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MOBILE AGENT-BASED DATA GATHERING APPROACHES FOR STATIC MULTIPLE MOBILE AGENT ITINERARY IN WIRELESS SENSOR NETWORKS

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By

HUTHIAFA Q QADORI

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DEDICATIONS

Allah Almighty says in the Qur'an:

"And who has (in mind) no favour from anyone to be paid back; Except to seek the Countenance of his Lord, the Most High; He surely will be satisfied"

Surat Al-Lail: Verse 19, 20 and 21

This work is dedicated to the sake of Allah

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

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In order to mitigate the problem of data congestion, increased latency, and high energy consumption in Wireless Sensor Networks (WSNs), Mobile Agent (MA) has been proven to be a viable alternative to the traditional client-server data gathering model. MA has the ability to migrate among the network nodes based on an assigned itinerary which can be formed via Single Itinerary Planning (SIP) or Multiple Itinerary Planning (MIP). MIP based data gathering solves the problems associated with SIP in terms of task duration, energy consumption, and reliability. However, the determination of the optimal number of distributed MAs and their itinerary in MIP remains a major challenge to minimize the energy consumption and task duration, as well as improve the successful MA's round-trip and event-to-sink throughput. In this regard, three problems and their corresponding proposed solutions in this thesis are given below:

Firstly, the existing MIP approaches assume that each MA starts and end its itinerary at the sink node. Furthermore, each MA has to carry its processing code (data aggregation code) for the data collection process. These assumptions would result in an increase in the number of MA's migration hops which leads to increase the energy consumption. Accordingly, a Spawn Mobile agent Itinerary Planning (SMIP) approach is proposed to address these issues. In SMIP, the Main MA (MMA) is able to spawn a new MA (SMA) which carries back the aggregated data of the MMA to the sink. This spawning mechanism has reduced the number of MA's migration hops, thereby reducing the energy consumption since the MMA does not need to get back to the sink to unload data and resume another MA journey. SMIP achieved promising results by 12.16% and 9.77% energy consumption decrease as compared to the well-known

CL-MIP approach and the existing GIGM-MIP approach, respectively.

Secondly, most of the proposed itineraries of the MA employ a single distance based parameter to determine the next MA's migration hop which results in an unsuccessful MA's round-trip, especially when the remaining energy of the selected node is very low. Also, certain nodes will be chosen more than once due to their nearest distance, thereby, these nodes lose their energy quickly and could lead to a substantial imbalance in the energy dissipation of the nodes. To deal with this, a Fuzzy-based Mobile Agent Migration approach (FuMAM) is proposed. In FuMAM, the next MA's migration hop is determined by considering three parameters: distance, remaining energy, and the number of neighbors. Such an approach has improved the success of MA's round-trip by 67.01% and 56.56% compared with CL-MIP and GIGM-MIP, respectively, through selecting the node based on the three parameters.

Lastly, attaining energy efficiency has been the main focus of previous MIP approaches which make them best suited for environmental monitoring applications as sensor nodes would be unattended to for a long period of time. These schemes perform poorly in real-time applications, which requires a higher event-to sink throughput to effectively deliver real-time data for timely decisions to be made within the network. As a solution, a Clone Mobile-agent Itinerary Planning approach (CMIP) is proposed. In CMIP, the MA cloning concept is used to decrease the task duration while maximizing data collection which has a direct impact on event-to sink throughput. CMIP approach reduces the task duration of CL-MIP and GIGM-MIP by 56.12% and 15.96%, respectively. Similarly, as compared to both CL-MIP and GIGM-MIP approaches, CMIP also improves the event-to-sink throughput by 93.05% and 21.9% respectively.

The performance of the above proposed approaches have been tested with the simulation benchmark using MATLAB.

