MULTI-R OUTE PLAN FOR RELIABLE SERVICES IN FOG COMPUTING-BASED HEALTHCARE MONITORING SYSTEMS

BY

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ABSTRACT

Fog computing is a network architecture that extends the traditional centralized cloud computing capabilities to the edge of the network and closer to where the data is generated in which fog nodes provide data processing and storage services to the end devices located within its zone. The main concern of fog computing paradigm is to reduce data transmission to the cloud which saves the bandwidth and mitigates the burden of processing on the cloud. Moreover, due to the shorter distance between the end-user and the fog nodes, users can get faster delivery of the services compared to the cloud. Therefore, fog computing is more suitable to handle time-sensitive situations like the critical data provided by the Internet of Things (IoT) technology. This may include sensory healthcare data, disaster detection data, and critical business data which needs rapid processing to make real-time decisions to prevent the harm or mitigate its effect. However, it is necessary to ensure the services' availability of these systems especially with the existence of fog node failure. The issue of service interruption during fog node failure in time-sensitive applications has not received much attention. Particularly for fog-based healthcare monitoring systems in which the rapid response for certain situations is needed such as detecting high blood pressure, heartbeat rate, and sugar level. Thus, providing efficient and reliable fog-based healthcare monitoring systems is necessary to ensure sustainable time-sensitive services as it is related to human life. This research work has reviewed and examined many relevant healthcare monitoring systems that exploited fog computing in their implementation. The focus is given on investigating the impact of fog node failure on healthcare monitoring systems' services. Furthermore, this research has employed the features of fog computing to propose a multi-route plan that aims to identify an alternative route to ensure the reliability of the services and avoid the impact of any interruption during critical situations. The proposed approach attempts to allocate the next nearest fog node as an alternative route if the primary fog node fails to accomplish the given task. Various real-life scenarios have been designed and implemented demonstrating different cases to evaluate the performance of the proposed strategy. The experimental results of this study illustrate that incorporating a fog-based multi-route plan in the implementation of time-sensitive systems such as healthcare monitoring systems would achieve less latency, lower energy consumption levels, and reasonable network use and execution cost that maintains high-reliability requirements compared to the most recent related work.

