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

Saad Mustafa, Kashif Bilal, and Sajjad A. Madani
COMSATS Institute of Information Technology, Pakistan
Email: {saadmustafa, kashifbilal}@ciit.net.pk

Nikos Tziritas
Chinese Academy of Sciences, China
Email: nikolaos@siat.ac.cn

Samee U. Khan
North Dakota State University, USA
Email: samee.khan@ndsu.edu

Laurence T. Yang
St. Francis Xavier University, Canada
Email: nikolaos@siat.ac.cn

Abstract— **Cloud computing is emerging computational paradigm that provide 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 offers 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 [1]. 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 [3]. Energy efficiency not only minimizes power expenses but also plays a vital role in the minimization of CO_2 and Green House Gases (GHG) emissions [4, 5]. Servers, cooling devices, and fossil oil energy generators are main contributors in the emission of aforesaid gases. According to Khosravi [4], in 2007, information and communication technology industry produced 2% of the total CO_2 emissions that was equivalent to aviation industry, worldwide. Moreover, in 2010, worldwide datacenters consumed 271.8 billion KWh electricity [5]. 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 [3, 7-17]. Techniques, such as, dynamic voltage/frequency scaling (DVFS), and workload consolidation are used to minimize the energy consumption [3]. Moreover, net-zero energy data centers are also introduced that use on-site renewable to avoid the use of non-renewable received from the grid [18].

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 [3].

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 [6] claim that it can be achieved by fully utilizing the active machines at lowest possible power levels. Authors in [3, 7, 8] 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 of the VM.

In [9], Mertzios *et al.* provide a solution to minimize energy consumption of servers that are actively hosting VMs. The proposed technique consolidates VMs with overlapping processing times. Authors in [10] design an ant colony based solution that considers the energy efficiency issue as a multi-dimensional bin-packing problem. Moreover, in [11] 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 [12-14] have come up with an idea of hierarchical RM. Resource managers are introduced at different levels that are responsible to perform specific tasks. In [12, 13] 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, [14] 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 [15-17] 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.* [15] provide a DVFS based scheduling algorithm for cloud datacenters. The algorithm maximizes server utilization that ultimately results in low energy consumption. [16] 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.* [17]. The framework is based proposes the use of game theory for RM, and DVFS enabled server to minimize the energy consumption.

III. Approach

In this study, we propose an SLA-aware version of BFD algorithm that attempts to minimize SLA violations encountered due to non-availability of CPU capacity. Moreover, we compare different variants of BFD based algorithms that attempt to minimize energy consumption in cloud environments. BFD algorithms achieve the aforementioned goal by consolidating workload on minimum number of servers. However, workload consolidation may lead to SLA violations. Therefore, we are using the parameters, such as **(a)** energy consumption, **(b)** average SLA violations, and **(c)** performance degradation due to VM migration, for the evaluation of the selected techniques. 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 (EMBFD), and (ii) SLA violations (SMBFD). 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 [3] 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 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 equation to calculate the energy consumption of a server at any given time [1, 4].

$$P = 0.7 * P_{max} + 0.3 * P_{max} * U \quad (1)$$

Where P is energy consumed by a server, P_{max} is maximum power that can be consumed by the machine, and U is the utilization of machine. Following equation is used to calculate difference between the power consumed before VM placement (P_{BP}) and after VM placement (P_{AP}).

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

Server with minimum value of P_{diff} is selected for the hosting of given VM [3].

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. In this study, we are using two versions of MBFD algorithm, EMBFD and SMBFD which are energy efficient and SLA-aware respectively.

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

PCA-BFD algorithm is another BFD based workloads consolidation technique that considers energy consumption, and CPU capacity while performing VM placement [7]. A ratio is calculated for each server by using equation 3, and the server with lowest ratio is selected for VM hosting.

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

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

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

EPOBF [8] 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.

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

Here, CPU_{max} is total CPU capacity of machine, and P_{diff} is the difference between power used before the placement, and power used after the placement of task. P_{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. Details of VM used in this study are given in Table II. 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 I. Workloads Details

Work loads	*#of servers*	*# of VMs*	*Dates of Workloads*
W1	800	1033	20-04-2011
W2	800	898	06-03-2011
W3	800	1061	09-03-2011
W4	800	1078	25-03-2011
W5	800	1054	12-04-2011
W6	800	1052	03-03-2011
W7	800	1516	22-03-2011
W8	800	1233	11-04-2011
W9	800	1358	09-04-2011
W10	800	1463	03-04-2011

