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REVIEW ARTICLE

An Integrated Review on Resource Management, Scheduling, and Energy Efficiency in Cloud Computing

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ABSTRACT

Cloud computing offers flexible and on-demand access to computing resources, and therefore resource management is a key issue of maintaining high performance, cost effectiveness, and sustainability. This paper will give an overview of the main issues of cloud resource management, such as the resource allocation strategies, scheduling methods, and the green (energy-efficient) practices of cloud computing. It addresses the problem of resource contention, over- and under-provisioning, fragmentation, and dynamism of workload variation, and their effect on Quality of Service (QoS) and service level agreements. The paper also looks at the case of static, dynamic, and QoS-driven scheduling, which are designed to provide a balance between the needs of the users and the objectives of the provider, and the ability to provide equitable and optimal resource utilization. Besides, energy efficiency is examined using the concept of the use of static and dynamic power control, virtualization, and green cloud to lower the cost of operation and environmental effects.

Key words: Artificial intelligence-driven scheduling, cloud computing, dynamic power management, edge computing, energy efficiency, green computing, quality of service, resource management, task scheduling, virtualization

INTRODUCTION

The development of cloud computing has significantly changed how the information technology (IT) sector functions today. Cloud computing makes it possible to investigate better IT services with lower expenses and less investment. The popularity of software as a service has increased because of cloud computing's impact on how IT hardware is developed and procured. It is an internet-based technology that gives users access to server-stored data as a service whenever they want.[1-3] Customers only pay for the service they use because it is a pay-as-you-go service. Cloud computing is a computing model in which massively scalable IT-enabled capabilities are offered as a service to numerous customers. It is the use of internet-based computer technology for a variety of services (as storage capacity, processing power, business applications, or components).[4,5] According to the architecture of cloud computing and the analysis of the ant colony algorithm, the resource management system of cloud computing is designed to have different rights management for users and administrators. It includes checking and applying the status of the virtual private server (VPS) (virtual machine [VM]) host, basic operation (switch, restart, etc.) to the VPS (VM) host, checking the task application and task execution schedule, and submitting computing tasks.

Due to the vast and ever-expanding size of cloud computing facilities and the ever-increasing number of users, energy consumption has emerged as one of the key challenges in the operation of complex cloud data centers.[6] It is reported that the average increase in energy consumption has reached 12%/year from 2005 to 2010, and has become higher and higher in recent years. High energy consumption not only translates to high cost but also produces excessive heat emissions, which often leads to system unreliability and performance degradation.[7,8] Among various ways toward energy-efficient cloud computing, being responsible for resource management and optimization, cloud task scheduling is deemed as one of the key areas to search for viable solutions to the energy consumption issue. Task scheduling

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has a direct impact on both the utilization of cloud resources and the quality of service (QoS) in response to user requests; therefore, it is the very place where it can explore innovative designs that can manage resources in an energy-efficient way while still meeting diverse user requirements in real time.

Structure of the Paper

The paper is structured as follows: Section 2 explores resource management in cloud computing. Section 3 focuses on scheduling techniques in cloud environments. Section 4 discusses energy efficiency in cloud computing. Section 5 presents a literature review summarizing recent advancements. Section 6 concludes the study and outlines future research directions for intelligent and energy-aware cloud systems.

RESOURCE MANAGEMENT IN CLOUD COMPUTING

Cloud computing enables customers to get resources in a flexible and dynamic manner.[9] The most key challenge in resource management is defining the proper number of needed resources for allocation in order to meet users' demand while simultaneously reducing costs from the users' perspective and making the optimum use of resources usage from the service providers' viewpoint. Resource management is the collective effort of inter-process communication, such as resource collection, distribution, and on-demand administration, to ensure the system's functionality.[10,11] The primary goal of resource management may differ for customers and service providers. The goal for users is to reduce operating and maintenance costs without owning physical systems, whereas the goal for cloud service providers is to earn profits through resource allocation and management. To achieve these goals, cloud customers must advise cloud service providers about whether resources will be assigned statically or dynamically.

Significance of Cloud Resource Management (CRM)

The motive of CRM is to provide application-based services by efficiently managing runtime resources. The traditional cloud would be replaced by hybrid components.[12] There is a need for managing heterogeneity, dynamism, and uncertainty while scheduling cloud resources. Cloud resource scheduling is an nondeterministic polynomial-time hard (NP-hard) problem that impacts performance. To overcome such a problem, the cloud needs a novel technique that can manage according to its characteristics. This comprehensive survey will help researchers develop a standard framework to enhance the quality of cloud services, cost-effectiveness, and usability.

