Metaheuristic Optimization Review

♦ ISSN: 2692-4048 Vol: 02, No. 01, 2024 ♦ PP. 09–16

Article DOI: https://doi.org/10.54216/MOR.020202



REVIEW ARTICLE

Metaheuristic Optimization for Scheduling in Cloud Computing Environments: A Review

Rokaia M. Zaki[1,*]

[1] Department of Electrical Engineering, Shoubra Faculty of Engineering, Benha University, Egypt

Emails: rukaia.emam@feng.bu.edu.eg

Received: June 02, 2024 Revised: September 14, 2024 Accepted: December 08, 2024 ⋆ Corresponding author

ABSTRACT

This review reviews metaheuristic optimization algorithms for solving various important issues in cloud computing, such as scheduling, resource provisioning and energy consumption. Specifically, PSO, GA, and DRL are application area-specific intelligent scheduling algorithms that offer high scalability, flexibility, and efficiency in solving NP-hard problems, thereby improving system performance and QoS. The following are some of the key strengths in the study: The energy utilization and the cost utilization as key strengths are presented; the weaknesses are programs and things such as scalability and integration issues that arise when using hybrid systems. The focus for the future lies in combining machine-learning techniques, improving the further development of hybrid approaches, and testing them in real cloud systems to cope with the increasing sophistication of distributed systems. This paper provides an outline of metaheuristic optimization with an emphasis on how this area can contribute to enhancements and further developments in the capacity, recyclability, and dependability of cloud computing.

Keywords: Metaheuristic optimization ▪ Cloud computing ▪ Task scheduling ▪ Resource allocation ▪ Energy management ▪ Hybrid algorithms

1. INTRODUCTION

Cloud computing has become one of the significant paradigms where resources can be acquired in a scalable manner, fulfilling different industries' demands on demand. As the volume and the level of work complexity increase dramatically, appropriate time management to achieve the maximum efficiency of resource use and high-quality services is a crucial issue (QoS). The old scheduling approach could be more efficient in cloud computing because it is stochastic and distributed and requires metaheuristic algorithms. An NP-hard problem is a problem for which the best-known efficient solution, an algorithm, is of high standard and can be used to solve problems relating to task scheduling and resource allocation. Here, we discuss the applications of metaheuristic optimization techniques in cloud task scheduling while elucidating their key benefits, possible drawbacks, and vital areas of improvement for enhancing future implementations.

1.1 Metaheuristic Optimization for Scheduling in Cloud Computing Environments

Cloud computing is arevolutionary model of computing that provides flexible, green and manageable Computing Resources on demand through the internet. Due to complex activities and utilization of cloud, I/O intertwined networks; technical advancements have posed increasing worry towards resource optimization. This necessity arises due to the elemental difficulties in resource management, activity formation, load distribution, and energy management used with the coupled demands of QoS provision [1]. Scheduling of tasks in the domain of cloud computing, by its nature, is an NP-hard one, for it features vast spaces to search and in-

© 2024 The Author(s). Published by ASPG. This article is licensed under CC BY 4.0.

tricate connectivity. Effective scheduling is critical to the system's performance, execution budgets and quality of service. Standard approaches to scheduling are seldom practical in making strategies for these issues, thus using metaheuristic algorithms. These algorithms provide near-optimal solutions in a manageable amount of time and help get better performance in cloud conditions [2].

1.2 Research Scope

This paper surveys metaheuristic optimization algorithms for scheduling in a cloud-computing environment. It assesses current approaches scientifically and can reveal the benefits and drawbacks of such approaches while also outlining their further evolution prospects.

1.3 Challenges in Workflow Scheduling

The different hurdles that are experienced when it comes to the scheduling of workflow Cloud environments foster business and other applications from bioinformatics, physics and astronomy that necessitate parallel and distributed solutions. These aspects are spread across works, and the high coupling between them means that scheduling has a high computational complexity. The work looks into the algorithms that handle this aspect: Particle Swarm Optimization (PSO), Genetic Algorithm (GA), and Ant Colony Optimization (ACO) [3], [4].

1.4 Contributions

This study provides:

- A detailed discussion and review of the metaheuristic algorithms concerning cloud task scheduling [5].
- Evaluations by comparing performance in terms of makes pan, response time, and system utilization [6].
- Features about the new generation of metaheuristics like Hybrid or Bio -Inspiration optimization

approaches, such as Cuckoo-based Discrete Symbiotic Organisms Search (C-DSOS) [7].

- Conceptualization of current and future research directions and challenges in the optimization domain

related to cloud computing [8]. Thus, metaheuristic algorithms continue to play a crucial role in responding to the scalability and efficiency requirements of current cloud systems. Their evolution even now defines the future of distributed computing; contributing to progress that improves cloud solutions' dependability and versatility [9]. It has been observed that metaheuristic algorithms are a boon for explaining task scheduling in a cloud computing landscape. As pertains to their versatility and quickness to resolve problems or solutions, they are employed beneficially in the ample search space and the multiple objectives entailing cloud systems. As previous sections have identified, some key app roaches applied in this work are bio -inspired and hybrid algorithms and results in terms of the efficiency of the scheduling methodology and the QoS offered by the system as a whole have been presented in this section. Although a fair amount of research h as been accomplished in this area, there are certain issues that are still open and prerequisites, especially in terms of scalability and possible combinations with other state-of-the-art methods, such as machine learning. Further development of metaheuris tic algorithms will remain essential for providing better adaptability to the dynamic and growing requirements of data services while improving cloud-computing services' dependability.

