Green Scheduling of Bag-of-tasks Applications in Cloud Data Center Using GreenCloud Simulator

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***Abstract*—The cloud provider provisions the resources of the data center to the user so as to satisfy the Quality of Service (QoS) negotiated between them and specified in the Service Level Agreements (SLA). To attain maximum profit, the cloud provider has to schedule the tasks in the data center efficiently in accordance to the users QoS requirements and also minimize the energy consumption thus reducing the operational expense (OPEX) of the data center. The energy efficient scheduling of cloud applications has to consider the QoS parameter specified as job deadline and assign them to minimum number of servers possible without affecting the performance so that the idle servers can be shutdown to reduce the energy consumed. This paper analyses this green scheduling for various workloads of the cloud users and provide information about the task completion and rejection at various data center load, the SLA violations and the degradation of system performance. It presents the server utilization specifying the number of busy and idle servers with their computational load and the energy consumed by them for different workloads. The paper also provides the insights on the utilization of the servers for the workloads and analyses the reasons for the underutilization of servers and how the scheduling can be improved without sacrificing the performance of the data center. The paper analyses the above observations of the green scheduling of the data center using GreenCloud.**

***Index Terms*—Cloud Data Center, green scheduling, GreenCloud, dynamic power management**

I. INTRODUCTION

Cloud computing is a dominant and emerging trend in computing in this modern era. Cloud Computing refers to the computer resources delivered as services over the Internet. The hardware and systems software in the datacenters that provide these services is called a Cloud [1]. Cloud computing enables to communicate, store and compute whenever and wherever the user needs. All these are made possible by the reliable and fast internet connectivity and the infrastructure of large data centers. The cloud provider provisions the underutilized resources of their data center as a utility on pay-per-use model [2]. The cloud provider needs to allocate the resources efficiently to minimize the operational cost of the data center since the prominent factor in operational expense is the cost of electricity consumed by the data center infrastructure, network devices, storage and servers [3]. Moreover, green IT is the need of the hour to reduce carbon emissions and maintain environmental sustainability which could be accomplished by minimizing the energy consumed to the extent possible.

The energy efficiency of a data center is mainly focused on the computing servers since they consume a major portion of the total energy consumption. It is generally measured by the metrics namely Power Usage Effectiveness (PUE) and Data Center Infrastructure Efficiency (DCiE) [4]. The power consumption of the server varies dynamically in proportion to its CPU utilization. Even an idle server consumes nearly one third of its peak power because of the other components such as the storage, memory and network devices that consume power [5]. Therefore, most of the scheduling policies assign tasks to minimum number of servers so that the idle servers can be shut down to reduce power consumption [6].

The scheduling of the tasks with different requirements of the resources such as computing, storage and network to provide the specified QoS and better system performance with reduced energy consumption is a challenging problem. The objectives of scheduling are to assign tasks to servers in such a way as to maintain system performance, maximize the profit of cloud providers and also provide better service as specified in the SLAs at low cost to the users.

The rest of the paper is organized as follows: Section II gives the related works on scheduling of cloud applications. The cloud data center architecture, the energy and simulator models are introduced in Section III. The data center topology and the simulation parameters of the simulated model are defined in Section IV. Section

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V evaluates the simulation results based on data center workload, server utilization, energy efficiency and QoS provided. Finally, the conclusion is outlined in Section VI.

II. RELATED WORKS

Cloud Computing applications and data are growing intensely that increases the need for larger servers, storage and high bandwidth networking links to process them quickly within the specified deadline. In recent years, more research is done in energy efficient, QoS preserving, load balancing, cost effective scheduling of cloud services. Dzmitry Kliazovich et al. [7] proposed energy-efficient scheduler using job concentration method and calculated the economic benefits of such scheduling in energy-efficient hardware.