TABLE II. VMs Details

VM Type	CPU (MIPS)	RAM (GB)
High-memory extra-large	3000	6
High-CPU medium instance	2500	0.85
Extra-large instance	2000	3.75
Small instance	1000	1.7
Micro instance	500	0.613

A. Energy Consumption

Results shown in figure 1-4 are generated on the basis previously discussed workloads and migration techniques. See

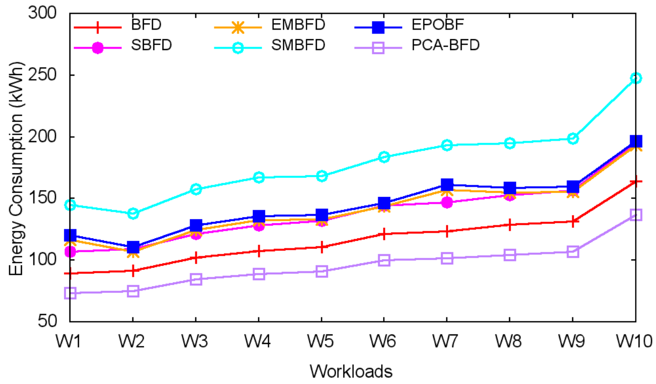

Figure 1: Energy consumption with Maximum Correlation (MC) migration technique

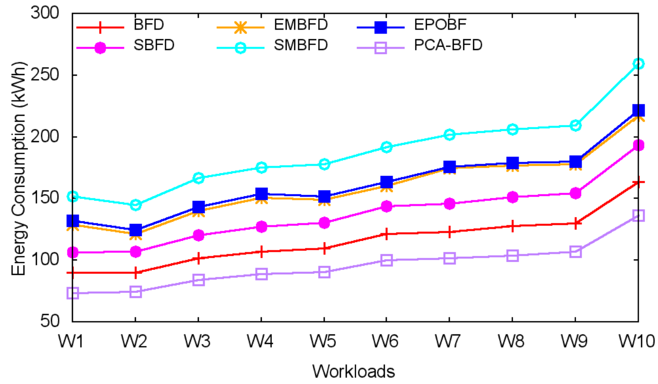

Figure 2: Energy consumption with Minimum Migration Time (MMT) migration technique

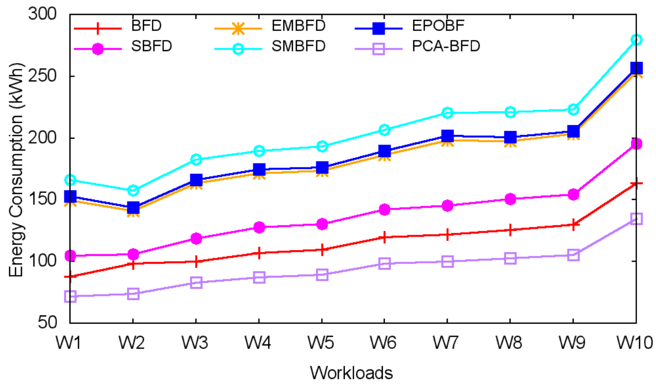

Figure 3: Energy consumption with Maximum Utilization (MU) migration technique

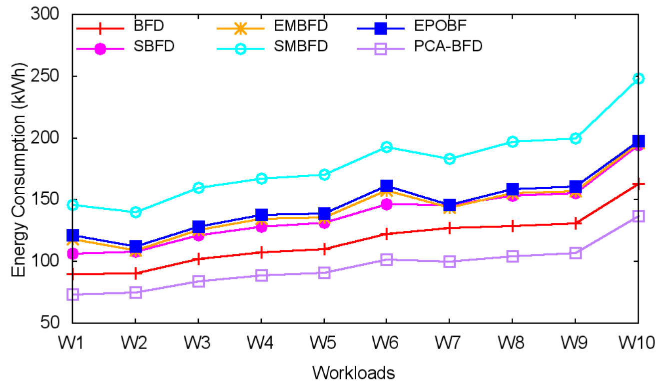

Figure 4: Energy consumption with Random Select (RS) migration technique

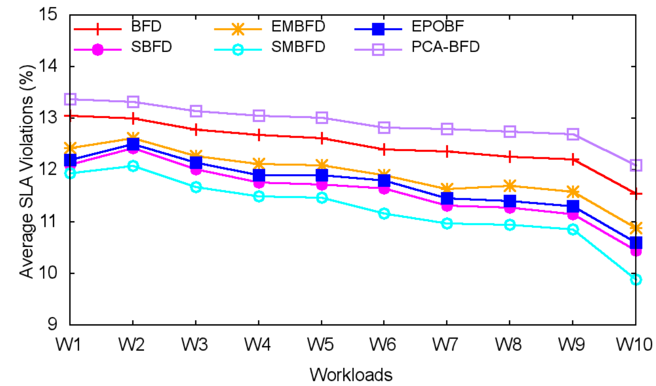

Figure 5: Average SLA violations with Maximum Correlation (MC) migration technique

