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SUSTAINABLE CLOUD COMPUTING

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ABSTRACT

Different algorithms, such as Ant colony optimization (ACO), Dynamic voltage frequency scaling (DVFS), artificial neural networks (ANN), and FinOps, are examined to promote energy efficiency, cut CO_2 exhaust, and utilize resources. Finally, the survey disseminates pros, cons, and future research considerations on further implementing sustainable cloud computing models that promote environmental stewardship and economic growth.

KEYWORDS: *Green Cloud Computing, Sustainable Computing, Ant Colony Optimization (ACO), Energy Efficiency, Cloud Scheduling, Virtualization, FinOps, Artificial Neural Networks (ANN), DVFS, Renewable Energy Integration, Resource Optimization, Literature Survey*

INTRODUCTION

The unprecedented evolution of cloud computing has led to a significant hike in energy use, carbon emissions, and electronic waste. As cloud data center's scale expands throughout the world, it has become imperative to adopt green cloud computing approaches to address environmental issues. Green computing is about designing and implementing cloud infrastructure in energyefficient and low-impact ways.

This literature survey reviews a select groups of papers that focus on a wide variety of green cloud computing strategies, technologies, and algorithms. In papers reviewed virtualization, energy-aware scheduling, ACO, DVFS, ANN, and FinOps are discussed techniques for reaching sustainability goals. All of the studies provided some level of insights into how cloud systems can balance the competing demands of performance, cost, and environmental impact. By reviewing the stated benefits and limitations, and methods through which the studies were conducted this survey aims to analyze and clarify the current trends in research, and potential paths forward in the field of sustainable cloud computing.

LITERATURE SURVEY

Sustainable Cloud Computing: Literature Review

Research Paper	Key Focus	Main Technologies	Primary Benefits	Major Challenges
Green Cloud Computing (GCC), Applications, Challenges and Future Research Directions (Abd ElMawla & Ibrahim, 2022)	Environmental protection through green cloud computing	• Ant Colony Optimization< br>• CloudSim Simulator • VM scheduling • Linear Regression model	• Reduces CO2 emissions • Improves energy efficiency • Supports 342 green hosting companies	• High adoption costs • Technical complexity • Varying international regulations

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Cloud Computing : Toward Sustainable Processes and Better Environmental Impact (Achar, 2022)	Energy usage and carbon footprint reduction	• Load balancing • Server virtualization< br>• Genetic algorithms • Green Cloud Scheduling Model	• Reduces energy costs • Enables remote work • Improves resource efficiency	• Security concerns • Vendor lockin • SLA violations
An Empirical Study for Mitigating Sustainable Cloud Computing Challenges Using ISM-ANN (Alwageed et al., 2024)	Ethical challenges and mitigation practices	• Interpretive Structural Modeling • Artificial Neural Networks • SCCCMM framework	• Identifies 66 mitigation practices • Systematic evaluation • Data-driven decisions	• Small sample size • Limited validity • Implementation complexity
Cloud Computing for Sustainable Development (Yenugula, Sahoo & Goswami, 2024)	Environmental, economic, and social benefits	• Energyefficient hardware • Renewable energy integration • Big data analytics	• Reduces emissions • Improves technology access • Cost-effective scalability	• Security vulnerabilities • Greenwashing risks • Resource depletion
Sustainable Cloud Computing : Leveraging FinOps for Environmental Responsibility (Kanumuri , 2023)	Financial operations aligned with sustainability	• FinOps practices • Right-sizing techniques • PUE, EER, CUE metrics	• Aligns cost with sustainability • Reduces wasted resources • Competitive advantage	• Implementation complexity • Requires monitoring • Initial investment costs

INTRODUCTION TO ANT COLONY OPTIMIZATION (ACO)

In this technique, artificial "ants" navigate through the set of potential solutions leaving a virtual chemical called pheromone along the way, allowing other ants to follow the best path. ACO has been applied to optimize task scheduling and resource allocation in cloud computing by effectively locating suitable tasks for virtual machines. ACO can reduce energy consumption, improve performance, and address load balancing in data centers.

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ROLE OF ANT COLONY OPTIMIZATION (ACO) IN CLOUD COMPUTING

- Locates the best path for allocating tasks to virtual machines.
- Lowers energy consumption in cloud data centers.
- Load balancing is improved by distributing tasks evenly.
- Improves system performance and execution time.
- Cuts operative costs due to efficient resource usage.
- Avoids server overload and causes better dependability.

ACO FOR GREEN/SUSTAINABLE CLOUD COMPUTING

The primary goal of ACO is to develop the most efficient ways of allocating tasks and managing resources across virtual machines (VMs).

