CPU Frequency Scaling Algorithm for Energy-saving in Cloud Data Centers

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***Abstract*— High energy consumption becomes an urgent problem in cloud datacenters. Based on virtualization technologies, the pay-as-you-go resource provision paradigm has become a trend. Specifically, Virtual Machine (VM) is the basic resource unit in data center for resource migration and provisioning. Many researches have been devoted to improve datacenter resource utilization and reduce power consumption by VM placement. As the most important power consumption resource, CPU has a fluctuant frequency range. Based on CPU frequency scaling, a new approach for VMs placement is proposed. The approach is realized in two stages. In the initial stage, we propose a multi-objective heuristic ant colony algorithm, which will find the optimization solution for energy saving as well as service-level agreement (SLA). In the dynamic stage, by using autoregressive prediction and CPU frequency scaling, the proposed approach can adjust the CPU utilization if needed, not depending on whole VM migration. The experiments show that the energy saving algorithms based on CPU frequency scaling are much better than the traditional BFD and FFD algorithms in saving energy and satisfying SLA.**

***Index Terms*— cloud datacenter, VM migration, energy consumption, Service Level Agreement, CPU frequency scaling**

I. INTRODUCTION

Datacenter is a large-scale sharing pool of computing, storing and software resources. It is also the center of data computing, switching and storing. These years has witnessed the high demand for dynamic and elastic resource provision like Amazon EC2. On-demand and effective resources management is crucial for the availability of a scalable cloud datacenter. In traditional datacenter, resource can be shared in a Physical Machine (PM) or among PMs. With the technical advantages and the hardware support, virtualization technology comes out once again. Based on the support of the process and server, Virtual Machine (VM) becomes the basic unit for resource management and sharing. It has high utilization efficiency and good isolation characteristic with each other.

High energy consumption has become a crucial problem in cloud datacenter[1]. According to statistics, The approximately 6,000 data centers in the United States consumed roughly 61 billion kilowatt-hours (kWh) of energy in 2006. The total cost of that energy, $4.5 billion, was more than the cost of electricity used by all the color televisions in the U.S. in the same year. data centers consumed 1.5% of all electricity in the U.S. in 2006. The Department of Energy (DOE) reports that their power demand is growing 12% a year, if data centers present rate of consumption continues[2]. Therefore, how to consolidate resources in cloud data center so as to satisfy service level agreement and cut down energy consumption becomes a new challenge.

Resource consolidation in cloud data centers is always divided into two stages: initial placement stage and dynamic management stage. Initial placement stage is to find out the optimal placement solution of VMs to PMs according to the requirements of resources, the SLA requirements set by user and the available resources each PM can provide. The solution in this stage has long term effects, which places an important role in efficient use of resources and energy saving in data centers. Dynamic management refers to that system should make quick decisions to adjust resources to match with the changes of workload during applications running time.

Initial placement is a NP-hard bin packing problem. There are many classical heuristic algorithms. Literature[3] proposes an optimal approach based on improved ant colony algorithm. Literature[4][5][6] puts forward its solution based on NSGA-II genetic algorithm. The premise of the above algorithms is based on the fixed CPU frequency, while literature[7] proposes that we can try to obtain the optimal solution under varied CPU frequency. The literatures[8][9] offer the relationship model between the energy consumption and frequency of CPU. However, the literatures consider fixed task size without changing with time.

Dynamic management is to consolidate resources according to the changes of workload in PMs. That is to solve the so-called 3W (when, which and where) problems[10], namely, when the VMs should be migrated, which VM will be migrated and where should the VM migrate to. The first W that when the VMs should be migrated has become a hot research topic for energy saving in cloud data center. In addition to the early algorithms by monitoring resources utilization and then making decision, most of the current algorithms[11-14] predict the next resource utilization through the analysis of time series. Auto regression method is used for the analysis of the correlation of the time series. The literature[12] proposes the approach of two layer threshold to catch the rising trend of resources utilization. The second and third W is the selection of migration VMs

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and migration destination PM. Literature[12] chooses to firstly migrate VMs which has low memory utilization or high ratio of CPU / memory. In this way, the cost of VMs migration can be reduced and CPU resources can be released. In order to save energy, a PM which has lager resource utilization but still enough to accommodate another VM is selected to reduce the whole number of PM by turning off the free PMs. Literature[13] proposes to migrate VM with the least resource utilization to the PM with the minimum resource utilization to ensure the new immigration will not result in the destination PMs lack of resources.

