MULTI-OBJECTIVE ALGORITHMS FOR EFFECTIVE RESOURCE MANAGEMENT IN EDGE-FOG-CLOUD COMPUTING

By

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

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Chair : Rohaya Binti Latip, PhD
Faculty : Computer Science and Information Technology

Edge-Fog-Cloud computing is a platform that facilitates the processing of IoT tasks that generate a massive amount of data from edge computing. Small or delay-sensitive tasks should be sent to fog computing, while complex or large-scale tasks must be transferred to the cloud data center due to its enormous capabilities in computation and storage.

However, workload allocation remains a critical concern, involving the allocation of sensitive tasks to edge-fog computing and large complex tasks to edge-cloud computing to meet user requirements based on their specific characteristics. The diversity of task attributes, such as input length, computing unit requirements, and sensitivity to delays, presents challenges in distributing workloads across different computing layers, resulting in both load overhead and increased transmission delays. The second crucial issue is task scheduling, which revolves around efficiently scheduling tasks to suitable resources across various computing layers while considering the unique characteristics of each task. Inefficient scheduling can result in increased transmission delays in edge-cloud computing, particularly due to the long distances involved, as well as higher energy consumption in edge-fog computing. The third problem concerns task offloading. When processing massive Edge tasks, computational devices may unexpectedly shut down due to the network's dynamic nature or power issues, leading to the interruption of task execution and incomplete processing. Offloading uncompleted tasks randomly to any computational node for execution can result in inefficient resource utilization and increased energy consumption.

There are three (3) main objectives laid out in this thesis to tackle these issues. First, proposed the Non-dominated Particle Swarm Optimization (NPSO) algorithm for workload allocation to reduce transmission delay in edge-cloud computing and imbalance load degree in edge-fog computing. Second, proposed a Multi-objective Grey

Wolf Optimizer (MGWO) algorithm for optimizing task scheduling to reduce transmission delay on edge-cloud computing and energy consumption on edge-fog computing. Third, proposed a Multi-objective Firefly (MFA) algorithm for task offloading to maximize resource utilization on edge-cloud computing and reduce energy consumption on edge-fog computing. Simulations were conducted to evaluate the proposed algorithms compared to the PSO algorithm, Cloud-Fog Cooperation Scheduling algorithm, and Task offloading algorithm. The experimental results prove the effectiveness of the proposed algorithms and outperform comparing them. Thus, the NPSO algorithm reduces the imbalance load degree in edge-fog computing by an average of 6% and the transmission delay in Edge-cloud computing by an average of 25%, respectively. In addition, the MLLF algorithm reduces the maximum delay threshold by an average of 11% compared with other related algorithms. Besides that, the MGWO algorithm reduces energy consumption in edge-fog computing by an average of 32% and the transmission delay on edge-cloud computing by an average of 22% compared to another approach. In comparison, the MFA algorithm reduces energy consumption in edge-fog computing and maximizes resource utilization in edge-cloud computing by an average of 23% and 86%, respectively. Finally, this study has several limitations that can serve as avenues for future research. These include the consideration of heterogeneous resources, the incorporation of additional QoS objectives, and the adoption of machine learning techniques for detecting threats within the edge-fog-cloud computing environment and predicting incoming tasks.

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

ALGORITMA BERGANDA UNTUK PENGURUSAN SUMBER YANG EFEKTIF DALAM KOMPUTASI HUJUNG-KABUT-AWAN

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Komputasi hujung- kabut- awan adalah satu platform yang memudahkan pemprosesan tugas-tugas IoT yang menghasilkan jumlah data yang besar daripada komputasi Hujung. Tugas-tugas yang kecil atau peka terhadap kelewatan sepatutnya dihantar kepada komputasi kabut, manakala tugas-tugas yang kompleks atau berskala besar harus dipindahkan ke pusat data awan kerana kapabilitinya yang besar dalam pengkomputeran dan penyimpanan.

