MINIMISING COVERAGE HOLES FOR PREDICTION-BASED MOBILE OBJECT TARGET TRACKING IN WIRELESS SENSOR NETWORKS

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FK 2020 1

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By

KHALID ABDULLAHI ALI

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

November 2017

DEDICATION

To spirits of my dear Mum, Zaynab Haji Hassan, my dear Dad, Abdullahi Ali Hayle whom I can feel everywhere, every time.

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

MINIMISING COVERAGE HOLES FOR PREDICTION-BASED MOBILE OBJECT TARGET TRACKING IN WIRELESS SENSOR NETWORKS

By

KHALID ABDULLAHI ALI

November 2017

Chairman : Professor Mohd. Fadlee A. Rasid, PhD
Faculty : Engineering

The use of small, cheap, networked devices to perform a collaborative task presents an attractive opportunity in many scenarios. One such scenario is tracking the coverage hole in sensing area and tracking an object moving through the region of interest in Wireless Sensor Network (WSN). This thesis presents a new framework for track- ing coverage hole and mobile object in wireless sensor network. Existing algorithms have been integrated and extended with this framework to perform target tracking for coverage hole in the Region of Interest (ROI) and tracking mobile object whilst managing accuracy of tracking and energy usage, in order to increase the lifetime of a sensor network. The node dies after energy depletion, and such consequence causes holes in the coverage area to be created. In a sensor network with movement capa- bilities, nodes can be moved to make redeployment. Hence, work presented in this thesis could be useful to WSN algorithms developers, and also to people who plan the deployment of nodes in a region of interest.

This thesis focuses on tracking moving objects scenarios, but the research presented is not limited to this. The aim is to increase the coverage environment through smaller mobility of sensor nodes, such that mobility distance is limited to 1-hop, and k-coverage of the nodes are not increased. By securing full coverage with no coverage hole, accuracy of target tracking can be improved. Novel improvement is presented here in performing target tracking of mobile objects where the target moves in a linear fashion. This thesis proposes a prediction-based scheme called Face-based Target Tracking Technique (FTTT) to minimize energy depletion and prolong the lifetime for sensor node while accurately tracking mobile objects. This strategy of tracking mobile ob- jects will influence accuracy of mobile objects tracking. In addition, we also introduce schemes for object tracking recovery to figure out the problem of object tracking loss. Through analysis from the simulation results, our presented prediction-

based scheme for tracking movable object can efficiently preserve energy and perfectly attain the aim of tracking mobile objects concurrently and accurately.

From the simulation results, the proposed coverage hole algorithm shows a coverage gain of up to 14%. However, on average, the proposed vector space algorithm shows 3% to 4% improvement in the percentage coverage, as compared to the previous algorithm. In the scenario of target tracking, the proposed prediction-based scheme for tracking mobile object can efficiently preserve energy and perfectly attain the aim of tracking moving mobile object concurrently. The proposed prediction-based optimistic object tracking scheme can save up to 24% energy consumption as compared to the related works. The accuracy of FTTT is still higher than 98%, which shows that optimistic design does not influence the tracking accuracy. Thus, FTTT appear to successfully conserve energy and accomplish the objective of moving objects tracking.