Traditional servers in data centers runs at a fixed CPU frequency,however the frequency may not be the fittest frequency to run this application.In addition,in dynamic management stage,traditional energy saving plans always migrate VMs to reduce workloads on hotspots(with heavy workload) or switch off coldspots(with light workload),making balance among each node to save energy.Literature[15] proposes an approach that migrates all VMs out on coldspots to save energy and migrating some VMs out on hotspots to reduce resources utilizations and clear away hotspots by predicting resources utilizations on each node.Literature[12] proposes the prediction of the trends for the same process by monitoring resources utilizations.However,there are two problems –wrong predictions and the costs of VMs migrations in the above approaches[16].

This paper proposes Scheduling algorithm for energy saving in data centers based on CPU Frequency Scaling(SCFS).This algorithm aims to save energy and meet Service-Level Agreement(SLA).In initial placement stage,a heuristic ant colony approach is proposed, which searches the solution space and try to find the best VMs placement solution.Compared with the traditional placements, SCFS can choose lower CPU frequencies,which leads to low energy comsumption.In dynamic management stage,if CPU utilization exceeds a pre-set threshold,SCFS can increase CPU frequency to make CPU utilization return to the normal range.In this way, some VM migration can be avoided and the whole VMs migration times can be reduced.Therefore,compared with the traditional approaches relying on VMs migration to adjust resources, SCFS has more complementary methods to optimize the data center resource management.

The rest of this paper is organized as follows.The VMs initial placements part of SCFS is discussed in Sect.II. Followed by the discussion of the dynamic management part of SCFS in Sect.III. Sect.IV is the experiments results between SCFS and traditional approaches. Conclusion is given in Sect.V.

II. The Initial Placement Part of SCFS

VMs initial placement can be considered as a variant packing problem:placing n VMs on m PMs,considering each PM has r frequencies and can select different CPU frequencies according to its workload.Then the solution space is $r^m m^n$.SCFS solves the conflicts among multiple objectives by using hierarchical sequence method[17],meeting SLA,energy saving and resources balancing in turn.In this way, the optimum solution of VMs placement can be searched out from $r^m m^n$ solution space.

A. Energy Consumption

$$f_{energy} = C + kf^3 u_{cpu} \tag{1}$$

f_{energy} indicates the instantaneous power of PMs,parameter c in formula (1) indicates energy consumption of PM in idle status,f indicates instantaneous frequency, u_{CPU} indicates CPU utilization,k is coefficient and indicates that dynamic energy consumption of CPU is proportional to the cubic of frequency and utilization[10].

The unbalance of resources utilizations will easily lead to a waste of resources.For instance, in a PM with multi-dimensional resources, only if all the resources are satisfied with VM requirements, the resources can be allocated to the VM. Therefore, we define Resources Balancing Degree as follows:

B. Resources Balancing Degree

$$f_{balance} = (1-\frac{u_{cpu}}{u})^2 + (1-\frac{u_{mem}}{u})^2 + (1-\frac{u_{bw}}{u})^2 \quad (u = \frac{u_{cpu}+u_{mem}+u_{bw}}{3}) \tag{2}$$

u_{mem} and u_{bw} indicate utilizations of memory and bandwidth on PMs respectively.According to the formula above,the value of $f_{balance}$ would be correspondingly small if the three kinds of resources utilizations are balancing.