Walau bagaimanapun, lokasi beban kerja tetap merupakan satu kebimbangan penting, yang melibatkan penyerahan tugas-tugas yang peka kepada komputasi Hujung-Kabut dan tugas yang kompleks kepada komputasi hujung-awan untuk memenuhi keperluan pengguna berdasarkan ciri-ciri khas mereka. Pelbagai ciri-ciri tugas, seperti panjang input tugas, keperluan unit pengkomputeran, dan kepekaan terhadap kelewatan, mencipta cabaran dalam pengagihan beban kerja di antara lapisan komputasi yang berbeza, mengakibatkan beban berlebihan dan peningkatan kelewatan penghantaran. Isu kedua yang penting adalah penjadualan tugas, yang berkisar dalam kecekapan menjadual tugas kepada sumber yang sesuai di seluruh lapisan komputasi yang berbeza sambil mempertimbangkan ciri-ciri unik setiap tugas. Penjadualan yang tidak cekap boleh mengakibatkan peningkatan kelewatan penghantaran di dalam komputasi hujung-awan, terutamanya disebabkan oleh jarak yang jauh, serta penggunaan tenaga yang lebih tinggi dalam komputasi Hujung-Kabut. Isu ketiga melibatkan penyerahan tugas. Apabila memproses tugas IoT yang besar, peranti pengkomputeran mungkin mati dengan tiba-tiba disebabkan oleh sifat dinamik rangkaian atau masalah kuasa, menyebabkan gangguan dalam pelaksanaan tugas dan pemprosesan yang tidak lengkap. Penyerahan tugas yang tidak lengkap secara rawak ke nod komputasi apa pun untuk pelaksanaan boleh menghasilkan penggunaan sumber yang tidak efisien dan peningkatan penggunaan tenaga.

Terdapat tiga (3) objektif utama yang ditetapkan dalam tesis ini untuk menangani isu-isu ini. Pertama, mencadangkan Algoritma Optimisasi Tumpuan Partikel yang Tidak Ditentukan (NPSO) untuk penyerahan beban kerja dengan tujuan mengurangkan kelewatan penghantaran dalam komputasi hujung-awan dan tahap ketidakseimbangan beban dalam komputasi hujung-kabut. Kedua, mencadangkan Algoritma Pengoptimum Serigala Kelabu Objektif Berganda (MGWO) untuk mengoptimalkan penjadualan tugas dengan tujuan mengurangkan kelewatan penghantaran di dalam komputasi Hujung-Awan dan penggunaan tenaga di dalam komputasi kabut. Ketiga, dicadangkan Algoritma Kunang-kunang Objektif Berganda (MFA) untuk penyerahan tugas dengan tujuan memaksimumkan penggunaan sumber dalam komputasi Hujung-Awan dan mengurangkan penggunaan tenaga dalam komputasi Hujung-Kabut. Simulasi telah dijalankan untuk menilai Algoritma yang dicadangkan berbanding dengan algoritma PSO, algoritma Penjadualan Kerjasama awan-kabut, dan algoritma Penyerahan Tugas. Keputusan eksperimen membuktikan keberkesanan Algoritma yang dicadangkan dan melebihi pendekatan yang dibandingkan. Oleh itu, Algoritma NPSO mengurangkan tahap ketidakseimbangan beban dalam komputasi hujung-kabut secara purata sebanyak 6% dan kelewatan penghantaran dalam komputasi hujung-awan secara purata sebanyak 25%. Selain itu, Algoritma MLLF mengurangkan ambang kelewatan maksimum secara purata sebanyak 11% berbanding dengan Algoritma yang berkaitan yang lain. Selain itu lagi, Algoritma MGWO mengurangkan penggunaan tenaga dalam komputasi Kabut secara purata sebanyak 32% dan kelewatan penghantaran dalam komputasi hujung-awan secara purata sebanyak 22% berbanding dengan pendekatan yang lain. Sebagai perbandingan, Algoritma MFA mengurangkan penggunaan tenaga dalam komputasi hujung-kabut dan memaksimumkan penggunaan sumber dalam komputasi hujung-awan secara purata sebanyak 23% dan 86% secara purata, masing-masing. Akhirnya, kajian ini mempunyai beberapa kelemahan yang boleh menjadi hala tuju untuk kajian masa depan. Ini termasuk mempertimbangkan sumber-sumber yang heterogen, menggabungkan objektif QoS tambahan, dan mengadopsi teknik pembelajaran mesin untuk mengesan ancaman dalam persekitaran hujung-kabut-awan computing dan meramalkan tugas-tugas yang akan datang.

