Advancements and Challenges in Multi-objective Workflow Scheduling Computing: A Comprehensive Survey

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Abstract

This survey paper provides a comprehensive review of resource scheduling techniques in cloud computing environments, addressing the critical challenges of optimizing performance metrics such as turnaround time, waiting time, and energy efficiency. It delves into the integration of security measures within scheduling frameworks to ensure data protection and secure transmissions, balancing these needs with energy consumption and real-time processing requirements. Additionally, the paper examines the latest advancements in hybrid and machine learning-based scheduling models, highlighting their superior capabilities in resource utilization, cost reduction, and load balancing compared to traditional methods. By exploring these innovative approaches, this survey aims to present a thorough understanding of the current state-of-the-art in resource scheduling, offering insights into potential future research directions and practical applications in dynamic computing environments.

Keywords: Cloud Computing, Dynamic Computing, Load Balancing, Turnaround Time, Waiting Time.

1 Introduction

In the rapidly evolving landscape of cloud computing, efficient resource scheduling has become a cornerstone for optimizing performance and ensuring seamless operation of computation-intensive applications and IoT devices. This survey paper aims to provide a comprehensive overview of the state-of-the-art scheduling techniques employed in these environments. It delves into the challenges of managing diverse and dynamic workloads, balancing performance metrics such as turnaround time, waiting time, and energy efficiency. Additionally, the paper examines the integration of security measures within scheduling frameworks to safeguard data and maintain secure transmissions. By exploring innovative hybrid and machine learning-based models, this survey sheds light on their superior capabilities in resource utilization and cost reduction, offering valuable insights into current practices and potential future advancements in the field[1]. presents a platform that facilitates the implementation and execution of scientific procedures across federated clouds. The framework possesses the ability to decrease expenses associated with cloud services and address runtime errors, an improved heterogeneous scheduling approach that makes use of fuzzy dominance sort. The objective of this method is to minimize both cost and makespan while taking into account the dependency restrictions of tasks in a scientific workflow application. The proposed approach by the authors of [2] is a workflow scheduling method that is specifically designed to exhibit resilience to failure. The approach takes into account the reliability of scientific applications during their execution. The probabilistic scheduling heuristic approach is designed to determine the deadline for each task with the goal of optimizing costs while adhering to deadline constraints. A heuristic method was developed using ant colony optimization to allocate each task to a server in a sequential manner, while ensuring compliance with the sub-deadline constraint. The workflow scheduling technique developed by [3] is based on the firefly algorithm. The analysis takes into account multiple factors, such as workload, makespan, resource consumption, and stability of cloud servers. The workflow scheduling technique incorporates a modified firefly algorithm. The conventional firefly method was improved by integrating quasi-reflection-based learning techniques and genetic operators. The resource provisioning framework proposed by[4] employs a hierarchical architecture, the Lyapunov optimization strategy, and an economically motivated greedy heuristic. The objective of this framework is to optimize the allocation of cloud resources with the aim of minimizing financial costs, while also ensuring the timely completion of workflows. However, the aforementioned works fail to address security considerations.

When transmitting workflows to cloud servers for execution, there exists a potential security vulnerability related to insecure execution resulting from unreliable communication. The utilization of cryptographic methods as security services allows Cloud Service Providers (CSPs) to securely transfer workloads across networks. Many users choose to lease security services in order to guarantee the safeguarding of their data. Cloud users must provide payment for the required security services. The developers of [5] have introduced the concept of security quality to evaluate the level of security offered by different security services in different job scenarios. The proposed strategy by the authors focuses on optimizing security quality and meeting time constraints in embedded systems through a task package scheduling approach, have proposed a heuristic method that utilizes forbidden search to minimize energy consumption. This method aims to satisfy the requirements for security, real-time performance, and dependability. In their study[6] introduced a genetic algorithm-based offloading technique for processes within the mobile edge computing environment. The objective of this technique is to minimize energy consumption while simultaneously satisfying security and time constraints, a task scheduling algorithm that is specifically tailored for a heterogeneous Internet of Things (IoT) environment with a focus on security. The purpose of this algorithm is to allocate security services to tasks and calculate the most efficient frequency at which these services should be performed. The developers of[7] have designed and implemented a prediction module and a security filtering algorithm to effectively utilize cloud resources while satisfying the security needs of cloud customers. The methodology developed by Du *et al.* [26] aims to evaluate the security requirements of cloud customers in time-constrained workflow application operations. Nevertheless, the aforementioned studies neglect to take into account the costs related to cloud services.