Based on Formula(1)(2), the objective function of VMs initial placement can be represented as:

$$\begin{aligned} &min \quad F = a\sum_{i=0}^{n-1} f_{energyi} + b\sum_{i=0}^{n-1} f_{balancei} \\ &s.t \quad u_{cpu} \le u_{sla}; u_{mem} \le u_{sla}; u_{bw} \le u_{sla} \end{aligned} \tag{3}$$

$f_{energyi}$ indicates the energy consumption of PM i,$f_{balancei}$indicates the resources balancing degree of PM i. a and b are weights which standing for the degree of importance on energy consumption and resources balancing.Objective SLA is implemented by constraining resources utilizations in f_{energy} and $f_{balance}$, u_{sla} indicates the upper limit of resources utilizations on PMs.

Function F is a multi-objective optimization problem.We consider each objective respectively by using hierarchical sequence method.More specifically, we set SLA, energy consumption and resources balancing as the first, second and third objective respectively.We then propose a heuristic ant colony optimization algorithm. The algorithm is described below.

Let VM_j and PM_i be a pair. Each pair indicates one path,assign each path an equal initial pheromone

p_{ji}=1.Each ant selects path for VM_j randomly.Pathes with larger pheromone are more likely to be selected ,After VMs are all selected for PM,a preliminary VMs placement solution is formed,N ants form n solutions.We set all the solutions meeting SLA constraining as the solution space of the second objective min $\sum_{i=0}^{n-1} f_{energyi}$.Let the minimum p percent of solution calculated by min $\sum_{i=0}^{n-1} f_{energyi}$ be the solution space of the third objective min $\sum_{i=0}^{n-1} f_{balancei}$,and then calculate the optimum solution for placement.The pheromone of pathes in the optimal placement are incremented in the given parameter.

Repeats the above process until the result of F does not change or changes in a small enough range.

III. THE DYNAMIC MANAGEMENT PART OF SCFS

After the initial placement,resources utilizations on PM would change due to the workload of applications change during running time.Therefore it is needed to monitor resources utilizations and adjust resources according to the changes of workload.Monitored the resources utilizations of the last N-1 time points and the current time point,system starts to determine whether adjust physical machine resources or not.There is a resources monitoring and management flowchart below:

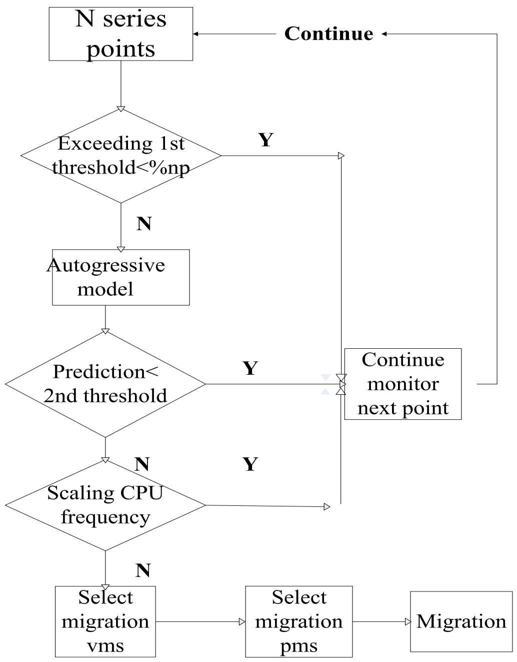

Figure 1. Resources monitoring and management flowchart.

As shown in figure 1,if there are more than a certain percent sequence points whose resources utilizations exceeding the first threshold,then analysis time series using autoregressive method and predict the resources utilizations of next time point.If the prediction exceeds the second threshold,then attempts to increase CPU frequency.If it does not work,migrates VMs.

Monitoring the PMs with a increasing tread of resources utilizations by double thresholds.The second threshold is higher than the first one.System monitors the resources utilizations on each PMs every certain period of time(for example,30 seconds),saves the resources utilizations of the latest time point as sequence.If there are more than a certain percent sequence points whose resources utilizations exceeding the first threshold,then predict the resources utilizations of next time point using n order autoregressive model in Literature[18],the prediction of the next n+1 time point u_{n+1} can be expressed as:

$$u_{n+1} = \alpha_1 u_1 + \alpha_2 u_2 + \cdots + \alpha_n u_n + \epsilon_{n+1} \quad (4)$$

α_i indicates autoregressive coefficient, u_i indicates resources utilization of time i, ϵ_{n+1} indicates noise meeting the normal distribution.