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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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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

IoT	Internet of Things
PSO	Particle Swarm Optimization algorithm
NPSO	Non-Dominated Particle Swarm Optimization algorithm
GWO	Grey Wolf Optimizer algorithm
MGWO	Multi-Objective Grey Wolf Optimizer algorithm
FA	Firefly Algorithm
MFA	Multi-Objective Firefly algorithm
LLF	Least Laxity First algorithm
MLLF	Modified Least Laxity First Algorithm
QoS	Quality of Service
STML	Scheduling to Minimize algorithm
FCFS	First Come First Serve
MoP	Multi-Objective Optimization
DES	Discrete Event Simulation
VM	Virtual Machine
RPS	Request Per Second
EC	Edge Computing
FC	Fog Computing
CC	Cloud Computing
D_{max}	Upper Bound of the Delay Threshold
EDF	Earliest Deadline First algorithm
WCET	Worst-Case Execution Time

WT	Waiting Time
CD	Crowding Distance
EA	External Archive
RU	Resource Utilization

CHAPTER 1

INTRODUCTION

This chapter presents the research background, problem statements, and motivations of the current work. It also discusses the research objectives, the scope of the research, and research significance. In addition, it highlights the research contributions that justify the benefits and clarify the implications of this research. Finally, this chapter summarizes the organization of this thesis.

1.1 Background

Internet of Things (IoT) has known as Edge computing which is a new paradigm representing the connectivity of the billions of physical devices over the world with the Internet (Ezechina et al., 2015), all gathering and sharing data with confirming the use of smart devices that can act without human involvement. Hence, the increasing growth of edge devices/sensors in daily life facilitates various aspects that enables devices, humans, and things to instantly communicate for making a smarter world, such as smart cities, smart transportation systems, smart health services, smart industries, smart homes, smart farming, and smart security. The total number of edge devices connected worldwide will increase to 30 million by 2020, and it will dramatically increase to 80 billion by 2025, almost triple within a five-year. In 2025 the prediction is that 152,000 new devices will connect to the Internet per minute (Kanellos, 2016). Even more, the astronomical amount of data that demands storage, decision-making, managing, and analysis is delivered to the Cloud computing, which are massive pools of virtualized resources that can be accessed and reconfigured dynamically for a large-scale workload that is valuable for the services of Cloud that are delivered with a pay-as-you-go cost model (Vaquero et al., 2009). Generally, the innovation of Cloud computing provides massive benefits to the IoT environments through its models that can be shared as services through the Internet, such as storage, the infrastructure of the network, computing energy, and online applications (Mebrek et al., 2017). On the other side, the innovation of fog computing provides a huge benefit to overcome the limitation of the cloud computing which is considered as a middleware containing multiple heterogeneous devices that are ubiquitously connected, such as base stations, routers, switches, surveillance cameras, and others that can deploy in places such as power poles, vehicles, and commercial centers. These devices are decentralized on the edge computing to provide instant processing of raw data from the sensors. Furthermore, fog computing can communicate within the same layer regarding processing problems (Aburukba et al., 2020). Fog commuting act as an intermediate layer between terminal devices and the cloud, and extend the cloud in low latency-sensitive application to the end users like video conferencing, online gaming, sensor networks, pipeline monitoring, smart connected vehicles, smart traffic lights, and so on (Deng et al., 2016b). However, the various features and capabilities of edge, fog, and cloud motivated the researchers to executing tasks in collaborated platform called edge-fog-cloud computing as seen in Figure 1.1 (Stojmenovic et al., 2016). It is a new paradigm that cooperates edge-fog-cloud in one platform to exploit their benefits for serving edge tasks. It consists of three-level: the bottom level consists of the edge layer with terminal devices, embedded systems, actuators, sensors, limited bandwidth, and energy that send the data from smart devices sends them to a higher level when they require a high computational. However, edge computing have limited battery life, storage, and processing power (Postoaca et al., 2020). Meanwhile, the second level comprises the fog layer, acting as a bridge between edge computing and cloud computing such as switches, gateways, routers, and access points that operate on various protocols such as Wi-Fi, LTE, 3G, and 4G. It has more storage and processing than terminal devices. While the upper level is the cloud computing that has high storage and processing power capabilities (Aburukba et al., 2020).