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

MEMINIMUMKAN LIPUTAN LUBANG BAGI PENJEJAKAN OBJEK SASARAN BERGERAK BERDASARKAN PERAMALAN DALAM JARINGAN SENSOR WAYARLES

Oleh

KHALID ABDULLAHI ALI

November 2017

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Penggunaan peranti kecil, murah dan berangkaian bagi melaksanakan sebuah tugasan secara koloboratif memberikan peluang yang menarik bagi kebanyakan senario. Salah satu senario ialah penjejakan liputan lubang dalam bidang sensing dan penjejakan sesebuah objek bergerak melalui sesuatu kawasan kepentingan. Sesebuah sensor tunggal kurang berkemampuan , tetapi sekumpulan sensor berpotensi untuk menyediakan sistem yang fleksibel, swaatur yang menjalankan tugasan dalam keadaan yang pedar bagi tempoh masa yang lama. Tesis ini mengemukakan kerangka baharu bagi penjejakan liputan lubang dan objek bergerak dalam jaringan sensor wayarles. Algoritma yang sedia ada bersifat bersepadu dan diperkembangkan dengan kerangka ini bagi melaksanakan penjejakan target bagi penutupan lubang dalam kawasan berkepentingan (ROI) dan penjejakan objek bergerak di samping menguruskan ketepatan bagi penjejakan dan penggunaan tenaga supaya dapat mengimbangi kualiti informasi dengan kos memperolehnya dan meningkatkan masa hayat jaringan sensor. Bagi senario pertama, peningkatan kawasan liputan sensing dalam jaringan sensor merupakan isu yang penting. Dalam WSN, nod sensor dapat diletakkan secara rawak dalam kawasan berkepentingan dan nod sensor mati selepas pengurangan tenaga, akibatnya lubang dalam kawasan liputan terbentuk. Dalam jaringan sensor dengan kemampuan pergerakan, nod sensor dapat digerakkan bagi membuat penyusunan semula . Dapatan kajian ini dapat digunakan oleh pemaju algoritma jaringan sensor wayarles, dan juga oleh individu yang merancang penyusunan semula noda dalam kawasan berkepentingan. Tesis ini memberikan fokus pada penjejakan senario objek bergerak, tetapi penyelidikan yang dikemukakan ini tidak terhad pada perkara ini.

Oleh sebab itu, kajian ini mencadangkan suatu algoritma bagi meminimumkan penutupan lubang melalui mobiliti. Tujuannya adalah untuk meningkatkan liputan persekitaran melalui mobiliti nod sensor yang lebih kecil supaya jarak mobiliti dihadkan

dengan nod lompatan I, dan liputan k tidak ditingkatkan. Bagi menjamin liputan lengkap tanpa liputan lubang, target dapat dikesan setepatnya bagi senario kedua. Penambahbaikan novel telah dikemukakan dalam melaksanakan penjejakan target objek bergerak , sesebuah target bergerak dalam bentuk yang linear meliputi terain yang pelbagai, dalam tesis ini, kajian ini mencadangkan skema berdasarkan peramalan yang dipanggil Teknik Penjejakan Target berdasarkan Permukaan (FTTT) bagi meminimumkan pengurangan tenaga, melanjutkan masa hayat nod sensor ketika menjejaki objek bergerak dan menjejaki objek tersebut setepat-tepatnya. Strategi penjejakan objek bergerak ini akan mempengaruhi penjejakan objek bergerak setepat-tepatnya. Di samping itu, kajian ini juga memperkenalkan skema bagi mendapatkan semula penjejakan objek untuk mengenal pasti masalah kehilangan penjejakan objek. Skema tersebut dapat meminimumkan bilangan sensor yang aktif dengan efektif berbanding dengan pengesanan semula penjejakan objek dengan menggunakan skema penghantaran mesej. Melalui analisis rom dapatan simulasi , skema berdasarkan ramalan bagi penjejakan objek bergerak dapat mengekalkan tenaga dengan efektif dan mencapai dengan sempurna matlamat penjejakan pemindahan objek bergerak serentak ,dan penjejakan objek bergerak dengan tepat.

ACKNOWLEDGEMENTS

All praise to almighty ALLAH, the Merciful and the Benevolent for blessing me with strong faith, enlightenment, and confidence and for facilitating all odds to accomplish my academic journey.

My next deep gratitude is to my father Abdullahi Ali, who installed the courage, inspirations, and endurances into my core and who had great expectations of me. My heartfelt appreciation and gratitude goes to my dedicated supervisor, Associate Professor Dr. Mohd. Fadlee b. A. Rasid, for his endless support, cooperative work, unreserved guidance and patience throughout my study. Moreover, for all the efforts he poured into my work through his advices and meticulous reading and correction to realize the finalization of his thesis.