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

PENDEKATAN EJEN MUDAH ALIH BERASASKAN DATA PERHIMPUNAN UNTUK JADUAL EJEN MUDAH ALIH PEGUN PELBAGAI DALAM RANGKAIAN SENSOR TANPA WAYAR

Oleh

HUTHIAFA Q QADORI

Oktober 2018

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Untuk mengurangkan masalah kesesakan data, peningkatan kependaman, dan penggunaan tenaga yang tinggi dalam Rangkaian Sensor Tanpa Wayar (WSN), Ejen Mudah Alih (MA) telah terbukti menjadi alternatif yang berdaya maju kepada model pengumpulan data pelayan pelanggan tradisional. MA mempunyai keupayaan untuk berhijrah di antara nod rangkaian berdasarkan jadual perjalanan yang ditetapkan yang boleh dibentuk melalui Perancangan Pelan Perjalanan Tunggal (SIP) atau Perancangan Pelan Perjalanan Pelbagai (MIP). Perhimpunan data berasaskan MIP menyelesaikan masalah yang berkaitan dengan SIP dari segi tempoh tugas, penggunaan tenaga, dan kebolehpercayaan. Walau bagaimanapun, penentuan bilangan optimum MA yang diedarkan dan pelan perjalanan dalam MIP kekal sebagai cabaran utama untuk meminimumkan penggunaan tenaga dan tempoh tugas, serta meningkatkan kecepatan dan perjalanan pulang MA. Sehubungan ini, tiga masalah dan penyelesaian telah dicadangkan dalam tesis ini seperti yang dibentangkan di bawah:

Pertama, pendekatan MIP sedia ada mengandaikan bahawa setiap MA bermula dan menamatkan perjalanannya di nod tenggelam. Selain itu, setiap MA perlu membawa kod pemprosesannya (kod agregasi data) untuk proses pengumpulan data. Andaian ini akan mengakibatkan peningkatan bilangan hop penghijrahan MA yang membawa kepada peningkatan penggunaan tenaga. Sehubungan itu, pendekatan Ejen Perintis Pelan Perjalanan Mudah Alih (SMIP) dicadangkan untuk menangani isu-isu ini. Di SMIP, MA Utama (MMA) dapat merintis MA baru (SMA) yang membawa kembali data agregat MMA ke dalam benaman. Mekanisme perintisan ini telah mengurangi jumlah hop penghijrahan MA, sehingga mengurangkan penggunaan tenaga kerana MMA tidak perlu kembali

ke dalam benaman untuk memunggah data dan meneruskan perjalanan MA yang lain. SMIP mencapai keputusan yang menjanjikan kadar penurunan penggunaan tenaga sebanyak 12.16% dan 9.77% berbanding dengan pendekatan CL-MIP yang terkenal dan pendekatan GIGM-MIP yang sedia ada.

Kedua, kebanyakan jadual perjalanan yang dicadangkan oleh MA menggunakan parameter jarak jauh tunggal untuk menentukan hop penghijrahan MA dan seterusnya menyebabkan perjalanan pusingan MA tidak berjaya, terutamanya apabila tenaga baki nod terpilih adalah sangat rendah. Selain itu, nod tertentu akan dipilih lebih dari sekali kerana jarak terdekatnya, oleh itu, nod-nod ini akan kehilangan tenaganya dengan cepat dan menyebabkan ketidakseimbangan yang besar dalam pelesapan tenaga nod tersebut. Untuk menangani perkara ini, pendekatan Migrasi Ejen Bergerak berasaskan Fuzzy (FuMAM) dicadangkan. Di FuMAM, hop penghijrahan MA seterusnya akan ditentukan dengan mempertimbangkan tiga parameter: jarak, baki tenaga, dan bilangan jiran. Pendekatan sedemikian telah meningkatkan kejayaan perjalanan pusingan MA sebanyak 67.01% dan 56.56% berbanding dengan CL-MIP dan GIGM-MIP, masing-masing, dengan memilih nod berdasarkan tiga parameter.

