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MECpVmS: an SLA aware energy-efficient virtual machine selection policy for green cloud computing

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Abstract

Cloud computing provides a service-oriented computing model to cloud users on a metered basis. Most of the cloud data centers are running on fossil fuels. It elevates the carbon emissions to the environment. Green cloud computing is the fusion of greenness in cloud computing to address the issues related to energy consumption and environmental sustainability. Virtual machine (VM) consolidation and live migration can provide standard solutions to energy consumption. The selection of VM for migration is a vital task. It should be performed effectively to trade-off between energy consumption and service level agreement violation (SLAV). The research activity in this article focuses on a new VM selection policy that chooses VM with high energy consumption and small size. Real-world workload traces were used to evaluate the performance of the proposed MECpVmS VM selection policy. Using CloudSim simulation, the MECpVmS VM selection policy has been implemented and assessed with existing VM selection policies. The results show an overall improvement in energy efficiency, energy consumption, SLAV.

Keywords Green cloud computing · Energy consumption · Virtual Machine selection · Quality of service · SLAV · Energy efficiency · MECpVmS

1 Introduction

In the modern world, every online user knowingly or unknowingly utilizes virtualized computing services hosted by different cloud service providers (CSP). These CSP provide different information communication technology (ICT) services to millions of cloud users through the internet. These services may include IT infrastructures, platforms, software, etc. Cloud users can utilize these services with dynamic provisioning and pay-per-use modelling. This results in rapid deployment of mobile applications with resource provisioning and minimal effort [1].

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The processing of these applications is mostly done in remote data centers. So, low-end mobiles are also able to utilize the benefits of these mobile applications.

The benefits of cloud computing include cost reduction as cloud users do not require to set up their infrastructure, and even the users do not require to be aware of the location of the processor that is processing their data. These services can be easily tailored to the users' needs. Large-scale heterogeneous data centers are built to host thousands of physical servers and network equipment that are used to provide these cloud services. The trend of using cloud services is increasing rapidly. These forced the CSP to expand the capacity of existing data centers and also increase the number of data centers in the world [2]. On the contrary, these rapid growths in data centers lead to gargantuan energy consumption [3].

On average, a single cloud data center consumes electricity that can be used to lighten 25000 households for a year [4]. An increase in energy consumption will also increase the operational cost. More importantly, energy consumption can directly impact carbon emissions and increase greenhouse gases as most of the energy is generated by burning fossil fuels. Azad et al. [5] predicted that by 2020 all data centers together would consume 140 billion KWh. of electricity. In reality, the energy consumption has crossed their prediction for that year. Liu et al. [6] have predicted that by the year 2030 energy consumption of data centers will cross 1500 billion kWh. Recent research shows that watching 30 minutes of Netflix generates 1.6 Kg of CO_2 which is equivalent to driving 6 km in a car [7]. To support this theory, Kamilya [8] estimated that only the Netflix streaming servers will consume 370 billion kWh of electricity per year. Data centers produce around 2% greenhouse gas equivalently to global airlines. Therefore, cloud service providers should increase energy efficiency and reduce energy consumption for a sustainable environment.

This brings the concept of green cloud computing that focuses on providing energy-efficient computing services to cloud users with the help of green data centers. Every component of a green data center will have maximized energy efficiency to provide environmental sustainability. But on the other hand, Quality of Service (QoS) should be maintained. The users' satisfaction is the most important criterion in service-based computing. The cloud users agreed on some terms of satisfaction with CSP using a service-level agreement (SLA). SLA ensures QoS by CSP. SLA violation (SLAV) is inversely proportional to energy consumption. The solution needs to have a trade-off between energy consumption and SLAV.

Inadequate and inefficient resource management is one of the reasons for energy waste in data centers. Resources including servers [9], network equipment [10], software resources [11] and even cooling units [12] are consuming electricity. Servers consume almost 26% of the electricity in data centers. And to cool down, the heat generated from these servers and other networking and computing equipment fare amount of electricity is consumed by cooling units. The performance of the servers must be optimized with software solutions for better resource optimization, energy efficiency, and thermal management.

Cloud computing is dependent on the Virtualization of resources. Physical servers are virtualized using a hypervisor to create virtual machines (VM). This improves the server utilization of the data centers. These virtual machines are used to serve customers' requirements [3]. Customers can request more resources at run-time and these requests must be processed hastily. Multiple VM are allotted to servers, thus if one or more VM are allowed to use more resources then the load on the server might exceed its capacity. This state of the server is known as overload. An overloaded server may increase response time and failure rate. An under-load situation might occur if very few of the resources of a server are utilized by some VM. These servers are known as underutilized servers and might increase energy consumption due to a lack of efficient resource utilization [13].

Over 6 months, 5000 servers were analyzed. The study shows that almost all the severs were active but only 10% - 50% were utilized all the time [11]. Another study shows that even idle servers consume around 70% of electricity compared to fully utilized servers [14]. Consequently, Consequently, evading servers from being overloaded can reduce energy consumption, decline SLAV, and reduce the temperature. Also, acknowledgment of idle and under-utilized servers and turning them off or hibernating could save energy wastage [13]. Thus, a reduced number of active servers can increase energy efficiency. And to prevent servers from overloading migrations of VM are required to perform promptly. Active VM are reallocated to another server at run-time. This is known as live migration. VM are consolidated to the minimum number of servers by migration. The reallocation of VM has a slight impact on the service delivery and performance of the VM. Though the performance degradation will be unnoticed by the customers, this contributes to SLAV. Another problem of migration will be that while some VM is in migration it uses resources of two different servers at the same time increasing the energy consumption of the overall system. Therefore a tread-off is required.

