Advancements in Green Cloud Computing: A Review of Energy Optimization Techniques and Green Computing Practices in Data Centers

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Abstract

This article explores the adoption and increasing use of cloud computing, which offers advantages such, as scalable capacity, on-demand resources and the provision of infrastructure, platforms, and software services. The focus of this study is on data centers which are crucial for cloud computing but also consume an amount of energy due to computational requirements and cooling needs. In light of growing concerns about the environment and economy, this article highlights the importance of implementing practices in order to strike a sustainable balance between operational efficiency and environmental responsibility. Specifically, it discusses how virtualization plays a role in promoting green cloud computing by optimizing resource allocation encouraging practices, and reducing energy consumption. As these systems are projected to experience an 11% growth in energy demands it becomes vital to prioritize awareness in cloud computing. The subsequent sections delve into research, on VM consolidation optimizing energy consumption levels, and task scheduling within cloud data centers. Ultimately this article provides an analysis of strategies aimed at encouraging eco-friendly practices in cloud computing.

Keywords

cloud computing; carbon emission; cloud data centers, energy consumption, green cloud, sustainability, virtualization, Cloud Computing, Energy Consumption, Efficiency, VM, Resource allocation, Task scheduling

Introduction

Cloud computing is becoming noticeably recognized by academic and industrial organizations because of the rapidly growing demand and applications of cloud computing. It is a model for computation with several benefits. There are various features including elastic scaling, on-demand resource availability, provision of infrastructure, platform, and software as services. Cloud computing is a concept wholly based on data centers and their functioning. Data centers are centralized facilities equipped with servers, storage systems, and networking infrastructure. The data centers store and process large amounts of data and deliver various cloud services to users worldwide.[1]

With the increase in the consumption of energy occurred due to the tremendous use of computing resources of data centers, there have been several environmental and economic concerns. It is noteworthy that heightened power consumption and amplified usage of cooling devices. After the implementation and functioning of data centers, the second most power-consuming task is the cooling and maintenance of data centers.[2]

Responsible computing practices prioritize environmental conservation through eco-friendly means. These practices entail reducing power consumption while optimizing cooling systems through energy-efficient technology. A crucial point worth highlighting is that data centers and cooling infrastructure represent significant sources of energy consumption. This accentuates the imperative nature of adopting ecologically conscious approaches in computing(i.e. Green computing). It uses devices, methodology, and related resources as its goal is to minimize the energy utilization of computing machines, servers, data centers, networks, and cooling systems.

Virtualization is a core aspect of promoting environmentally-friendly cloud computing practices, known as green cloud computing.[2] It has brought about a significant transformation in the field by improving the efficiency of resource utilization and enabling seamless migration of resources. This technology allows for better allocation of computing power, ultimately contributing to a more sustainable and eco-friendly cloud computing ecosystem. It is estimated that the energy consumption of these systems will continue to grow by 11% annually. [1]

Background and Motivation

The virtual realm is built upon infrastructure and all those stacks of buzzing servers consume amounts of power. Currently, data centers worldwide account for 2% of electricity consumption. If this issue is left unattended energy usage could escalate in line, with the growth of internet usage. Therefore it becomes crucial to optimize data centers' efficiency to the extent. This paper has been centralized on three different categories of techniques. 1. VM consolidation 2. Task scheduling, and 3. optimizing energy consumption levels.

VM consolidation is an approach to improve energy efficiency in cloud computing. It involves combining machines onto fewer physical servers. By reducing the number of servers it greatly decreases the energy usage of underutilized resources. Several algorithms have been suggested for VM consolidation considering factors such, as performance, quality of service (QoS), and power management. Advanced machine learning techniques, like reinforcement learning and deep learning, have also been utilized to forecast resource requirements and facilitate VM migration and consolidation.

