ENERGY-EFFICIENT RESOURCE ALLOCATION SCHEME BASED ON ENHANCED FLOWER POLLINATION ALGORITHM FOR CLOUD COMPUTING DATA CENTER

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Specially Dedicated to my self Usman Mohammed Joda

My Parents

My Lovely Brothers and Sisters

My love to you will always remain and thank you for your

Support, Guidance, Patience, Joyfulness to make this experience complete.

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ABSTRACT

Cloud Computing (CC) has rapidly emerged as a successful paradigm for providing ICT infrastructure. Efficient and environmental-friendly resource allocation mechanisms, responsible for allocatinpg Cloud data center resources to execute user applications in the form of requests are undoubtedly required. One of the promising Nature-Inspired techniques for addressing virtualization, consolidation and energy-aware problems is the Flower Pollination Algorithm (FPA). However, FPA suffers from entrapment and its static control parameters cannot maintain a balance between local and global search which could also lead to high energy consumption and inadequate resource utilization. This research developed an enhanced FPA-based energy efficient resource allocation scheme for Cloud data center which provides efficient resource utilization and energy efficiency with less probable Service Level Agreement (SLA) violations. Firstly, an Enhanced Flower Pollination Algorithm for Energy-Efficient Virtual Machine Placement (EFPA-EEVMP) was developed. In this algorithm, a Dynamic Switching Probability (DSP) strategy was adopted to balance the local and global search space in FPA used to minimize the energy consumption and maximize resource utilization. Secondly, Multi-Objective Hybrid Flower Pollination Resource Consolidation (MOH-FPRC) algorithm was developed. In this algorithm, Local Neighborhood Search (LNS) and Pareto optimisation strategies were combined with Clustering algorithm to avoid local trapping and address Cloud service providers conflicting objectives such as energy consumption and SLA violation. Lastly, Energy-Aware Multi-Cloud Flower Pollination Optimization (EAM-FPO) scheme was developed for distributed Multi-Cloud data center environment. In this scheme, Power Usage Effectiveness (PUE) and migration controller were utilised to obtain the optimal solution in a larger search space of the CC environment. The scheme was tested on MultiRecCloudSim simulator. Results of the simulation were compared with OEMACS, ACS-VMC, and EA-DP. The scheme produced outstanding performance improvement rate on the data center energy consumption by 20.5%, resource utilization by 23.9%, and SLA violation by 13.5%. The combined algorithms have reduced entrapment and maintaned balance between local and global search. Therefore, based on the findings the developed scheme has proven to be efficient in minimizing energy consumption while at the same time improving the data center resource allocation with minimum SLA violation.

ABSTRAK

Pengkomputeran Awan (CC) telah muncul dengan pesat sebagai paradigma yang berjaya untuk menyediakan infrastruktur ICT. Mekanisme peruntukan sumber yang cekap dan mesra alam, yang bertanggungjawab untuk memperuntukkan sumber pusat data Awan untuk melaksanakan aplikasi pengguna dalam bentuk permintaan tiada syak lagi amat diperlukan. Salah satu teknik inspirasi alam untuk mengatasi permasalahan maya, penyatuan dan sedar-tenaga adalah Algoritma Pendebungaan Bunga (FPA). Walau bagaimanapun, FPA mengalami kegagalan dalam pemerangkapan dan parameter kawalan statiknya tidak dapat mengekalkan keseimbangan antara carian tempatan dan global yang juga boleh menyebabkan penggunaan tenaga yang tinggi dan penggunaan sumber yang tidak mencukupi. Kajian ini telah membangunkan skim peruntukan sumber cekap tenaga berasaskan FPA yang dipertingkatkan untuk pusat data Awan yang membolehkan penggunaan sumber dan tenaga yang cekap dengan kemungkinan pelanggaran Perjanjian Tahap Perkhidmatan (SLA) yang kurang. Pertama, Algoritma Pendebungaan Bunga Dipertingkat untuk Penempatan Mesin Maya Cekap Tenaga (EFPA-EEVMP) telah dibangunkan. Dalam algoritma ini, strategi *Dynamic Switching Probability* (DSP) digunakan untuk mengimbangi ruang pencarian tempatan dan global dalam FPA untuk meminimumkan penggunaan tenaga dan memaksimumkan penggunaan sumber. Kedua, algoritma Penyatuan Sumber Pendebungaan Bunga Hibrid Multi-Objektif (MOH-FPRC) telah dibangunkan. Dalam algoritma ini, strategi Carian Kejiranan Tempatan (LNS) dan *Pareto Optimization* digabungkan dengan algoritma *Clustering* untuk mengelakkan perangkap tempatan dan menangani objektif bercanggah penyedia perkhidmatan Awan seperti penggunaan tenaga dan pelanggaran SLA. Akhir sekali, Skim Pengoptimuman Pendebungaan Bunga Berbilang Awan Sedar Tenaga (EAM-FPO) telah dibangunkan untuk persekitaran pusat data berbilang-Awan teragih. Dalam skim ini, Keberkesanan Penggunaan Kuasa (PUE) dan pengawal perpindahan telah digunakan untuk mendapatkan penyelesaian yang optimum dalam ruang carian yang lebih besar dalam persekitaran CC. Skim ini diuji pada simulator *MultiRecCloudSim*. Keputusan simulasi dibandingkan dengan OEMACS, ACS-VMC dan EA-DP. Skim ini menghasilkan kadar peningkatan prestasi cemerlang dengan penggunaan tenaga data pusat sebanyak 20.5%, penggunaan sumber sebanyak 23.9%, dan pelanggaran SLA sebanyak 13.5%. Algoritma gabungan telah mengurangkan masalah pemerangkapan dan mengekalkan keseimbangan antara carian tempatan dan global. Oleh itu, berdasarkan dapatan skim yang dibangunkan terbukti cekap dalam meminimumkan penggunaan tenaga dan pada masa yang sama meningkatkan peruntukan sumber pusat data dengan pelanggaran SLA yang minimum.