If u_{n+1} exceeds the second threshold,then determines the resources utilization on this PM would exceeds threshold.That is a appropriate method to monitor PMs with increasing tread of resources utilizations which can match workload changes on PMs more accurately.

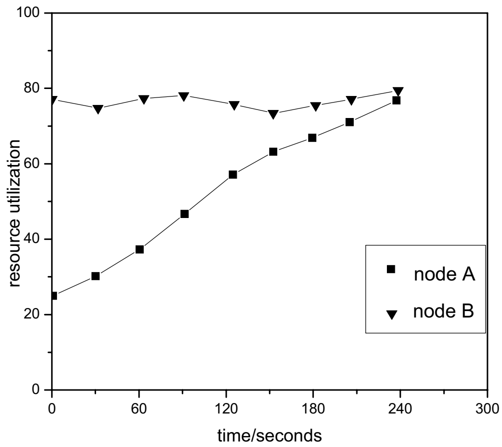

Figure 2. Different trends of resources utilization on PMs.

As shown from figure 2,these two PMs have similar utilizations of resources at this moment.However,node A would be substantial growth while node B would be basically unchanged.Therefore getting treads of resources utilizations is very important.

A. Adjusting CPU Frequency Response to Workload Changes

Since CPU is the most active resources element,so when prediction result exceeds the second threshold and only CPU resource utilization exceeds threshold,we can adjust CPU frequency instead of migrating VMs.

CPU utilization on PMs violating threshold can be classified into two situation:one is CPU utilization is more than the high threshold set by SLA;the other is CPU utilization is less than the low threshold,in this situation PM consume plenty of static energy while do not run corresponding workload.We attempt to increase CPU frequency to return CPU utilization to normal level for the first situation;we decrease CPU frequency down to make the energy consumption match with the workload on PMs for the second situation.

B. The Selections of Migrate VMs and Destination PMs

1) The Selections of Migrate VMs

We can only migrate VMs for the situations that adjusting CPU frequency does not work or there are other kind of resources violating thresholds.Since it spends plenty of costs on network to migrate VMs[19], we migrate VMs with less memory priority to ensure a smaller migration cost.Migrate VMs out in descending order of (abnormal resource utilization)/(memory utilization) until resource utilization returning to normal levels.This migrates as little as possible memory to return resources utilizations to normal level.

We migrate all VMs out on PM with low resources utilizations and then switch off the PM to reduce the static energy consumed by PM.

2) The Selections of Destination PMs

Appropriate PMs need to be selected to accept the migrating VMs.It is unrealistic to migrate VMs between a pair of random source PM and destination PM in data centers with tens of thousands PMs today[20].We need divide data centers into some sub-regions and limit the scope of migrations in the sub-regions.For example,we can select a pair of PMs in the same access network or rack as source node and destination node of a migration.The location relationship in SAN between the source PM and destination PM is also needed to be considered in migrations of VMs considering SAN has become the mainstream of storage in data centers[20][21].

Based on the principle of large package first load,sort the all migrating VMs as their comprehensive utilizations of resources u(u=p*u_{mem}+q*u_{cpu}+r*u_{bw}) in descending order and then select destination PMs for them in the above sequence.The coefficients p,q,r in the formula represent the wights of memory,CPU and bandwith.The setting of p,q,r is a multi-objects problem,till now there are no methods teach us how to set the exact values of p,q,r.We can only learn some experiences in similar situation and test large amount of values to find a suitable one,in this way we set p,q,r to 5,3,1 respectively in experiments.

