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A Comprehensive Review of Energy-Efficient Task Scheduling Algorithms in Cloud Computing: The Case of Green Cloud Sched

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Abstract— **Cloud computing has revolutionized modern IT infrastructure by providing scalable, on-demand services; however, its exponential growth has significantly increased energy consumption, leading to environmental and operational concerns. Energy-efficient task scheduling has emerged as a critical solution to mitigate power usage without compromising performance. This paper presents a comprehensive review of state-of-the-art energy-efficient task scheduling algorithms in cloud computing, emphasizing their methodologies, strengths, limitations, and real-world applicability. Special attention is given to GreenCloudSched, a novel scheduling algorithm designed to optimize energy consumption and cloud resource utilization through intelligent task placement and dynamic workload management. The review categorizes scheduling strategies based on heuristic, metaheuristic, and hybrid approaches and evaluates them against key performance metrics such as energy savings, makespan, throughput, and service level agreement (SLA) compliance. By systematically analyzing existing techniques and positioning GreenCloudSched within the broader research landscape, this study offers insights into current trends, research gaps, and future directions for sustainable cloud computing.**

Keywords— **Cloud Computing, Energy-Efficient Scheduling, Task Allocation, GreenCloudSched, Resource Optimization, Heuristic Algorithms, Sustainable Computing, Cloud Infrastructure, Workload Management, Energy-Aware Systems.**

I. INTRODUCTION

In recent years, cloud computing has emerged as a dominant paradigm for delivering computing resources and services over the internet, offering scalability, flexibility, and cost-effectiveness to users and businesses alike. The proliferation of cloud services has led to an exponential growth in demand for computing resources, resulting in a significant increase in energy consumption and carbon emissions by data centers worldwide. As the environmental and economic impacts of traditional data center operations become increasingly apparent, there is a growing imperative to develop energy-efficient solutions to mitigate these challenges.

Task scheduling, a fundamental aspect of cloud computing, plays a pivotal role in optimizing resource utilization and energy efficiency in cloud environments. Task scheduling involves allocating computing resources to tasks or jobs in a manner that maximizes system performance while minimizing energy consumption and operational costs. Energy-efficient task scheduling algorithms aim to achieve this goal by intelligently allocating tasks to available resources based on various criteria, such as workload characteristics, resource availability, and energy consumption profiles.

The design and implementation of energy-efficient task scheduling algorithms present a multifaceted challenge due to the dynamic and heterogeneous nature of cloud environments. Cloud data centers typically consist of a diverse set of resources, including virtual machines (VMs), physical servers, and networking infrastructure, each with its own energy consumption characteristics and performance attributes. Moreover, the workload in cloud environments can vary dynamically over time, making it challenging to devise static scheduling policies that adapt effectively to changing conditions.

The goal of this review is to provide a comprehensive overview of recent advancements in energy-efficient task scheduling algorithms in cloud computing. We aim to survey the state-of-the-art approaches, analyze their strengths and weaknesses, and identify emerging trends and future research directions in this domain. By synthesizing existing literature and insights from experts in the field, we seek to contribute to a deeper understanding of the challenges and opportunities in energy-efficient task scheduling in cloud computing.

The remainder of this paper is organized as follows: Section 2 provides an overview of the key concepts and challenges in cloud computing and energy-efficient task scheduling. Section 3 presents a comprehensive review of existing literature on energy-efficient task scheduling algorithms, categorizing them based on their underlying techniques and approaches. In Section 4, we analyze the strengths and weaknesses of the reviewed algorithms and discuss their applicability in different cloud computing scenarios. Section 5 highlights emerging trends and future research directions in energy-efficient task scheduling, while Section 6 concludes the paper with a summary of key findings and insights.

Overall, this review aims to serve as a valuable resource for researchers, practitioners, and policymakers interested in energy-efficient computing and sustainable cloud infrastructure. By examining the current landscape of energy-efficient task scheduling algorithms and identifying areas for future exploration, we hope to contribute to the development of innovative solutions that optimize resource utilization, reduce energy consumption, and mitigate the environmental impact of cloud computing operations.