Also, my thanks to my co-supervisors, Professor Dr. Borhanuddin b. Mohd. Ali and Associate Professor Ir. Dr. Aduwati Sali, for their ceaseless assistance and guidance in my research and thesis writing. Last but not least, I would like to thank my brothers and sisters for everything they are provided to support me for this achievement.

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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CHAPTER 1

INTRODUCTION

1.1 Introduction

Wireless Sensor Networks (WSNs) are being widely used to track target that enter region of interest, for example in battlefields, monitoring wildlife or habitat, and monitoring the chemical industries during their operation. At that time if the sensor has mobile objects in the sensing area range and have accurately tracked the target, the sensor gathers the mobile objects behaviors and will send the collaborative rely data from the sensor to the base station. Based on the collected data and by using the prediction mechanism, the base station will process the data to predict the next location which the mobile object might move to Only sensor in the area where the object is will activate to minimize the energy consumption and maximize the target accuracy. Because of the nature of deployment area, the sensors cannot have permanent or fixed source of power. Hence, sensors are equipped with batteries to work on. This maximize the sensors to adopt many different functions, and also propose energy limitation. This situation (problem) can be prevented by assuming that each sensor can autonomously and individually change its status among the following three states: active, listen, and sleep This schedule achieves uniform power saving among all sensors.

The mobile object mostly moves in the area of interest, and from one location to another location there a cooperation of nodes that detect the object, and the sensors send in the boundary coverage to alert the sensor that the object is on their way. By using the prediction mechanism, the nodes in that location will be in listen status, and their status will change after the object enters in their region to be in active status. In the condition that object might move off to a location that is predicted, the sensor will miss the target. In such condition it is interesting to have mobility capability among the sensors. In advances the field have mobile condition among

and the sensors are made available to capture any missing target in the field. Even then, such mobile sensors appear to be costly. Mobile and static sensors in combination (heterogeneous) minimizes little deployment cost. However, in our situation we activate more then one hop to detect the missing mobile event and after detection the sensors that are not in target location will return to sleep state so as to minimize energy consumption. Because sensor mobility is expensive in terms of energy, it becomes important to decide which mobile sensor should be moved to track events, while the future requirement of the WSN should be kept in mind.

1.2 Components and Characteristics of Wireless Sensor Networks

A quintessential wireless sensor network is shown in Figure 1.1 The three distinct elements that compose most sensor networks are: Sink Node (Base Station), Sensor Nodes and Targets (Events).

The sensor nodes, most commonly called as sensors, are dispersed over a regular or irregular surveillance region. These sensor nodes track the target that is within their environmental region and send collected data to the sink node. The target could be a mobile object which move in within the environmental region in a familiar way or a random style. In this work, we focused on mobile objects (targets) to start at random location and continue in a linear motion path.

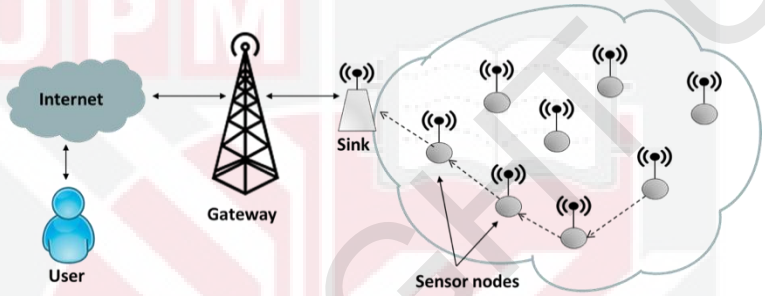

Figure 1.1 : The three Elements that Make up of Most Sensor Networks

The wireless sensor networks have a distinguished set of attributes that have a huge impression on their work and capabilities. The major areas dealt with are limited battery power, coverage hole, and tracking target accurately. As for power depletion in sensor nodes, unsophisticated way of employing the available sensor nodes can effectively minimize the effectiveness of sensor networks by minimizing the lifetime and can cause coverage hole in the surveillance region during the lifetime of the network. Furthermore, the target tracking accuracy produces erroneous result, and high missed target ratio during the network lifetime. Some of sensor nodes can be in sleep mode to preserve their energy. These nodes will then be in active mode at the time the target are in their region (environment) and thus play a role to increase the network lifetime, tracking target accuracy, and guarantee the best network coverage. The networks are also characterized by low bandwidths and the sensors lack high computation capabilities.

