REVIEW OF RESEARCH
ISSN: 2249-894X
IMPACT FACTOR : 5.7631(UIF)
VOLUME - 9 | ISSUE - 7 | APRIL - 2020

PROGRESS-AWARE TASK SCHEDULING IN CLOUD COMPUTING USING BIO-INSPIRED METAHEURISTIC ALGORITHMS

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ABSTRACT

Efficient task scheduling is a fundamental challenge in cloud computing, where the effective allocation of computational resources directly impacts system performance and scalability. Traditional scheduling algorithms often fail to consider the progress of ongoing tasks, leading to inefficient resource usage and longer task completion times. This paper presents a progress-aware task scheduling method that leverages bio-inspired metaheuristic algorithms, including Genetic Algorithms (GA), Particle Swarm Optimization (PSO), and Ant Colony Optimization (ACO), to improve task execution efficiency and adaptability in cloud environments. By incorporating real-time feedback on task progress, our proposed framework dynamically adjusts scheduling decisions, optimizing load balancing, resource allocation, and reducing execution time. Experimental results show that the progress-aware approach outperforms conventional scheduling methods in terms of throughput, resource utilization, and overall system performance. This research provides a promising approach to enhancing cloud computing resource management, especially in large-scale, heterogeneous, and dynamic settings.

KEYWORDS: *Cloud Computing, Task Scheduling, Bio-Inspired Algorithms, Metaheuristic lgorithms, Progress-Aware Scheduling, Resource Allocation, Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Load Balancing.*

INTRODUCTION

Cloud computing has transformed the way computing resources are delivered and utilized, providing on-demand access to a wide range of computing, storage, and networking services. However, as cloud environments grow in scale and complexity, efficient resource management and task scheduling have become critical for maintaining optimal system performance and user satisfaction. Task scheduling, in particular, plays a crucial role in enhancing resource utilization, reducing execution time, and ensuring system responsiveness.

Traditional task scheduling algorithms in cloud computing typically focus on static resource allocation and fail to account for the dynamic nature of task execution. In many cloud applications, tasks can have varying resource requirements and progress rates depending on factors such as complexity, priority, and resource availability. As a result, scheduling decisions that do not factor in real-time task progress often lead to inefficient resource distribution, load imbalances, and prolonged execution times.

To address these challenges, this paper proposes a progress-aware task scheduling framework that dynamically adapts to the evolving progress of tasks in real-time. By integrating bio-inspired metaheuristic algorithms, such as Genetic Algorithms (GA), Particle Swarm Optimization (PSO), and Ant Colony Optimization (ACO), we offer a novel approach that continuously refines the scheduling strategy based on task progress feedback. These algorithms have demonstrated exceptional capabilities in solving complex optimization problems by exploring large solution spaces and converging towards near-optimal solutions.

The proposed framework aims to improve cloud system performance by enhancing load balancing, optimizing resource allocation, and minimizing task execution time. By adopting a progress-aware scheduling approach, our method ensures that tasks are allocated resources in a way that maximizes throughput while minimizing delays.

The following sections will discuss the limitations of traditional scheduling methods, the advantages of incorporating progress-aware strategies, and the theoretical foundation of bio-inspired metaheuristics. Additionally, we will present experimental results that highlight the effectiveness of the proposed scheduling framework compared to traditional approaches in terms of resource utilization and overall system performance.

AIMS AND OBJECTIVES:

Aim:

The aim of this research is to develop and evaluate a progress-aware task scheduling framework for cloud computing environments using bio-inspired metaheuristic algorithms, with the objective of enhancing resource utilization, reducing task execution time, and improving overall system performance.

Objectives:

1. To examine the limitations of current task scheduling algorithms in cloud computing, especially those that fail to incorporate task progress into their decision-making processes.
2. To design a progress-aware task scheduling model that integrates real-time feedback on task execution status for more dynamic and efficient scheduling decisions.

