Nature-Inspired Virtual Machine Allocation for Cloud Infrastructure: A Comparative Analysis

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Abstract

Strategically allocating Virtual Machines (VMs) is crucial for optimizing resources in cloud computing. Traditional methods have been effective, but nature-inspired approaches, drawing inspiration from biological systems, offer promising alternatives. This paper focuses solely on analyzing nature-inspired VM placement strategies within cloud environments. By harnessing concepts from evolutionary algorithms, swarm intelligence, or other natural systems, these approaches aim to improve resource allocation efficiency. Through a comparative analysis, we evaluate the effectiveness of nature-inspired techniques in optimizing VM placement.

Keywords : Particle swarm optimization, Virtual Machine Placement **,**Ant Colony Optimization, Physical Machines , Simulated Annealing, Krill Herd Algorithm, Harmony Search ,Genetic Algorithm

I Introduction

With rising demand for pervasive computing models, emergence of cloud computing has introduced a transformative approach. Cloud computing enables users from diverse locations and devices to access shared computing resources flexibly, ensuring accessibility without fixed commitments [1]. Unlike traditional methods, cloud computing relies on adaptive resource allocation management to efficiently handle the varying workloads of multiple applications with distinct resource requirements.
To further optimize resource utilization, virtualization using Virtual Machines (VMs) has gained popularity over traditional Physical Machines (PMs). Within this context, VM placement, a critical task in the VM migration process, seeks to identify the most suitable PM to host VMs. While various VM placement algorithms have been developed to enhance data center efficiency and VM execution, the integration of nature-inspired principles introduces a promising avenue for innovation.
Nature-inspired VM allocation strategies draw inspiration from biological systems, leveraging concepts such as evolutionary algorithms or swarm intelligence. These approaches aim to dynamically allocate resources in a manner akin to natural processes, enhancing adaptability and efficiency. However, the applicability of nature-inspired algorithms may vary depending on the specific environment and scenario. Therefore, analyzing their strengths and weaknesses thoroughly is essential to determine their suitability for different contexts

By delving into the nuances of nature-inspired VM placement schemes, we can gain valuable insights into their potential benefits and comparative advantages over traditional methods. This understanding enables us to make informed decisions about the most appropriate VM allocation approach for a given situation, ultimately driving efficiency and performance in cloud infrastructure.

The paper's structure is delineated as follows: Section 2 furnishes a comprehensive theoretical foundation on virtual machine placement, along with a classification of its algorithms inspired by nature. Sections 3 to 8 detail the six main strategies and approaches for Virtual Machine Placement in Cloud Infrastructure. Sections 9 compare these approaches using performance metrics and assess their effectiveness in various scenarios. Finally, Section 10 offers concluding remarks

2. Virtual Machine Placement [VMP]

The Infrastructure as a Service (IaaS) model enables resource multiplexing through virtualization technology, allowing applications to operate independently of the physical resources they require. This separation of resources is facilitated by virtual machines (VMs), each encapsulating a specific set of functionalities. Within a virtualized environment, multiple applications run on individual VMs, and these VMs are then allocated to one or more Physical Machines (PMs) within the cloud based data center [2]. The process of VM placement is pivotal, as it determines the optimal selection of PM or server to accommodate each VM. Choosing an right host is crucial for enhancing power efficiency and optimizing resource utilization.

As discussed in [3] [4] Virtual Machine Placement is a type of a non-deterministic bin packing problem. Meta-heuristic techniques are widely used for this type of problem as it provides near optimal solution for it. Hence, these techniques are considered by various researchers due to its efficiency in solving complex and large problem. Numerous metaheuristic algorithms are available in literature as follows -

3.**Particle swarm optimization [PSO] –**

In cloud computing ,Particle Swarm Optimization is a nature-inspired algorithm widely utilized in cloud computing for efficiently allocates Virtual Machines (VMs) to Host Servers, drawing inspiration from bird flocking or fish schooling behavior. Each potential solution is represented as a particle, which iteratively adjusts its position based on personal and swarm experience. [5] The goal is to discover the most efficient VM placement that minimizes resource wastage, maximizes resource utilization, and fulfills specified Quality of Service (QoS) criteria. PSO updates particles' positions and velocities iteratively, leveraging individual and collective experiences to converge towards the best solution [6] .Drawing upon the collective wisdom of the swarm, this method collaboratively explores the solution space, akin to a group of individuals pooling their insights, to unearth optimal solutions.

