UNIVERSITI PUTRA MALAYSIA

EFFICIENT TASK SCHEDULING STRATEGIES USING SYMBIOTIC ORGANISMS SEARCH ALGORITHM FOR CLOUD COMPUTING ENVIRONMENT

SULEIMAN SA'AD

FSKTM 2022 3

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By

SULEIMAN SA'AD

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

January 2022

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DEDICATION

To my beloved parents, Sa'adu Hamidu Damare and Hajja Hafsatu Muhammad Mai.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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January 2022

Chairman : Associate Professor Abdullah bin Muhammed, PhD
Faculty : Computer Science and Information Technology

In recent times, the cloud computing model is gaining tremendous migration of users in both private and government organisations. Users are charged based on their resources usage as well as Quality of Service (QoS) desired due to its pay-as-you-go feature. As such, task scheduling approaches play a vital role in specifying and ensuring an adequate set of resources to execute the users' applications (i.e., tasks). Hence, schedule decisions using task scheduling approaches are according to the users' outlined QoS requirements. Task scheduling in the cloud environment is an NP-Complete problem, because of its dynamism and huge search space given by problem instances that are large scale. Although many approaches (heuristics and metaheuristics) were proposed, they incur high computational complexity as well as not that efficient in terms of obtaining global optimum solutions. Recently, a nature-inspired metaheuristic known as Symbiotic Organisms Search (SOS) optimisation algorithm was proposed. It imitates the survival relationships (mutualism, commensalism and parasitism) between organisms in an ecosystem.

The SOS and its variants Discrete Symbiotic Organisms Search (DSOS) algorithm have been used to solve different optimisation problems including tasks scheduling in cloud computing environment where results obtained are promising in comparison with state-of-the-art metaheuristic algorithms. However, the efficiency of the clouds drops as the size of the search space gets larger, like in the case of most metaheuristic optimisation algorithms. Furthermore, existing tasks scheduling solutions suffer from local optima entrapment due to inadequate diversification of their local search space, a high degree of imbalance because of their static control parameters cannot maintain a balance between local and global search space and scalability issue as a result of static benefit factors.

In this study, an enhanced Discrete Symbiotic Organisms Search (eDSOS), a Cuckoo-based Symbiotic Organisms Search (CDSOS), and an Adaptive Symbiotic Organisms Search (ADSOS) approaches are proposed to address the issues of local optima entrapment, load balancing as well as scalability due to large scale task scheduling optimisation problem in IaaS cloud computing environment. To solve the issue of local optima entrapment, the concept of diversifying the local search space by enhancing SOS named eDSOS approach to avoid entrapment in local optima for global convergence. Then CDSOS approach further improves the SOS algorithm by hybridising it with Cuckoo search's levy flight to minimise the degree of imbalance between the local search space and the global search thereby improving the tasks to VM mapping. Finally, to solve the issue of scalability ADSOS approach adaptively turn SOS benefit factors to make SOS more efficient for solving large scale task scheduling problems as well as faster convergence speed. To assess the effectiveness of the proposed approaches (eDSOS, CDSOS, and ADSOS) CloudSim simulator was used, using synthesised workloads (normal, left-half, right-half and uniform distributions). Moreover, a comparison of the proposed approaches was done with DSOS, SASOS and OTB-CSO, respectively.

The proposed approaches obtained considerable improvement in terms of the following metrics: makespan, response time, degree of imbalance, execution cost and execution time while meeting the desired QoS requirements. Furthermore, the simulation results showed that the eDSOS task scheduling approach outperformed the benchmark algorithm, produced better makespan time performance of 15.93%, 16.22%, 19.69% and 14.54% whereas the benchmark algorithm produced 18.04%, 19.64%, 16.08% and 14.72%, when implemented on the same dataset. Also, the results of the simulations on normal, left-half, right-half and uniform datasets showed the proposed scheduling approach obtained a better performance on degree of imbalance over the benchmarked OTB-CSO algorithm. Moreover, the results of the simulations also showed the ADSOS produced Performance Improvement Rate (PIR%) of 39.45%, 35.08% and 23.91%, 21.36% compared to the benchmarked algorithm in term of execution cost and execution time respectively. Hence, these gives a superior middle way between the execution of cost and time which makes it be dependable for its implementation in a real cloud computing environment. Consequently, the approaches proposed have abilities to better the QoS delivery. The research made some recommendations such as to implement the proposed SOS-based task scheduling approaches using NASA Ames iPSC/860 and HPC2N workloads as well a real cloud environment to validate their performances.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