Four principles need to be considered when selecting destination PMs:the first is avoiding new migrations.That is to say migrations would not cause resources utilizations cross thresholds,or migrations would not cause new migrations.The second is balancing resources.The migration VMs and destination PMs can be complementary in kinds of resources.For example,CPU resource and memory resource would be complementary if migrating the memory-intensive VM to the CPU-intensive PM.The third is reducing energy consumption.We can select the PM with the least energy increasing after accepted the migration VMs by taking the energy consumption model and the instantaneous CPU frequency of each PM account.The last is forbidding two-way migrations.That is to say a PM would not accept VMs while migrate VMs out.Because PMs migrate VMs in and out at the same time may lead resources deadlock.

IV. Experiments and Performance Analysis

This section evaluates the performance of energy-saving scheduling algorithm based on CPU modulation by experiments.It is divided into two parts.Firstly,we compare the different performance among SCFS, FFD, BFD,single-objective method SCFS-balance and SCFS-energy in the initial placement stage;Secondly,we compares different comprehensive performance among SCF-S,Xu method,single-objective SCFS-balance and SCFS-energy in the initial placement and dynamic management stage.

FFD(First Fit Descending):VMs placement algorithm in initial stage.The VMs are arranged in descending order by comprehensive resources utilizations u(Comprehensive utilization of resources u=p*u_{mem}+q*u_{cpu}+r*u_{bw}),And then VM are placed to the first PM which can accommodate it in turn.This placement algorithm tends to select PMs with more available resources.It can avoid the situation of SLA violation because of lack of resources.

BFD(Best Fit Descending):VMs placement algorithm in initial stage.The VMs are arranged in ascending order by comprehensive resources utilizations u. Take turns to select the closet full PM which still can accommodate this VM as the destination PM. The main idea of the algorithm is to prevent wasting resources and keeping the running PMs as less as possible.

The Xu method:Xu proposes a comprehensive management program including VMs initial placement algorithm and dynamic management algorithm in ref.[12][22].Initial placement algorithm will get the optimum solution with the multi-objectives of resources utilizations,energy consumption and temperature by heuristic genetic algorithm;dynamic management algorithm predicts resources utilizations by using autoregressive method,monitoring the upwards trends of resources utilizations by two-level thresholds and then determines whether to make a migration.

SCFS-balance and SCFS-energy:these two methods are SCFS with single goal in resource balance and low energy consumption respectively.

A. Experimental Environment

Our experiments run on a cluster containing 21 nodes with OpenStack as its cloud infrastructure platform.We configure one IBM System x3650 server as the control node and the other 20 Lenovo R510G7 servers as the compute nodes.All nodes connected by a Gigabit Ethernet.

We simulate CPU intensive applications by calculating the value of π with Monte Carlo algorithm in experiments,CPU utilization fluctuates according to the sleeping time changing; and simulate the I/O intensive applications by running processes reading and writing files,the I/O utilization fluctuates with the amount of data reading and writing.The characteristics of each algorithm is compared in different stages and under types of applications through three experiments. The first two experiments compare the effects of running I/O intensive applications and CPU intensive applications between each algorithm in initial placement stage respectively.The resources utilizations of VMs are set constant to preventing resources utilizations violating the thresholds in dynamic management stage.The third experiment compares the integrated effects among each method.Each method creates a VMs initial placement solution and places VMs to PMs according to the solution.During the dynamic management stage,the resource utilizations of VMs are fluctuated with the workload changing. We compare and evaluate the effort of each method.

B. Experiments Results

The following will explore the advantages,disadvantages and scopes of applications by probing the inherent characteristics and the experimental results of these algorithms.

1) Initial placement of VMs: The experiment system consists of 21 PMs which hosting 60 VMs,The first two experiments run I/O intensive applications and CPU intensive applications with constant resources utilizations.We place VMs to PMs according to the initial placement solution of SCFS, SCFS-balance(SCFS-b), SCFS-energy(SCFS-e),BFD and FFD respectively and evaluate for two hours.The final results of energy consumption are shown as the figure 3.