4. Ant Colony Optimization [ACO] –

In cloud computing, Ant Colony Optimization (ACO) is a bio-inspired technique that mimics the resource-seeking instincts of ants as found in [7]. ACO-based VM placement, VMs and PMs are represented as nodes and edges in a graph, respectively, with ants constructing solutions by traversing this graph. Ants select VMs to be placed on PMs based on pheromone levels and heuristic information, depositing pheromone along the traversed edges proportional to solution quality. Heuristic information guides ants in their decisions, considering factors like VM distance and PM capacity. Iterative updates to pheromone trails drive the convergence towards optimal solutions, efficiently exploring the solution space. Ultimately, ACO-based VM placement aims to minimize resource wastage, maximize utilization, and meet Quality of Service (QoS) requirements, utilizing the collective intelligence of the ant colony to find high-quality solutions within a reasonable computational time [8].

5. Genetic Algorithm [GA] –

In cloud computing, Genetic Algorithm (GA) is a widely used nature-inspired optimization technique for Virtual Machine (VM) placement [9]. GA represents potential solutions as individuals in a population, with each individual encoding a possible allocation of VMs to Physical Machines (PMs). Across successive generations, GA assesses the fitness of individuals by considering factors like Quality of Service (QoS) metrics and resource utilization, selects individuals for reproduction, and applies crossover and mutation operations to generate offspring with potentially improved fitness. [10]By mimicking the principles of natural selection and genetic evolution, GA efficiently explores the solution space to converge towards optimal VM placement solutions that minimize resource wastage, maximize utilization, and satisfy QoS requirements.

6. Simulated Annealing [SA] –

In cloud computing, Simulated Annealing (SA) stands as a powerful optimization technique employed for Virtual Machine (VM) placement. Inspired by the annealing process in metallurgy, SA mimics the process of gradual cooling in material to reduce energy and achieve a low-energy state [11]. In VM placement, SA begins with an initial solution and iteratively explores the solution space by accepting moves that decrease an objective function, which could be related to resource utilization, energy consumption, or Quality of Service (QoS) metrics. SA gradually decreases the "temperature," controlling the likelihood of accepting moves that increase the objective function, allowing the algorithm to escape local optima and converge towards a globally optimal solution. Through this process, SA efficiently explores the solution space and finds high-quality solutions for VM placement in cloud computing environments.

7. Harmony Search [HS] –

In cloud computing, Harmony Search (HS) finds its roots in the world of metaheuristic optimization, mirroring the improvisational journey undertaken by musicians in their quest for harmony. HS refines candidate solutions iteratively to determine the optimal allocation of VMs to Hosts [12]. During each iteration, HS generates new solutions by harmonizing existing ones, where each solution represents a potential allocation of VMs to PMs. Through a process of improvisation and refinement, HS iteratively adjusts the allocation of VMs to minimize resource wastage, maximize utilization, and satisfy Quality of Service (QoS) requirements [13]. By leveraging principles of musical harmony, HS efficiently explores the solution space to converge towards high-quality solutions for VM placement in cloud computing environments.

8. Krill Herd Algorithm [KH] –

The Krill Herd Algorithm (KHA) is a nature-inspired optimization method modeled after the collective behavior of krill in swarms. In the realm of cloud computing, KHA serves as a population-based metaheuristic approach for Virtual Machine (VM) placement, aiming to efficiently allocate VMs to Physical Machines (PMs) while considering diverse constraints and objectives [14]. Similar to other metaheuristic algorithms, KHA iteratively refines candidate solutions, adjusting VM allocations to minimize resource wastage, maximize utilization, and fulfill Quality of Service (QoS) requirements. Harnessing the collective intelligence of the krill swarm, KHA adeptly navigates the solution space, seeking high-quality solutions for efficiently organizing virtual machine resources , thereby contributing to enhanced resource efficiency and QoS satisfaction [15].