2. LITERATURE REVIEW

Cloud computing; therefore, has become known as the new computing paradigm that makes available, sustainable and controllable resources over the internet. The interconnectedness of cloud environments and the recent exponential growth of complex tasks and models have created the need for resource optimizatio n schemes. Several studies have been invested in addressing issues that involve resource management, activity planning, load distribution, and energy management, all to improve quality of service (QoS). Consequently, these problems constitute metaheuristic algorithms that promise realistic solutions within areasonable timeframe because they are NP-hard optimization problems. Based on the thorough analysis of the existing literature, this literature review aims to discuss the use of present -day metaheuristic algorithm optimization techniques in cloud computing and the strengths, weaknesses, and future development directions. As outlined in the paper [10], cloud computing enables access to shared virtual servers through public and private networks, offering scalable and multitenant computing solutions such as Infrastructure as a Service (IaaS), Software as a Service (SaaS), and Platform as a Service (PaaS) on a pay-per-use basis. Scientific workflow applications have been extensively used in fields such as as tronomy, physics, earth science, and bioinformatics to model real-world problems in parallel and distributed computing environments. However, achieving efficient workflow scheduling remains challenging due to the enormous task sets generated by these appli cations and their complex dependencies, which complicate finding optimal solutions within polynomial time. This research provided a comprehensive survey of state-of-the-art metaheuristic algorithms for workflow scheduling in cloud and grid computing enviro nments, analyzing existing metaheuristics, scheduling efficiency, system performance, execution budget, and quality of service (QoS) metrics while identifying key research gaps and proposing future directions to optimize workflow scheduling in distributed computing frameworks. As detailed in the paper [11], cloud computing has gained significant research attention due to the rapid evolution and migration of numerous network services to this computational environment. The primary challenge lies in efficientl y managing and utilizing extensive computing resources. The study briefly retrospect is traditional scheduling approaches, followed by a comprehensive review of metaheuristic algorithms for addressing scheduling problems within a unified framework. Additiona lly, it surveys recent advancements in metaheuristic scheduling solutions for cloud computing and highlights critical issues and open questions to guide future research on scheduling in cloud environments. As outlined in the paper [12], cloud computing as a delivery model has gained significant prominence because it allows multiple users to share

