Performance Evaluation of Energy-aware Best Fit Decreasing Algorithms for Cloud Environments

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Abstract—Cloud computing is emerging computational paradigm that provides resources to perform complex tasks. Large datacenters are used to facilitate the incoming tasks by providing resources, such as CPU, memory, storage, and network bandwidth. Datacenters offer hosting and processing of complex tasks and services, where servers and cooling systems consume huge amount of energy. Excessive amount of energy consumption results in large power bills and Green House gases (GHG) emissions. Substantial amount of energy can be saved by powering down servers that are idle. Various authors have come up with energy efficient solutions that try to minimize overall energy consumption. One set of energy-efficient solutions is based on best fit decreasing (BFD) algorithm. In this paper, we evaluate the performance of existing energy efficient BFD algorithms based on various workloads and migration techniques. Moreover, considering the significance of Service Level Agreement (SLA), we introduce SLA-awareness in traditional BFD algorithm to minimize the SLA violation. We present the analysis and observations for each of the considered techniques based on total energy consumption, average SLA violations, and SLA performance degradation due to migration.

Index Terms—Cloud Computing, Resource Management, Energy Efficiency, Best Fit Decreasing, Performance Evaluation

I. INTRODUCTION

Cloud computing has gained enormous popularity in recent years due to dynamic, flexible, and on-demand resource provisioning [1]. The concept of virtualization is used to host tasks of multiple users on a single server by consolidating multiple virtual machines (VMs) [2]. Resource management (RM) techniques are used to manage the available set of resources on each server. RM technique not only allocates the resources, but also enables the system to utilize resources efficiently [3]. Several features, such as, energy efficiency, service level agreement (SLA) violation avoidance, profit maximization, network load, fault tolerance, and load balancing, needs to be considered while devising a RM technique. However, generally the researchers only consider one or couple of aforementioned features in their techniques.

Energy efficiency is one of the pivotal RM features today [4]. Energy efficiency not only minimizes power expenses but also plays a vital role in the minimization of CO₂ and Green House Gases (GHG) emissions [5, 6]. Servers, cooling devices, and fossil oil energy generators are main contributors in the emission of aforementioned gases. According to Khosravi [5], in 2007, information and communication technology industry produced 2% of the total CO₂ emissions that was equivalent to aviation industry, worldwide. Moreover, in 2010, worldwide datacenters consumed 271.8 billion KWh electricity [6]. Therefore, researchers are focusing on providing energy efficient solutions for datacenters. In recent years, researchers have come up with various solutions to achieve energy efficiency [4, 8-18]. Techniques, such as, dynamic voltage/frequency scaling (DVFS), and workload consolidation are used to minimize the energy consumption [4].

In this paper, we focus on workload consolidation algorithms that are based on Best Fit Decreasing (BFD) technique. BFD algorithms are best known for online bin packing, and considered good for VM placement in cloud environments. BFD algorithms are considered better compared to next fit, and first fit algorithms in terms of worst case and average uniform case. Moreover, BFD algorithms can also be enhanced to manage multi-criteria optimization as done in [4].

Currently, there is no detailed study available that evaluates the BFD algorithm based on different scenarios. Therefore, a comparative study has been conducted that evaluates the BFD techniques based on various workloads and migration techniques. Moreover, we introduce a SLA-aware and energy-efficient BFD algorithm that attempts to minimize SLA violations, while keeping the energy consumption low. A detailed performance comparison of the BFD techniques is presented considering energy consumption, average SLA violations, and SLA performance degradation due to migration.

The remainder of the paper is organized as follows. Section II briefly presents the existing work in the context of gaining energy efficiency for cloud environments. Section III describes the working of BFD algorithms studied in this paper while section IV presents the experimental setup and results. Finally, we draw our conclusions in section V.

II. RELATED WORK

Service providers aim to minimize the overall operational cost incurred due to power consumption. Various solutions have been provided to minimize energy consumption, and resulting expenditures. Researchers in [7] claim that it can be
achieved by fully utilizing the active machines at lowest possible power levels. Authors in [4, 8, 9] use the BFD approach that is originally devised for bin packing problem. The basic difference between aforementioned techniques is the selection criterion that is used to select a suitable server for hosting the VM.