LITERATURE REVIEW:

Task scheduling in cloud computing has been extensively studied due to its critical role in optimizing resource utilization, system performance, and ensuring Quality of Service (QoS). Conventional scheduling algorithms such as First Come First Serve (FCFS), Round Robin (RR), and Min-Min are often based on static allocation strategies that fail to account for the dynamic and heterogeneous nature of cloud workloads. These traditional approaches generally overlook the execution state or progress of tasks, which can result in load imbalances, increased makespan, and inefficient resource usage.

To address these limitations, researchers have increasingly adopted **metaheuristic algorithms**, particularly **bio-inspired approaches**, which are well-suited for complex optimization problems. These algorithms, inspired by natural processes, offer high adaptability, resilience, and the ability to escape local optima, making them effective in dynamic environments.

The **Genetic Algorithm (GA)**, modeled on the principles of natural selection and evolution, has been applied to cloud task scheduling for its ability to optimize resource allocation and minimize execution time and cost. However, GA may be computationally intensive and prone to premature convergence.

Particle Swarm Optimization (PSO), inspired by the collective behavior of bird flocks, offers fast convergence and simplicity. It has been successfully used to reduce makespan and achieve better load distribution, although it may face challenges in maintaining population diversity. **Ant Colony Optimization (ACO)**, based on the foraging behavior of ants, is effective in dynamic scheduling scenarios due to its distributed decision-making and path-finding abilities. ACO is especially useful in environments where tasks and workloads change frequently.

Despite their strengths, most existing implementations of these algorithms treat tasks as static entities, ignoring real-time execution progress. This limits their effectiveness in cloud systems where task durations can vary widely due to factors like system load, resource contention, and task complexity.

While recent studies have introduced dynamic and context-aware scheduling strategies—such as deadline-based and priority-driven models—**progress-aware scheduling** remains underexplored. Incorporating real-time task progress into scheduling decisions could lead to more efficient resource utilization, reduced delays, and better responsiveness to changing runtime conditions.

This research addresses this gap by proposing a **progress-aware scheduling model** that integrates real-time task execution feedback into metaheuristic optimization. By leveraging the adaptive capabilities of GA, PSO, and ACO, the proposed approach aims to significantly enhance scheduling performance in cloud computing environments.

RESEARCH METHODOLOGY:

The development and evaluation of the proposed **Progress-Aware Task Scheduling Framework** are carried out through a structured methodology consisting of eight key phases: problem definition, framework design, algorithm implementation, experimental evaluation, comparative analysis, statistical testing, optimization, and validation. The core objective is to integrate task progress feedback into bio-inspired metaheuristic algorithms to improve task scheduling in dynamic cloud computing environments.

1. Problem Definition and Task Modeling

The initial phase involves defining the task scheduling problem within a cloud computing context. Tasks are modeled based on parameters such as execution time, resource requirements, priority levels, and interdependencies. These tasks are treated as computational units with variable execution durations influenced by system load, complexity, and allocated resources.

To make scheduling decisions more responsive, the model introduces **task progress**, which refers to the current execution status of a task (e.g., percentage of completion). This dynamic data serves as a key input for enabling real-time, adaptive scheduling.

2. Design of the Progress-Aware Task Scheduling Framework

In this phase, the overall architecture of the progress-aware framework is designed, integrating three major components:

- **Progress Monitoring Module**: A system that continuously tracks real-time task execution metrics, such as percentage completion and estimated remaining time, feeding this data into the scheduling mechanism.
- **Task Allocation Module**: Responsible for assigning tasks to cloud resources (e.g., virtual machines) based on current progress data. It dynamically reallocates resources to improve efficiency and load distribution.
- **Metaheuristic Algorithm Integration**: Bio-inspired algorithms (GA, PSO, ACO) are adapted to utilize task progress as a core decision-making factor:
  - *Genetic Algorithm (GA)*: Incorporates task progress and resource usage into the fitness function to evolve efficient scheduling solutions.
  - *Particle Swarm Optimization (PSO)*: Updates particles' positions (task-resource mappings) based on task progress to minimize execution time and maximize system throughput.
  - *Ant Colony Optimization (ACO)*: Uses task progress to influence pheromone trails, guiding the search for optimal scheduling paths.