Hsu Mon Kyi et al. [8] designed an analytical model to analyze the performance of efficient scheduling and allocation on cloud infrastructure. This model is implemented using Eucalyptus open source system for private cloud that provisions the heterogeneous VM requests. Gaurav Raj et al. [9] implements a framework for assigning the task and obtaining results in optimum time and cost and analyzes for Round Robin and FCFS scheduling policy of CloudSim. Anton Beloglazov et al.

[10] discuss various techniques to make the data center energy efficient. Dzmitry Kliazovich et al. [11] proposes an energy efficient scheduling for cloud applications focusing on the communicational demands of the applications so as to reduce the communication-delays and congestion-related packet losses and evaluates using GreenCloud simulator.

Kyong Hoon Kim et al. [12] proposes various scheduling algorithms for bag-of-tasks applications with deadline constraints to minimize power consumption and meet deadlines on DVS-enabled cluster system. Luqun Li [13] develops a queuing model for cloud computing and analyzes the self-adaptive job scheduling system that meet the QoS requirements and minimize the system cost thus maximizing the profit of the cloud service providers. Moreover, Srikantiah et al. [14] formulates a heuristic bin packing problem for the consolidation of workloads with different resource utilization in a way to optimize the energy usage while providing the required performance.

In this paper, the energy efficient scheduling of cloud applications in the data center with several homogeneous servers is analyzed. The study is performed by varying the number of cloud users submitting workload consisting of bag-of-tasks to understand the scheduling performance based on the deadline as QoS parameter and using server consolidation technique to reduce the number of servers utilized. The relationship between data center load, QoS provided and the energy consumption for various target data center load is observed. The experiments are done using the GreenCloud simulator of NS2 [15].

III. SYSTEM MODEL

A. Data Center Architecture

Data center consists of large number of servers grouped together using communication networks to the cloud applications. There are various data center network architectures such as fat-tree hierarchical architecture, BCube, DCell, DPillar, VL2, FiConn, Helios [16].Most commonly used data center architecture is the three-tier architecture based on fat tree structure. The three-tier data center architecture consists of three layers of switching and routing elements as shown in Figure 1 [17].