computing resources over the World Wide Web in real -time. Being built on virtualization technology it is easy to scale, affordable and follows the pay-per-use model attractive to large enterprises working in distributed computing environments. Task scheduling remains a significant research challenge in cloud computing, as it requires mapping cloud tasks to available resources to optimize single or multiple objective s. The NP-hard nature of task scheduling arises from its complexity and ample search space. The study provides an analysis of existing heuristic and metaheuristic strategies and their application in cloud environments, along with a comparative evaluation o f algorithms such as Particle Swarm Optimization (PSO), Genetic Algorithm (GA), and Ant Colony Optimization (ACO) Results, standards, and compliance with service-level agreements demanded by cloud service providers. The primary goal is to map workloads e fficiently to computing resources to enhance system performance. Load balancing is categorized as an NP-hard problem due to the vast solution space, making it challenging to identify optimal solutions within polynomial time. Metaheuristic strategies have b een shown to deliver accurate solutions efficiently for such issues. The study provides a comparative analysis of metaheuristic load balancing algorithms, evaluating their performance based on metrics such as make pan, degree of imbalance, response time, data center processing time, flow time, and resource utilization. Simulation results reveal that the Particle Swarm Optimization method outperforms others by improving makespan, flow time, throughput, response time, and the degree of imbalance. In the article denoted as [13], cloud computing offers extensive processing and storage resources on a pay - per-use basis, managed by data centers considering demand, availability, reliability, and security. Task scheduling, influenced by task size and workflow interd ependence, is a critical process affecting overall system performance. The study emphasizes optimizing task scheduling by addressing cost, failure rate, and makes pan . Metaheuristic strategies, particularly those based on swarm intelligence, have been widel y utilized to tackle these scheduling challenges. The research provides an overview of metaheuristic approaches and a comparative analysis of their application in cloud task scheduling. It highlights how hybrid methods leveraging diverse metaheuristic algo rithms have improved scheduling performance, supported by comparisons of algorithms, environments, simulation tools, scheduling objectives, and related metrics. As detailed in the paper [14], the rapid growth of the cloud-computing paradigm, alongside the shift from traditional IT infrastructure and other distributed computing methods, has intensified the need for optimized task scheduling techniques. Task scheduling in cloud environments involves allocating numerous tasks to a limited number of diverse virtual machines to minimize the imbalance between local and global search spaces and optimize system utilization. The study addresses the NP -complete nature of task scheduling, which precludes exact solutions, especially for large-scale tasks, and proposes the Cuckoo-based Discrete Symbiotic Organisms Search (C-DSOS) algorithm. This algorithm incorporates Levy -Flight into the Standard Symbiotic Organism Search (SOS), a nature -inspired metaheuristic optimization technique simulating ecosystem mutualism, commensalism, and parasitism relationships. The proposed C-DSOS strategy aims to minimize the imbalance in task scheduling within cloud environments. Using the CloudSim toolkit simulator for evaluation, the study demonstrates that C-DSOS outperforms the Simulate d Annealing Symbiotic Organism Search (SASOS) algorithm, displaying better convergence rates, especially in larger search spaces. Statistical analysis using a t-test confirms that C-DSOS achieves statistically significant improvements over SASOS, particularly in scenarios with extensive search spaces, making it a robust solution for task scheduling in cloud computing. Similar to the work in [15], this review and analysis paper explores how metaheuristic optimization algorithms inspired by nature have been used to solve optimization problems in cloud computing. Cloud computing, known for its flexibility in allowing the sharing of resources on a metered basis as needed, is both a high -tech idea and a high -complexity challenge in terms of resource management. Bio-inspired metaheuristic algorithms are a highly efficient solution to optimization problems in almost all fields. This paper gives an overview of these algorithms with respect to the cloud computing environment, continued discussions on their strengths and weaknesses, and arecommendation on their use in solving problems like resource allocation, scheduling, load balancing energy consumption, and security. A comparative result of the proposed approach is provided where the execution time (ms) of each alg orithm is compared. Furthermore, the paper also points out the limitations of this study. It provides recommendations for future studies on enhancements of applying metaheuristic algorithms inspired by nature to optimize the configurations of cloud computing systems and to benefit future improvements in resource usage and scheduling of cloud computing. As noted in the analysis made in [16], the emergence of many applications powered by clouds and stimulated by high-speed internet connections raised high requirements for efficient scheduling of jobs. When there are many applications and users in the cloud platform, the importance of scheduling algorithms to allocate time, processing power, and memory, among others, has become inevitable. Traditionally develop ed job sequencing algorithms work towards finding the sequence of execution that would be most optimally feasible regarding resources. Meta -hybrid approaches have proved to be more useful in tackling the problem associated with the scheduling of tasks to ensure that cost implication is optimized than when other methods are used individually. This work presents a systematic literature review of task scheduling strategies for cloud computing environments, emphasizing hybrid metaheuristic methods, such as Gene tic Algorithm, Tabu Search, Harmony Search, Artificial Bee Colony, and particle swarm optimization. Moreover, the research also focuses on the performance evaluation metrics where a section has been provided on their use and relevance in the literature. In the research carried out in [17], Metaheuristic (MH) algorithms are described in detail for their application to cloud and fog computing (CFC), with emphasis on how they can be used to enhance resource management and achieve the intended performance goals in these complex networks. Task Scheduling is deemed a key factor in improving resource management and utilization in CFC. The study provides an overview of the different MH algorithms: Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Grey Wolf Optimizer (GWO), and Ant Colony Optimization (ACO) to overcome the challenges associated with these computing paradigms. They have been