Resource Allocation in Cloud Computing

Allocation of the resources is the process by which the proper resources are allocated to the tasks required by the consumer so that these tasks are finished proficiently. In cloud computing, it implies designating a VM fulfilling the properties defined by the consumers. Users should submit their task, which may have its own time imperatives.[13,14] The viable way in which these workloads can be allotted to the VMs and handled is another type of resource allocation, a possible technique in the cloud. Simply, it is all about defining when a computational action should begin or finish, dependent upon: resources assigned, time taken, predecessor actions, and predecessor relationships.[15] In addition, resource allocation in cloud computing includes the resource disclosure, choice, provisioning, application planning, and administration of resources.

The strategies of resource allocation can be defined as the mechanism for obtaining guaranteed VM and/or physical resources allocation to the cloud users with minimal resource struggle, avoiding over-, under-provisioning conditions, and other parameters, as shown in Figure 1. This needs the amount and types of resources required by the applications in order to satisfy the user's tasks, the time of allocations of the resources, and its sequels also matter in case of the resource allocation mechanism.

Let's discuss these criteria of avoidance one by one:

- Resource contention condition ascends when two applications claim to access the same resource at the identical time
- Shortage of resources arises when there are inadequate resources
- Resource fragmentation condition arises when the resources are out of the way. [There will be adequate resources, but not enough intelligence to allocate to the desired application]

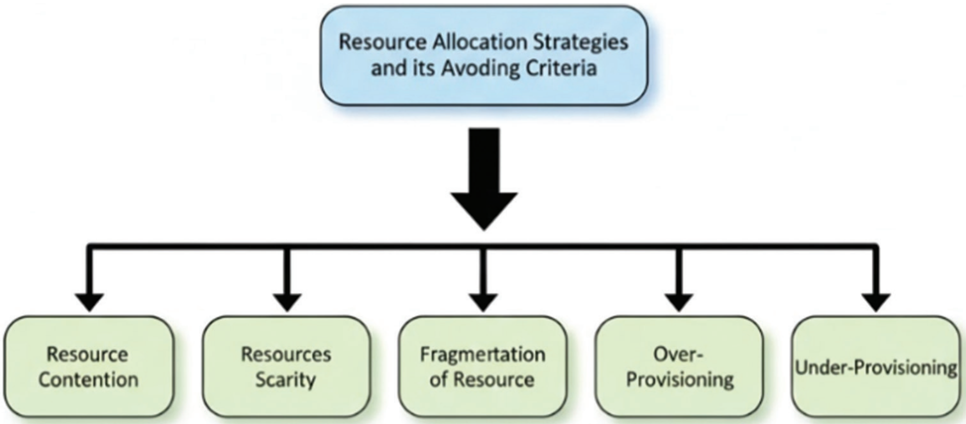

Figure 1: Resource allocation strategies and its avoiding criteria

- Over-provisioning of resources happens when the said tasks get spare resources than the actual demand
- Under-provisioning of resources befalls when the user's tasks are allotted with fewer quantities of resources than the actual demand.[16]

SCHEDULING TECHNIQUES IN CLOUD ENVIRONMENTS

The rapid growth of cloud environment applications is executed in parallel to achieve minimum execution time. Tasks are assigned to machines, and the execution order of the tasks is referred to as scheduling. Scheduling is one of the ways to achieve the QoS in the cloud environment. To improve the QoS, any scheduling algorithm or scheduling method can be implemented.[17] In a cloud environment, many cloud consumers want different QoS requirements. The different consumer requirements are efficient scheduling, traffic control, dynamic resource provisioning, admission control, etc. Scheduling allows optimal allocation of resources among given tasks in a finite time to achieve desired QoS. Formally, the scheduling problem involves tasks that must be scheduled on resources subject to some constraints to optimize some objective function.

Classification of Scheduling

Scheduling plays a vital role in cloud computing by ensuring efficient utilization of resources and timely execution of tasks. It involves assigning workloads to available computing resources while meeting specific performance requirements, such as cost and execution time. Scheduling methods are broadly classified into three categories: Task scheduling, resource scheduling, and workflow scheduling.[18] These techniques cater to both centralized and decentralized systems, accommodating homogeneous and heterogeneous environments. Task scheduling, in particular, is critical as it determines the execution flow of tasks on cloud infrastructure.[19] This section explores various scheduling strategies and highlights their importance in optimizing cloud performance and service delivery.