To control the number and migration and energy consumption, it is very essential to select the appropriate VM for migration that reduces the energy consumption as well as SLAV. The VM selection policies are used for this purpose. VM selection process creates a migration pool with all the selected VM from overloaded servers. These

VM from the migration pool are to be allocated to moderately loaded servers. This will ensure controlled SLAV and reduced energy consumption. In this research article, Maximum energy consumption per unit VM size (*MECpVmS*) VM Selection Policy has been proposed that selects the VM having higher energy consumption but smaller in size. The proposed VM selection policy is used to optimize energy consumption and SLAV. The proposed VM selection policy has been implemented in CloudSim 4.0 Simulation [15] environment following the VM consolidation architecture proposed by Belglazov and Buyya. [16]. The performance of the proposed *MECpVmS* VM selection policy has been compared with some recently published works by worldwide researchers.

The organization of the research article is as follows. Some similar works are covered in Sect. 2. Section 3 explains the working of the proposed (MECpVmS) VM Selection Policy in a detailed manner. In Sect. 4, the VM consolidation framework based on the (MECpVmS) VM Selection Policy is discussed. The outcomes of the implemented algorithms are analyzed with various existing algorithms of similar kinds, in Sect. 5. Section 6 wraps up the essay by summarising the research findings.

2 Literature survey

VM selection policies play a major role in the energy VM selection policies play an important role in reducing the energy consumption and SLAV of cloud data centers. The VM selection policies are used to select some VM from overutilized Hosts. These selected VM are then migrated to moderate-loaded Hosts. The VM migration reduces SLAV and helps in better energy management. The number of VM migrations is proportional to the energy consumption of virtualized data centers [17]. Beloglazov and Buyya [16] have proposed several VM selection policies like The Minimum Migration Time (MMT) policy, The Random Choice (RC), and The Maximum Correlation (MC) policy. In MMT policy selects those VM that will take minimum time for migration as compared to others. In MC select those VM that have a maximum correlation of utilization of CPU with other VM. As the name suggests, the RC policy selects VM randomly for migration.

Yadav et al. [18] have proposed a new algorithm called GradCent based on the Stochastic Gradient Descent technique. With the help of real CPU overload, the algorithm easily evolves a threshold for upper CPU utilization that successfully detects overloaded hosts. In that work, Minimum Size Utilization (MSU), the VM selection algorithm minimizes energy consumption by 23% and SLA violation by 27.5%.

Moghaddam et al. [19] proposed a new method that is divided into three stages. The algorithm works in two phases. Firstly, The algorithm predicts overutilized hosts using the machine learning method. Then, the Multi-objective VM selection method selects the VM in the overutilization host for migration. Finally, Best Fit Decreasing (BFD) has been developed for finding the host where the VM can migrate. That machine learning-based algorithm improved energy consumption by 26% and SLAVs by 50% over local regression-based MMT and power-aware best fit policy.

In the article [20] the researchers have combined the best fit decreasing bin packing method and multi-pass optimization to achieve efficient VM placement for cloud datacenters. They have proposed an SLA-aware VM selection policy, that claimed to have better performance than existing ones. In [21] the researchers have carefully examined the existing energy-efficient algorithms and made detailed comparisons among those. In that survey paper, all the algorithms are traced with CloudSim.

Mandal et al. [22] proposed a power-aware VM selection policy for VM consolidation and live migration. Here the researchers have analyzed the utilization of the VM and selected the maximum utilized VM for migration from overloaded Hosts. The proposed policy has been implemented and proved to have improved several parameters like no of migrations, energy consumption, SLA violations, etc. For the optimization of energy efficiency and service quality EQ-VMC, a VM consolidation method was proposed by Li et al. [23]. In the article, a discrete differential evolution algorithm was proposed for VM placement for getting a globally optimum solution. These algorithms jointly reduced energy consumption and improved QoS over previous VM consolidation methods.

Gholipour et al. [24] have proposed a new architecture for joint VM and container consolidation and implemented the JVCMMD algorithm that has reduced energy consumption and optimized SLA violation. They have considered consolidation to be the primary solution for green cloud computing. With the combination of multi-criteria decision-making and join VM and container migration approach, they have developed JVCMMD.

In [25] authors have proposed a New Linear Regression (NLR) prediction model along with host overload/underload, a VM placement policy to deal with energy consumption and SLAV. They have predicted the future CPU utilization and allocated VM to Hosts according to the parameter. Sum of Squares Utilization Rate (MdSSUR) VM Selection policy proposed in [26]. In the article, the researchers have focused on multimedia datacenter specifically. MdSSUR policy reduce consumed energy and Service Level Agreement violation (SLAV). The authors have claimed to achieve 28.37% improvements on EC, 89.47% on the number of migrations, and 79.14% on SLAV.

Alhammadi et al. [27] have proposed Multi-objective Virtual Machine selection (MOVMS) for selecting VM for migration. They have also proposed a Multi-objective Modified Best Fit Decreasing (MOMBFD) algorithm to allocate VM to Hosts. They have simulated the algorithms in CloudSim and claimed their proposed policies outsmart existing ones. In Li et al. [28] have proposed an evidence-efficient affinity propagation scheme for the VM placement (EEAP-VMP) algorithm. The algorithm was designed for load-balancing among various physical machines (PMs). The researchers have claimed their scheme produces better results when compared to ST-MC, ST-MMT, and ST-RS policies. The EEAP-VMP scheme reduced energy consumption, and SLA violation in comparison to FFD, and UPBFD algorithms [29, 30]. The simulations are done in the Alibaba Cluster Data V2018 dataset.

In [31], researchers have proposed ATEA (adaptive three-threshold energy-aware algorithm) for reducing energy consumption and SLA Violation. In that algorithm, the researcher examined the hosts and classified them into four sets: hosts with a heavy load, hosts with moderate loads, hosts with a light load, and hosts with little load. VM migration is done from heavy or light loaded host to little loaded host. The threshold values are determined by two adaptive threshold algorithms: KAM and KAI. Along with ATEA, these two algorithms produce better results.

