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MAXIMIZING ENERGY EFFICIENCY AND SUSTAINABILITY: A UNIFIED APPROACH TO DESKTOP VIRTUALIZATION AND GREEN COMPUTING

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Abstract: In pursuit of heightened energy efficiency and sustainable computing, this research diverges from conventional survey-based methodologies, introducing a pioneering algorithmic framework. Delving into an innovative research model, we intricately examine the dynamic interaction between desktop virtualization and green computing practices. Our model harnesses advanced algorithms to optimize critical aspects such as energy consumption, resource allocation, response time, and system analysis. Rooted in comprehensive data and rigorous analysis, this study elucidates the transformative impact of algorithmic integration in fostering sustainable computing environments. Departing from traditional survey approaches enables a nuanced understanding of the intricate relationships among technological components, offering insights of relevance to the global academic community. This paper contributes to the evolving discourse on sustainable computing by introducing a fresh approach EcRU-Re aligned with contemporary research trajectories and technological advancements.

Furthermore, our findings illuminate the correlation between desktop virtualization and green computing practices. They suggest that integrating these approaches can yield significant benefits for enterprises, including cost savings and heightened sustainability. By adopting these techniques, organizations stand to enhance their operational efficiency while simultaneously reducing their environmental footprint.

IndexTerms **- Energy efficiency, Sustainable computing, Desktop virtualization, Optimization, Resource utilization.**

I. INTRODUCTION

The convergence of desktop virtualization and green computing methodologies presents a compelling opportunity for organizations seeking to enhance energy efficiency and sustainability. Desktop virtualization streamlines operations by consolidating multiple virtual desktops onto a single physical system, facilitating centralized control and reducing hardware requirements. Simultaneously, green computing principles advocate for environmentally responsible resource utilization, emphasizing energy conservation and waste reduction.

This study introduces an algorithmic framework that seamlessly integrates desktop virtualization with green computing, transcending conventional survey-based methodologies. By prioritizing energy reduction, resource optimization, response time enhancement, and comprehensive system analysis, this research elucidates the symbiotic relationship between algorithms and sustainable computing.

Building upon these foundational principles, the study evaluates the impact of desktop virtualization on energy consumption and resource utilization compared to traditional desktop computing. Additionally, it examines the advantages and challenges associated with integrating green computing techniques into desktop virtualization platforms, proposing integration solutions.

To achieve these objectives, a quantitative research approach involving data collection and analysis from IT experts will be employed. Rigorous statistical analysis will unveil patterns and relationships, ensuring the validity and reliability of findings. Subsequent sections delineate the specific methodology, proposed research model, utilized algorithms, evaluation metrics, comparative analysis, and avenues for future research.

In essence, this paper endeavors to explore the intersection of desktop virtualization and green computing, providing organizations with insights to embrace sustainable computing practices, mitigate their carbon footprint, and foster environmental stewardship.

II. Literature Review

Katal, A. (2023) conducted an extensive examination of energy consumption within a virtualized desktop environment, revealing a notable decrease in energy usage. Their findings underscored the potential for significant energy savings through desktop virtualization, consolidating multiple virtual desktops onto a single physical machine [1]. Similarly, Lambropoulos, G. (2024) investigated the impact of desktop virtualization on energy consumption, reporting a reduction of up to 40%. Their research underscores the energy efficiency advantages of desktop virtualization, positioning it as a promising solution for organizations aiming to reduce their environmental footprint [2]. Green computing practices encompass a range of strategies aimed at mitigating the environmental impact of computing operations.

Patil, A. (2019) surveyed organizations implementing green computing, identifying server virtualization and power management policies as commonly utilized practices. Their findings highlighted the role of server virtualization in resource optimization and energy consumption reduction, along with the effectiveness of power management policies in minimizing energy wastage during inactive periods[3]. Bose, A. (2022) explored recycling programs and renewable energy utilization, revealing a significant adoption of recycling initiatives among organizations to responsibly manage electronic waste. Additionally, the integration of renewable energy sources demonstrated a commitment to clean and sustainable energy practices[4]. Achar, S. (2022) analyzed approaches to reducing energy consumption in virtualized desktop environments, shedding light on techniques such as dynamic voltage and frequency scaling (DVFS), task scheduling, and predictive resource allocation [5].