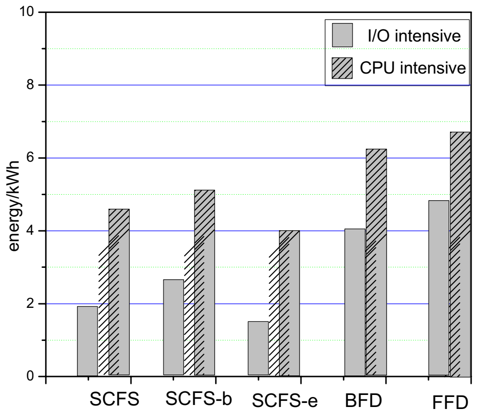

Figure 3. Energy consumption comparison among different algorithms.

As shown in Figure 3,no matter running the I/O intensive or CPU intensive applications, SCFS,SCFS-b,SCFS-e which scaling the CPU frequency make significantly less energy consumption than BFD and FFD with fixed CPU frequency.SCFS-e costs the least energy consumption among SCFS,SCFS-e and SCFS-b because it only considers energy consumption.The second one is SCFS which considers energy consumption and resources balancing together.The last one is SCFS-b of considering resources balancing only.Keep PM resource balance can effectively cope with the workload changes,that help PM not to waste idle resources in case of bucket effect when the workload fluctuates fiercely.In this experiment, The workload is unchanging, which means resource utilizations are constant.In figure 3, BFD and FFD are the algorithms with fixed CPU frequency.BFD prefers to fill up PMs, It takes up at least 15% of the PMs less than FFD.Its total energy consumption is less than FFD after switching off those idle PMs.

More specifically in figure 3,there are some differences between the results of the first experiment(running I/O intensive applications) and the second experiment(running CPU intensive applications).Firstly, CPU intensive application will cause a high CPU frequency on PM. Moreover,CPU energy consumption is one of the main aspects of physical energy consumption.Therefore,energy consumption of the second experiment increases at least 41% than that of the first group of experiment(As shown in Figure 3).Secondly,High CPU frequency of the second experiment will reduce the scaling range of the working frequency of CPU.As the result,the effect of energy consumption of SCFS, SCFS-b, SCFS-e in the first experiment is not as good as the result of the second experiment.while on the other hand,it can't create so many idle PMs according to BFD due to the high CPU resource utilization in the second experiment.Therefore,the good performance of BFD compared to FFD is decreased in the second experiment.

2) Two-phase experiment: The Third experiment compare effects of the initial placement and dynamic management among SCFS, SCFS-e, SCFS-b and Xu.The experiment system consist of 21 PMs,60 VMs.30 VMs execute the CPU intensive applications amd the remaining 30 VMs execute I/O applications.The resource utilization of these two kinds of application changes according to the sine and cosine fluctuation pattern respectively.(As shown in figure 4)

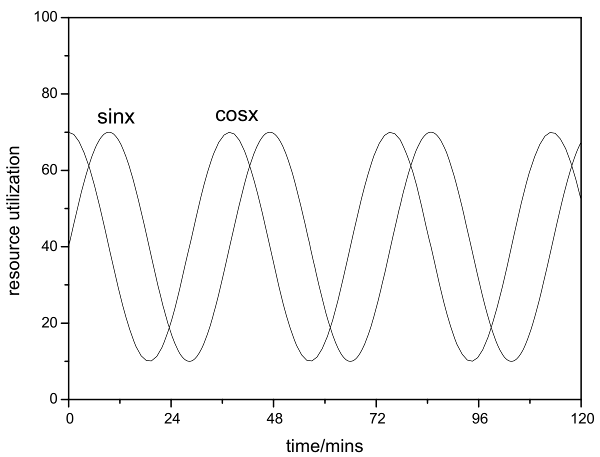

Figure 4. Periodic changes of the resources utilizations of the applications.

In figure 4,sine function curve represents the CPU utilization of CPU intensive applications.Cosine function curve represents the I/O utilization of I/O intensive applications.These two applications used to simulate the applications in practical data center environment.

