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A green energy-efficient scheduling algorithm using the DVFS technique for cloud datacenters

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HIGHLIGHTS

- We design a scheduling algorithm for the cloud datacenter with a dynamic voltage frequency scaling technique.
- Our scheduling algorithm can efficiently increase resource utilization to reduce the energy consumption of servers in cloud datacenters.
- The simulation results show that our method can reduce the energy consumption by 5%–25%.

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ABSTRACT

Information and communication technology (ICT) has a profound impact on environment because of its large amount of CO_2 emissions. In the past years, the research field of "green" and low power consumption networking infrastructures is of great importance for both service/network providers and equipment manufacturers. An emerging technology called Cloud computing can increase the utilization and efficiency of hardware equipment. The job scheduler is needed by a cloud datacenter to arrange resources for executing jobs. In this paper, we propose a scheduling algorithm for the cloud datacenter with a dynamic voltage frequency scaling technique. Our scheduling algorithm can efficiently increase resource utilization; hence, it can decrease the energy consumption for executing jobs. Experimental results show that our scheme can reduce more energy consumption than other schemes do. The performance of executing jobs is not sacrificed in our scheme. We provide a green energy-efficient scheduling algorithm using the DVFS technique for Cloud computing datacenters.

1. Introduction

Recently information and communication technology (ICT) has a profound impact on economy and environment. According to some research reports, in the United States, energy consumed by the ICT equipment is roughly 8% of the total energy consumption, and it will increase 50% within a decade [1,2]. In addition to energy consumption, the ICT equipment has a large amount of CO_2 emissions. According to Gartner, which is the world's leading information technology research and advisory company, estimation, the ICT equipment is responsible for 2% of global CO_2 emissions in 2007 [3].

Cloud computing is a paradigm that changes the behavior in the consumption and delivery of information technology (IT) services. Users use web service interfaces to demand resources and pay only for the resources that they actually consume [4,5]. In addition to providing on-demand resources, clouds can deploy a custom-made environment for a given application. With the dynamical provision of resources, Cloud computing can increase the utilization of resources and hence reduces the number of IT hardware equipment. It can potentially reduce the global CO_2 emission. Furthermore, without purchasing, operating, maintaining, and periodically upgrading local computing infrastructures, Cloud computing can lower the cost of IT services for an enterprise [6,7].

A cloud datacenter usually contains large group of servers connected by the Internet. A job scheduler is needed in a cloud datacenter to arrange job executions. The job scheduler has to efficiently utilize the resources of the cloud datacenter to execute jobs. The performance issues of the scheduling algorithm include the execution time and resource utilization. A good scheduler can use fewer resources and times to run jobs. Using fewer resources implies that less energy is consumed. The power consumption is one of the major issues for building large-scale clouds.

The dynamic voltage frequency scaling (DVFS) technique can be used to reduce the power consumption of the IT equipment. The DVFS enables processors to run at different combinations of frequencies with voltages to reduce the power consumption of the processor. The energy consumption of a processor is approximately proportional to processor frequency and to the square of the

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processor voltage. Decreasing the processor voltage and frequency will lower down the performance of the processor. However, if the execution performance is not so important, we can decrease the processor voltage and frequency to reduce the power consumption of the processor.

Researches in [8–13] use the DVFS technique to reduce the energy consumption of distributed systems. However, in these researches, the performance is sacrificed. In this paper, we provide a scheduling algorithm for allocating jobs in the cloud datacenter with DVFS techniques. Our scheduling algorithm efficiently assigns proper resources to jobs according to requirements of jobs. In addition to saving energy, our work does not sacrifice the system performance. Service Level Agreement (SLA) is also taken into account in our scheduling algorithm. Our scheme can reduce energy consumption, increase resource utilization, and meet SLA requirement. We provide an efficient solution for scheduling problems in Cloud computing.

The rest of this paper is organized as follows. Section 2 presents related works. The system model and our algorithm are illustrated in Section 3. Section 4 shows the experimental results. In Section 5, we will give some concluding remarks.

2. Related works

The dynamic voltage and frequency scaling (DVFS) technique is commonly used to reduce the power consumption of electrical devices such as cell phones, PDAs, and PCs. The power consumption of an integrated circuit is proportional to the simple formula fcv^2, with f the frequency, c the capacitance, and v the voltage. Thus, the supply voltage and work frequency profoundly affect the energy consumption of integrated circuits. The DVFS enables integrated circuits to run at different combinations of frequencies and voltages. Voltage supply can be increased or decreased depending upon circumstances. The DVFS can dynamically lower down the supply voltage and work frequency to reduce the energy consumption while the performance can satisfy the requirement of a job.