analyzed regarding reliability in resource allocation, energy utilization, system efficiency, strengths, weaknesses, and new prospects for using them. The research contributes insight into the situation with the intention of helping researchers, practitioners, and decision - makers manage the difficulties of the operation of CFC environments. The study identifies Cloud comput ing as one of the critical paradigms in HPC [18]. Cloud computing is defined as the on-demand provision of shared computing resources over the internet on which consumers can self-provision, which are dynamically and metered. The task of scheduling is featured as a daunting research area for productivity enhancement while requiring the assignment of jobs to available resources with the enhancement of multiple goals as an objective. Due to the NP-hard nature of scheduling, involving a solution space that has far-reaching implications, the search for exact solutions takes a great deal of time, and therefore, approximation solutions done in shorter periods is the expected aim. Metaheuristic techniques like ACO, PSO, GA and the recently developed LCA have been found helpful in offering near-optimal solutions in a domain within prescribed periods. The following is a comprehensive literature review of these optimization algorithms and the appropriateness and efficiency of each in solving scheduling issues in cloud platforms. As discussed in [19], the recent switch toward the cloud-computing model due to the shift from the conventional IT architecture and other DCM approaches further fuels the necessity for efficient scheduling strategies. A vast number of tasks can be dealt with simultaneously, and there must be proper scheduling of the tasks; a vast variety of virtual machines can be handled effectively in a limited number to maintain a balance between the local and the global search space to make the best use of the total system configuration. As aresult, task scheduling is inherently challenging, belonging to the NP-complete complexity class, which makes it difficult to speak of exact solutions, let alone for large -scale systems, and, therefore, requires near- optimal approaches. This work proposes a Cuckoo -based Discrete Symbiotic Organisms Search (C-DSOS) algorithm with the integration of Levy -Flight to realize the issue of effective task scheduling such that the degree of imbalance is reduced to the optimum. The Cloud Sim toolkit simulator evaluated C-DSOS based on the Standard Symbiotic Organism Search (SOS) algorithm, reflecting the coexistence of mutualism, commensalism, and parasitism in any ecosystem. The results show that the proposed C-DSOS has better average fitness convergence than the SASOS algorithm in the expanded exploration space. Subsequently, using a t-test, the results were further validated for their statistical significance of using C-DSOS as against SASOS, which made C-DSOS an efficient tool for task scheduling in a cloud environment. According to the publication cited here as [20], this has been occasioned by the complexity and volumes of data being processed by software systems, leading to the adoption of high-performance distributed computing systems characterized by cloud computing to support dynamic and elastic service requirements. Resource scheduling is presented as one of the central problems of cloud computing since inefficient scheduling leads to high-energy consumption and costs, reduced service life of physically utilized equipment, and increased response times. The study advises that resource scheduling is crucial to enhance resource utilization, increase QoS, decrease costs, and minimize the negative environmental impact due to its NP-hard nature. Ordinary scheduling approaches offer some challenges when ordinary scheduling approaches offer some challenges when scheduling these vastly distributed cloud systems. However, with the application of machine learning, particularly Deep Reinforcement Learning (DRL), there is light at the end of the tunnel. Deep Reinforcement Learning, or DRL, integrates deep learning with reinforcement learning and provides advanced solutions for scheduling resources in cloud computing. This survey explore s prior research on resource scheduling techniques, specifically the DRL-based methodology. It reviews the use and discusses the issues and potential of DRL for cloud computing resource scheduling. Ref [21] highlighted that in cloud computing systems, perf ormance degradations may be triggered by unpredictable perturbation; hence, there is a need to quantify their effects to design appropriate scheduling mechanisms that will enable effective cloud computing systems. The mathematical modeling of the cloud environment starts with the analysis of the supply-demand chain between CSPs and customers based on two goals – profit and waiting time. After illustrating measures for the minimum acceptable profit for providers and maximum acceptable waiting time for consum ers, the research outlines a robustness metric technique. This method helps maintain efforts of server configurations, particularly the numbers and speeds of servers, within practicable regions to support system performance under perturbations. The study e valuates the robustness metric method, highlighting further scenarios and presenting a heuristic optimization algorithm to enhance system robustness. The performance comparisons with DE and PSO algorithms authenticate the proposed algorithm and show its capability to recover from perturbations and maintain system stability. According to the research undertaken in [22], cloud computing can be described as a model of computing where programs are offered as services over the network. The flexibility and size o f the current and future data centers make resource-scheduling essential to manage such facilities effectively. The fundamental goal of scheduling is to assign activities to the most suitable resources to improve at least one or several objectives. Scheduling tasks in a cloud environment is a critical problem since the usual scheduling algorithms do not work for this purpose, and satisfactory solutions must be developed in polynomial time. However, the inference is that the sub -optimal solutions are launche d at a much shorter period. These metaheuristic techniques have readily proved effective in providing near-optimal or optimal solutions within areasonable time for such problems. This paper initiates the notion of resource scheduling and presents a compar ative study of different task scheduling techniques concerning different optimization metrics to tackle the difficulties of the cloud environment. In the article [23], the use of metaheuristic algorithms imitating nature for optimization in the cloud computing environment and the challenges of efficient resource allocation and management are considered. All these algorithms have solved optimization problems in the following areas of application: resource management, scheduling, load distribution, power usag e, and security. This work outlines the role of these algorithms in cloud computing and assesses both the benefits of their utilization and the effectiveness of various application options. An algorithm

performance comparison is then made using execution t ime (ms) as a significant criterion to determine suitability for solving cloud optimization issues. This paper also discusses the research gap and future work to improve the application of these algorithms as a guide to improving service resource allocation and utilization in cloud contexts. As described in the paper [24], cloud computing is based on shared virtual servers on public and private networks that provide IaaS, SaaS, and PaaS at the cost of utilization in a multitenant architecture. Computer science students from astronomy, physics, earth science or bioinformatics have incorporated scientific workflow applications in modeling real -world problems in parallel and distributed computing systems. However, efficient workflow scheduling becomes difficult once again due to these applications' enormous task sets and interdependencies, where finding a solution that is of eminence within the polynomial time is not feasible. This paper systematically reviews workflow scheduling in cloud and grid computing syst ems based on the latest metaheuristic algorithms. It analyzes the literature from four perspectives: from the existing metaheuristics, scheduling performance and effectiveness, and time and cost required for scheduling, scheduling context, or QoS factors. In addition, the paper highlights possible issues and directions for the development of further research in WfS for cloud computing environments. The review of the literature on metaheuristic optimization techniques applied to cloud computing settings is presented in Table 1. These include scheduling, resource management, and system reliability, and they present new foci, tools, and results from numerous studies. Some approaches include the Cuckoo - based Discrete Symbiotic Organisms Search (C-DSOS) and Deep Reinfor cement Learning (DRL) to address NP - hard optimization problems with greater efficiency and scalability. The studies also stress that the proposed techniques should be combined to improve resource efficiency, minimize energy consumption, and improve QoS characteristics. Combined, the results offer a clear research agenda for the future, highlighting the trend of hybrid approaches and methods of integration with machine learning to address the increasing complexity of cloud systems.