خلاصة البحث

الحوسبة الضبابية هي أحد هيكليات الشبكة التي تعمل على تمديد الإمكانات التقليدية للحوسبة السحابية المركزية إلى حافة الشبكة وأقرب إلى مصدر البيانات، بحيث توفر نقاط الضبابة خدمات المعالجة و التخزين للاجهزة التي تقع ضمن نطاقها. الهدف الأساسي لتواجد نموذج الحوسبة الضبابية هو تقليل عمليات نقل البيانات إلى السحابة مما يحفظ النطاق الترددي ويقلل من عبء المعالجة المعتاد على السحابة. علاوة على ذلك، قصر المسافة بين المستخدم النهائي و نقاط الضبابة يمكن للمستخدمين الحصول على الخدمات بشكل أسرع مقارنةً بالسحابة، لذلك تعد الحوسبة الضبابية أكثر ملاءمة للتعامل مع الحالات التي يكون الوقت فيها عامل حساس، مثل بعض البيانات التي تصدر عن الأجهزة التحسسية التي توفرها تقنيات إنترنت الأشياء (IoT). قد يشمل ذلك بيانات الرعاية الصحية، وبيانات الكشف عن الكوارث، وبيانات الأعمال الهامة التي تحتاج إلى معالجة سريعة لاتخاذ قرارات فورية في وقت حاسم لمنع وقوع الضرر المحتمل أو الحد من آثاره. لذالك من الضروري ضمان توفر خدمات هذه الأنظمة حتى في حالات فشل النقاط الضبابية. قضية انقطاع الخدمة أثناء فشل نقاط الضباب في التطبيقات الحساسة للوقت لم تلق الكثير من الاهتمام، و على وجه الخصوص أنظمة مراقبة الرعاية الصحية التي تعتمد بشكل أساسي على الحوسبة الضبابية والتي تتطلب استجابة سريعة لحالات معينة مثل اكتشاف ارتفاع ضغط الدم ومعدل ضربات القلب ومستوى السكر في الدم. وبالتالي، فإن توفير أنظمة رعاية صحية فعالة وموثوقة أمر ضروري لضمان توفر خدماتها الحساسة للوقت بسبب ارتباطها بحياة الإنسان. استعرض هذا البحث العديد من أنظمة مراقبة الرعاية الصحية ذات الصلة التي اعتمدت على حوسبة الضباب في بنائها و تم التركيز على التحقق من تأثير فشل النقاط الضبابية على خدمات أنظمة مراقبة الرعاية الصحية. علاوة على ذلك، قام هذا البحث باستغلال ميزات الحوسبة الضبابية في اقتراح خطة متعددة المسارات تهدف إلى تحديد طريق بديل لضمان توفر الخدمات وتجنب الأثار التي قد تنتج عن أي انقطاعها أثناء الحالات المستعجلة. يحاول النهج المقترح أن يحدد أقرب نقطة ضباب متوفرة كمسار بديل في حالة فشل نقطة الضباب الأساسية عن إنجاز المهمة المحددة. تم تصميم وتنفيذ سيناريوهات مختلفة تعكس حالات واقعية لفشل النقطة الضبابية بهدف تقييم أداء الاستراتيجية المقترحة. توضح النتائج التجريبية لهذه الدراسة أن دمج خطة متعددة المسارات في تطبيقات النظام الحساسة للوقت مثل أنظمة مراقبة الرعاية الصحية القائمة على الحوسبة الضبابية من شأنه أن يحقق وقت أقصر في تنفيد المهام، ومستويات أقل لاستهلاك الطاقة و أقل تكلفة مساهمة في المحافظة على متطلبات موثوقية عالية مقارنة بأحدث الأعمال السابقة المتعلقة بهذا البحث.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion; it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Master of Information Technology.

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DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently Submitted as a whole for any other degrees at IIUM or other institutions.

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Signature   Date

To my Dearest and First Teachers: My Father and Mother

To my beloved siblings and lovely niece

To my dear friends and colleagues

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

1.1 OVERVIEW

Over the last decade, the rapid development of electronic technologies has emerged in every aspect of our life including but not limited to e-learning, e-commerce, e-banking and e-health (electronic health). According to the European Commission 2012, e-health uses ICT in healthcare services, products and processes to improve the health of people, increase productivity and efficiency in healthcare delivery, which reflects on the economic and social value of health (Al-rimawi, 2016; Da Silva, Gonçalves, & Dantas, 2019; Menghi, Papetti, & Germani, 2019; Syed, Jabeen, S., & Alsaeedi, 2019).

Using ICT in e-health can improve the delivery of healthcare services, disease-tracking, diagnostic monitoring and related medical procedures (Park et al., 2019; Etim et al., 2020). The use of Internet of Thing (IoT) and wireless technologies to monitor patients remotely are attracting great interest. This is due to the fact that IoT and the wireless technologies brought various benefits including a cost-effective and reliable way of managing the health services and activities (Syed et al., 2019). It also offers sustainable and personalized services to patients, as well as maintaining a better relationship among patients and healthcare specialists (Sanna, Serafin, & Maganetti, 2014).

The current trends show that in the 21st century, hospitals are applying more remote consultations, patient referral, disease mapping, e-registration of patients, online record keeping, and ICT based patient's health information system (Cerina et al., 2017).

The e-healthcare systems both web-based and mobile-based versions use wireless personal area networks (WPAN) or/and wireless body sensor networks (WBSN) for delivering high quality real-time medical services and efficient medical treatments to the patients (Sanna et al., 2014). In such systems, sensors are fixed around the patient's body to collect the vital information of the patient such as oxygen level, sugar level, heart rate, and pulse rate. This collected data is reported immediately to the remote designated physician and/or to a healthcare service provider attempting to ensure taking the suitable action when detecting abnormalities, which is an application of Cloud-based e-healthcare systems (Xu et al., 2018; Park et al., 2019).

