Energy Efficient Virtual Machine Placement Algorithms

Research report submitted for partial fulfillment of the requirements for the degree of

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in

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by

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1 Introduction

Cloud computing has emerged as a transformative force in the realm of information technology, reshaping the way businesses operate and manage their data. Its scalability, flexibility, and cost-efficiency have made it an indispensable asset for organizations of all sizes, enabling them to harness vast computational power and storage capabilities on-demand [1]. However, this technological advancement is not without its challenges, and one pressing concern that looms over the cloud computing landscape is its environmental impact, specifically the significant energy consumption associated with cloud data centers [2].

The world is today focused on obtaining sustainable and green solutions to the problems that we face, Cloud computing is no exception [3]. Green-energy-focused solutions to cloud computing can be a game changer in the cloud industry. Some research is already carried out for this purpose, like proposing new algorithms or optimizing already existing algorithms [4].

This research proposal focuses on improving the power usage efficiency of cloud virtual machines in order to handle the new difficulties in the field of cloud computing [5]. The context of this research problem is addressing the escalating energy consumption challenges while balancing resource allocation and maintaining quality of service, within the rapidly growing field of cloud computing [6]. The significance of this study for computer science engineering is that it may open the door to a deeper understanding of algorithms for placing virtual machines [7].

A key element of cloud computing is virtual machines. On a single physical server, they can run numerous operating systems and applications at once because they are software-based representations of actual computers [8]. The cloud, which powers the current internet, is run by these virtual machines. Any failure or performance blip could cause a significant loss. These virtual computers are power-hungry devices, thus optimizing their power utilization is necessary to improve performance. Algorithms for placing virtual machines can help us solve this problem [9].

This research study explores the various virtual machine placement strategies. It charts the development of algorithms from early attempts to more modern ones, noting their advantages and disadvantages. The goal of this study is to contribute to the creation of reliable and effective virtual machine placement algorithms by analyzing and expanding upon prior studies.

2 Research Problem

The rapid growth of cloud computing, which has altered how companies of all sizes manage and offer their IT services, is what motivated me for the selection of this study subject. Modern businesses cannot function without cloud data centers because they provide scalable and affordable solutions. But from an economic and environmental standpoint, their energy consumption has become a big issue. Due to increased energy costs brought on by outside factors, which have an impact on how businesses operate and might harm modern organizations, this energy consumption issue could become a burden for the company in the future. This worrying issue is a key factor in the choice of this study question.

This project's research goal is the placement optimization of virtual machines (VMs) within cloud data centers to reduce the problems associated with rising energy consumption while preserving or enhancing resource allocation and quality of service (QoS).

3 Research Objectives

This study intends to accomplish the following goals in light of the urgent issues caused by energy consumption in cloud data centers and the possible advantages of improving virtual machine (VM) placement:

- **Evaluate Traditional VM Placement Algorithms**: To assess the performance and energy efficiency of well-established VM placement algorithms, including Next-Fit (NF), First-Fit (FF), and Best-Fit (BF), within cloud data centers.
- **Examine Recent VM Placement Algorithms**: To investigate and analyze the effectiveness of recent advancements in VM placement algorithms, specifically Medium-Fit Power Efficient Decreasing (MFPED) and Power Aware Best Fit Decreasing (PABFD), in optimizing energy consumption and resource allocation.
- **Compare Algorithmic Performance**: To compare the performance of the selected VM placement algorithms in terms of energy consumption reduction, resource utilization improvement, and the ability to maintain or enhance quality of service (QoS).
- **Develop Optimization Metrics**: To design and implement appropriate metrics and benchmarks for evaluating the efficiency and effectiveness of VM placement strategies, ensuring a comprehensive assessment of their impact on cloud data center operations.
- **Simulate VM Placement Scenarios**: To simulate various VM placement scenarios and configurations within a controlled environment, reflecting real-world cloud data center conditions to assess the algorithms' practical applicability.
- **Provide Recommendations**: To generate practical recommendations and guidelines for cloud service providers and data center operators based on the findings, highlighting the most effective VM placement strategies for different use cases and workloads.

- **Contribute to Knowledge**: To contribute to the existing body of knowledge in the field of computer science engineering by advancing our understanding of VM placement techniques and their role in optimizing cloud performance while reducing energy consumption.