Table 1. Summary of Literature Review

Ref.	Focus Area	Methods	Key Findings
[10]	C-DSOS algorithm for task scheduling	C-DSOS with Levy-Flight; CloudSim toolkit; t-test validation	Outperformed SASOS with better convergence in large exploration spaces.
[11]	Metaheuristic scheduling in cloud computing	Unified review of metaheuristic scheduling frameworks	Identified critical scheduling issues and future research questions.
[12]	QoS-based cloud scheduling	PSO, GA, ACO and heuristic approaches	Compared scheduling algorithms based on QoS parameters.
[16]	Hybrid task scheduling	GA, Tabu Search, Harmony Search, ABC, PSO	Hybrid methods optimize cost and resource utilization better than standalone algorithms.
[17]	Cloud-fog task scheduling	GA, PSO, GWO, ACO	Evaluated reliability, energy utilization, and system efficiency.
[20]	Resource scheduling	Deep reinforcement learning	DRL offers adaptive scheduling for complex cloud systems.

Reference Focus Area Key Methods/Algorithms Key Findings [10] Cuckoo-based Discrete Symbiotic Organisms Search (C- DSOS) algorithm for task scheduling C-DSOS with Levy -Flight; CloudSim toolkit; t-test validation C-DSOS outperformed SASOS, achieving better convergence in large search spaces [11] Deep Reinforcement Learning (DRL) for resource scheduling in cloud computing Deep Reinforcement Learning (DRL) integrates deep learning with reinforcement learning. DRL methods show promise for improving resource utilization and QoS [12] Robust scheduling under perturbations in cloud systems using heuristic optimization Heuristic optimization algorithm; robustness metric evaluation Proposed methods enhance system stability and recoverability under perturbations [13] Metaheuristic techniques for resource scheduling in cloud computing Comparative analysis of heuristic and metaheuristic techniques Metaheuristic techniques provide near - optimal solutions for complex scheduling problems [14] Nature-inspired metaheuristic algorithms for cloud computing optimization Bio-inspired algorithms; comparative performance analysis based on execution time Hybrid and bio -inspired algorithms improve resource allocation and energy management [15] Workflow scheduling in cloud and grid computing using metaheuristic algorithms Comparative evaluation of scheduling performance and QoS factors using metaheuristics Metaheuristic approaches improve scheduling efficiency in distributed systems. [15] Systematic revi ew of workflow scheduling in cloud and grid systems Review of metaheuristics, including PSO, ACO, GA, for scheduling Metaheuristic methods improve scheduling and resource allocation efficiency [16] Task scheduling in cloud computing using hybrid metaheuristics Hybrid algorithms: Genetic Algorithm (GA), Tabu Search, Harmony Search Hybrid methods optimize costs and resource utilization better than standalone algorithms [17] Analysis of metaheuristic algorithms for task scheduling in cloud-fog computing Evaluation of GA, PSO, GWO, ACO in cloud-fog computing scenarios GA, PSO, and other methods enhance resource management in distributed systems [18] Survey of optimization techniques for cloud computing Comparative study of optimization methods including LCA, PSO Optimization algorithms provide robust solutions for complex cloud environments [19] Advanced scheduling techniques for distributed cloud systems C-DSOS algorithm with statistical performance evaluation C-DSOS achieves higher efficiency and stability in scheduling tasks [20] Resource management optimization in high -complexity cloud environments Comparative analysis of nature-inspired optimization methods Bio-inspired techniques show potential for improving energy and resource management [21] Evaluation of cloud systems' resource scheduling using reinforcement learning Deep Reinforcement Learning (DRL) for adaptive scheduling solutions DRL-based scheduling enhances scalability and efficiency in resource management [22] Improving scheduling robustness under dynamic conditions in cloud computing Heuristic and optimization -based scheduling techniques Proposed methods improve adaptability and system robustness under changing workloads [23] Task scheduling challenges in high-performance cloud computing environments Hybrid metaheuristics combining swarm and evolutionary strategies Hybrid approaches outperform standalone methods in large -scale scheduling scenarios [24] Integration of nature -inspired algorithms for cloud resource allocation and

scheduling Bio-inspired algorithms evaluated for cost, energy, and QoS performance Nature-inspired methods optimize resource allocation and improve cloud service reliability It also makes us aware of the importance of metaheuristic algorithms for viewing and solving the complex issues of cloud computing optimization. In this analysis, the applications of the two super classes are analyzed using various tasks, including scheduling, resource allocation, and energy management, giving a clear view of their performances and drawbacks. Although the presented work contributes to enhancement in the current approaches, there are still some issues, holes in the current literature, and prospects for creating more reliable, versatile, and composite optimization methods. Future works should be directed towards these research gaps and fascinating features, incorporating machine learning and improving current approaches to adapt to the growing sophistication of cloud environments. These will go a long way in developing mor e effective, reliable and elastic cloud computing systems.