Akhir sekali, mencapai kecekapan tenaga yang memuaskan telah menjadi tumpuan utama pendekatan MIP terdahulu yang menjadikan ia paling sesuai untuk aplikasi pemantauan alam sekitar sebagai nod sensor dan ia juga akan dijaga untuk jangka masa yang lama. Skim-skim ini tidak berfungsi dengan baik dalam aplikasi masa nyata, kerana ia memerlukan daya pemproses peristiwa tenggelam yang lebih tinggi untuk menyampaikan data masa nyata secara efektif untuk membuat keputusan secara tepat pada masanya dalam sesuatu rangkaian. Sebagai penyelesaian, pendekatan Perancangan Pelan Perancang Klon Mudah Alih (CMIP) dicadangkan. Dalam CMIP, konsep pengklonan MA digunakan untuk mengurangkan tempoh tugas sambil memaksimumkan pengumpulan data yang mempunyai kesan langsung untuk mencapai peristiwa tenggelam. Pendekatan CMIP mengurangkan tempoh tugas CL-MIP dan GIGM-MIP masing-masing sebanyak 56.12% dan 15.96%. Selain itu, perbandingan diantara pendekatan CL-MIP dan GIGM-MIP, CMIP masing-masing meningkatkan kecepatan acara menyeberang sebanyak 93.05% dan 21.9%.

Prestasi pendekatan yang dicadangkan di atas telah diuji dengan penanda aras simulasi menggunakan MATLAB.

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LIST OF ABBREVIATIONS

BST	Balanced minimum Spanning Tree
CIS	Computational Intelligent System
CL-MIP	Central Location-based MIP
CMA	Cloned MA
CMIP	Clone Mobile-agent Itinerary Planning
CSA-MIP	Clonal Selection Algorithm-based MIP
DSG-MIP	Directional Source Grouping-based MIP
ECRP	Efficient Clustering Routing Protocol
FLS	Fuzzy Logic System
FSN	Farthest Source Node
FuMAM	Fuzzy-based Mobile Agent Migration
GA-MIP	Genetic Algorithm-based MIP
GCF	Global Closest First
GIGM-MIP	Greatest Information in the Greater Memory-based MIP
IEMA	Itinerary Energy Minimum Algorithm
IEMF	Itinerary Energy Minimum for First
ILS	Iterated Local Search
LCF	Local Closest First
MA	Mobile Agent
MADD	MA-based Directed Diffusion
MAs	Mobile Agents
MF	Membership Function
MIP	Multiple Itinerary Planning
MMA	Main MA
MWSNs	Mobile Wireless Sensor Networks
NOID	Near-Optimal Itinerary Design
OMIP	Optimal Multi-Agents Itinerary Planning
PC	Potential Cost
RAM	Random Access Memory
SIP	Single Itinerary Planning
SMA	Spawning Mobile Agent
SMIP	Spawn Mobile-agent Itinerary Planning
TBID	Tree-based Itinerary Design
TCG	Totally Connected Graph
UAV	Unmanned Aerial Vehicle
VCL	Visiting Central Location
WSN	Wireless Sensor Network
WSNs	Wireless Sensor Networks

CHAPTER 1

INTRODUCTION

1.1 Background and Motivation

The merging of low-cost wireless communication, computation, and sensing has spawned a new generation of small and cheap intelligent devices. The deployment of tens to thousands of these tiny devices in self-organizing networks has established a new network known as Wireless Sensor Networks (WSNs). The emergence of WSNs has attracted considerable interest and has also become an active research area (Kumar and Singh, 2017; Mishra et al., 2019).

A Wireless Sensor Network (WSN) can be generally described as the deployment of a vast number of tiny sensor nodes that connect to each other via wireless communication. The advantages of these sensor nodes (such as easy installation, low cost, small size and low power consumption) make this type of networks useful in various applications (Puccinelli and Haenggi, 2005). It can be applied in agriculture, industrial automation, transportation, health care, and military (Ramson and Moni, 2017; Torres-Ruiz et al., 2018), to mention a few.

