Energy-aware Management of Virtual Machines in Cloud Data Centers

Efthymios Oikonomou
Department of Digital Systems
University of Piraeus
Piraeus, Greece
oikonomouef@unipi.gr

Dimitra Panagiotou
Department of Digital Systems
University of Piraeus
Piraeus, Greece
dpanagiot@unipi.gr

Angelos Rouskas
Department of Digital Systems
University of Piraeus
Piraeus, Greece
arouskas@unipi.gr

ABSTRACT
The demand for more resources in computational power, memory and disk storage by modern applications and enterprises, results in the consumption of huge amounts of electrical power at cloud data centers. Consequently, cloud service providers, should not only attempt to provide competitive services to their customers, but also keep at the same time their operational costs at acceptable levels by minimizing energy consumption. The reduction of the number of active servers, using live virtual machine (VM) migrations, while keeping the system performance within the levels specified by the SLAs with customers, are main objectives of cloud service providers towards the above goals. In this paper, an efficient VM provisioning mechanism for cloud data center environments is proposed. We first describe our proposed VM allocation policy and then perform a series of simulation experiments based on CloudSim [1] toolkit. Simulation results show that all variations of our proposed provisioning mechanism behave better, in terms of energy consumption and reduction of SLA violations, than the well-known and efficient LrMmt provisioning mechanism [2].

General Terms
Cloud computing, data center, virtualization, migration, energy efficiency

Keywords
Data centers, energy consumption, VM provisioning, VM migration, Service Level Agreement, Quality of Service, CloudSim

1. INTRODUCTION
Nowadays, the development and evolution of the ICT industry through the cloud computing technology has revolutionized the way of utilizing and providing computing resources. Taking the advantage of the virtualization technology and the pay-as-you-go model, enterprises are able to outsource their computational needs to the cloud where cloud providers are responsible to handle with it and provide the agreed services to their customers made through Service Level Agreements (SLAs).

16th EANN workshops, September 25 - 28, 2015, Rhodes Island, Greece
© 2015 ACM. ISBN 978-1-4503-3580-5/15/09…$15.00
DOI: http://dx.doi.org/10.1145/2797143.2797153

On the other hand, the ongoing growth of data centers due to the increased needs for cloud services, results in huge amounts of energy consumption. It has been observed that most of the time physical servers operate at 10-50% [3] of their full performance whilst idle servers consume about 70% of their peak power [4]. One way in order to optimize the energy consumption in a data center is the leverage of the virtualization technology where idle or low utilized hosts can be shut down [2].

With Virtual Machine live migration [5] a dynamic VM consolidation in fewer servers can be accomplished. Furthermore, cloud service providers should ensure that the agreed Quality of Service (QoS) defined by the SLAs is delivered to their customers. The dynamic consolidation of VM in minimum servers can cause a performance degradation and as a result a violation in the SLA [2]. So, a tradeoff between minimizing energy consumption while meeting the QoS in terms of SLA is present and a compromise between the two goals is essential.

The main objective of this research work is to propose a mechanism for efficient virtual machine provisioning in Cloud data centers. The proposed mechanism attempts on one hand to minimize the number of active hosts, thus keeping energy consumption at low levels, and on the other hand reduce the number of consequent virtual machine (VM) migrations, as well as the occurrences of service level agreements violations. We use the CloudSim [1] toolkit as the simulation platform in order to model and evaluate the proposed mechanism. Results show that the proposed scheme can achieve high system performance with low levels of energy consumption.

The remainder of the paper is organized as follows. In Section 2 related research is presented. Section 3 discusses the system model and problem formulation. Section 4 presents the proposed provisioning policy considering energy consumption and SLA violations. In sections 5 and 6 the performance metrics for evaluating the proposed mechanism and the experimental set up using CloudSim 3.0.3 simulator are respectively presented. Section 7 discusses and evaluates the obtained simulation results while Section 8 concludes our work and provides directions for future research.

2. RELATED WORK
Many research works in the literature address the dynamic consolidation of VMs running in fewer active servers, attempting to not only reduce energy consumption, but also keep the system performance at high levels.

Guérout et al. [6] have presented a comparison between energy-aware simulations and real experiments, using Dynamic Voltage and Frequency Scaling (DVFS) model. DVFS can have different implementations in different operating systems. Especially in Linux operating system, DVFS can have five different implementation modes: Performance, Conservative, PowerSaver, UserSpace, and OnDemand. Each mode is associated with a governor in order to decide whether to increase or decrease the frequency of the processor and CloudSim simulator is used to validate its energy aware functionality.

