Design and Development of Power Saving Selection and Placement Methods for Consolidating Virtual Machine Effectively in Cloud Computing

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Summary
The most critical issue in cloud computing consists of a tremendous increase in power consumption because of increased cloud users. Many techniques have been proposed to reduce power consumption while meeting service level agreement between service providers and users. Most existing approaches are able to conserve power to some extent but at the cost of performance degradation or increased number of service level agreement violations. In this work, we propose power saving Virtual Machine selection and virtual machine placement methods for or effective Virtual Machine consolidation process. The proposed methods have been designed based on the current CPU utilisation of the physical machine. These methods have been validated using cloud Sim software. The experimental results demonstrate the proposed Virtual Machine selection and placement methods as effective methods in reducing power consumption, number of virtual machine migrations, and number of service level agreement violations compared to the existing methods, random straight, the maximum utilisation, maximum correlation method and minimum migration time method for provisioning computing resources in cloud computing.
Keywords:
VM consolidation; Cloud computing; VM Placement; VM selection policy; Energy efficiency;

1. Introduction

Cloud computing has enabled cloud users to share configurable computing resources on demand [1, 2]. It provides computing resources such as processing power, storage, network bandwidth as a service to its users. It uses modern technology such as virtualization and utility based prices to use computing resources at a reduced cost with more flexibility without the intervention of service providers. It has the advantage of providing better services than traditional hour based infrastructure and other services due to paying as you use basis model [3].

These computing resources can be allocated and deallocated quickly with minimal intervention of cloud service providers [4]. Cloud Computing environment may contain multiple cloud data centre that can be distributed geographically. Different data centres contain a number of physical machines to provide computing resources to cloud users. Cloud users are offered services in the form of virtual machines running on physical machines in the cloud data centre [5]. Virtual machines with different capabilities in computing resources are provided to cloud users as per their workload requirements.

Cloud Computing provided these advantages in using increased computational power and other computing resources at the cost of scaling up the cloud data centre and tremendous power consumption [6, 7]. It has resulted in an exponential growth in power consumption in recent years, causing an increase in carbon footprints [8]. The increase in carbon footprints adds to Global Warming.

In recent years, the cloud data centre has tried many techniques, including online virtual machine migrations, for balancing the workload among physical machines and optimizing power consumption [9]. Online virtual machine migration requires allocating virtual machines to Physical machines to maintain the optimal number of active physical machines, reduce under loaded physical machines, and maximize computing resource utilization [6]. This process is called Virtual Machine consolidation, which helps decrease the power consumption of cloud computing to a considerable level. However, it has increased the number of service level agreement violations. Therefore, Virtual Machine consolidation must be practical, reducing power consumption while meeting service level agreement.

The existing Virtual Machine consolidation methods mainly focused on managing power consumption based upon setting threshold values of the utilization of different computing resources such as CPU, memory and bandwidth. However, they have ignored over usage of cloud resources and corresponding workload. The existing techniques lack finding proper active physical machines to place virtual machines. They may start new physical machines, leading to an increase in the number of physical machines and the number of virtual machine migrations [10]. An effective Virtual Machine consolidation comprises significant three steps [7].

- **Step 1:** detection of overloaded and under loaded physical machines in cloud data centres causes service level

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agreement violation due to the lack of computing resources in physical machines. Cloud data centre's power consumption can be decreased by detecting underutilized physical machines, followed by migrating all virtual machines and turning underutilized physical machines to power saving mode.

- **Step 2:** Select appropriate virtual machines from over utilized physical machines to reduce the workload of those physical machines with the aim of reducing migration time [6], Virtual Machine migrations [11], Virtual Machine migration latency.
- **Step 3:** Select a proper physical machine for placing the selected virtual machine that requires migration to reduce the overall power consumption of the cloud data centre [6].

Several methods have been developed for each step described above for the Virtual Machine consolidation process. However, consolidating virtual machines effectively involves Virtual Machine placement and Virtual Machine selection methods for reducing power consumption while meeting service level agreements between cloud users and cloud Service providers [13].

This work focuses on reducing power consumption of cloud data centre by proposing an effective Virtual Machine selection and placement method based upon the current CPU utilization of physical machines while meeting service level agreements between cloud users and service providers.