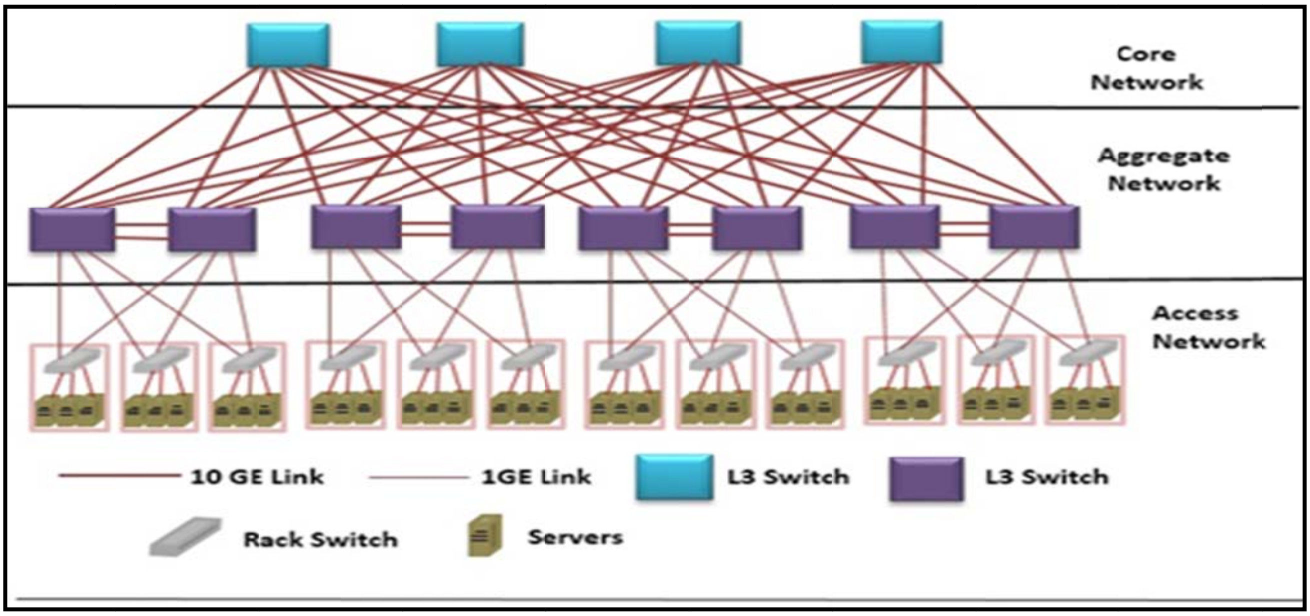

Figure 1. Data center architecture

The servers are organized into racks and are connected through a Top-of-the-Rack Switch (ToR) using 1Gbps links. These access switches are then inter-connected through the aggregate switches using 10 Gbps links. In three-tier topologies there exists another layer which consists of the aggregate switches connected using the core switches at 10 Gbps. This architecture can be scaled because of the presence of the aggregate layer. It also provides fault tolerance since a ToR switch is usually connected to more than one aggregate switches. This architecture requires a large number of links since it is fully connected.

B. Simulator Model

GreenCloud is a cloud computing simulator which offers a detailed energy consumption model of the data center components such as servers, switches and links [17]. The power model used to estimate the energy consumption of servers is dependent on its CPU utilization and the server state, active or idle. A server consumes 66% of its peak power when it is idle and only the remaining 33% of the server's peak consumption vary with the CPU load [4]. The power consumption of the networking switches is almost constant and varies at a very small quantity depending on the transmission rate [18]. GreenCloud allows configuring various workload arrival rate/pattern such as Exponential, CBR, and Pareto or from traces log files. The workload type such as computational, data intensive and communicational can also be generated. The power management techniques that can be implemented are Dynamic Network Shutdown (DNS), Dynamic Voltage and Frequency Scaling (DVFS) and DVFS with DNS. DNS approach consolidates the workload in minimum number of servers possible and shut down the idle servers to save energy. DVFS is based on saving energy by operating the server components at low load sacrificing the computing performance. The structure of the GreenCloud simulator is shown in Figure 2 [15].

The cloud data center implemented in GreenCloud is composed of multiple host servers and layers of network components connecting the servers as shown in Figure 1. The servers implement single core processors with same processing capability specified in terms of Million Instructions per Second (MIPS) without virtualization [18]. The job submitted by the cloud user is considered as the workload which consists of multiple independent tasks of same characteristics with no intercommunication among them. The workload of the cloud user is specified as the target data center load relative to the computing capability of the data center. The computational requirement of the task is specified in terms of MIPS and the communicational requirement as the task size and task output in terms of bytes. The server with required computing capacity is assigned to the task and on completion, the task output is sent back to the user. The task duration is the QoS constraint that insists the tasks must be completed before the deadline.

C. Energy Efficient Scheduling

The data center receives the applications that consist of several similar tasks from the cloud users through the network links. The data center has the centralized task scheduler which schedules the tasks to the servers of the data center. The simulator provides two default schedulers namely **Green Scheduler** and **Round Robin Scheduler**. To analyze the efficiency of scheduling and

