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A Self-Adaptive Resource Provisioning Approach using Fuzzy Logic for Cloud-Based Applications

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Abstract: The resource adaptation on demand is an important factor in the field of cloud computing. During runtime, autonomic resource provisioning is not an easy task to choose the accurate amount of resources for service-based cloud applications. For this reason, it is required to guess the future demands for self-adaptive resources to deal with the irregular requests based on runtime workload changes of service-based cloud applications. In this paper, an efficient approach to increase the utilization of resources is proposed that is based on self-adaptive computing with fuzzy logic. Additionally, the proposed fuzzy logic approach enhanced the performance of planning phase for better decision making. Based on fuzzy logic, cloud applications having self-learning provisioning resources outperformed the hybrid resource provisioning approach. To calculate the quality of the proposed technique, real-world ClarkNet and NASA workload traces are used. The results of experiments show that the proposed technique has decreased the entire cost and has boosted the utilization of resources as compared to the other contemporary techniques.

Keywords: Autonomic computing, Cloud computing, Fuzzy logic, Resource adaptation

1. INTRODUCTION

In the field of information technology, cloud computing has become a source of knowledge that is useful to access the information, media, resources, and services. Cloud computing is a modern style of computation through which users, consumers, and customers can get the benefits of virtualized resource access. To handle the uncertainty and dynamics of resource access, the term "self-adaptively" is used in field of cloud computing. Here, the autonomic system is considered as a system that is able to adjust the performance according to the prediction of the uncertain state and its environment. Nowadays, self-adaptively has become a hot topic for challenging research in the cloud-based applications [1].

Self-adaptive can be explained with the help of its properties including, self-configuring, self-healing, self-optimizing and self-protecting. Self-configuration means installing, integrating and composing of software entities according to the change of uncertain environment. Self-healing is a process of diagnosing, discovering, and responding to interruptions. It also performs some actions to avoid the failure. Self-optimizing can also be considered as self-adjusting or self-tuning, is the ability of resource allocation and manage performance to full-fill the requirements of users. Self-protection enables the system more secure and effective [2].

In cloud computing, self-adaptive resource utilization is not an easy task to select an optimal amount of resources for service cloud. For that purpose, it's necessary to predict the future demands on the basis of past and current utilization of resources. In this context, to guess the future demands is a great achievement. The purpose of resource prediction is to minimize the cost and to maximize the utilization of demanded resources. Zia Ullah et al. [3] introduced a real-time system of resource utilization on the basis of previous demands predictions. For this purpose, researchers followed Gaussian distribution which includes Autoregressive Integrated

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Moving Average (ARIMA) and Autoregressive Neural Network (AR-NN). In the experiment, the reported system was evaluated by real traces of central processing unit utilization in the context of infrastructure as a service cloud.

In the cloud-based applications, business models are designed to facilitate the customers. The demand for Software as a Service (SaaS) is highly encouraged due to the user-friendly environment in cloud computing. In large-scale distributed systems, it's a challenge to manage the distributed servers. Iranpour et al. [4] presented an algorithm to resolve the distributed resource management problem. According to the reported work, the load balancing and admission control was handled in large scales and was scalable to control the tasks by dividing to the proxy and application servers. The advantage of the division is to manage the tasks and resources independently. The main part of the work was to manage the admission process of requests. Self-provisioning type-2 fuzzy controllers are introduced to manage the load balancing and admission control for large-scale distributed systems.

In parallel applications, cloud elasticity can play a significant role to access the designated demands of resources. Time-consuming proactive and threshold-based reactive elasticity approaches are commonly used to achieve the task of cloud elasticity. In this context, the researcher introduced elasticity technique in [5] for cloud-based parallel applications named as Helpar. The reported technique defines an elasticity architecture that applies to the runtime values of upper and lower thresholds. Runtime values are achieved from Live Thresholding (LT) technique to control the elasticity. With the Helpar technique, users can easily run the applications through the lightweight plug and play service at the Platform as a Service (PaaS) level of a cloud.

