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# SLA-Aware Energy Efficient Resource Management for Cloud Environments

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**ABSTRACT** Cloud computing provides online services to customers using pay as you go model. The Cloud computing enables customers to outsource the large and complex tasks to the cloud data centers for the execution and result generations. Cloud data centers host the incoming tasks by providing resources, such as CPU, RAM, storage, and bandwidth. As the large data centers provide the basic resources to hosted tasks, they also consume a huge amount of energy, which leads to higher operating cost and CO<sub>2</sub> traces. Therefore, research community felt the need to provide energy-efficient solutions that reduce the impact of the aforementioned issues. Consequently, researchers proposed many solutions, and majority of them are based upon the concept of consolidation. Consolidation techniques place the incoming tasks on minimum possible servers, thus increasing the resource utilization and decreasing energy consumption. In this paper, we use the same workload consolidation concept and present two techniques that reduce energy consumption while ensuring the negotiated quality-of-service. Moreover, we enhanced two existing techniques by improving the energy efficiency and introducing service level agreement (SLA) awareness to minimize the overall SLA violations. Performance evaluation of the proposed techniques is done based on fluctuating workloads, and results show that our techniques outperform existing techniques in terms of energy efficiency, SLA compliance, and performance assurance at the network level. Moreover, correctness of the proposed techniques is demonstrated by modeling and verifying them with the help of high-level Petri Nets, SMT-Lib, and Z3 solver.

**INDEX TERMS** Cloud computing, energy efficiency, resource management, resource allocation, SLA awareness.

## I. INTRODUCTION

Cloud computing is emerging as one of the popular solutions for on-demand and dynamic resource provisioning [1]. The provisioning and maintenance of cloud resources are done with the help of resource management (RM) techniques [2], [3]. RM techniques are responsible to keep the track of free resources and assign the resources from the free pool to incoming tasks. Along with certain advantages, RM techniques introduce a set of research challenges that need to be addressed. One of the key research challenges in RM is the energy efficiency, and researchers are focusing on this challenge [4]–[6]. Energy efficiency not only minimizes the overall the expenditure of the cloud data centers (DCs), but also have a positive effect on environment [7], [8]. CO<sub>2</sub> and Green House Gases (GHG) play an important role in environmental pollution [12]–[14], and reports published in 2007 highlight the fact that Information and

Communication Technology (ICT) industry produced about 2% of total CO<sub>2</sub> emissions. Moreover, recent report predicts that the CO<sub>2</sub> emissions of ICT industry will increase to 12% by 2020 [15]. On the other hand, big ICT companies like Google are already hosting hundred and thousands of servers and in 2010 these companies consumed about 271.8 billion kWh electricity [9], [10]. Furthermore, recent reports suggest that the energy consumption of ICT industry will grow to about 1963 billion kWh in 2020 [11].

In computational DCs, servers are considered as key energy consumers. Servers consume about 80% of the total energy, whereas, the rest of 20% is consumed by networking and storage devices [16]. The main reason for the aforementioned fact is the frequent use of servers for hosting and computing of users' tasks. Recently, researchers have proposed various energy-efficient solutions that tend to reduce energy consumption at the server level [17]. The proposed solutions

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