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A Novel Study on Virtual Machine Placement Techniques for Cloud Data Centers

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Abstract
Efficient Virtual Machine (VM) placement is a critical challenge in cloud computing environments, influencing resource utilization, energy efficiency, cost, and Quality of Service (QoS). Over the years, numerous approaches have been proposed to optimize VM placement, ranging from heuristic and meta heuristic algorithms to machine learning. In this paper we provide a comprehensive review on various VM placement techniques which mainly focussed on factors such as energy consumption, VM migration, resource utilization and SLA violations.

Keywords: Virtual Machine, Data Centers, Energy Efficiency, VM Consolidation, Cloud Computing, VM placement.

1. Introduction

The effective management of computing resources, energy, and performance is one of the important issues in cloud-based Data Centers (DC). Hence, the cloud computing paradigm is partitioned into two major units, namely front end and backend units that are linked to the network. The frontend part consists of all the essential things that the client should possess for cloud access like browsers and connections. The backend part comprises with all the components of cloud like data storage, servers, and hosts. Typically, cloud provisioning techniques are broadly categorized into three types like Software as a Service (SaaS) [1], Infrastructure as a Service (IaaS) [2], and Platform as a Service (PaaS) [3]. Virtualization allows cloud computing to process and it paves a path to attain good resource usage from cloud environment. A Physical Machine (PM) has ability to provide multiple Operating Systems (OSs) and they process in a secure manner. However, VM is used to share available resources and it also offers a convenient environment to run OS effectively.

While performance affects cloud economics, excessive energy use has an effect on the environment and raises energy expenses. Cloud service providers are focusing on developing innovative methods for energy- and performance-aware computing since physical computer clusters have significant operating costs. The aim may be achieved in two ways: (i) assigning only the resources that are required (ii) Allocating workload to fewer physical machines by leveraging virtual machine migration and shutting down unused computers. However, the ability to migrate virtual machines (VMs) offers a number of benefits, such as increased resource usage, improved management, and energy savings. On the other hand, it results in downtime, which reduces job efficiency. Costly migrations may not even be suitable in dynamic cloud environments, where hundreds of virtual machine requests are received every hour. Effective VM placement techniques are therefore required to save energy and cost while improving QoS and user satisfaction.

In the next section, we will delve into various researches by different researchers on VM placement techniques [8].

2. Literature Survey

As Effective VM placement techniques are necessary to improve energy usage, Sindhu Rashmi et al. [4] developed an efficient VM placement method which is used for its minimization of migrations algorithm to identify the hotspot and categorize the host as normal, over utilized, or underutilized after using the Modified Best Fit Decreasing (MBFD) algorithm to rank VMs according to their resource requirements. A swarm-based technique Dragonfly Algorithm (DA) that detects overloaded hosts and moves VMs from overloaded to underloaded hosts to optimize energy use in Cloud DC comes next. When compared to power usage, SLA violations, and migration costs, the outcomes of the suggested work are better. Dragonfly Algorithm with Modified Best Fit Decreasing (DA-MBFD) has reduced SLA violations, increased the number of migrations, and improved power usage.

Arash Hadadi and Alireza Shameli-Sendi [5] examined one of the most significant studies conducted in the past ten years, with a variety of objectives, which has been the solution of the VM placement problem. These objectives include cutting down on DC energy use, balancing server resources, upholding SLAs, implementing security, and more. Improving user service quality in the event of workload changes is one of the objectives that has gotten less attention. They provide a novel placement strategy that takes service quality into account in this article. The findings demonstrate that user's unexpected workload may be effectively managed by considering the criteria for maximizing the quality of service in dynamic placement. One of the problems with this type of deployment is the high volume of VM migrations. To address this issue, we limited the placement objective function's number of migrations.