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LIST OF ABBREVIATION

ABC	-	Artificial Bee Colony
ACO	-	Ant Colony Optimization
ACS	-	Ant Colony System
ACS-VMC	-	Ant Colony System Virtual Machine Consolidation
BBO	-	Biogeography-Based Optimization
BFA	-	Bacterial Foraging Algorithm
CPU	-	Central Processing Unit
CSA	-	Clonal Selection Algorithm
CUE	-	Carbon Usage Effectiveness
DC	-	Dynamic Clustering
DCIE	-	Data Center Infrastructure Effectiveness
DE	-	Differential Evolution
DRM	-	Data Center Resource Management
DSP	-	Dynamic Switching Probability
DVF	-	Dynamic Voltage Frequency
DVFS	-	Dynamic Voltage Frequency Scaling
EA-DP	-	Energy-Aware with Dynamic PUE
EA-MOGA	-	Energy-Aware Multi-Objective Genetic Algorithm
EA-SP	-	Energy-Aware with Static PUE
EA-VMP	-	Energy-Aware Virtual Machine Placement
EAM-FPO	-	Energy-Aware Multi-Cloud Flower Pollination Optimization
EFPA-EEVMP	-	Enhanced Flower Pollination Algorithm Energy-Efficient Virtual Machine Placement
FFD	-	First Fit Decreasing
FOA	-	Fruit Fly Optimization Algorithm
FPA	-	Flower Pollination Algorithm

GA	-	Genetic Algorithm
GAPA	-	Genetic Algorithm for Energy-Aware
IaaS	-	Infrastructure as a Service
IQR	-	Inter Quartile Range
IT	-	Information Technology
LNS	-	Local Neighborhood Search Strategy
MCRM	-	Multi-Cloud Resource Management
MOACS	-	Multi-Objective Ant Colony System
MOGA	-	Multi-Objective Genetic Algorithm
MOH-FPRC	-	Multi-Objective Hybrid Flower Pollination Resource Consolidation
MOO	-	Multi-Objective Optimization
MOPSO	-	Multi-Objective Particle Swarm Optimization
NIST	-	National Institute of Standard and Technology
OEM	-	Order Exchange Migration
OEMACS	-	Order of Exchange Migration Ant Colony System
OS	-	Operating System
PaaS	-	Platform as a Service
PI	-	Performance Improvement
PM	-	Physical Machine
PSO	-	Particle Swarm Optimization
PUE	-	Power Usage effectiveness
QoS	-	Quality of Service
RU	-	Resource Utilization
SA	-	Simulated Annealing
SaaS	-	Software as a Service
SAPSO	-	Simulated Annealing Particle Swarm Optimization
SDSC	-	San Diego Supercomputer Center
SI	-	Swarm Intelligence
SLA	-	Service Level Agreement
SLAV	-	Service Level Agreement Violation
SOA	-	Service-Oriented Architecture
SOO	-	Single Objective Optimization

SOS	-	Symbiotic Organism Search
SPEC	-	System Performance Evaluation Corporations
ST	-	Static Threshold
SWF	-	Standard Workload Format
TSP	-	Traveling Sales Man
VM	-	Virtual Machine
WDA	-	Water Drop Algorithm

LIST OF SYMBOLS

RU^{DC}	-	Data center resource utilization
R^{c}	-	Resource consolidation
E_{t_i}	-	Execution time
$A_i \in ב_n$	-	Represents a partition
DC_U^{Energy}	-	Data center energy efficiency
S_{t_i}	-	Starting time
∇_{VM_i}	-	Estimate of PDMof VM_i due to migration
$Active_u^3$	-	Utilization of the PM components in the data centers
A_i	-	Components of the VMs
EU_{Active}	-	Energy consumption when the PMs are active
EU_{static}	-	Energy consumption when the PMs are static
g_*	-	Best solution
$H_{i=1}^{n}$	-	Total distinct group within each cluster
L_i	-	Distinct cluster group
$Max_{iteration}$	-	Maximum iterations of the proposed scheme
P_{max}	-	Power when memory utilization is 100%
R^{A}	-	Objective function
$T_{PM_j\ iactive}$	-	Total time of PM_j considered active
T_{PM_j}	-	Total time PM_j reached 100% resource utilization
TEC_j^{α}	-	Total Energy Consumption
TEC^{β}	-	Memory power
TEC^{γ}	-	Storage power
v_i	-	Velocity vector
$X_{i,S}$	-	Parameter vector

x_i	-	Position vector
$X_{n\text{-}best_i s}$	-	Best vector
α_s^i	-	CPU component
β_s^i	-	Memory component
γ_s^i	-	Storage component
Δdc_1	-	Data center sites
B_j	-	VM migration to PM
ΔVM_s	-	Total resource capacity of VM_i
$\in$	-	Random walk *L*
EU	-	Memory utilization
EU(t)	-	PM utilization at the given time
L	-	Parameter drawn from a Levy distribution
n	-	Set of solutions
N	-	Number of VMs,
p	-	Probability
Q	-	Pheromone updating constant
r	-	Total host memory
t	-	Current iteration
UR	-	User request
α	-	Pheromone tracking weight
β	-	Heuristic information weight
Υ	-	Consolidation parameter.
ω	-	Inertia factor