- **Support Sustainable Computing**: To align the research with sustainability goals and support efforts to reduce the environmental impact of cloud data centers, offering insights into more eco-friendly computing practices.

4 Research Questions

In an effort to further its core objective of optimizing energy efficiency, resource utilization, and quality of service (QoS) in cloud data centers, this study addresses the following research topics and hypotheses:

1. How do traditional VM placement algorithms (Next-Fit, First-Fit, Best-Fit) impact energy consumption, resource utilization, and quality of service (QoS) within cloud data centers?

2. What is the comparative performance of recent VM placement algorithms (Medium-Fit Power Efficient Decreasing and Power Aware Best Fit Decreasing) concerning energy efficiency, resource allocation, and QoS maintenance when compared to traditional algorithms?

3. How do the selected VM placement algorithms perform when subjected to various simulated scenarios representing real-world cloud data center conditions, including dynamic workload changes and resource constraints?

4. What metrics and benchmarks can be effectively employed to evaluate the efficiency and effectiveness of VM placement algorithms, considering both energy consumption reduction and resource utilization enhancement?

Hypotheses:
The following hypotheses will be tested as part of this research:

1. Hypothesis 1: Traditional VM placement algorithms, such as Next-Fit, First-Fit, and Best-Fit, will exhibit varying degrees of energy efficiency, resource utilization, and QoS maintenance in different cloud data center scenarios.

2. Hypothesis 2: Recent VM placement algorithms, including Medium-Fit Power Efficient Decreasing and Power Aware Best Fit Decreasing, will demonstrate improved energy efficiency and resource allocation capabilities compared to traditional algorithms while maintaining or enhancing QoS in certain conditions.

3. Hypothesis 3: The performance of VM placement algorithms will depend on factors such as workload characteristics, data center configurations, and resource constraints, leading to variable outcomes across different scenarios.

5 Literature Review

The significant consequences for energy economy, resource utilization, and quality of service (QoS) have made the optimization of virtual machine (VM) placement in cloud data centers a hot topic in recent years. This study of the literature will give a succinct summary of the most important findings from pertinent studies and identify any knowledge gaps that need to be filled.

Virtual machine placement can be optimized by using various algorithms and there is still room for improvement. Beloglazov *et al.* signified the importance of optimization of VM placement in reducing energy consumption [10]. Various fields of cloud computing can be improvised, like virtualization, energy consumption, and green infrastructure. A good effort needs to be made to improvise these fields and then also to find green-solutions for cloud computing [11].

Since the world is more green-solutions-based than ever, there is a significant need of power-aware VM allocation in cloud data centers, as it helps us in reducing energy consumption [12]. The virtual machine allocation problem is NP-complete, which means that it is difficult to find the optimal solution efficiently [12]. So much of research is carried out in cloud computing, but very few were focused on considering the priority of resources, new algorithms need to be made for this purpose [13]. Han *et al.*, in his research work, proposed a new VM placement algorithm of Power Aware Best Fit Decreasing algorithm. He implemented the algorithm and this marked a significant improvement in cloud computing sector. [14]. In the search of new techniques, dymanic virtual machine consolidation can be a promising one for reducing energy consumption in cloud data centers. However, we should also look into the Quality of Service constraints while consolidating these algorithms [15].

Knowledge Gaps: While existing research has provided valuable insights into VM placement algorithms, there is a need for comprehensive comparisons between traditional and recent algorithms, considering their performance across various cloud data center scenarios. Real-world simulations that closely mimic cloud data center conditions are an underexplored area. These simulations are essential to evaluate the practical applicability of VM placement algorithms. Another area of knowledge that has to be filled is the creation of defined measurements and standards for judging the effectiveness and efficiency of VM placement algorithms.

6 Methodology

Experimentation and Simulation:

- **Experimental Setup**: A controlled experimental environment will be created to simulate cloud data center scenarios. The experiments will be conducted using a testbed that emulates typical cloud infrastructure, including physical servers, virtual machines, and network configurations.

CPU Utilization	0	10	20	30	40	50	60	70	80	90	100
G4	86	89.4	92.6	96	99.5	102	106	108	112	114	117
G5	93.7	97	101	105	110	116	121	125	129	133	135

Table 1: CPU utilization

- **VM Placement Algorithms**: Various VM placement algorithms, including Next-Fit (NF), First-Fit (FF), Best-Fit (BF), MFPED, and PABFD, will be implemented and integrated into the experimental setup.
- **Dynamic Workload Scenarios**: Simulated workloads with different configurations will be generated to mimic real-world cloud data center conditions. These workloads will include dynamic changes in resource requirements to assess the adaptability of the algorithms.