STRATEGI PENJADUALAN TUGASAN YANG CEKAP MENGGUNAKAN ALGORITMA PENCARIAN ORGANISMA SIMBIOTIK UNTUK PERSEKITARAN PENGKOMPUTERAN AWAN

Oleh

SULEIMAN SA'AD

Januari 2022

Pengerusi : Profesor Madya Abdullah bin Muhammed, PhD
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Mutakhir ini, model pengkomputeran awan telah mendapat perhatian pengguna yang luar biasa di kalangan organisasi swasta dan kerajaan. Pengguna dikenakan bayaran berdasarkan penggunaan sumber dan kualiti-perkhidmatan (QoS) yang diinginkan menggunakan konsep pay-as-you-go. Jadi, pendekatan penjadualan tugas memainkan peranan sangat penting dalam menentu dan memastikan sumber yang cukup untuk melaksanakan aplikasi pengguna (cth. tugas). Oleh itu, keputusan jadual menggunakan pendekatan penjadualan tugas adalah mengikut keperluan QoS pengguna.

Penjadualan tugas dalam persekitaran awan merupakan suatu masalah NP-Complete berikutan sifatnya yang dinamik dan ruang carian yang besar dalam masalah berskala besar. Walaupun banyak pendekatan (heuristik dan meta-heuristik) yang telah dicadangkan, namun mereka masih mengalami kerumitan komputasi yang tinggi dan tidak begitu efisien dalam mendapatkan penyelesaian umum yang optima. Baru-baru ini, algoritma pengoptimuman meta-heuristik yang berinspirasikan alam semula jadi dikenali sebagai Symbiotic Organisms Search (SOS) telah dicadangkan. Ianya meniru hubungan kelangsungan hidup (mutualisma, komensalisma dan parasitisma) antara organisma dalam ekosistem.

Algoritma SOS dan variannya Discrete Symbiotic Organisms Search (DSOS) telah digunakan untuk menyelesaikan pelbagai masalah pengoptimuman di mana hasil yang diperoleh didapati memberansangkan berbanding dengan algoritma metaheuristik sedia ada. Walau bagaimanapun, kecekapan algoritma DSOS menurun apabila saiz ruang carian semakin besar seperti yang berlaku dalam algoritma pengoptimuman metaheuristik yang lain. Tambahan pula, penyelesaian penjadualan tugas sedia ada mudah mengalami perangkap optima tempatan berikutan kepelbagaian ruang carian tempatan yang tidak mencukupi, tahap ketidakseimbangan yang tinggi berikutan parameter kawalan statiknya tidak dapat mengekalkan keseimbangan antara ruang carian

tempatan dan umum, dan masalah kebolehskalaan akibat faktor statik. Dalam kajian ini, peningkatan Discrete Symbiotic Organisms Search (eDSOS), Pencarian Organisma Symbiotic berasaskan Cuckoo (CDSOS), dan strategi Adaptive Symbiotic Organisms Search (ADSOS) dicadangkan untuk mengatasi masalah perangkap optima tempatan, pengimbangan beban serta kebolehskalaan berikutan masalah pengoptimuman penjadualan tugas skala besar dalam persekitaran pengkomputeran awan IaaS.