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CHAPTER 1

INTRODUCTION

1.1 Overview

Cloud Computing (CC) 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. The facilities of the Cloud allows companies, industries, and organizations to use these resources as a utility service on pay-per-use basis instead of building and keeping computing infrastructures in their premises. CC has rapidly emerged as a successful paradigm for providing ICT infrastructure over the last few years. Over the recent years the use of services offered by CC systems has increased. These Cloud services are being offered in different ways and at different levels of the Cloud data centers, namely, Infrastructure as a Service (IaaS), Platform as a Service (PaaS) and Software as a service (SaaS) (Foster *et al.*, 2008). IaaS provides access to flexible and scalable computing resources for large-scale application deployment. PaaS provides application developers with platform for development, testing and hosting of applications while SaaS service model delivers applications to end users via Internet, and these applications are accessed using client applications like web browsers. SaaS is usually used for service applications like web-mail, and document editing applications.

The CC promises various benefits that are attractive to organizations and users of their services. The main benefits of using CC are pay-per-use, on-demand self-service provisioning, rapid elasticity, and resource pooling. These benefits encourage more business organizations, institutes, and users in need of computing resources to migrate to the Cloud. The broader acceptance of CC has contributed to the formation of large-scale data centers that provide Cloud services (Prasanth *et al*., 2015). This high demand of CC service is addressed through large-scale data centers that usually employed a technique of virtualizing thousands of physical servers into virtual machine and later consolidate them with other infrastructures such as network systems, cooling system, and storage space. Many Internet hosting companies such as Yahoo, Microsoft, IBM, Apple, Google, Alibaba, eBay, and Amazon owned big data centers across the globe (Gleeson, 2009; Buyya *et al*., 2008). They enable the users to access the services available in them instantly by creating the virtualized instances.

Furthermore, there are two parties in CC environment, the Cloud service providers and Cloud service consumers. Providers own high Computing resources housed in data centers, and the resources are leased to consumers on pay-per-use model. Whereas, the Cloud service consumers lease resources from providers to execute user's applications. On one hand, the target of provider is to maximize return on investment as much as possible. To that end, providers allocate and schedule as many user applications as possible on each resources to maximize the utilization of resources and reduce energy consumption without violating the Service Level Agreement (SLA). On the other hand, consumers demand to have their requests served at minimal cost.

SLA is a set of contract expectations between the consumer and service provider (Wustenhoff, 2002). In a CC context, there are infrastructure SLA and service SLA. Infrastructure SLA is set of contract terms between IaaS providers and service providers to sufficiently guarantee resource and uptime while service SLA is established between service providers and Cloud service consumers that is usually measured in QoS metrics such as application response time and throughput (Ahmed *et al*., 2015). Resource allocation is one of the challenges of CC because end-users can access resources from anywhere and at any time with the kind of service stipulated in SLA as the legal written document describing QoS requirements (Rimal *et al*., 2009).

Therefore, SLA is the foundation of how the Cloud service provider sets and keeps responsibilities to the service of the Cloud consumer. Moreover, optimizing resource utilization without violating the SLA is also of extreme importance for data center operators.

Meanwhile, Computing and information processing capacity of several private and public organizations have brought increased flexibility in the data center . CC provides a lot of support in the field of computing ability to institutions and various organizations that are in need of the latest ICT technology that will allow them to process enormous data in their daily operation (Buyya et al., 2008). The high demand by users to access resources and process data has led to higher consumption in energy of the data centers. Thus, CC data centers are the strength of today's demanding ICT infrastructure, for these reasons, energy efficiency and resource utilization is becoming increasingly important for CC data centers. Further, the data centers are not only expensive to maintain but they are unfriendly to the environment. Because they produce significant carbon emissions, which poses threats to human life and the environment (Green, 2010). However, resource management in large-scale data centers is still a complex and challenging issue. Therefore, the focus of this research work is on energy-efficient resource allocation in IaaS Clouds on service provider's perspective because data and Computing applications are growing rapidly, which lead to demand for large servers, storages, and network infrastructure for faster processing.

1.2 Background of the Problem

Cloud data center offer abundance resources, which makes the CC model support on-demand elastic resource allocation. However, such abundance also lead to non-optimal IaaS resource allocation which cannot be optimally handled with existing resource scheduling techniques (Shen *et al.*, 2013; Tsai *et al.*, 2014; Singh and Chana, 2016). Energy efficiency and resource allocation are among the important challenges of resource scheduling in Cloud Computing. This is because of the number of individuals and organizations shifting their workload to Cloud data centers is growing more than ever and at the same time being environmentally-friendly due to the carbon footprint as a result of the energy consumed by the data centers (Khosravi *et al.*, 2013). The resources in a Cloud cannot be requested directly but can be accessed through Simple Object Access Protocol (SOAP) and Representational State Transfer (REST) web APIs that map requests for computations or storage are mapped to virtualized ICT resources. Therefore, a resource scheduler has to be aware of respective challenges introduced by essential features of the CC environment (Dikaiakos *et al.*, 2009).