Beloglazov and Buyya [7] proposed and evaluated an efficient resource management policy for virtualized Cloud data centers. With continuous consolidation of VMs, leveraging live migration and switching off idle nodes tried to minimize power consumption, while providing reliable Quality of Service. The evaluation of this scheme showed that with dynamic reallocation of VMs substantial energy savings can be achieved.

Buyya et al. [8] made a survey in energy efficient cloud computing. They addressed architectural principles for energy efficient management of Clouds, energy efficient resource allocation policies and scheduling algorithms considering QoS expectations and power usage characteristics of the devices. This work substantially contributes to both resource providers and consumers. CloudSim toolkit is used to evaluate their approach showing that significant energy savings are achieved and there is high potential for improvement in energy efficiency under dynamic workload.

Beloglazov and Buyya [9] introduced a novel technique for dynamic consolidation of VMs while ensuring Service Level Agreements (SLA). Based on a Markov chain model, for any known stationary workload and a given state configuration, their approach optimally solves the problem of host overload detection under the specified Quality of Service goal.

Beloglazov et al. [2], based on an analysis of historical data from the resource usage by VMs, present adaptive heuristics for dynamic consolidation of VMs. They use statistical methods to determine overutilized and underutilized hosts, combined with VM selection policies for migration and utilizing workload from PlanetLab[1]. Based on simulation results, LrMmt (Local regression combined with the Minimum migration time of VM selection policy) provisioning mechanism outperforms the other proposed schemes due to the reduced number of VM migrations and low levels of SLA violations.

Nai-Wei Lo et al. [10] proposed a VM provisioning mechanism taking into consideration the minimization of energy consumption while meeting QoS in terms of SLA. According to simulation results, their scheme is very efficient in terms of CPU utilization and produces less number of virtual machine migrations in comparison with existing provisioning mechanisms such as LrMmt. Although it is not as energy efficient as LrMmt it achieves fewer VM migrations, fewer SLA violations and higher CPU utilization per host.

3. SYSTEM MODEL AND PROBLEM FORMULATION

In this paper, we consider a large-scale data center as a resource provider that includes *N* heterogeneous physical nodes named hosts, based on the CloudSim architecture. The main characteristics of hosts are the CPU performance defined in Millions Instructions Per Second (MIPS), amount of RAM, disk storage and network bandwidth. Each host can serve several VMs and each VM satisfies user requests specified in millions of instructions (MI). The VMs, characterized by requirements to CPU performance, RAM amount, network bandwidth and disk storage, are allocated to hosts according to the requested characteristics.

As the VMs experience dynamic workloads, SLAs are established. In order to reduce energy consumption and SLA violations, VMs are reallocated according to the current requested resources. When a host's utilization exceeds an upper threshold, it has to be reconfigured and some of its VMs need to be reallocated to underutilized hosts. In addition, since underutilized Hosts are energy inefficient with respect to the carried workload, if the utilization of resources on a host is low, all of its VMs should be transferred to other hosts and the underutilized host should be switched off. The problem at hand is to define a suitable policy with criteria that optimize host selection for VM reallocation and VM placement, so that both SLA violations and energy consumption are simultaneously kept at minimum levels.

4. PROPOSED PROVISIONING POLICY

The proposed algorithm is based on the idea of keeping operational only those hosts whose utilization is between acceptable lower and upper bounds: the lower utilization threshold will benefit energy consumption of hosts, while the upper threshold will prevent QoS deterioration of a host's VMs. The idea of setting an upper utilization threshold for hosts and keeping the total utilization of CPU by all the VMs below that threshold is not a new idea. However, our proposal, at the same time, also tries to reallocate all VMs from hosts with low utilization so that these hosts become candidates for possible switch off. In addition, the algorithm examines hosts' historical data collected in order to prevent potential SLA violations and decides whether a host fulfilling a proper criterion will become also a candidate for VM reallocation even if its CPU is properly utilized. Finally, candidate hosts for hosting the reallocated VMs are the hosts whose utilization is above a lower threshold thus keeping energy consumption at appropriate levels.