Untuk menyelesaikan masalah perangkap optima tempatan, konsep mempelbagaikan ruang pencarian tempatan dengan meningkatkan pendekatan SOS yang dinamakan eDSOS untuk mengelakkan ianya terjebak dalam optima tempatan untuk penumpuan umum. Kemudian pendekatan CDSOS meningkatkan lagi prestasi algoritma SOS dengan menghibridkannya dengan levy flight carian Cuckoo untuk mengurangkan tahap ketidakseimbangan antara ruang carian tempatan dan carian umum justeru meningkatkan keseimbangan beban. Akhir sekali, untuk menyelesaikan masalah kebolehskalaan, pendekatan ADSOS secara adaptif mengubah faktor SOS menjadikannya lebih cekap untuk menyelesaikan masalah penjadu- alan tugas berskala besar serta kelajuan penumpuan yang lebih cepat. Simulator CloudSim digunakan untuk menilai prestasi pendekatan yang dicadangkan (eDSOS, CDSOS, dan ADSOS) dengan menggunakan beban kerja yang disintesis (taburan normal, separuh kiri, separuh kanan dan seragam). Selain itu, pendekatan yang dicadangkan juga dibandingkan dengan DSOS, SASOS dan OTB-CSO.

Pendekatan yang dicadangkan memperolehi peningkatan yang besar dari segi metrik berikut; makespan, masa tindak balas, tahap ketidakseimbangan, kos pelaksanaan dan masa pelaksanaan di samping memenuhi keperluan QoS yang dikehendaki. Tambahan pula, hasil simulasi menunjukkan pendekatan penjadualan tugas eDSOS mengatasi algoritma penanda aras, menghasilkan prestasi masa makespan (masa tindak balas VM) yang lebih baik iaitu 15.93%, 16.22%, 19.69% dan 14.54% berbanding algoritma penanda aras yang menghasilkan 18.04%, 19.64%, 16.08%, 16.08% dan 16.08% apabila dilaksanakan ke atas dataset yang sama. Selain itu, keputusan simulasi bagi dataset biasa, separuh kiri, separuh kanan dan seragam menunjukkan pendekatan penjadualan yang dicadangkan memperoleh prestasi yang lebih baik pada tahap ketidakseimbangan berbanding algoritma penanda aras OTB-CSO. Selain itu, hasil simulasi juga menunjukkan Kadar Peningkatan Prestasi (PIR%) yang dihasilkan ADSOS ialah 39.45%, 35.08% dan 23.91%, 21.36% berbanding algoritma penanda aras dari segi kos pelaksanaan dan masa pelaksanaan masing-masing. Oleh itu, keputusan ini mencadangkan keseimbangan di antara pelaksanaan kos dan masa yang saling berkait untuk pelaksanaan dalam persekitaran pengkomputeran awan sebenar. Justeru, pendekatan yang dicadangkan berupaya meningkatkan penyampaian QoS. Penyelidikan mengutarakan beberapa cadangan seperti melaksanakan pendekatan penjadualan tugas berasaskan SOS yang dicadangkan menggunakan beban kerja NASA Ames iPSC/860 dan HPC2N serta persekitaran awan sebenar untuk mengesahkan prestasi mereka.

ACKNOWLEDGEMENTS

First and foremost, all praises be to ALLAH (Subhanahu Wa Ta'ala), the Almighty, on whom we ultimately depend for sustenance and guidance. My profound gratitude goes to my supervisor, Assoc. Prof. Dr. Abdullah Bin Muhammed as well as members of my supervisory committee Assoc. Prof. Dr. Azizol B Hj Abdullah, Dr. Fahrul Hakim Bin Huyop Ayob for their guidance, patience, and diligence without which this effort of ensuring the success of this research work cannot be achieved. Many thanks also, to my examiners Assoc. Prof. Dr. Rohaya Latip, Prof. Dato' Dr. Shamala K. Subramaniam and Dr. Amir Rizaan Abdul Rahiman for providing feedbacks that helped immensely in improving this thesis. I Also, appreciate the support received from lecturers, faculty members and staff of Faculty of Computer Science and Information Technology, Universiti Putra Malaysia for their assistance in one way or the other and series of programmes which aided this work.