Since cloud computing technology is developing so quickly, cloud service providers have focused many emphasis on building massive DC, which can be done using virtualization technology. VM placement is the process of assigning VMs to servers according to user requirements. Because it is an important process for improving power efficiency and resource use in a cloud environment, VM placement is a difficult undertaking. To address these demands, Pushpa R and Dr. M Siddappa [6] used a recently established method called Adaptive-Artificial Bee Cat Swarm Optimization algorithm (ABCSO) to create an efficient plan for the best location of virtual machines in cloud computing. Here, a number of system parameters, including CPU, memory, MIPS, bandwidth, power, and migration cost, will be taken into consideration while placing the virtual machine.

Shilpa B. Kodli and Sujata Terdal [7] proposed an energy efficient load-balancing approach comprising workload submission, central manager (CM), and migration modules for cloud environments. The Self Adaptive BES (SA-BES) optimization algorithm is introduced for VM selection and resource allocation, incorporating a safety constraint with the Pearson Correlation Coefficient (PCC). Global Agent (GA) and correlation-based VM placement are utilized for effective load balancing, demonstrating a comprehensive strategy to improve distributed system performance.

Riman Mandal et al. [8] proposed a novel SLA and energy-aware VM Placement policy for the VM consolidation framework. The Proposed policy works for VM Placement and VM reallocation in a cloud environment. Through the results and performance analysis in section V-A, we have shown our proposed

VM placement policy is an improvement over renowned existing VM placement policies. One of the downsides of our approach could be a high search time because computing the SLA parameter for each PM takes some extra time.

Mohammed Alharthi et al. [9] introduced a MILP model to optimize VM placement and reduce power consumption in a cascaded Arrayed Waveguide Grating Routers (AWGRs). Three goal functions were taken into consideration. The first step is to assign VMs at random. Second, the power consumption of the processing servers hosting VMs should be decreased. Third, the power consumption of the processing servers should be decreased in addition to that of the special server that has an ONU for intercellular communication. Various numbers of VM were used to assess the power consumption under the three objectives. Furthermore, the results demonstrated that, for the evaluated 7, 14, and 21VM, the overall power consumption under the goal of minimizing the power consumption at the processing and networking level was decreased by 16%, 25%, and 6%, respectively, in comparison to the goal of minimizing the power consumption at the processing level only.

Neeraj Kumar Sharma et al. [10] offered a two-phase Branch-and-Price-based VM allocation and Multi-Dimensional Virtual Machine Migration (MDVMM) approach. A Branch-and-Price-based VM allocation mechanism that increases resource utilization and decreases energy consumption is introduced in the first phase. Compared to other cutting-edge methods, the suggested Branch-and-Price based allocation algorithm enhanced average resource usage by 20.7% and decreased power consumption by about 31%. Furthermore, we applied Google cluster load to the DC to evaluate the effectiveness of the suggested MDVMM approach. The cloud DCs SLA violation was prevented and energy usage was decreased using the suggested MDVMM technique.

Through empirical analysis, revealed how different VM placement and consolidation strategies, as well as techniques like aggregation and segregation, will impact the cost, performance, and energy efficiencies of major IaaS providers. According to Muhammad Zakarya [11] findings, combining different workload types on the same servers could result in significant energy savings while maintaining performance. Moreover, more servers can be turned off to conserve energy by combining tasks of comparable duration. However, workloads experience significant performance reduction if they are grouped according to their categories or other characteristics. Additionally, their analysis indicates that segregation-based placement strategies may perform better than aggregation-based strategies if containers—rather than VM—are grouped according to the sorts of workloads they handle rather than run lengths.

It is necessary to use a cloud environment with optimal VM allocation to Physical Machines (PMs) to enhance cloud performance. A consolidation model presented by Shilpa B. Kodli and Sujata Terdal [12] focused on three modules: task submission, Central Machine (CM), and migration. Users submit the jobs in the cloud throughout the workload submission process. Resource allocation and migration were completed in the second phase. The Improved Pearson Correlation Coefficient (IPCC) model was employed to establish a new safety restriction during the VM transfer. Additionally, a novel method called Spider Monkey-Induced Cat Swarm Optimization (SMI-CSO) is used to allocate VM across hosts in the most effective method. Ultimately, the superiority among the suggested technique over the conventional systems was demonstrated regarding several criteria using both random data and PlanetLab datasets. On noticing the outcomes, the metrics such as Service Level Agreement Violation (SLAV), combined metrics Energy and SLA violation (ESV), and Energy, SLA violation and migration (ESM) are less compared to other existing methods ensuring the enhancement of the system performance.