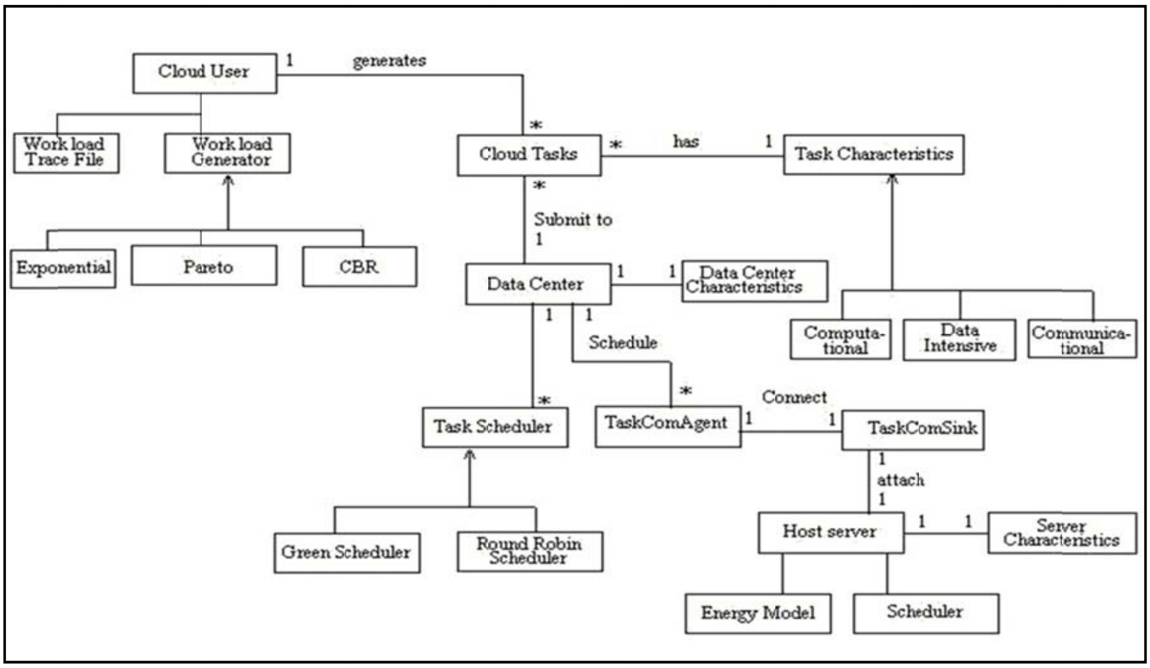

Figure 2. Structure of GreenCloud simulator

allocation on cloud infrastructure, the simulations are done with the green scheduler. The results are obtained by varying the size of the workloads and the number of cloud users with similar workload. The tasks generated by the cloud users, the number of servers utilized the computational load of each server and the energy consumed by the servers to complete the tasks within the specified deadline is analyzed.

The main objective of the Green scheduler is to complete the tasks within their deadline by assigning them to minimum number of servers possible so that idle servers can be turned off to reduce energy consumed by them. The data center maintains the list of tasks received and assigns each task to the scheduler to schedule them to servers so as to complete them within their deadline. The scheduler searches for a server with remaining computing capability equivalent to the minimum processing rate required by the task.

Task deadline = Task Submission time + Task duration

Minimum task rate required = Task computing requirement / (Task deadline – Scheduling time)

Remaining computing capacity of server = Server computing capacity – Current server load

The Green Scheduler always allocates the task to the first server with the required capacity from the list of servers in such a way that the task is assigned to a busy server. Whenever the task could not be assigned to busy servers, it is assigned to the next server that is idle to complete the task within the deadline sacrificing energy efficiency. If the server is available, the task is sent to the server over the data center network. When all the servers are at peak load, no server is found with the required computing capacity. Hence the task could not be scheduled within the deadline and it is rejected and sends to the first server in the list of servers. The server has its own scheduler to schedule the tasks and execute them using multitasking. On completion, the task generates the output and sends it through the rack to the data center. If the deadline of the task is less and the task is more urgent, total consolidation of workloads to minimum number of servers is not possible. In such situations, the Green Scheduler sacrifices the energy efficiency so as to satisfy the QoS constraint of the cloud users.

IV. SIMULATED SCENARIO

A. Simulated Data Center Architecture

The data center architecture considered for the simulations is the commonly used three-tier data center architecture which is shown in Figure 1. It consists of 1536 servers organized into 512 racks of 3 servers each. The racks are interconnected by 8 core and 16 aggregate switches. The parameters of the data center topology are summarized below.