- Scheduling methods are classified into three main groups: Task scheduling, resource scheduling, and workflow scheduling. The distribution of virtual resources among servers (physical machines) is done by resource scheduling. To schedule a workflow comprising an entire job in an efficient order. Task scheduling involves allocating tasks to appropriate resources to ensure their efficient execution.[20,21] The Task scheduling method is for centralized as well as decentralized structures, and also for homogeneous and heterogeneous environments.
- Static scheduling allows for pre-fetching required data and pipelining different stages of task execution. Static scheduling imposes less runtime overhead. In the case of dynamic scheduling, information about the job components/tasks is not known beforehand.[22] Thus, the execution time of the task may not be known, and the allocation of tasks is done on the fly as the application executes.

The QoS-Driven Scheduler

In this section, it is explained how the QoS-driven scheduler operates. The QoS-driven scheduler is a pre-emptive one. Thus, if the available resources are not enough to accommodate all the instances associated with the admitted requests, then some requests are kept in a pending queue. Instances associated with requests in the pending queue have either been preempted or never executed.[23] These requests remain in the pending queue until the scheduler decides they should run, and allocates the required resources in some host of the infrastructure.

- The scheduler keeps track of the service level indicator (SLIs) of each instance in the system (pending or running), as well as the service class to which the requests and their associated instances belong. Availability, resource isolation, and security are examples of metrics AQ5 that can be used to define SLIs and SLOs.[24] Thus, it's considered that each service class is associated with a service level agreement (SLA) that includes a single availability SLO. The availability SLO defined for the class indicates the QoS promised to each request submitted to that class.
- The QoS-driven policy aims at keeping the QoS delivered to all instances at or above their respective SLOs. It also tries to provide fairer treatment for requests of the same class by allowing these instances to preempt each other. In this regard, it seeks to reduce the variance of the QoS delivered to the instances of the same class that are competing for resources in the system. However, it is inadequate to simply consider the current availability of instances to decide which of them to preempt.
- Whenever the scheduler is executed, it first sorts the pending queue in increasing order of the QoS metric. Then, it processes the pending queue, one request at a time, trying to find a suitable host to allocate the instance associated with the request it is processing.[25] Like other schedulers proposed in the literature, when the scheduler needs to decide where to allocate an instance j associated with a request in the pending queue, it performs two steps: Feasibility checking and ranking.

ENERGY EFFICIENCY IN CLOUD COMPUTING

Energy-saving techniques in computing equipment have been classified as static power management (SPM) and dynamic power management (DPM). SPM and DPM are completely different in categorization. SPMs are more energy efficient at the single system and are supposed to be under the category of hardware-level techniques, and since SPM techniques are related to hardware-level efficiency, low-power consumption circuit designing is an example of this technique.[26] On the other side, DPMs are more energy efficient in large systems and are supposed to be under the category of level resource management methods.[27] Furthermore, DPM techniques are mostly implemented in software or on the network layer, for example, protocol design and algorithms. Energy-aware scheduling, energy-efficient routing, load balancing, virtualization, resource consolidation, and migration. Since high availability, as well as QoS and performance guarantee, are still ignored, which is most required in such distributed environments, as the customers pay for their provisioned resources.

Existing Works on Green Computing

In recent times, Green Cloud Computing usage has seen a considerable increase. Numerous sorts of exploration have been done to integrate and boost the appropriateness of green cloud in a genuine circumstance with the assistance of various boundaries.[28,29] The utilization of energy is altogether expanding in data server centers. Costs on cloud server farms operation and maintenance are done in the cloud are slowly but surely rising. Here, it has been attentive to the workload allocation between the data centers so that the energy used up can be estimated in terms of the small packet level. Packet-level correspondence is accomplished with this technique.

The two elements of green cloud architecture are: server-side and client-side. On the customer side, the manager and the consumers are available, which manages with the implementation end of the work, and on the worker side, the green cloud middleware, green cloud broker, storage servers, sub servers, such as handling servers, are present.

Real-time Ransomware Detection

Deep learning-based ransomware detection models show promise but are less effective due to insufficient real-world evaluation. Timely detection is crucial to mitigating ransomware attacks. Advanced evasion methods, such as process injection, require real-time detection and secure environmental activation.[30] For example, new ransomware variants can rapidly spread and encrypt files across networks. Although ML-based detection systems exist, they may take minutes or hours to analyze each file, allowing significant data compromise before identifying the ransomware. Future research should focus on developing and evaluating real-time detection techniques to minimize damage. Current solutions are often too costly or inflexible for rapid detection and response, highlighting an under-researched area.