The rest of the paper is organized as follows. Section 2 provides state of the art in cloud computing concerning Virtual Machine selection and Virtual Machine placement. Section 3 highlights the proposed Virtual Machine selection and placement method that resulted in deceasing cloud data centre's power consumption while meeting service level agreement between cloud user and service provider. Section 4 describes experimental setup and results with their analysis and discussion to validate the proposed Virtual Machine placement and selection methods in cloud computing. Finally, Section 5 conclude the paper at the end.

2. Related work

Power consumption is a critical issue in the cloud computing environment due to the increased utilization of cloud-based services structures infrastructure as a service, platform as a service, software as a service, etc. Most research work in the cloud computing area focused on measuring power consumption using CPU usage of physical machines [12, 14, 16, 17]. Researchers of the field attempted to compute power consumption by considering virtual machines running on the physical machine. Therefore, different Virtual Machine related tasks such as selecting Virtual Machine, allocating physical machines to Virtual Machines, migrating Virtual Machines, and placing Virtual Machines have remained a target for achieving power consumption reduction while meeting service level agreements between cloud users and cloud service providers. The virtual machine consolidation method effectively reduces power consumption, requiring selecting appropriate virtual machines from over utilized physical machines and migrating to other underutilized physical machines in data centre.

Several researchers have proposed different methods for selecting and placing virtual machines to appropriate physical machines to reduce the power consumption of cloud data centres. For example, Beloglazov et al. (2012) [15] initially proposed a virtual machine consolidation method to reduce power consumption while meeting service level agreement based upon CPU utilization threshold levels at the upper and lower end. The researchers tried to maintain physical machine utilization between threshold levels. This work was further extended by Beloglazov and Buyya (2013) [18], introducing an adaptive heuristic based virtual machine consolidation method. They used previous data to compute workload changes and adjust threshold values accordingly. They have also proposed three methods for detecting overloaded physical machines, median absolute deviation method, local regression method and interquartile range method. These methods help to reduce power consumption and minimize service level agreement violations.

Ahamed et al. [19] proposed and non predictive method for consolidating virtual machines in the cloud data centre. They proposed that physical machines with more than 90% CPU usage can be considered an over loaded physical machine. Therefore, it requires migrating a few virtual machines to another cloud server to reduce CPU usage within the defined threshold value. They have also proposed that physical machines with CPU usage below 10% should be considered under utilized cloud server in the cloud data centre. Therefore, its active virtual machines must be shifted to another cloud server, and it must be switched off to reduce power consumption [20].

Mohammad et al. [21] propose a predictive method for consolidating virtual machines using an iterative weighted linear regression method to detect overloaded physical machines. They utilized the iterative weighted linear regression method to predict the physical machine's future CPU utilization based upon historical data and current utilization. Similarly, Suhib et al. [22] proposed a method for predicting overloaded physical machines using the first order Markov chain method. They categorized physical machines into three different states defined based upon CPU utilization. They defined normal utilized physical machines, over utilized physical machines, and under utilized physical machines. They have proposed the use of a state transition probability matrix for predicting the state of the machine in the next time slot. Accordingly, virtual machines are migrated from one physical machine to another.

Dabbagh et al.[23] proposed using the random choice Virtual Machine method for placing them in physical machines. They proposed to select an active physical machine for placing virtual machines randomly. In case there is no available active physical machine, they proposed switching on the new physical machines to accommodate the virtual machine to be migrated.

Farahnakian et al. [24] introduce the concept of best fit Virtual Machine placement. They suggested choosing an active physical machine with the least residual computing resources to accommodate migrated virtual machines.

Speitkamp and Bichler [25] suggested using integer linear programming to optimize cost of physical machine while consolidating Virtual Machines by minimizing active cloud servers of the cloud data centre.

Several researchers focused on evolutionary methods for optimizing the power consumption of physical machines in the cloud data centre. For instance, Kansal and Chana [26] suggested the use of the artificial Bee Colony Optimisation method to achieve reduced power consumption by scheduling cloud jobs execution on the minimum required computing resources. Similarly, the authors of [27] used a genetic algorithm for placing the virtual machine in the cloud computing environment. They formulated the Virtual Machine placement problem as a multi capacity Bin packing problem. Using a multi capacity Bin packing problem, they identified optimal allocation of virtual machines to physical machines. They used cross over operators to produce optimal solutions for Virtual Machine placement problem that contain a sorted list of physical machines as per their computing resources usage.