Healthcare data needs a cloud platform to manage the large volume of generated data instead of relying on limited computing resources. However, this causes a high delay that affects healthcare services negatively especially those requiring an immediate response which is one of cloud computing drawbacks (Ahmad et al., 2016; Zhan et al., 2019).

In this regard, in 2014, Cisco announced a new computing concept which is fog computing, a new infrastructure paradigm to go beyond the confines of cloud computing (Bonomi et al., 2014). Fog computing is an extended form of the cloud, that brings its capabilities and resources closer to the user. It also offers storage, processing, and enable edge devices to communicate, in aim to augment and facilitate privacy and security, mobility, network bandwidth, and decreasing latency (Firdhous, Ghazali, & Hassan, 2014; Ni, Zhang, & Yu, 2018). Fog computing infrastructure, on one hand, consists of many fog nodes, virtualized data centers, and IoT devices, which have an established connection with the cloud for more implementation of permanent storage and powerful computational capabilities (Dutta & Roy, 2017; Naranjo, Shojafar, Mostafaei, Pooranian, & Baccarelli, 2017).

Fog computing is held to be a suitable paradigm when it comes to design real-time or latency-sensitive healthcare applications. It is significantly contributing to healthcare applications such as Ambient Assisting Living (AAL) applications, remote home nursing that serves elderly people, and real-time tracking of chronic diseases (Al-Khafajiy, Webster, Baker, & Waraich, 2018; Awad, Khanapi, Ghani, & Arunkumar, 2019). However, due to its infancy; several other issues relevant to fog computing can be highlighted like sensor node failure or removal, external attack on BAN/WBAN, environmental coincidences, loss or limited power, loss of connectivity, failure of the network, network congestion. Most importantly, the compatibility issue due to different network standards. Thus, system failure should be carefully addressed while designing emergency or real-time e-healthcare systems (Kher, 2016).

Emergency is an immediate threat that is posed to life, health, asset or environment. It happens suddenly to anyone anywhere, at any time and in so many forms such as accidents, fire, floods, earthquakes, robbery, kidnapping or murder. Having a dependable and reliable method of notifying the related department has become a necessity to handle such disasters to reduce the damage when it happens. Technology advancement of smartphone devices, IoT networks, cloud computing, and its extended form fog computing has added more capabilities to create more efficient services for emergency management (Aazam & Huh, 2015; Kazem, 2019).

1.2 PROBLEM STATEMENT

In modern societies, healthcare applications generate a large amount of data especially with the emergent of IoT devices. Cloud-based systems have to deal with this large volume of data which in consequence increased the load on its servers, adding more complexity on carrying out the operations with longer latency (Escamilla-Ambrosio, Rodríguez-Mota, Aguirre-Anaya, Acosta-Bermejo, & Salinas-Rosales, 2018; Vora, Tanwar, Tyagi, Kumar, & Rodrigues, 2017). Most services and applications provided by the cloud are built upon unreliable commercial off-the-shelf components, which also increase the failure rate of the hardware and software components of those systems and may cause loss of the operations and services that are running on those nodes (Lavriv, Grynkevych, & Vasylenko, 2018).

Node failure has a direct impact on many aspects of the system including deteriorate the performance of the system, service disruption, increase the cost of operation, delay in service delivery time and unpleasant user experience (Satria, Park, & Jo, 2017; Ullah, Sehr, Akbar, & Ning, 2018). Most importantly, the issue of node failure has a significant negative effect on medical services in a healthcare monitoring system. This is because any medical service disruption due to the node failure might results in a potential loss of human life if the most appropriate action is not taken within the required time. Hence, due to the high potential damage that comes from the node failure, system designers and administrations are more concerned about the problem of the node failure in healthcare monitoring systems. They are trying to develop systems that reduce data loss and enable the tackling of node failure whenever it occurs (Naranjo et al., 2017; Satria et al., 2017).

As cloud computing services are extended to the edge of the network, fog node failure has also been a serious issue in fog computing, which may cause a system failure or performance degradation that we cannot sacrifice in critical time-sensitive applications, such as healthcare-related services that are based on fog computing (Dutta & Roy, 2017; Rahmani et al., 2018).