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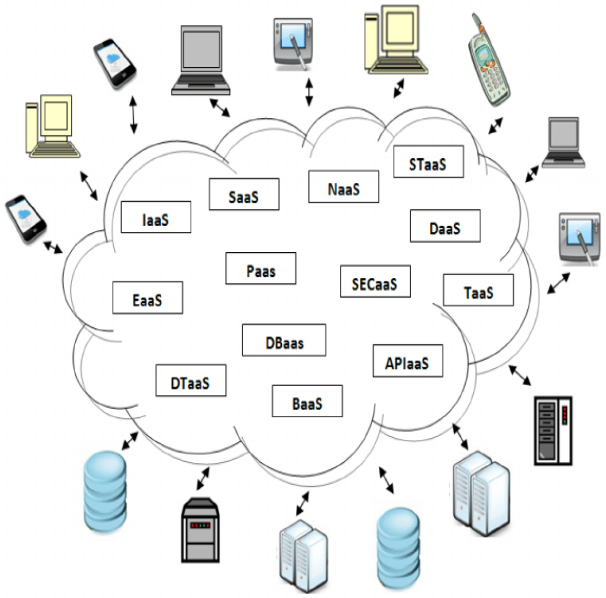

Figure 1. Cloud Computing Diagram

II. LITERATURE SURVEY

Cloud computing has revolutionized the way computing resources are provisioned, offering unparalleled scalability, flexibility, and cost-efficiency to users and businesses. However, the rapid growth of cloud services has led to an unprecedented increase in energy consumption by data centers, raising concerns about environmental sustainability and operational costs. Task scheduling, as a fundamental aspect of cloud computing, plays a crucial role in optimizing resource utilization and energy efficiency. In this literature review, we survey existing research on energy-efficient task scheduling algorithms in cloud computing, examining various approaches, techniques, and challenges in this domain.

Traditional Scheduling Algorithms: Traditional task scheduling algorithms, such as First-Come-First-Serve (FCFS), Round Robin, and Shortest Job First (SJF), are commonly used in cloud environments. While these algorithms are simple to implement and understand, they do not consider energy consumption as a primary optimization criterion. FCFS schedules tasks in the order they arrive, without regard to resource availability or energy efficiency. Round Robin allocates resources to tasks in a cyclic fashion, which may lead to inefficient resource utilization and increased energy consumption. SJF prioritizes shorter tasks over longer ones, aiming to minimize average response time but overlooking energy efficiency considerations.

Heuristic-Based Approaches: Heuristic-based approaches leverage domain-specific knowledge and heuristics to devise energy-efficient task scheduling strategies. These algorithms aim to strike a balance between system performance and energy consumption by considering factors such as task characteristics, resource availability, and workload dynamics. For example, the Min-Min algorithm minimizes the makespan by selecting the task with the minimum execution time and assigning it to the resource with the earliest completion time. Similarly, the Max-Min algorithm prioritizes tasks with the maximum execution time, aiming to achieve load balancing and resource utilization optimization.

Genetic Algorithms: Genetic algorithms (GAs) are evolutionary optimization techniques inspired by the process of natural selection. In the context of task scheduling, GAs are used to evolve solutions that optimize energy consumption and performance metrics. These algorithms employ a population-based approach, where potential solutions (chromosomes) representing task schedules are subjected to selection, crossover, and mutation operations to produce offspring with improved fitness. Researchers have proposed various genetic-based approaches for energy-efficient task scheduling in cloud computing, such as the Genetic Load Balancing Algorithm and Genetic Scheduling Algorithm. These algorithms explore the solution space iteratively to find near-optimal task schedules that minimize energy consumption while meeting performance requirements.

Machine Learning-Based Techniques: Machine learning (ML) techniques have gained prominence in recent years for their ability to learn patterns and make predictions from data. In the context of energy-efficient task scheduling, ML algorithms can analyze historical workload data, resource utilization patterns, and environmental factors to make informed scheduling decisions. For instance, supervised learning algorithms such as support vector machines (SVM) and neural networks can be trained on labeled datasets to predict task execution times and resource requirements, enabling more efficient resource allocation and scheduling. Reinforcement learning techniques, such as Q-learning and deep reinforcement learning, have also been explored for dynamic task scheduling in cloud environments, where agents learn optimal scheduling policies through trial and error.