The following modes characterizing a host according its utilization, namely *overutilized*, *properly-utilized*, *underutilized* are necessary for the discussion that follows. We define as *overutilized* (a) the hosts whose utilization is higher than an upper threshold, eg. 90%, as well as (b) those hosts that are possible to encounter an SLA violation, based on historical data, even if their utilization is less than the upper threshold. These data are the number of VMs and the total requested MIPS for each host when a previous SLA violation occurred. The hosts with utilization under a lower threshold, eg.30%, are referred to as *underutilized*. Finally, the hosts whose utilization is between an upper and a lower threshold eg. 30% to 90%, are referred as *properly utilized* hosts. The inactive hosts are the hosts with zero CPU utilization and these can be switched off.

The main goal of the provisioning policy is twofold: (a) to prevent an SLA violation occurrence by turning overutilized hosts to properly-utilized hosts and (b) to minimize the energy consumption by switching off as many underutilized hosts as possible. Thus, the overutilized and the underutilized hosts are candidates for reconfiguration, in other words reallocating a subset or the whole set of their VMs to other hosts. More

[1] http://www.planet-lab.org/

specifically, apart from the hosts whose utilization exceeds the upper threshold as described above, we also consider as overutilized, and take into consideration for reconfiguration, those hosts that both their current number of VMs and current total requested MIPs from their VMs are greater than those resided in hosts when SLA violation occurred last time.

Once overutilized and underutilized hosts are determined, the VMs reallocation process begins. During this process, *some* VMs from overutilized hosts and *all* VMs from underutilized hosts are examined for reallocation to properly-utilized hosts, as long as the properly-utilized candidates for hosting the reallocated VMs will not change their mode to overutilized. In case no more properly-utilized host exists to host the VMs of underutilized or overutilized hosts, our scheme examines as candidates for hosting the reallocated VMs some of the underutilized hosts. Of course, in this case these underutilized hosts will remain active and will not reallocate their VMs to other hosts.

Based on LrMmt, our proposed algorithm incorporates the aforementioned modifications to enhance QoS and energy consumption. The procedure yields an optimal VM allocation policy, based on previous utilization samples. The flowchart of our scheme is shown in Figure 1.

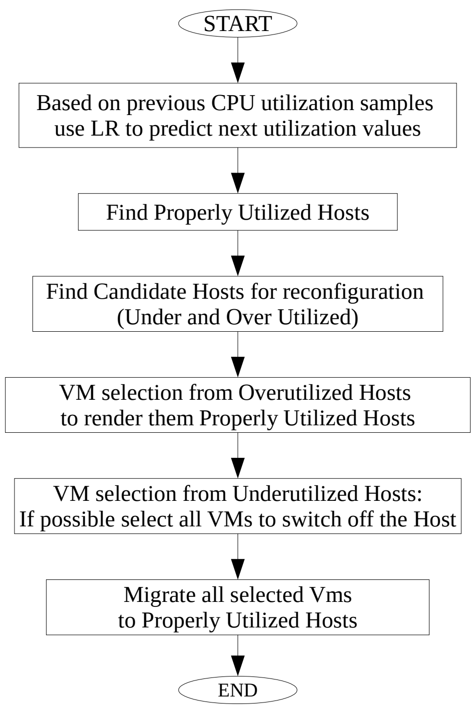

Figure 1. Proposed algorithm

5. PERFORMANCE METRICS

The metrics [2], described in the following are taken into account for evaluating the performance of the proposed provisioning policy. We assume a system with *N* hosts and *M* VMs.

5.1 Energy Consumption

The total energy (E) consumed by a physical server, shown in Equation (1), is defined as the power consumption function over a period of time where *U(t)* is the CPU utilization as a function of time.

$$E = \int_{t_0}^{t_1} P\left(U\left(T\right)\right) dt \tag{1}$$

5.2 Service Level Agreement Violation

The Service Level Agreement that is delivered to the applications is characterized by QoS and performance measures such as availability, throughput, response time, time outs and reliability. In the context of this work, an SLA violation occurs when the available CPU capacity cannot fulfill the CPU requirements triggered by an excess demand for computational power.

5.2.1 SLAV Time per Active Host

It is almost certain that applications residing in a fully utilized host will experience SLA violation. *SLATAH* metric, shown in Equation (2), is defined as the percentage of time during which an active host experiences a utilization of 100%.

$$SLATAH = \frac{1}{N} \sum_{i=1}^{N} \frac{T_{s_i}}{T_{a_i}} \tag{2}$$

where T_{S_i} is the total time that host *i* experiences 100% utilization and T_{a_i} is the total time host *i* is in an active state.