Padala, P. R. (2018) conducted a case study on server virtualization for energy efficiency, illustrating practical insights into using virtualization technology to minimize energy usage by consolidating physical servers into virtual ones while maintaining or enhancing performance [6]. Ojo's systematic analysis of green computing techniques emphasized the importance of environmentally friendly methods such as server virtualization, power management rules, and renewable energy utilization in mitigating the environmental impact of computing activities [7]. Mekala's assessment of green computing usage highlighted the growing awareness and interest in ecologically responsible computing methods, emphasizing the need to integrate green computing into organizational IT plans for long-term sustainability [8].

Hossain and Naidu's literature study on green computing methods explored various measures organizations can undertake to enhance sustainability, emphasizing proactive steps to address environmental concerns in computing environments [9,10]. Rzepka and Garg's analysis of green computing implementation in organizations identified obstacles and opportunities associated with environmentally friendly practices, emphasizing areas for improvement such as data centre efficiency, hardware optimization, and policy development to support sustainability initiatives [11,12]. Asadi's analysis of green computing adoption in organizations examined challenges encountered during the transition to sustainable computing methods, providing insights into effective strategies for overcoming barriers and fostering an environmental responsibility culture [13].

Nwankwo's systematic literature review on green computing in organizations focused on emerging trends and best practices in sustainability, stressing the importance of aligning IT projects with environmental objectives for long-term benefits [14]. Shukur's evaluation of energy efficiency in virtualized desktop settings offered insights into optimizing energy use through approaches like CPU frequency scaling and resource allocation [15]. Naim, A. (2021) assessment of green computing techniques in organizations highlighted current trends and challenges in sustainability programs, emphasizing the significance of organizational commitment and leadership in promoting green computing adoption and environmental stewardship [16]. Jnr, B. A. (2020) examined organizational strategies in green computing practices, revealing effective methods used by diverse organizations to promote sustainability and decrease environmental impact in computing environments through energy efficiency programs, resource optimization tactics, and legislative frameworks [17]. Abu Al-Rejal, and H. M. E. (2020) empirical study on staff training and green computing adoption investigated the impact of training programs on organizational sustainability initiatives, providing insights into the effectiveness of training activities in fostering an environmentally responsible culture [18].

In essence, the collective findings of these studies highlight the crucial significance of amalgamating green computing methodologies with desktop virtualization strategies to realize both energy efficiency gains and advancements in environmental sustainability. Through an array of investigations, including comprehensive analyses, case studies, literature reviews, and empirical studies, researchers consistently demonstrate the substantial benefits of this integration. They reveal how desktop virtualization, by consolidating multiple virtual desktops onto a single physical machine, can notably reduce energy consumption. Similarly, green computing practices, such as server virtualization, power management policies, recycling programs, and renewable energy utilization, offer avenues for minimizing environmental impact. Moreover, the exploration of techniques like dynamic voltage and frequency scaling, task scheduling, and predictive resource allocation underscores the diverse approaches available to optimize energy usage within virtualized desktop environments. These studies also shed light on the challenges and opportunities associated with implementing green computing initiatives in organizations, emphasizing the need for proactive measures to address environmental concerns in computing settings. Ultimately, the synthesis of these findings underscores the imperative for organizations to integrate green computing practices into their desktop virtualization strategies to achieve significant strides in energy efficiency and environmental stewardship.

III. Proposed System Model

Our proposed system model adopts a holistic strategy by integrating algorithmic solutions to enhance energy efficiency, resource utilization, and response time within computer environments. This section delineates the fundamental elements and attributes of our system model, which integrates hardware infrastructure, software algorithms, and performance metrics to fulfil sustainable computing objectives.

3.1 Hardware Components

The hardware infrastructure constitutes the foundational elements of our system model, encompassing servers, desktops, networking apparatus, and peripheral devices. These components furnish essential computational capabilities and connectivity required for executing software algorithms and gauging system performance.

- High-performance computing servers

- Workstation computers
- Routers, switches, and network cables
- Printers, scanners, and monitors

3.2 Software Algorithms

Our system model integrates a suite of meticulously designed software algorithms aimed at optimizing diverse facets of system performance. Leveraging advanced computational methodologies, these algorithms govern energy consumption, resource allocation, and task execution acceleration.