Core nodes (C1) : 8
Aggregate nodes (C2) : 16
Access switches (C3) : 512
Servers(S) : 1536
Link (C1-C2) :10GE
Link (C2-C3) : 1GE
Link (C3-S) : 1GE

B. Energy Model

The Table 1 and Table 2 present the power consumption of the data center components based on the Intel Xeon 4-core Processor and the Layer 3 and Layer 2 Ethernet Switches of bandwidth 1Gb/s, 10Gb/s, 100Gb/s [15].

TABLE 1.
POWER CONSUMPTION OF DATA CENTER SERVER

Server	CPU	Memory, peripherals, motherboard, fan	Total
Server at Peak	130	171	301
Idle Server	-	-	198

TABLE 2.
.POWER CONSUMPTION OF DATA CENTER SWITCHES

Switches	Chassis	Linecard	Port transceiver
Access links (1 GE)	146	-	0.42
Aggregate links (10 GE)	1.5K	1K	0.3K
Core links (100 GE)	15K	12K	1.6K

C. Simulation Parameters

The data center consists of homogeneous servers with computing capability measured in Million Instructions per Second (MIPS). The CPU requirement of the application is given in terms of the computational requirement of the tasks specified in MIPS. The workload size and tasks generation of the cloud user is exponentially distributed. The workload consists of several tasks and the task is defined by the task size, task computational requirement, task duration and task output. The parameters for the simulation setup are shown in Table 3.

TABLE 3.
SIMULATION SETUP PARAMETERS

Data center starting load	30%
Task distribution	Exponential
Task computing requirement (T_c)	1000000 MIPS
Task size (T_s)	8500 Bytes
Task output size (T_{op})	2500000 Bytes
Task duration (T_d)	1 Second
Server computing capacity (S_c)	1000000 MIPS
Power management techniques	No
Simulation time	60 seconds

V. PERFORMANCE EVALUATION

The scheduling of the tasks by the Green scheduler is studied by carrying out each simulation for 60 seconds. The tasks that constitute the workload is exponentially generated for each cloud users. The simulations are done for 1 to 5 cloud users by varying the workload from 0.1 to 1.0 for each cloud user.

Figure 3 shows the workload generation of the cloud users with target workload varying from 0.1 to 1.0.The workload generation and the tasks in the workloads are distributed exponentially as seen in the graph. The workload is generated in terms of the computing capability of the data center, the computational requirement of each task and the simulation period.

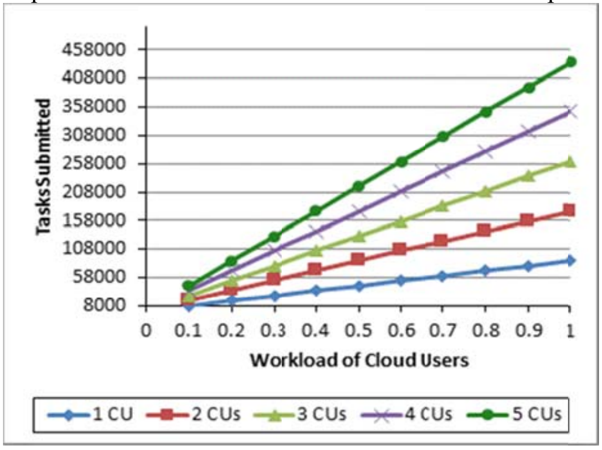

Figure 3. Tasks submitted for various workload

The rate at which task is generated by the cloud user to attain the target workload is specified as

Task submission rate (T_{sr}) = $N_s * S_c / T_c * W$

N_s is the total number of servers, S_c is server computing capability, T_c is the computing requirement of each task and W is the target workload of the cloud user.

