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Energy Efficient Computing Strategies for Green Cloud

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***Abstract* --** Cloud computing requires the provision of computing services on demand, typically via the internet and with a pay-as-you-go model. It represents a specialized variant of distributed computing aimed at remotely provisioning scalable and measurable resources. These technologies offer scalability, reliability, high performance, and trustworthiness at a comparatively low cost. This paradigm shift is reshaping contemporary networking, offering both technological and economic benefits alongside environmental conservation. The development of eco-friendly cloud solutions, characterized by enhanced energy efficiency and reduced carbon footprints and electronic waste, is called as Green Cloud computing. This paper explores various computing strategies designed for Green Cloud. It begins with an overview of Green Cloud computing, followed by an exploration of recent strategies designed to address diverse environmental concerns. Finally, it examines the challenges inherent in Green Cloud computing.

***Keywords* --** *Green cloud computing, Data Centers, CO2 emission, energy efficiency, Virtualization.*

Introduction

Going green is not the need of the hour anymore, but it is the prerequisite to a healthy and years-long future. Green computing is all about finding ways to make computers and gadgets while considering their impact on the environment – from how they're made to how they're used and eventually thrown away. In the last two decades, people who create and use computer stuff have started caring more about making it sustainable because using a lot of energy is becoming a big problem. Studies from 2021 show that information and communication technologies (ICTs) are responsible for emitting 2.1% to 3.9% of the world's greenhouse gases, which really harms the environment. That's why it's super important to focus on green and sustainable development to take care of our planet.

As more and more people use cloud computing (where you use the internet to store and access data instead of your computer's hard drive) and become aware of using eco-friendly resources, researchers are now looking into something called green cloud computing. Cloud computing is closely connected to big data centers, and these centers use abundant energy and produce tons of carbon dioxide (CO_2), which is bad for the environment (as shown in Figure 1). So, it's crucial for green cloud computing to come up with ways and smart ideas to reduce energy waste. Green cloud computing, along with green data centers and other energy-efficient technologies, is essential to use less power and make a smaller impact on the planet, while also finding smart ways to reuse energy. The following sections discusses about different environmental issues and how green cloud computing is working to solve them, as shown in Figure 3.

Computing Strategies Of Green Cloud

Researchers have introduced numerous new models, methods, architectures, frameworks, and algorithms in cloud computing to address environmental concerns stemming from traditional practices. These solutions focus on enhancing energy efficiency, effectively managing data centers, cutting operational expenses, and ultimately decreasing carbon emissions. The subsequent sections delve into environmental challenges and the corresponding computing strategies in green cloud technology.

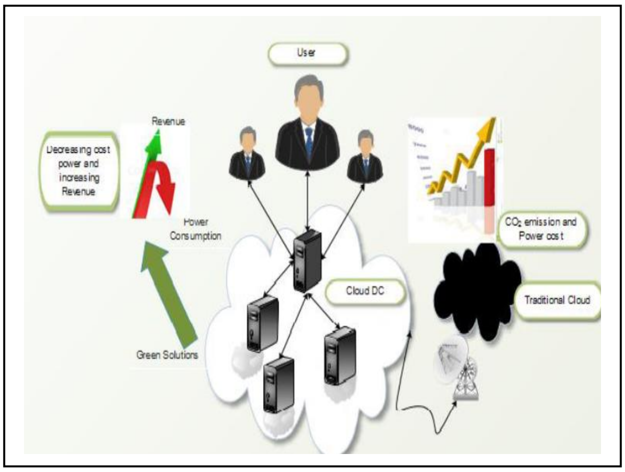

Figure1. Traditional Cloud computing Environment

A. Improving Energy-Efficiency

i) Server related techniques

The consumption of energy by data centers all over the world is depicted in Figure 2. In green cloud environments, energy usage is curtailed by substituting high-powered computers with low-powered ones. This section explores straightforward methods for reducing server energy consumption. These include turning off or putting servers to sleep when not in use [1,2], powering off idle parts of chips or server components, adjusting CPU clock speeds to enhance performance per watt, and ensuring servers can operate in higher temperature environments with adequate cooling systems. Additionally, server virtualization techniques enable improved resource management [3,4,5], while auto-scaling mechanisms create new, more environmentally friendly computing infrastructures [6]. The development of green data centers further enhances energy efficiency [7]. Consequently, implementing these techniques minimizes server energy consumption within the green cloud computing paradigm.

ii) Improved Hardware techniques

Many elements like network equipment, servers, storage, data centers, lighting & cooling devices, etc., comprise the cloud infrastructure. It is crucial to optimize these hardware components to lower energy consumption. Researchers primarily employ Dynamic Voltage Frequency Scaling (DVFS) techniques [8,9] and utilize Dynamic Power Management (DPM) technologies [10,11] to effectively reduce power consumption.