Hybrid Approaches: Hybrid approaches combine multiple techniques, such as heuristic algorithms, genetic algorithms, and machine learning, to leverage their respective strengths and mitigate their limitations. These approaches aim to achieve synergy by integrating complementary optimization strategies, thereby improving the overall effectiveness of task scheduling in cloud computing. For example, a hybrid algorithm may use heuristics to generate initial solutions, which are then refined using genetic algorithms or machine learning models to optimize energy consumption and performance metrics further. By combining different optimization paradigms, hybrid approaches offer promising avenues for addressing the complex challenges of energy-efficient task scheduling in dynamic cloud environments.

Challenges and Future Directions: Despite significant progress in energy-efficient task scheduling research, several challenges remain to be addressed. The dynamic nature of cloud environments, fluctuating workload patterns, and the heterogeneity of resources pose ongoing challenges for designing robust and adaptive scheduling algorithms. Moreover, the scalability and efficiency of scheduling algorithms must be carefully evaluated to ensure practical feasibility in large-scale cloud deployments. Future research directions in this domain include the development of adaptive scheduling techniques that can dynamically adjust to changing workload conditions, the integration of renewable energy sources into scheduling decisions to promote sustainability, and

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the exploration of emerging technologies such as edge computing and serverless architectures for energy-efficient task execution.

In energy-efficient task scheduling is a critical research area in cloud computing, with significant implications for resource utilization, energy consumption, and environmental sustainability. By exploring various scheduling algorithms and techniques, researchers aim to develop innovative solutions that optimize energy efficiency while meeting performance requirements in dynamic cloud environments. Continued advancements in this field hold the promise of making cloud computing more sustainable, cost-effective, and environmentally friendly.

III. OVERVIEW OF CLOUD COMPUTING

In Cloud Computing, we talk about a disseminated design that brings together server assets on a versatile stage, so that accommodate cloud administrations and on-request figuring assets. Cloud specialist co-ops (CSP‟s) propose cloud stages for their customer's fulfillment by using and making their web administrations. Web access suppliers (ISP‟s) offer customers to enhance the fast broadband to get to the web. CSPs and ISPs (Internet Service Providers) together offer administrations. Distributed computing is an imperative model that permits increasingly advantageous to access, on-request organize access to a mutual pool of configurable figuring assets like systems, servers, stockpiling, applications that can be immediately provisioned and discharged with administration provider's communication or negligible administration exertion. By and large, cloud providers offer three sorts of administrations, i.e. programming as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS). There are a few explanations behind associations to move towards IT arrangements that incorporate distributed computing as they are basically required to pay for the assets on utilization premise. Mists are the development of the dispersed frameworks in the creative pattern, the ancestor of cloud being the matrix. The client does not ready to require skill or colleague to control the framework of mists; it gives just deliberation idea. It tends to be produced as an administration of an Internet with increment adaptability, higher throughput, enhances nature of administration and registering power. Distributed computing suppliers convey visit online business applications, which are gotten to through an internet browser from servers [1].

A. Characteristics of Cloud Computing

- **Ultra large-scale:** In ultra vast scale processing, the size of cloud is extensive union. The billow of Google has possessed more than one million servers get to. For instance, IBM, Microsoft, Yahoo, Rediff, Amazon they have more than several thousand servers. There are many servers in a venture control get to.
- **Virtualization:** Distributed computing makes client to get to benefit all over, through a terminal. All that you can finish the procedure through a web access by utilizing a note pad PC or an advanced cell or a Tablet or a Laptop. Clients can accomplish or share it safely through a straightforward way, whenever, anyplace. Clients can finish an assignment that can't be finished in a solitary PC.
- **High reliability:** Cloud applies information multi transcript blame tolerant, the calculation hub isomorphism interchangeable thus as to enhance and guarantee the high unwavering quality of the cloud benefit. By utilizing distributed computing is profoundly dependable than neighborhood PC process connection.
- **Versatility:** Distributed computing can create a few sorts of uses upheld by cloud administration, and single cloud can keep up various applications running in the meantime.
- **High extendibility:** The size of cloud can exceptionally stretch out or progressively want to meet the expanding necessity of cloud administrations.
- **On demand service:** Cloud is a huge asset pool, which will you can pay as per your prerequisite; cloud is much the same as that running water, electric, and gas that can be charged by the sum that you utilized.
- **Extremely inexpensive**: The focused on the board of cloud makes the endeavor needn't embrace the administration cost of the server farm that expansion speed of the administration. The flexibility can enhance the usage rate of the available assets contrasted and conventional frameworks, accordingly clients can thoroughly appreciate the cloud administration and minimal effort as favorable position or to a great degree modest.