In [14], the authors propose a virtualization security assurance architecture, *CyberGuarder*, for green Cloud computing environments. CyberGuarder provides three different kinds of services including the virtual machine security service, the virtual network security service and the policy based trust management service. These services have been carried out on the *iVIC* platform designed by the authors, with promising results. This research provides the important results and experience for large-scale, energy-efficient/green Cloud computing.

In [15], an energy-aware resource allocation heuristics for efficient management of datacenters for Cloud computing is presented. The proposed method can improve energy efficiency of the data center, while delivering the negotiated Quality of Service (QoS). This work provides architectural principles for energy-efficient management of clouds, energy-efficient resource allocation policies and scheduling algorithms. Their method has to sacrifice system performance.

In [16], the Maximum and Minimum Frequencies DFVS (MMF-DVFS) algorithm is presented to reduce the energy consumption of processors. In this paper, authors model an optimal energy consumption formula. They use the linear combination of the minimum and maximum processor frequencies to approach the optimal energy consumption. However, this method can only be used in homogeneous computing systems. The research presented in [17] addresses the task scheduling problem on heterogeneous computing systems (HCSs).

In [17], authors propose an energy-conscious scheduling heuristic (ECS) to reduce the energy consumption for high-performance computing systems. This heuristic can easily be applied in loosely coupled HCSs (e.g., grids) using the advanced reservation and various sets of frequency–voltage pairs. The ECS scheduling algorithm incorporates the DVFS technique to reduce the energy consumption. For scheduling algorithms, there is a trade-off between the performance and energy consumption of schedules (makespans). The energy reduction phase in the ECS uses the makespan-conservative energy reduction technique (MCER) to decrease the energy consumed by jobs. In this phase, the schedule generated by the scheduling phase in the ECS is scrutinized to check whether it has chance to further reduce the energy consumption. The time complexity of the ECS is low. However, authors do not consider the resource utilization.

In [18], a scheduling algorithm in DVFS-enabled clusters is proposed for executing parallel tasks. The proposed algorithm finds the slack time for non-critical jobs without increasing the scheduling length. They also develop a green SLA-based mechanism to reduce energy consumption by increasing scheduling makespans. In their work, they sacrifice the performance to reduce the power consumption or CO_2 emission. They provide an acceptable extension of execution time to meet the green SLA.

In [19], they use small environmental monitoring sensors to lower the electrical costs and improve the energy efficiency. The deployed sensors can measure the temperature of the computer room while servers are running. Scheduling algorithms can efficiently arrange works for servers to lower the room temperature according to the information delivered from the deployed sensors. Their system design including hardware and software provides a good experiment for building a green big data center.

3. Scheduling algorithm

3.1. Problem model

In Cloud computing, a data center can run on several heterogeneous servers. Each server is equipped with different hardware such as the processor, RAM, and the hard disk. For reducing energy consumption, each server can adjust its work frequency according to workloads. To standardize capacities of heterogeneous servers, we make some definitions as follows.

Definition 1. Let $S = \{S_1, S_2, S_3, \ldots, S_n\}$ denote the set of servers inside a data center and let every $S_i = \{R_{\min}, R_{\max}\}$ denote the minimum and maximum resources of the server S_i.

$R_{\min}$ and $R_{\max}$ can be considered the minimum and maximum amounts of resources or capacities in a server. For example, we assume that the maximum working frequency and minimum working frequency of a server are 700 MHz and 100 MHz, respectively. A job requires 200 MHz working frequency to execute. The server can use 200 MHz working frequency to execute this job for saving energy. Because the maximum working frequency is 700 MHz, this server has remainder capacity to execute another job whose working frequency requirement cannot excess 500 MHz.

The VMs created on a server also have limited capacity according to the resources provided by the server. While allocating a job to proper VMs, we also have to know the resources of the related VMs. We can derive the energy consumption of VMs from the resources used by VMs. In our work, we want to lower the working frequency to reduce the energy consumption of executing jobs. Hence we focus on the working frequency rather than other resources.

Definition 2. Let $V = \{V_1, V_2, V_3, \ldots, V_m\}$ denote a set of VMs and let every $V_i = \{F_{\min}, F_{\max}\}$ denote the minimum and maximum working frequencies of a VM.

An example is as follows. The minimum and maximum working frequency requirements for executing job **A** are 100 and 600 MHz, respectively. Three VMs in a cloud are available to deploy this