3. DISCUSSION

Metaheuristic optimization has been widely adopted as the fundamental approach in handling diverse, complicated issues in cloud environments. These techniques handle some of the most im portant aspects, including the schedule related to tasking, internal resource things, and energy usage fundamental to improving the cloud system. Cognitive algorithms such as particle swarm optimization (PSO), genetic algorithms (GA), and deep reinforcemen t learning (DRL) are thus more suitable for NP-hard problems in dynamic and distributed environments. The major hurdles that have yet to be appropriately conquered include scalability issues, integration issues and an ability to change in real time. The pr esent section presents the metaheuristic optimization technique, its merits and demerits, and the prospects of using the techniques to enhance cloud computing efficiency.

3.1 Advancements and Challenges in Metaheuristic Optimization for Cloud Computing

The rev iewed studies highlight the importance of metaheuristic optimization in solving challenging scheduling and resource allocation issues in cloud computing. Algorithms like Cuckoo -based Discrete Symbiotic Organisms Search and Deep Reinforcement Learning show a clear upward trend in enhancing cloud settings. The possibility of offering nearly the best solutions for NP-hard cases is crucial for addressing the growing needs of distributed systems [25].

3.2 Advantages of metaheuristic algorithms

- Efficiency and Scalability: The same C-DSOS algorithm improves the convergence rate by using

intelligent search techniques in large volumes to search spaces because of the increased efficiency in scheduling compared to typical approaches [26].

- Adaptability: DRL and hybri d algorithms use complex approaches to work with challenging dynamic

and distributed cloud tenancy scenarios to improve resource allocation and workload distribution [27].

- Energy and Cost Optimization: It is also important for sustainable cloud operations to decrease

operational costs and energy consumption: we use Bio -inspired methods, such as Particle Swarm Optimization (PSO) and Genetic Algorithms (GA) [28].

3.3 Challenges and Limitations

- Scalability Constraints: The metaheuristic techniques are, however, found to be very competent but may

face the issue of high computational overheads when applied in large-scale systems. [29]

- Complexity in Integration: When two or more algorithms are integrated into a single model, the overall

implementation process and resource requirements become complicated [30].

- Dynamic Environment Adaptability: While DRL and heuristic methods allow for proper control, their

use in responding to real-time disturbances and dynamic changes in cloud environments still needs to be more adequately researched.

3.4 Future Directions

- Machine Learning Integration: When combined with machine learning, metaheuristics, and

reinforcement learning, it seems possible to build systems that are more intelligent.

- Hybridization of Techniques: Bio -inspired approaches should be combined with heuristic methods to

improve scheduling and resources controlling processes tasks.

- Focus on Sustainability: Energy efficiency and its connection with environmental considerations must

also be incorporated into optimization models, which is still aresearch imperative.

- Real-world Applications and Validation: Extending these algorithms in practical real cloud

environments other than the CloudSim simulation toolkit can prove their feasibility and practicality. Metaheuristic optimization is still gradually developing as a fundamental area of cloud computing investigation. This way, such algorithms that represent an improvement upon existing limitations and employ new ideas can only go a long way toward strengthening the dependability, eff ectiveness and longevity of today and future cloud systems [31].

4. CONCLUSION

Algorithmic conceptualization has confirmed metaheuristic optimization as a critical avenue in solving the complex issues of cloud computing, such as task scheduling, resource p rovisioning and energy efficiency. Due to the nature of these problems, all of them belong to complex classes of combinatorial optimization, which is why they are NP-hard, which means that only excellent and flexible methods should be used to control them in the areas with large search spaces and variable functioning conditions. The literature surveyed in this paper demonstrates the efficiencies of different algorithms that can be classified as bio -inspired, such as PSO and ACO, hybrid methods, and sophisti cated techniques, including DRL. The algorithms presented in this study show significantly higher performance in improving various performance parameters like makespan cost, resource utilization, and QoS. However, several issues still need to be addressed regarding the optimal implementation of metaheuristic optimization in cloud computing systems. Scalability is still an issue of concern because a set of algorithms is often less efficient in large-scale systems. Some of the challenges tagged with the application of integration include the complexity of integration within hybrid algorithms and the inability to predict abrupt changes in cloud computing environments, thus requiring real -time reconfiguration. Further, there are tools like CloudSim available that simulate the workload distribution, which is a valuable aspect but needs to show the actual engineering application of many of the proposed methods. Given these limitations, future research requires advancing new directions that would be embraced in providing the best strategies in the healthcare delivery system. Combining machine learning, especially reinforcement learning and meta-heuristic techniques, can be a foundation for effectively making intelligent systems to handle dynamic cloud -related issues. This perspective should be extended to hybridization heuristics to enhance them to integrate the promising aspects of different optimization paradigms while addressing the concerns about System Complexity and Resource Usage. Furthermore, sustainable computing must be kept as aresearch imperative, particularly for energy awareness and the mitigation of practitioners' ecological footprints per mammoth cloud infrastructures. Metaheuristic optimization has remained essential in improving the performance, robu stness, and expandability of cloud computing service-oriented solutions. If the existing gaps are solved and the potential of advanced methodologies are utilized, the researchers and IT personnel can significantly improve cloud systems. This constant growt h effectively enhances existing cloud research and development and provides roots from which the subsequent development of distributed computing may evolve.