With IaaS model, virtualized compute resources called Virtual Machines (VMs) with pre-configured CPU, storage, memory, and bandwidth are leased to users by imposing subscription for what they use only. Various VM instances are available to the users at different prices to serve their various application needs; this gives users the freedom to utilize computing resources at their disposal. IaaS provides three inherent benefits to users. First, users lease resource on demand, and are charged based on pay-per-usage similar to basic utilities like electricity, gas, and water. This enables users to shrink or expand their resource subscription based on the needs of their application. Second, IaaS Cloud provides direct resource provisioning which improves the performance of user applications. Third, users can demand for leased resources anytime and anywhere according to the desired level of service. However, determining the adequate number of resources to execute a set of large-scale allocation of resources on IaaS Cloud is still an open problem (Wu *et al.*, 2015).

The problem of resource allocation to Cloud has a key influence on the computational efficiency of the Cloud system giving the dynamic variation of application requirement by the Cloud users such as resource capacity demand and access pattern. This is generally known to be an $\mathcal{NP}$-hard problem (Alkhanak *et al.*, 2015; Bagheri and Jahanshahi, 2015; Alkhanak *et al.*, 2016), where there is no deterministic algorithm that can find optimum solution to the scheduling problem within an acceptable period of time. Figure 1.1 shows the resource scheduling problem

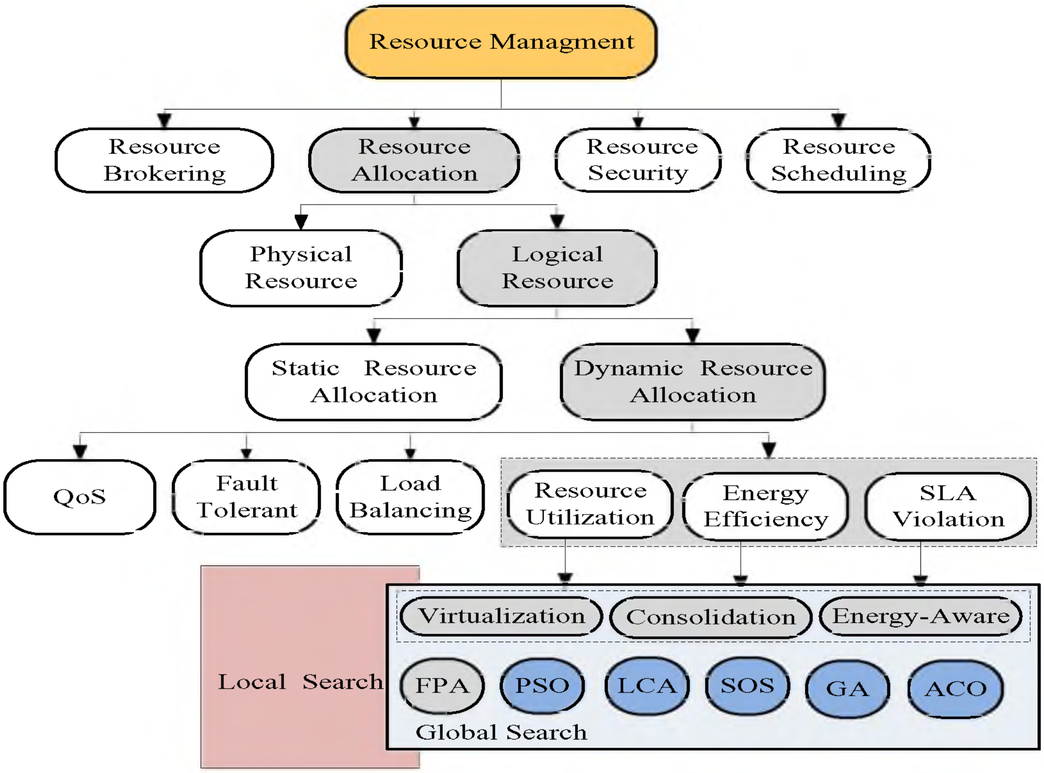

Figure 1.1 Resource management classification in Cloud Computing

addressed in this research. This problem is a computationally NP-hard problem and researchers have been making efforts to solve the said problem (Srikanth *et al.*, 2015). It is already revealed that energy-aware resource management deals with under-utilized resources, particularly in a Cloud environment with large number of user requests account for a substantial amount of the actual energy use (Mandal and Kahar, 2015). Energy consumption and resource utilization in Clouds are highly coupled. Specifically, resources with a low utilization rate still consume an unacceptable amount of energy compared with their energy consumption when they are fully utilized or sufficiently loaded. For example, Hamilton (2009), found out the servers consume more energy in a data center than other Computing devices and account for about 60% of data centers' energy consumption, and thus the overall energy efficiency of the data center is affected by the efficiency of the servers. A typical server in data center exhibits inefficiency when it is at low utilization level. Figure 1.2 illustrates three different servers' power consumption plotted against their load levels. At load 0%, the server is completely idle while 100% indicates that the server is fully utilized.