The significant increase in the development of the Internet of Things application is still facing challenges according to the great distance between the edge computing and the cloud computing. Besides, most edge tasks are typically manipulated on the fog layer near where the data is generated. However, the computational capacity of fog computing is limited, which is not compatible with the continuous growth of real-time edge tasks and the demand for computational. Consequently, it motivated to Figure out alternative techniques to exploit the features of edge-fog-cloud computing through the collaboration between them and present a new distributed computing platform, the edge-fog-cloud computing. It is a promising platform that can serve billions of edge devices by processing delay-sensitive data in applications that require real-time response (J. Xu et al., 2019). It contains local fog computing and remote cloud computing to reduce delays and network traffic while increasing energy efficiency.

Furthermore, it enables the processing of tasks from edge tasks via a suitable layer among edge, fog, and cloud. This platform becomes a promising platform to guarantee high performance to facilitate utilizing the edge tasks that demand high computation from the cloud besides the low latency and meet the QoS requirements (Y. Yang et al., 2018). The main features of the collaboration are exploiting the ability of fog computing to minimize the transmission latency of utilizing cloud resources. While cloud computing plays a prominent role in satisfying large-scale applications' offloading. The new paradigm becomes the proper technology to optimize the energy consumption and ultra-low-latency application of edge that needs real-time responses (J. Xu et al., 2019). The environment of edge-fog-cloud are distributed geographically and jointly over the network and connected to the cloud simultaneously, such as train terminals, parks, and shopping points. The primary role of fog computing is to store data before sending it to the cloud computing and manipulate the requests between the edge computing and the cloud computing. This feature promotes reducing the latency to satisfy the user's requirements. On the other hand, if the limitations of fog computing fail to process large-scale tasks and latency tolerant, in this case, the tasks send to the cloud computing (J. Xu et al., 2019).

However, besides the massive benefits of executing tasks in edge-fog-cloud-computing but still facing the critical challenges in resource management due to the diversity of generating tasks from edge computing in their characteristic and requirement to meet the user's requirements. Hence, the most three challenges in the resource management are workload allocation, task scheduling, and task offloading. Thus, it is mandatory to discuss the resource management which plays a crucial role in optimizing the utilization of network resources (Javaid et al., 2018). This study has primarily focused on the key sub-areas of resource management impacting edge-fog-cloud computing, as follows.

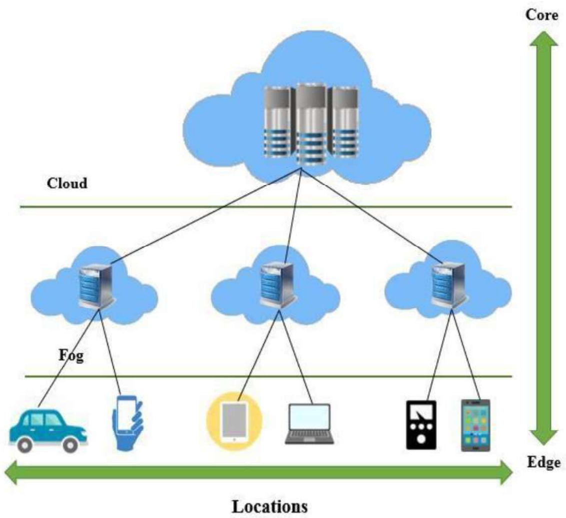

Figure 1.1: IoT environment
(Stojmenovic et al., 2016)

- **Workload and Delay**

Transmasculine data from edge devices to data computing causes applicable propagation delays due to the long distance between cloud computing and generated tasks, and that makes cloud computing a critical challenge. To this end, a novel technology known as edge computing has emerged to enable data processing with a minimum delay that is due to the proximity of these devices to users, requests see minimal emission delay and are responded to more quickly. Edge-based devices and network cores, such as base stations, modems, and routers, welcome computations and storage spaces requested by users, thereby acting as a replacement for clouds. As a direct consequence of bringing the processing resources and storage spaces closer to the end-users, the transmission delay is reduced (Abbasi et al., 2020). Given the importance of latency, the loads must be continuously distributed between the cloud and the fog so that the optimal values can be achieved on this parameter. Thus, Workload allocation among edge-fog-cloud computing is a key technique that affects QoS provisioning. It determines where a task is serviced in fog computing. However, the dynamic traffic characteristics and computation capabilities of fog nodes and the cloud center present many challenges for workload allocation. Hence, the tasks are generated stochastically and the amount of computation also varies for different tasks and over time and an online algorithm would thus be required to solve a workload allocation (Li et al., 2019).