In [32], a VM selection method called Minimize Number and Cost of Migrations (MNCM) was proposed by Zhang et al. In that article, they tried to minimize the number of migrations of VM as the number of VM migrations is proportional to energy consumption. VRO is calculated from VRA and VRR, and VM with a larger VRO is considered for migration. Their policy successfully reduced the energy consumption that is simulated in the CloudSim environment with PlanetLab data. Yadav et al. [33] have introduced a VM selection algorithm called Maximum Utilization Minimum Size (MuMs). That MuMs algorithm was developed for the selection of VM from overloaded hosts. In this algorithm, the VM with maximum CPU utilization per size is selected for migration. The algorithm has reduced energy consumption and SLA Violation as the prime objective of the article. Another VM selection algorithm was proposed by Akhter et.al [34] based on a load of physical hosts and heuristic analysis. The algorithm is used to dynamically allocate, deallocate, and reallocate the virtual machines (VM) in an appropriate host. That VM selection algorithm was also simulated on CloudSim and used different real-world planet lab data. It was found, that the algorithm is around 19% more energy efficient than the existing algorithms. Khttar et al. [35] have suggested a QoS-aware VM consolidation framework. The framework not only aggressively reduced energy consumption but also maintain the Quality of Services. This algorithm produced quite impressive results more specifically on energy consumption and Service level agreement violation.

All the before-mentioned VM selection policies have tried to minimize energy consumption. Though their primary objective was to reduce energy consumption, none of these research articles addressed the problem using estimated energy consumption after a VM is migrated from a host. The *MECpVmS* VM selection policy has measured the estimated energy consumption of the hosts and selects the VM that consumes maximum energy for the host.

3 Maximum energy consumption per unit VM size (*MECpVmS*) VM selection policy

The VM selection policy applied to a set of overloaded hosts in a large-scale heterogeneous data center. *MECpVmS* VM selection policy creates a pool of migratable VM by selecting the VM that devours maximum energy while the size of the VM is comparatively small from each overloaded host. The target here is to shift the load from overloaded hosts to moderately loaded hosts and create a balance. Overloaded hosts will increase the *SLAV* while a large number of migrations will cost energy consumption (*EC*) and operational cost. *MECpVmS* VM selection policy seeks to create a trade-off between EC and *SLAV*. *MECpVmS* VM selection policy has five steps: finding current *EC* of the host (cEC_{host}), finding the predicted *EC* of the host (pEC_{host}) if a selected VM is migrated from host, finding the *EC* consumed by the selected VM (EC_{vm}) using Eq. 1, finding the ratio of EC_{vm} and VM Size ($size_{vm}$) as selection criteria (*SC*) (Eq. 2) and lastly select the VM that has maximum *SC* and add it to the VM migration pool.

$$EC_{vm} = cEC_{host} - pEC_{host} \tag{1}$$

$$SC = \frac{EC_{vm}}{size_{vm}} \tag{2}$$

EC of the hosts are calculated based on the CPU utilization of the hosts. The CPU utilization ($utCPU_{host}$) is computed by the Eq. 3.

$$utCPU_{host} = \frac{usdMIPS_{host}}{totMIPS_{host}} \tag{3}$$

Where $usdMIPS_{host}$ is the used processing capability of the host and $totMIPS_{host}$ is the total MIPS of a host. MIPS (million instructions per second) is the processing unit of hosts and VM. A linear power model is used to calculate the energy consumption of hosts. The power consumption characteristics of hosts are retrieved from Table I in [16].

3.1 Used MIPS of a host ($usdMIPS_{host}$)

Algorithm 1: Used MIPS of a Host ($usdMIPS_{host}$)

Input: $host$ = An Active Host
Output: $usedMIPS$ = Total MIPS used by the $host$

1 start
2 $usedMIPS \leftarrow 0.0$
3 $vm_list \leftarrow$ host.vmList()
4 **foreach** vm *in* vm_list **do**
5   **if** *!(vm is migrating in to host))* **then**
6         $usedMIPS \leftarrow usedMIPS + allocatedMIPS_{VM_i} * 0.75$
7   **end**
8     $usedMIPS \leftarrow usedMIPS + allocatedMIPS_{VM_i}$
9 **end**
10 **return** $usedMIPS$ stop

The $usdMIPS_{host}$ can be computed using Eq. 4.

$$usdMIPS_{host} = \sum_{i=1}^{n} \left[allocatedMIPS_{VM_i} + \rho * allocatedMIPS_{VM_i} * 0.75 \right] \tag{4}$$

Where ρ is a Boolean value representing 1 if VM_i is in migration, otherwise 0. $allocatedMIPS_{VM_i}$ represents the allocated MIPS for VM_i. $usdMIPS_{host}$ is the sum of allocated MIPS for all the VM residing in the host. 75% of $allocatedMIPS_{VM_i}$ is to be included if some of the VM are migrating into the host. Algorithm 1 is used to calculate $usdMIPS_{host}$ for a given host. Input to the algorithm is an active host and output is used MIPS of the host. Line numbers 4 – 5 are used to calculate $usdMIPS_{host}$ of the host.

3.2 Potential CPU utilization of a host ($pUtCPU_{host}$)

The Potential CPU utilization of a host is the predictive CPU utilization of the host, if a selected VM would have to be migrated from the host. It can be calculated by subtracting the $allocatedMIPS$ of selected VM from the $usdMIPS_{host}$ and then applying Eq. 3 to find the potential CPU Utilization. The algorithm 2 is used to find the potential CPU utilization of a host. An active host and one of the VM allocated to the host are given as input to the algorithm and the algorithm finds the $pUtCPU_{host}$ and returns it. Line 2 is used to fetch the allocated MIPS for the VM, line 3 uses algorithm 1 to find the current used MIPS by the host, line 4 calculates potential used MIPS of host if the input VM is to be migrated from the input host, Line 5 and 6 calculates the potential CPU utilization of the input host and returns it.