Although many data protection strategies and failure recovery techniques are effectively applied in cloud computing (Tamimi, Dawood, & Sadaqa, 2019), yet it is still a challenge in fog computing (Aazam & Huh, 2015). Hence, a significant design feature of these strategies and recovery techniques must ensure service protection with low latency and less expensive execution cost (Khan, Parkinson, & Qin, 2017). Most of the previous approaches designed for healthcare monitoring systems assumed that the main fog node is always available and can entertain the user request, particularly for time-critical cases. However, this assumption is not always true, and it might happen that the designated fog node fails to entertain the user request and the latency to respond to the user becomes extremely long. Therefore, preventing the patient from getting the necessary immediate aid. For instance, if the most recent heartbeat rate reading from the user indicates that the patient facing a potential heart attack problem, so an urgent response from the hospital is highly needed. Hence, longer latency might result in negative implications (death of the person) if the fog node fails to send the generated alert within a reasonable time. Thus, an efficient approach is needed to consider such cases. The approach has to identify and establish an alternative path through more than one fog node to be involved in such critical situations to ensure system reliability requirements in a way it ensures the achievement of the operation within the suitable time.

1.3 RESEARCH QUESTIONS

This section outlines the research questions to be answered in this research work.

These questions are described as follows:

1. What is the impact of fog node failure on healthcare monitoring systems' services?

2. What is the most appropriate plan to handle the issue of node failure that best fit with healthcare monitoring systems in fog computing to handle the critical cases and avoid service disruptions?
3. How to examine the effectiveness and efficiency of the proposed plan that avoid service disruption when node failure occurs in healthcare monitoring systems?

1.4 RESEARCH OBJECTIVES

The main aim of this research work is to achieve the following objectives:

1. To investigate the impact of fog node failure on healthcare monitoring systems' services.
2. To propose an approach that tackles the issue of fog node failure aiming at ensuring the sustainability of healthcare monitoring systems' services to handle the critical cases and avoid service disruption.
3. To evaluate the effectiveness and the performance of the proposed approach in terms of latency, energy consumption, network usage, and execution cost.

1.5 RESEARCH SCOPE

The research scope of this study is outlined as follows:

1. This research work proposes an approach that aims at establishing an alternative path to entertain the medical services for healthcare monitoring systems. The approach tries to make sure that the system is reliable in which the critical alerts can be reached to the fog node and the cloud instead of

relying on a single path only that might lead to signal loss in any failure case. Adding more than two paths requires exploring the new possible paths by performing some analysis and carryout some preprocessing operations before deciding the alternative path, this will add more time, cost and complexity that is required by this research.

2. *iFogsim* simulator is used to carry out the experiment due to its suitable and comfortable features as it is used by many studies in this area.

3. A synthetic data set is used in the experiment by using a Java code that generates random heart rate to emulate the generic nature of sensory data.

4. Various healthcare real-life scenarios have been designed and involved in this research work representing the time-sensitive applications.

1.6 SIGNIFICANCE OF THE STUDY

This research work emphasizes the problem of service disruption for fob-based healthcare monitoring systems when node failure occurs. It highlights the importance of exploring the idea of identifying an alternative route for fog-based healthcare time-sensitive services when the primary node is failed is carrying out the needed service. We believe this study can assist interested researchers in the area of fog computing healthcare monitoring systems to obtain an insightful understanding of the issue of node failure in fog computing. This work can also benefit to determine the most critical factors that contribute to design reliable and trustworthy healthcare services in fog-based systems. The proposed solution applies path redundancy concept which is a way to ensure different dependability objectives, namely: availability, reliability, and quality of service (QoS). Moreover, the proposed solution can also be applied to other domains in which time is the most critical factor that needs to be considered in these applications such as disaster detection and accident detection.

1.7 ORGANIZATION OF THE DISSERTATION

This dissertation comprises six chapters including the introduction chapter. A summary of these chapters is given below.