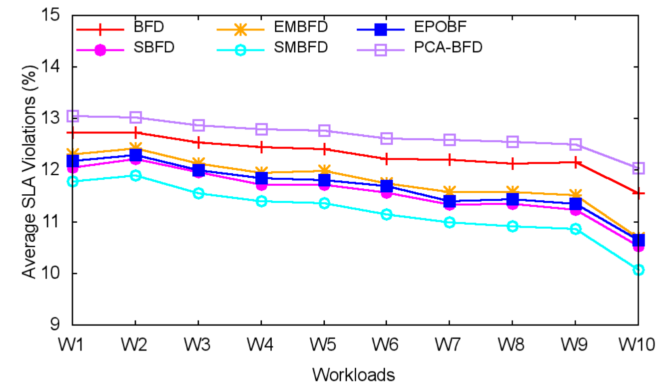

Figure 6: Average SLA violations with Minimum Migration Time (MMT) migration technique

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 10 is more as compared to other workloads. The increase in energy consumption is due to the increase in tasks and tasks that require more resources. In case of higher resource demand, 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 a VM that is using higher amount of resources. Higher resources consumption, such as RAM, leads to higher migration time which results in higher energy consumption. MMT consumes comparatively low energy because selected VMs are the one with low migration times. Low migration time results in low network load and energy consumption by transmitting and forwarding nodes.

B. Average SLA Violations

In this section, we discuss the impact of workloads, and migration techniques on SLA violations. Figures 5-8, show

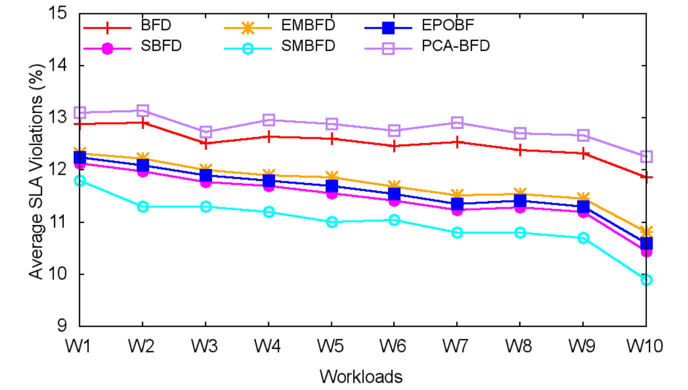

Figure 7: Average SLA violations with Maximum Utilization (MU) migration technique

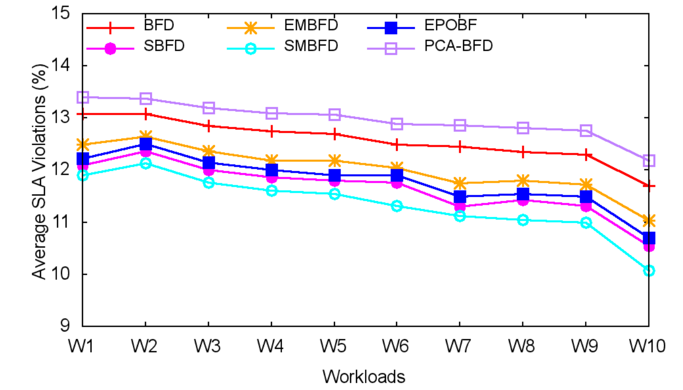

Figure 8: Average SLA violations with Random Select (RS) migration technique

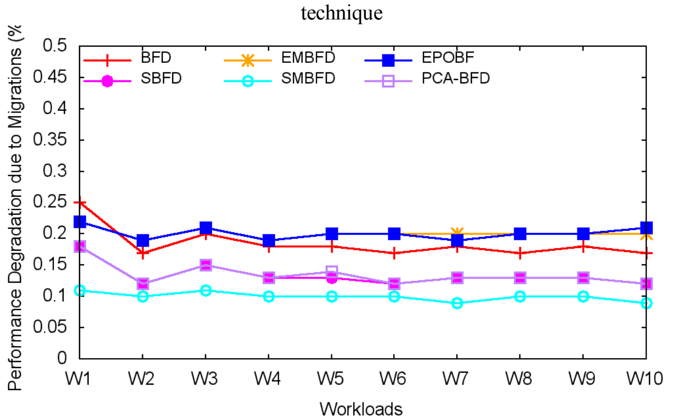

Figure 9: SLA performance degradation due to VM migrations with Maximum Correlation (MC) migration technique