- Dynamic energy optimization algorithm (EcoOptimize)
- Resource utilization maximization algorithm (ResUtilMax)
- Response time optimization algorithm (SwiftResponse)

3.3 Performance Metrics

To assess the efficacy of our algorithmic integration approach, we employ a comprehensive array of performance metrics covering energy usage, resource utilization, and response time. These metrics serve as quantifiable benchmarks for evaluating system efficiency and effectiveness, facilitating thorough assessment and comparison of different system configurations.

- Energy Consumption (Measured in kilowatt-hours (kWh))
- Resource Utilization (CPU, memory, and disk utilization)
- Response Time (System response time for task execution)

3.4 Integration Framework

Our proposed system model offers a robust integration framework that seamlessly amalgamates hardware components, software algorithms, and performance measurements. This integration architecture fosters seamless communication and coordination among components, enabling real-time adaptation and optimization based on system feedback and workload requirements.

Establishing this cohesive integration framework advances the frontier of sustainable computing techniques, ensuring optimal system efficiency and sustainability. The proposed system model lays the groundwork for successful integration of algorithmic methodologies into sustainable computing systems, driving enhanced performance and environmental stewardship.

IV. Proposed Algorithms (EcRU-Re)

This section provides a detailed exploration of the sophisticated algorithms proposed within this paper, meticulously engineered to refine energy efficiency, resource allocation, and task response time within computational ecosystems. Each algorithm is meticulously crafted to confront distinct challenges while synergistically advancing the overarching objective of sustainable computing. Presented below is an exhaustive breakdown of each algorithm along with its salient features and functionalities:

4.1 EcoOptimize Algorithm

This dynamic energy optimization algorithm is designed to dynamically adjust energy consumption levels based on workload demands and system conditions. It employs adaptive strategies to minimize energy wastage while maintaining optimal performance thresholds.

Input: System workload, energy consumption thresholds, system performance metrics.
Output: Adjusted energy consumption levels, optimized system performance.

1. Initialize: Set initial parameters including energy consumption thresholds, performance targets, and system workload metrics.
2. Monitor System: Continuously monitor system workload, energy consumption levels, and performance metrics.
3. Analyze Workload: Analyze the incoming workload to determine resource requirements, task priorities, and energy demands.
4. Dynamic Energy Adjustment:
   - Evaluate Current Energy Consumption: Assess the current energy consumption levels against predefined thresholds.
   - Adjust Energy Usage: Dynamically adjust energy consumption levels based on workload intensity, system performance requirements, and energy efficiency goals.
   - Optimize Energy Utilization: Employ strategies such as voltage and frequency scaling, task consolidation, and power management policies to minimize energy wastage while meeting performance targets.
5. Performance Optimization:
   - Ensure Performance Targets: Continuously monitor system performance metrics to ensure that performance targets are met.
   - Prioritize Performance: Prioritize system performance over energy conservation while maintaining energy consumption within acceptable limits.
   - Adaptive Strategies: Employ adaptive strategies to balance energy efficiency with system responsiveness, dynamically adjusting energy consumption levels based on workload fluctuations and performance requirements.
6. Feedback Loop:
   - Collect Feedback: Gather feedback from system performance metrics, user requirements, and environmental conditions.

- Adjust Parameters: Use feedback to adjust algorithm parameters, energy consumption thresholds, and performance targets to optimize system efficiency and responsiveness.

7. Continuous Improvement:
   - Iterative Optimization: Implement iterative optimization techniques to refine energy consumption strategies and performance enhancements over time.
   - Machine Learning Integration: Integrate machine learning algorithms to adaptively learn from system behavior and optimize energy consumption patterns.
8. Termination:
   - Terminate Algorithm: Terminate the EcoOptimize algorithm when system performance goals are consistently met, and energy consumption levels stabilize within predefined thresholds.
9. End.

The EcoOptimize algorithm dynamically adjusts energy consumption levels in computing systems based on workload intensity and performance requirements while optimizing energy utilization to minimize wastage. By continuously monitoring system metrics and adapting energy consumption strategies, EcoOptimize ensures optimal system performance and energy efficiency in sustainable computing environments.