Advantages and Disadvantages of Green Cloud Computing

Scheduling plays a vital role in cloud computing by ensuring efficient utilization of resources and timely execution of tasks. It involves assigning workloads to available computing resources while meeting specific performance requirements, such as cost and execution time. Scheduling methods are broadly classified into three categories: task scheduling, resource scheduling, and workflow scheduling.[31] These techniques cater to both centralized and decentralized systems, accommodating homogeneous and heterogeneous environments. Task scheduling, in particular, is critical as it determines the execution flow of tasks on cloud infrastructure. This section explores various scheduling strategies and highlights their importance in optimizing cloud performance and service delivery.

- Among the highest priority objectives at companies are to reduce costs and minimize the size of its data centers without affecting the efficiency of services or the security of data. This can be achieved using the green cloud computing technique, which allows the ability to access applications and data without the need to purchase equipment or build data centers.[32] Finally, green cloud computing reduces the environmental impact by storing the information in digital format on the cloud, which will eliminate the physical counterparts and the storage devices since all the data will be available at all times on the cloud with data centers using green cloud computing methods.

Green computing faces the same problems and challenges as cloud computing, including:

- Green computing requires awareness among all computing stakeholders, including users, manufacturers, and organizations.
- Each nation's government must adopt a uniform green computing policy.[33]
- Due to a lack of user awareness, many eco-friendly or green initiative supporting organizations still do not include green computing in their plans
- Green computing necessitates the development of skilled labor, which is still an issue in India due to the outdated nature of the majority of computer science programs offered in Indian universities
- Funding for resource allocation, cloud architecture, and deployment optimization remains crucial issues
- A significant problem today is the design and development of energy-efficient algorithms
- Various virtualization techniques could occasionally malfunction
- Indian IT companies are still uninterested in creating user-friendly models.

LITERATURE REVIEW

This section, Table 1, represents the literature review on the topic of resource management, scheduling, and energy efficiency in cloud computing:

Ma *et al.* (2025) outlines the development trend of AI cloud management services, proposes a cloud-based standard model for large model engineering delivery, which is a modeling method for assessing the full-stack technical service capabilities of model delivery cloud management service providers for large model engineering delivery under large model public cloud hosting, private cloud deployment, and large model hybrid cloud scenarios, and verifies the accuracy of the standard model through multiple enterprise data and universality.[34]

Wang *et al.* (2025) reveal the operational mechanisms and application values of cloud computing throughout the entire life cycle of smart highways. It provides essential scientific references for the important issue of how to build smart highways, and is also expected to shed light on the relevant practices for the transformation and upgrading of the transportation industry.[35]

Ansari *et al.* (2024) investigate the efficacy and scalability of GA-grounded resource operation

Table 1: Summary on resource management, scheduling, and energy efficiency in cloud computing

Author (s)	Study on	Approach	Key findings	Challenges	Future direction
Ma *et al*., (2025)	AI Cloud management services for large model engineering delivery	Proposed a standard model to assess cloud service providers' capabilities in public, private, and hybrid clouds	Verified the accuracy and universality of the model using enterprise data	Evaluating full-stack services across diverse cloud deployment models	Generalization and industrial adoption of the standard model
Wang *et al*., (2025)	Lifecycle application of cloud computing in smart highways	Analyzed cloud computing mechanisms across the full lifecycle of smart highway systems	Demonstrated value in planning, building, and transforming smart highway infrastructure	Lack of proven cloud implementation strategies in the transport sector	Applying findings to guide smart transportation upgrades
Ansari *et al*., (2024)	GA-based resource operation in cloud computing systems	Literature review and case studies on Genetic Algorithm-based resource management strategies	Improved scalability, performance, and energy efficiency	Real-time adaptation and complexity in large-scale systems	Development of adaptive, intelligent GA-based cloud resource frameworks
Kai *et al*., (2024)	Cloud Resource Scheduling and Allocation	Simulation comparing the proposed scheduling model with traditional resource allocation methods	Increased efficiency, higher utilization, and reduced operational costs	Complexity in handling dynamic workloads	Extending the model to heterogeneous, large-scale systems
Arun *et al*., (2024)	Blockchain-based Cloud Resource Management	Utilized the Ethereum blockchain to improve the efficiency, security, and scalability of cloud systems	Improved resource utilization, transaction throughput, and system robustness	Blockchain integration overhead: ensuring cost-effectiveness	Exploring decentralized cloud systems with enhanced trust and resilience
Luan and Damian (2023)	Cloud Scheduling using RWGWO Algorithm	Compared RWGWO with GWO and RW algorithms via simulations	Lower completion time, reduced costs, and improved VM resource utilization	Algorithm performance consistency across variable workloads	Optimization and testing of RWGWO in real-time, large-scale environments
Nayak and Shetty (2023)	ML-based Smart Resource Management System	Developed an ML-driven system to predict and allocate CPU, memory, and cost resources based on user data	Reduced waiting time and operational costs; better workload prediction	Maintaining ML prediction accuracy in fluctuating environments	Advancing adaptive ML models for real-time cloud resource management