In public cloud computing, scheduling strategy is used to improve the processing time, response time, and entire cost. In [6] researchers presented that fuzzy logic can progress the scheduling strategy of process and response time for cloud-based applications. During runtime applications of cloud computing, resources are assigned according to the demands. Parallel processing of distributed systems can create workload in cloud computing. To address this problem, researcher introduced an approach to design self-provisioning auto-scalar. The comparison of two reinforcement learning (RL) methods, including Fuzzy Q-Learning and Fuzzy SARSA Learning was performed to reduce the total activation cost and save the service level agreements (SLA) violations [7]. A self-adaptation of resource provisioning is a current challenge to minimize the entire cost and maximize the resource utilization. This problem can be resolved by various methods including reinforcement learning, hybrid approaches, and also with the help of fuzzy logic. In the proposed technique, we extended the planning phase of existing technique [8] to improve the results with the application of fuzzy logic.

Rest of the paper is organized as, introduction of autonomic resource provisioning in cloud computing is presented in section 2. The proposed method is defined in section 3 and experimental results are presented in section 4. At the end, section 4 concludes the discussion.

2. Related Work

In the cloud computing, during autonomic resource provisioning, add and remove of resources is a challenging task due to the fluctuations of workload, cost, and few other quality parameters. Ghobaei-Arani et al. [8] introduced a self- adaptive resource provisioning technique for cloud-based applications. A hybrid approach is introduced with the combination of reinforcement learning and autonomic computing. IBM [9] introduced a reference model named as MAPE (Monitor, Analysis, Plan, and Execute) loop to achieve the autonomic computing. Russel and Norvig [10] designed a general agent model that is relevant to the MAPE control loop. In this model, an intelligent machine identifies the current situation with the help of sensors and utilizes the achieved information for the decision making of execution in the environment. In [8] control MAPE loop technique was applied as a collaboration of the applied approach. In the first part of MAPE loop, all the information related to resources is monitored and in the analysis phase, achieved information is used to guess the resource utilization for future. In the next phase, planning is performed for the reasonable resource adaptation and at the end, execution of selected resources is applied. In the proposed technique, we extended the planning phase according to the future work of [8] to improve the results with the application of fuzzy logic.

In the cloud-based applications, the main focus of research is to improve performance [11], save energy [12] and increase profit [13]. Ramzezani [14] introduced a prediction technique of virtual machine (VM) migration and VM workload using fuzzy based systems. Ramzezani presented a simple model for prediction, not in a detailed way. On other hand, [15] explained a fuzzy prediction technique to control the fluctuation of the workload with the use of type1 and type 2 fuzzy logic based systems. With the use of a fuzzy algorithm, the performance of the prediction technique is better but the accuracy is reduced.

Many machine learning algorithms are used to predict the workload of resources, because of a nonlinear feature of workload. The neural network is widely used as a prediction approach in different areas of service computing [10]. Specifically, to predict the workload, sliding window technique [16], exponential smoothing method [17], and auto regression model [18] are used as predicting methods. The fuzzy neural network is also used to obtain better results of prediction in the case of workload.

The fuzzy control system is widely used for effective resource provisioning in cloud-based applications. In [19], a novel approach was presented on the basis of the neuro-fuzzy controller autonomic resource provisioning method. According to the extended approach, researchers reconfigure the different resources of cloud-based virtual machines to manage the fluctuations of workload. The reported technique was applied on Xen virtualized cloud-based environment and the obtained results show that NFC adaptive resource provisioning performed better than the existing fuzzy logic systems in terms of SLA violations and minimum cost of resource utilization.

In [20] researchers introduced the architectural principles to increase the utilization of resources and decrease the total cost. According to the architectural principles, researchers can improve the operation and development of autonomic cloud-based systems. In the field of services computing, heterogeneous and distributed cloud-based architectures become a cause of uncertainty that is not sufficiently addressed. For this challenge, the declared architectural principles focused on self-adaptive architectural patterns and principles for model-based and control-theoretic architectures.