Task scheduling plays a role, in green cloud computing as it influences system performance and energy consumption. Its objective is to assign tasks to resources in a way that optimizes goals, such as minimizing energy usage, execution time, or cost. Traditional scheduling algorithms have been enhanced with heuristics, metaheuristics and machine learning techniques to prioritize energy efficiency. More recent approaches involve objective scheduling, which considers aspects like load balancing, energy efficiency, and quality of service (QoS) simultaneously. Evolutionary algorithms such as Genetic Algorithms (GA) Particle Swarm Optimization (PSO) and Ant Colony Optimization (ACO) are gaining popularity, for their ability to find solutions within a vast solution space. [5]

Optimizing energy consumption involves utilizing both software and hardware solutions to reduce power usage while ensuring the performance of cloud services. On the software front, a used technique is voltage and frequency scaling (DVFS) which adjusts energy consumption based on workload. To make scheduling decisions and anticipate server power needs, various power models and machine-learning approaches have been developed. Additionally, containerization solutions, like Docker have emerged to help optimize resource utilization.

Optimization Algorithms and Techniques

I. VM consolidation

The virtual world relies heavily on physical infrastructure, with numerous servers that consume significant energy. As a result, modern data centers account for about 2% of global electricity usage, and the growing demand for internet services could further exacerbate this problem. Therefore, improving data center efficiency is a significant challenge.

The DCMMT Approach

The proposed approach, Dynamic Consolidation with Minimization of Migration Thrashing (DCMMT), targets Virtual Machines (VMs) with high capacity to reduce migration thrashing and the number of migrations, thereby maintaining the Service-Level Agreement (SLA). DCMMT keeps VMs, that are likely to suffer from migration thrashing, in the same physical servers instead of migrating. The approach results in a 28% improvement in migration thrashing metric, a 21% reduction in the number of migrations, and a 19% enhancement in the SLAV metric. [1]

VM Consolidation and Live Migration

Live migration, a significant advantage of virtualization, manages cloud environment resources effectively. It enables seamless and transparent VM migration from one physical server to another. This migration process, known as VM consolidation, consolidates VMs to the minimum physical servers dynamically when user demand changes and VMs need resource reallocation. This method effectively reduces a cloud data center's power consumption by shutting down unused servers.

Challenges of VM Consolidation:

The VM consolidation problem faces several challenges, including its NP-hard nature, which makes obtaining solutions time- and resource-consuming. Moreover, VM consolidation may negatively impact the system's performance due to the potential need for frequent migrations resulting from dynamic workload changes.

VM Distribution and Dynamic Consolidation (DC)

In cloud data centers, VM distribution problem can be mapped to the bin-packing problem, which is NP-hard. Suboptimal solutions are provided using heuristic algorithms like first-fit, next-fit, best-fit, and best-fit decreasing. Dynamic Consolidation (DC) can perform necessary configuration changes in response to current load resource demands by utilizing VM migration. However, DC can lead to a decrease in VM's performance and cause migration thrashing (MT).[1]

The Minimization of Migrations (MM) Policy

To determine which VMs should be migrated, the MM policy is employed. It selects a minimum number of VMs to migrate to lower CPU utilization below the upper utilization threshold, set at 70% in this case.

Problem Formulation of DC

The DC problem aims at minimizing the number of required physical servers, with constraints on VM mapping and resource consumption. The objective function minimizes the number of used servers, while various constraints ensure efficient resource management and prevent overload.

DC Problem Divisions and the DCMMT Approach

The basic DC problem is divided into four parts: overload determination, underload determination, VM migration selection from overloaded servers, and new placement for migrating VMs. This paper focuses on the latter two parts, proposing a novel DCMMT approach, which minimizes MT by identifying VMs with appropriate capacity.

VM Placement Algorithm

The pseudocode for the VM placement algorithm sorts all VMs in decreasing order of their current CPU utilization and all servers in ascending order of their current CPU utilization. VMs are then assigned to servers with sufficient resources. The complexity of the algorithm is proportional to the product of the number of VMs needing migration and the total number of servers.