REFERENCES

[1] J. K. Konjaang and L. Xu, "Meta-heuristic Approaches for Effective Scheduling in In frastructure as a Service Cloud: A Systematic Review," Journal of Network and Systems Management, vol. 29, no. 2, pp. 1–57, Apr. 2021, doi: 10.1007/S10922-020-09577-2/FIGURES/6.

[2] C. W. Tsai and J. J. P. C. Rodrigues, "Metaheuristic scheduling for cloud: A survey," IEEE Syst J, vol. 8, no. 1, pp. 279–291, Mar. 2014, doi: 10.1109/JSYST.2013.2256731.

[3] "Advances in Iot and Security With Computational Intelligence | PDF | Metaheuristic | Cloud Computing." Accessed: Dec. 14, 2024. [Online]. Available: https://www.scribd.com/document/777456354/978-981-99-5088-1

[4] S. Jomah and A. S, "Meta -Heuristic Scheduling: A Review on Swarm Intelligenc e and Hybrid Meta-Heuristics Algorithms for Cloud Computing," SN Operations Research Forum, vol. 5, no. 4, pp. 1–42, Dec. 2024, doi: 10.1007/S43069-024-00382-0.

[5] S. Sa'ad, A. Muhammed, M. Abdullahi, and A. Abdullah, "An optimised cuckoo-based discrete symbiotic organisms search strategy for tasks scheduling in cloud computing environment," Nov. 2023, Accessed: Dec. 14, 2024. [Online]. Available: https://arxiv.org/abs/2311.15358v1

[6] M. C. Pandey and P. S. Rawat, "Nature -Inspired Metaheuristic Algorithms for Optimization in Cloud Computing: A Review and Analysis," 2023 10th IEEE Uttar Pradesh Section International Conference on Electrical, Electronics and Computer Engineering, UPCON 2023, pp. 57–62, 2023, doi: 10.1109/UPCON59197.2023.10434926.

[7] S. K. Medishetti, R. K. Donthi, G. Soma Sekhar, G. R. Karri, and K. V. Kumar, "Analysis of Meta Heuristic Algorithms in Task Scheduling for Cloud -Fog Computing: A future Perspective," IEEE International Conference on Data Engineering and Communication Systems, ICDECS 2024, 2024, doi: 10.1109/ICDECS59733.2023.10503263.

[8] S. R. Shishira, A. Kandasamy, and K. Chandrasekaran, "Survey on metaheuristic optimization techniques in cloud computing," International Conference on Advances in Computing, Communications and Informatics , pp. 1434 –1440, Nov. 2016, doi: 10.1109/ICACCI.2016.7732249.

[9] G. Zhou, W. Tian, R. Buyya, R. Xue, and L. Song, "Deep reinforcement learning -based methods for resource scheduling in cloud computing: areview and future directions," Artificial Intelligence Review 2024 57:5, vol. 57, no. 5, pp. 1–42, Apr. 2024, doi: 10.1007/S10462-024-10756-9.

[10] J. K. Konjaang and L. Xu, "Meta-heuristic Approaches for Effective Scheduling in Infrastructure as a Service Cloud: A Systematic Review," Journal of Network and Systems Management, vol. 29, no. 2, pp. 1–57, Apr. 2021, doi: 10.1007/S10922-020-09577-2/FIGURES/6.

[11] C. W. Tsai and J. J. P. C. Rodrigues, "Metaheuristic scheduling for cloud: A survey," IEEE Syst J, vol. 8, no. 1, pp. 279–291, Mar. 2014, doi: 10.1109/JSYST.2013.2256731.

[12] J. Chauhan and T. Alam, "Comparative Study of Metaheuristic Algorithms for Scheduling in Cloud Computing Based on QoS Parameters," Lecture Notes in Networks and Systems, vol. 756 LNNS, pp. 1–13, 2023, doi: 10.1007/978-981-99-5088-1_1/FIGURES/3.

[13] S. Jomah and A. S, "Meta -Heuristic Scheduling: A Review on Swarm Intelligence and Hybrid Meta-Heuristics Algorithms for Cloud Computing," Operations Research Forum, vol. 5, no. 4, pp. 1–42, Dec. 2024, doi: 10.1007/S43069-024-00382-0/METRICS.

[14] S. Sa'ad, A. Muhammed, M. Abdullahi, and A. Abdullah, "An optimised cuckoo -based discrete symbiotic organisms search strategy for tasks scheduling in cloud computing environment," Nov. 2023, Accessed: Dec. 14, 2024. [Online]. Available: https://arxiv.org/abs/2311.15358v1

[15] M. C. Pandey and P. S. Rawat, "Nature -Inspired Metaheuristic Algorithms for Optimization in Cloud Computing: A Review and Analysis," 2023 10th IEEE Uttar Pradesh Section Internatio nal Conference on Electrical, Electronics and Computer Engineering, UPCON 2023, pp. 57–62, 2023, doi: 10.1109/UPCON59197.2023.10434926.