5.2.2 Performance Degradation due to Migration

Applications running in VMs that are in migration mode experience also performance degradation. The model used to represent performance loss due to VM migration assumes a degradation percentage of the total performance requested. The performance degradation due to migration *PDM* metric is depicted in Equation (3), where C_{d_j} is the estimate of the performance degradation percentage (expressed in MIPs) during all migrations of VM *j*, and C_{r_j} is the total CPU capacity requested by VM *j*.

$$PDM = \frac{1}{M} \sum_{j=1}^{M} \frac{C_{d_j}}{C_{r_j}} \tag{3}$$

5.2.3 Service Level Agreement Violation

The SLA Violation (*SLAV*) metric shown in (4) is calculated as the product of the SLA violation Time per Active Host and Performance Degradation due to Migration metric.

$$SLAV = SLATAH * PDM \tag{4}$$

5.3 ESV

The goal of an energy-aware resource management system is the minimization of both Energy consumption and service degradation denoted by the violations of SLA parameters. Thus, a proper performance metric *ESV*, which combines the above parameters is calculated as the product of Energy consumed and SLA violations, as shown in Equation (5).

$$ESV = Energy * SLAV \tag{5}$$

5.4 Number of SLAVs

Whenever the promised QoS (in terms of MIPS) cannot be delivered to the VM, an SLA violation occurs. The number of

SLA violations is also an important metric as an increased number is translated to penalties for the providers of cloud services, or cost for refunds towards the cloud users and should be minimized.

5.5 Number of VM Migrations

The performance degradation due to VM migration as it is described and modeled above, is estimated as a percentage of the CPU utilization. Thus, whenever a VM migration takes place a violation in the SLA may occur. Hence, it is important to minimize not only the SLAV metric but also the number of VM migrations.

6. EXPERIMENTAL SET UP

The performance of the proposed provisioning mechanism was evaluated through simulations, conducted with CloudSim [1] 3.0.3 toolkit. This multi-layered open source framework is a discrete event driven simulator widely used to model and simulate cloud computing infrastructures and application services. The detailed configuration of the simulation environment is given in the following.

6.1 Data Center

Two types of servers are hosted in the simulated data center. In total, 800 hosts are present, half of them are HP ProLiant ML110 G4[2] (1 x [Xeon 3040 1860 MHz, 2 cores], 4GB, 1 Gbit/s) and the rest are HP ProLiant ML110 G5[3] [x] (1 x [Xeon 3075 2660 MHz, 2 cores], 4GB, 1 Gbit/s).

The energy consumption in a data center depends on the CPU, memory, disk storage, power supplies and cooling systems [11]. According to [2] there is a linear relationship between the power consumption of servers and CPU utilization. The power model used in our experiment is based on real data provided by the results of the SPECpower[4] benchmark and the power characteristics of servers are presented in Table 1.

Table 1. Power consumption in Watts at different load levels (Benchmark Results)

Server Name	Load Levels / Power Consumption					
	0%	**10%**	**20%**	**30%**	**40%**	**50%**
HP ProLiant G4	86	89.4	92.6	96	99.5	102
HP ProLiant G5	93.7	97	101	105	110	116
Server Name	**Load Levels / Power Consumption**					
	60%	**70%**	**80%**	**90%**	**100%**	
HP ProLiant G4	106	108	112	114	117	
HP ProLiant G5	121	125	129	133	135	

[2] http://www.spec.org/power_ssj2008/results/res2011q1/power_ssj2008-20110124-00338.html

[3] http://www.spec.org/power_ssj2008/results/res2011q1/power_ssj2008-20110124-00339.html

[4] http://www.spec.org/power_ssj2008/

The four different types of VM instances selected for the simulation are shown in Table 2, each one requiring one CPU core.