The dynamic VM consolidation techniques use live migration of virtual machines to optimize resource utilization and minimize energy consumption. However, excessive migration may deteriorate application performance due to runtime overhead. This paper proposes a normalization-based VM consolidation (NVMC) strategy that places virtual machines in an online manner while minimizing energy consumption, SLA violations, and the number of VM migrations. Data center resource usage is characterized by high operational and power consumption costs. Virtualization technology maps multiple virtual machines to a physical machine, reducing operational costs and capital investment. Over-utilization of physical machines can occur during the execution of user applications, and physical servers and cooling systems account for a significant share of power consumption. Hence, an efficient VM consolidation strategy is essential to minimize energy consumption, SLA violations, and the number of VM migrations.

Importance of Live Migration

Dynamic VM consolidation and placement techniques aim to consolidate virtual machines to the minimum possible physical machines through live migration. Excessive live migration may, however, deteriorate performance. The rest of the servers are turned to low-energy sleep or hibernate modes to further optimize resource utilization.

The Proposed Approach

The proposed approach, NVMC, minimizes energy consumption and SLA violations by reducing the number of live VM migrations. It achieves this by identifying under-utilized hosts and migrating their VMs to other hosts. SLA violations, which may occur due to host over-utilization or excessive live migration, are limited by using comparative capacity-based criteria for identifying over-utilized hosts.

The NVMC algorithm takes m hosts (H) and n virtual machines (V) as input. The algorithm computes resource weights through normalization that scales resource parameters for both physical hosts and virtual machines. The algorithm also involves steps for detecting over-utilized hosts and making VM placements. This section also discusses the `isOverUtilized` and `findVmPlacement` algorithms in detail.

The NVMC algorithm proposed in this paper involves several steps for effective VM consolidation.

1. NVMC Algorithm

The algorithm takes m hosts (H) and n virtual machines (V) as inputs, where each host is equipped with q resource parameters (P) utilized by the virtual machines executing user applications. Initially, the algorithm computes resource weights through normalization, scaling resource parameters for both physical hosts and virtual machines. These scaled values are subsequently used in detecting over-utilized hosts.

The process starts with initializing the set of available hosts. Then, for each host, the algorithm determines maximum and minimum values of resource parameters, computes resource weights, and places them in a map R. The weights represent normalized values scaled to exist in the interval [0,1]. The map R is filled with the host as key and the sum of its resource weights as the value. The algorithm then identifies sets of virtual machines executing on over-utilized and under-utilized hosts, represented by Vo and Vu, respectively.

Once over-utilization is determined, the algorithm removes virtual machines from the over-utilized host until the host is no longer over-utilized. Then, the findVMPlacement algorithm is invoked to determine appropriate hosts for the virtual machines in the set Vo. After determining over-utilized hosts, the algorithm identifies under-utilized hosts. All the virtual machines from these hosts are added to the set Vu. The findVMPlacement algorithm is once again invoked to determine the migration map for virtual machines from under-utilized hosts. The algorithm finally merges these maps to generate the final migration map that is returned by the NVMC algorithm.

2. The isOverUtilized Algorithm

This algorithm takes a host h as input and determines whether it is over-utilized, indicating if the virtual machines need to be migrated to other hosts. It initializes maximum and minimum values for each resource requested by the virtual machine. These values are updated iteratively to find values for all virtual machines running on host h. The values for requested resources are then normalized to exist in the interval [0,1]. The difference between the normalized resource weights of the host and its virtual machines, corresponding to a single resource, is computed. If this computed value exceeds a threshold value T, the algorithm returns that the host is over-utilized.

3. The findVmPlacement Algorithm

This algorithm takes as input the set of virtual machines and the set of available hosts to generate a map w. This map contains virtual machines and the hosts on which these virtual machines should be hosted. The virtual machines are initially sorted with respect to their CPU utilization. A host is then allocated to a virtual machine based on this sorting.

The intricacy of the NVMC algorithm, the isOverUtilized algorithm, and the findVmPlacement algorithm collectively aim to minimize energy consumption and SLA violations while reducing the number of live VM migrations.