Analysis and Evaluation:

- **Performance Metrics**: The VM placement algorithms' performance will be tested based on power efficiency, total VM migrations, host shutdowns, SLR, and other parameters.
- **Comparative Analysis**: Comparative analysis will be conducted to evaluate the relative performance of traditional algorithms (NF, FF, BF) against recent algorithms (MFPED and PABFD) under various workload conditions.

7 Proposed Approach

Algorithm 1 The Power-Aware Best Fit Decreasing

Input: hostList,vmList

Output: vmPlacement

```
Sort vmList in the order of decreasing CPU utilization
for each vm in vmList do
    minPower ← ∞
    allocatedHost ← NULL
    for each host in hostList do
        if host has enough resources for vm then
            power ← estimatePower(host, vm)
            if power < minPower then
                allocatedHost ← host
                minPower ← power
            end if
        end if
    end for
    if allocatedHost ≠ NULL then
        add(allocatedHost, vm) to vmPlacement
    end if
end for=0
```

Result: vmPlacement

Figure 1: Pseudocode of PABFD

```
Algorithm 2 The Medium-Fit Power Efficient Decreasing Algorithm
Input: hostList, vmList
Output: vmPlacement
LD ← 0.6
Sort vmList in the order of decreasing CPU utilization
for each vm in vmList do
    minDiff ← ∞
    allocatedHost ← NULL
    for each host in hostList do
        if host is active and has enough resources for vm then
            diff ← |getUtilization(host) − LD|
            if diff < minDiff then
                allocatedHost ← host
                minDiff ← diff
            else
                if diff = minDiff then
                    if PE(host) > PE(allocatedHost) then
                        allocatedHost ← host
                    end if
                end if
            end if
        end if
    end for
    if allocatedHost ≠ NULL then
        add(allocatedHost, vm) to vmPlacement
    end if
end for
Result: vmPlacement =0
```

Figure 2: Pseudocode of MFPED

PABFD and MFPED are my two proposed algorithms. I will implement and test these algorithms along with traditional algorithms to check their performance in power efficiency, VMs migrations and other parameters.

8 Expected Contributions

With regard to cloud computing and energy-efficient infrastructure management in particular, this research aims to significantly advance the field of computer science engineering. This research's predicted contributions and prospective effects can be summed up as follows:

1. By conducting a thorough evaluation of traditional and specialized VM placement algorithms, this research aims to provide in-depth insights into their strengths and weaknesses. This can facilitate algorithmic advancements and refinements, potentially leading to the development of more efficient VM placement strategies.

2. The research findings are expected to contribute to the optimization techniques used in cloud data centers. Through the identification of the optimal VM placement strategy, cloud providers can fine-tune their resource allocation strategies to minimize energy consumption, reduce operational costs, and maintain QoS.
3. The research seeks to quantify the energy savings achievable by implementing the identified optimal VM placement strategy. These findings can play a pivotal role in reducing the environmental footprint of cloud data centers, aligning with global efforts to combat climate change.
4. With insights into energy-efficient VM placement, the research can contribute to making cloud computing more sustainable. This aligns with the growing importance of sustainable technology solutions in today's world.
5. The research aims to demonstrate the potential cost reductions achievable through energy-efficient VM placement. This can have a direct impact on the financial bottom line of businesses relying on cloud services.
6. The research findings will be translated into practical recommendations for cloud service providers and businesses. This guidance will empower them to implement energy-efficient VM placement strategies, harnessing the potential benefits outlined in this research.

The practical insights derived from this research can have a direct and tangible impact on the way cloud resources are managed, making cloud computing more cost-effective and sustainable for organizations of all sizes.

9 Ethical Considerations

A variety of ethical issues must be acknowledged and taken into account when researching the best virtual machine (VM) location in cloud data centers. The appropriate and ethical conduct of research in the field of computer science engineering depends heavily on these factors. Following are the ethical issues that have been noted, along with the associated solutions:

- The use of data in cloud computing research, especially when utilizing real-world data sets or simulating cloud environments, raises concerns about privacy and data security.
- To address this concern, the research will employ anonymization and pseudonymization techniques to protect sensitive data. Any data collected or used in the experiments will be appropriately anonymized, and personal information will be safeguarded.
- It is crucial to ensure that the research is transparent and reproducible, allowing others in the field to validate the findings and build upon them.
- The research will adhere to open and transparent research practices. This includes sharing details of the experimental setup, algorithms used, and data collected. Code implementations and configurations will be made available for review by the research community.