The task scheduling model was presented by the authors in [8] and consists of three stages. In the initial stage, a fast scheduler was developed that utilizes enhanced Cat Swarm Optimization to effectively manage throughput and makespan. The second stage of the process entails the incorporation of an algorithm that takes into account load and bandwidth limitations, along with a scheduler that utilizes neural network technology. The third step employs a thin and secure authentication technique to bolster the level of protection. The authors performed a comparative analysis of the Round Robin (RR) and First Come First Serve (FCFS) algorithms, as well as their own Resource Allocation Security with Task Scheduling (RATS-HM) methods. The simulation results have demonstrated the efficiency of RATS-HM in terms of reaction time and energy usage. Optimizing resource utilization and minimizing task latency are crucial considerations for cloud providers when designing and organizing large-scale workloads in a cloud environment. The authors in proposed a range of scheduling models to automate the scheduling process using machine learning. One of the approaches used by the researchers was the utilization of Long-Short Term Memory (LSTM) to develop a model for the scheduler. Among the various hybridized approaches, Deep Reinforcement was also employed. The utilization of virtual resources and reduction in waiting time has been significantly improved through the application of learning-based LSTM with Deep Reinforcement Learning (DRL-LSTM). This approach has shown better performance compared to baseline techniques such as Shortest Job First (SJF), Particle Swarm Optimization (PSO), and RR. The cloud computing paradigm presents a notable challenge in the area of load balancing. The process of load balancing entails the dynamic distribution of tasks among different virtual resources.

The [10] have developed a hybridized method to enhance the efficiency of workflow planning on virtual machines. The strategy was simulated using the Grey Wolf Optimization (GWO) and Particle Swarm Optimization (PSO) algorithms. Workflowsim is a software tool designed for conducting simulations of real-time scientific processes. The results obtained from the simulations indicate that the PSO-GWO technique has successfully decreased both the execution time and cost in comparison to previous techniques. The developers of [23] designed a scheduling system with the objective of evenly distributing job loads across Virtual Machines (VMs) and minimizing both makespan and costs. The Reference Vector Guided Evolutionary Approach (RVEA) was utilized to articulate and devise the multi-objective processes that were previously discussed. The simulation in Workflowsim used real-time processes as input. The results showed that using RVEA resulted in a notable decrease in costs and makespan. The primary objective of process scheduling is to optimize the allocation of resources and prioritize the execution of tasks, rather than solely focusing on minimizing the makespan. However, ensuring reliable workflow execution while managing budgetary constraints can be a challenging task. To ensure the successful implementation of the aforementioned scenario, a framework was developed by writers in[11]. The framework implements a proactive approach by allocating a budget for each step, thereby normalizing the process. The workflow is standardized through the utilization of the min-max method. The simulation results demonstrate that the Normalization based Reliable Budget Constraint Workflow Scheduling (NRBWS) method effectively reduces makespan and enhances dependability in comparison to existing state-of-the-art approaches. The management of energy consumption is a critical aspect of green cloud computing and a primary concern for cloud providers seeking to minimize costs related to energy usage.

1.1 Motivation and Contribution

In the dynamic and ever-evolving landscape of cloud computing, efficient workflow scheduling has emerged as a crucial factor in optimizing resource utilization and achieving cost-effectiveness. This survey paper is motivated by the pressing need to address key challenges in cloud computing, including minimizing energy consumption, reducing makespan, and ensuring robust security. As cloud computing becomes integral to a wide range of applications, from scientific research to real-time data analytics, developing models that effectively manage these aspects is paramount. The focus on designing and developing an Efficient Workflow Scheduling Model to minimize energy consumption and makespan aims to contribute to sustainable computing practices. Similarly, a Security-Aware Workflow Scheduling Model is vital for maintaining data integrity and protection while optimizing resource management and VM utilization. Additionally, a Cost-Effective Workflow Scheduling Model that enhances VM utilization to achieve energy efficiency and reduced makespan addresses economic constraints faced by cloud service providers and users alike. By evaluating these models against various workflows and performing a comparative analysis, this paper seeks to demonstrate the efficacy and practical benefits of these advanced scheduling approaches in real-world cloud environments.

- **Resource Scheduling Optimization**: The paper reviews advanced scheduling techniques in cloud computing, focusing on improving turnaround time, waiting time, and energy efficiency for computation-intensive and IoT applications.
- **Security-Enhanced Scheduling**: It evaluates scheduling models that integrate cryptographic algorithms to secure data transmissions, balancing security, energy consumption, and real-time processing.
- **Hybrid and ML-Based Techniques**: The paper examines innovative hybrid and machine learning-based scheduling models, highlighting their improvements in resource utilization, execution costs, and load balancing over traditional algorithms.