In [10], Mertzios et al. provide a solution to minimize energy consumption of servers that are actively hosting VMs. Proposed technique consolidate VMs with overlapping processing times. Authors in [11] design an ant colony based solution that considers the energy efficiency issue as a multi-dimensional bin-packing problem. Moreover, in [12] authors have come up with two workload consolidation algorithms. According to authors, energy consumption and processor utilization have a linear relationship. However, major difference between the aforesaid algorithms is of cost function. One uses the difference between actual energy consumption and minimum energy consumption, whereas, other one uses CPU utilization for the selection of hosting machine.

Authors in [13-15] have come up with an idea of hierarchical RM. Resource managers are introduced at different levels that are responsible to perform specific tasks. In [13, 14] central manager is responsible to divide the servers on the basis of class of service that will be hosted on each set. Moreover, servers are further partitioned in various VMs based on the running tasks. On the other hand, application managers are responsible for VM placement, VM migration, load balancing, and frequency scaling. In contrast, [15] uses a predictor to forecast the future needs of each VM. After the prediction, central manager dynamically assigns the resource based on the predictor’s suggestions.

Authors in [16-18] use the concept of DVFS to minimize the overall energy consumption. DVFS enables servers to run at various combinations of voltage and frequencies to minimize the energy consumption of processor. Wu et al. [16] provide a DVFS based scheduling algorithm for cloud datacenters. Algorithm maximizes the machines utilization that ultimately results in low energy consumption. [17] provides an energy efficient solution for CPU-intensive Bags-of-Tasks applications. Solution uses an intelligent scheduler, and DVFS module to minimize energy consumption and meet the task’s completion deadline. A multi-objective game theory framework has been proposed by Ren et al. [18]. Framework uses DVFS enabled CPUs for energy minimization, and game theory based algorithm for RM.

III. APPROACH

We propose an SLA-aware BFD algorithm (SBFD) that is based on traditional BFD algorithm. Proposed algorithm attempts to minimize SLA violations that are encountered due to non-availability of CPU capacity. Moreover, we compare variants of BFD algorithms that attempt to minimize overall energy consumption in cloud environments. BFD algorithms achieve the aforementioned goal by consolidating workload on minimum number of servers. The parameters considered for conducting this work are: (a) energy consumption, (b) average SLA violations, and (c) SLA performance degradation due to VM migration. Moreover, we also examine the effect of different workloads and migration techniques on aforementioned parameters.

The techniques considered for conducting the current study are: (a) SLA-aware BFD, (b) traditional best fit decreasing (BFD), (c) modified best fit decreasing (MBFD), (d) power and computing capacity aware best fir decreasing (PCA-BFD), and (e) energy-aware and performance per watt oriented best fit (EPOBF). Moreover, we are considering the MBFD algorithm with respect to two aspects, (i) energy efficiency, and (ii) SLA violations. Similarly, we have also modified basic BFD technique by introducing SLA-awareness.

SLA violations can be encountered due to non-availability of resources, higher network load, and system failure [19]. When we talk about the SLA violations in energy efficient environment, it is mainly due to workload consolidation on minimum number of servers. In such scenario, servers are fully utilized to minimize the overall energy consumption. However, whenever the VM’s demand for resources increases, we may encounter an SLA violation due to non-availability of required resources at the current physical machine.

Working of all the aforementioned algorithms is discussed in subsequent sections.

A. Best Fit Decreasing (BFD)

Traditional BFD algorithm sort the incoming tasks in the descending order based on the CPU requirements [20]. After sorting, task at the top of list is selected and placed on an already used server that has minimum CPU capacity. In case of non-availability of resource on used server(s), task is placed on a new server that has minimum CPU capacity.

B. SLA-aware Best Fit Decreasing (SBFD)

We propose SBFD that follows the same steps of traditional BFD algorithm [20]. In first phase, all the received tasks are sorted on the basis of CPU requirements. In second phase, a server is selected with minimum CPU capacity. In third phase, a VM is created for each task on selected server. In fourth step, task is placed on the created VM. To minimize the chances of SLA violations, a threshold is set that keeps the overall CPU utilization below the predefined value. In case the utilization exceeds the threshold, VM or set of VMs is transferred to other server(s).