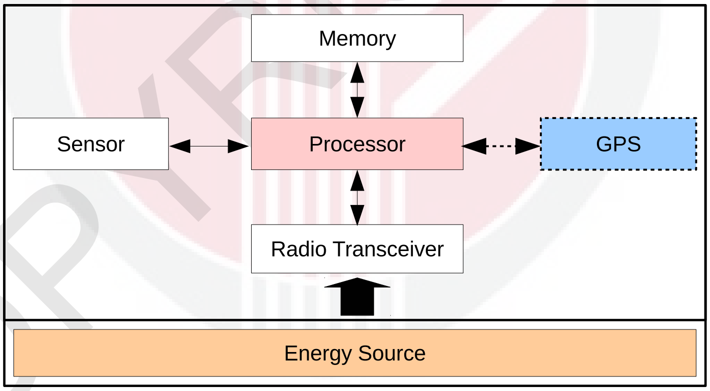

Figure 1.1: Node Architecture

Unlike conventional networks, WSNs have constrained resources such as energy source, processing ability, memory capacity and network communication bandwidth (Flinn and Satyanarayanan, 1999; Raghunathan et al., 2002). Each typical sensor node in WSNs consists of four main components (Figure 1.1): radio transceiver, a processor, sensors and an energy source like a battery (Sarangi and Thankchan, 2012). Among these components, the energy source is the most important, since the other components are powered and operated by it. In most cases, the energy source of sensor node is supplied by a finite battery, and in some applications, it is not possible to replace or recharge the battery due to unreachable human environments such as disaster, flood and forest fire environments (Singh et al., 2013; Sumitra et al., 2017; Bayo et al., 2010). Owing to this fact, it is of utmost importance to efficiently manage the power consumption of the sensor nodes. An efficient power consumption among the nodes results in a prolonged network lifetime, since the lifespan of an energy constrained node is determined by how fast the sensor node consumes energy (Malik et al., 2013).

The main objective of WSN deployment is to gather/collect environmental data and reported to the end user (Al-Karaki and Kamal, 2004). Typically, in a WSN, the sensor nodes are deployed in a field of interest and it has the ability to perform several tasks such as sensing, surveillance, environmental monitoring, and processing and storing the sensed/monitored data. The sensed/monitored data need to be transmitted to a collection point in the network (called processing unit or sink) for further analysis. The transmission of data is done via single or multi-hop wireless communication. However, in large scale network with dense node deployment, the nodes often generate a redundant and highly correlated data. Transmitting enormous amount of generated data to the sink cause increases the network traffic which adversely consumes the node's resources. Here, the generated redundant data from multiple nodes can be aggregated using a key method called data aggregation. Such a kind method is typically used in WSNs to reduce the task energy consumption since the number of data transmissions to the sink is reduced (Krishnamachari et al., 2002).

Most of the energy-efficient data gathering proposals are based on the conventional client-server model, where each sensor node involved transmits data packets to the sink. Since the link bandwidth of a WSN is much lower than a wired network, a set of connected wireless links need to be established from these node to the sink to forward data packets. Consequently, this could increase the network's data traffic and as a result, increase network resources consumed. As a solution to this overwhelming data traffic, (Qi et al., 2003) has proposed a Mobile Agent (MA)- model for data gathering in WSNs. In this model, a software component (called MA) is forwarded throughout the network and visit the source nodes one by one following an itinerary and performs data gathering process locally at each source node. Upon completing data gathering, the MA bring back the aggregated data to the sink . Consequently, this data combination decreases the number of packets transmitted to the sink and result in a decrease in the communication costs, bandwidth utilization, network congestion and energy consumption.

MA migration itinerary planning is a challenging issue in MA-based data gathering. The MA itinerary is the source-visiting sequence for the MA to follow during its migration. It has been noted that finding an optimal itinerary for the MA is (NP)-complete problem (Chen et al., 2007a). A sub-optimal MA itinerary may lead to a highly inefficient overall network performance.

In WSNs, MA-based data gathering employs two schemes of itinerary: Single Itinerary Planning (SIP) and Multiple Itinerary Planning (MIP). SIP utilizes single MA to roam the network for data gathering, whereas MIP utilizes multiple MAs that work in parallel to perform data gathering. In large scale networks, SIP is however characterized by long delays, increase in MA's packet size and low reliability. To overcome these drawbacks, MIP (Chen et al., 2009a; Cai et al., 2011; Bendjima and Feham, 2012; Venetis et al., 2017; Rais et al., 2018) was proposed. In MIP, several MAs are distributed to the network and work concurrently to visit groups (partitions) of source nodes. Each MA is assigned to one partition and migrates to a subset of source nodes. This process enables a reduction in the MA packet size, which further leads to a decrease in the energy consumed as compared to the SIP scheme. Moreover, due to the distribution of aggregation tasks among multi MAs, the task duration is minimized (e.g. lower delay).