Wu et al. [28] proposed a Virtual Machine placement method using the simulated annealing technique. They used the simulated annealing technique for determining better solutions as simulated annealing configurations. They used two criteria for finding a new configuration of possible and reduced power consumption.

Wen et al. [29] suggested a metaheuristic approach for Virtual Machine migration. They used ant Colony Optimization algorithm for obtaining optimal solutions of virtual machine migration to Physical machines. They used computing resource usage and traversal methods of the ant Colony Optimization algorithm to determine the allocation of virtual machines to physical machines. There should be a minimum number of virtual machine migrations.

Cho et al. [30] used a hybrid approach of metaheuristic algorithms. They proposed a hybrid approach of particle Swarm Optimization and ant Colony Optimization algorithms to find the optimal schedule of virtual machines according to their work load based upon computing resource requirements and rejected unfulfilled requirements.

Several metaheuristic methods have also been proposed to solve the Virtual Machine placement problem. For example, Abdessamia et al. [31] applied the Particle Swarm Optimization method for placing virtual machines in cloud computing by reducing power consumption. They defined a correspondence between physical machine and virtual machine as a matrix representing the number of rows and columns in terms of the number of virtual machines and the number of physical machines. They represented particles and their velocities and initialized them randomly. They evaluated their proposed solution as per Virtual Machine placement conditions. They used the fitness function to determine optimal global and local solutions to minimize power consumption. In executing their proposed model, they proposed that their particle will update their position as per their velocity. If they find bit in velocity matrix 1, they revise the particle Matrix accordingly. Fitness function helps find updates of particles and their positions as a local position. Global Solutions are updated during each iteration to find the best Global optimal solution for the Virtual Machine placement problem.

3. Performance evaluation models and metrics

This section explains the model for evaluating the proposed virtual machine selection and Virtual Machine placement method in cloud computing and performance metrics used to measure these methods' performance.

3.1 Power Model

The proposed virtual machine selection method and Virtual Machine placement method have been designed based upon CPU utilisation of machine in cloud data centre. We consider that power consumption of physical machine is directly associated with CPU utilisation [4, 12, 14]. The power consumption of a physical machine is computed as per equation 1. It is assumed that idle cloud server can eat up to 70% of power than that of 100% utilised physical machines.

$$PC(UC) = 0.7 * PC_{full} + 0.3 * PC_{full} * UC \quad (1)$$

Where PC_{full} denotes the maximum power consumed by a physical machine when if *CPU* is fully utilised. *UC* indicates the current utilisation of the *CPU* of a physical machine. *CPU* utilisation of a physical machine changes with the time as per workload of the cloud users. Therefore Total energy consumption of a physical machine over a time can be computed using equation 2.

$$EU = \int PC(UC(t))dt \quad (2)$$

3.1 Live Migration Cost

Live migration of virtual machines in a cloud computing environment enables shifting of virtual machines among physical machines without suspending its execution with short downtime [33]. Live migration of virtual machines negatively affects applications running on virtual machines during the migration process. Many researchers experimentally proved the negative impact while migrating virtual machines and formulated expressions for computing the live migration's cost of virtual machines [34]. Live migration of virtual machines can result in service level agreement violations. Therefore, it is necessary to minimize the number of live migrations of virtual machines. The total migration time of the virtual machine is computed using equation 3.

$$MTime_i = \frac{M_{util}}{BandW_j} \quad (3)$$

Where $MTime_i$ represents total migration time for ith virtual machine. M_{util} is total memory utilization, and $BandW_j$ is total bandwidth utilization for ith virtual machine.

The performance degradation due to virtual machine live migration can be computed using equation 4.

$$PD_i = 0.1 * \int UC(t)dt \quad (4)$$

Where PD_i represents performance degradation of ith virtual machine over the period of $t0 + MTime_i$.

3.3 Performance Metrics

Several meterics have been proposed for measuring the performance of virtual machine selection and placement policies in cloud computing. The most commonly used metrics are described below.