IV. DEPLOYMENT MODELS OF CLOUD

The cloud can be deployed in three models. They are described in different ways. In generalized it is described as below:

A. Public Cloud: Open cloud depicts distributed computing in the customary standard sense, whereby assets are progressively provisioned on a fine-grained, self-benefit premise over the Internet, through web applications/web administrations, from an off-website outsider supplier who charges on a fine-grained utility registering premise. This is a general cloud accessible to open over Internet.

B. Private Cloud: A private cloud is one in which the administrations and foundation are kept up on a private system. These mists offer the best dimension of security and control, however they require the organization to at present buy and keep up all the product and framework, which lessens the cost funds.

C. Hybrid Cloud: A half and half cloud condition comprising of different inward as well as outer suppliers "will be normal for generally ventures". By incorporating numerous cloud administrations clients might have the capacity to facilitate the change to open cloud administrations while staying away from issues, for example, PCI consistence.

V. SERVICES PROVIDED BY CLOUD

The different types of services provided by cloud are IaaS, PaaS and SaaS, shows in figure 2.

A. Infrastructure as a Service (IaaS): IP's deal with a bigger arrangement of figuring assets, for example,

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putting away and preparing limit. Through virtualization, they can part, allot and progressively resize the assets to manufacture impromptu frameworks as requested by the clients, the Service suppliers. They send the product stacks that run their administrations. This is framework as an administration.

B. **Platform as a Service (PaaS)**: Cloud frameworks can offer an extra reflection levels as opposed to providing a virtualized foundation. They can give the product stage where frameworks keep running on. The measuring of equipment assets is made in a straightforward way.

C. **Software as a Service (SaaS)**: There are administrations of potential enthusiasm to a wide assortment of clients facilitated in a cloud framework. This is a substitute to locally running application. A case of this is online option of run of the mill office applications, for example, word processor.

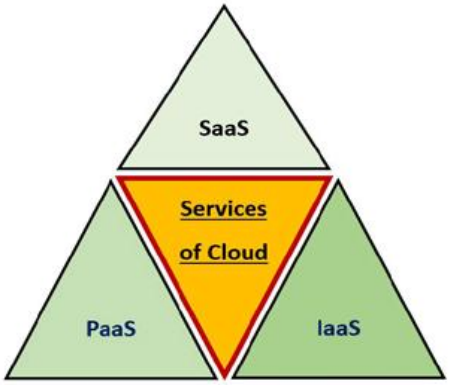

Figure 2. Services Provided By Cloud

VI. SECURITY ALGORITHMS

In Cloud Storage, any person's or association's information is depicting about open and keep up from various associated and conveyed assets that give to a cloud. Encryption calculation [25] assumes a critical job to give secure correspondence over associated and appropriated assets by utilizing the key device for ensuring the information. Encryption calculation has fundamentally changed over the information into mixed kind to ensure by utilizing "the key" and transmitter client just have the way to unscramble the information. There are two kinds of key encryption systems utilized in security calculations; they are symmetric key encryption and awry key encryption. In symmetric key encryption, single key is utilized to scramble and decode the information. Two keys are principally utilized in uneven key encryption. They are private key and open key. In Public key process, it is utilized for encryption. Another private key is utilized for unscrambling [26]. There are various existing procedures used to acknowledge security in distributed storage. The principle center is about cryptography to make information secure while transmitted over the system. Cryptography idea is that the reconsider and practice of procedures for anchoring correspondence and information inside the nearness of foes. In cryptography idea, encryption and unscrambling strategies are utilized. An encryption procedure changes over message or plaintext into figure content and decoding strategy separates the first message or plaintext into similar figure content. At first, the data must be encoded and transmitted by utilizing the encryption calculation in cryptography. Besides, the data ought to be unscrambled by utilizing the decoding strategy the collector side can peruse the first data. To give security to cloud a few calculations are planned and depict beneath, show in table 1.