C. Modified Best Fit Decreasing (MBFD)

MBFD [4] algorithm is another version of BFD method. Basic working of the MBFD algorithm is same as that of BFD. However, the main difference is between the selection criteria on the basis of which a server is selected for task hosting. BFD selects a machine that has minimum CPU capacity, whereas, MBFD selects a host that shows a minimum change in the energy consumption if the task is placed on it. MBFD uses the following formula to check the energy consumption of the machine in case of task placement.

\[ P_{AP} = 0.7 \times P_{max} + 0.3 \times P_{max} \times U \]  (1)
Where $P_{AP}$ is energy after VM placement on the given machine, $P_{\text{max}}$ is maximum power that can be consumed by the machine, and $U$ is the utilization of machine after hosting of task. After calculation of $P_{AP}$, following formula is used to calculate difference between the power consumed before VM placement ($P_{BP}$) and $P_{AP}$.

$$P_{\text{diff}} = P_{AP} - P_{BP} \quad (2)$$

Server with minimum value of $P_{\text{diff}}$ is selected for the hosting of given VM.

MBFD algorithm also uses the threshold mechanism to keep the number of SLA violations low. An upper threshold is used to keep the check on the overall utilization of CPU. On the contrary, a lower threshold is used to keep an eye on under-utilized CPU. In case of breach of both the thresholds, VM(s) are migrated to other suitable servers.

**D. Power and Computing Capacity-Aware Best Fit Decreasing (PCA-BFD)**

PCA-BFD algorithm also sorts the received tasks in descending order and then selects the task from top of the list [8]. For server selection, following formula is used and the server with lowest ratio is selected.

$$R = \frac{P_{\text{max}}}{CPU_{\text{max}}} \quad (3)$$

Here, $P_{\text{max}}$ is maximum power that can be consumed by the machine, and $CPU_{\text{max}}$ is total CPU capacity.

**E. Energy-aware and Performance per watt Oriented Best Fit (EPOBF)**

EPOBF [9] is a BFD algorithm that uses total CPU capacity and rise in the energy consumption of machine after task placement, for the selection of host machine. Server with maximum ratio is selected for the hosting. Ratio of each machine is calculated on the basis of following formula.

$$R = \frac{CPU_{\text{max}}}{P_{\text{diff}}} \quad (4)$$

Here, $CPU_{\text{max}}$ is total CPU capacity of machine, and $P_{\text{diff}}$ is the difference between power used before the placement, and power used after the placement of task. $P_{\text{diff}}$ can be calculated by using the equation 2.

**IV. EVALUATION**

In this section, we present performance analysis of various BFD algorithms. Performance evaluation of each technique is conducted in CloudSim [21]. CloudSim is an open source java based simulation tool that provides various parameters to evaluate the performance of energy efficient RM techniques. Moreover, techniques discussed in previous section are evaluated on the basis of real world workloads provided by the PlanetLab. Table I. presents the details of all the workload that mainly differ in terms of number of VMs and size of VMs. Size of a VM is defined as the capacity of various resources required to host a specific task. Furthermore, following parameters are used for evaluation:

- Energy consumption
- Average SLA violations
- SLA performance degradation due to migration

We have also conducted experiments to evaluate the performance of the selected techniques combined with various migration techniques. The objective is to analyze the performance of VM placement and migration techniques in combination. Selected migration techniques are minimum migration time (MMT), random selection (RS), maximum correlation (MC), and maximum utilization (MU). MMT selects a VM that requires minimum time for migration from current server to new one [22]. Whereas, RS generates a random number, and based on that number, a VM is selected for migration. MC finds a correlation between VMs and migrates the VMs with maximum correlation. Finally, MU selects a VM that consumes maximum CPU capacity and migrates selected VM to a new machine.