1.2 Challenges

- **Energy Consumption Optimization**: One of the primary challenges is minimizing the energy consumption of cloud data centers while maintaining high performance. Efficiently scheduling workflows to reduce energy use without compromising computational power is critical for sustainable cloud computing practices.
- **Reducing Makespan**: Achieving the shortest possible makespan (the total time taken to complete a set of workflows) while dealing with diverse and dynamic workloads presents a significant challenge. Effective scheduling algorithms must optimize task execution times and manage dependencies efficiently to minimize delays.
- **Security Concerns**: Ensuring robust security measures in workflow scheduling is vital to protect sensitive data and maintain user trust. Incorporating efficient resource management and VM utilization without compromising security requires innovative approaches to safeguard data during transmission and storage.
- **Resource Management and VM Utilization**: Efficiently managing resources and utilizing VMs to their full potential is a complex task. Balancing the load, preventing resource contention, and optimizing VM allocation to handle varying workloads are ongoing challenges in cloud environments.
- **Cost-Effectiveness**: Developing cost-effective workflow scheduling models that minimize operational costs while maximizing resource efficiency is essential. This involves creating algorithms that optimize resource usage and reduce unnecessary expenditures without sacrificing performance.
- **Comparative Analysis and Model Evaluation**: Evaluating the developed models against various workflows and performing a comprehensive comparative analysis to prove their efficiency is challenging. This requires rigorous testing, benchmarking, and validation to ensure the proposed models outperform existing solutions in terms of energy consumption, makespan, security, and cost-effectiveness

2 Literature survey

The literature survey examines a wide array of research methodologies that have been proposed to tackle the challenges of resource scheduling in cloud computing. Numerous studies have explored various algorithms and frameworks aimed at optimizing key performance metrics such as turnaround time, waiting time, and energy efficiency. The literature reveals a significant focus on integrating security measures within scheduling models to protect data and ensure secure transmissions, highlighting the trade-offs between security, performance, and energy consumption. Additionally, innovative approaches leveraging hybrid and machine learning-based techniques have been developed to enhance resource utilization and cost efficiency, surpassing traditional methods. This section synthesizes these contributions, providing a critical analysis of their effectiveness and identifying gaps and opportunities for future research in the dynamic and rapidly advancing field of cloud computing. The paper [12] introduces a multi-objective scheduling technique that focuses on prioritizing workflow activities and arranging them in the execution queue. When a resource failure occurs, a Markov decision model is utilized to evaluate whether a task needs to be resubmitted. The Double Deep Q-Network (DDQN) algorithm is utilized to optimize the allocation of jobs to VMs with the goals of minimizing makespan, enhancing resource utilization, and improving fault tolerance. The significance of ensuring workflow reliability in the scheduling process cannot be emphasized enough.

With the framework, runtime errors may be corrected and cloud service expenses may be reduced. An enhanced heterogeneous scheduling technique with fuzzy dominance sort was introduced by [13]. In a scientific process application, this method seeks to reduce costs and makespan simultaneously while accounting for task-dependent restrictions. The workflow scheduling technique aims to withstand failures with resilience. This approach considers the dependability of scientific applications in practice. By determining the deadline for each activity, probabilistic scheduling heuristic approach aims to maximize expenses while respecting deadline constraints. Then, in order to stick to the sub-deadline constraint while assigning each job in turn to the proper server, an ant colony optimization heuristic was developed[14], developed a workflow scheduling technique based on the firefly algorithm. The system considers several factors, such as cloud server uptime, workload, makespan, and resource use proposed a workflow scheduling technique that makes use of a modified firefly method. To enhance the conventional firefly technique, genetic operators and quasi-reflection-based learning methodologies were incorporated. A resource provisioning system using a hierarchical architecture, the Lyapunov optimization approach, and an economically driven greedy heuristic were reported[15]. The goal of this framework is to ensure that process deadlines are met, save costs, and allocate cloud resources in an effective manner. However, the projects previously mentioned do not solve security-related challenges.