1.2 Problem Statement

Despite the successes achieved by MIP, determining the optimal number of MAs in MIP and finding the optimal itinerary for each MA still remain critical issues. In this context, these issues have attracted researchers' interests. The previous MIP related works such as GIGM-MIP (Aloui et al., 2015), have proposed various algorithms to mitigate the MIP issues and achieved their objectives. However, several other deficiencies associated with MIP are left unsolved:

- The existing MIP approaches assume that the itinerary of each MA has to start and end at the sink node. Furthermore, each MA has to carry its processing code (data aggregation code) to collect the sensory data and get back to the sink with the accumulated data. These assumptions would result in an increases in the number of MA's migration hops whenever the number of source nodes increase, which leads to increase in task energy consumption during the data gathering process.
- Most of the proposed itineraries of the MA employs a single distance based parameter to determine the next MA's migration hop, while other parameters such as the remaining energy and number of neighbors have not been considered. Considering only the distance between the nodes may affect the MA migration and result in an unsuccessful MA's round-trip, especially when the remaining energy of the selected node is insufficient to transfer the MA to the next node. In this case, the probability that the MA will be dropped is very high. Additionally, certain nodes will be chosen more than once during the construction of MA's itinerary due to their nearest distance. As a result, these nodes lose their energy quickly when compared to others. Meanwhile, other nodes located farther away would not be used at all. This could lead to a substantial imbalance in the energy dissipation of the nodes.
- Attaining energy efficiency has been the main focus of previous MIP approaches which make them best suited for environmental monitoring ap-

plications as sensor nodes would be unattended to for a long period of time. These schemes perform poorly in real-time applications, which requires a higher event-to sink throughput to effectively deliver real-time data for timely decisions to be made within the network.

This thesis addresses these above problems associated with MIP-based data gathering. The GIGM-MIP approach by (Aloui et al., 2015) has been chosen as the main comparison benchmark. This is because GIGM-MIP approach has achieved successful network performance in terms of energy and task duration among other proposed MIP approaches.

1.3 Research Objectives

The main objective of this thesis is to improve on the task energy consumption, successful MA's round-trip and event-to-sink throughput performance of MIP-based data gathering in WSNs. In this respect, specific objectives are as follows:

- To propose an algorithm that based on the agent spawning concept. Such algorithm mainly aims to reduce the task energy consumption of the MA by decreasing the MA's migration hops and data payload.
- To propose a mobile agent migration algorithm that based on Fuzzy Logic System (FLS). The main aim of this algorithm is to increase the successful MA's round-trip rate and network lifetime by determines an optimal MA's itinerary by taking into consideration three parameters.
- To propose an algorithm that based on agent cloning concept. This algorithm aims to improve the event-to-sink throughput by reducing the task duration of data gathering process while maximizing data collection.

1.4 Research Scope

This section outlines the scope of this study as illustrated in the shaded portion of the hierarchy in Figure 1.2. Since there are several issues in WSNs' design, this research aims to study data gathering issue. It mainly focuses on Multi MAs-based data gathering approaches that are designed to reduce the task energy consumption and task duration during data gathering process. Furthermore, it focuses on improving the rate of success MA's round-trip and increasing the network lifetime. Since the Multi-MAs approach was proposed for data gathering over both flat and hierarchical network topologies, and in homogeneous and heterogeneous network, this thesis focuses on improving the performance of Multi MAs over a flat topology with homogeneous network. It concentrates on static MA itinerary determination where the nodes visiting list is predetermined at the sink node before the MAs are dispatched to the