Evaluation Metrics

The metrics used for evaluation are energy consumption, SLA violations (SLAV), number of VM migrations, Cost Impact Factor (CIF), and Overall Performance Enhancement (OPE). These metrics represent various aspects of VM consolidation, from energy consumption to performance degradation due to migration.

Comparative Study

The performance results of the proposed NVMC algorithm have been compared with the dynamic energy-aware consolidation (EAC) implemented in the CloudSim framework. The strategies used for host overload detection include interquartile range (IQR), Median Absolute Deviation (MAD), and Local Regression Robust (LRR).

[3]

It has been observed that placing machines (VMs) is a task that involves optimizing various resource constraints.

To address this challenge we conceptualize the mappings, between VMs and physical machines (PMs) as a subset of a search space. This concept aligns with the idea of a population within an algorithm. Each member of this population represents a mapping between VMs and PMs during the process of consolidating VMs.

We then introduce a model for optimizing VM placement aiming to find the mapping between VMs and PMs within the given search space. To achieve this we employ an improved algorithm that guarantees globally optimal results specifically identifying the most effective scheme for placing VMs.

Furthermore our approach called EQ VMC incorporates sub algorithms to detect hosts, appropriate VMs and identify under loaded hosts – all crucial elements for successful VM consolidation. We. Compare our approach using the CloudSim toolkit. The experimental results demonstrate that EQ VMC effectively reduces energy consumption and minimizes the risk of host overloading while enhancing quality of service (QoS). This confirms its effectiveness and efficiency, in practice. [4]

II. Task scheduling

The evolving landscape of cloud computing offers significant advantages to businesses in terms of scalability, availability, and efficiency. Its three main service models—Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS)—proffer a broad range of capabilities that cater to diverse needs.

Recent research indicates that processing tasks in cloud environments can be more energy-efficient than conducting the same operations on local systems. A key reason for this is the extraordinary energy efficiency achieved by hyper-scale data centers. Essentially, these cloud data centers are designed and managed to optimize both energy usage and resource utilization. The resources in these centers—computing, storage, and networking—are typically shared amongst numerous users. This multi-tenant model contrasts with traditional standalone servers that are used by a single entity, often leading to underutilization and inefficiency. The aim of this review paper is to explore task scheduling in virtual machines within the broader context of cloud computing.

In this context, it's crucial to delve into the methods that businesses can utilize to enhance energy efficiency and reduce the carbon footprint associated with the design, development, deployment, and operation of software. These optimizations must be achieved while maintaining software quality and adhering to agreed service levels.

Cloud computing has emerged as an indispensable element of IT-based organizations and individual users, providing on-demand computing resources for executing multi-tier applications in the form of virtual machines. The pay-as-you-go model, on-demand network services, enhanced security, rapid elasticity, and remote reliable storage are some of the enticing features that have given cloud computing an edge over traditional IT services.

However, with the upsurge in the demand for cloud computing resources, data centers have had to increase their capacities, leading to a significant surge in energy consumption. This energy consumption, majorly caused by servers, has a direct impact on cost, performance, return on investment, and carbon dioxide emission, necessitating research in the field to minimize energy consumption of cloud data centers.

One efficient way of addressing this challenge is through task scheduling methods. These methods aim to map user-submitted tasks to specific virtual machines with the goal of optimizing the objectives of the cloud data center while maintaining throughput, minimizing energy consumption, and ensuring service level agreement and required quality of service. However, solving the task scheduling problem, particularly considering many tasks and virtual machines, remains an NP-hard problem.

Task Scheduling and Metaheuristic Approaches

To solve such complex problems, heuristic and metaheuristic methods have been developed. While heuristic methods target a specific scheduling problem, metaheuristic methods strive to find near-optimal solutions, which are particularly useful for task scheduling problems.

These methods have been traditionally used in three ways: Single Objective (SO) scheduling, Multi-objective as Single Objective (MOSO) scheduling, and Multi-objective as Multi-objective (MOMO) scheduling. However, SO and MOSO methods often face challenges while dealing with multi-objective problems, especially when a concave-shaped Pareto front is involved. Thus, numerous MOMO-based optimizing methods have been devised, including the non-dominated sorting genetic algorithm (NSGA).