- **Scheduling and Energy**

In recent times, there has been a rising fascination with the examination of energy communities. Consequently, the escalating energy consumption, driven by the substantial computational requirements of users, poses a significant environmental concern (Cruz-De-Jesús et al., 2023). Where is minimizing energy usage represents a crucial necessity for service providers when managing resources in light of the substantial computational demands (Salimi et al., 2021). Thus, among the numerous approaches to achieving energy efficiency, the responsibility for resource management and optimization, particularly in the realm of task scheduling, is considered a pivotal area to explore for effective solutions to address the problem of energy consumption. Task scheduling plays a crucial role in influencing both resource utilization and Quality of Service (QoS) in response to user requests. Hence, it represents a prime arena for exploring innovative designs aimed at efficiently managing resources while simultaneously meeting a variety of real-time user requirements in an energy-efficient manner (Ding et al., 2020). Utilizing an efficient scheduling technique presents an appealing avenue for reducing energy consumption without compromising Service Level Agreement (SLA) adherence. Additionally, this approach not only effectively shortens user task response times and accommodates varying constraints but also enhances the utilization of cloud resources, leading to reduced energy consumption and operational costs. Energy consumption and scheduling performance represent critical concerns when enhancing the task scheduling algorithm for executing cloud applications within a data center. Task execution performance is not only the primary determinant of suitable task scheduling, but it also encompasses the energy consumed during task execution by the processors. Inefficient allocation of cloud applications across multiple processors can lead to some processors operating with low utilization rates. Consequently, this inefficient processor execution results in wasted energy within the data center (Kumar et al., 2019).

- **Offloading and Migration**

Numerous researches have undertaken studies on improving energy efficiency in distributed environments, taking into account various factors like virtual machine (VM) migration, device offloading, and VM allocation algorithms (Abro et al., 2019). Hence, Migration is among the most prevalent methods for computational offloading, involving the transfer of intermediate-level instructions between a mobile device and a server (Yousafzai et al., 2020). Therefore, in a dynamic environment, the design of a migration strategy should be shaped by the prevailing conditions, and this strategy should continuously adapt and evolve in response to changing circumstances (Cui et al., 2019). Even more, optimized task migration can additionally alleviate congestion in the access network and compensate for deficiencies in local devices and Edge computing nodes regarding computing and storage capacity (Abro et al., 2019). The migration process can introduce extra costs in terms of energy consumption and time delays. Migration failures may arise due to issues like tardy migration, premature migration, or migrating to a Fog Computing Node (FCN) with significantly higher latency. Furthermore, there may be situations where the targeted FCN lacks sufficient available capacity to support new User Equipment's (UEs). In such cases, newly migrated tasks must queue up for execution, resulting in increased time delays and the consumption of storage space (Wang et al., 2019).

1.2 Problem statement

The revolution of edge tasks in various fields contributes to facilities people and companies, along with the cooperation of edge-fog-cloud computing by exploiting their benefits to accomplish the end-user's tasks and guarantee to satisfy the users' requirements in minimum time. However, besides the capabilities of edge-fog-cloud computing still faces barriers that affect the manipulation of the edge tasks and that need to optimize enhance the performance of resource management to satisfy the QoS.

Although, many studies have been conducted to address the problems of resource management in edge-fog-cloud computing with significant contributions, several issues have been left unaddressed. Three of such problems are described in what follows:

1- workload allocation trend that is yet to subside; instead, it is progressing rapidly in multiple perspectives to enhance the performance of the edge-fog-cloud computing. Hence, workload allocation is an essential technique that significantly improves the execution of tasks incurred in data processing, especially when end users choose the appropriate resource to send their workload to. In addition, it plays a leading role in determining the most suitable computing layer for processing tasks, like allocating sensitive tasks to the edge-fog computing and large complex tasks to the edge-cloud computing to meet user requirements according to their characteristics. However, the dynamic nature of the edge environment and the diversity of task characteristics, such as task input length, computing unit requirements, and degree of delay sensitivity, pose challenges when distributing workloads across different computing layers. Randomly allocating workloads to resources or disproportionately assigning workloads to one resource over another can result in a load overhead. This, in turn, affects task processing and leads to an increase in transmission delay, particularly when workloads are allocated to cloud computing due to the significant distance from edge computing.