9. Comparative analysis for VM placement techniques–

The different techniques for VM placement explored in prior literature were examined to find out the better technique for it. Below are the parameters commonly used for the same [3] [4]

TABLE I

Consumed Energy	The consumed energy count is calculated as the cumulative power consumption over a specific period of time as - $$e(t) = \int_t p(t)$$
SLA	The Service level Agreement indicates the grade of service quality in agreement between the the provider of cloud services and the client. It ensures that all the service features essential for it is to be provided. This metric quantifies the portion of the total SLA violation time during which a host has sustained 100% utilization. It is derived from $$SLATAH = \frac{1}{n}\sum_{x=1}^{n}\frac{t_{s_x}}{t_{a_x}}$$ Where: n : number of hosts tsx : duration during which physical machine X operates at full capacity tax : the period during which host X has sustained 100% utilization SLATAH – time duration during which each active host experiences a violation
Number of hosts shutdown	It says the count of host machines switched off as a result of being under loaded during the VM consolidation process.
Number of migrations	It denotes the tally of migrations instigated by the VM manager in response to VM deployments.

Based on the various VMP algorithms found in the literature so far, we present the below chart which gives a comparative analysis of various VM placement Algorithms.

The Analysis is based on the following points-

a) Which resources are considered such as CPU, Memory or Network?
b) The experimental setup used by the respective algorithms.
c) Which parameters are considered while experimenting?
d) It finally gives the limitation of the respective algorithm used during analysis.\

TABLE III

VM placement Algorithm	**Exp. Setup**	**Resources**			**Parameter**				**Limitation**
		CPU	**Memory**	**Network**	**Consumed Energy**	**No of VM migration**	**No of host shutdown**	**SLA violation**	
ACO	**Cloud Sim**	√	×	×	√	√	√	√	Introducing additional objective functions involves a trade-off with time complexity and could potentially result in decreased performance.
GA	**Java**	√	√	√	√	×	×	×	Interconnecting equipment and inter-data center communication is not considered.
SA	**Cloud Sim**	×	√	×	√	×	×	×	Only energy consumption is considered
HS	**Cloud Sim**	√	√	×	√	√	√	√	Workload forecasting can be considered in future for improvements
KH	**Cloud Sim**	√	×	×	√	√	√	√	SLA is violated.
PAPSO	**Cloud Sim**	√	×	×	√	√	√	√	Limited resource considered but more factors can be taken into consideration like memory, bandwidth and Network.

The comparative table above offers a comprehensive overview of the resources and parameters considered by different algorithms used for VM placement. Upon analyzing various comparative parameters and limitations, it is evident that the PAPSO algorithm, rooted in swarm intelligence, shows promising potential for further development. The current implementation primarily focuses on CPU as a resource, but there is room for improvement by incorporating additional factors such as memory, network, and bandwidth. This opens up ample opportunities for enhancing the output through further study and refinement.

Studies in [5] suggests that Nature-Inspired Optimization (NIO) algorithms have demonstrated superior efficacy in addressing real-world nonlinear optimization problems. These algorithms draw inspiration from the rich diversity and creativity inherent in nature, which is considered the pinnacle of mankind's power. Nature's vast and varied creations make algorithms designed with its principles in mind more effective in problem-solving.