I am extremely grateful to my family for their moral and financial supports as well encouragements. Thank you for always being my source of strength while pursuing my goals in life. Firstly, I would like to express my deepest and profound gratitude to my parents Alh. Sa'adu Hamidu Damare (Baba) and Hajjiya Hafsatu Sa'adu Damare (Mama), for everything they have done to me in life. None of my achievements would have been possible without their steadfast encouragement and support. A special thanks goes to my beloved wife, Fadimatu Muhammad Marafa (Yusrah), and daughters; Hafsah (Hibba) and Fadimah (Nihlah) for their endless love, tireless support and prayers throughout my study indeed you're the coldness of my eyes! Not forgetting my brothers and sisters especially Alh. Hamidu (Bappah), Muhammed (Chubado), AbdulAziz, Turai, Zainab, Sumayya and Jamila for their priceless support. I must also thank Alh. Muhammad Yahya Marafa, Hajiya Zainab Mahmud Abba (Mummy Shagari), Hajja Fadimatu Muhammad Mai, Prof. Hauwa'u Isa Yahya, Hajja Maryam Muhammad Mai, Hajja Hussaina Muhammad Mai, Alh. Dahiru Mai, Dr. Murtala Mai, Arc Hamza Mai, Prof. Muktar Mai, Prof. Hassan Mai, Engr. Bello Mai, Alh. Yusuf Abubakar, Maryam Marafa, Barr. Aisha Marafa, Alh. Mohammed Hamid Girei, Muhammad Abubakar Mai (Babirawo), Zakariya'u Hamid Girei, Engr. Huzaifa Isa Yahya, Arc Aminu Sharu, Mal. Musa Hamid Girei, Abubakar Marafa (Sadiq).

Many thanks to my friends and colleagues especially Dr. Mohammed Bashir Ribadu, Dr. Abdulmaji B. Umaru, Dr. Abdulkarim Bello, Dr. Abubakar Mohammed, Dr. Tahir Shittu, Dr. Abdullahi Mohammed, Dr. Usman Joda and Dr. Masir Abubakar Kafinsoli for all their inputs during the numerous discussions. So also, Assoc. Prof A. S. Bashir, Prof. Athur Ume, Mal. Musa Ibarhim Jalo, Mal. Dahiru Usman Haruna, Mal. Kabiru Ismail, Mrs. Aisha Tukur, Mr. Hilary Watsilla, Dr. Ilyasu Adamu and Mrs. Aisha Shuibu who have been a source of moral support through their fervent prayers. I am lucky and glad to have them in my life.

Finally, my gratitude goes to Modibbo Adama University (MAU), Yola Nigeria for finding me worthy of the fellowship as well as Tertiary Education Trust Fund (TETFund) Nigeria, for providing the funding through MAU, Yola without which this work could not have been a reality.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

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LIST OF ABBREVIATIONS

ABC	Artificial Bee Colony
ACO	Ant Colony Optimisation
ADSOS	Adaptive Discrete Symbiotic Organisms Search
BA	Bat Algorithm
CDSOS	Cuckoo-based Discrete Symbiotic Organisms Search
CRO	Chemical Reaction Optimisation
CS	Cuckoo Search
CSO	Cat Swarm Optimisation
DEA	Differential Evolutionary Algorithm
DSOS	Discrete Symbiotic Organisms Search
eDSOS	Enhanced Discrete Symbiotic Organisms Search
EFT	Earliest Finish Time
ETC	Expected Time to Compute
FCFS	First Come First Served
GA	Genetic Algorithm
HDD-PLB	Hybrid Deadline-contrained Dynamic VM Provisioning and Load Balancing
IaaS	Infrastructure as a Service
LBACO	Load Balancing Ant Colony Optimisation
LBIMM	Load Balance Improved Min-Min Scheduling
LCA	League Championship Algorithm
LLCF	Least Loaded Cloud First
MIPS	Million Instructions Per Second
NSGA-II	Non-Static Genetic Algorithm II