2-The second crucial issue raised in this research is focused on task scheduling. It is one of the main factors in edge-fog-cloud computing during the processing of edge tasks for assigning tasks to appropriate resources based on the QoS. Task scheduling significantly accelerates the processing of tasks and is compatible with the dynamic nature of the edge environment. Eventually, the researchers and developers are eagerly focusing on enhancing the strategies in various perceptions to improve the performance of task scheduling in edge-fog-cloud computing. The challenge lies in how to efficiently schedule tasks to appropriate resources, taking into account the diverse characteristics of tasks, such as their varying lengths, computing unit requirements, and latency sensitivities, across the pools of computing nodes in edge-fog cloud computing, each with its unique execution capabilities. Inefficient scheduling can create obstacles to task execution, leading to increased energy consumption in fog computing from the user's perspective. Moreover, inefficient scheduling can lead to longer task scheduling times, thereby increasing transmission delays, especially given the long distances involved.

3- The third problem addressed in this research is task offloading, which is the main factor in resource management. It is about offloading tasks to another suitable computational device. However, when processing massive edge tasks, the computation device shuts off due to the dynamic nature of the network or runs power-off, and that leads to interrupting the execution and unfinished processing of tasks. The critical issue is offloading uncompleted tasks randomly to any computational node for execution, and that leads to wasteful utilization of resources and then increases energy consumption. This issue requires finding an ideal solution to utilizing the resources effectively and reducing energy consumption on edge-fog-cloud computing.

1.3 Motivation

Numerous advantages gain by gathering edge, fog, and cloud computing in one platform. First, the close distance between edge computing and fog computing connected via a LAN network can guarantee rapid response and the giant capabilities of cloud computing for analyzing the processing and storage of the high complexity of tasks. Thus, improving the problem of workload allocation, task scheduling, and task offloading will provide a significant effect during processing edge tasks effectively by exploiting the capabilities of various computing among edge, fog, and cloud computing according to the task's characteristics. On the other side, energy consumption and transmission delay are the most objectives that require to consider due to their critical impact. Hence, processing edge tasks in fog computing will increase energy consumption. In contrast, transferring tasks to the cloud will increase transmission. Thus, providing a solution to develop the system's performance according to the energy consumption and delay will improve the edge industry in various aspects. For instance, in intensive care, the patients have connected to many wearable devices to sense vital science such as thermometers, blood pressure, Electrocardiography, etc. Even more, CCTV is placed in the patient's room for recording. All these signs monitor all seconds and send the results. In this case, these critical signs must send to the fog computing due to the proximity. Hence, these are considered complex tasks and require sending to the cloud for analysis, processing, and storage. In the case of the critical case, the sensor detects it and then sends a direct notification to the doctor for instant response to get action.

This notification required rapid processing and analysis from a shorter distance to save a patient's life see Figure 1.2 Furthermore, tackling these challenges will improve the network traffic and avoid overload which causes long delays and that is not compatible with the edge requirements.

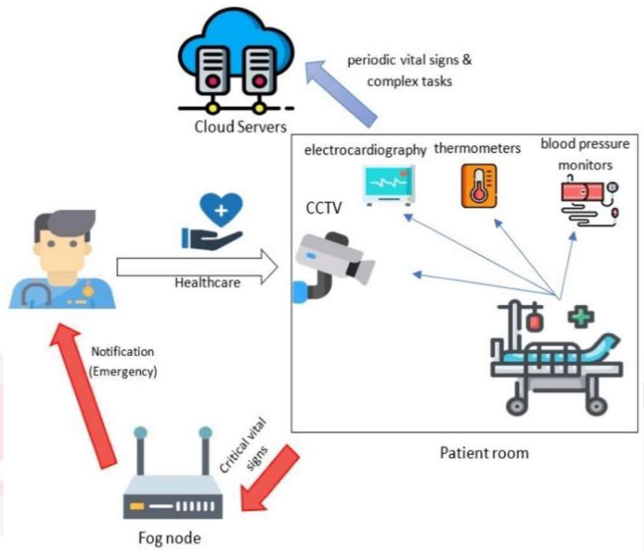

Figure 1.2: Example of The Intensive Care Operation with Edge-Fog-Cloud Computing

1.4 Research Objectives

The main objectives of this research are to achieve the following:

1- To propose Non-dominates Particle Swarm Optimization (NPSO) algorithm for workload allocation to reduce the imbalance load degree in edge-fog computing and the transmission delay in edge-cloud computing.