In the cloud-based systems, the exponential increases in the data centers with a lot of computational nodes exist. Because of this problem, resource scaling method is introduced that is based on the migration technique. Son et al. [21] explained the resource scaling technique on the basis of fuzzy logic systems. The reported technique was used to reduce the energy efficiency effect by a metric. To minimize the resource utilization cost and to increase the profit of cloud-based applications, fuzzy systems perform better roles.

In the cloud-based applications, Ramezani et al. [22] introduced a novel VM workload predication technique with the help of fuzzy logic. According to their problem statement, sometimes historical data cannot help for prediction technique, so fuzzy based workload prediction approach is introduced that observes both current and historical virtual machine utilization and also to predict VMs which have poor performance. This technique can also guess the utilization of actual machine resources for the discovery of virtual resource. In [23], Wei, Y., et al. presented self-provisional rental approach to facilitate the SaaS providers and help to the adjustment decisions for IaaS on the basis of Q-learning.

3. Proposed Technique

The proposed method better explained the utilization of resources and reduces the cost as compared to the hybrid approach. In the hybrid resource allocation technique, reinforcement learning and self-adaptive technique were used simultaneously, and there was a problem about the failure to convince the initial cost of the virtual machine. For the maximum utilization of resources and to reduce the cost, a novel approach is proposed with the use of fuzzy logic. As the fuzzy logic approach is easy to understand and also simple to implement. In the hybrid autonomous resource provisioning technique, control MAPE-K loop is used for autonomic control. In the MAPE-loop, there are four main phases, including, (M) monitor, (A) analysis, (P) planning, and (E) execution. In the proposed model, fuzzy logic is implemented on the planning phase for better decision making to add and remove the resources as shown in Figure 1.

Figure 1 demonstrates the proposed fuzzy logic resource allocation framework on the basis of MAPE loop. The whole structure of proposed technique contains three layers named as SaaS, PaaS, and IaaS layers. The SaaS layer contains cloud services recommended by SaaS providers to the end users. The Platform as a Service layer works for resource allocation to the cloud services provided by the SaaS layer. The responsibility of this layer is to control the resource allocation algorithm on the basis of MAPE loop. The end users send requests for the utilization of cloud services that are provided by a SaaS provider. The IaaS layer contains data centers to the host the virtual machines and it also offers virtual machines to the SaaS providers. Furthermore, it dispatches virtual machines to execute on the provisional resources. To own the cloud application, SaaS provider plays a hosting role for it. SaaS utilizes the entire resources of data centers as well as leases resources to the third party IaaS providers including Amazon. Moreover, there are two kinds of SLA, including resource SLA and user SLA. The resource SLA is the deal with IaaS provider and the SaaS provider and also includes data transfer speed, processing speed, VM type and service time. Similarly, the user SLA is a deal between users, SaaS providers and also includes some basic terms such as request length, budget, penalty rate and deadline. In this work, the main focus is about the fuzzy logic based relations of SaaS provider and users, calculation of SLA violations. The main goal of fuzzy based planner is to maximize the profit. To attain this goal, the main purpose of SaaS providers is to reduce the payment for the use of resources offered by IaaS and also quality of service requirements for the end users.

A. *Proposed Planning Phase*

In this phase, fuzzy logic approach is proposed to obtain the optimal solution. It is also considered as the main component of the proposed model. In the Markov Decision Process (MDP) model there are three states to specify the requirements of resource provisioning including, requirement under-provisioned and over-provisioned. In Figure 2, there is a detailed representation of the fuzzy logic system, in which planner receives historical data from the analyzer and plan it as a cloud workload service *Ci* with every time interval Δt, after that the process of fuzzification is applied and move the control to the dataset/ workload traces. On the next step, fuzzy rule construction is performed and gets better decision making results. The monitor part is used to collect the information belongs to the users and resources. It can also be divided into two parts one for user monitoring and other for resource monitoring. In resource monitoring, there is knowledge about matrices of storage, computation and also network traffic. User monitoring contains the information of workload including (the type of request, request rate, size of the request, pending request, processed request, dropped request) received by users. In the analyzer phase, collected information is processed for analysis that the data is standardized according to the service level agreements. Execution phase is divided into two parts, one of them is VM manager and other is a load balancer. The load balancer is responsible to collect the user's requests and assign them to the proper VM followed by load balancing rules. But VM manager is used to directly execute the actions specified by the planner.