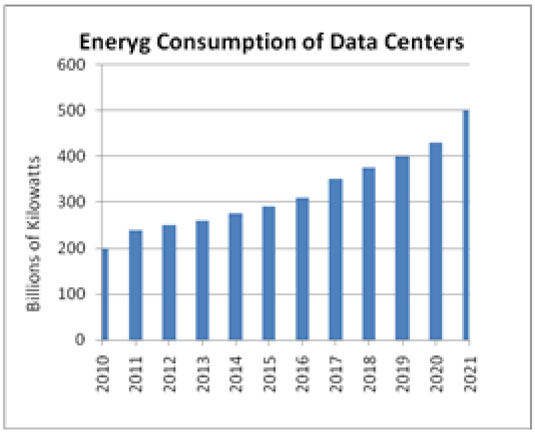

Figure2.Energy consumption of Data centers world-wide

iii) Improved Software techniques

Green cloud computing involves designing methods to minimize storage consumption and to enhance program efficiency. Employing High-performance computing, Distributed computing, and Grid computing [12,13,14] facilitates the speedy execution of large-scale problems at reduced costs. Virtual Machine (VM) migration is utilized to transfer operating system instances across multiple physical machines. VM Dynamic Migration technology [15] optimizes VM placement strategies, resulting in a 27% reduction in energy consumption compared to traditional cloud setups, while also providing enhanced load balancing and fault tolerance.

Algorithms for optimizing cloud resources [16] and search algorithms for dynamically scheduling resources are employed to boost energy efficiency in the cloud. Green cloud implementations also make use of Genetic Algorithms (GA) for dynamically scheduling tasks. GA minimizes task completion time and cost while maximizing resource utilization, thereby minimizing energy consumption and CO_2 emissions.

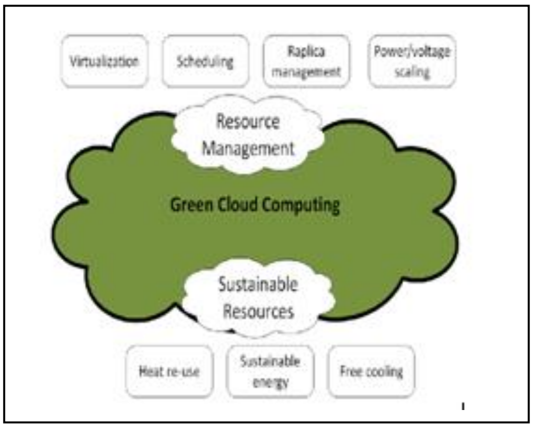

Figure3. Green Cloud Computing Environment

B. Energy Efficient Resource Allocation Strategies for Green Cloud Computing.

Resource allocation holds significant importance in cloud computing, particularly in the context of pay-per-use models where the emphasis shifts from tool enumeration to service provisioning. Cloud Service Providers (CSPs) are running numerous numbers of virtualized data centers to meet client demands. However, the continuous operation of these data centers for service provision necessitates a considerable amount of power. Consequently, it becomes crucial to allocate resources in a manner that maximizes energy efficiency. Improper resource allocation can lead to significant energy consumption issues, making it a critical concern.

The challenge lies in allocating resources effectively to perform computations with minimal energy consumption and without breaching Service Level Agreements (SLAs). Identifying a technique in the cloud environment that addresses both Quality of Service (QoS) requirements and minimized energy consumption proves to be a daunting task. This section presents significant research conducted on resource allocation for environmentally sustainable cloud computing.