<table>
<thead>
<tr>
<th>Workloads</th>
<th>#of servers</th>
<th># of VMs</th>
<th>Dates of Workloads</th>
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</thead>
<tbody>
<tr>
<td>W1</td>
<td>800</td>
<td>1052</td>
<td>03-03-2011</td>
</tr>
<tr>
<td>W2</td>
<td>800</td>
<td>898</td>
<td>06-03-2011</td>
</tr>
<tr>
<td>W3</td>
<td>800</td>
<td>1061</td>
<td>09-03-2011</td>
</tr>
<tr>
<td>W4</td>
<td>800</td>
<td>1516</td>
<td>22-03-2011</td>
</tr>
<tr>
<td>W5</td>
<td>800</td>
<td>1078</td>
<td>25-03-2011</td>
</tr>
<tr>
<td>W6</td>
<td>800</td>
<td>1463</td>
<td>03-04-2011</td>
</tr>
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<td>800</td>
<td>1358</td>
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</tr>
<tr>
<td>W8</td>
<td>800</td>
<td>1233</td>
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</tr>
<tr>
<td>W9</td>
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</tr>
<tr>
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<td>1033</td>
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</tr>
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</table>

**A. Energy Consumption**

Results shown in figure 1-4 are generated on the basis previously discussed workloads and migration techniques. See the experimental results indicate that power consumption of PCA-BFD is better due to its efficient server selection criteria. On the other hand, energy consumption of SLA-aware techniques is higher compared to their counter-parts. SLA-aware techniques consume more power because some of the CPU capacity on each server is kept free to avoid the SLA violations. Therefore, we can say that SLA-aware techniques do not fully utilize the available resources. Moreover, workloads are also affecting the performance of each technique. We can see that energy consumption on workload 6 is more as compared to other workloads. The increase in energy consumption is due to the tasks that require more resources. In case of large tasks, more servers are used to provide resources. It can also be observed from the figures 1-4.
that different migration techniques do not have any significant impact on the energy consumption. Only MU shows some increase in energy consumption because it selects the VMs with higher sizes for the migration. Whenever the higher sizes of VMs are migrated, they generate high network traffic that results in higher energy consumption. MMT consumes comparatively low energy because selected VMs are the one with low migration times.

B. Average SLA Violations
In this section, we discuss the impact of workloads, and migration techniques on SLA violations. Figures 5-8, show average SLA violations in percentage that are encountered while testing BFD algorithms on different workloads and migration techniques. It can be noticed that PCA-BFD algorithm has the highest SLA violations percentage. Reason behind the higher SLA violations is efficient workload consolidation. PCA-BFD efficiently consolidates the hosted
VMs on minimum number of servers. Consequently, when a VM resource requirement is increased, SLA violation is encountered. On the contrary, SMBFD and SBFD are more efficient in terms of SLA violations compared to their counterparts. Results also show the effect of different workloads on the violations. Workloads with large size of tasks consume more energy but have fewer SLA violations. Reason for such behavior is non-optimal workload consolidation. When a large task is received and VM is created, resultant VM cannot be placed on a server with less number of resources.

Therefore, some resources of servers remain free that are used in the scenario when VM’s requires more resources. On the other hand, migration techniques also affect the percentage of SLA violations. MMT shows better results compared to other techniques because of low network traffic generated during migration.

C. Performance Degradation due to Migration

Results in figure 9-12 highlight effects of migration techniques on performance degradation. Higher numbers of
migration result in higher performance degradation due to resultant network traffic. It can be noticed that MMT show minimum performance degradation due to migration because it selects the VMs with minimum time required for migration. On the other hand, MU technique has more performance degradation because it selects a VM with largest size. Migration of largest VM increases the overall network traffic and thus results in performance degradation. Workloads also affect the performance of migration techniques. Workloads with large number of tasks will increase the overall network traffic in case of VM migration.

V. CONCLUSIONS

In this work, we have we have evaluated the performance of various BFD algorithms with respect to energy consumption, average SLA violations, and performance degradation due to migrations. It has been noticed that tasks with high resource requirements result in more energy consumption. Moreover, migrations techniques also affect the overall system performance, and higher numbers of migrations result in significant performance degradation. Besides aforementioned factors, server selection criteria also affect the performance of RM techniques. Server hosting higher number of VMs is more susceptible to SLA violations than a server with lower hosting list. It is also a known fact that workload consolidation may lead to SLA violations. Therefore, we modified one of the existing techniques to minimize the SLA violations that occur due to non-availability of resources. Results show that proposed scheme minimizes SLA violations as compared to its counterpart.

REFERENCES