Figure 4 presents the tasks completed within their deadline among the tasks submitted by the cloud users. When the computing requirement of the workload of all the cloud users goes beyond the computing capability of the data center, the workload cannot be completed within its deadline. The graph shows that all the tasks of the workload submitted by a single cloud user is completed. For 2 cloud users, the tasks completed reaches its maximum for the workload 0.5 each since the total workload submitted is 1.0. After this point the increase in the tasks completed is not proportional to the tasks submitted. When the workload submitted goes beyond a limit the tasks get rejected and the tasks completed remains constant. This limit gives the maximum tasks that could be completed within the deadline by the data center which is calculated as follows

Maximum number of tasks completed = $N_s * S_c / T_c * T_d$

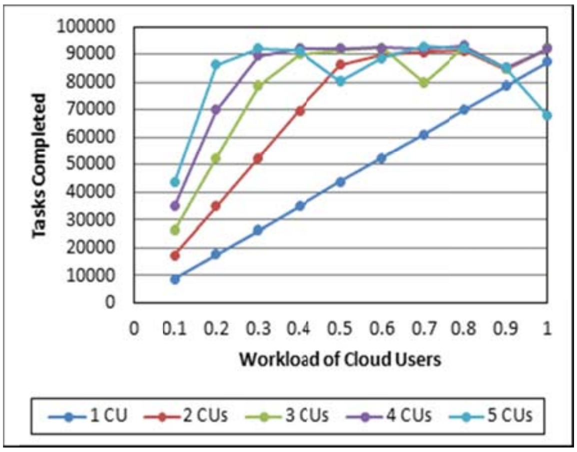

Figure 4. Completed tasks of the workload

From Figure 3 and Figure 4 the difference between the tasks submitted and the tasks completed by the data center can be observed.

Figure 5 presents the percentage of SLA violations for the workload submitted by the cloud users. The non-execution of the task within the deadline by the data center is considered as the violation of the QoS specified in the SLA. This also gives the performance degradation of the data center at different workloads. The percentage of SLA violations is calculated as follows.

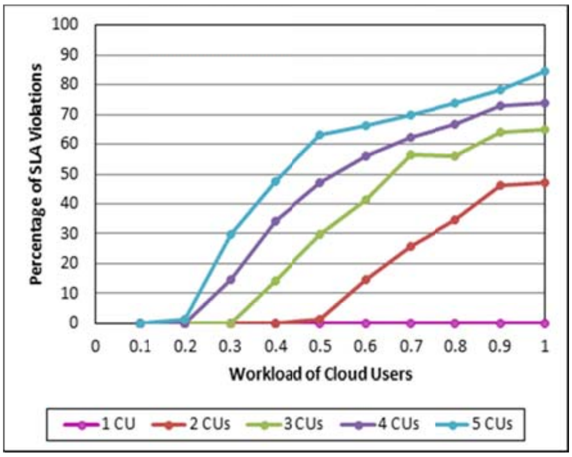

Figure 5. Percentage of SLA violations

Percentage of SLA violations = (Tasks submitted – Tasks completed) / Tasks submitted *100

Figure 6 gives the energy consumption of the data center for the workload being executed for the cloud users. As shown in this figure, the energy consumed is in proportion with the tasks completed by the data center. The energy consumed by the data center is remaining stable at full CPU utilization of all the servers in the data center.

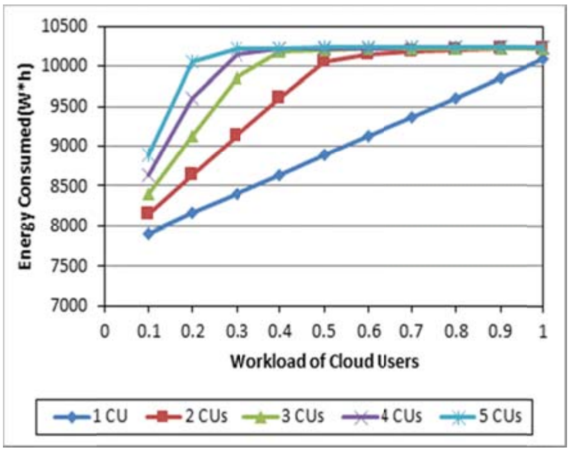

Figure 6 Energy consumption of data center

Figure 7 shows the number of servers utilized and their respective load for 10 cloud users with target workload 0.1. As seen in the graph, some of the servers are assigned with less number of tasks and more number of servers are utilized. The total consolidation of tasks in minimum number of servers is not obtained by the scheduler. This is due to the urgency of the task execution within the deadline to satisfy the QoS constraint and the load balancing performed for redistributing the traffic from congested links that wake up more idle servers for utilization. As a result, the energy efficiency is sacrificed to issue better performance to the cloud user as agreed in the SLAs.