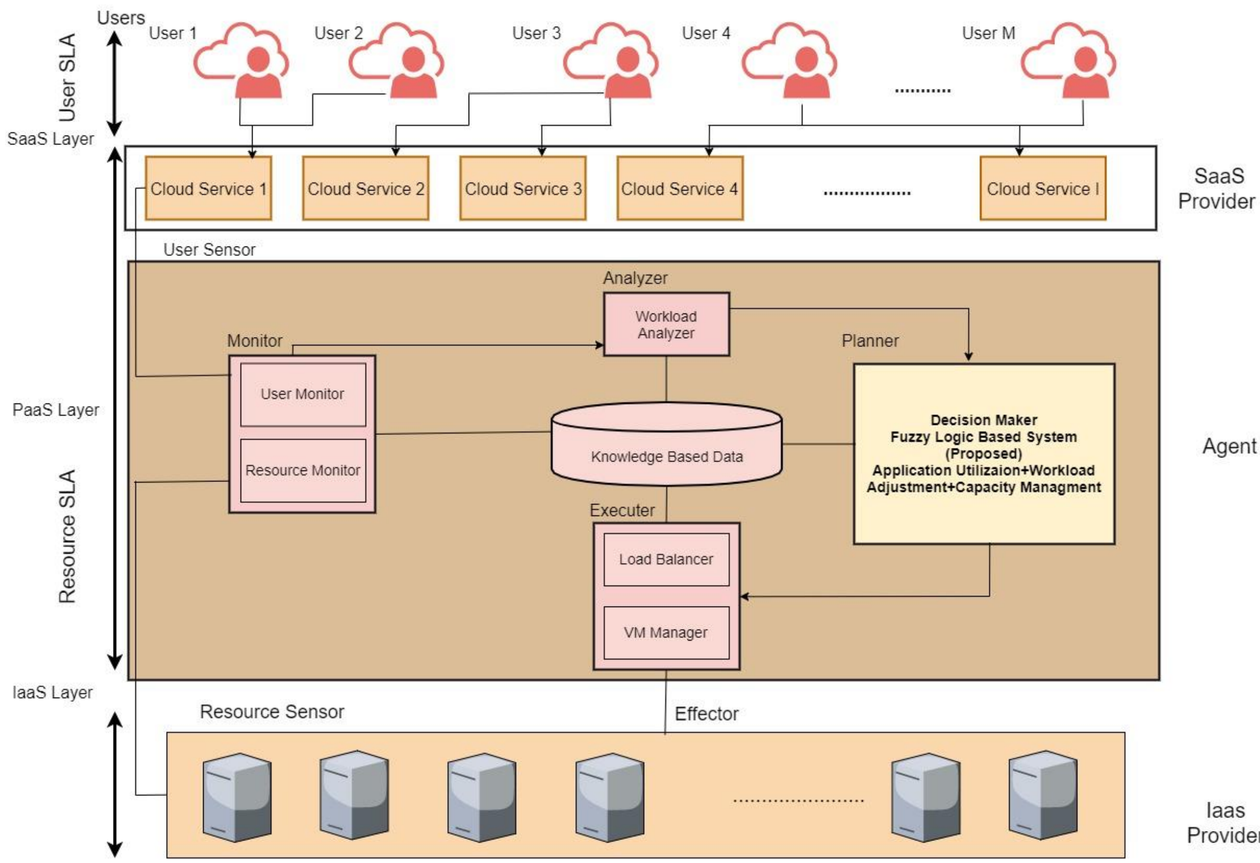

Figure 1. Proposed fuzzy logic resource provisioning framework based on the control MAPE loop

Fuzzy logic-based provisioning technique is a brain of the self-adaptive resource allocator model. It is used to determine the coefficient of the CPU controller, to find out the number of cores. It can be done with the help of fuzzy logic approach. Sensor part is used to collect the information about virtual machines. Information includes the number of threads by the application and its loading status. The obtained values are used into the fuzzy logic planner for efficient decision making.