Algorithm 2: Potential CPU Utilization of a Host ($pUtCPU_{host}$)

Input: $host$ = An Active Host, vm = An active VM allocated in $host$
Output: $pUtCPU_{host}$ = potential CPU Utilization of $host$ if vm is selected to be migrated from $host$

1 start
2 $allocatedMIPS \leftarrow vm$.allocatedMIPS()
3 $usedMIPSHost \leftarrow usedMIPS(host)$ [Using algorithm 1]
4 $potentialusedMIPS \leftarrow usedMIPSHost - allocatedMIPS$
5 $pUtCPU_{host} \leftarrow \frac{potentialusedMIPS}{totalMIPS(host)}$
6 **return** $pUtCPU_{host}$
7 stop

3.3 Energy consumption of a host (EC_{host})

Algorithm 3: Energy Consumption of a Host (EC_{host})

Input: $utCPU_{host}$ = CPU Utilization of a host
Output: EC_{host} = Energy consumption of the host based on CPU utilization

1 start
2 $EC_{host} \leftarrow 0.0$
3 **if** $utCPU_{host} \geq 0.0\&\&utCPU_{host} \leq 1.0$ **then**
4     $EC_{host} \leftarrow$PowerModel.getPower($utCPU_{host}$)
5 **end**
6 **return** EC_{host}
7 stop

The energy consumption (EC_{host}) of a host is the collective energy consumed by the VM allocated to the host. EC_{host} is computed using linear power utilization model with the help of Table I in [16]. The EC_{host} of a host is directly proportional to the CPU utilization of the host ($utCPU_{host}$). Algorithm 3 is used to find the EC_{host} of a host providing $utCPU_{host}$ as an input to the algorithm. Line number 4 consults with the PowerModel class implemented in CloudSim [15] to determine the EC_{host} for $utCPU_{host}$.

3.4 *MECpVmS* VM selection policy

Overloaded hosts are limited by resources. VM running on overloaded hosts can not execute to their fullest potential because dynamic resource provisioning is temporarily stalled. Overloaded hosts are responsible for *SLAV* and dilute the QoS provided by the cloud provider. *MECpVmS* VM selection policy (algorithm 4) is used on overloaded hosts to select appropriate VM for migration. All the VM from overloaded hosts are collected in a migration pool for reallocation to moderately loaded hosts. Algorithm 4 starts with a list of active hosts and creates a list of VM need migration. For all the overloaded hosts, Line 4 initiates a *vm_list* with all the allocated VM. Lines 7 and 8 calculates $utCPU_{host}$ and cEC_{host} respectively. Using algorithm 2 and algorithm 3 the $pUtCPU_{host}$ and pEC_{host} are calculated in lines 11 and 12 respectively. The VM with a maximum *SC* is selected using lines 14 to 18. In line 21 list of VM created by adding all the VM selected for migration from different overloaded hosts. The flowchart of the *MECpVmS* VM selection policy is shown in Fig. 1.

Algorithm 4: *MECpVmS* VM selection Policy

Input: *host_list* = Active host list
Output: *VMsToMigrateList* = Migration List containing VM to migrate

1 start
2 **foreach** ***host**, in host_list* **do**
3   **if** *isHostOverloaded(host)* **then**
4         $vm\_list \leftarrow$ host.getAllocatedVMs()
5   vmToMigrate $\leftarrow$ null
6         $maxSC \leftarrow Double.MinValue()$
7         $utCPU_{host} \leftarrow \frac{usedMIPS(host)}{totalMIPS(host)}$
8         $cEC_{host} \leftarrow$ getEnergyConsumption($utCPU_{host}$)
9   **foreach** ***vm** in vm_list* **do**
10   **if** *!(isInMigration(vm))* **then**
11                 $pUtCPU_{host} \leftarrow$ getPotentialUtilization(host, vm)
12                 $pEC_{host} \leftarrow$ getEnergyConsumption($pUtCPU_{host}$)
13                 $EC_{vm} \leftarrow cEC_{host} - pEC_{host}$
14                 $SC \leftarrow \frac{EC_{vm}}{size_{vm}}$
15   **if** $SC > maxSC$ **then**
16                     $maxSC \leftarrow SC$
17   vmToMigrate $\leftarrow$ vm
18   **end**
19   **end**
20   **end**
21   VMsToMigrateList.add(vmToMigrate)
22   **end**
23 **end**
24 **return** *VMsToMigrateList*
25 stop

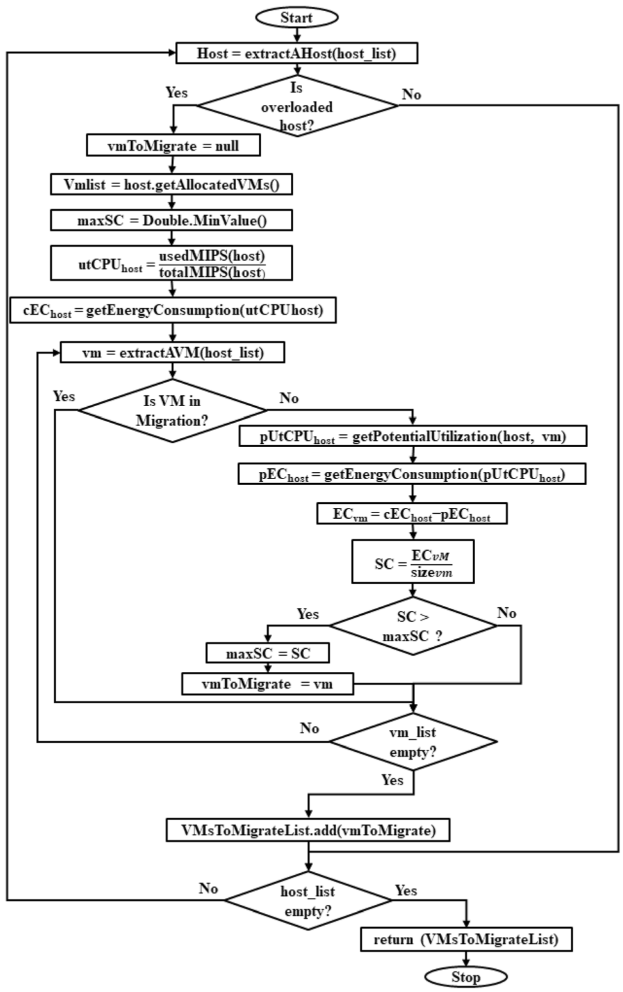

Fig. 1 Flowchart *MECpVmS* VM selection policy

4 VM consolidation framework based on *MECpVmS* VM selection policy

Beloglazov and Buyya [16] have proposed a VM consolidation framework consisting the following steps: overloaded host detection, underutilized host detection, VM selection, VM allocation.