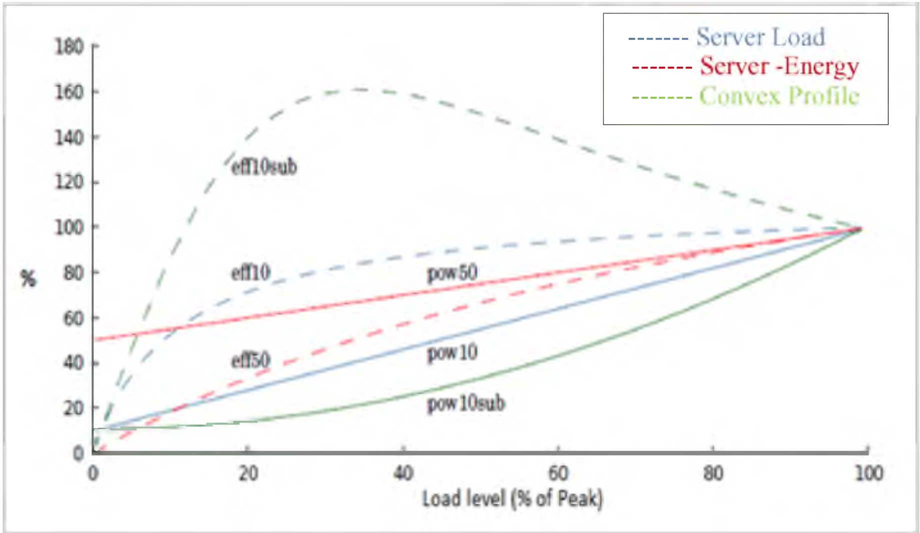

Figure 1.2 Energy consumption of the server (Hamilton, 2009)

The eff10 and eff50 represents energy efficiency at 10% and 50% of the server utilization. The eff10sub is the variation value of the efficiency at 10% of the server utilization. The pow10sub and pow50 represents the power consumption of the servers in data centers. The pow10sub is the variation value of the power consumption at 10% of the server utilization. The green, blue and red dash lines depict the energy efficiency at 10%, 10% and 50% utilization of the server respectively. While the green, blue and red lines in the figure shows the power consumption at 10%, 10% and 50% utilization of the server respectively. The higher the load, the higher the energy consumption with pow as the power consumption while the eff indicate the server efficiency. From the graph, the solid red line indicates the level of energy consumption against the server load. The graph further illustrates the linear relationship between load and energy, i.e. red and blue lines, although a green curve line indicates a hypothetical convex profile, at the initial stage, the energy consumption increases hypothetically in a linear form, putting most of its energy efficient operating point below 100% utilization.

Due to the increasing concern with actual use of resources and challenges of allocating them on large scale data center, scheduling of resources have become an emerging research in CC and have attracted significant attention of researchers in recent times. Various heuristics algorithms have been applied to solve resource allocation and energy consumption problems which generate optimal solutions for small size problems (Chen *et al.*, 2013; Ming and Li, 2012; Mao *et al.*, 2014; Patel *et al.*, 2015). However, the performance of the techniques degrades badly as the problem size and number of variables involved increas. Also, these heuristic methods do not have provisions and support for meeting SLA requirements to improve resource management. In contrast, many Cloud providers have certain objective in managing the Cloud infrastructure, which include load balancing, resource utilization, throughput, energy consumption, priority constraint, cost constraint, deadline and dependency of application request.

Many researchers attempt to address resource allocation problems using Nature-Inspired algorithms (Hameed *et al.*, 2014; Xu *et al.*, 2015; Singh and Chana, 2016b). Utilizing Nature-Inspired algorithms for solving resource allocation problems in Cloud have shown promising improvements in achieving efficiency in reasonable amount of time. However, Nature-Inspired algorithms incur high computational time and in some cases return local optimum solution especially when dealing with large solution space; also, these techniques may suffer from premature convergence and imbalance between local and global search (Guzek *et al.*, 2015; Kalra and Singh, 2015; Zhan *et al.*, 2015; Xue *et al.*, 2016; Meena *et al.*, 2016). These limitations result to sub-optimal resource allocation solutions which affects the performance of service provisioned by the service provider.

Energy-efficient resource management approaches either focused on Single Objective Optimization (SOO) or Multi-Objective Optimization (MOO). The SOO attempt to optimize either energy or resource utilization with some constraints, especially SLA, deadline and budget (Feller *et al.*, 2011; Ferdaus *et al.*, 2014; Moganarangan *et al.*, 2016; Sharma and Reddy, 2015b). However, due to the rapid development in Cloud data center , several objectives may need to be considered which make resource management a MOO problem. The complexity of MOO arises due to the different optimization goals of users and providers. Users are mainly concerned with minimizing makespan and cost, whereas providers want to maximize resource utilization and energy consumption while meeting user SLA requirements (Pascual *et* *al*., 2015; *Saber et al*., 2014; Sait *et al*., 2016; Yassa *et al*., 2013). Generally, Cloud providers offer heterogeneous set of resources to users with different performance and capacity. In this way, the resource management has to be formulated as optimization problem that intend to optimize Cloud data center resources. The optimization of the resources is carried out as a resource allocation problem with the aim of reducing energy consumption, resource wastage, SLA violation, hot spot, service monitoring and cost using either virtualization, consolidation, thermal-aware, and energy-aware schemes. However, most of the existing schemes suffer from imbalance between the local search and the global search, local optima entrapment and high complexity that make them inefficient in managing data center resources (Fister *et al*., 2013). The following subsections elaborate the issues of existing Nature-Inspired energy-efficient resource management schemes in more detail.

