Recent advances in Nature-Inspired energy efficiency techniques: Cloud datacenter perspective

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**ABSTRACT**
Cloud computing is a general term for the delivery of hosted services and resources over the Internet that are pre-packaged in the form of virtual machines. Cloud computing allows clients to operate on pay-per-use basis instead of building and owning computing infrastructure in their premises; thereby, reducing cost and ease of operations. However, energy consumption becomes a crucial issue in the design of Cloud datacenters as the datacenters scaled up to meet ever increasing business and scientific applications demand. Thus, the datacenters emit large carbon emissions, posing threats to human life and the environment. Several techniques have been proposed to reduce energy consumption as well carbon emission of datacenters. This paper presents a recent advances on Nature-Inspired techniques for improving energy efficiency of Cloud datacenters. Analyzing the existing techniques and understanding their methods is relevant to inform the design of energy-efficient and environmentally sustainable Cloud datacenters that emit low carbon emissions. Finally future research direction in this area are provided for researchers to explore.

1. Introduction

Cloud computing has rapidly emerged as a successful paradigm for providing ICT infrastructure over the last few years. Its broader acceptance and virtualization technologies have contributed to the formation of large-scale datacenters that provide Cloud services. These services are offered at the different levels which include Infrastructure as a Service (IaaS), Software as a service (SaaS) and Platform as a Service (PaaS) [1, 2]. Cloud computing provides on-demand and elastic computing resources on pay-per-use basis there by reducing economic cost and increasing convenience of usage. Fig1 shows the characteristics of Cloud Computing model. Energy-efficiency has become an issue in different domain of computer science and application including Internet of things, smart city application and wireless sensor networks [3, 4]. The ever increasing demand of Cloud services have led to higher energy consumption of the Cloud datacenters, as datacenters store thousands of servers and networking equipment that require huge energy utilization for efficient operations. Moreover, in many instances, the datacenter infrastructures are over-provisioned to guarantee absolute service reliability and availability [5]. Also, more than 30% of the physical machines (PM) or servers within Cloud datacenters are usually idle, and often utilizes 10-15% of their resource capacity [6]. Underutilization of resources of the datacenter is the reason for the high energy consumption [7, 8]. Figure 1 shows classification and model of Cloud computing and their respective components Usman, Ismail [9].

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![Figure 1: Classification and Models of Cloud Computing](image-url)
consumption which can power 200,000 houses [10]. As a result, the infrastructure are not only expensive to maintain but hazardous to our environment because of the carbon emission (CO₂) [2]. In general, energy consumption in Cloud datacenters is a NP-hard problem and various methods have been proposed to address the problem [11]. However, Nature-Inspired algorithms provide better solutions to energy consumption issues. These algorithms are inspired by the imitation processes of nature and thus, are considered more efficient compared to other methods [12, 13]. Thus, the Nature-Inspired algorithms are required to solve the energy consumption issues of the Cloud datacenters. Due to their efficiency, several researchers have used them to propose various energy consumption reduction techniques to improve the energy-efficiency of the datacenters. The reviews of the existing literature reveal that nature inspired algorithms are used to achieve single and multi-objective solutions.

This paper explores the state-of-the-art methods that have employed the Nature-Inspired techniques in addressing energy consumption issues in Cloud datacenters. In this way, we can provide better understanding of the existing methods, identify their advantages and weaknesses, and point out future research direction in this area. This review can provide a solid ground for researchers to develop improved energy-efficient techniques.

2. Nature-Inspired algorithms:

Nature inspired algorithms relates to purely physics, chemistry, and or biology inspired algorithms. The algorithms are categorized into Evolutionary Intelligence, Swarm Intelligence and Bio-Intelligence as show in Figure 2.

![Image of Categorization of Nature-Inspired Techniques]

**Figure 2:** Classification of Nature-Inspired algorithms

The term has its foundation in the biological components of nature such as humans, animals, and environment; they are self-optimizing, self-healing, self-learning and self-processing [12, 13]. The nature inspired algorithms are used in many areas such as in optimization problems resource scheduling /allocation, load balancing and for optimal search solutions. They have proven to be more advantageous compared to non-nature inspired algorithms as they are faster in solving complex problems.


The Nature-Inspired techniques are categorized into three. These are Virtualization, Consolidation and Energy-aware. All the techniques employ either the single or multi-objective (SOO or MOO) approach to reduce the energy consumption of the datacenters. Some of the research works that have used these techniques are summarized in the following sections.

3.1 Virtualization technique:

Virtualization is the most essential and useful component of cloud computing. The biggest reward for deploying this technology in a cloud datacenters environment is enormous. These include portability of high-level functions, resource sharing, and aggregation of actual physical resources [14]. Evolutionary Intelligence has been the first MOO techniques used for improving datacenters energy-efficiency. The problems have been modelled as NP-hard with the use of GA as the best ideal solutions as in Xu, Zeng [15], Song, Fan [16], Shigeta, Yamashima [17] and Gao, Guan [18]. Javanmardi, Shojafar [19] and Shojafar, Javanmardi [20] presented a scheduling strategy that uses hybridization concept of fuzzy theory with GA to improve the resource scheduling of the Cloud datacenter. The authors modify the GA to reduce the time taken to search for an optimal solutions with the help of the fuzzy theory. The approach considered execution cost with total execution time of the datacenter resources that result in efficient performance. Sharma and Reddy [21] have combined DVFS and GA to reduce the energy consumption of a datacenter, increased resource utilization and convergence of the solutions. Moganarangan, Babukarthik [22] propose a Hybrid Algorithm (HA) for reducing energy consumption and makespan in cloud datacenters. The algorithm combines ACO and Cuckoo Search Algorithms (CSA) to reduce the energy consumption of datacenter. An Energy-efficient scheduling on a green datacenter using multi-objective co-evolutionary algorithm (OL-PICEA-g) is explored by Lei, Wang [23]. The authors
address the energy-efficient scheduling issue for a green datacenter partly maintained by renewable energy and convention energy source.