Manoel C. Silva Filho et al. [13] provided a broad analysis of the literature and propose a solution that

uses the Modern Portfolio Theory (MPT) to balance risk and return of VM portfolios for clusters of hosts. Using the Welford online algorithm, it defines a simplified way to compute return/risk for port folios, which, to the best of our knowledge, has not been used for large-scale VM placement scenarios. The proposal combines a distributed architecture, decentralized management, partial neighbourhood view and return/risk balance. The Welford algorithm drastically reduced computational complexity and memory footprint, moving from linear to constant time. Considering 100 k VMs in the scenario, it moves from 40 GB of utilization history to a negligible 14 MB for one year of operation. That makes our proposal suitable for large-scale cloud computing infrastructures.
Sudheer Mangalampalli et al. [14] suggest that since the workload that enters cloud computing is dynamic and changing, an effective virtual machine placement mechanism is required. They developed an effective VM placement method to deal with this dynamic situation. Cuckoo search is utilized as the optimization approach, and maintained a threshold value to determine the physical host state depending on CPU consumption. The Performance metrics such as makespan and SLA have been reduced significantly by proposed method as shown by simulation results on Cloudsim, a platform used for simulation. SLA violations affect the cloud's quality of service, which is significant for both cloud providers and users. Their suggested method is contrasted with the PSO and GA algorithms that are already in use. Based on the outcomes of the simulation, they have determined that their suggested method significantly reduces makespan and SLA Violations.
Offline VM selection is a critical component of developing a VM placement strategy intended for use across wide area network (WAN) links. In order to minimize resource demands on the hosts in question, the main goal of offline virtual machine selection is to carefully pick one or more possible virtual machines for placement. The Twin Fold Moth Flame Algorithm (TF-MFA) model, which is based on three main objectives—maximizing computer time unit (CTU) consumption, guaranteeing system stability, and lowering placement costs—is used to accomplish this task. The TF-MFA model provides a thorough and efficient solution for the strategic deployment of virtual machines (VMs) by addressing these objectives. It is especially well-suited for situations requiring WAN connectivity in cloud computing environments. The efficiency of the model proposed by Umer Nauman et al. [15] was evaluated through computation times, placement costs, and stability evaluation.

Table 1: Reviews on conventional techniques

Author	Algorithm used	Findings	Research Gaps
Sindhu Rashmi et al. [4]	Dragonfly Algorithm (DA)	❖ Energy Efficiency ❖ Service Level Agreement (SLA) Violation Reduction ❖ Migration Optimization	❖ Scalability and Large-Scale Deployment ❖ Dynamic Resource Allocation ❖ Computational Overhead
Arash Hadadi and Alireza Shameli-Sendi [5]	Quality of Service-Aware Virtual Machine Placement Algorithm	❖ Improvement in Service Quality ❖ Reduction in Migrations	❖ Limited Scope on Multi-Tenant Scenarios

