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OPTIMIZING PEAK LOAD MANAGEMENT IN DATA CENTERS THROUGH THE WATER SHOWER MODEL APPROACH FOR ENHANCED RESOURCE UTILIZATION AND CARBON EMISSION REDUCTION

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Abstract

Data centers are important for addressing increasing demand for digital services, yet peak user requests sometimes causes server overload, slow response time, high energy use and high carbon emissions. Water Shower Model (WSM) is a novel data center peak load control system that optimizes resource efficiency and reduces carbon emissions. Research suddenly highlights the challenges of managing user demands, which often causes server overload, slow response time and high energy consumption. The purpose of this project is to appropriately allocate server workloads, reducing the carbon footprint. Qualitative Research is complemented by simulation experiments using the results of the Vellore Institute of Technology using the Publication System and Learning Management System Log Records. WSM framework user request types using a balanced exemplary dynamic voltage carbon scaling (BET-Devcs) and multi-kui scheduling using a finished queue monitor to allocate containers and virtual machines based on ROR or RWR. WSM performs better than an ant colony and honey bees by equally assigning the workload in all servers, preventing overloads, reducing the reaction time and reducing carbon emissions. Compared to the baseline model, the user's bases had rapid average response time and low power consumption and carbon counterparts. Parallel distribution cloud infrastructure improves reliability and stability. The management of data center workload with WSM is scalable and environmentally friendly. It improves user satisfaction, reduces operational costs, and environmentally promotes durable IT practices, making it a viable pattern for future cloud infrastructure.

INTRODUCTION:

The rapid dissemination of digital services and cloud infrastructure resulted in sufficient increase in data center workloads, which lead to a lot of issues in managing irregular peak-time demands. During these intervals, servers often experience overload or undertussion, resulting in prolonged response time, excessive energy use, and inability to emitting elevated carbon emissions, which increase environmental issues. Traditional load-balance methods, such as ant colony and honey bees, have been investigated to reduce these challenges; However, they are often reduced to obtaining uniform allocation of workloads, causing server bottlenecks and excessive energy consumption [1, 2]. In this context, the Water Shower Model (WSM) concept has been introduced as a novel technique to enhance peak load management in data centers to facilitate parallel and equitable charge allocation, which is also similar to water spread through a shower outlets [3, 4, 5]. The model incorporates a prepared queue monitor with a multi-Qui scheduling method to customize the allocation and uses a balanced exemplary dynamic voltage carbon scaling (BET-DVC) mechanism to reduce energy consumption and carbon emissions. In addition, the WSM differences between reading only requests (ROR) and Reed Right Request (RWR), which allocates them to containers or virtual machines according to their suitability, which adapt to resources consumption.

This research performance underlines the imperative of developing scalable, environmentally sustainable computational structure through a double emphasis on adaptation and ecological responsibility. The Water Shower Model effectively resolves the technical challenge of peak-time load balance by promoting environmentally durable IT practices, which combines data center operations with global stability initiative.

LITERATURE REVIEW:

Research on data center workload distribution and resource management has increased due to demand for sustainable and energy-efficient cloud computing. Buyya, Ilager, and Arroba (2024) [6] stressed the importance of integrated data center resource management frameworks for next-generation cloud computing, focusing on energy efficiency and sustainability. They advocate dynamic workload-power consumption balance to reduce environmental impact and preserve service quality. Nuthalapati (2024) [7] introduced machine learning-based workload forecasting models that improved user need prediction and server performance, reducing energy usage. Zhang et al. (2024) [8] examined prosumer micro energy networks in data centers and proposed renewable energy methods to improve infrastructure cleanliness and durability. William, Ghaffar, and Charles (2025) [9] proposed a model in which artificial intelligence actively reduces emissions while improving system performance by automating environmentally friendly business processes with carbon capture mechanisms and energy-efficient algorithms. Oloruntoba (2024) [10] investigated green cloud computing techniques that use AI for sustainable database administration, highlighting the importance of intelligent automation in reducing energy usage in large database activities. These studies demonstrate a strong correlation between energy-aware task management, AI-driven optimization, and sustainability. Despite advances, load balancing, real-time forecasting, and carbon reduction efforts are still not integrated. This study introduces the Water Shower Model (WSM), which combines load distribution, carbon scaling, and intelligent resource utilization to improve data center performance and sustainability.