The content discusses various approaches and techniques for achieving energy efficiency and optimal resource allocation in virtualized cloud data centers. One approach focuses on a decentralized architecture that incorporates VM placement techniques along with techniques for Network and Thermal Optimization, to enhance Quality of Service (QoS) and reduce operating expenses through energy conservation. Another strategy employs an Adaptive Threshold-Based Approach, using adaptive utilization thresholds to balance energy consumption and meet service level agreements, thereby maximizing both energy efficiency and QoS. Load Balancing and Virtual Machine

Migration are utilized in a Green Power Management scheme to minimize power consumption effectively. Other methods include the bee colony and Ant Colony techniques for job rescheduling and energy reduction, an Energy-Efficient Scheduling Scheme aiming to distribute workload across fewer virtual machines for energy conservation, and a Prediction-Based Energy Conserving Resources Allocation Scheme using Exponential Smoothing to predict job features.

Techniques	**Metrics**				
	Reliability	**Deployment**	**Violation of SLA**	**Load balancing**	**Energy efficiency**
Energy Efficient Resource [23]	Maximum	Maximum	Moderate	Minimum	Maximum
Adaptive Threshold-Based Approach [24]	Maximum	Maximum	Moderate	Minimum	Maximum
GPM with DRA for Cloud [25]	Minimum	Maximum	Maximum	Maximum	Moderate
Green Cloud [26]	Minimum	Maximum	Minimum	Moderate	Moderate
Energy-Efficient Scheduling Scheme [27]	Minimum	Maximum	Minimum	Moderate	Moderate
A Prediction Based Energy Conserving[28]	Maximum	Moderate	Minimum	Moderate	Maximum
Green Cloud: Smart Resource [29]	Moderate	Maximum	Moderate	Minimum	Moderate
A Power Efficient Genetic Algorithm [30]	Moderate	Moderate	Minimum	Minimum	Maximum
Dynamic Resource [31]	Moderate	Maximum	Minimum	Maximum	Maximum
Power Aware Resource VM Allocation[32]	Minimum	Maximum	Minimum	Minimum	Moderate

Table1. Comparative analysis of performance Metrics for Resource allocation strategies.

Simulated Annealing is employed in a Smart Resource Allocation and Optimization approach, while the Power Efficient Genetic Algorithm combines Genetic Algorithm, Multi-objective Gas, and Static scheduling to improve energy efficiency, reduce task completion time, and decrease power consumption. Live Migration is employed in Dynamic Resource Allocation to address overloaded and under-utilized machines, aiming for a balance between job completion time and power consumption. Finally, a Power Aware Resource Virtual Machine Allocation Policy discusses using a linear power model to reduce energy consumption and operational costs while ensuring proper load balancing in cloud infrastructure. The range of strategies provides insights into the diverse methods employed to enhance energy efficiency and resource allocation in cloud computing environments.

In Table 1, the performance metrics for resource allocation strategies, encompassing Reliability, Deployment Ease, Service Level Agreements (SLA), Load Balancing and Energy Efficiency are presented. Reliability denotes a system's ability to consistently execute requested tasks without failure; high reliability is achieved when system performance remains unaffected by an increase in user numbers. Conversely, a system is deemed unreliable when it struggles with multiple constraints. Easiness in deployment pertains to the simplicity of implementing the system model, with a high rating indicating readily available infrastructure for deployment. SLA represents the agreed-upon service attributes between a cloud service provider and its users. Load balancing refers to the optimization of distributing workload on select, heavily utilized Physical Machines (PMs) instead of dispersing them across various PMs. Energy Efficiency is defined as the minimum electricity consumption by active physical machines, networking switches, and cooling systems.

C. Efficient Management of Data Centers

Sustainable energy comprises two crucial aspects: energy efficiency and the utilization of renewable energy sources. Enterprise data centers are increasingly integrating cloud computing resources to safeguard and manage on-site resources effectively. These data centers play a vital role in storing, sharing, accessing, and processing data across the enterprise. To function optimally, data centers require cooling systems, energy supply, network access, and uninterruptible power supplies (UPS). Effective thermal management is essential for their smooth operation, as cooling systems consume significant amounts of power. Green data centers address this challenge by optimizing hardware layout to enhance the flow of hot and cold air, while also upgrading cold air delivery systems with intelligent controllers. Selecting an ideal geographical location with temperatures of 13°C or lower for at least a quarter of the year is optimal for green data centers [17]. Additionally, these data centers must rely on renewable energy sources [18] like tidal, solar or wind energy to ensure complete sustainability.