Proposed Metaheuristic Framework: MDVMA

This paper introduces a new metaheuristic framework called MDVMA for dynamic virtual machine allocation with optimized task scheduling in a cloud computing environment. This framework employs NSGA-II, a genetic algorithm for optimizing task scheduling, aiming to minimize energy usage, makespan, and cost simultaneously. This simultaneous optimization provides a trade-off to the cloud service providers as per their requirements.

Task Estimation Module

MDVMA utilizes a task estimation module that employs the most common metrics - energy usage, cost, and makespan as evaluation factors. The module calculates energy usage for each task, with makespan referring to the time for the complete execution of the last task. The aim is to reduce the execution time and meet the deadline of the task.

Task Allocation Module
The task allocation module of the MDVMA framework assigns selected non-inferior schedules for optimized values of evolution factors to virtual machines. The tasks of the selected non-inferior task schedule can be manually chosen by domain experts or automatically based on certain criteria as per the requirement of the cloud service providers.

Performance Evaluation
The performance of the MDVMA framework was compared with existing approaches like the Artificial Bee Colony (ABC) algorithm, Whale Optimization Algorithm (WOA), and Particle Swarm Optimization (PSO) algorithm using two data sets. The first is the HCSP dataset, a benchmark that is based on the Expected Time to Compute (ETC) matrix having m number of tasks and n number of VMs. This dataset takes into account three key properties of the ETC model: machine heterogeneity, task heterogeneity, and consistency. The second dataset used is a synthetic dataset.
Results and Analysis
The experimental results demonstrate a superior performance of the MDVMA approach over the existing methods. The MDVMA framework outperforms existing approaches by reducing energy usage by 35.82 %, 25.88 %, and 16.13 %; makespan by 16.89 %, 10.64 %, and 7.15 %; and cost by 15.60 %, 9.34 %, and 5.85 % over ABC algorithm, WOA algorithm, and PSO algorithm, respectively, using the synthetic data set.

Notably, the MDVMA framework also achieved a significant reduction in energy usage, makespan, and cost for the benchmark data instance 2048×64 of the HCSP data set, further attesting to its efficiency.

[5]

III. optimizing energy consumption levels

With the accelerated expansion of cloud computing services, due to digital transformation and high elasticity, enhancing the electrical energy efficiency of cloud data centers has become paramount. Consequently, there has been a shift towards green computing services, which focus on minimizing power consumption in data centers. This review presents an in-depth exploration of an energy-efficient hybrid (EEH) framework, which combines request scheduling and server consolidation approaches to improve power efficiency in data centers.

Proposed Energy-Efficient Hybrid Framework
The unique feature of the EEH framework is its reliance on both scheduling and consolidation techniques, in contrast to the majority of existing works that depend solely on one approach. It begins by sorting customers' requests based on their time and power needs before initiating the scheduling process. The scheduling algorithm factors in power consumption when making scheduling decisions, thus significantly reducing power consumption.

On the other hand, the consolidation algorithm identifies underloaded servers to be put in sleep or hibernate mode, and overloaded servers, thereby efficiently managing power usage. It also determines the virtual machines to be migrated and the servers that will host the migrated VMs. Finally, the framework includes a migration algorithm for transferring the migrated VMs to new servers.

Existing Techniques in Power-Efficient Task Scheduling
Several existing algorithms have attempted to address the trade-off between time and power consumption needs. For instance, a rack-aware scheduling algorithm has been proposed to minimize service time and power consumption. Kumar and Sharma proposed a scheduling algorithm based on particle swarm optimization to reduce

energy consumption and optimize both time and monetary costs. Another technique proposed the sorting of requests according to the type of workload of VMs, with a main target of minimizing service level agreement violations and energy consumption levels.