- **RSA Algorithm**: RSA calculation has utilized open key encryption strategy. This calculation is conveyed to life by Ron Rivest, Adi Shamir and Len Adelman in 1977. It is latest uneven key cryptography calculation. It might conceivably very much used to give mystery assurance. In this calculation uses the best number to concoct open key and private key contingent upon numerical precision and duplicating extensive numbers together. It uses the square size of information amid transmission; that its plain-content and figure content numbers among 0 and n for a lot of n esteems. Size of information n (i.e.values) is known as 1024 bits. The genuine test inside the instance of RSA calculation would be the age and choice of people in general key and private key. At interims these two diverse keys can be performed encryption and unscrambling systems. As the sender knows about in regards to the encryption key and recipient perceives about the unscrambling key, these systems we can create encryption and decoding get into RSA.

- **Blowfish Algorithm**: Blowfish calculation is a symmetric key calculation that was created in 1993 by Bruce Schneier. Its working is about relatively like DES, anyway in DES enter is little in size and can be decoded in basic way, anyway in Blowfish calculation the measure of the key is monstrous [27] and it can contrast from 32 to 448 bits. Blowfish additionally comprises of 16 rounds like DES [28]. Blowfish calculation can encode information having various size of eight and if the span of the message isn't different of eight than bits are secured. In Blowfish calculation additionally 64 bits of plain content are isolated into two sections of message as size 32 bits length. One section procures as the left piece of message and another is correct piece of the message. The left piece of the message is XOR with the components of the P - exhibit which makes some esteem, after that esteem is transmitted through change work F. The esteem started from the change work is again handled XOR with the other portion of the message i.e. with right bits, after that F| work is called which supplant the left 50% of the message and P| supplant the correct side of the message.

- **Data Encryption Standard (DES) Algorithm:** The Data cryptography standard (DES) [29] is a symmetric-key square figure found as FIPS-46 inside the Federal Register in January 1977 by the National Institute of Standards and Technology (NIST). In encryption site, DES takes a 64-bit plaintext and makes a 64-bit figure content, after that the unscrambling site, it takes a 64-bit figure message and

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makes a 64-bit plaintext. Every encryption and unscrambling methods are utilized for same 56 bit figure key. The encryption procedure is made of two changes (P-boxes), that we tend to call introductory and last stage, and sixteen Feistel rounds [30]. Each round transmits an alternate 48-bit round key produced from the figure key encryption.

- **EI Gamel**: The ElGamal encryption framework is an uneven key encryption calculation for performing open key cryptography, which depends on the Diffie–Hellman key trade process by utilizing cryptography. It was represented by Taher Elgamal in 1984. ElGamal encryption is ensured in the free GNU Privacy Guard programming, most recent forms of PGP, and different cryptosystems. The Digital Signature Algorithm is nitty gritty about a variation of the ElGamal signature conspire, which ought not be mistaken for ElGamal encryption. ElGamal encryption can be portrayed over any cyclic gathering G. Its security dependent on the trouble of a specific issue in G identified with processing discrete logarithms.

- **Advance Encryption Algorithm (AES):** (Advanced Encryption Standard), is the new encryption standard recommended by NIST to supplant DES. The Brute power assault, in this aggressor endeavors to test all the character mixes to open the encryption, it is the main viable assault known against assurance. Together AES and DES are square figures. It has an uneven key length of 128, 192, or 256 bits; default 256 bits. It scrambles information squares of 128 bits in 10, 12 and 14 round relies on the key length. AES Encryption is fast and adaptable; it very well may be executed on various stages especially in little gadgets. What's more, AES has been painstakingly tried for various security applications. [31][32].