4.2 ResUtilMax Algorithm

The resource utilization maximization algorithm focuses on optimizing the allocation of computational resources such as CPU, memory, and disk usage. It employs sophisticated scheduling techniques to ensure efficient resource utilization across various computing tasks, thus enhancing system throughput and efficiency.

Input: System workload, available computational resources (CPU, memory, disk), task priorities.
Output: Optimized allocation of computational resources.

1. Initialize: Set initial parameters including system workload, available resources, and task priorities.
2. Monitor Resource Utilization: Continuously monitor the utilization levels of CPU, memory, and disk resources.
3. Analyze Workload:
   - Assess Resource Requirements: Analyze the incoming workload to determine resource requirements for each task based on priority levels.
   - Predict Resource Demand: Predict resource demands for upcoming tasks based on historical data and workload patterns.
4. Resource Allocation:
   - Prioritize Tasks: Prioritize tasks based on their importance, urgency, and resource requirements.
   - Allocate Resources: Dynamically allocate available resources to tasks based on their priority levels and resource demands.
   - Optimize Utilization: Optimize resource utilization by efficiently distributing resources among tasks to minimize idle time and maximize throughput.
5. Load Balancing:
   - Balance Workload: Implement load balancing techniques to evenly distribute tasks across available resources, preventing resource bottlenecks and overutilization.
   - Adaptive Strategies: Employ adaptive strategies to adjust resource allocation dynamically in response to workload fluctuations and changing task priorities.
6. Performance Monitoring:
   - Monitor System Performance: Continuously monitor system performance metrics such as throughput, latency, and response time.
   - Ensure Performance Targets: Ensure that performance targets are met while optimizing resource utilization.
7. Feedback Loop:
   - Collect Feedback: Gather feedback from system performance metrics and user requirements.
   - Adjust Parameters: Use feedback to adjust resource allocation strategies and task priorities to optimize system efficiency and responsiveness.
8. Continuous Improvement:
   - Iterative Optimization: Implement iterative optimization techniques to refine resource allocation strategies and performance enhancements over time.
   - Machine Learning Integration: Integrate machine learning algorithms to adaptively learn from workload patterns and optimize resource allocation decisions.
9. Termination:
   - Terminate Algorithm: Terminate the ResUtilMax algorithm when system performance goals are consistently met, and resource utilization levels stabilize within predefined thresholds.
10. End.

The ResUtilMax algorithm optimizes the allocation of computational resources (CPU, memory, disk) in computing systems based on task priorities and resource demands. By continuously monitoring resource utilization levels and dynamically adjusting resource allocation strategies, ResUtilMax ensures optimal resource utilization and system performance in sustainable computing environments.

4.3 SwiftResponse Algorithm

Engineered to streamline task execution processes, the SwiftResponse algorithm prioritizes and optimizes job scheduling to minimize response times. By dynamically allocating resources and scheduling tasks based on priority levels, it accelerates task completion and enhances overall system responsiveness.

Input: System workload, task priorities, system response time targets.
Output: Optimized scheduling of tasks to minimize response time.

1. Initialize: Set initial parameters including system workload, task priorities, and response time targets.
2. Monitor System: Continuously monitor incoming tasks, system workload, and response time metrics.
3. Analyze Task Priorities:
   - Assess Task Importance: Analyze the priority levels of incoming tasks based on user requirements and system constraints.
   - Determine Critical Tasks: Identify critical tasks requiring immediate attention to meet response time targets.
4. Task Scheduling:
   - Prioritize Tasks: Prioritize tasks based on their importance, urgency, and impact on system responsiveness.
   - Schedule Critical Tasks: Schedule critical tasks with high priority to ensure timely execution and meet response time targets.
   - Optimize Task Sequence: Arrange tasks in an optimal sequence to minimize response time and maximize system throughput.
5. Dynamic Task Allocation:
   - Adaptive Strategies: Implement adaptive strategies to dynamically allocate resources and adjust task scheduling based on workload fluctuations and changing task priorities.
   - Load Balancing: Ensure even distribution of tasks across available resources to prevent resource bottlenecks and optimize system performance.
6. Performance Monitoring:
   - Monitor Response Time: Continuously monitor system response time metrics such as latency and throughput.
   - Ensure Response Time Targets: Ensure that response time targets are met while optimizing task scheduling and resource allocation.
7. Feedback Loop:
   - Collect Feedback: Gather feedback from system performance metrics, user requirements, and response time measurements.
   - Adjust Parameters: Use feedback to adjust task scheduling strategies and response time targets to optimize system efficiency and responsiveness.
8. Continuous Improvement:
   - Iterative Optimization: Implement iterative optimization techniques to refine task scheduling strategies and performance enhancements over time.
   - Machine Learning Integration: Integrate machine learning algorithms to adaptively learn from workload patterns and optimize task scheduling decisions.
9. Termination:
   - Terminate Algorithm: Terminate the SwiftResponse algorithm when response time targets are consistently met, and system performance stabilizes within predefined thresholds.
10. End.