1.2.1 Imbalance Between Local Search and Global Search

Local search is the ability of a search algorithm to exploit the surrounding search area for possible improvement of the current solution. Global search is the ability of the algorithm to search for new solution far from the current solution in the search space. Finding an algorithm that could adequately strike a balance between local and global search is challenging. Various Nature-Inspired algorithms are used in virtualized CC (Vouk, 2008; Beloglazov *et al*, 2012; Cearley and Reeves, 2011; Kim *et al*., 2011). Once the Cloud data center receives an application request from a customer or a Cloud user, a VM is created to host the application based on the required resources (CPU, memory, storage) and the type of operating system specified by the customer. Then, the VM is assigned to one available Physical Machine (PM) according to the placement strategy. However, the algorithms may not achieve optimal allocation of assigning the VMs to suitable PMs due to the slow convergence of their solution within the search space.

VM allocation techniques based on Artificial Bee Colony (ABC) have been proposed to optimize resources in Cloud data center (Benali *et al*., 2015; Kimpan and Kruekaew, 2016; Kruekaew and Kimpan, 2014). The allocation strategy adopted selects the resource that match the user request and at the same time reduce the resource under-utilization by running multiple VMs on a single PM. However, the techniques cannot scale well since the efficiency of ABC algorithms cannot gurantee optimal resource allocation in a global search space; thus, resulting in high energy consumption due to sub-optimal results. Similarly, Ant Colony Optimization (ACO) algorithms have been used in solving the VM placement problem in Cloud environment by Setzer and Stage (2010) and Liu *et al*. (2014b). The approach deposits pheromone between VMs to track the past desirability of placing them in the same PM. ACO VM placement strategy has also been proposed by Liu *et al*. (2016), to attained optimal VM goal. Even though ACO has been combined with a local search strategy known as Order Exchange Migration (OEM) that reduces the number of PMs used for VM allocation from a global optimization view. The OEM strategy has been adopted to help speed up global convergence. Although the proposed strategy is effective, but based on the parameter analysis, it is not efficient when the size of VM placement increase due to slow convergence of the algorithm which then leads then to inefficient resource utilization and high energy consumption by the data center.

Joseph *et al*. (2015), Wu *et al*. (2012) and Wang *et al*. (2012a) proposed VM placement using Genetic Algorithm (GA) to improve the convergence speed of the GA to produce optimal solution of the resource scheduling in Cloud data center. Furthermore, Particle Swarm Optimization (PSO) algorithm has been explore by various researchers (Pacini *et al*., 2014; Wang *et al*., 2013). However, these algorithms mostly focus in searching global optimum solutions. Some of the most important features for the research to take into consideration when choosing a Nature-Inspired algorithm are: intensification and diversification. An intensified search means searching a small solution space with intensity until an optimal solution is found in that region, which is known as local optimum. Equally, a diversified search implies searching a larger solution space for an optimal solution, which is known as global optimum. Unfortunately, a larger solution search space does not always assure a superior optimal solution (Tsai and Rodrigues, 2014). This shows the importance of striking a balance between local and global optima, which may have a strong impact on the quality of the resource allocation results based on the quality of near optimal solution produce by the optimization algorithm.

1.2.2 Entrapment of Search Procedure in Local Optima

Local optima is defined as the relative best solutions within a neighbor solution set, which is sometimes not necessarily an optimal; local optima entrapment could result to slow convergence and non-optimal resource consolidation. Consolidation technique is also another method used for energy efficient resource scheduling in Cloud environment that utilizes one PM to host multiple isolated VMs, each performing the work of a server. Thus, the PM resources are shared and accessed by different users and applications.

The energy consumption of under-utilized PM and other resources, particularly in a Cloud environment, accounts for a substantial amount of the actual energy used (Lee and Zomaya, 2012). It is attributed to the problem of local entrapment in Particle Swarm Optmizaton (PSO) algorithm that results in inefficient resource allocation policy of the data center (Mandal and Kahar, 2015). Maximizing energy efficiency while ensuring the user's SLA is very important for the Cloud service providers (Zhao *et al.*, 2016). Cloud providers have to apply energy-efficient resource management strategies, such as dynamic consolidation of VMs and switching idle servers to power-saving modes (Beloglazov and Buyya, 2012). The consolidation is not trivial, as it may result in violations of the SLA negotiated with service consumers. Beloglazov *et al.* (2012) proposed an approach based on the idea of setting fixed utilization thresholds of servers in Cloud. However, fixed utilization thresholds are not efficient for IaaS Cloud environments with mixed workloads that exhibit nonstationary resource usage patterns. Even though servers are idle, that is, no user is logged in, they still consume a lot of energy. One of the main reasons for the resource inefficiency in today’s data centers is overprovisioning (Lovász *et al.*, 2013). Existing Nature-Inspired scheduling algorithm in Cloud cannot work well if the problem of local entrapment has not been addressed adequately. Because the solution obtained by the algorithm is not guaranteed as the best solution within the search space.

The underutilization of PMs or CPU attributed to inefficient resource allocation policy of the data center (Mandal and Kahar, 2015). Although, CPU are the most popular resource, it all depends on the PM configuration and the data center set up. These resources are considered as the single largest energy consumer within the Cloud data center. In addition, other resources are a necessity for the data center to perform its function. For example, a PM may also have some components apart from the CPU, such as memory, disk drive, and other peripherals. Therefore, it can be easily generalized to say inefficient CPU utilization to an underutilized PM of the data center, but in reality all components are to meet the expected results although, the CPU is apparently underutilized, other components are already working at their limit. Farahnakian *et al.* (2015) present a green Cloud using ACO system. The approach uses dynamic VM migration to move the under-loaded PMs to the averagely loaded PMs so that some PMs will be switch off, stand by and/or hibernate while reducing energy consumption and increase data center performance. The approach uses two regression model to predict the CPU utilization of the PMs in order to reduce SLA violation and energy usage. This has led to the achievement of near optimal solution based on the specified objective function. However, the migration has been done considering CPU utilization while other components are still working which also consumes energy. The approach produces sub-optimal results in terms of resource utilization and the energy consumption.