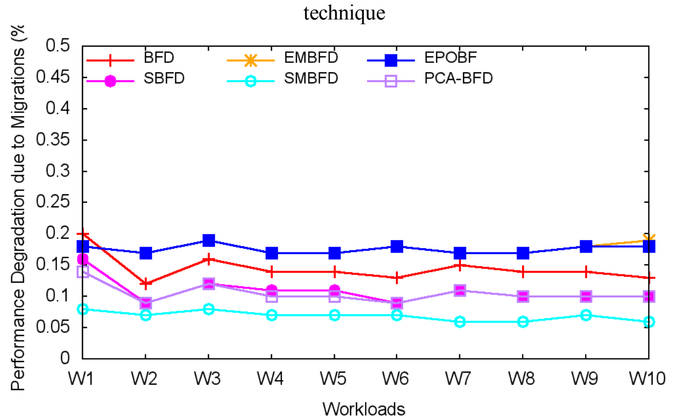

Figure 10: SLA performance degradation due to VM migrations with Minimum Migration Time (MMT) migration technique

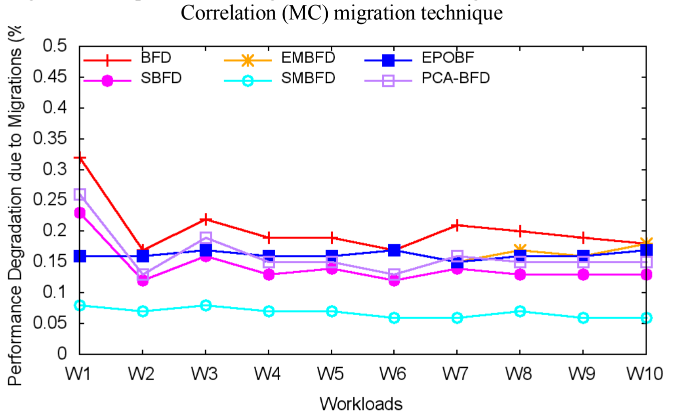

Figure 11: SLA performance degradation due to VM migrations with Maximum Utilization (MU) migration technique

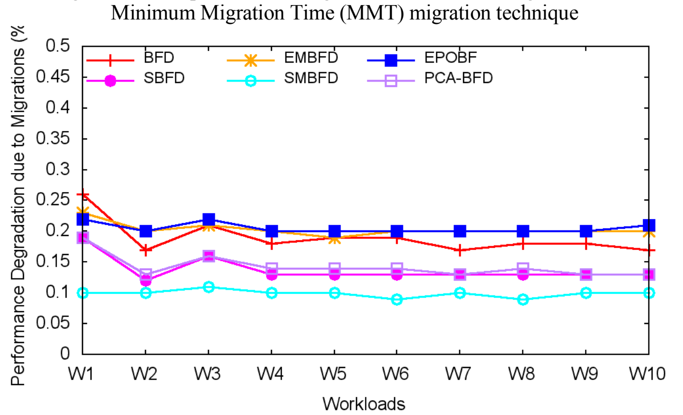

Figure 12: SLA performance degradation due to VM migrations with Random Select (RS) migration technique

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 VMs on minimum number of servers. Consequently, when a VM resource requirement is increased, SLA violation is 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 migration traffic.

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

[1] S. Mustafa, K. Bilal, A. Hayat, A. R. Khan, S. A. Madani, “Resource management in cloud computing: Taxonomy, prospects, and challenges”, Computers and Electrical Engineering, 2015, DOI:10.1016/j.compeleceng.2015.07.021

[2] V. Medina, J. García, “A survey of migration mechanisms of virtual machines”, ACM Computing Surveys (CSUR), Volume 46 (3), 2014

[3] A. Beloglazov, J. H. Abawajy, R. Buyya, "Energy-aware resource allocation heuristics for efficient management of data centers for Cloud computing", Future Generation Computer Systems, Volume 28(5), pp 755-768, 2012

[4] A. Khosravi, S. K. Garg, R. Buyya, “Energy and Carbon-Efficient Placement of Virtual Machines in Distributed Cloud”, Euro-Par 2013 Parallel Processing, Lecture Notes in Computer Science, Volume 8097, pp 317-328, 2013