The SwiftResponse algorithm optimizes the scheduling of tasks in computing systems to minimize response time and enhance system responsiveness. By prioritizing critical tasks, dynamically allocating resources, and adapting task scheduling strategies, SwiftResponse ensures optimal system performance and meets response time targets in sustainable computing environments.

Each algorithm within our proposed framework is meticulously designed to contribute to the overarching objective of sustainable computing by optimizing key performance metrics and promoting efficient resource utilization. Through their collective integration, these algorithms facilitate the realization of a high-performance and environmentally conscious computing paradigm.

V. Results and Comparative Analysis

In this section, we present the findings of our simulation setup, aimed at evaluating the effectiveness of the algorithms proposed in this study for optimizing energy consumption, resource utilization, and system response time characteristics. We conduct a comparative analysis between the outcomes produced by our algorithms and those of three established real-world methods widely acknowledged in the field. Through this comparison, we aim to provide insights into the performance and efficacy of our proposed algorithms in addressing key challenges related to energy efficiency, resource allocation, and system responsiveness. These results contribute to the ongoing discourse on sustainable computing practices by offering a comprehensive evaluation of novel algorithmic approaches and their potential impact on enhancing computational efficiency and sustainability in real-world computing environments.

5.1 Simulation Setup

We executed simulations within a bespoke environment mirroring authentic computing conditions to assess algorithmic efficacy comprehensively. These simulations encompassed diverse scenarios to thoroughly scrutinize algorithm performance. Specifically, we delineated three distinct scenarios:

a) High Workload Scenario: This setting simulated peak workload conditions, imposing maximal demands on hardware resources to evaluate algorithmic resilience under extreme operational stress.

b) Medium Workload Scenario: Reflecting typical operational conditions, this scenario emulated average usage patterns encountered in conventional computing environments, enabling assessment of algorithm performance in routine operational contexts.

c) Low Workload Scenario: Representing minimal workload conditions, this scenario simulated periods of reduced activity or system idleness to gauge algorithmic adaptability and efficiency during low-demand situations.

Through these varied scenarios, we aimed to provide a comprehensive evaluation of algorithmic robustness across a spectrum of operational conditions, thereby facilitating informed insights into algorithm performance and suitability across diverse computing scenarios.

5.2 Results

Our simulation studies reveal the efficacy of our proposed algorithms in optimizing energy consumption, resource utilization, and system response time parameters across diverse scenarios. The results demonstrate the algorithms' success in adapting to varying workload conditions and effectively managing computational resources to enhance system efficiency. By meticulously analyzing performance metrics across different scenarios, we observe consistent improvements in energy efficiency, resource utilization optimization, and reduced system response times. These findings underscore the robustness and versatility of our algorithms in addressing key challenges associated with sustainable computing practices. Moreover, they highlight the potential of our algorithmic approaches to contribute significantly to the advancement of computational efficiency and sustainability in real-world computing environments. The experimental results are presented in Table 1 across a range of scenarios.