10 Resources and Budget

Access to a variety of resources and, in some cases, funding for special requirements are necessary for doing research in the field of computer science engineering, particularly in the context of cloud computing and energy-efficient infrastructure management. To do the research work on this topic, we require some softwares.

We need access to simulation tools like CloudSim to build and operate the simulated cloud infrastructure. These software programs are frequently free or intended for academic use. To ensure adherence to licensing agreements, we shall either purchase the required licenses or get the program from reliable sources.

11 Timeline

This research project will be carried out over an expected 3-month period with the goal of optimizing virtual machine (VM) deployment in cloud data centers for energy efficiency, cost reduction, and quality of service (QoS) improvement. A general timeline detailing the major research tasks and achievements is provided below:

- Month1: Gather thorough knowledge about the research topic and related works and softwares used. Formulate an abstract for the research topic.
- Month2: Conduct an extensive literature review on VM placement algorithms, cloud computing efficiency, and resource utilization algorithms. Implement these algorithms. Begin running experiments with different configurations, and workloads.
- Month3: Collect data on energy consumption, resource utilization, and QoS parameters. Analyze the collected data using statistical methods and software tools. Identify patterns and algorithmic performance.

12 Results

I have conducted a comprehensive evaluation of virtual machine placement algorithms, comparing modern power-efficient algorithms, namely PABFD and MFPED with traditional algorithms including First-Fit, Next-Fit, and Best-Fit. A detailed comparison is shown through graphs and tables in this section.
The parameters used are the Number of Hosts and the number of VMs. We took the Number of Hosts as 800 and the Number of VMs as 1052.
The below tables are the comparison between power-aware and traditional VM placement algorithms. The comparison is done for IQR MMT, IQR selection policy and MMT allocation policy. From the table, it is clearly evident that power-aware algorithms are efficient than traditional algorithms. MFPED is more power-efficient than PABFD, whereas PABFD takes less number of VM migrations and SLA performance.