AI: Artificial intelligence, GA: Genetic algorithm, ML: Machine learning, CPU: Central processing unit, RW: Random walk, GWO: Grey wolf optimization, VM: Virtual machine

strategies in cloud computing systems, with the thing of enhancing performance, resource application, and energy effectiveness. This is fulfilled by conducting a conflation of literature and case studies. One of the ultimate pretensions of this exploration is to donate to the development of resource operation results that are both intelligent and adaptive, and that can meet the ever-changing conditions of cloud computing surroundings.[36]

Kai *et al*. (2024) simulation results show that the model has significantly improved the resource allocation efficiency compared with traditional methods, which not only greatly improves the resource utilization rate but also effectively reduces the operating costs of enterprises. The cloud computing resource scheduling algorithm shows higher computing efficiency and economic benefits when dealing with complex resource allocation problems.[37]

Arun *et al.* (2024) implementation utilizes Ethereum's blockchain and evaluates real-world cloud environments' efficiency for resource utilization, transaction throughput, cost, and robustness. This paper examines how blockchain has the propensity to redesign the means through which cloud computing resource management is conducted while improving its security, efficiency, and scalability.[38]

Luan and Damian, (2023) simulation results show that the maximum completion time of the research method is lower than that of the gray wolf optimizer (GWO) algorithm and the random walk (RW) algorithm. During the task completion process, the RWGWO algorithm has the lowest execution cost and the highest VM resource utilization efficiency. When the number of VMs is 4, RWGWO has an average improvement of 12.33% and 5.12% compared to the RW algorithm and GWO algorithm, respectively. The research method not only reduces the maximum completion time but also reduces costs, which can effectively save cloud resources.[39]

Nayak and Shetty (2023) propose a smart system that enables machine-learning algorithms in predicting and managing resources such as CPU, memory, and cost. The system, after analyzing past data files and understanding user needs, predicts workloads with an approach to resources that adapts automatically. Doing so does allow resources to be managed more efficiently, thereby saving both costs and time. The system was put to the test on real data files and showed clearer performance with less waiting time and cost-saving efforts while keeping the users satisfied.[40]

CONCLUSION AND FUTURE WORK

Cloud computing has emerged as a foundational pillar of the contemporary digital infrastructure; the resource management, smart scheduling, and energy-conscious operations of such a system are essential in fulfilling the ever-increasing demand for scalable and trustworthy services. This paper offered a critical review of CRM strategies and pointed out the major challenges confronting CRM, which included resource contention, dynamic provisioning, complexity of scheduling, and energy consumption in large-scale data centers of large scale. The scheduling techniques, especially QoS-based scheduling, were discussed as the means of satisfying the requirements of the SLA and the profitability of the provider at the same time. Furthermore, green cloud computing methods were demonstrated as necessary to minimize the cost of operation and environmental impact due to using energy-efficient resource utilization, virtualization, and consolidation methods. The fact that security features are present, in particular, real-time ransomware detection, makes it clear that cloud systems should not only be efficient and sustainable but also be safe and resilient to the ever-changing cyber threats.

Future scope should be to create intelligent resource management and scheduling systems that are based on AI and can adjust to very dynamic and heterogeneous cloud environments. The combination of machine learning and deep learning methods in predictive resource distribution, energy optimization, and anomaly detection can be used to boost cloud performance and security substantially. Furthermore, more attention should be paid to real-time and cost-effective ransomware detection systems that can perform effectively on a large scale. Green cloud policies that are standardized, enhanced awareness, and creation of energy-efficient algorithms and tools will also play roles in developing sustainable, secure, and user-centric cloud computing extended systems.

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