ACO reduces power consumption through resource management, which will power down servers that are underutilized and balancing the workload across servers to maximize their energy efficiency . The pheromone-based mechanism allows theAOC algorithm to dynamically adapt to changing workloads to ensure the cloud resources are used in an energy-efficient manner.

In general, ACO technologies will also optimize operational costs while minimizing environmental impacts through its task scheduling, load balancing and VM placement capabilities. As a result, it supports green and sustainable goals through reduced CO_2 emissions and by balancing workloads that extend the life of hardware.

ACO ALGORITHM WORKING PROCESS

Steps of the ACO Algorithm

1. Initialization o Identify the problem (e.g., task scheduling in cloud).
   - o Set the parameters, such as number of ants, pheromone value, and iterations.
2. Solutions Construction
   - o Each artificial ant will chooce a path (solution) depending on pheromones or

heuristics a partner-based weight for example on the performance of resources or energy usage.

3. Fitness evaluation
   - o The performance of solution is computed or results are provided, solutions are

measured by energy usage, run-time, or cost.

4. Pheromone update
   - o Good solutions receive more pheromones (increasing the probability of being

chosen again).

   - o Bad solutions lose pheromones over time (decreasing their probability of being

selected).

5. Convergence
   - o Following several iterations the ants focus on the same path that yields the best

solutions for energy efficiency for allocation for tasks.

6. Output o The system outputs the best resource for scheduling tasks at utilities.

LIMITATIONS / CHALLENGES OF ACO

- Slow Convergence: In some cases, ACO converges slowly to a solution and may take a relatively large number of iterations to achieve an optimal or near-optimal solution.
- Scalability Issues: ACO may also become cumbersome and resourceintensive when applied to large-scale cloud systems when this happens.
- Potential for Local Optima: ACO has the potential to converge with a local best solution instead of discovering the global best solution.

COMPARATIVE ANALYSIS WITH OTHER ALGORITHMS

- Against Genetic Algorithm (GA):
  ACO is generally superior in stability and load balancing although GA can achieve slightly faster convergence, but with less stable solutions on smaller datasets.
- Against Particle Swarm Optimization (PSO):
  ACO performs well on discrete optimization problems like task scheduling. GA, on the other hand, is mostly effective on continuous optimization problems. Although ACO may take longer to reach the optimum, it still achieves the best overall solution.
- Against Traditional Scheduling Algorithms:
  ACO optimally adapts to workload changes, is more energy-efficient, and better balance throughout, whereas traditional methods ultimately fail to optimize energy usage and provide a better balance on workloads in their scheduling process.
  In conclusion, ACO is superior in terms of resource utilization, energy efficiency, and adaptability against random evolutionary methods (GA, PSO) and traditional scheduling methods.

FUTURE SCOPE AND RESEARCH DIRECTIONS

Both academics and industrial experts are extending its benefits by offering research focusing on aspects of ACO such as its speed, accuracy, and adaptability, to relate better to contemporary large-scale cloud systems.

- Dynamic Cloud Environments:

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The future may also focus ACO at real-time and multi-cloud environments, or any environments where workloads dynamically change over time.

- Energy-Aware and Carbon-Aware Models:
  Further advancement of ACO's sustainability performance can come from models that minimize energy use, and also help to minimize the amount of carbon emissions associated with energy patterns.
- Integration Utilizing Renewable Sources:
  ACO can also be adapted for managing the availability of energy based on renewable energy sources, such as sun and wind.
- Improved Parameter Control:
  Enhanced accuracy for ACO can also come from tuning the parameters of ACO, including pheromone-based rates, and evaporation factor rates, and as such combined make ACO easier to utilize while becoming more accurate.
- Cloud-Edge Applications / IoT Applications:
  Use cases of ACO with edge computing and/or IOT systems can make suggestions to help with energy and cloud resource optimization processes better in place across distributed samples.
  In conclusion, ACO will continue to be researched with hybrid models, dynamic environments, and energy aware processes for faster and sustainable types of computing.

CONCLUSION

Ant Colony Optimization (ACO) is a robust bio-inspired algorithm that has a significant role in supporting green and sustainable cloud computing. The biophysical behavior of ants is emulated by ACO which addresses task scheduling, resource allocation, and load balancing in cloud computing environments. In addition to these, it reduces energy consumption, execution time, and operational costs leading to greener and subsequent sustainable cloud computing.

While ACO provides many advantages such as energy efficiency and adaptability it faces challenges related to high computation time, tuning parameters, and complicated implementations. However, researchers are leveraging continual research and hybrid approaches, integrating machine learning, genetic algorithms, or renewable energy management to facilitate improved performance.