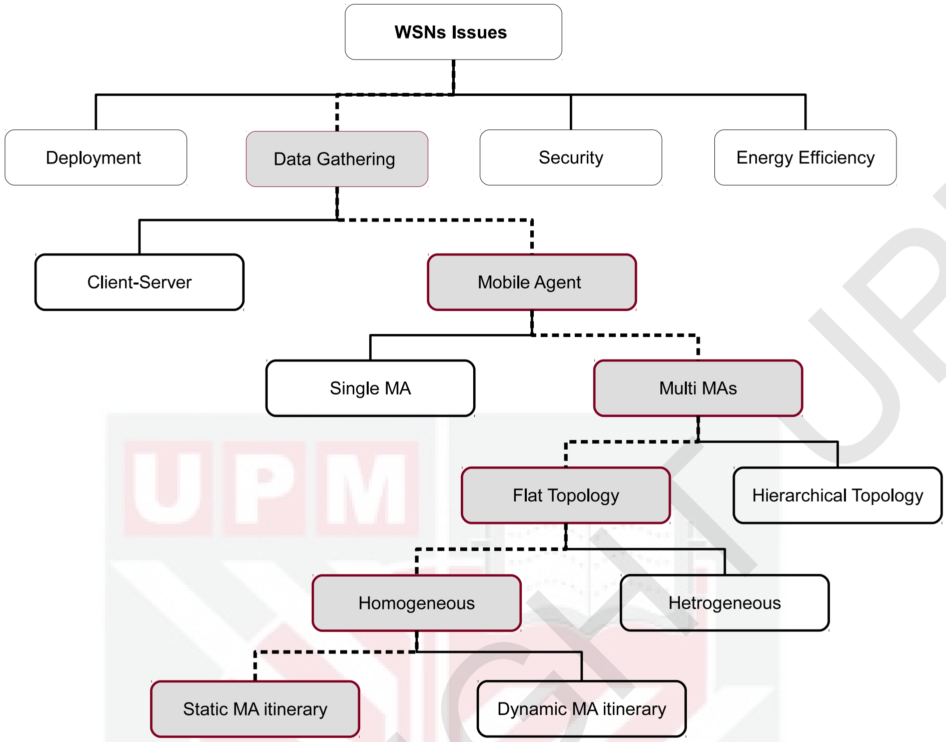

Figure 1.2: Research scope

network. Thus, the implementation of the approaches with dynamic MA itinerary determination lies beyond the scope of this research.

1.5 Thesis Organization

The rest of this thesis is organized as follows:

Chapter 2 presents a literature review on data gathering in WSNs. It first discusses (in brief) the data gathering based on client-server model. Then, it discusses the data gathering based on MA model. This chapter also shows the related works proposed in literature for data gathering based on both SIP and MIP approaches. Finally, the chapter presents a comparison of different SIP and MIP data gathering schemes.

Chapter 3 presents the research methodology used in this thesis. It first identifies the notations and definition used throughout the thesis. Then, it presents the research framework, experimental setup, network topology and finally the evaluation method. Finally, the performance metrics and their validation are presented in this chapter.

Chapter 4 presents a Spawn Mobile Agent Itinerary Planning (SMIP) algorithm used to reduce the energy consumption of data gathering tasks in WSN. It shows the design of the proposed SMIP algorithm, and present the evaluation and performance comparison of the proposed algorithm with existing algorithms such as GIGM-MIP and CL-MIP.

Chapter 5 presents the design of the proposed Fuzzy-based Mobile Agent Migration (FuMAM) algorithm. It also describes the parameters used for the fuzzy logic system in order to select the next hop MA's migration. The performance evaluation and results of the proposed algorithm is presented and compared against GIGM-MIP and CL-MIP schemes.

Chapter 6 presents the proposed Clone Mobile Agent Itinerary Planning (CMIP) algorithm to reduce the task duration and also improve the event-to-sink throughput. It presents the performance evaluation and results comparison of the proposed CMIP with GIGM-MIP and CL-MIP schemes.

Chapter 7 concludes the thesis and recommends some promising directions for future research.

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LIST OF PUBLICATIONS

International Refereed Journals

Huthiafa Q Qadori, Zuriati A Zulkarnain, Zurina Mohd Hanapi, Shamala Subramaniam (2017). Multi-mobile agent itinerary planning algorithms for data gathering in wireless sensor networks: A review paper. *International Journal of Distributed Sensor Networks*, Vol 13, no.1. **(Published 2017, IF = 1.239, Q3, ISI, JCR)**

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