Consolidation Algorithm

The consolidation algorithm of the EEH framework has four main tasks: addressing the underloaded and overloaded servers, defining the list of VMs to be migrated from the underloaded and overloaded servers, performing the migration, and issuing sleep orders to freed servers. By shutting down servers, the power consumption is drastically reduced, albeit with the caveat of more time and power required to turn the servers back on. The server monitoring unit plays a crucial role in monitoring server operations and providing updates on their status.

Performance Evaluation

Simulation experiments were conducted to evaluate the performance of the proposed EEH framework. The results were compared with those of other related methods, including the Proactive and Reactive Scheduling (PRS) algorithm, the Enhanced Conscious Task Consolidation (ECTC) technique, the Maximum Utilization (MaxUtil) technique, and the Energy-performance Trade-off Multi-resource Cloud Task Scheduling Algorithm (ETMCTSA).

The PRS was selected due to its focus on reducing power consumption for real-time requests, while ECTC and MaxUtil were chosen because they focus on server consolidation. Finally, ETMCTSA, which centers on scheduling-based power reduction, was included for comparison to demonstrate the effectiveness of the consolidation approach in the EEH framework. [6]

The surge in data communication and data computing due to the advent of advanced technologies such as cloud computing and big data has resulted in a significant increase in energy consumption by data centers worldwide. In light of these developments, this paper presents a review on a recent study that proposes a new method for predicting future energy consumption and carbon emissions of global data centers based on global data center traffic and power usage effectiveness (PUE). This review also discusses the potential benefits of establishing data centers in the high-latitude Pan-Arctic region.

The exponential growth of data centers is driving an increase in global energy consumption. By 2025, data centers are expected to account for 4.5% of the world's total energy consumption, up from 3% in 2017. A recent study, which this paper reviews, has proposed a novel method to predict and analyze future energy consumption and carbon emissions of data centers. This method leverages global data center traffic and power usage effectiveness (PUE), offering insights into the potential benefits of situating data centers in high-latitude areas like the Pan-Arctic region.

Energy Consumption of Data Centers

Data centers' energy consumption can be divided into four major components: IT equipment systems (50%), air conditioning and cooling systems (37%), distribution systems (10%), and auxiliary lighting systems (3%). [7] Of these, the air conditioning and cooling systems are the second largest consumers of energy, prompting increasing interest in the natural energy-saving benefits of the Pan-Arctic region.

Methodology

The study utilized global data center traffic predictions from Cisco's Research Report and employed a polynomial fitting method to project future data center traffic. This traffic was then combined with dynamic global average PUE and high-latitude PUE data obtained via the Romonet simulation model. The study analyzed global data center energy consumption in two scenarios: decentralized and centralized.

The study's predictions suggested that by 2030, global data center energy consumption would reach 1800 TWh in the decentralized scenario. This is more than a quarter of China's total annual electricity consumption in 2017. [7] However, the centralized scenario, involving the establishment of data centers in the Pan-Arctic region, demonstrated significant energy savings and reduced carbon emissions. Specifically, in the centralized scenario, the global data center energy consumption and carbon emissions in 2030 are expected to be reduced by approximately 301 billion kWh and 720 million tons of CO_2, respectively, compared to the decentralized scenario. [7]

Conclusion

The DCMMT approach sets a new precedent in the realm of VM migration thrashing. It distinguishes itself from existing DC solutions by identifying VMs with appropriate capacity and limiting the migration of high-capacity VMs during server overload. Future work could further refine and optimize this approach through extensive real-world testing and simulation.

The experimentation results show that the proposed NVMC approach outperforms other VM consolidation strategies. It significantly optimizes the energy consumption, number of VM migrations, and SLA violations. The NVMC approach is able to achieve 1.61, 10.33 and 6.82 times improvement over other energy-aware strategies with the best performance corresponding to energy consumption, number of VM migrations, and SLA violations, respectively.

The MDVMA framework presents a promising approach for dynamic virtual machine allocation with optimized task scheduling in a cloud computing environment. The experimental results, using both synthetic and real-world datasets, demonstrate its efficacy and superiority over existing approaches. Future research will focus on developing optimal workflow scheduling strategies for virtual machine selection and placement in the cloud computing environment, making the MDVMA framework more comprehensive and robust.