OTB-CSO	Orthogonal Taguchi based Cat Swarm Optimisation
PaaS	Platform as a Service
PBA	Particle Bee Algorithm
PSO	Particle Swarm Optimisation
QoS	Quality of Service
SA	Simulated Annealing
SaaS	Software as a Service
SASOS	Simulated Annealing Symbiotic Organisms Search
SFLA	Shuffled Frog Leaping Algorithm
SLA	Service Level Agreement
SOS	Symbiotic Organisms Search
TS	Tabu Search
VM	Virtual Machine
VNS	Variable Neighbourhood Search

CHAPTER 1

INTRODUCTION

1.1 Background

Cloud computing is a model for enabling ubiquitous, convenient, and on-demand network access to a shared pool of configurable computing resources (networks, servers, storage, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. This cloud model is composed of five essential characteristics which are; resource pooling, on-demand self-service, rapid elasticity, broad network access, measured services. Further, there are three service models of Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS) as well as four deployment models of public, private, community and hybrid clouds (Mell and Grance, 2011).

More so, cloud computing is developed from a disruption to an expected approach to traditional as well as next-general Information Technology (IT) (Gartner, 2017). Gartner's Rob van der Meulen (2016) says directly or indirectly by 2020 Cloud Shift will affect more than $1 Trillion in IT spending. According to their statistics cloud shift rate through 2020 will be 37%, 10% and 17% for SaaS, PaaS and IaaS models respectively. In this view cloud computing is quite big and it is getting bigger everyday where high computationally intensive tasks can be computed on pay-as-you-go basis. In a cloud computing environment, resources are distributed all over the world for servicing various users (Dasgupta et al., 2013; Apostu et al., 2013). Therefore, the users with the aid of internet can easily have access to resources anywhere, anytime through devices such as desktops, laptops, tablets, PDAs and cell phones.

Furthermore, cloud computing is exhibiting tremendous growth now and in years to come due to its features of scalability, flexibility, elasticity as well as pay-as-you-go model. These features eliminate the need for organisations to invest in maintaining software resources and hardware. Moreover, large-scale industrial and scientific applications such as data mining, bioinformatics, business-informatics, physics and astronomy demand huge computational power for execution within reasonable amount of time (Juve et al., 2013; Deelman et al., 2009). Large-scale applications which are executed on IaaS clouds comprise of vast number of tasks. According to Wu et al. (2015), IaaS offers access to scalable and flexible computing resources for large-scale deployment of application. It is a virtualised compute resources known as virtual machines (VMs) where network bandwidth, memory, storage as well as pre-configured CPU are leased to customers through paying providers only for what they consume. Consumers are avail with several VM instances at different prices to dish out their needs for ap- plication, hence consumers are at liberty to control compute resource at their disposition. Further, there are three underlying consumer benefits provided by IaaS; firstly, on-demand leasing of resource and like basic utilities charged based on pay-per-usage such as water, gas, and electricity. This gives consumers the ability to

expand/shrink resource subscription based on applications needs. Secondly, it offers provisioning of direct resource to improve performance of consumer applications. Thirdly, leased resources can be demanded by consumers anywhere and anytime according to level of service desired. Nevertheless, to determine number of resources adequately to execute a set of large-scale tasks on the IaaS cloud remains an issue that is open.

In addressing the issue of determining resources (VMs) to execute number of tasks, many scheduling algorithms are proposed. The scheduling algorithms are both heuristics and metaheuristics, but the latter is more prevalent in addressing scheduling problems in cloud computing environment. For example, Abdullahi et al. (2016), designed and implemented a discrete version of Symbiotic Organisms Search (DSOS) meta- heuristic algorithm from standard SOS. The continuous version of the algorithm (SOS) that is inspired by symbiotic relationships exhibited by organisms in a habitat. The algorithm imitates the mutualism, commensalism and parasitism relationship to improve the quality of a given objective function. The method was implemented to schedule in- dependent tasks. Makespan, response time, and degree of imbalance among VMs were parameters measured in their work. Authors in (Abdullahi et al., 2019; Abdulhamid et al., 2018; Xu et al., 2017) also measured more parameters in their works which includes load balancing, execution costs, execution time, reducing downtime and so on.

