 Analysis of the VM migration number

The VM migration number is also an important factor in measuring the quality of the VM migration algorithm. Figure 3 shows the comparison of VM migration numbers for these three algorithms. In the early stage, compared with the other two algorithms, the EVMA algorithm is less in the migration number, because EVMA sets an adaptive lower threshold, and the migration will not happen if the host load is no less than this threshold value. In the later stage, the migration number for the EVMA algorithm is obviously increased, the reason is that once the host loads are detected to be not enough, all VM on this host computer will be migrated to the suitable destination host. In addition, when the EVMA algorithm chooses the destination host, the host with the minimum migration overhead is chosen to migrate. The energy consumption generated by the migration is far less than that generated by the unnecessary activated physical host.

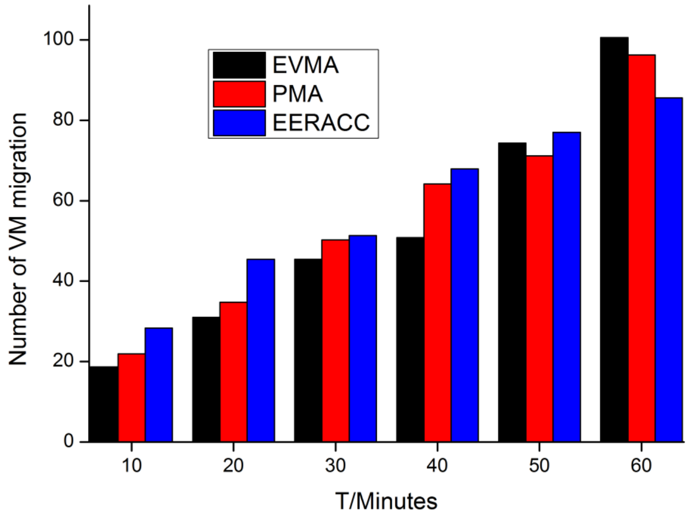

Fig. 3. Comparison of the VM migration number

4.3 Energy consumption analysis

The energy consumption not only includes the energy consumption generated by the VMs hosted on hosts, but also contains the energy consumption generated in the VM migration process of the host and the network devices. The total energy consumption of the cloud data center is defined as the energy consumption of all the hosts in the data center, and the energy consumption generated in the VM migration process, as shown in the formula (11).

$$E_{total} = E_S \times E_{migrate} = E_S + E_M + E_N \tag{11}$$

When the total energy consumption of the whole cloud system is taken into consideration, the energy consumption generated during the migration process is also included. Figure 4 shows the comparative analysis of the total energy consumption for the three algorithms of the EVMA, PMA, EERACC. Figure 4 illustrates that EVMA performs the best in total energy consumption. The reason can be explained by the fact that EVMA algorithm predicts the load effectively by the use of the Markov model, and migrates the VM to the correct destination host reasonably, which decreases the number of VM migration and lowers the total energy consumption of the data center.

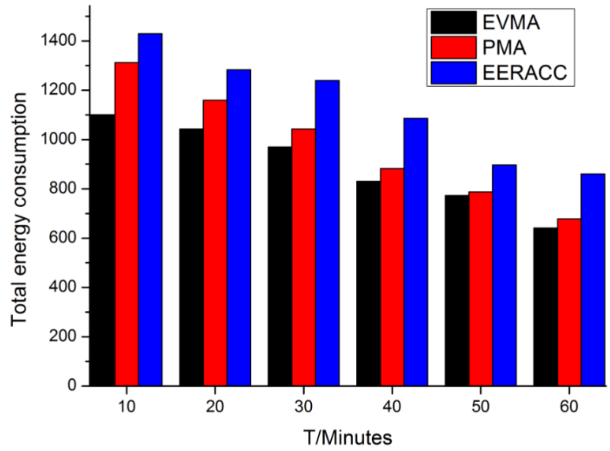

Fig. 4. Comparison of the total energy consumption for the data center

5. Summary and Prospect

A VM migration algorithm named EVMA is proposed in this paper. Firstly, the prediction algorithm for the host load based on the Markov model is proposed. Secondly, based on the current and future load of the host, the algorithm is evaluated per the host state to make the correct migration decision. Finally, the simulation tests are done by using the CloudSim cloud platform to verify the effectiveness and correctness of the EVMA algorithm.

The proposed algorithm EVMA is expected to apply in cloud-based platforms to reduce the energy consumption, thus improving the Return on Investment of the enterprises.

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