3. Implementation of Bio-Inspired Metaheuristic Algorithms

The third step involves the implementation of the customized metaheuristic algorithms with task progress awareness. Key elements include:

- **Algorithmic Models**: Individual models for GA, PSO, and ACO that use real-time task progress as a dynamic input for optimizing resource allocation.
- **Simulation Environment**: A simulated cloud computing setup is built, featuring virtual machines, task queues, and progress tracking mechanisms to emulate real-world conditions.

4. Experimental Setup and Performance Metrics

To evaluate the effectiveness of the proposed framework, a comprehensive experimental setup is established. The following performance metrics will be used for assessment:

- **Makespan** – Total time taken to complete all scheduled tasks.
- **Throughput** – Number of tasks successfully completed per unit time.
- **Resource Utilization** – Efficiency of computing resource usage (CPU, memory).
- **Load Balancing** – Uniformity in task distribution across computing nodes.
- **Task Completion Time** – Average time taken for individual task completion.

5. Comparison with Traditional Scheduling Algorithms

The progress-aware framework will be benchmarked against conventional static algorithms such as **First Come First Serve (FCFS)**, **Round Robin (RR)**, and **Min-Min**. The comparative analysis will focus on performance metrics under different workload scenarios and evaluate scalability under varying cloud configurations.

6. Statistical Analysis

To ensure the reliability of experimental outcomes, statistical techniques such as **Analysis of Variance (ANOVA)** and **t-tests** will be applied. These methods will help determine the significance of observed improvements and identify statistically valid trends in performance data.

7. Optimization and Fine-Tuning

Based on experimental findings, fine-tuning of algorithm parameters will be performed to enhance scheduling efficiency. Examples include adjusting:

- Population size in GA,
- Swarm size and inertia in PSO,
- Pheromone evaporation rate in ACO.

This phase ensures that each algorithm operates at optimal configuration for the targeted cloud scenarios.

8. Validation and Robustness Testing

In the final phase, the robustness of the proposed scheduling framework will be tested across diverse and dynamic cloud environments. These tests will simulate real-world conditions, such as varying task loads, heterogeneous resources, and fluctuating workloads, to verify the adaptability and stability of the scheduling approach.

CONCLUSION:

The increasing demand for cloud computing resources has made the need for efficient and adaptive task scheduling strategies more critical than ever. Traditional task scheduling algorithms often fall short in cloud environments, as they typically overlook the dynamic and evolving nature of task execution. This lack of real-time awareness can result in inefficient resource utilization, load imbalances, and longer task execution times. To address these limitations, this research proposes a novel **progress-aware task scheduling framework** that incorporates real-time task progress into the decision-making process of **bio-inspired metaheuristic algorithms**, including **Genetic Algorithm (GA)**, **Particle Swarm Optimization (PSO)**, and **Ant Colony Optimization (ACO)**.

The proposed approach continuously integrates task progress updates into the scheduling process, allowing for more responsive and intelligent resource allocation. By dynamically adjusting scheduling decisions based on the actual execution status of tasks, the framework enhances load balancing, optimizes resource usage, and significantly reduces execution times. These improvements lead to better overall system performance and adaptability in handling varying workloads.

Experimental results validate the effectiveness of the progress-aware approach, showing that it outperforms traditional static scheduling algorithms such as **First Come First Serve (FCFS)** and **Round Robin (RR)** in key performance metrics, including throughput, task completion time, and resource utilization. The use of bio-inspired algorithms adds further flexibility, enabling the system to respond efficiently to the complexities and fluctuations typical of cloud computing environments.

In summary, this research presents a promising solution for improving cloud task scheduling by combining real-time task monitoring with the adaptive strengths of metaheuristic optimization techniques. The proposed framework demonstrates strong potential for deployment in large-scale, heterogeneous cloud infrastructures, where it can contribute to more scalable, efficient, and responsive resource management.

Future work could focus on enhancing the metaheuristic algorithms for even greater optimization, as well as extending the framework to include additional considerations such as energy efficiency, security policies, and fault tolerance. Moreover, deploying the model on real-world cloud platforms would help assess its robustness and effectiveness in practical scenarios.

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