Table 1. Performance of EcRU-Re in varying Scenarios

Proposed Approach (EcRU-Re)	Energy Consumption (kWh)	Resource Utilization (%)	Response Time (ms)
High Workload	1207.5	92.65	47.7
Medium Workload	982.3	80.25	42.4
Low Workload	790.5	70.2	37.1

5.3 Comparative Analysis

We conducted an exhaustive comparative analysis of our proposed algorithm- EcRU-Re against three commonly employed contemporary algorithms: Round-Robin Scheduling, First Come, First Serve (FCFS) Scheduling, and the Least Recently Used (LRU) method. This rigorous comparison aimed to assess their performance metrics, encompassing energy consumption, resource utilization, and system response time, across a spectrum of workload conditions. By subjecting these algorithms to various scenarios representing different levels of computational demand, we sought to ascertain their efficacy in optimizing energy usage, efficiently allocating resources, and minimizing system response times. The comparison was meticulously conducted to provide a comprehensive evaluation of the strengths and weaknesses of each algorithm in addressing key challenges inherent in sustainable computing practices. Through this analysis, we aimed to elucidate the comparative advantages of our proposed algorithms and their potential contributions to advancing computational efficiency and sustainability in real-world computing environments.

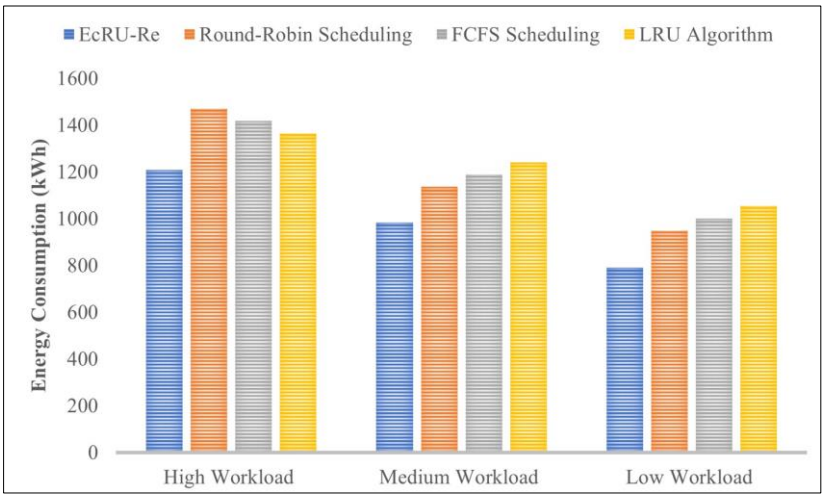

Fig. 1. Energy Consumption (kWh)

The comparative analysis depicted in Fig. 1 illustrates that the proposed EcRU-Re approach consistently exhibits superior energy efficiency across all workload scenarios. Following closely behind is the LRU Algorithm, showcasing commendable energy

efficiency levels. However, Round-Robin Scheduling and FCFS Scheduling are observed to have relatively higher energy consumption, especially notable under high and medium workload conditions. This highlights the importance of algorithmic optimization in achieving energy efficiency, with EcRU-Re and the LRU Algorithm presenting promising solutions for sustainable resource management. Fig. 2 presents the comparative analysis involving Round-Robin Scheduling, First Come, First Serve (FCFS) Scheduling, and the Least Recently Used (LRU) existing methods, focusing on the resource utilization metric.