There are other research works that used the ACO system to proposed solutions for data center consolidation (Liu *et al.*, 2017; Ashraf and Porres, 2017; Ashraf and Porres, 2014; Ferdaus *et al.*, 2014; Murtazaev and Oh, 2011). In these cases, the Nature-Inspired algorithm runs around a local solution continuously without any progress, otherwise reaches the iteration limits. Hence, if the value remains constant for a series of runs, then the algorithm traps in a local minimum after some generation. These techniques suffer from issues like entrapment of search procedure in local optima, premature convergence, and imbalance between global search and local search, resulting to sub-optimal consolidation which led to inefficient resource utilization and energy wastage. In other words, trapping is the serious problem of Nature-Inspired algorithms in Cloud data center resource management. Furthermore, the approaches do not take into consideration of the SLA violation due to the migration of VMs. Thus, addressing resource allocation optimization problem using consolidation technique that avoids local optima entrapment by balancing the local and global search space is still an active research area to be explored.

1.2.3 High Computational Complexity

The complexity of the schemes is determined by the cost of evaluating the objective function and the amount of evaluations performed at each iteration step due to the large size of the search space. The main reason for this is the increase in the number of VMs request and the number of data centers with large number resources.

Due to the high computational complexity of the Cloud data center environment, energy-aware resource utilization solution are suggested which employed Artificial Bee Colony (ABC) algorithm that return optimum result to the Cloud environment is developed (Kansal and Chana, 2015). To save energy, the under-utilized resources need to be improved, to achieve that, resources need to be efficiently allocated in such a way that performance and energy efficiency are maximize. However, the schemes takes longer time to make allocation decision due to the evalution method of the objective function constraint of the ABC.

Energy-aware resource allocation is not only about the scheduler, it includes the integration of the overall energy management framework of the data center (Mandal and Kahar, 2015). Energy-aware hybrid algorithm of ACO and Cuckoo

Search algorithm (CSA) using voltage scaling has been design and implemented considering constraint deadline and energy consumed by PM resources (Babukarthik *et al.*, 2012). Another energy-aware for enhancing Cloud data center that uses PSO and Tabu Search (TS) algorithm has been presented with the aim of maximizing resource utilization and energy efficiency (Wang *et al.*, 2012b). This implies that, no algorithm with a number of steps polynomial in the size of the instances is known for solving any of them, and that finding one would entail obtaining one for each and all of them. Therefore, practitioners are often satisfied with an approximate solution which may sometimes not be an optimal solution.

Similarly, Lawanyashri *et al.* (2017) proposed energy-aware optimization technique by hybridizing Fruitfly Optimization Algorithm (FOA) with Simulated Annealing (SA) to achieve optimal resource utilization and energy consumption by improving the convergence rate and accuracy of the algorithms. The approach uses fruitfly for aging behavior to balance data center resource utilization which make it popular among other technique. However, due to the few searching parameters used by the technique becomes vulnerable to high complexity due to large size of instances for an exact solution to be found in reasonable time. Although, the hybridization with SA has overcome the drawback, but the global search ability of the approach cannot be guaranteed on the large-scale search space. Most of the existing approaches lack coordination between the energy-aware scheduling algorithms to avoid conflicting suboptimal solutions due to the complexity. However, the schedulers do not have information regarding the request capacity of the user in order to make efficient allocation of resources based on resource utilization and current energy consumption of the PM. Therefore, in view of the aforementioned problems, there is an urgent need of energy-aware resource allocation scheme in Cloud data center with less complexity and speed convergence. The new scheme will help in managing the IaaS resources so that there can be an efficient utilization of resources and performance enhancement of multiple distributed data centers.

1.3 Problem Statement

In CC environment, resource allocation technique plays an important role in meeting service provider's optimization requirements. This research addresses the problem of resource utilization and energy consumption of infrastructure within the Cloud data center. The rapid growth and integration with Computing components in delivering various end user requests can severely degrade Cloud performance if not properly managed. Resources with a low utilization rate still consume an unacceptable amount of energy compared with their energy consumption when they are fully utilized or sufficiently loaded. In particular, for energy efficient resource delivery, three critical aspects are considered in this research: VM allocation, resource consolidation and energy-aware resource scheduling of Cloud IaaS.

There are some grid-based heuristic resource management algorithms that have been adapted for Cloud environment. However, these algorithms provide solution in limited ways. These heuristic based algorithms produce optimal results for small size problems. Furthermore, their performance degrades with large size problems. Resource allocation in CC is known to be a NP-hard problem because of the growing transition to the Cloud data center as well as the dynamic and heterogeneous nature of the resources within the CC infrastructure. Computational complexity of these algorithms increases exponentially as the problem size increases. Moreover, local optimum solutions are re-evaluated in other cases, and these techniques still suffer from issues like entrapment of search procedure in local optima, premature convergence, and imbalance between global search and local search, resulting in sub-optimal results. Most of the existing works failed to capture the essential features of CC like heterogeneity, dynamism, and uncertainty of multiple Computing resources (CPU, memory and storage) there by fail to fulfil service provider's objectives. These resources are susceptible to high energy consumption due to performance variations such as resource utilization, service level agreements (SLA) violation, and workloads diversity.