Moreover, how to coordinate different optimisation goals and ensure their consistency is still a future research challenge. Due to rapid increase in cloud users, efficient task scheduling approaches in cloud computing environment become a challenging issue. Hence, existing task scheduling approaches suffer from premature convergence, stuck in local optima issue, poor convergence speed (Sethi et al., 2018). Therefore, to mitigate these issues efficient task scheduling approaches based on meta-heuristic algorithm has been proposed in this study.

1.2 Problem Statement

Nowadays, users demand resources (networks, servers, storage, applications and services) on a pay-as-you-go model and performing these types of tasks is very difficult and requires knowledge in managing these resources through the IaaS platform. The fact that the efficiency of the cloud should not be vulnerable means that the output of the cloud should be directly proportional to the efficient use of the cloud resources. More-over, special attention is expected when these tasks change their demand for resources which are changeable and handling the resource demand would be a big challenge in the cloud environment due to its dynamic nature (Domanal et al., 2017). As a result of inefficient approaches to task scheduling in a cloud computing environment due to lack of solution diversity, load balancing and scalability are major challenges. Var- ious studies (Gabi et al., 2018; Akbari et al., 2017; Li et al., 2017; Ali et al., 2017; Devi et al., 2016; Abdullahi et al., 2016; Gogos et al., 2016; Srisakthi and Shanthi, 2015; Zhou and Zhigang, 2014) have been conducted on efficient task scheduling and scalable approaches while ensuring QoS requirements for another application. Despite these studies, many challenges remain unsolved in the research area of task scheduling in cloud computing environment. Therefore, the three main gaps motivating this study are outlined as follows:

- The task scheduling problems in cloud computing environment are known to be non-deterministic polynomial times hard (NP-hard). Therefore, the performance of cloud computing systems is mainly affected by a long period of time during task scheduling. Existing meta-heuristics that deal with such a problem suffer from the inclusion of local optima due to their slow convergence rate (Gabi et al., 2018; Abdullahi et al., 2016; Al-Maamari and Omara, 2015), resulting in a longer makespan time and response time. Delay in task execution is predictable due to inefficient task scheduling, which greatly affects the performance of cloud computing systems. Inefficient scheduling is mostly due to the inability of a scheduling approach to optimally utilise the available resources for scheduling tasks in the cloud. This results in a longer time span and response time. Many scheduling approaches in cloud computing have some disadvantages because they can no longer adapt to the dynamics of the cloud environment when it comes to man- aging a large task scheduling problem, which affects the makespan time and response time.

- Existing meta-heuristic algorithms for task scheduling have indeed achieved tremendous success. However, the imbalance between global and local search of metaheuristics is still a challenge, resulting in a poor solution that may not guarantee better QoS. The fact that the cloud continues to grow rapidly leads to a huge task problem that needs to be scheduled appropriately, which affects the performance of task scheduling algorithms due to the global convergence problem. Although global search explores a huge solution space, it does not always provide a better solution and therefore leads to high computational complexity, which affects the performance of the algorithms. Consequently, a meta-heuristic approach to load balancing is crucial to solve this problem in a cloud computing environment.

- As the cloud grows exponentially in terms of scalability, several cloud scheduling approaches become obsolete due to lack of scalability to maintain a good state of reliability for a large number of tasks. Scalability in task scheduling plays an important role in scheduling large tasks as it ensures good consistency in terms of minimum execution cost and execution time while meeting the QoS expectations of the customers (Ramezani et al., 2015; Alkhanak et al., 2016)

Against this background, there is a need to propose efficient SOS-based approaches to task scheduling in the context of cloud computing, which could be achieved by meta-heuristic algorithms. Also, by hybridising SOS with a cuckoo search algorithm and an adaptive SOS approach. The proposed approaches address problems related to the inclusion of local optima, which leads to high makespan and response times. And the challenge of load balancing due to the imbalance between the local and global search space, leading to a higher degree of imbalance. There is also a need to improve scalability to meet customer expectations in terms of minimising execution costs and execution time. Finally, a performance improvement rate is achieved in comparison to other state-of-art scheduling approaches.