In figure 4,I/O intensive application begin with its lowest value in time 0, while the CPU intensive applications begin with a normal value.I/O applications mainly cost memory and disk resources,CPU applications mainly cost CPU resources.Each algorithm generates a initial placement solution respectively.SCFS placement solution considers the resource balancing degree among each dimension of resources.About 50% of PMs are allocated with 1 I/O CPU intensive VMs in one PM,and the rest PMs are allocated with 2 I/O intensive VMs and 1 CPU intensive VM in one PM.The PMs with more CPU intensive VMs have a higher CPU frequency than the PMs with more I/O intensive VMs.SCFS-b generates a similar solution, however all of the PMs have a high CPU frequency.SCFS-e generates a solution with 1 or 2 CPU intensive VMs and n I/O intensive VMs in one PM.The algorithm does not consider the resource balancing degree, the value of n are quite different on different PMs.The algorithm of Xu considers the temperature of PM.Therefore,it keeps each PM CPU utilization consistency because the heat is mainly produced by CPU.Xu generates a solution with 50% PMs allocated by 2 CPU intensive VMs, and 50% PMs allocated by 3 I/O intensive VMs and 1 CPU intensive VM.

With the above initial placement solution,each algorithm shows different effects in dynamic management stage.As shown in figure 5.

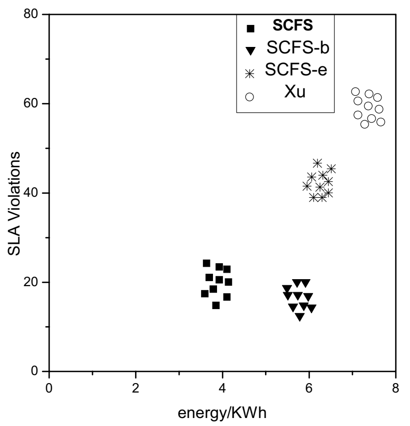

Figure 5. Energy consumption and SLA violations in dynamic management stage.

In Figure 5,by using CPU frequency scaling,SCFS,SCFS-b and SCFS-e produce significantly less energy consumption and SLA violations than Xu which dose not used CPU frequency scaling.In Xu's solution,I/O-intensive VMs are too concentrated on some PMs which causes a lack of resources when applications fluctuates.It can only rely on migrating VMs to ease the lack of resources on some PMs.

Among the three algorithms of scaling CPU frequency,SCFS-e prefers to pursuit the lowest energy consumption,but resources are not balancing and the CPU frequency is lower,which is easy to violate the low resources thresholds.And SCFS-e does not care resources balancing degree when selecting the migration destination PMs,which will lead to the migration again,thus greatly increases the total energy consumption.The energy consumption and SLA violation is 57% and 115% higher than SCFS.SCFS-b mainly pursues resources balancing and does not care energy consumption,which cause its CPU frequency staying at a high level (compared to SCFS),therefore the energy consumption is higher than SCFS .But the resource utilizations rarely violate the thresholds and the SLA violations is comparatively lower in SCFS-b.Its energy consumption and SLA violation is 145% and 90% of that of SCFS.

We can see that the great decreasing of resources utilizations violating thresholds and VM placement states becoming similar to VMs initial placement solution of SCFS in the later time of SCFS-e and Xu experiments,which indicates SCFS-e and Xu adjusts VMs placement adapting to the regular changing applications. The difference between them is the time of adjusting,SCFS-e has a shorter adjusting time. Because in the initial placement solution of SCFS-e,I/O intensive VMs are placed unbalanced.When I/O applications reach its peak value,I/O intensive VM is migrated to the PMs with less I/O intensive VMs,then balancing solution formed soon(before I/O application reaches its peak value second time).The initial placement of Xu has a problem of I/O applications over-concentrated in one PM.And it also considers temperature balancing,which limits I/O intensive VMs' migration to PMs with high CPU utilization and less I/O intensive VMs.There are significantly reduction of thresholds violation until I/O applications reach its peak value the forth time in Xu.It can be concluded that the optimal dynamic solutions have the ability to deal with regular changing applications.However the initial placement solutions which better fit for the applications and the dynamic management algorithm with a more integrated objectives can make a quicker adjusting.