- Service level agreement violation time par active physical machine metric: it is defined as the percentage of time the given physical machine achieves 100% *CPU* utilisation. It is computed as per equation 5.

$$SLA\_PM = \left(\frac{1}{PMs}\right) * \sum\left(\frac{T_{full}}{T_{active}}\right) \quad (5)$$

Where PMs denotes physical machine numbers. Tfull give cumulative during which physical machine remained 100% utilized. Tacitve give the cumulative time during which the physical machine remained active.

- Overall performance degradation metric: The overall performance degradation due to live Migration of a virtual machine is computed as per equation 6.

$$P_{deg} = \left(\frac{1}{VMs}\right) * \sum\left(\frac{CPU_{mt}}{CPU_{total}}\right) \quad (6)$$

Where P_{deg} computes the performance degradation while migrating virtual machines. VMs gives total number of virtual machines. CPU_{mt} gives degradation in performance during migration of virtual machines. CPU_{total} is total CPU requirement during lifetime of virtual machine.

- Service level agreement violation metric: It is computed as a combined metric consisting of performance degradation and service level agreement violations per active physical machine as per the equation 7.

$$SLAV = SLA_{PM} * P_{deg} \quad (7)$$

- Combined metric of service level agreement violations and energy consumption: Power consumption plays a significant role in determining the efficiency of virtual machine selection methods. However, it has been observed that power may be reduced considerably by ignoring violations of service level agreement. But it is not a good option to minimize power consumption. In order to obtain a tradeoff between violations of service level agreement and power consumption, a metric has been defined as per equation 8 [18].

$$P_{SLV} = PC * SLAV \quad (8)$$

Where *PC* represents total power consumption and SLAV shows service level agreement violations.

4. The proposed system model

In cloud computing, virtualization plays a significant role in enhancing computing resource uses of cloud data centres [35]. It enables the online virtual machine migration among cloud servers as per the needs of cloud users. It allows to resize and consolidate virtual machines to maintain minimum active physical machines. It helps to identify idle physical machines and switch them to power saving mode for reducing power consumption of cloud data centres. However, it has been observed that during the allocation of computing resources, allocation of virtual machines is not considered for reducing power consumption while meeting service level agreement between cloud users and service providers and delivering high performance to cloud users.

In order to deliver high performance and optimal power consumption of cloud data centres, the following concerns must be addressed. Over utilized physical machines can result in degraded performance of virtual machines, hence violating service level agreement. Therefore over utilized physical machines must be detected. Virtual machines running on overloaded physical machines must be shifted to another physical machine. During migration, it may be possible that some virtual machines or not allocate required computing resources during peak workload hours due to abrupt changes in computing resource requirements. It can lead to service level agreement failure between cloud users and Cloud Service providers.

Therefore, it is a need of hours to determine overloaded physical machines, migrate suitable virtual machines to other physical machines, and turn idle physical machines to power saving mode to reduce the cloud data centre's power consumption.

The following sections describe effective Virtual Machine selection and Virtual Machine selection placement methods in cloud computing that help to achieve optimal power consumption of cloud data centre based on physical machine's CPU utilization.

4.1 The proposed power saving CPU utilization based VM selection method (CUVMS)

This section explains the algorithm for the proposed power saving virtual machine selection (CUVMS) method, presented in algorithm 1. It focuses on both virtual machines selection. The proposed power saving Virtual Machine selection placement method enable selection of appropriate virtual machine from overloaded physical machines and places it to appropriate under loaded physical machine for minimizing power consumption of data centre and decreasing Virtual Machine migration while meeting service level agreement between cloud users and service provider.

As depicted in algorithm 1, virtual machine selection is performed based on the current CPU utilization of the physical machine and its resource capacity. PSVMSP method computes current CPU utilization of physical machine as per equation 9.

$$CPU\_util_{pm} = \frac{w_{pm} + \sum CPU\_util_{vms}}{R\_capacity_{pm}} \quad (9)$$

Where CPU_util denotes CPU usage of the cloud server. CPU_util_{vms} is the CPU utilization of all virtual machines on the current physical machine. $R\_capacity$ is the CPU resource capacity of the physical machine.

4.2 The proposed power saving CPU utilization based VM placement method (CUVMP)

This section describes the algorithm for the proposed power saving virtual machine placement (CUVMP) method, presented in algorithm 2. It focuses on virtual machine placement on physical machine. The proposed power saving Virtual Machine placement method enable placing the selected virtual machine on an appropriate under loaded cloud server for minimizing power consumption of data centre and decreasing Virtual

Machine migration while meeting service level agreement between cloud users and service provider.