D. Reducing Carbon Footprints

Environmental sustainability in cloud is gauged through the measurement of CO2 emissions. The emission of CO2 is directly and indirectly connected to energy consumption. Integrating renewable energy sources helps mitigate CO2 emissions. The development of a novel cloud architecture featuring eco-friendly data centers and optimizing virtual machine (VM) efficiency contributes to a reduction in CO2 emissions [19]. Innovative techniques for VM allocation and migration are designed to place VMs on hosts with minimal CO2 emissions within the data center [1]. At the application level, reducing CO2 emissions can be achieved through the implementation of an application controller, enhancing quality of service while concurrently diminishing the carbon footprint.

Cloud users should consistently opt for a cloud provider that is conscious of carbon emissions. Select cloud vendors and services that operate on renewable energy sources. Additionally, it is crucial to have well-established carbon measurement and reporting plans in place for a cloud infrastructure. These measures contribute to a diminished carbon footprint.

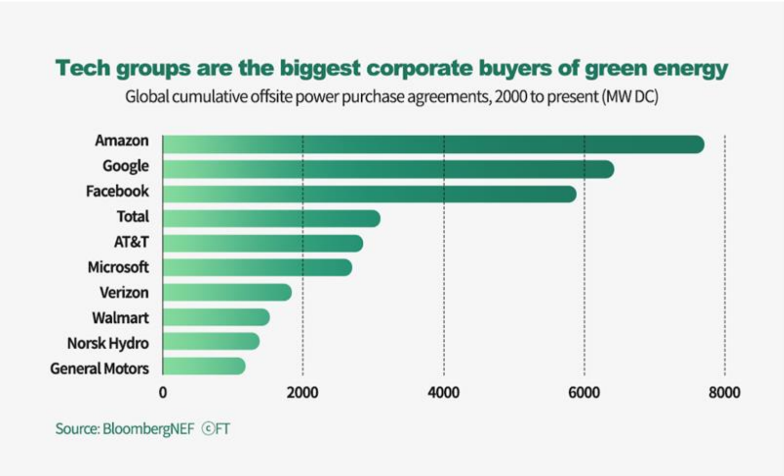

Figure4. Utilization of Green Energy by Tech groups world-wide

E. Reducing Operational Costs

Adopting Green Cloud computing brings about cost savings for both cloud providers and users. Cloud providers can reduce their energy expenses, leading to a subsequent decrease in the cost of cloud services for users. Implementing efficient cooling systems and energy-saving techniques in cloud operations results in lower maintenance and operational costs. A streamlined cloud infrastructure reduces e-waste generated by users of cloud services [10,20]. Green Data centers further contribute to e-waste minimization through the recycling and reuse of data center components.

Smart task assignment algorithms [10,21,8] in green cloud computing determine task assignments based on resource availability, minimizing overall execution and communication costs. The use of a power-efficient Immune Clonal Optimization algorithm [22] for task scheduling also contributes to operational cost reduction in green cloud environments.

In summary, green cloud computing establishes an efficient computing environment characterized by decreased energy usage, diminished green-house gas emissions, and dematerialization achieved by leveraging renewable energy sources.

II. CHALLENGES IN GREEN CLOUD COMPUTING

Challenges and issues encountered in green cloud computing are discussed below:

- Limited awareness about green computing among various stakeholders (manufacturers, providers, users, organizations, etc.) involved in computing.
- While green cloud computing proves to be cost-effective in the long run, the initial upfront costs are substantial. This can potentially clash with short-term profit maximization goals.
- Implementing green IT solutions can impose additional burdens on individuals and entail significant maintenance efforts.
- Although green cloud computing promotes material reuse, certain materials cannot be effectively reused. Consequently, the reduction of e-waste may not meet expected levels.

Conclusion

In the evolving landscape of technology, there is a imperative for a shift towards green computing within the computing environment. Green cloud computing not just trims down energy expenses for organizations, but also employs renewable energy sources, thereby diminishing the carbon footprint and electronic waste associated with IT assets. Consequently, Green cloud computing offers environmental sustainability, preserving natural resources and safeguarding the global ecosystem to promote health and well-being, both in the present and for the future.

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