### 3.2 Energy-aware technique

To reduce energy demand, energy-aware techniques have been used to schedule resources in cloud datacenters as in Mezmar, Melab [24], Malakooti, Sheikh [25] and Raju, Amudhavel [26]. The technique uses resource scheduling to improve resource utilization resulting in sustainable datacenters. The techniques use GA and Bat Intelligence (BI) to schedule resources for execution in the datacenter taking into consideration of the energy consumption, tardiness, and makespan. Liu, Zhan [27] suggest Energy-Aware VM (EAVM-ACO) placement scheduling based on ACO. The EAVM-ACO is presented as an alternate way to improving resource utilization and energy efficiency. Energy Aware VM Placement Scheduling in Cloud Computing using Firefly Optimization (FOA) approach is presented by [28]. It makes energy-aware decisions based on the past resource utilization and energy consumption data. Duan, Chen [29] propose PreAntPolicy, an energy-aware scheduling for VMs in heterogeneous cloud computing systems. PreAntPolicy is composed of a prediction model that is based on fractal mathematics, and a scheduler from an improved ACO.

### 3.3 Consolidation technique

Consolidation technique uses live VM migration to consolidate VMs periodically so that over utilized PMs can be reduced and migrated to underutilize ones. The most important aspect here is to determine which VM to migrate from over and or underutilized PM that will have an impact on the resource utilization and energy-efficiency. The benefit of this technique is that it optimizes energy-efficiency of servers in the datacenter.

A multi-objective machine reassignment algorithm for datacenters called GeNePi is proposed by Saber, Ventresque [30] to reduce datacenter energy consumption. GeNePi combines three algorithms to form a hybrid technique in the optimization procedure. ACS-based VM Consolidation (ACS-VMC) is proposed by Farahnakian, Ashraf [31] to consolidate VMs for Green Cloud Computing. The authors formulate energy-efficient VM consolidation as a multi-objective optimization problem to optimize three conflicting objectives. Sait, Bala [32] proposed a Multi-Objective CSO Algorithm (MO-CSOA) to minimize the number of PMs used for reducing energy-consumption. Marotta and Avallone [33] have proposed a combined Mixed Integer Linear Programming (MILP) and Simulated Annealing (SA) for energy consumption reduction in a datacenter. A modified PSO (MPSO) to consolidate VMs to avoid falling into a track of local optima is proposed by Li, Zhu [34]. MPSO takes into consideration the impact of multi-resource and accurate scheduling of VM on energy efficiency in a real environment. It focuses only on the CPU and disk to measure the resource utilization and energy consumption but leaves out other components of the server and network. Gabaldon, Guirado [35] have proposed a PSO-AE (Energy-Aware) technique that uses computational resources of a real workload traces to determine the task allocation to available resources with minimum energy consumption.

In summary, the researchers tried to minimize the energy consumption and increase resource utilization of cloud datacenters infrastructure, but, still a major component of data centers which is network are not seen in the scene. Therefore, because of the aforementioned weaknesses of existing techniques, developing new approaches that can efficiently and proactively improve on energy efficiency, resource utilization and reduce carbon emission are a real necessity.

### 4. Future research direction

- **Energy-aware workload Constraint**: The workloads consumes significant amount of datacenter resources. Researchers are encouraged to investigate the type of workload which can be efficiently connected to a PM while performing consolidation of VMs for energy optimization and resource utilization. This will significantly improve resource provisioning and energy savings in the datacenter environment.
- **Multi-tenancy Cloud Datacenters**: Cloud resource provisioning, sharing, and sustainable datacenters are interesting topics in Cloud Computing domain. They are used in minimizing the capital expenses of Cloud service providers. Future researchers can be conducted targeting this limitation of existing literature. This will reduce resource the overhead when managing multiple datacenters and carbon emission; there by, making our environment free from pollution.
- **Integrating Cloud with Fog Computing and Big Data**: It would be interesting and rewarding to investigate the role of energy consumption as a whole in the growth of Cloud Computing and its resource scheduling.
in the presence of Big Data and Fog Computing through the Internet. Adopting this concept will open new areas of research and collaboration.

- **Heterogeneous Cloud:** There is uttermost need to consider heterogeneity in both IaaS and the multi-Cloud perspective. Heterogeneity in Cloud datacenter IaaS need to be consider in at least in two ways. The first is in the context of multi-clouds and the second is concerned with low-level heterogeneity at the IaaS level, in which different types of processors are combined to offer VMs resources.

5. Conclusion

Over the years, energy consumption has been a major concern in cloud computing datacenters and this will influence the future of cloud computing paradigm. In this paper, we presented recent advances and techniques used in reducing the datacenter energy consumption. This is necessary in order to develop some new appropriate technique that can serve as an improvement over the current techniques. The reviewed done so far have disclosed certain limitations as linked to existing cloud-based energy efficiency techniques. This limitation ranges from inability to determine proper resource allocation strategy, data center management scheme, SLA violation, and environmental sustainability. The classification of the technique was done to clearly indicate the levels of implementation of energy efficiency measures within the cloud datacenters with the affected resource and their characteristics. Finally a future research direction has been outlined.

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