1.3 Problem Statement

The arising WSNs technology is anticipated to provide a wide range of applications, such as battlefield surveillance, environmental monitoring, smart spaces and so on. The Usage of WSN has become a powerful tool that connects the physical and digital world. Currently, WSNs are applied in numerous applications such as the monitoring

border and border control. Among countries, border protection is a sensitive issue and measures are being taken to improve security at the borders. In addition to physical fencing, smart methods using technology are being employed to increase the alertness of security officials at the borders. Border control using wireless sensor network is one way to do. However, in recent years, unmanned aerial vehicls and grouped sensors eqquped surveillance towers have been added as border control measurments. For instance, many linear prediction mechanism technique were proposed for border monitoring applications (Boaz et al. (2014),Adejo et al. (2013),Hammoudeh et al. (2015)). such protocols, suffer from problems ranging from false alarms to line of sight limitations. In addition, there is lack of a coordination unit to provide accuracy to the system. The scope and limitation of this research will be based on border monitoring related issues.

Coverage problem is a basic issue in WSN, which mostly occur due to the random deployment of a sensor node in the environment. The problem caused WSN deployment to be unable to provide a balanced sensor distribution over the monitoring region, and therefore localization problem is also a major issue. In WSN, coverage holes are also created after initial random deployment of sensors or limited power source of sensors were consumed. Therefore, target tracking accuracy is a major issue in wireless sensor network. In many scenarios, there are multiple targets in the Region of Interest (ROI) that have to be tracked by at least sensors for improved accuracy in target localization by certifying the outcomes. One of the widely known is the use of n= 3 sensors in the method of trilateration, that is used for localizing target. The nodes that are in ROI that cannot sense a mobile object enclosed in their range should not be active. So, there is a contemplate (consider) different state of modes for sensors from SLEEP, LISTEN, and ACTIVE to minimize energy depletion.

It is essential to maintain the network coverage and connectivity as a small unmonitored area can spoil the whole purpose of the network, if it goes undetected. Besides, density of the nodes throughout the network may not be uniform due to random deployment of the sensors. Though, some researchers have proposed coverage and connectivity maintenance algorithms, to the best of our knowledge, none of the work proposes how to recover the coverage holes with limited mobility of nodes and without increasing the highest coverage of a mobile node after mobility.

The problems can be summerized as below;

1. Coverage hole occur due to the random deployment of a sensor node.
2. Failure of sensors due to natural events such as fire or physical damage such as crushing by animals, vehicles or even depletion of battery leads to the occurrence of coverage holes. the occurrence of these holes could disturb the effectiveness of network. In (Qin et al., 2015), the authors design a localized coverage force division algorithm to find the coverage quality in WSNs. However, their algorithm can neither detect the coverage holes nor find the shape and size of a hole.

3. A mobile sensor has much higher cost than in static sensor, with similar sensing capability, and deploying only mobile sensor can cause the sensor cost to be too high.
4. Energy is a critical resource in WSNs and system lifetime needs to be prolonged through the use of energy conscious sensing strategies during system operation. the minimization of energy consumption for an active sensor network with target activities is more complicated since target detection involves collaborative sensing and communication involving different nodes.
5. Target tracking mobile in WSNs has many important applications. As it is often the case in prior work that the tracking quality heavily depends on high accuracy in localization, which is never perfect in practice. These bring a cumulative effect on tracking, for example, target missing, Recovering from the effect and also frequent interactions between nodes and a central server result in a high energy consumption.

Due to the uncertainty and unpredictability of object motion, the tracking algorithm is needed to adapt to real-time changes of velocities and directions of a moving target. Moreover, the energy consumption of the tracking algorithm has to be considered because of the inherent limitations of wireless sensor.