METHODOLOGY:

This study uses qualitative methods and experimental simulation to evaluate the Water Shower Model (WSM) for data center peak load control. Qualitative technology was chosen to check how the workload distribution, energy efficiency, and a decrease in carbon emissions fit within a permanent computing paradigm. The result publication system and learning management system log records of Vellore Institute of Technology, including ROR and RWR, were used to simulate the summit and general load conditions. To identify the user's requirements and simulate the system performance under various assaults, the dataset was reviewed. Claudsim was used to create a ready queue monitor to WSM Framework that distributes workloads between containers and virtual machines using multi-Qui scheduling. To reduce carbon emissions, a balanced execual dynamic voltage carbon scaling (BET-DVCs) system monitored energy use and dynamic allocated resources. WSM was compared to Ant Colony and Honey Bees for response time, workload allocation efficiency, energy consumption, and carbon emission equivalents. Iterative modelling revealed WSM's performance benefits over standard models and sustainability contributions. The proposed model's technical efficiency and environmental impact on modern data centre operations were captured by this methodical approach.

The suggested methodology (figure 1) utilizes a Ready Queue Monitor with a load balancer to classify user requests as Read Only (ROR) or Read Write (RWR) and allocate them to the suitable resource, either containers or virtual machines, within the Virtual Data Center (VDC). This guarantees effective job allocation, diminished reaction time, and enhanced energy efficiency while preserving sustainability via equitable resource utilization.

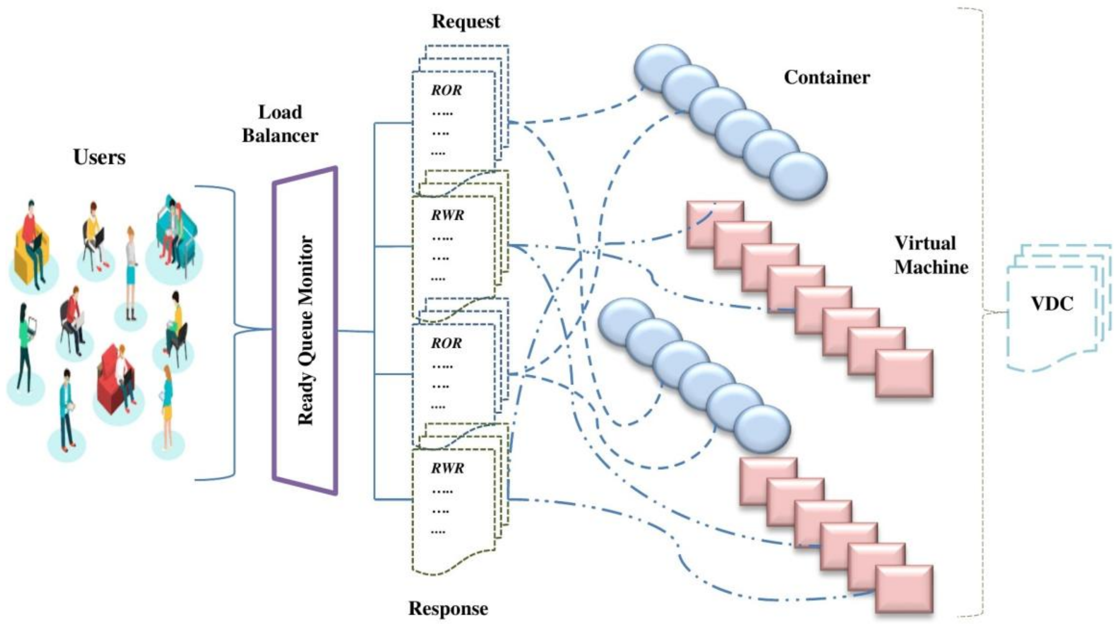

Figure 1: Load Balancer with Proposed Methodologies

RESULTS AND DISCUSSION:

Table 1 demonstrates that the Water Shower Model (WSM) consistently surpasses the Honey Bees and Ant Colony algorithms across all user bases by delivering reduced minimum, average, and maximum response times. Honey Bees exhibits the most subpar performance, characterized by significantly elevated average and maximum delays, particularly at UB3 and UB6, signifying inadequate management of peak loads. The Ant Colony outperforms Honey Bees but demonstrates longer response times than WSM, especially in high-load areas such as UB5 and UB6. WSM exhibits stability by uniformly dispersing workloads, resulting in expedited reaction times and less variability during both standard and peak load scenarios. WSM demonstrates superior efficiency and sustainability, enhancing user experience and optimizing resource consumption in data centres.