Table 2. VM instance types

VM Characteristics	Instance Type 1	Instance Type 2	Instance Type 3	Instance Type 4
VM MIPS	2500	2000	1000	500
VM RAM (GB)	870	1740	1740	613
VM BW (Mbit/s)	100	100	100	100
VM SIZE (GB)	2.5	2.5	2.5	2.5

6.2 Workload Data

Real data were used from the CoMon project [2], [12] a monitoring infrastructure for PlanetLab, which is a distributed execution environment for performing benchmarked experiments. The workload set, specified in Table 3, obtained from servers located at more than 500 places around the world are data traces collected during a period of ten days of the project. These real workload data contain PlanetLab's VMs CPU utilization values measured every 5 minutes for one day (288 samples per day per VM).

Table 3. Workload Data – CPU Utilization

Date	Number of VMs	Mean
03-03-2011	1052	12.31%
06-03-2011	898	11.44%
09-03-2011	1061	10.70%
22-03-2011	1516	9.26%
25-03-2011	1078	10.56%
03-04-2011	1463	12.39%
09-04-2011	1358	11.12%
11-04-2011	1233	11.56%
12-04-2011	1054	11.54%
20-04-2011	1033	10.43%

Likewise, the simulation time was set to 24 hours with 5 minutes time interval between successive utilization measurements.

7. SIMULATION RESULTS

After conducting initial simulation experiments, we reached the conclusion that proper values for the upper and lower utilization thresholds are 90% and 30% respectively. Thus, the results gathered and presented in the following are the outcome with these threshold values.

Different variations of the proposed algorithm were defined by varying (a) the criteria for characterizing as overutilized a host (besides the hosts whose CPU utilization exceeds the upper threshold value) and (b) the number of utilization samples necessary for the local regression policy.

- Criterion 1: the current number of VMs of a host is equal or greater than the number of VMs recorded when SLA violation last occurred, and

- <u>Criterion 2</u>: the current total requested MIPS are equal or greater than the total requested MIPS recorded when SLA violation last happened.
- The length variations used were 10, 20 and 30 values.

An <u>*AND*</u> variation of the algorithm is assumed if both Criteria 1 and 2 should be met to characterize a host as overutilized, Similarly an <u>*OR*</u> variation of the algorithm is assumed if at least one of the criteria suffices to characterize that a host is overutilized. By also varying the number of regression values, we finally reach a total of 6 different policy variations, namely L10_AND, L10_OR, L20_AND, L20_OR, L30_AND, and L30_OR.

We compare these 6 variations of our proposed provisioning algorithm against LrMmt policy, which is the best policy presented in [2] and stands for Local Regression (LR) VM allocation policy and Minimum Migration Time (MMT) VM selection policy. Table 4 compares the results, gathered for the performance metrics presented in Section 5, among our proposed policy variations and LrMmt algorithm. According to Table 4 our proposed mechanism can achieve better results for each performance metrics listed, where the reduction of consumed energy and improvement in terms of QoS are about 10% and 80% respectively.

Table 4. Proposed Vs LrMmt performance

Metrics	Policy		% reduction
	Average values over all proposed variations	LrMmt	
Energy in KWh	146.68	161.87	9.38
SLAV	6.73E-06	4.97E-05	86.45
ESV	9.69E-04	8.05E-03	87.96
Number of SLAVs	8665	49006	82.32
Number of VM Migrations	4885	281759	82.66

Figure 2 presents the results of average energy consumption for all policy variations and LrMmt scheme using the workload data from Table 3. We set the CPU utilization degradation percentage at 10% to estimate the degradation C_{d_j} in MIPs during all migrations of VM *j* [2]. All our variations achieve lower energy consumption with values between 138.54 and 161.62 KWh compared to 161.87 KWh consumed by LrMmt algorithm. From Figure 2, we also conclude that if both criteria 1 and 2 hold simultaneously, the algorithm makes better guesses to identify overutilized hosts. As a result, fewer properly and underutilized hosts are necessary to host VM reallocations, thus fewer hosts remain active.

The average SLA violations in our proposed schemes are 86.45% fewer compared to LrMmt as shown in Table 4, and this is mainly justified by the fact that our schemes try to keep the hosts properly utilized and minimizing the number of VM migrations. In addition, by observing Figure 3, we conclude that when the length of Local regression values is either 20 or 30 the algorithms achieve their best performance. This comes with a slight increase in computation to carry out the regression analysis.