1.4 Aims and Objectives

The aim of this thesis is to design and develop target coverage and mobile object detection schemes. The desire coverage over the entire operational lifetime of the network, also to predict target moving directions and to wakeup suitable nodes, to reduce the risk target miss and prevent target loss due to possible prediction errors, and the last goal is to enhance energy consumption as it allows appropriate nodes to track the target and the rest of nodes to be in sleep mode to save energy. The following are objectives of the thesis:

1. To recover coverage hole by using vector space method in order to maintain coverage area for WSN.
2. To propose a mobile target tracking detection algorithm using Received Signal Strength Indication (RSSI) utilizing face structure construction in Region of Interest (ROI).
3. To perform moving object prediction by using linear prediction method.

1.5 Contribution

The main contribution in this thesis can be presented as follows:

- It proposed a distributed method to improve and recover holes in the region of interest (ROI) by using vector space to decide the magnitude and direction of mobile node. We proposed a distributed method to improve and recover holes in the ROI by using vector space to decide the magnitude and direction of the mobile node.
- Vector space algorithms are able to improve coverage holes regarding abnormal shapes while not enhancing the optimum coverage from the movable nodes. Throughout our method, evaluation regarding mobility needs minimal computation and for that reason is much more effective as compared with various other hole healing methods.
- In addition, proposed Face-based Target Tracking Technique (FTTT) in order to incorporate obtaining and repair of target location thereafter achieve more functionality that is effective when it comes to communication cost.
- Target discovery is dependent on an optimistic technique to be able to preserve energy. Therefore, FTTT can smartly figure out the optimum time towards next discovery of target. By doing this, sensor power is preserved. Additionally, we carried out comprehensive experiments to evaluate efficiency. In this study, FTTT executed much better than related object tracking method.

1.6 Study Module

Overall this thesis is to address the recovery coverage hole by using a *vector* space as being method to estimate the degree and path of mobile or portable *nodes*. Also to study as mobility of the nodes consumes more energy, the moving distance is limited with only one hop. Moreover, it is to maintain the desired coverage over the entire network operational lifetime. Additionally, mobility prediction for the next event movement in the monitoring area will be worked on.

Furthermore, this thesis addresses an approach for target tracking in WSNs, most of the studies are focused on multiple-target tracking, as an extended work from single target tracking algorithms at different times. To attain efficiency in energy, they work in a few parameters. Meanwhile, there is a specified network structure that can save more energy and equalize the operation load for distributed nodes. There are many network structures, such as tree structure and cluster structure. In this thesis, face structure was used in view on the fact that reliance to the face design can minimize the transmission amount.For the energy depletion face structure, when a group of nodes detect coming mobile objects, those nodes face to the object and spread along the way that mobile object moves. As based on the face structure, only sensor nodes that receive the wakeup message and are in the moving object direction could be wakeup and constantly observe the target within the next period of time. Other nodes that get

the active message but are not in the location of the mobile object would go back into sleep mode to maximize energy efficiency and minimize energy depletion. So, the use of face design impacts parameters include: neighbouring location of the sensor with consideration to the target motion, tracking multiple targets by the sensor, and residual energy in the sensor. There is a wide simulation conducted to receive their impact on the energy efficiency of the singly WSN and in a collectively manner. So, their effectiveness is governed by the network structure and prediction mechanism used. The prediction mechanism used in this work is to track moving object efficiently. The prediction mechanism is capable of identifying the correct set of nodes that track targets, based on its local conditions in a distributed environment, which make centralized situation unneeded.