Figure 2 illustrates the VM consolidation framework based on *MECpVmS* VM Selection Policy. Upon receiving cloud service requests from cloud users data center broker selects an appropriate VM for the job. The VM is allocated to physical hosts based on the VM allocation policy. Power-Aware Best Fit Decreasing (PABFD) [16] VM allocation policy is used in this research. Over time, more and more cloud tasks are allocated to physical hosts. The host monitoring system monitors all the physical hosts and uses an overload and underload detection algorithm to categorize hosts into three categories: overloaded hosts, moderately loaded hosts, and underutilized hosts. In this research, the Local Regression Robust (LRR) [16] method is used as an overload and underload detection policy. Overloaded hosts are responsible for SLA violations and energy is wasted due to underutilized hosts. All VM from underutilized hosts are added to a migration pool along with some of the VM from overloaded hosts. The selection of VM from overloaded hosts is an important aspect of reducing energy consumption and SLAV. Without the proper selection of VM number of VM migrations might increase. While a VM is in-migration state, the VM consumes double the energy from both the participating hosts. The *MECpVmS* VM Selection Policy is used to select the VM optimally based on their energy consumption and size. All the VM from the migration pool are again allocated to moderately loaded hosts using the PABFD policy.

5 Performance evaluation

The *MECpVmS* VM Selection Policy is implemented using CloudSim simulation toolkit [15]. From the cloud users' perspective, cloud computing or cloud environment is an unlimited pool of virtualized computing resources. For better analysis of any cloud computing policies, it is necessary to implement the policy on extensively large virtualized data centers. Experimenting with real-cloud infrastructure is limited by the cost and time to reconfigure the whole cloud infrastructure every time. Thus it is a good practice to simulate cloud experiments before implementing them into real-cloud infrastructure. Cloud simulation provides the flexibilities of reconfiguration of cloud architecture in any instance with zero cost. Experiments can be performed repetitively with minor changes in different policies. CloudSim is one of the renowned cloud simulation tools that can simulate large-scale heterogeneous cloud data centers. It is capable of cloud-task management with the features like dynamic provisioning of resources, virtualized servers, power consumption monitoring, and green cloud computing application management.

5.1 Experimental setup

In CloudSim, a large-scale heterogeneous data center is prepared and equipped with 800 physical hosts (or servers). The HP Pro Liant G4 and The Hp Pro Liant G5 Servers are used as physical hosts. The characteristics of the hosts are shown in Table 1. The G4 uses Xeon 3040 processor with an 1860 MHz clock speed, and G5 uses Xeon 3075 processor with a 2600 MHz clock speed. Both the hosts use 1 Gbps network bandwidth.

Real-world VM replicated from Amazon EC2 [36] are implemented as VM instances for the cloud environment.

Fig. 2 VM consolidation framework based on *MECpVmS* VM selection policy

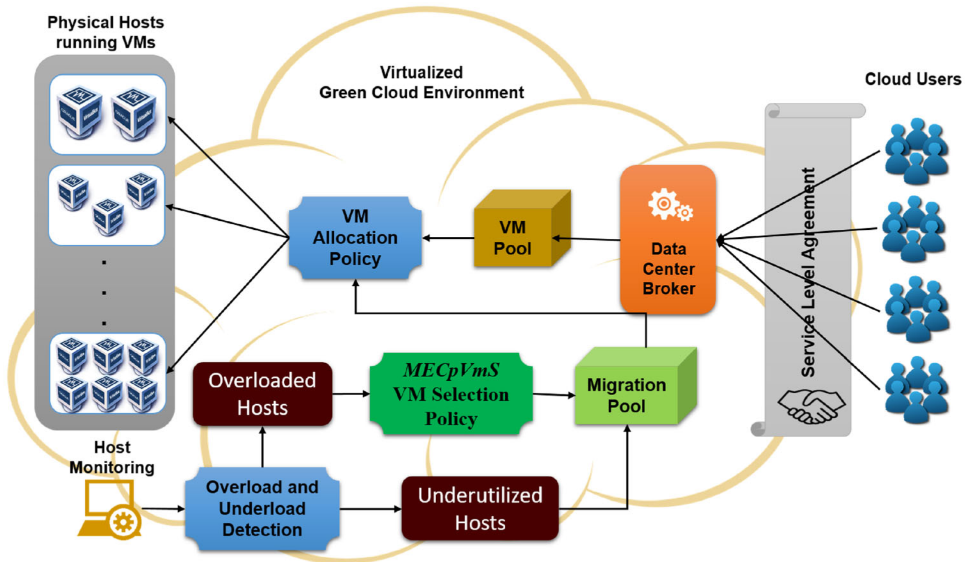

Table 2 provides the brief characteristics of the VM instances. The data center broker analyses the workloads and selects one of the VM for the job. The VM are allocated to one of the hosts using the VM placement policy. Each VM utilizes 2500 MB of storage and 100 Mbps internet bandwidth.

For the adequate evaluation of simulation-based approaches, it is essential to use data closely related to the real world. In this research, some trace-based real workload data is used, collected from project CoMon monitored by PlanetLab [37]. From different places, thousands of VM were analyzed over eight weeks. PlanetLab recorded utilization data of each VM every 300 s for ten random days. The data for three days is selected for analysis of the *MECpVmS* VM Selection Policy. The characteristics of the workloads are provided in Table 3.

5.2 Results and analysis

To measure the performance and efficiency of the proposed *MECpVmS* VM Selection policy it is compared with some recent renowned VM selection policies. These VM selection policies are Maximum Utilization (MXU) [22], Minimum Migration based on TESA (MIMT) [31], Maximum Utilization Minimum Size (MUMS) [33], and Maximum Migration Time(MXMT) [34]. Beloglazov and Buyya [16] have proposed some performance evaluation metrics: the number of migrations (NoM), Performance degradation due to migration (PDM), SLA time per active hosts (SLATH), SLA Violation (SLAV), energy consumption (EC), and energy and SLAV (ESV). Another performance metric energy efficiency proposed by Khattar et al. is used for evaluation. The consecutive sections will have a detailed analysis based on all these performance metrics.