The energy-efficient hybrid framework, which takes into account the time-based power consumption model, was proposed and evaluated. Unlike other techniques, the proposed framework utilizes both scheduling and consolidation approaches. Initial results show a significant reduction in power consumption, with improvements in Power Usage Effectiveness (PUE), data center energy productivity (DCEP), average execution time, throughput, and cost-saving.

The framework's superiority over techniques that depend solely on either approach proves the effectiveness of the hybrid approach. The EEH framework presents a promising direction for providing green computing services in cloud computing environments. Future research is needed to continue developing and refining this hybrid approach for further enhancements in energy efficiency.

The reviewed study offers valuable insights into the future energy consumption of global data centers and suggests potential strategies for mitigating this through the establishment of data centers in the Pan-Arctic region. The significant reduction in energy consumption and carbon emissions in the centralized scenario underscore the potential of this strategy. As such, the reviewed study provides critical support for global energy consumption predictions and the planning of future global data center locations. Moreover, it provides a strong case for the integration of energy and information networks under the Global Energy Interconnection concept.

Citations

1. Virtual Machine Consolidation with Minimization of Migration Thrashing for Cloud Data Centers - Liu, X., Wu, J., Sha, G., & Li, S. (2020). Virtual Machine Consolidation with Minimization of Migration Thrashing for Cloud Data Centers. Mathematical Problems in Engineering, 2020, 1–13. https://doi.org/10.1155/2020/7848232

2. Bharany, S., Sharma, S., Khalaf, O. I., Abdulsahib, G. M., Al Humaimeedy, A. S., Aldhyani, T. H. H., Maashi, M., & Alkahtani, H. (2022). A Systematic Survey on Energy-Efficient Techniques in Sustainable Cloud Computing. Sustainability, 14(10), 6256. https://doi.org/10.3390/su14106256
3. an efficient energy-aware approach for dynamic VM consolidation on cloud platforms - Khan, M.A. An efficient energy-aware approach for dynamic VM consolidation on cloud platforms. Cluster Comput 24, 3293–3310 (2021). https://doi.org/10.1007/s10586-021-03341-0
4. Energy-efficient and quality-aware VM consolidation method - Zhihua Li, Xinrong Yu, Lei Yu, Shujie Guo, Victor Chang, Energy-efficient and quality-aware VM consolidation method, Future Generation Computer Systems, Volume 102, 2020, Pages 789-809, ISSN 0167-739X, https://doi.org/10.1016/j.future.2019.08.004. (https://www.sciencedirect.com/science/article/pii/S0167739X18324713)
5. A Metaheuristic Framework for Dynamic Virtual Machine Allocation With Optimized Task Scheduling in Cloud Data Centers - D. Alsadie, "A Metaheuristic Framework for Dynamic Virtual Machine Allocation With Optimized Task Scheduling in Cloud Data Centers," in IEEE Access, vol. 9, pp. 74218-74233, 2021, doi: 10.1109/ACCESS.2021.3077901.
6. Energy-Efficient Hybrid Framework for Green Cloud Computing - A. Alarifi et al., "Energy-Efficient Hybrid Framework for Green Cloud Computing," in IEEE Access, vol. 8, pp. 115356-115369, 2020, doi: 10.1109/ACCESS.2020.3002184.
7. Energy consumption and emission mitigation prediction based on data center traffic and PUE for global data centers - Yanan Liu, Xiaoxia Wei, Jinyu Xiao, Zhijie Liu, Yang Xu, Yun Tian, Energy consumption and emission mitigation prediction based on data center traffic and PUE for global data centers, Global Energy Interconnection, Volume 3, Issue 3, 2020, Pages 272-282, ISSN 2096-5117, https://doi.org/10.1016/j.gloei.2020.07.008. (https://www.sciencedirect.com/science/article/pii/S2096511720300761)