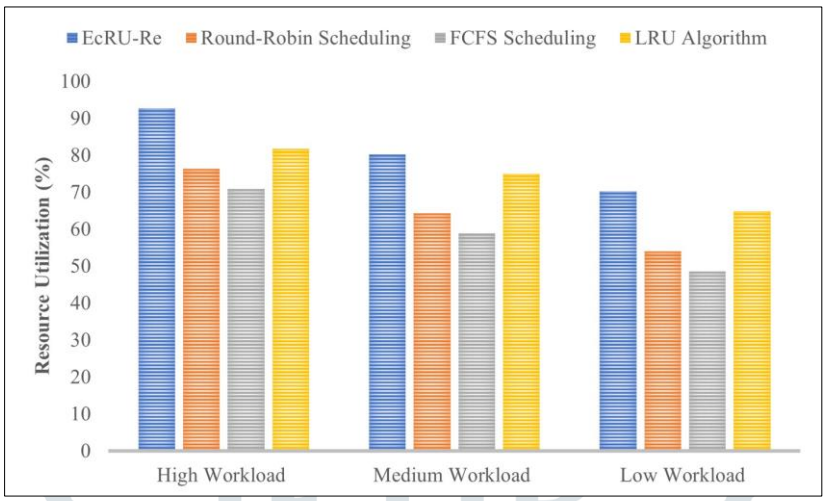

Fig. 2. Resource Utilization

The comparative analysis of resource utilization across the algorithmic approaches reveals varying efficiencies under different workload scenarios. The EcRU-Re approach consistently demonstrates higher resource utilization compared to Round-Robin Scheduling, FCFS Scheduling, and the LRU Algorithm across all workload levels. This indicates EcRU-Re's adeptness at effectively utilizing computational resources, making it a favorable choice for optimizing resource usage. Conversely, Round-Robin Scheduling and FCFS Scheduling exhibit lower resource utilization across all workload scenarios, suggesting suboptimal resource management strategies. The LRU Algorithm falls between EcRU-Re and Round-Robin Scheduling/FCFS Scheduling, demonstrating moderate resource utilization levels. Overall, the findings underscore EcRU-Re's superiority in maximizing resource utilization, followed by the LRU Algorithm, while Round-Robin Scheduling and FCFS Scheduling lag behind in efficiently utilizing computational resources. Fig. 3 illustrates the comparative analysis of the suggested EcRU-Re algorithm with existing methods based on the Response Time metric.

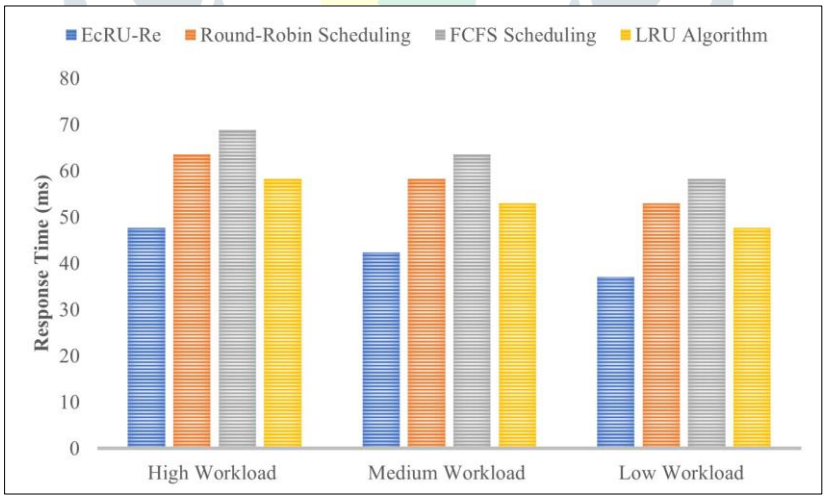

Fig. 3. Response Time

The comparative analysis of response time across the algorithmic approaches reveals notable differences in performance under varying workload conditions. The EcRU-Re approach consistently demonstrates lower response times compared to Round-Robin Scheduling, FCFS Scheduling, and the LRU Algorithm across all workload levels. This indicates EcRU-Re's efficiency in executing tasks promptly, making it advantageous for applications requiring rapid responsiveness. In contrast, Round-Robin Scheduling and FCFS Scheduling exhibit higher response times across all workload scenarios, suggesting delays in task execution. The LRU Algorithm falls between EcRU-Re and Round-Robin Scheduling/FCFS Scheduling, showing moderate response time levels. Overall, the findings highlight EcRU-Re's superiority in minimizing response times, followed by the LRU Algorithm, while Round-Robin Scheduling and FCFS Scheduling lag behind in prompt task execution.

VI. Conclusion and Future Scope

In conclusion, our comparative analysis across various algorithmic approaches demonstrates the efficacy of the proposed EcRU-Re algorithm in achieving superior energy efficiency, resource utilization, and response time metrics across different

workload scenarios. EcRU-Re consistently outperforms existing methods, including Round-Robin Scheduling, FCFS Scheduling, and the LRU Algorithm, showcasing its potential for optimizing computational resources and enhancing system performance. These findings underscore the significance of algorithmic optimization in sustainable computing practices, emphasizing the importance of developing innovative approaches like EcRU-Re to address the evolving demands of modern computing environments.