5.2.1 Performance based on migrations

To control SLAV, live VM migration is essential. The VM allocated to overloaded hosts cannot acquire more resources from hosts. Dynamic provisioning becomes limited by the configuration of a physical host. It violates the terms with cloud users and degrades QoS provided by the VM. On the other side, excessive migration could escalate the energy consumption, and performance degradation of VM. Also, the communication link will be busy most of the time for excessive migration. The number of migrations (*NoM*) represents the total number of live migrations performed throughout the cloud ecosystem while executing a workload. Figure 3 demonstrates the analysis based on *NoM*. The y-axis in the figure represents *NoM*, and the x-axis represents different VM selection policies for different workloads. For all the workloads proposed *MECpVmS* VM Selection policy has outperformed the existing ones. Table 4 shows a comparative study of *NoS* for all the workloads.

5.2.2 Performance based on SLAV

QoS is an essential measure of cloud services. QoS establishes between cloud users and cloud providers through SLA. SLAV is used to represent the percentage of time a cloud provider has violated the terms in SLA. Beloglazov and Buyya [16] have recommended a measure to find the SLAV in terms of performance degradation due to migration (PDM) and SLA time per active host (SLATH). The SLA is represented using Eq. 6.

Table 1 Characteristics of hosts in data center

Host	Cores	Clock speed (MHz)	RAM (GB)	Max energy consumption (in Watt)	Min energy consumption (in Watt)
G4	2	1860	4	117	86
G5	2	2600	4	135	93.7

Table 2 Characteristics of VM

VM instances	MIPS	Cores	RAM (in MB)
VM_Type1	2500	1	870
VM_Type2	2000	1	1740
VM_Type3	1000	1	1740
VM_Type4	500	1	613

Table 3 Characteristics of workloads

Workload	Date	No. of VM	Mean	SD
Workload 1	11/03/2011	1052	12.31	17.09
Workload 2	11/04/2011	1463	12.39	16.55
Workload 3	20/04/2011	1033	10.43	15.21

$$SLAV = PDM \times SLATH \tag{5}$$

An overloaded host is unable to allocate more resources to its' VM. That limits the potential dynamic resource requests by the VM. VM can not use more resources to cloud users even if the users want to. So it is necessary to capture the amount of active host that has experienced an overload. SLATH measures the overall percentage of time some host has experienced 100% utilization. Equation 6 is used to compute SLATH. The SLATH comparison shown in Fig. 4 and Table 5 imply the *MECpVmS* VM selection policy has minimal SLATH than other VM selection policies.

$$SLAV = \frac{1}{NoH}\sum_{i=1}^{NoH}\frac{T_{OL_i}}{T_{run_i}} \tag{6}$$

Where,

- NoH represents number of hosts,
- T_{OL_i} represents the time i th host was overloaded,
- T_{run_i} represents total running time of i th host.

For overloaded hosts, migration is essential to free up space to allow VM to operate on full potential. During live migration some performance distortion happened for the VM. PDM represents the performance degradation due to migration. It can be calculated using Eq. 7.

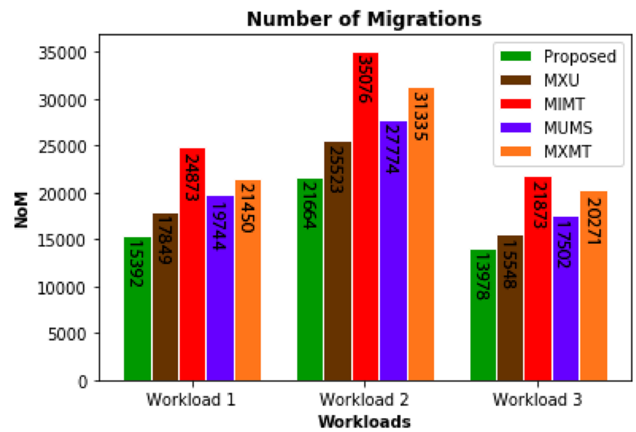

Fig. 3 Analysis based on *NoM*

Table 4 Comparison of *NoM*

Workload	MECpVmS	MXU	MIMT	MUMS	MXMT
Workload 1	15,392	17,849	24,873	19,744	21,450
Workload 2	21,664	25,523	35,076	27,774	31,335
Workload 3	13,978	15,548	21,873	17,502	20,271

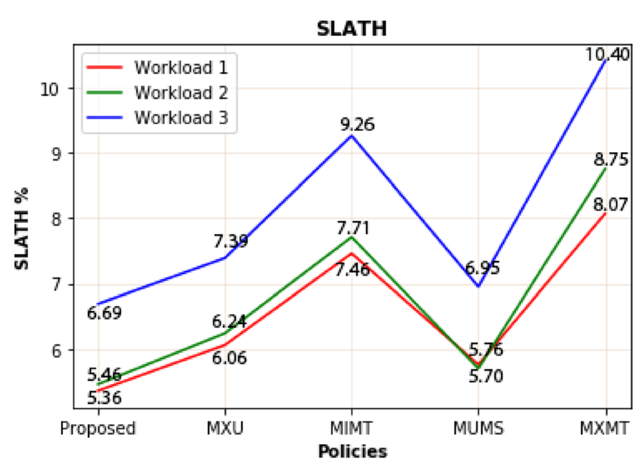

Fig. 4 Analysis based on *SLATH*

Table 5 Comparison of *SLATH*

Workload	MECpVmS (%)	MXU (%)	MIMT (%)	MUMS (%)	MXMT (%)
Workload 1	5.36	6.06	7.46	5.76	8.07
Workload 2	5.46	6.24	7.71	5.70	8.75
Workload 3	6.69	7.39	9.26	6.95	10.40