When CPU resource utilization exceeds the high threshold,scaling the frequency or migrating VMs both can ease the competition of the resource.However,the efforts of these two methods are different from each other.

Figure 6 shows the significant different results while dealing with the competition of CPU resource using SCFS and Xu algorithms respectively.The square legend represents the threshold violation of CPU resource.The triangle legend represents the threshold violation of memory resource.The above two lines are the the results of SCFS algorithm. The bottom two lines shows the situation of Xu algorithm. As it can be seen in the SCFS,most of the the threshold violations of CPU resource can be avoided by scaling the CPU frequency. At the moment of 12 minutes CPU applications reach their peak value,sufficient resource can not be provided through the CPU frequency regulation(Figure 4), the algorithm will

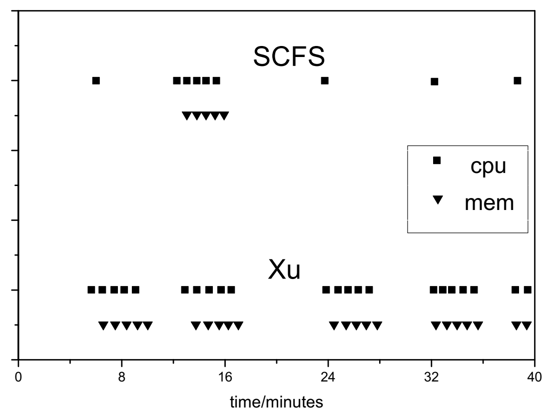

Figure 6. Parts of SLA violations comparison between SCFS and Xu.

adopt VMs migration.The huge cost of the migration process cause the shortage of the CPU and memory resources on the next time point simultaneously, five continuous squares and triangles stand for the threshold violation of CPU and memory resource utilizations.In the most of the time,SCFS can simply scale the CPU frequency to respond to CPU threshold violation.The bottom two lines of Xu show that each occurrence of CPU threshold violation can only be resolved by migrating VMs.Each migration process will be accompanied by a number of SLA violation on CPU and memory resources.

We can see that heuristic algorithms combined with valid resources prediction have certain abilities to self-regulate when handles the applications with complicate changing rules.

In practical cloud data centers, PMs accommodate VMs with different applications,which may keep changing in its resources utilizations.Our experiments have tried to simulate the practical environment of the cloud data centers.However it is harder to define an actual application between I/O intensive or CPU intensive.The demands for each dimension of resources sometimes alternate, which adds the difficulty for resources utilizations prediction.Moreover, applications in practical environment may not fluctuate as sine or cosine curves. There are two approaches to solve this problem.One is to improve the learning and self-adaptive abilities of our algorithm in dynamic stage.The other is to find out changing rules of applications or classifications from immense applications in data centers by data mining.

V. CONCLUSIONS

IWe propose cloud data centers energy-saving Scheduling algorithm based on CPU Frequency Scaling(SCFS) in this article.SCFS is consist of two parts,acting on the stage of VMs initial placement and dynamic management.The first part search out a optimal solution of VMs placement considering both energy consumption and SLA by heuristic ant colony optimization algorithm.System places VMs on corresponding PMs according to optimal solution.The second part predicts resources utilizations of next time on PMs by using autoregressive method on history resource utilizations.Then SCFS will decide whether adjust CPU frequency or migrate VMs to optimize resource utilizations. The experiments on the OpenStack cloud management platform show that SCFS has the ability of adapting to CPU-intensive and I/O-intensive applications.SCFS shows significant advantages in energy consumption and SLA satisfaction compared to the traditional VMs placement algorithms such as BFD,FFD,CPU frequency scaling method with single-objective–SCFS-e,SCFS-b and integrated solution Xu.

Here we consider I/O intensive applications consume constant energy when running.Practically,I/O intensive applications experience consumption energy changing during running time.And network intensive applications also occupy increasingly important places in data centers.So we will focus on these two points in our future research.

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