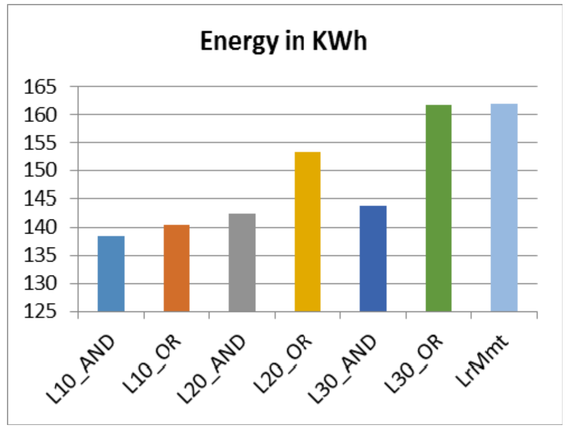

Figure 2. Energy in KWh metric

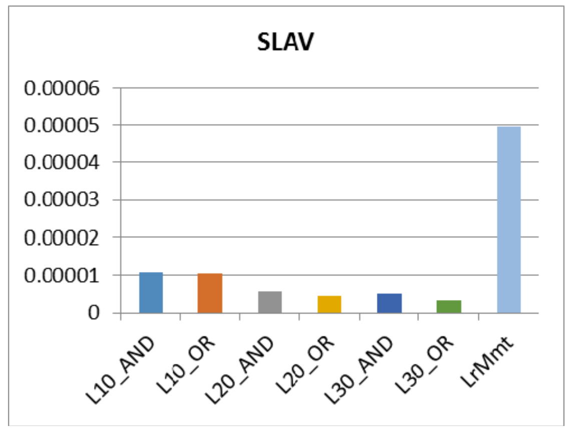

Figure 3. SLAV metric

As presented in Figure 4, the L30_OR variation of our proposed scheme achieves the best ESV value, which is consistent with the results in Figures 2 and 3, as the corresponding very low SLAV value influences most ESV, which is the product of Energy and SLAV metrics.

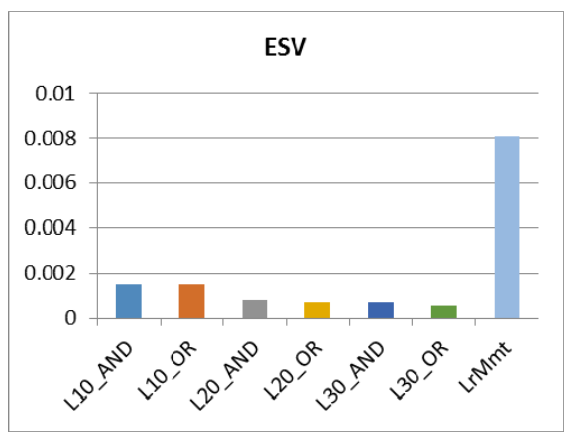

Figure 4. ESV metric

Finally, based on Figure 5 and Figure 6 it is concluded that the proposed mechanism outperforms LrMmt as the number of VM migrations and SLAVs are fewer. By achieving fewer VM migrations, our scheme, yields a fewer number of SLAVs as well.

The L30_OR variation yields the least number of VM migrations and the least number of SLAVs, with values 3349 and 6410 respectively.