2- To propose a Multi-objectives Grey Wolf Optimizer (MGWO) algorithm for task scheduling to reduce delay in edge-cloud computing and energy consumption in edge-fog computing.

3- To propose Multi-objectives Firefly (MFA) algorithm for task offloading to complete unfinished tasks to increase the resource utilization in edge-cloud computing and reduce energy consumption in edge-fog computing.

1.5 Research Scope

This research focuses on developing resource management in edge-fog-cloud computing, with the primary emphasis on multi-objectives using metaheuristic algorithms to meet QoS requirements. Firstly, the research aims to provide effective solutions for resource management. It concentrates on reducing the imbalance in workload distribution on fog computing and minimizing delays in cloud computing during workload allocation by proposing an NPSO. Additionally, to ensure a reduction in delays, the study introduces the MLLF algorithm to lower the upper bound as the delay threshold. To tackle the scheduling optimization problem, an efficient metaheuristic called the MGWO algorithm is proposed for task scheduling techniques, creating an optimization strategy to reduce delays in cloud computing and energy consumption in fog computing, thereby enhancing resource management. Finally, the research investigates how to maximize resource utilization in cloud computing to prevent idle states, which simultaneously accelerates processing and reduces energy consumption in fog computing. All of these strategies contribute to the overall effectiveness of resource management.

Unlike the advanced techniques from other researchers, this research does not require additional costing nor resources. An extensive experiment was conducted for individual contributions in this research. The results showed advancement QoS objectives. Similar to the base work research, simulation was led using the MATLAB R2018b simulation tool, and all related objectives were proven analytically.

1.6 Research Significance

The improvement of workload allocation, task scheduling, and task offloading has numerous significances in edge-fog-cloud computing, like increasing the efficiency and quality of service while processing edge applications. Even more, it achieves minimum energy consumption, and that plays a significant impact in guaranteeing the QoS, especially indirectly affecting the experience of users. Besides, reducing the transmission delay will shorten the execution time of tasks and is a significant factor, especially in the delay-sensitive application.

This study aims to enhance metaheuristic algorithms that are well-suited for distributed environments and for large-size problems that are compatible with a variety of edge tasks. These algorithms are chosen for their low complexity, which ensures a reduction in task execution times on resources, consequently minimizing overall energy consumption. Moreover, by reducing execution times, it can also decrease transmission delay.

1.7 Thesis Organization

This thesis is organized as follows:

Chapter 1 presents the research background, problem statements and motivations of this work. It discusses the research objectives, scope and research significance. It also highlights the research contributions that justify the benefits of this research.

Chapter 2 presents a thorough discussion on the taxonomy of optimization mode, the research framework, related works that share workload allocation, task scheduling, and task offloading. Similar research works are further detailed on the proposed algorithms, advantages and disadvantages of the algorithms.

Chapter 3 The methodology illustrated more about the research framework and explains the research stages. The algorithm, the method used, the parameters and workloads included as well as the simulator used and validation of the model, are also presented in this chapter.

Chapter 4 presents the proposed an NPSO algorithm for workload allocation. It describes the Algorithm and shows the enhancement in the results obtained with respect to reduce the delay and increase the load balancing.

Chapter 5 demonstrates the proposed MGWO algorithm for task scheduling. Show the framework of Fog broker operation for assigning tasks between Fog and Cloud servers. It explains the operations of the algorithm and provides the performance evaluation in terms of delay and energy consumption.

Chapter 6 presents the proposed MFA algorithm for task offloading. The Chapter also highlights the performance evaluation of the algorithm in term of energy consumption and resource utilization compares it with other previous works.

Chapter 7 concludes this thesis and recommends promising directions for further research.

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