[16] S. K. Patel and A. Singh, "Task Scheduling in Cloud Computing Using Hybrid Meta-heuristic: A Review," pp. 453–472, Jan. 2022, doi: 10.1007/978-981-15-7533-4_35.

[17] S. K. Medishetti, R. K. Donthi, G. Soma Sekhar, G. R. Karri, and K. V. Kumar, "Analysis of Meta Heuristic Algorithms in Task Scheduling for Cloud -Fog Computing: A future Perspective," IEEE International Conference on Data Engineering and Communication Systems, ICDECS 2024, 2024, doi: 10.1109/ICDECS59733.2023.10503263.

[18] S. R. Shishira, A. Kandasamy, and K. Chandrasekaran, "Survey on metaheuristic optimization techniques in cloud computing," 2016 Interna tional Conference on Advances in Computing, Communications and Informatics, ICACCI 2016 , pp. 1434 –1440, Nov. 2016, doi: 10.1109/ICACCI.2016.7732249.

[19] S. Sa'ad, A. Muhammed, M. Abdullahi, and A. Abdullah, "An optimised cuckoo -based discrete symbiotic organisms search strategy for tasks scheduling in cloud computing environment," Nov. 2023, Accessed: Dec. 14, 2024. [Online]. Available: https://arxiv.org/abs/2311.15358v1

[20] G. Zhou, W. Tian, R. Buyya, R. Xue, and L. Song, "Deep Reinforcement Learning-based Methods for Resource Scheduling in Cloud Computing: A Review and Future Directions," Artif Intell Rev, vol. 57, no. 5, May 2021, doi: 10.1007/S10462-024-10756-9.

[21] J. Zhou, S. Chen, and H. Kuang, "Robust Scheduling in Cloud Environment Based on Heuri stic Optimization Algorithm," Nov. 2023, Accessed: Dec. 14, 2024. [Online]. Available: https://arxiv.org/abs/2311.17757v1

[22] R. Al-Arasi and A. Saif, "Task scheduling in cloud computing based on metaheuristic techniques: A review paper," EAI Endorsed Transactions on Cloud Systems, Vol. "6," no. 17, p. 162829, Jan. 2020, doi: 10.4108/EAI.13-7-2018.162829.

[23] M. C. Pandey and P. S. Rawat, "Nature -Inspired Metaheuristic Algorithms for Optimization in Cloud Computing: A Review and Analysis," 2023 10th IEEE Uttar Pradesh Section International Conference on Electrical, Electronics and Computer Engineering, UPCON 2023, pp. 57–62, 2023, doi: 10.1109/UPCON59197.2023.10434926.

[24] J. K. Konjaang and L. Xu, "Meta-heuristic Approaches for Effective Scheduling in In frastructure as a Service Cloud: A Systematic Review," Journal of Network and Systems Management, vol. 29, no. 2, pp. 1–57, Apr. 2021, doi: 10.1007/S10922-020-09577-2/FIGURES/6.

[25] M. Abdullahi, M. A. Ngadi, and S. M. Abdulhamid, "Symbiotic Organism Sear ch optimization based task scheduling in cloud computing environment," Future Generation Computer Systems , vol. 56, pp. 640–650, Mar. 2016, doi: 10.1016/J.FUTURE.2015.08.006.

[26] G. Zhou, W. Tian, R. Buyya, R. Xue, and L. Song, "Deep Reinforcement Learning-based Methods for Resource Scheduling in Cloud Computing: A Review and Future Directions," Artif Intell Rev, vol. 57, no. 5, May 2021, doi: 10.1007/S10462-024-10756-9.

[27] D. Rahbari, "Analyzing Meta -Heuristic Algorithms for Task Scheduling in a Fog -Based IoT Application," Algorithms 2022, Vol. 15, Page 397 , vol. 15, no. 11, p. 397, Oct. 2022, doi: 10.3390/A15110397.

[28] J. K. Konjaang and L. Xu, "Meta-heuristic Approaches for Effective Scheduling in Infrastructure as a Service Cloud: A Systematic Review," Journal of Network and Systems Management, vol. 29, no. 2, Apr. 2021, doi: 10.1007/S10922-020-09577-2.

[29] V. Tomar, M. Bansal, and P. Singh, "Metaheuristic Algorithms for Optimization: A Brief Review," Engineering Proceedings 2023, Vol. 59, Page 238 , vol. 59, no. 1, p. 238, Mar. 2024, doi: 10.3390/ENGPROC2023059238.

[30] "Advances in Iot and Security With Computational Intelligence | PDF | Metaheuristic | Cloud Computing." Accessed: Dec. 14, 2024. [Online]. Available: https://www.scribd.com/document/777456354/978-981-99-5088-1

[31] J. Zhou, S. Chen, and H. Kuang, "Robust Scheduling in Cloud Environment Based on Heuristic Optimization Algorithm," Nov. 2023, Accessed: Dec. 14, 2024. [Online]. Available: https://arxiv.org/abs/2311.17757v1