Ghobaei-Arani et al. [8] introduced the control MAPE loop model for self-adaptive resource allocation. In the section of future work, researchers discussed the fuzzy logic system to extend the planning phase to obtain better results of autonomic resource provisioning. In the proposed method, the extended research work is implemented with the use of fuzzy logic and attained better results from the hybrid approach. The proposed model is shown in the Figure 2 which better explains the fuzzy logic based autonomic resource provisioning approach.

Fuzzy logic based resource provisioning approach is handled with the MAPE control loop. In this portion, the detail about the proposed fuzzy logic based resource provisioning algorithm in the cloud applications is demonstrated. In the cloud-based system, the novel algorithm runs until there will be no running cloud-based services remain in the software as a service provider. Algorithm demonstrates the MAPE loop and supervises the virtual machines that are assigned to every cloud-based service *Ci* in the interval of time Δt. Initially, algorithm boosts itself for the proper number of virtual machines based on the prediction technique (line1).

For each cloud service *Ci*, provided by SaaS-based on fuzzy logic executes in loop, with the time interval Δt (line4). After that MAPE control executes in the specific interval of time for favorable resource allocation regarding the workload of cloud-based services (lines 5 to 10).

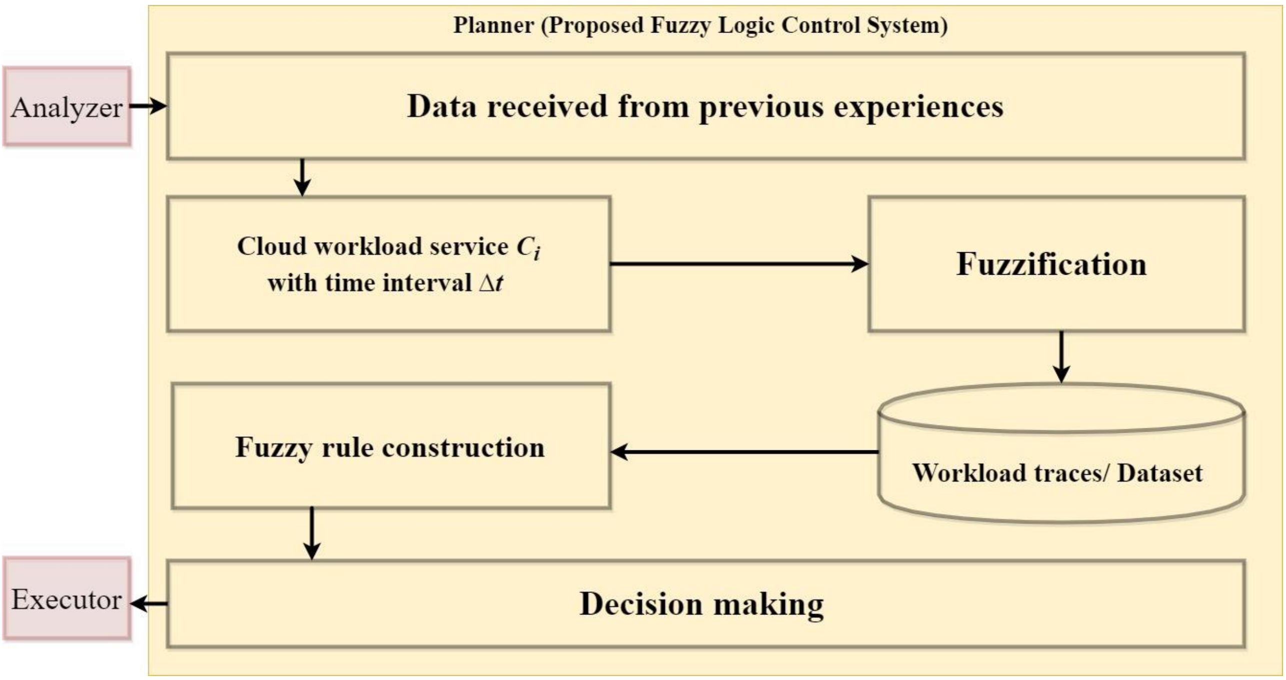

Figure 2. The Proposed Fuzzy Logic Control System

Algorithm 1: Pseudo Code for Fuzzy Logic-based Resource Provisioning Technique

1: Start: Initialize specific number of VMs
2: While (Cloud system is running and at the start of interval Δt *with fuzzy logic) do*
3: begin
4: for (cloud service Ci at the interval Δt *with fuzzy logic) do*
5: begin
6: Monitor
7: Analyzer
*8: Planner/*Fuzzy logic-based decisions making */*
9: Execute
10: End for
11: End while

Algorithm 2: Pseudo code of Fuzzy logic-based for Planning Phase

1: Begin
2: Request for cloud service with prediction value C_i
*3: Initialize: Table of value (s, a) /*S is state and a is action and table have Q-values*/*
*4: while (t<200)/*The internet of time is 200 second*/*
5: begin
6: Calculate the utilization of CPU by fuzzy logic of cloud service C_i *in the time* $t(C_i(t))$
7: if $(C_i(t)>$*upper threshold then current-state=over-utilization*
8: else if $(C_i(t)<$*lower threshold) then current-state=under-utilization*
9: else current-state=normal-utilization
10: end while
11: if (prediction value $(C_i)>f_i(\Delta t)$*) then next-state=over-utilization*