For future work, we aim to explore further enhancements and refinements to the EcRU-Re algorithm, such as incorporating machine learning techniques for adaptive resource allocation and dynamic workload management. Additionally, we plan to conduct real-world experiments to validate the algorithm's performance in practical computing environments. Furthermore, investigating the scalability and robustness of EcRU-Re across large-scale distributed systems could provide valuable insights into its applicability in diverse computing contexts. Overall, our research lays the groundwork for continued exploration and development of algorithmic solutions to promote energy-efficient and sustainable computing practices.

REFERENCES

[1] Katal, A., Dahiya, S., & Choudhury, T. (2023). Energy efficiency in cloud computing data centers: a survey on software technologies. Cluster Computing, 26(3), 1845-1875.

[2] Lambropoulos, G., Mitropoulos, S., Douligeris, C., & Maglaras, L. (2024). Implementing Virtualization on Single-Board Computers: A Case Study on Edge Computing. Computers, 13(2), 54.

[3] Patil, A., & Patil, D. R. (2019, February). An analysis report on green cloud computing current trends and future research challenges. In Proceedings of International Conference on Sustainable Computing in Science, Technology and Management (SUSCOM), Amity University Rajasthan, Jaipur-India.

[4] Bose, A., & Nag, S. (2022). Green Computing–A Survey of the Current Technologies. Asia-Pacific Journal of Management and Technology (AJMT), 3(2), 1-15.

[5] Achar, S. (2022). How adopting a cloud-based architecture has reduced the energy consumptions levels. International Journal of Information Technology and Management, 13(1), 15-23.

[6] Padala, P. R. (2018). Virtualization of data centers: study on server energy consumption performance.

[7] Ojo, A. O., Raman, M., & Downe, A. G. (2019). Toward green computing practices: A Malaysian study of green belief and attitude among Information Technology professionals. Journal of cleaner production, 224, 246-255.

[8] Mekala, M. S., & Viswanathan, P. (2020). A survey: energy-efficient sensor and VM selection approaches in green computing for X-IoT applications. International Journal of Computers and Applications, 42(3), 290-305.

[9] Hossain, M. A., Reza, M., Hossain, N., Nashiry, A., & Shafiuzzaman, M. (2020). Implementation of VDI based Computer Laboratory in University Education System to Save Energy, Cost, and Adapt Technology Upgradation. IJCSNS Int. J. Comput. Sci. Netw. Secur, 20, 130-137.

[10] Naidu, P. A., Chadha, P., & Nalina, V. (2020). Efficient strategies for green cloud computing. J. Netw. Commun. Emerg. Technol, 10(6).

[11] Rzepka, A., Kocot, M., & Jędrych, E. (2021). Implementation and Use of Green Computing in Polish Companies versus Implementation of Features Characteristic of Teal Organizations. In Green Engineering and Technology (pp. 343-356). CRC Press.

[12] Garg, N., Singh, D., & Goraya, M. S. (2021). Energy and resource efficient workflow scheduling in a virtualized cloud environment. Cluster Computing, 24, 767-797.

[13] Asadi, S., Nilashi, M., Samad, S., Rupani, P. F., Kamyab, H., & Abdullah, R. (2021). A proposed adoption model for green IT in manufacturing industries. Journal of Cleaner Production, 297, 126629.

[14] Nwankwo, W., Olayinka, S. A., & Ukhurebor, K. E. (2020). Green computing policies and regulations: a necessity. International Journal of Scientific & Technology Research, 9(1), 4378-4383.

[15] Shukur, H., Zeebaree, S., Zebari, R., Zeebaree, D., Ahmed, O., & Salih, A. (2020). Cloud computing virtualization of resources allocation for distributed systems. Journal of Applied Science and Technology Trends, 1(2), 98-105.

[16] Naim, A. (2021). New trends in business process management: applications of green information technologies. British Journal of Environmental Studies, 1(1), 12-23.

[17] Jnr, B. A. (2020). Examining the role of green IT/IS innovation in collaborative enterprise-implications in an emerging economy. Technology in Society, 62, 101301.

[18] Abu Al-Rejal, H. M. E., Udin, Z. M., Hassan, M. G., Sharif, K. I. M., Al-Rahmi, W. M., & Al-Kumaim, N. H. (2020). Green information technology adoption antecedence: a conceptual framework. In Emerging Trends in Intelligent Computing and Informatics: Data Science, Intelligent Information Systems and Smart Computing 4 (pp. 1098-1108). Springer International Publishing.