Number of Hosts	800
Number of VMs	1052

Table 2: Parameters used

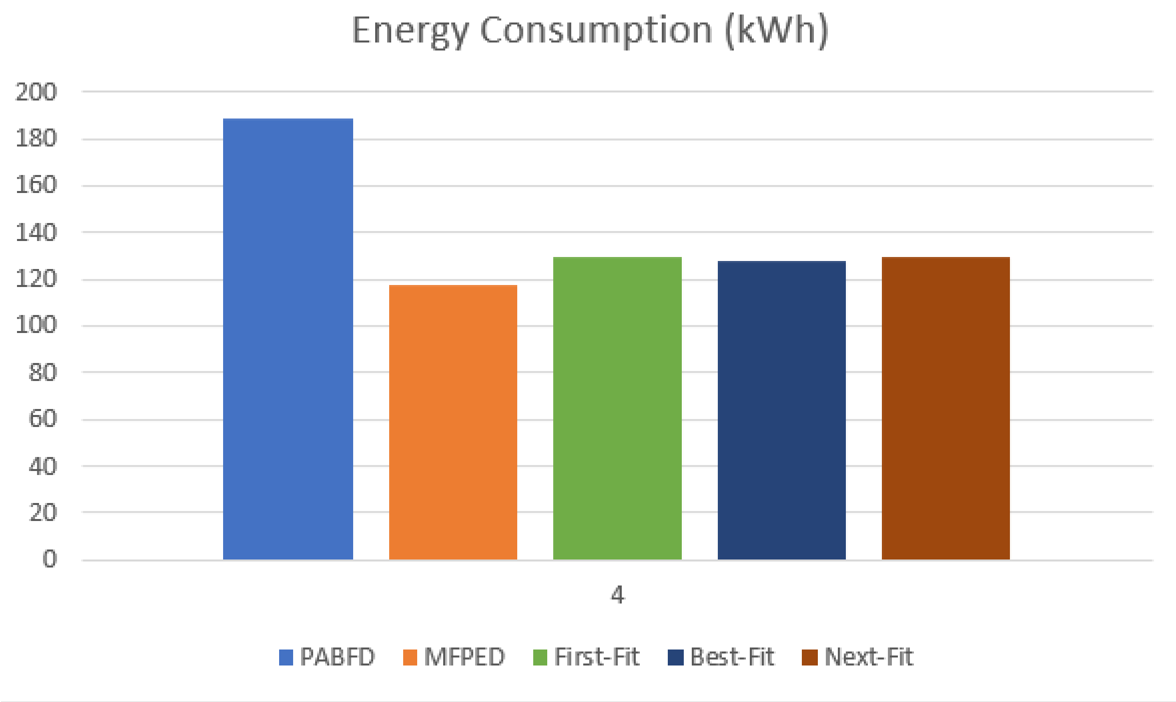

Figure 3: Energy Consumption Comparison

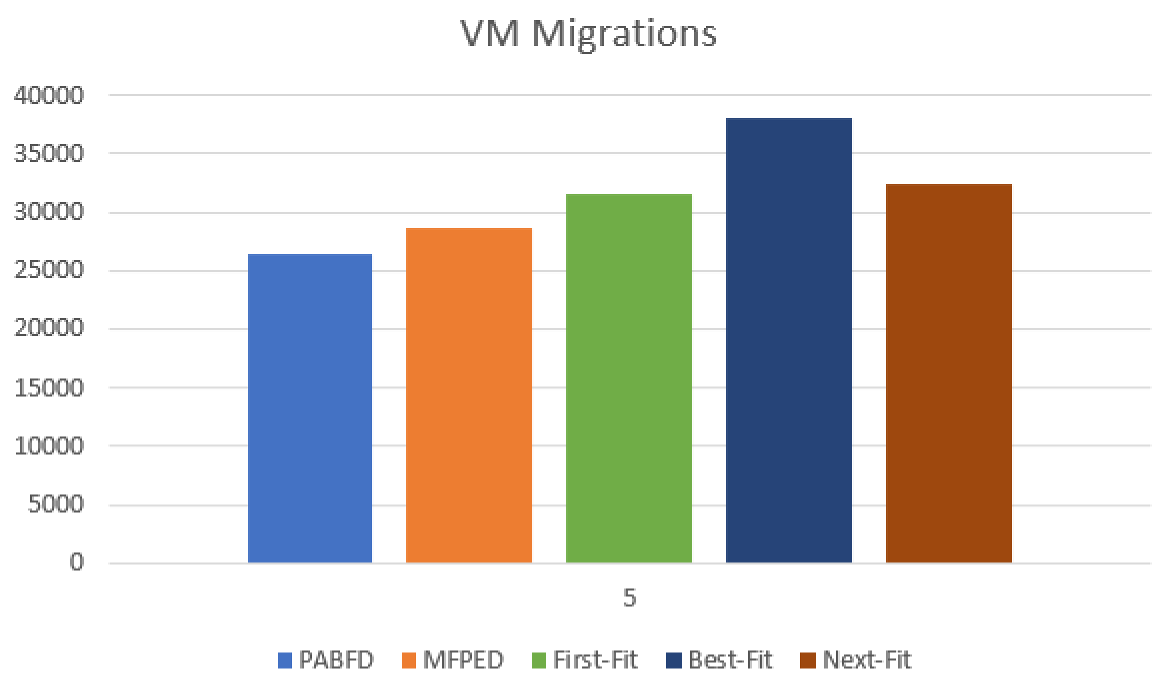

Figure 4: Total Number of VM Migrations Comparison

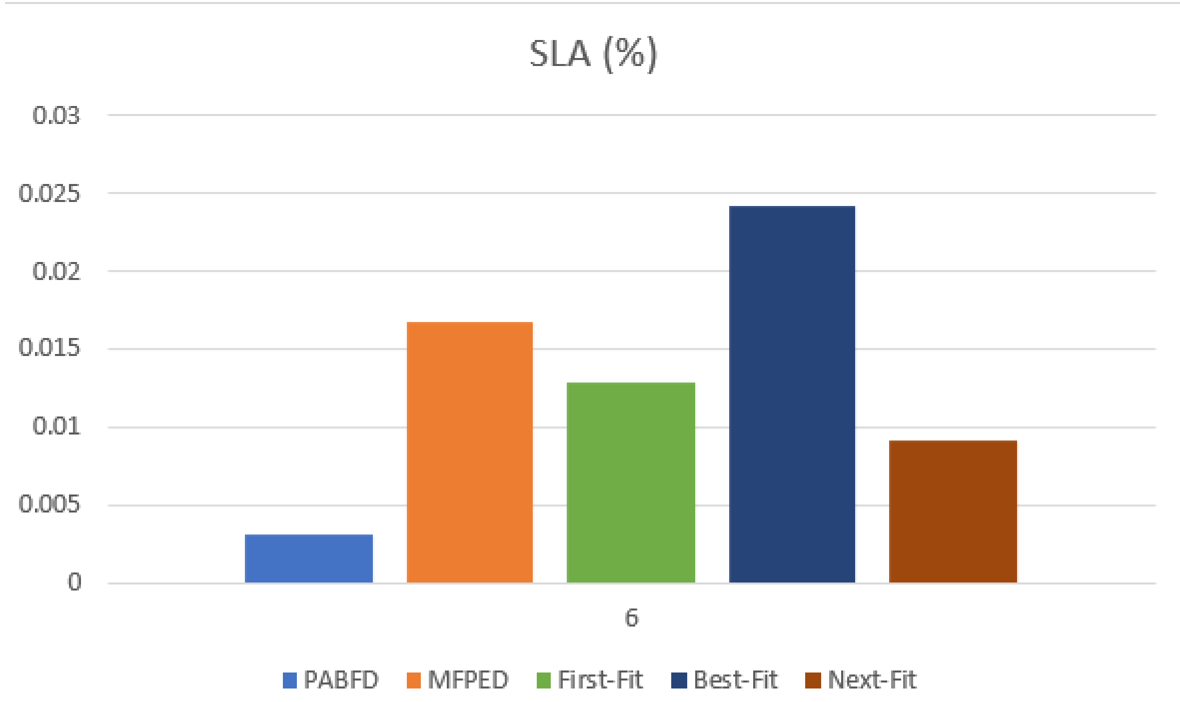

Figure 5: SLA Comparison

Algorithm	Energy Consumption (kWh)	VM Migrations	SLA (%)	Host Shutdowns
First-Fit	129.74	31566	0.01293	1130
Best-Fit	127.87	38078	0.02423	1006
Next-Fit	129.62	32470	0.00919	1176
PABFD	188.86	26476	0.00315	5827
MFPED	117.33	28690	0.0167	879

Table 3: Comparison of VM placement algorithms

Algorithm	SLA1 (%)	SLA2 (%)	SLA3 (%)	SLA4 (%)
First-Fit	0.11	11.62	0.29	8.89
Best-Fit	0.13	18.04	0.45	8.84
Next-Fit	0.11	8.44	0.22	10.09
PABFD	0.06	4.96	0.07	9.98
MFPED	0.11	15.49	0.36	8.7

Table 4: SLA Comparison of VM placement algorithms

SLA1 = SLA perf degradation due to migration, SLA2 = SLA time per active host, SLA3 = Overall SLA violation, SLA4 = Average SLA violation

13 Conclusion

We have presented a thorough strategy in this study proposal to investigate the placement optimization of virtual machines (VMs) in cloud data centers. The study problem, objectives, methods, ethical issues, anticipated contributions, and resource requirements have all been covered in the proposal.

Reducing energy usage in cloud data centers while preserving or increasing resource allocation and quality of service (QoS) is the central research challenge. The increasing expansion of cloud computing and its effects on the environment make this problem of utmost concern. The literature review highlighted the existing knowledge gaps and areas where this research can contribute, referencing relevant studies in the field of cloud computing and VM placement. Performance evaluation of traditional and modern (PABFD and MFPED) is done and the results are shown. PABFD and MFPED perform better than the traditional VM placement algorithms. This research can be very helpful for businesses and cloud providers to have a look into the comparison of the VM placement algorithms. This research also puts light on the importance of optimizing VM placement for a green future.

In conclusion, this research proposal underscores the significance of optimizing VM placement in cloud data centers to address energy consumption challenges, reduce operational costs, and improve cloud performance. The potential outcomes of this study extend to a more sustainable and efficient cloud computing ecosystem, benefiting businesses, cloud users, and the environment. By systematically evaluating and advancing VM placement strategies, this research project aims to contribute to the evolving field of computer science engineering and shape the future of cloud data center operations.

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