12: else if (prediction value $(C_i)<f_i(\Delta t)$*) then next-state=under-utilization*
13: else next-state=normal-utilization
14: selective action (C_i) *=look up(next-state; fuzzy logic based value)*
15: return selective action (C_i)
16: end

In this section, fuzzy logic-based technique is proposed for better self-adaptive resource provisioning. In this algorithm, the types of resource utilization are defined, includes; under-utilization, normal utilization, and over-utilization. Under-utilization means when the CPU utilization will be less and there will be a lower threshold and when there will be Over-utilization, then the CPU utilization will be greater with an upper threshold and other state is called normal-utilization. According to Algorithm 2, the values table is initialized with (s, a) (line 3). The utilization of CPU with time interval Δt is calculated by the fuzzy logic of cloud service *Ci*. (line 6). Fuzzy logic based resource provisioning is proposed by comparing with the predicted cloud-based service *Ci* after every interval of the time line (11 to 14). Finally, the favorable action for cloud-based service *Ci* is looking up the next value in the predicted table.

The utilization of CPU of cloud-based service *Ci* at the interval of time Δt is presented as the ratio among the machine instruction per second (MIPS) of virtual machines for the calls of cloud-based service *Ci*. According to the fuzzy logic-based approach predicated values are better utilized for resource allocation and de-allocation.

4. Experimental Results and Discussion

The quality of the proposed technique is calculated with the help of real-world traces for metrics based on workload named ClarkNet and NASA. Cloudsim toolkit [24] is a framework that is used for simulating and modeling of cloud computing services and its infrastructure. Table 1 shows the workload of ClarkNet and NASA with the comparison of the hybrid approach and proposed approach. The workload of real-world traces includes utilization, SLA violation in percentage, total cost and profit in dollars, allocated virtual machines in the number of virtual machines as shown in Table 1.

A. Evaluation on the Basis of Metrics

According to the experimental results of Table 1, the data is shown in the graphical representation. Figure 3 shows the differences in CPU utilization and also the total cost of resource utilization between proposed and existing approaches, with ClarkNet workloads traces at every interval. Similarly, in the Figure 4 there is a demonstration of NASA workload traces to compare the difference of CPU utilization and the resource utilization cost regarding proposed and existing approaches.