- **DSA**: DSA is the full type of Digital Signature Algorithm. DSA is a Federal Information Processing Standard for handling advanced marks. It was anticipated by the National Institute of Standards and Technology (NIST) in August 1991 to be utilized in their Digital Signature Standard (DSS) and endorsed as FIPS 186 in 1993.Four audits to the underlying detail has been discharged: FIPS 186-1 in 1996,FIPS 186-2 in2000,FIPS 186-3 in 2009and FIPS 186-4 of every 2013. In DSA, key age has depicted around two stages. In essential stage is to settle on calculation parameters that can be shared between various clients of the framework. Second stage is to register open and private keys for giving to a solitary client. The irregular mark esteems k are increasingly vital for performing entropy, mystery, and uniqueness. These three necessities can unveil the entire private key to an assaulter.
- **3DES**: This was produced as an enhancement of DES in 1998. In this run of the mill the encryption strategy is identified with unique DES however connected multiple times to enhance the encryption level. Be that as it may, 3DES is slower than other square figure systems. This is an improvement of DES and 64 bit square length with 192 bits key size. 3DES has lessened execution as far as throughput level and power utilization when contrasted and DES. It in every case needs additional time than DES because of its triple stage encryption attributes [33] [24].

Table 1. Security Algorithms

Algorithm	DES	AES	BLOWFISH	RSA	DSA
Developed	IBM in1975	Joan Daeman Vincet Rijman in1978	Bruce Schneir in1998	Ron Rivest, Adi sharmir ,L Adleman in 1977	NIST in 1991
Key Size	56	128 192 256	32 -448	1024-4096	-
Security	adequate	Secure	Secure	secure	secure
Memory Usage	High	Medium	Very Low	-	-
Confidentiality	Low	High	Very High	High	-
Power consumption	Low	Low	Very High	High	-
Encryption	Medium	High	Very High	High	-

- **MD5-** (Message-Digest calculation 5): Generally, the cryptographic hash work calculation is utilized with a 128-piece hash esteem and procedures a variable length message into a settled size yield of 128 bits. At first, the information message is separated into lumps of 512-piece squares a short time later the message is secured so its aggregate length is distinct by 512. In this procedure, the transmitter of the information uses the general population key to encode the message and the collector utilizes its private key to decode the message.

VII. CONCLUSION

In conclusion, this review has provided a comprehensive overview of energy-efficient task scheduling algorithms in cloud computing, highlighting the diverse approaches, techniques, and challenges in this domain. Task scheduling plays a critical role in optimizing resource utilization and energy efficiency in cloud environments, where the dynamic nature of workloads and the heterogeneity of resources pose significant challenges.

Through our exploration of existing literature, we identified several key findings and insights:

Diverse Approaches: Researchers have proposed a variety of approaches for energy-efficient task scheduling, including heuristic-based algorithms, genetic algorithms, machine learning techniques, and hybrid approaches. Each approach offers unique advantages and trade-offs, depending on factors such as workload characteristics, system requirements, and computational complexity.

Optimization Criteria: Energy-efficient task scheduling algorithms aim to minimize energy consumption while meeting performance objectives such as task completion time, resource utilization, and fairness. Balancing these conflicting objectives

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requires careful consideration of trade-offs and compromises to achieve optimal solutions.

Challenges and Opportunities: Despite significant progress in energy-efficient task scheduling research, several challenges remain to be addressed. The dynamic nature of cloud environments, fluctuating workload patterns, and the heterogeneity of resources pose ongoing challenges for designing adaptive and robust scheduling algorithms. Future research directions include the development of adaptive scheduling techniques, integration of renewable energy sources, and exploration of emerging technologies for energy-efficient task execution.

Practical Implications: Energy-efficient task scheduling algorithms have practical implications for cloud providers, users, and policymakers. By optimizing resource utilization and energy consumption, these algorithms can reduce operational costs, improve performance, and promote environmental sustainability in cloud computing operations.

In light of these findings, it is evident that energy-efficient task scheduling is a critical research area with significant implications for the sustainability and efficiency of cloud computing. Continued advancements in this field hold the promise of making cloud computing more sustainable, cost-effective, and environmentally friendly.

As we look towards the future, collaboration between researchers, practitioners, and policymakers will be essential to address the complex challenges of energy-efficient task scheduling in cloud computing. By leveraging interdisciplinary insights and innovative technologies, we can develop solutions that optimize resource utilization, reduce energy consumption, and mitigate the environmental impact of cloud computing operations.

In conclusion, energy-efficient task scheduling algorithms represent a promising avenue for improving the sustainability and efficiency of cloud computing, with far-reaching implications for the future of digital infrastructure and environmental stewardship. computing.

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