We propose to ignore under utilized cloud server to place virtual machines to be shifted. The proposed Virtual Machine placement algorithm working involves the addition of over utilized and switch off physical machine Tu To excluded

ALGORITHM 1: THE PROPOSED VM SELECTION METHOD (CUVMS)

```
          Input: PML = Active physical machine list
           VML = Active virtual machines list
           on physical machines
          ThsUp = Upper threshold level for the usage
          of a physical machine
          ThsLow = Lower threshold level for the usage
          of a physical machine
          Output: VMML = list of virtual machines
          requiring migration
Step 1.   Start
Step 2.   Load PML
Step 3.   Load VML
Step 4.   For m in PML do
Step 5.     | PUm ← physical machine m's current usage
Step 6.     | If PUm < ThsUp then
Step 7.     |   | Go to Step 11
Step 8.     | Else
Step 9.     |   | Go to Step 26
Step 10.    | End if
Step 11.    | Sorted_VMLm ← VMLm list in reverse orde
            | r of usage running on physical machine m
Step 12.    | DFm ← current Usage of Sorted_VMLm – ThsUp
Step 13.    | For vm in Sorted_VMLm
Step 14.    |   | RUsage_vm ← current_utilization of VM - DFm
Step 15.    | End for
Step 16.    | For vm in Sorted_VMLm
Step 17.    |   | If ( RUsage_vm ) > = ( RUsage_m) then
Step 18.    |   | XL.append(vm)
Step 19.    | End for
Step 20.    | If XL is empty then
Step 21.    |   | VMML.append ( max( RUsage_vm ) )
Step 22.    | Else
Step 23.    |   | VMML.append( max( XL ( RUsage_vm ) ) )
Step 24.    | End if
Step 25.  End for
Step 26.  For vm in VML
Step 27.    | VMML.append ( vm )
Step 28.  End for
Step 29.  End
```

physical machine for determining underutilized physical machines as presented in algorithm 2. It is followed by the addition of excluded physical machines for finding appropriate physical machines to place virtual machines requiring migration.

We propose determining their corresponding allocation path for each under utilized physical machine that leads to optimizing power consumption in cloud computing. We also considered that existing physical machines may not get overloaded by placing virtual machines.

5. Performance validation

This section explains the experimental setup for demonstrating the applicability of the proposed Virtual Machine selection and placement methods of cloud computing. It also presents and analyses experimental results in terms of migration based metrics, service level agreement based metrics, energy based metrics and computational based metrics in the following subsections.

5.1 Experimental setup

In this work, we conducted experiments in a simulated environment because it is very expensive to conduct repeatable experiments in Real Time systems for demonstrating the performance of the proposed Virtual Machine selection and placement policies [36, 37]. Therefore, we preferred cloudSim simulation software for modelling Cloud Computing environments. CloudSim software is developed at Melbourne University for supporting simulations of cloud computing environment. It enables the demonstration of the proposed virtual machine selection and placement strategies along with other Cloud Computing provisioning policies. CloudSim software provide facilities to simulate virtual computing resources such as cloud data centre, physical machine, virtual machines etc.

This work uses cloudsim software for simulating cloud data centre consisting of 800 physical machines with 400 physical machines having configuration HP ProLiant ML110 G4 servers and 400 machines having configuration HP ProLiant ML110 G5 servers. We simulated 500 virtual machines and divided them into four categories based on their CPU processing power, high cpu medium virtual machine, extra large virtual machine, micro virtual machine, and small virtual machine. All virtual machines are allocated different computing resources capacities that can be changed as per the work load of cloud computing requests.

The proposed Virtual Machine selection and placement methods have been validated based on CPU utilisation traces collected from thousands of virtual machines.

5.2 Results and Analysis

We conducted two experiments in this word to demonstrate the performance of the virtual machine selection method and the Virtual Machine placement method. For virtual machine selection method validation, we computed the proposed approach's performance in terms of metrics defined in Section 3 Along with the performance of the most commonly used Virtual Machine selection method, random strategy, maximum utilisation, minimum migration time and maximum correlation.