[5] K. Bilal, S. U. Khan, A. Y. Zomaya, "Green Data Center Networks: Challenges and Opportunities", 11th International Conference on Frontiers of Information Technology (FIT), pp 229 - 234, 2013

[6] Environmental Protection Agency (EPA): Report to Congress on Server and Data Center Energy Efficiency Public Law, pp 109-431, 2007

[7] N. Tziritas, C.-Z. Xu, T. Loukopoulos, S. U. Khan, Z. Yu, "Application-aware Workload Consolidation to Minimize both Energy Consumption and Network Load in Cloud Environments", 42nd IEEE International Conference on Parallel Processing (ICPP), 2013

[8] N. Quang-Hung, N. Thoai,, N. Son, "Epobf: Energy efficient allocation of virtual machines in high performance computing", Journal of Science and Technology, Vietnamese Academy of Science and Technology, Special on International Conference on Advanced Computing and Applications (ACOMP2013), Volume 51, pp 173-182, 2013

[9] G. B. Mertzios, M. Shalom, A. Voloshin, P. W. H. Wong, S. Zaks, "Optimizing Busy Time on Parallel Machines", International Parallel and Distributed Processing Symposium (IPDPS), 2012

[10] E. Feller, L. Rilling, C. Morin, "Energy-Aware Ant Colony Based Workload Placement in Clouds", IEEE/ACM International Conference on Grid Computing (GRID), 2011

[11] Y. C. Lee, A. Y. Zomaya, "Energy efficient utilization of resources in cloud computing systems", Journal of Supercomputing, Volume 60(2), pp 268-280, 2012

[12] T. Nowicki, M.S. Squillante, C.W. Wu, "Fundamentals of Dynamic Decentralized Optimization in Autonomic Computing Systems", Self-Star Properties in Complex Information Systems, pp 204-218, Springer-Verlag, 2005

[13] B. Addis, D. Ardagna, B. Panicucci, M. S. Squillante, L. Zhang, "A hierarchical approach for the RM of very large cloud platforms", IEEE Transactions on Dependable and Secure Computing, Volume 10(5), pp 253−272, 2013

[14] D. Ardagna, B. Panicucci, M. Trubian, L. Zhang, "Energy-Aware Autonomic Resource Allocation in Multitier Virtualized Environments", IEEE Transactions Services Computing, Volume 5(1), pp 2-19, 2012

[15] C. M. Wu, R. S. Chang, H. Y. Chan, “A green energy-efficient scheduling algorithm using the DVFS technique for cloud datacenters”, Future Generation Computer Systems, Volume 37, pp 141-147, 2014

[16] R. N. Calheiros, R. Buyya, "Energy-Efficient Scheduling of Urgent Bag-of-Tasks Applications in Clouds through DVFS", in IEEE 6th International Conference on Cloud Computing Technology and Science, 2014

[17] Y. Ren, j. Suzuki, C. Lee, "Balancing Performance, Resource Efficiency and Energy Efficiency for Virtual Machine Deployment in DVFS-enabled Clouds: An Evolutionary Game Theoretic Approach", in GECCO’14, July 12–16, Vancouver, BC, Canada, 2014

[18] M. Arlitt, C. Bash, S. Blagodurov, Y. Chen, T. Christian, D. Gmach, C. Hyser, N. Kumari, Z. Liu, M. Marwah, A. McReynolds, C. Patel, A. Shah, Z. Wang, R. Zhou, “Towards the Design and Operation of Net-Zero Energy Data Centers”, IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electrical Systems, pp. 552-561, 2012

[19] R. Buyya, C. Yeo, S. Venugopal, J. Broberg, I. Brandic, “Cloud Computing and Emerging IT Platforms: Vision, Hype, and Reality for Delivering Computing as the 5th Utility”, Future Generation Computer Systems, Volume 25, pp 599-616, 2009

[20] S. Martello, P. Toth, "Knapsack Problems–Algorithms and Computer Implementations", *John Wiley & Sons*, 1990

[21] R. N. Calheiros, R. Ranjan, A. Beloglazov, C. A. F. De Rose, R. Buyya, "CloudSim: a toolkit for modeling and simulation of cloud computing environments and evaluation of resource provisioning algorithms", Journal of Software: Practice and Experience, Volume 41(1), pp 23-50, 2011

[22] A. Beloglazov, R. Buyya, "Optimal Online Deterministic Algorithms and Adaptive Heuristics for Energy and Performance Efficient Dynamic Consolidation of Virtual Machines in Cloud Data Centers", Concurrency and Computation: Practice and Experience, Volume 24, pp. 1397-1420, 2012