			❖ Energy Efficiency Not Directly Addressed
Pushpa R and Dr. M Siddappa [6]	Adaptive-Artificial Bee Cat Swarm Optimization algorithm	❖ Improvements in resource utilization, energy efficiency, and migration cost.	❖ Incorporation of additional optimization algorithms to further enhance performance. ❖ Exploration of hybrid approaches for resource utilization and network load balancing.
S. B. Kodli and S. Terdal [7]	Self-Adaptive Bald Eagle Search (SA-BES) algorithm.	❖ Efficiency in Load Balancing ❖ Resource Optimization ❖ Dynamic VM Migration	❖ Does not address other critical factors like fault tolerance or real-time user demand variability.
Riman Mandal et al. [8]	SLA and Energy-aware Virtual Machine (VM) Placement Algorithm	❖ Reduces the energy consumption of data centers. ❖ Improved SLA Compliance ❖ Reduced Migration Time	❖ High Search Time ❖ Need for Real-world Implementation ❖ Scalability Issues
Mohammed Alharthi et al. [9]	Mixed Integer Linear Programming (MILP) Model	❖ Networking power consumption decreased significantly	❖ The study suggests designing heuristic algorithms that mimic the MILP model for real-time VM placement.
Neeraj Kumar Sharma et al. [10]	Branch-and-Price Algorithm	❖ The proposed algorithms reduced energy consumption by more than 31% and increased average resource utilization by 21.7%	❖ The need for better statistical models or machine learning techniques for predicting PM utilization.

			❖ Current algorithms do not address network device energy consumption in cloud data centers, which remains an open area for future work.
Muhammad Zakarya et al. [11]	VM Placement Algorithm and Consolidation Technique	❖ Energy-aware VM placement and consolidation ❖ Aggregation and segregation policies	❖ Handling resource contention among aggregated VMs
S. B. Kodli and S. Terdal [12]	Spider Monkey-Induced Cat Swarm Optimization (SMI-CSO)	❖ Minimizes SLAV, energy consumption, and the number of VM migrations. ❖ Significant reduction in metrics such as DI, energy utilization, SLAV, and ESM	❖ Hybrid optimization models like SMI-CSO may introduce higher complexity and overhead, which were not fully addressed.
Manoel C. Silva Filho et al. [13]	Modern Portfolio Theory (MPT)	❖ Significantly reduces computational complexity and memory footprint ❖ Reduces idle server time, minimizing energy wastage	❖ Dynamic VM Demand Prediction ❖ Heterogeneous and Multi-Objective Scenarios ❖ Inter-Cluster Coordination ❖ Validation in Real Cloud Environments
Sudheer Mangalampalli et al. [14]	Cuckoo Search Optimization Algorithm (CSOA)	❖ Improved Efficiency and Resource Utilization ❖ Reduced Operational Costs	❖ Scalability ❖ Comparison with Advanced Methods ❖ Dynamic Environment Adaptation ❖ Energy and Cost Trade-offs
Umer Nauman et al. [15]	Twin Fold Moth Flame Algorithm (TF-MFA)	❖ TF-MFA achieves superior performance compared to other algorithms like	❖ While addressing denial of service (DoS) and, emerging threats in

		Artificial Bee Colony (ABC) + Bat Algorithm, Ant Colony Optimization (ACO), Whale Optimization Genetic Algorithm (WOGA), and others.	dynamic cloud environments remain underexplored.

The above table provides an overview of various techniques used for optimizing VM placement in cloud computing. It highlights the findings of each study, such as improvements in energy efficiency, SLA compliance, resource utilization, and migration cost reduction. At the same time, it identifies research gaps, including scalability challenges, computational overhead, lack of real-world validation, and unaddressed dynamic or security issues. Overall, the studies demonstrate significant advancements but also underscore the need for hybrid approaches, better scalability, and practical implementation.

3. Conclusion

The proposed study addresses the critical challenges of energy efficiency and resource optimization in heterogeneous IaaS cloud environments by focusing on virtual machine (VM) placement and consolidation. Moreover, the study highlighted the broader implications of integrating advanced optimization techniques, such as adaptive heuristic algorithms into cloud management strategies. These techniques offer scalable and sustainable solutions for addressing growing demands in modern data centers, supporting the development of greener and more efficient cloud infrastructures. And it also effectively balances the trade-offs between minimizing SLA violations, reducing migration costs, and maintaining operational efficiency.

In future, to enhance the performance of cloud computing, we try to submerge technologies like AI and Machine Learning for dynamic and secure VM placement. We emphasize on addressing the gaps by proposing hybrid optimization algorithms and user-centric metrics for adaptability and reliability.

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