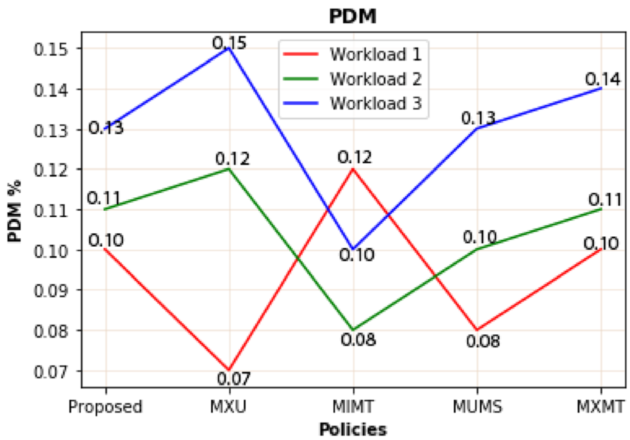

Fig. 5 Analysis based on *PDM*

$$PDM = \frac{1}{NoV}\sum_{i=1}^{NoV}\frac{PerfDeg_i}{MIPS_i} \quad (7)$$

Where,

- NoV represents number of VM,
- $PerfDeg_i$ is the performance degradation due to migration for VM_i,
- $MIPS_i$ is the requested MIPS of VM_i.

Figure 5 and Table 6 demonstrate the PDM comparison between all the VM selection policies for different workloads.

The SLAV comparison for all the VM selection policies is shown in Fig. 6. The figure implies that the proposed *MECpVmS* VM selection policy outperforms other VM selection policies for all the workloads. Table 7 shows a comparative study based on SLAV.

5.3 Analysis based on energy consumption

Energy consumption (EC) of the data center can be computed using Eq. 8.

$$EC = \sum_{i=1}^{NoH}\int_t EC_i(t) \quad (8)$$

where,

- $EC_i(t)$ is the total energy consumption of i_{th} host over time t.

Energy consumption is directly proportional to carbon emission as most of the electricity is generated from fossil fuels. Minimizing energy consumption is a critical aspect of this research. Figure 7 and Table 8 represents the energy consumption comparison of all the VM selection policies. Figure 7 and Table 8 illustrate that the proposed *MECpVmS* VM selection policy consumes less energy than other policies for all the workloads.

5.3.1 Analysis based on energy and SLAV (ESV)

Individually energy consumption and SLAV are not enough to measure the performance of the green cloud computing system [38–40]. Energy consumption and SLAV are inversely proportional to each other. Beloglazov and Buyya [16] have designed a special parameter known as Energy and SLAV (ESV) to measure the performance of green cloud computing applications. The ESV is calculated using Eq. 9.

$$ESV = EC \times SLAV \quad (9)$$

Table 9 and Fig. 8 shows the ESV comparison of different VM selection policies. The proposed *MECpVmS* VM selection policy has minimal ESV.

5.3.2 Analysis based on energy efficiency

Energy efficiency measures how much electricity can be saved using different VM selection policies. It can be calculated using Eq. 10. Energy efficiency should be maximized for better performance.

Table 6 Comparison of *PDM*

Workload	MECpVmS (%)	MXU (%)	MIMT (%)	MUMS (%)	MXMT (%)
Workload 1	0.10	0.07	0.12	0.08	0.10
Workload 2	0.11	0.12	0.08	0.10	0.11
Workload 3	0.13	0.15	0.10	0.13	0.14

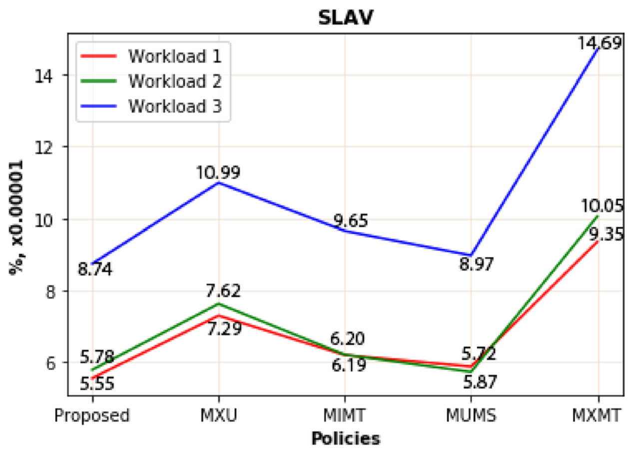

Fig. 6 Analysis based on *SLAV*

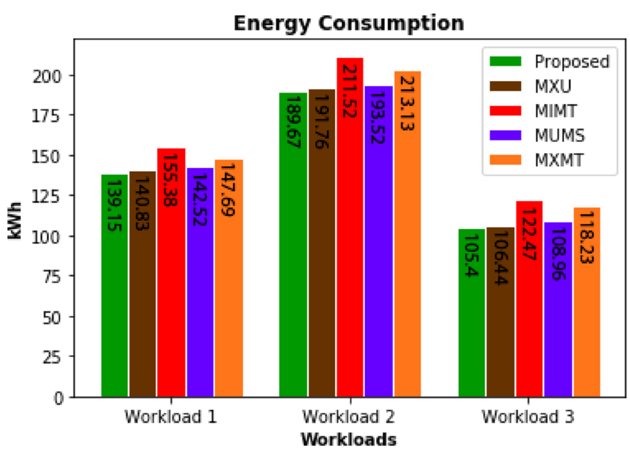

Fig. 7 Analysis based on *EC*

Table 7 Comparison of $SLAVX10^{-5}$

Workload	MECpVmS	MXU	MIMT	MUMS	MXMT
Workload 1	5.55	7.29	6.19	5.87	9.35
Workload 2	5.78	7.62	6.20	5.72	10.05
Workload 3	8.74	10.99	9.65	8.97	14.69

$$Energy\ Efficiency = \frac{1}{EC \times SLAV} \tag{10}$$

The comparison based on energy efficiency is illustrated in Fig. 9 and Table 10. The *MECpVmS* VM selection policy yields maximum energy efficiency considering any workload.

Table 8 Comparison of *EC* (in kWh.)