After observation of both resultant representations, Fuzzy resource allocation planner shows that the CPU utilization is increased than the hybrid approach and the total cost of resources is less than the hybrid approach. Comparatively, the results also show that, the proposed fuzzy logic system is able to maximum CPU utilization and the hybrid approach wastes many resources in both ClarkNet and NASA workloads in most intervals. It happens because of static and conservative allocation of virtual machines by the hybrid approach. On the basis of accuracy prediction, the comparison of cost-aware with fuzzy logic approach outperforms the existing hybrid approach, especially in the case of CPU utilization.

B. Cost of Proposed Technique

In the cloud computing environment, it is important to dynamically resource allocation according to the demands. But, this process is time consuming, depends on the start-up time of VMs, and includes booting of operating system, configuration of operating system and allocation of IP address, which is based on the number of machines, type of machines and location of data centre. In this paper, there is also a goal to decrease the total cost of VMs in terms of time and also machine's initiation cost. For every virtual machine, the initiation cost is based on start-up time of VM and price is based on the type of VM. It can be calculated with equation (1).

$$TotalCost(VM) = Price(TypeVM) \times Time(StartupVM) \quad (1)$$

TABLE I. Comparison of proposed technique and existing hybrid resource provisioning approach

ClarkNet workload	**Proposed Approach**	**Hybrid Approach [8]**
CPU Utilization (%)	98.27	97.21
SLA violation (%)	0.91	0.94
Total cost ($/h)	3.20302	3.62202
Profit ($/h)	76.0324	70.7221
Allocated VMs(#VMs)	17.7321	14.6875
NASA workload	**Proposed Approach**	**Hybrid Approach [8]**
CPU Utilization (%)	95.23	93.91
SLA violation (%)	0.73	0.88
Total cost ($/h)	1.9831	2.4835
Profit ($/h)	59.7521	50.9831
Allocated VMs(#VMs)	13.9318	10.9583

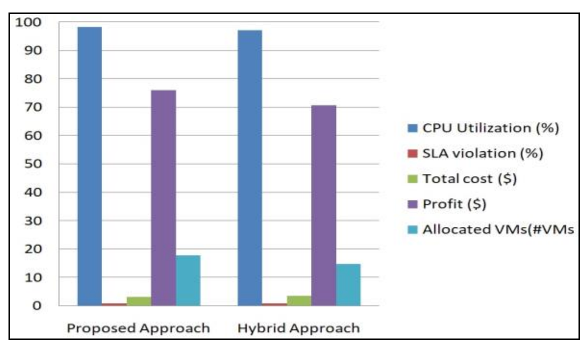

Figure 3. Comparison between resource provisioning and hybrid approach with ClarkNet workload

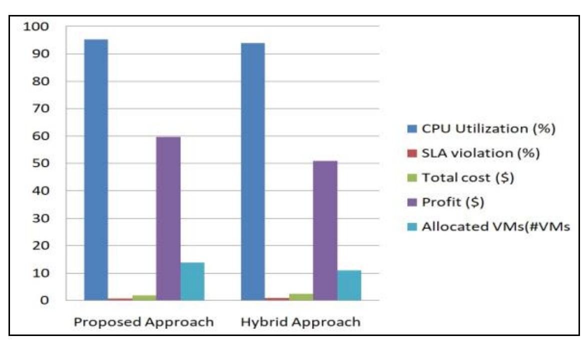

Figure 4. Comparison between resource provisioning and hybrid approach with NASA workload

5. CONCLUSION

In this paper, fuzzy logic-based system is applied for self-adaptive resource provisioning to obtain better performance during the fluctuations and imbalance state of CPU utilization and resources workload. For this challenge, the Fuzzy logic system applied on the planning phase of control MAPE loop and obtained better results from other traditional approaches. For the evaluation of the proposed technique, real-world ClarkNet and NASA workload traces are used with different metrics obtained by cloudsim toolkit. The attained results show that the proposed technique outperforms the existing hybrid approach. In the future work, fuzzy logic system can also be applied on the sensor phase and can perform better decisions in the start of control MAPE loop.

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