1.3 Research Aim and Objectives

The main aim of this research is to design and implement symbiotic organisms search based approaches for efficient task scheduling in a cloud computing environment, considering issues of efficiency, load balancing and scalability. Therefore, to achieve the main aim of the study, the following specific objectives are outlined:

i. To propose a meta-heuristic approach that addresses the problem of local optima entrapment to minimise the makespan and response times in the cloud computing environment.

ii. To propose a load balancing approach to address the imbalance between local and global search thereby balancing the allocation of tasks to VMs in the clouds.

iii. To propose a scalable task scheduling approach that meets customers' QoS expectations based on minimised execution cost and execution time.

1.4 Scope of the Research

In this study symbiotic organisms search algorithm-based approaches were proposed and they are three independently approaches that addresses task scheduling problems in cloud computing environment. Also, the simulation is running for 100 to 1000 task size because of the works in the literature such as those in the based paper. Likewise, there are two 2 nodes are used in the datacenter settings. Furthermore, this research work is carried out within the following scope:

i. The research is carried out through experimentation via simulation using a simulation toolkit (CloudSim).

ii. This study covers task scheduling on IaaS cloud environment only.

iii. All tasks to be scheduled are of the same priority as such no priority constraints.

1.5 Research Contribution

The contributions of this study are based on the design and development of meta-heuristic task scheduling approaches for cloud computing environment, they are as follows:

i. An Enhanced Discrete Symbiotic Organisms Search approach for optimal tasks scheduling in cloud computing environment that minimised makespan and response time.

ii. A Cuckoo-based Discrete Symbiotic Organisms Search approach for large scale load balancing in cloud computing environment that optimises load balance;

hence reducing degree of imbalance and computational time as well as improve global convergence.

iii. An adaptive Discrete Symbiotic Organisms Search scalable approach for cloud computing environment that minimised the execution cost and execution time, thereby improving the overall system's performance.

1.6 Organisation of Thesis

The remaining part of the thesis is organised as follows:

Chapter 2 reviews related existing literature as well analyses the veering challenges in task scheduling optimisation approaches found in the environment of cloud computing which is the basis for realisation of the approaches of the research. Different task scheduling approaches were reviewed, and it was mainly on meta-heuristic algorithms because of their ability to handle large scale task scheduling problems efficiently, in IaaS Cloud. Finally, SOS algorithms applications and evolution were elaborated, as a possible solution for large-scale task scheduling.

Chapter 3 dwells on the research methodology, it covers the general framework that outlines the ways of attaining the set research objectives systematically. The proposed approaches essential steps for design and development are drew. Moreover, the experimental testbed which consists of the tools for simulation, as well as workloads for evaluating the efficacy of the proposed approaches are laid down and metrics of evaluation and comparison with bench-marking algorithms.

Chapter 4 presents the design and implementation of the proposed enhanced DSOS approach for task scheduling in cloud computing environment, as well as detailed discussion of the results obtained. The proposed approach addressed the issue of local optima entrapment through minimising makespan and response time.

Chapter 5 presents the second objective where design and implementation of Cuckoo-based DSOS approach for task scheduling in clouds and elaborated discussion of results obtained were made. It addressed the issue of imbalance between the local and global search space which leads to higher degree of imbalance by minimising the degree of imbalance thereby efficiently load balancing the task in clouds.

Chapter 6 presents the design and implementation of the proposed adaptive DSOS within cloud computing environment. Also, the results obtained were analysed and discussed.

Chapter 7 summarises the thesis, the contributions and future works of the research were presented.

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