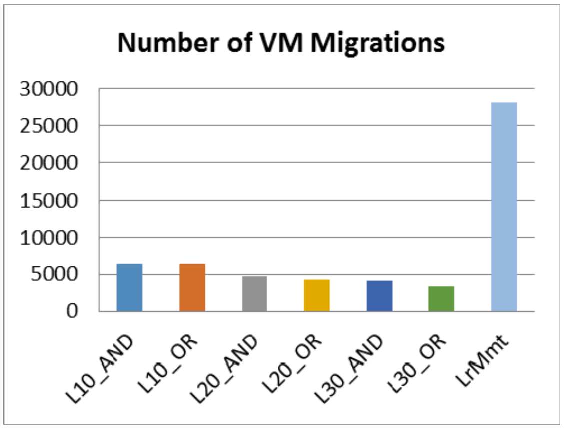

Figure 5. Number of VM Migrations metric

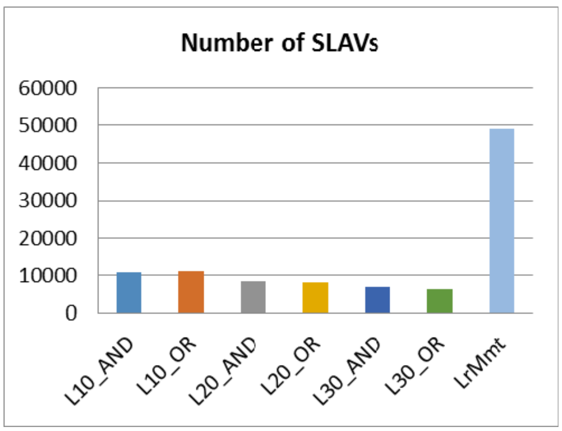

Figure 6. Number of SLAVs metric

8. CONCLUSION AND FUTURE WORK

In this paper, we presented an efficient virtual machine provisioning mechanism to reduce energy consumption as well as SLA Violation in the Cloud data centers. By taking into consideration more historical data from the data center and trying to keep utilized hosts between specified thresholds, we achieve better results in system performance. According to our simulation results, all proposed variations of the proposed provisioning algorithm outperform the LrMmt mechanism, which is defined as the best among the VM allocation policy mechanisms proposed in [2]. Comparing to LrMmt, our mechanisms achieve better results in absolute Energy consumption in KWh, ESV and number of VM Migrations causing fewer SLA Violations. Thoughts for future research work would be a further investigation for more robust and efficient heuristics schemes.

9. ACKNOWLEDGMENTS

This research has been co-financed by the European Union (European Social Fund – ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: Thales - ENDECON.

10. REFERENCES

[1] R. N. Calheiros, R. Ranjan, A. Beloglazov, C. A. F. D. Rose, and R. Buyya,“CloudSim: A toolkit for modeling and simulation of Cloud computing environments and evaluation of resource provisioning algorithms,” Software: Practice and Experience, vol. 41, no. 1, pp. 23–50, 2011

[2] Anton Beloglazov and Rajkumar 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, 24(13):1397–1420, 2012

[3] Barroso LA, Holzle U. The case for energy-proportional computing. Computer 2007; 40(12):33–37.

[4] Fan X, Weber WD, Barroso LA. Power provisioning for a warehouse-sized computer. Proceedings of the 34th Annual International Symposium on Computer Architecture (ISCA 2007), ACM New York, NY, USA, 2007; 13–23

[5] C. Clark, K. Fraser, S. Hand, J. G. Hansen, E. Jul, C. Limpet, I. Pratt, A. Warfield, “Live migration of Virtual Machines,” In Proceedings of the 2nd conference on Symposium on Networked Systems Design & Implementation - Volume 2, Berkeley, CA, USA: USENIX Association, 2005, pp.273–286.

[6] Tom Guérout, Thierry Monteil, Georges Da Costa, Rodrigo Neves Calheiros, Rajkumar Buyya, Mihai Alexandru, Energy-aware simulation with DVFS, Simulation Modelling Practice and Theory, Volume 39, December 2013, Pages 76-91, ISSN 1569-190X.

[7] Beloglazov, A.; Buyya, R., "Energy Efficient Allocation of Virtual Machines in Cloud Data Centers," Cluster, Cloud and Grid Computing (CCGrid), 2010 10th IEEE/ACM International Conference on , vol., no., pp.577,578, 17-20 May 2010.

[8] Buyya R, Beloglazov A, Abawajy J. Energy-efficient management of data center resources for cloud computing: a vision, architectural elements, and open challenges” in Proceedings of the 2010 International Conference on Parallel and Distributed Processing Techniques and Applications (PDPTA 2010). Las Vegas, USA, July 2010.

[9] Beloglazov, A.; Buyya, R., "Managing Overloaded Hosts for Dynamic Consolidation of Virtual Machines in Cloud Data Centers under Quality of Service Constraints", Parallel and Distributed Systems, IEEE Transactions on , vol.24, no.7, pp.1366,1379, July 2013.

[10] Nai-Wei Lo; Pei-Chi Fan; Tzong-Chen Wu, "An efficient virtual machine provisioning mechanism for Cloud data center," Electronics, Computer and Applications, 2014 IEEE Workshop on , vol., no., pp.703,706, 8-9 May 2014.

[11] L. Minas and B. Ellison, Energy Efficiency for Information Technology: How to Reduce Power Consumption in Servers and Data Centers. Intel Press, 2009.

[12] K. Park and V. Pai, “CoMon: a mostly-scalable monitoring system for PlanetLab,” ACM SIGOPS Operating Systems Review, vol. 40, pp. 65 – 74, 2006.