Processes transferred to cloud servers for execution may be carried out in an insecure way because of inconsistent connectivity. By using cryptographic approaches as security services, Cloud Service Providers (CSPs) may move workloads across networks safely. A lot of customers choose to hire security services in order to safeguard their data. Users of the cloud are required to pay for these security services. The authors of[16] introduced the idea of security quality as a means of assessing the level of security provided by different security services in relation to work usage. The authors proposed a task package scheduling method for embedded systems that aims to strike a compromise between time constraints and security quality optimization. According to[17], the authors used forbidden search to develop a heuristic approach that maximizes energy consumption while satisfying security, dependability, and real-time performance requirements[25]. A genetic algorithm uses offloading technique for mobile edge computing to minimize energy consumption and ensure compliance with time and security constraints[18]. created a security-critical job scheduling method specifically for a heterogeneous IoT environment. This algorithm's goal is to efficiently assign security services to tasks and determine how frequently they should be finished[15], have developed prediction modules and security filtering algorithms to ensure that cloud resources are used as efficiently as possible while meeting the security requirements of cloud customers. Du et al. developed a method for evaluating cloud customers' security requirements in workflow application operations under time limitations[26]. However, the previously cited research does not account for the expenses associated with cloud services.

The authors[19] suggested three phases of a job scheduling paradigm. A fast scheduler was developed in the first step, using an enhanced Cat Swarm Optimization technique to manage throughput and makespan. The second phase involves integrating an algorithm that considers load and bandwidth limits with a neural network-based scheduler. In the third level, a secure and lightweight authentication mechanism is employed to further increase security. The authors conducted a comparison between the RR and FCFS algorithms and the RATS-HM (Resource Allocation Security with Task Scheduling) technique. The results of the simulation demonstrated how responsive and energy-efficient RATS-HM is. When organizing and overseeing massive workloads in an environment, cloud providers must prioritize minimizing task delays and optimizing resource use. Additionally, authors in [20] offered many scheduling models in an attempt to use machine learning to automate the scheduling process. One of these techniques that the researchers employed to create a scheduler model was Long-Short Term Memory (LSTM). In addition to using all the hybridization techniques, Deep Reinforcement was also employed. Significant reductions in virtual resource usage and waiting times have been reported when comparing the learning-based LSTM algorithm, or DRL-LSTM, to baseline techniques like SJF, PSO and RR. A significant hindrance to the cloud paradigm is load balancing, which refers to the flexible allocation of workload among various virtual resources. By integrating Q-learning with artificial bee colony approaches, the multi-objective scheduling system presented by the authors in [21] efficiently schedules work and distributes it fairly across different virtual resources. The strategy was compared to the Multi Objective Particle Swarm Optimization (MOPSO) and Multi Objective Crow search (MOCS) techniques. Multi Objective Artificial Bee Colony Q-learning (MOABCQ) has shown to be more effective than previous approaches because of its effective scheduling and load balancing methodologies.

The authors developed a hybridized method in [22] for efficient workflow planning on virtual machines. The GWO and PSO algorithms were used to model this strategy. Workflowsim is one piece of software that simulates scientific processes in real time. The results of these simulations demonstrate that the PSO-GWO technique has demonstrated a reduction in execution time and cost when compared to previous approaches. The purpose of the scheduling mechanism developed by the creators of [23] was to evenly divide workloads among VMs in order to minimize makespan and costs. The RVEA was used to explain and plan the multi-objective processes that were previously discussed. The workflow simulation was run using real-time processes as input, and the results shown that RVEA greatly reduces costs and makespan. Process scheduling is not primarily focused on minimizing makespan. Rather, it's a challenging problem to strike a balance between your budget and consistent process execution. The authors of[24] established a structure that ensures the successful implementation of the scenario that was previously provided. This method normalizes the process by allocating a budget ahead of time for each step. The method is standardized through the use of the min-max technique. The simulation findings demonstrate that Normalization based Reliable Budget Constraint Workflow Scheduling (NRBWS) improves dependability and lowers makespan when compared to state-of-the-art methods. Energy management is a keystone of green cloud computing and a primary concern for cloud providers seeking to minimize energy-related costs.

The paper [26] presents a multi-objective scheduling technique based on workflow activity prioritization and execution queue placement. When a resource fails, a Markov decision model is used to decide whether or not a work has to be redone. A method for optimizing workload distribution across VMs is the Double Deep Q-Network (DDQN) algorithm. The objectives are to minimize the makespan, optimize resource utilization, and fortify fault tolerance. The importance of reliable workflows in the scheduling process cannot be overstated.