For a demonstration of the virtual machine placement method, the performance of the proposed approach is compared with the most commonly used approach Power Aware Best Fit Decreasing (PABFD) [38], in terms of power consumption, service level agreement violation and number of virtual machine migrations.

1) Virtual machine selection CUVMS method based analysis

The following subsection provides experimental result analysis based on different categories of the metrics.

- Analyzing energy based metrics

Figure 1 presents the comparative analysis of the performance of the proposed approach with representative Virtual Machine selection method, random strategy, maximum utilisation, minimum migration time, and maximum correlation methods with respect to power consumption. Result presented in figure 1 validate that the proposed Virtual Machine selection method resulted in minimum cloud data centre's power consumption in comparison to other existing Virtual Machine selection method Under all scenarios of Interquartile Range (IQR), Median Absolute Deviation (MAD), Local Robust Regression (LRR) and Local Regression (LR) [38].

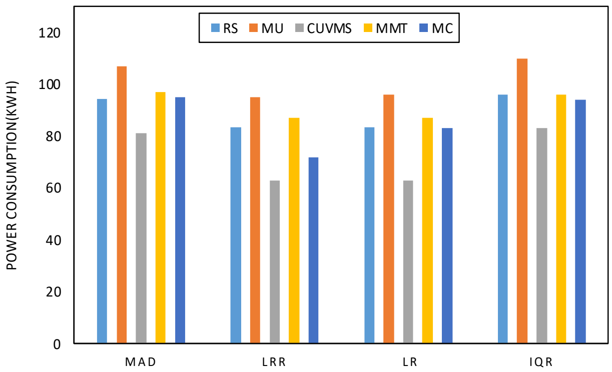

Figure 1. Power consumption based performance analysis for CUVMS method

Table 1 present the percentage change in power consumption over existing Virtual Machine selection methods. It can be observed that the proposed Method can lead to reducing power consumption about 32% over random strategy method under LRR and LR scenarios, 52% over maximum utilisation method under LR scenario, 38% over minimum migration time method under LRR and LR scenarios, and 31% over maximum correlation method under LR scenario.

Table 1. %age change in power consumption using CUVMS method

	RS	MU	MMT	MC
MAD	-16.54%	-32.1%	-19.75%	-17.28%
LRR	-32.22%	-50.79%	-38.1%	-14.29%
LR	-32.54%	-52.38%	-38.1%	-31.75%
IQR	-15.78%	-32.53%	-15.66%	-13.25%

- Analyzing SLA based metrics

Figure 2 presents the proposed approach's performance analysis with existing Virtual Machine selection methods in terms of service level agreement violation metric. It can be concluded from figure 2 that the proposed Virtual Machine selection method has resulted reduce service level agreement violation in comparison to other existing methods under different scenarios.

Table 2 shows the percentage change in service level agreement violation due to the proposed Virtual Machine selection method compared to the existing method. It can be e observed from table 2 that the proposed Method can lead to

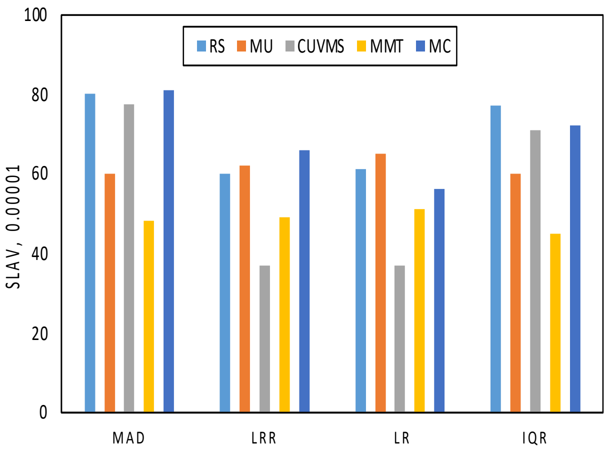

Figure 2. Service level agreement violation based performance analysis for CUVMS method

production in from table 2 that the proposed Method can lead to production in service level agreement violations up to 32% over random strategy method under LRR and LR scenarios, 52% over maximum utilisation method under LR scenario, 38% over minimum migration time method under LRR and LR scenarios, and 31% over maximum correlation method under LR scenario.