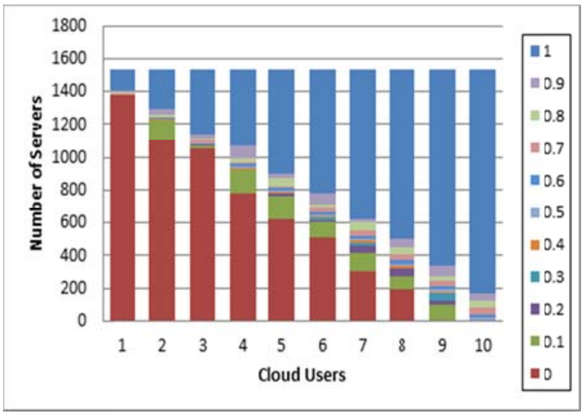

Figure 7 Server utilization for the cloud users

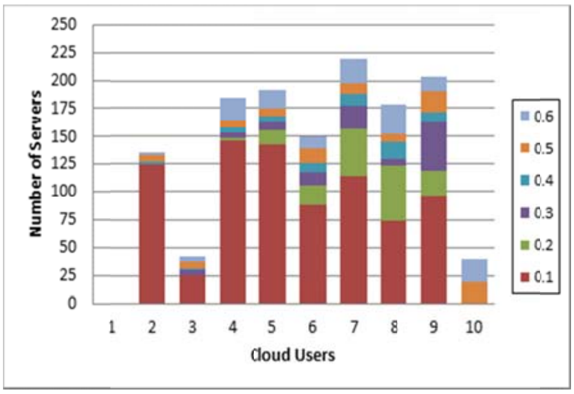

Figure 8 Underutilization of servers

Figure 8 presents only the underutilized servers with load less than 60%. The servers with load 0.1 and 0.2 are more than the servers with load between 0.3 and 0.6. The reason is the exponential distribution of the job and more tasks arrive in due course and the tasks cannot be assigned to the active servers because of the non-availability of the servers with remaining computing capability equivalent to the required task computing rate. Hence the idle servers are woken up for utilization so as to complete the tasks within the deadline. If the tasks assigned to these servers can be consolidated in the servers with more load, then these servers will be idle and can be shut down. The Dynamic Voltage and Frequency Scaling (DVFS) power management technique can be applied to the servers with less load to reduce the power consumption [19]. The server utilization can be maximized and consolidated in minimum servers when the deadline of the tasks is more and the required computing rate is less than the available server computing capability of the data center.

When a task is rejected, there is no monetary benefit for the cloud service provider, and also the cloud user experiences low QoS. Whenever the chances of such occurrence are more, the cloud user may turn away from the service of the data center. The cost of the resources provisioned for the cloud users can be based on the urgency of the task or the required computing rate of the service in order to encourage the users to submit the tasks with more deadlines.

VI CONCLUSION AND FUTURE WORK

From the above observations, the workload generation and the scheduling of the tasks by GreenCloud has been analyzed. The energy consumed by the data center for the workloads of the cloud applications is also obtained. The above simulations help to understand how the tasks are being assigned to the servers by the Green scheduler. The server utilization and the load of servers give insight for the improvement of scheduling process. From the observations made, it is necessary to take into consideration the task parameters that affect the green scheduling and also prioritize the tasks according to the required computing rate and duration. The server utilization has to be maximized and the number of servers that could be left unused and shutdown has to be increased so as to minimize the energy consumption and thus reduce the operational expense of the data center infrastructure. In future work, the impact of task parameters on green scheduling is to be experimented and develop an optimal solution for the scheduling process. The other factors such as network congestion, system performance, heat produced also has to be considered for energy efficient scheduling in a data center.

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