Table 1: Survey of the various perspectives of different authors

Ref.	**Method**	**Advantage**	**Disadvantage**	**Research Gap**
[8]	RATS-HM (Cat Swarm Optimization, Neural Network Scheduler, Secure Authentication)	Effective in terms of response time and energy consumption	High complexity and limited real-time adaptability	Enhancing real-time adaptability and simplifying the model
[9]	Probabilistic Scheduling Heuristic (Ant Colony Optimization)	Optimizes deadline-constrained cost	Limited scalability and high computational overhead	Scaling the model for larger and more complex workflows
[10]	Multi-Objective Scheduling (Q-learning, Artificial Bee Colony)	Effective task scheduling and load balancing	Complexity and potential scalability issues	Simplifying the model while maintaining effectiveness
[13]	Federated Cloud Framework	Solves runtime failures and optimizes monetary costs	Limited consideration of security issues	Integration of security measures with cost optimization
[14]	Improved Heterogeneous Scheduling (Fuzzy Dominance Sort)	Reduces cost and makespan under task dependency constraints	Does not address security and reliability	Incorporating security and reliability into cost and makespan optimization
[15]	Failure-Robust Workflow Scheduling	Enhances execution reliability	Higher complexity and potentially increased costs	Simplifying the approach while maintaining reliability
[16]	Firefly Algorithm-Based Scheduling	Considers workload, makespan, resource utilization, and reliability	Limited focus on energy efficiency and security	Integrating energy efficiency and security into the model
[17]	Modified Firefly Algorithm with Genetic Operators	Improves traditional firefly algorithm performance	Increased complexity and potential	Balancing complexity with performance gains

			performance overhead	
[20]	Heuristic Algorithm (Taboo Search)	Minimizes energy consumption under reliability, real-time, and security requirements	High computational cost and complexity	Reducing computational cost while maintaining efficiency
[21]	Offloading Strategy (Genetic Algorithm)	Minimizes energy consumption while meeting security and deadline constraints	Complexity in implementation and potential scalability issues	Simplifying implementation and improving scalability
[22]	Security-Critical Task Scheduling	Determines operation frequency and security services allocation	Ignores cost considerations	Balancing security measures with cost-effectiveness
[23]	Reference Vector Guided Evolutionary Approach (RVEA)	Minimizes makespan and balances load	High complexity and implementation difficulty	Reducing complexity and improving ease of implementation
[24]	Normalization-Based Reliable Budget Constraint Workflow Scheduling (NRBWS)	Minimizes makespan and improves reliability	Ignores energy consumption	Incorporating energy consumption optimization

2.1 Research gap

- **Integration of Energy Efficiency and Performance Optimization**: Existing models often focus on either energy efficiency or performance optimization, but not both simultaneously. There is a need for comprehensive models that effectively balance energy consumption with high-performance requirements.
- **Holistic Security-Aware Scheduling**: While some models address security concerns, they typically do so at the expense of resource management efficiency. There is a research gap in developing security-aware scheduling models that do not compromise on VM utilization and resource allocation efficiency.
- **Dynamic and Real-Time Scheduling**: Current scheduling algorithms often fail to adapt in real-time to the dynamic nature of cloud environments. Research is needed to develop adaptive scheduling models that can respond to changing workloads and resource availability in real-time.
- **Cost-Effectiveness in Multi-Cloud Environments**: Many studies focus on single-cloud environments, leaving a gap in understanding and optimizing cost-effective scheduling in multi-cloud or federated cloud scenarios where resources can be distributed across multiple service providers.
- **Comprehensive Comparative Analysis**: There is a lack of extensive comparative analysis and benchmarking of new scheduling models against existing state-of-the-art methods. Research should focus on developing standardized evaluation frameworks to assess the effectiveness of new models across diverse workflows and environments.
- **Addressing Task Dependency and Workflow Complexity**: Current models often oversimplify the dependencies and complexities of workflows. There is a need for

advanced scheduling algorithms that can handle complex task dependencies and heterogeneous workflow structures more efficiently.

- **User-Centric Customization and Adaptability**: Existing scheduling models do not adequately address the need for customization based on user-specific requirements and preferences. Research should focus on developing flexible scheduling models that can be easily tailored to meet the unique needs of different users and applications.

3. Conclusion

In conclusion, this survey paper has highlighted the significant advancements and ongoing challenges in resource scheduling for cloud computing environments. Through a detailed analysis of various scheduling techniques, we have underscored the importance of optimizing performance metrics such as turnaround time, waiting time, and energy efficiency to meet the demands of computation-intensive applications and IoT devices. The integration of security measures within scheduling frameworks has been shown to be crucial for protecting data and ensuring secure transmissions while balancing energy consumption and real-time processing needs. Furthermore, the exploration of hybrid and machine learning-based scheduling models has demonstrated their potential to surpass traditional methods in terms of resource utilization, cost reduction, and load balancing. These insights not only reflect the current state-of-the-art in resource scheduling but also provide a foundation for future research and practical implementations in dynamic and scalable computing environments. As the landscape of cloud computing continues to evolve, ongoing innovation and adaptation of these scheduling techniques will be essential for achieving optimal performance and security.

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