Table 2. %age change in SLA violation using CUVMS method

	RS	MU	MMT	MC
MAD	-3.23%	22.58%	38.06%	-4.52%
LRR	-62.16%	-67.57%	-32.43%	-78.38%
LR	-64.86%	-75.68%	-37.84%	-51.35%
IQR	-8.45%	15.49%	36.62%	-1.41%

- Analyzing migration-based metrics

Figure 3 depicts the performance analysis of the proposed Virtual Machine selection method in terms of the number of virtual machine migrations and compare it with existing methods, namely,

methods, namely, Random strategy, maximum utilisation, minimum migration time and maximum correlation method.

It can be seen from figure 3 that the proposed approach leads to the minimum number of virtual machine migration than other existing methods under different scenarios of Interquartile Range (IQR), Median Absolute Deviation (MAD), Local Robust Regression (LRR) and Local Regression (LR) [38].

Figure 3. virtual machine migration based performance analysis for CUVMS method

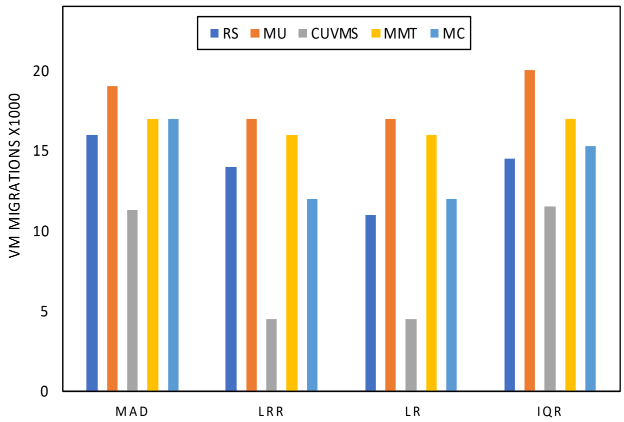

Table 3 presents the percentage change in the number of virtual machine migrations using the purpose Virtual Machine selection method over existing methods in different scenarios. It can be observed from table 3 that the proposed method has resulted in a significant change in the number of virtual machine migrations. The proposed approach has produced approximately 211% fewer virtual machine migrations over the random strategy method under the LRR scenario. Similarly, it has also reduced the number of migrations up to 277% over the maximum utilisation method under LRR and LR scenarios, 255% over the minimum migration time method under LRR

Table 3. %age change in virtual machine migration using CUVMS method

	RS	MU	MMT	MC
MAD	-41.59%	-68.14%	-50.44%	-50.44%
LRR	-211.11%	-277.78%	-255.56%	-166.67%
LR	-144.44%	-277.78%	-255.56%	-166.67%
IQR	-26.09%	-73.91%	-47.83%	-33.04%

and LR scenarios, and 166% over the maximum correlation method under LRR and LR scenarios.

2) Virtual machine placement CUVMP method based analysis

The following subsection provides experimental result analysis based on different categories of the metrics.

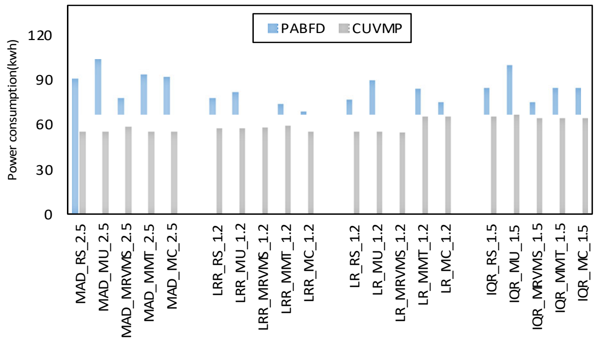

Figure 4. power consumption based performance analysis for CUVMP method

Figure 4 present power consumption of the proposed Virtual Machine placement method in comparison to the most commonly used PABFD [38] method. It can be observed that the proposed CUVMP method has resulted in a considerable reduction in power consumption over the existing method.