10. Conclusion and future scope

This study we set out to investigate nature-inspired methods for optimizing virtual machine placement in cloud computing environments, We evaluated algorithms such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Harmony Search (HS), and Simulated Annealing (SA). Our findings underscore the effectiveness of these approaches in optimizing resource allocation, and meeting Quality of Service (QoS) requirements by drawing insights from natural systems. However, we also identified distinct strengths and limitations for each algorithm, highlighting the need to select the most appropriate approach based on specific environmental and operational considerations. Looking ahead, future research should prioritize refining existing algorithms, exploring hybrid strategies, and accommodating dynamic and heterogeneous cloud environments to enhance VM placement mechanisms. Additionally, integrating machine learning and artificial intelligence techniques can further bolster the adaptability and intelligence of these methods. Addressing sustainability concerns through energy-efficient VM placement strategies and conducting empirical studies to validate effectiveness and scalability in practical cloud computing scenarios are crucial next steps. Overall, the future prospects for research and development in this domain are extensive, offering numerous opportunities for innovation and progress.

REFERENCES

[1] P. M. a. T. Grance, “The NIST Definition of Cloud Computing (Special Publication 800-145) National Institute of Standards and Technology,” Sept. 2011.

[2] M. K. N. J. U. D. M. V. Amarnath V, “Review on Energy Efficiency Green Data Centers,” *IJRES,* vol. Volume 5, no. Issue 2, pp. 21-26, , Mar-Apr 2018.

[3] P. P. V. K. K. M. Divya Bharathi P, “Virtual machine placement strategies in cloud computing,” in *International Conference on Innovations in Power and Advanced Computing Technologies,* 2017.

[4] D. Alsadie, “Virtual Machine Placement Methods using Metaheuristic Algorithms in a Cloud Environment – A Comprehensive Review,” *International Journal of Computer Science and Network Security,* vol. VOL.22, April 2022.

[5] M. N. ,. H. A. A. ABDELHAMEED IBRAHIM, “PAPSO: A Power-Aware VM Placement Technique Based on Particle Swarm Optimization,” *IEEE,* vol. 8, pp. 81747-81764, April 2020.

[6] I. P. P. V. ATUL TRIPATHI, “Energy Efficient VM Placement for Effective Resource Utilization using Modified Binary PSO,” *The British Computer Society,* pp. 832-845, November 2017.

[7] P. T. Anjali Verma, “Rank Based Ant Colony Optimization for Energy Efficient VM Placement On Cloud,” in *Second International Conference on Inventive Systems and Control,* 2018.

[8] b. Y.-C. T. M. T. W.-Z. Z. Fares Alharbia, “An Ant Colony System for Energy-efficient Dynamic Virtual Machine Placement in Data Centers,” *Expert Systems With Applications,* 2019.

[9] N. Avinash Kumar Sharma, “A Multi-Objective Genetic Algorithm for Virtual Machine Placement in Cloud Computing,” *International Journal of Innovative Technology and Exploring Engineering (IJITEE),* Vols. Volume-8 , no. Issue-8, pp. 231-235, June, 2019.

[10] M. H. R. Elnaz Parvizi, “Utilization-aware energy-efficient virtual machine placement in cloud networks using NSGA-III meta-heuristic approach,” *Cluster Computing,* 2020.

[11] S. C. S. A. N. Kalka Dubey, “A Simulated Annealing based Energy-Efficient VM Placement Policy in Cloud Computing,” in *International Conference on Emerging Trends in Information Technology and Engineering,* 2020.

[12] R. A. b. N. S. Minoo Soltanshahi a, “Energy-aware virtual machines allocation by krill herd algorithm in cloud data centers,” *Heliyon,* 2019.

[13] S. H. J. a. K. S. K. Ho Yeong Yun, “Workload Stability-Aware Virtual Machine Consolidation Using Adaptive Harmony Search in Cloud Datacenters,” *Appl. Sci. ,* 2020.

[14] S. V. B. K. M. Baalamurugan, “Amulti-objective krill herd algorithm for virtual machine placement in cloud computing,” *The Journal of Supercomputing,* 2018.

[15] D. B. I. Krishnaveni. S, “ISSUES ON GREEN CLOUD COMPUTING TOWARDS ENERGY SAVING,” *IJASTEMS,* vol. Volume.3, no. Special Issue.1, pp. 219-223, March.2017.