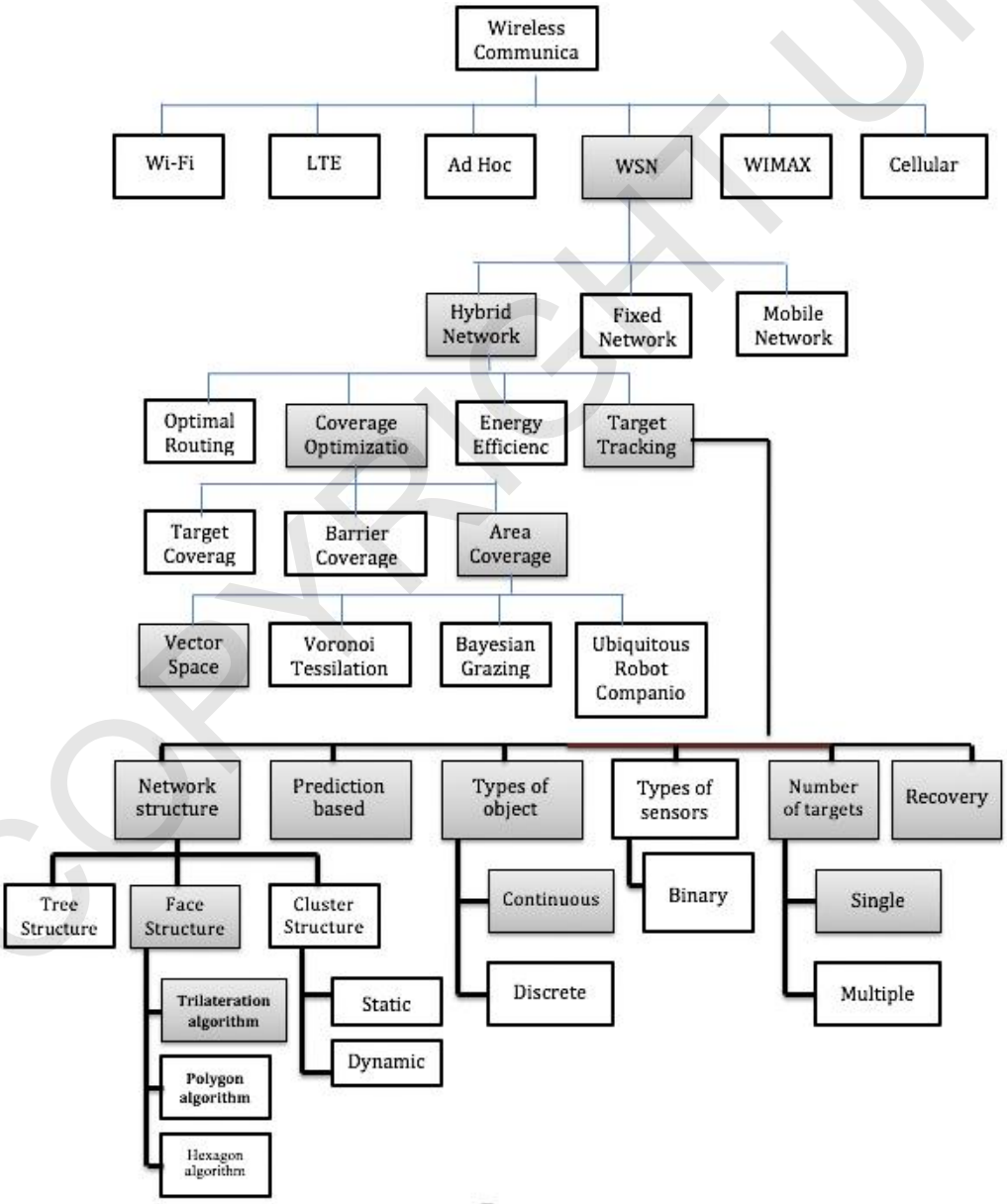

Figure 1.2 : Study Module

1.7 Thesis Organization

This thesis is organized as follows. Chapter 1 describes the overview of WSN, objectives, the problem statement and the research contribution. Chapter 2 presents a review of related literature. This includes methods followed by other researchers to solve coverage problem in the area of interest, target tracking problems in wireless sensor networks, their success as well as shortcomings. In Chapter 3, the methodology of the proposed algorithms is presented. Chapter 4 discusses results obtained from the simulation by using NS2 and Matlab software together with comparison of various results obtained from the different scenarios and performance metrics. In Chapter 5, the thesis is concluded and the direction for future work is recommended.

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