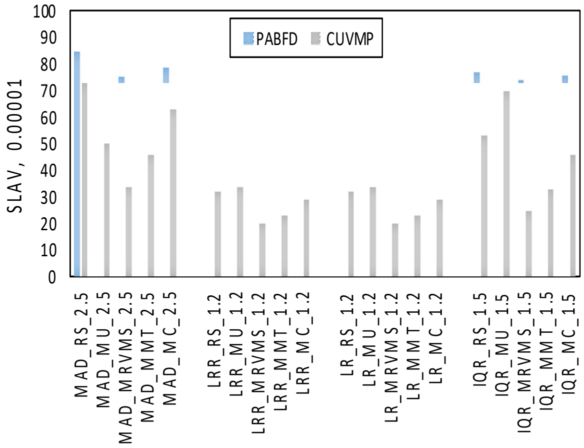

Figure 5. service level agreement violation based performance analysis for CUVMP method

Figure 5 shows service level agreement violations due to the proposed Virtual Machine placement method in comparison to the existing method. It can be observed that there is a significant increase in the number of service level agreement violations because of the proposed method.

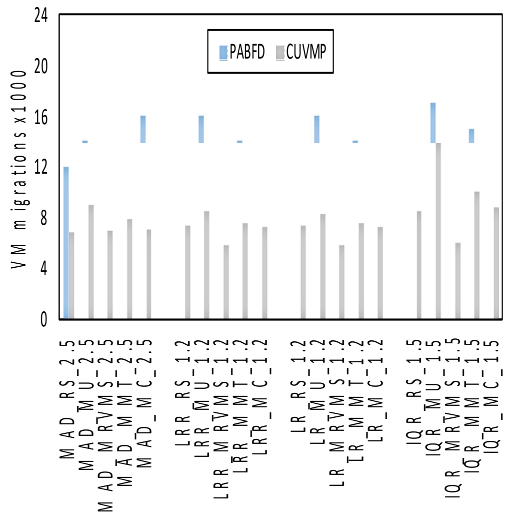

Figure 6. virtual machine migration based performance analysis for CUVMP method

Figure 6 demonstrate the number of virtual machine migration caused due to the proposed Virtual Machine placement method. It also compares number of virtual machine migration with the existing method. It can be concluded from figure 6 that the proposed method has significantly reduced virtual machine migrations compared to the existing method.

6. conclusion

A recently massive increase in the use of cloud computing resources by cloud users in different disciplines increased the power consumption of data centres tremendously. Increase in power consumption of data centres have also contributed in increasing carbon footprints and global warming to some extent. Therefore, it becomes necessary to decrease data centres' power consumption by developing efficient cloud provisioning policies.

Virtual Machine consolidation is one of the most effective techniques for decreasing the power consumption of cloud data centres. It involves determining under loaded and over loaded cloud servers, selecting suitable vacuum machines from over utilised physical machines and placing them to appropriate physical machines so that aggregate power consumption of data centre get decreased.

To that end, this work proposes an effective virtual machine selection method and Virtual Machine placement method. The methods have been proposed based upon the current utilisation of physical machine leading to a reduction in power consumption, the number of virtual machine violations and the number of virtual machine migration significantly over existing methods, random strategy, maximum utilisation, minimum migration time and maximum correlation under different scenarios.

The proposed methods have been validated in a simulated environment using cloudSim software. Real time workload traces have been collected to demonstrate the performance of proposed Virtual Machine selection and placement methods.

Experimental results demonstrate better performance of the proposed methods over the identified and existing methods. CUVMS method results indicate a decrease in power consumption upto 32% over random strategy method under LRR and LR scenarios, 52% over maximum utilisation method under LR scenario, 38% over minimum migration time method under LRR and LR scenarios, and 31% over maximum correlation method under LR scenario. CUVMS method led to a reduction in service level agreement violations up to 32% over random strategy method under LRR and LR scenarios, 52% over maximum utilisation method under LR scenario, 38% over minimum migration time method under LRR and LR scenarios, and 31% over maximum correlation method under LR scenario. It also resulted in 211% fewer virtual machine migrations over the random strategy method under the LRR scenario. Similarly, it has also reduced number of migrations up to 277% over the maximum utilisation method under LRR and LR scenarios, 255% over the minimum migration time method under LRR and LR scenarios, and 166% over the maximum correlation method under LRR and LR scenarios.

The proposed Virtual Machine placement method has also significantly improved over the PABFD [38] method in terms of power consumption, the number of service level agreement violations, and the number of virtual machine migrations.

The experimental results validate the proposed approaches, CUVMS and CUVMP applicable for effective reduction in cloud data center's power consumption.

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