1.4 Research Questions

With reference to the research problem stated in Section 1.3, this study addresses the following research questions:

i) What are the appropriate methods used to increase the global convergence of Nature-Inspired algorithm to achieve efficient resource utilization and energy consumption in Cloud data center environment?
ii) How can local trapping in Nature-Inspired algorithm based resource optimization technique be handle in order to maximize energy efficiency and minimize Service Level Agreement (SLA) violation in Cloud data center?
iii) Is there need to enhance the performance of Nature-inspired algorithm in (i) to optimize resource allocation in a Multi-Cloud data center to reduce energy consumption?

1.5 Research Goal

The aim of this research is to develop an energy-efficient resource allocation scheme for IaaS CC Environment based on the state-of-the-art Nature-Inspired Flower Pollination Algorithm (FPA) that is scalable and able of avoiding local optima entrapment to ensure faster convergence, and maintain a balance between local and global global search for near-optimal solution.

1.6 Research Objectives

The overall aim of this research is to design and develop a resource allocation scheme that reduces energy consumption for single and multiple distributed data centers. To achieve this aim, the following objectives are meant to be accomplished:

i) To design and develop an efficient resource optimization scheme that maintains a balance between local and global search for ensuring near-optimal solution in order to reduce energy consumption for Cloud data center.

ii) To design a VM consolidation optimization scheme that avoids entrapment in local optima in order to maximize energy efficiency and minimize Service Level Agreement (SLA) violations.

iii) To design energy-aware resource allocation optimization scheme that can reduce energy consumption in a distributed Multi-Cloud data center.

1.7 Scope of the Research

The scope of this research are as follows:

i) This research focused on IaaS Cloud to address the challenge of resource management by making energy consumption and resource utilization Cloud data centers more efficient.

ii) The research is to address the issues of resource allocation and energy consumption within Cloud data center comprising of heterogeneous physical and logical resources of IaaS environment.

iii) All tasks are generated from the Parallel Workload Archive (Hazlewood, 2015) which contains 73,496 tasks traces. This workload archive is made available by San Diego Supercomputer Center (SDSC) and is in the Standard Workload Format (SWF) and also in the CloudSim's workload planet.The proposed techniques and algorithm focus on resource allocation, VM migration and energy consumption in single and Multi-Cloud data center by single provider.

iv) The developed algorithms are evaluated using MultiRecCloudSim 3.0.3 simulation framework.

1.8 Contributions of the Research

This research focuses on developing energy efficient and resource allocation scheme for Cloud data centers. Therefore, the main contributions of this research are listed in accordance to the objectives as follows:

i) Enhanced Flower Pollination Algorithm for Energy-Efficient Virtual Machine Placement (EFPA-EEVMP) for Cloud data center environment that can reduce energy consumption, resource under-utilization and improving global convergence of optimal solutions.
ii) Multi-Objective Hybrid Flower Pollination Resource Consolidation (MOH-FPRC) algorithm that integrates data center Physical Machine (PM) resource components to find optimal tradeoffs between energy consumption and SLA violation, thereby ensuring faster convergence that avoid local entrapments.
iii) Energy-Aware Multi-Cloud Flower Pollination Optimization (EAM-FPO) scheme that enhances the search practice, reduces computational complexity, improves resource utilization and reduces energy consumption.

1.9 Organization of the Thesis

The thesis is organized as follows:

Chapter 1 presents the problem statement, objectives, contributions, and outline of this thesis. Chapter 2 begins by laying out the theoretical dimensions of the research which provides background materials for subsequent discussion and explain how similar works together with that strenghts and limitations. Key concepts of energy efficiency and benefits of reducing the energy consumption of Cloud data centers are discuss.

Chapter 3 describes the methodology used for this study; it covers the general framework that list the approaches of achieving the research objectives in a systematic manner. The steps required for design and development of the proposed schemes are outlined. Furthermore, the experimental test bed which comprises the simulation tools, and workloads for evaluating the efficacy of the proposed schemes are established as well as metrics of evaluation and comparison with other relevant scheme for benchmark.

Chapter 4 presents the design and development of Enhanced Flower Pollination Algorithm for Energy-Efficient Virtual Machine Placement (EFPA- EEVMP) scheme to reduce the data center energy consumption. In addition, the efficacy of VM placement algorithm is evaluated and analyzed against other similar VM placement algorithms in terms of different performance evaluation metrics.

Chapter 5 presents the proposed design and development of Multi-Objective Hybrid Flower Pollination Resource Consolidation (MOH-FPRC) scheme that integrates data center Physical Machine resources. Furthermore, results of experiments are shown in order to measure the relative performance of MOH-FPR scheme against other similar algorithms.

Chapter 6 presents the design and development of Energy-Aware Multi-Cloud Flower Pollination Optimization (EAM-FPO) scheme that balance the local and global search practice in order to improve resource utilization, energy efficiency and avoid local entrapment. Furthermore, the simulation based performance evaluation is carried out by means of different performance metrics against relevant energy-aware resource allocation algorithms.

Chapter 7 presents the conclusion and describes the contributions made by this study as well as suggests future directions. The chapter also present the achievements of the objectives and their comparative performance evaluations.

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