Table 1: User Base Response Time by Region

User Base	Response Time by Region								
	Honey Bees Algorithm			Ant Colony Algorithm			WSM Algorithm		
	Min (ms)	Avg (ms)	Max (ms)	Min (ms)	Avg (ms)	Max (ms)	Min (ms)	Avg (ms)	Max (ms)
UB1	37.63	82.78	93.38	37.63	61.77	72.38	35.63	52.02	62.38
UB2	38.77	82.74	92.52	38.77	61.58	72.02	36.77	45.63	56.27
UB3	39.25	89.43	408.26	39.25	61.87	74.26	37.25	45.82	55.75
UB4	39.51	83.60	93.26	39.51	58.01	71.51	37.51	69.02	55.26
UB5	225.52	333.01	390.02	225.52	312.03	373.51	223.52	295.91	356.52
UB6	155.14	294.53	440.5	155.14	211.54	253.64	153.14	195.66	236.64

Figure 1 compares Honey, ANT, and WSM reaction times (in milliseconds) across six user base locations (UB1–UB6). The blue bars represent Honey, the red bars ANT, and the green bars WSM. The data shows that WSM consistently has the lowest response times across all user locations, proving its efficiency. WSM detects 52.02 ms in UB1, much lower than Honey (82.78 ms) and ANT (61.77 ms). WSM outperforms performance in UB2 and UB3 with 45.63 and 45.82 ms, respectively, whereas Honey and ANT have higher latency. In UB4, WSM is 69.02 ms, topping Honey (88.60) and ANT (58.01). The differences are more pronounced in UB5 and UB6, which have larger user bases. Honey has the highest latency in UB5, at 333.01 ms, followed by ANT at 312.03 and WSM at 295.91. In UB6, WSM logs 195.66 ms, while Honey and ANT log 294.53 and 211.54 ms, respectively. Results show that WSM scales well with more users, improving processing times and stability under high demand. In conclusion, all three systems show higher reaction times with bigger user bases, but WSM is the most optimized and stable, making it the best choice for diverse and growing user bases. This comparison shows that algorithmic efficiency is crucial to low latency and user experience, especially in large distributed or network-based systems

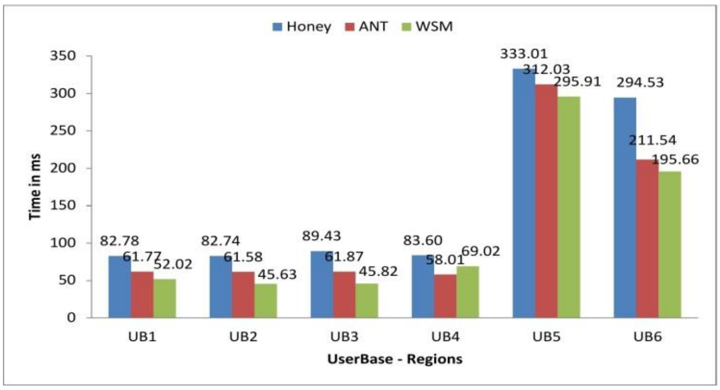

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Figure 1: Analysis and Comparison of Algorithms with Average Response Time

The proposed Water Shower Model (WSM) study addresses workload distribution, carbon emission management, and user responsiveness to improve energy-efficient and sustainable cloud computing research. Buyya, Ilager, and Arroba (2024) [6] stressed the importance of energy efficiency and sustainability in future cloud systems and the need for comprehensive frameworks to integrate workload and resource management. Their research proposed integrated management but was mostly theoretical, while the WSM implements these principles through parallel job allocation, server efficiency, and carbon emission supervision. Nuthalapati (2024) [7] improved cloud data center performance with machine learning-driven workload estimates, predictive resource allocation, and power waste reduction. Forecasting improves readiness, but the WSM deals with real-time peak load balancing by dynamically classifying user requests (Read Only vs. Read Write) and distributing them to containers or virtual machines for fair processing.

Zhang et al. (2024) [8] used prosumer microgrids to improve data centers using renewable energy. They promote sustainability through external energy sources, while the WSM optimizes computational and workload processes, suggesting future synergies may combine energy and workload advances. William, Ghaffar, and Charles (2025) [9] presented Sustainable AI by merging carbon capture technologies with energy-efficient algorithms to expedite ecologically beneficial corporate processes, highlighting AI's growing role in carbon reduction. WSM uses balanced exothermic Dynamic Voltage Carbon Scaling (bet-DVCS) to optimize energy utilization and reduce emissions, a comparable sustainability technique to carbon capture. AI in sustainable database administration was shown by Oloruntoba (2024) [10] to reduce energy usage in large storage activities. WSM implements intelligent scheduling system-wide instead than just on databases, but both emphasize automation to produce more sustainable computing. In conclusion, the proposed WSM combines real-time load balancing, request-type differentiation, and carbon-aware scaling. Combining theoretical concepts, predictive optimization, renewable integration, and AI-driven sustainability initiatives, it ensures sustainability and improves peak demand user responsiveness.

CONCLUSION:

The study reveals that the WSM improves data centre peak load management by distributing workload evenly, lowering reaction time, and minimizing carbon emissions. WSM is more efficient and sustainable than standard algorithms, making it a scalable, environmentally friendly cloud computing infrastructure solution.

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