- **Chapter 1:** an introductory chapter that discusses the research problem and presents its objectives, the research scope as well as exposing the benefits that this study brings.
- **Chapter 2:** a background chapter that defines fog computing and its fundamental concepts including the Internet of Things (IoT) and Cloud Computing. This chapter also presents the role of fog computing in healthcare monitoring systems and explains how the reliability of fog systems can be achieved through redundancy techniques. Lastly, this chapter also reviews the previous works of healthcare monitoring systems based on fog computing.
- **Chapter 3:** research methodology chapter, it describes how this research work was conducted. Also, the chapter discusses the different phases of this research work and the methodology followed during each phase. The performance metrics and the dataset that has been used in the experiments are presented and explained.
- **Chapter 4:** introduces the proposed approach for identifying the alternative route to continue providing the services for healthcare monitoring systems. The steps of the proposed approach have been explained in detail. This chapter also explains the different scenarios implemented for the evaluation purposes.

- **Chapter 5:** illustrates the results of the experiment conducted to evaluate the performance and the efficiency of the proposed approach for determining an alternative path to sustain the time-critical services in healthcare monitoring systems in the context of fog computing environment. The experiment focuses on comparing the results of the proposed approach with both: the best practice results in which the system is working properly and no need for the alternative route and the existing approach that relies on the cloud for any node failure cases.
- **Chapter 6:** Conclusion chapter, provides a summary of the findings of this research followed by research limitations. Future work recommendations are also presented in this chapter.

CHAPTER TWO

BACKGROUND AND LITERATURE REVIEW

2.1 INTRODUCTION

System failure is a critical issue that should be carefully taken into consideration especially with the systems that provide real-time services. More importantly, when it's about saving a human life or lessen the harm caused by some disasters if not preventing the harm totally from happening. This chapter presents a background of the fundamental concepts related to fog computing and exposes its architecture. In Section 2.2 we present an overview of fog computing. Section 2.3 explains the architecture of fog computing. The role of fog computing in different real-time healthcare systems is presented and explained in Section 2.4. Furthermore, Section 2.5 discusses how healthcare monitoring systems work. The potential benefits of redundancy for reliable healthcare services are explained in Section 2.6. In Section 2.7, the previous approaches proposed of healthcare monitoring systems in fog computing are examined. The summary of this chapter is given in Section 2.8.

2.2 OVERVIEW OF FOG COMPUTING

Fog computing comprises of three layers, namely: cloud layer, fog layer, and edge layer. The edge layer contains many of the IoT devices that use to collect and read the required data.

2.2.1 Internet of Things (IoT)

According to (Aazam, Hung, & Huh, 2014) Internet of Things (IoT) is a network paradigm that connects many physical (real) objects through embedded sensors and enables data collection and exchange between them in either real-time or near real-time. The term ‘things’ is any smart or dumb object that is connected to a network by an attached sensor to it, these objects become a communicating nodes over the internet network through different communication protocols that allow the interaction with each other remotely as well as with people without a need for human intervention (Kortuem et al., 2010; Hassanalieragh et al., 2015; Huacarpuma et al., 2017). The ‘Things’ in IoT needs low power to operate and they can be self-powered through solar energy as well, which makes them cheap, plentiful, and can interact directly with the internet or with internet-connected devices. IoT sensors generate data that are transferred through different wireless technologies, such as Radio Frequency Identification (RFID), Near Field Communication (NFC), Wi-Fi, and Bluetooth for short-range local area networks. However, for long-distance, transmission can be done through existing mobile networks, satellite connections or wired links including Ethernet (Ghapar, Yussof, & Bakar, 2018; Oteafy & Hassanein, 2018).

2.2.2 Cloud Computing

Cloud computing is an on-demand delivery network that provides a centralized shared pool of data, services, applications, infrastructure, and recourses, as well as it provides functionality of storing and powerful processing to a large amount of generated data via heterogeneous IoT devices, as it is also responsible for the management and maintenance processes of these resources, which simplifies the computing jobs of the end-user (Goyal, Parashar, & Shrotriya, 2018). Figure 2.1 demonstrates the interaction between IoTs and cloud computing (Shwe et al. 2016).