Workload	MECpVmS	MXU	MIMT	MUMS	MXMT
Workload 1	139.15	140.83	155.38	142.52	147.69
Workload 2	189.67	191.76	211.52	193.52	203.13
Workload 3	105.04	106.44	122.47	108.96	118.23

Table 9 Comparison of $ESV \times 10^{-4}$

Workload	MECpVmS	MXU	MIMT	MUMS	MXMT
Workload 1	13.0000	16.0000	16.0000	15.0000	20.0000
Workload 2	15.0000	17.0000	17.0000	15.0000	21.0000
Workload 3	26.0000	30.0000	43.0000	27.0000	46.0000

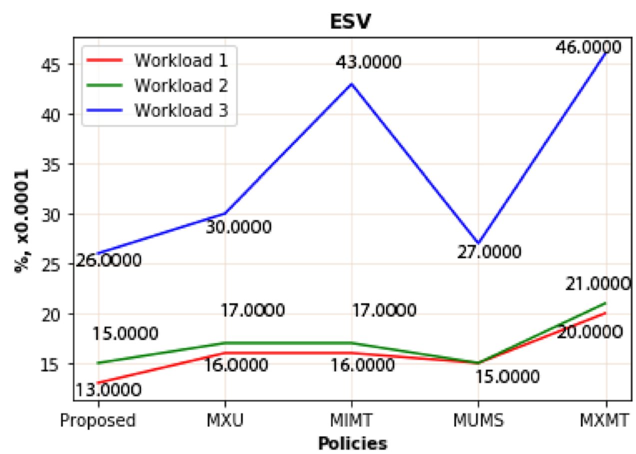

Fig. 8 Analysis based on *ESV*

5.3.3 Analysis based on average execution time

In green cloud computing, execution time is similarly vital as any other metric. Average Execution time determines how fast tasks are executed by the cloud processing in a single workload.

The average execution time comparison is shown in Fig. 10 and Table 11. The average execution time for the *MECpVmS* VM selection policy is minimal compared to other VM selection policies.

6 Conclusion

In the era of global warming, environmental sustainability is society's biggest concern. Service-based cloud computing has become an integral part of our lifestyle. The

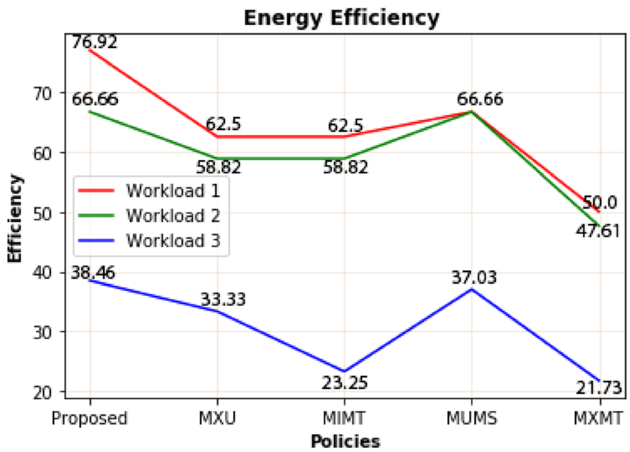

Fig. 9 Analysis based on energy efficiency

Table 10 Comparison of energy efficiency

Workload	MECpVmS	MXU	MIMT	MUMS	MXMT
Workload 1	38.46	33.33	23.25	37.03	21.73
Workload 2	66.66	58.82	58.85	66.66	47.61
Workload 3	76.92	62.50	62.50	66.66	50.00

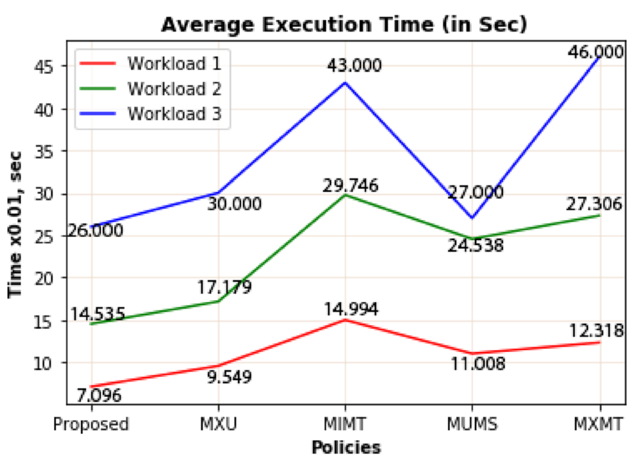

Fig. 10 Analysis based on average execution time

demand for cloud services is increasing rapidly so are data centers blooming. The data centers gulp a lot of energy produced by fossil fuels leaving carbon footprints on the environment. Efficient energy management in the data center is essential for sustainability and a green environment. This research article highlighted the issue of energy consumption and used the VM consolidation framework for better energy management and reducing SLAV. VM selection is an integral part of VM consolidation. In this article, a new *MECpVmS* VM selection policy is proposed that selects VM from overloaded hosts for migration. The proposed algorithm is proven to be more energy-efficient than existing solutions. Also, the *MECpVmS* VM selection policy has less SLAV compared to its predecessors.

Table 11 Comparison of Average Execution Time (x 10^{-2} Sec.)

Workload	*MECpVmS*	MXU	MIMT	MUMS	MXMT
Workload 1	7.096	9.549	14.994	11.008	12.318
Workload 2	14.535	17.179	29.746	24.538	27.306
Workload 3	5.601	6.184	9.701	6.197	10.091

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Author contributions RM: Conceptualization, Methodology, Software, Data curation, Validation, Investigation, Visualization, Writing— original draft. MM: Supervision, Conceptualization, Methodology, Investigation, Writing—review and editing. SB: Supervision, Methodology, Validation, Writing—review and editing. WA: Writing—review and editing. GS: Methodology, Validation, Writing—review and editing. UG: Methodology, Writing—review and editing, UB: Methodology, Writing—review and editing.

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Code availability Code available on request from the authors.

Declarations

Conflict of interest The authors have no conflicts of interest to declare for this manuscript.

Ethical approval For this type of study formal consent was not required. This manuscript does not contain any studies with human participants or animals performed by any of the authors.

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