MULTI-STAGE MOBILE BEACONS-ASSISTED LOCALIZATION SCHEME FOR LARGE SCALE UNDERWATER SENSOR NETWORK

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DEDICATION

This thesis is dedicated to my beloved parent, Mr. Mohamed Bin Mohammad Daud and Madam Rahimah Binti Nahmad, to my lovely wife Norhidayah Bte Dalib, my adorable children Muhammad Aqil Zuhair and Nur Alisha Zuhaira. Thanks for the enduring love, patience, motivation and support.

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ABSTRACT

Localization is one of the most important issues in Underwater Wireless Sensor Networks (UWSN) as sensor nodes are considerably difficult to be deployed at determined locations. Beacon nodes static or mobile are responsible to disseminate their location information to unknown nodes in order to determine the location of each deployed underwater. The key challenge is to provide a scalable localization scheme to cover all sensor node with sufficient beacon message, while reducing localization error in estimating node position and decreasing localization time. Mobile-beacon assisted localization is the best option for large-scale network due to its high accuracy and cost-effectiveness compared to static beacons. However, the effect of water current causes a non-uniform deployment of underwater sensor and influences the variable speed of sound in acoustic signal, and thus making the existing mobile-beacon localization schemes requires high communication cost and generates low localization accuracy. Therefore, to overcome this issue, this study proposed the improved mobile beacon assisted localization scheme. Firstly, Adaptive Underwater Cluster-based (AUC) algorithm based on communication range control was suggested for underwater sensor network to improve localization coverage and reduce the estimation error. Secondly, Efficient Dynamic Mobile beacon Path Planning (EDMPP) algorithm was put forward to improve the placement of virtual beacon point and reduce the communication overhead. Thirdly to maintain the localization coverage as well as reduce the communication overhead between mobile beacon and sensor node in large-scale UWSN Hybrid Mobile beacon Path Planning (HybMPP) algorithm was also proposed. Result on non-uniform deployment for UWSN simulation indicated that AUC improve 23% of localization accuracy compared to MDS-MAP(p) and 52% compared to MDS-MAP. In beacon message transmission, EDMPP reduced communication overhead by 38.42% in comparison to 3D Hilbert; and 37.08% when compared to 3D SCAN. Moreover, EDMPP decreased localization time by 47.36% compared to 3D Hilbert and 10.48% compared to 3D SCAN. Subsequently, as compared to EDMPP in a deep sea environment, HybMPP lessened communication overhead by 56.27% for sensor node discovery. This illustrates that the suggested approach outperformed the existing algorithm in the localization process.

ABSTRAK

Lokalisasi merupakan satu isu penting dalam sensor wayarles dalam air (UWSN) kerana nod sensor sukar untuk digunakan di lokasi yang ditetapkan. Beacon statik atau mudah alih bertanggung jawab menyebarkan maklumat lokasi kepada nod yang tidak berlokasi bagi menentukan kedudukan setiap nod sensor dalam air yang ditaburkan. Cabaran utama adalah menyediakan skema lokalisasi berskala bagi meliputi semua nod sensor dengan mesej beacon yang mencukupi, disamping mengurangkan ralat lokalisasi dalam anggaran kedudukan nod serta mengurangkan masa lokalisasi. Lokalisasi berbantukan beacon mudah alih merupakan pilihan terbaik bagi rangkaian berskala besar kerana ianya memberikan ketepatan yang tinggi dan keberkesanan kos berbanding beacon statik. Walaupun begitu, kesan arus air telah mengakibatkan taburan tidak seragam bagi sensor bawah air serta mempengaruhi pemboleh ubah kelajuan bunyi dalam isyarat akustik. Oleh itu, skema lokalisasi beacon mudah alih sedia ada memerlukan kos komunikasi yang tinggi serta memberikan ketepatan lokalisasi yang rendah. Justeru, untuk mengatasi isu ini, penyelidikan ini mencadangkan skema lokalisasi berbantukan beacon mudah alih yang dipertingkatkan. Pertama, algoritma adaptif berasaskan kelompok dalam air (AUC) berdasarkan kawalan julat komunikasi dicadangkan bagi UWSN untuk meningkatkan liputan lokalisasi dan mengurangkan ralat anggaran. Kedua, algoritma perancangan laluan dinamik untuk beacon mudah alih (EDMPP) diusulkan bagi menambah baik penempatan titik beacon maya dan mengurangkan overhed komunikasi. Ketiga, bagi mengekalkan liputan lokalisasi serta mengurangkan overhed komunikasi antara beacon mudah alih dan nod sensor dalam UWSN berskala besar, algoritma perancangan laluan beacon mudah alih Hibrid (HybMPP) juga telah dicadangkan. Hasil simulasi bagi taburan tidak seragam untuk UWSN menunjukkan bahawa AUC meningkatkan 23% ketepatan lokalisasi berbanding MDS-MAP(p) dan 52% berbanding MDS-MAP. EDMPP mengurangkan kira-kira 38.42% overhed komunikasi dalam penghantaran mesej beacon berbanding 3D Hilbert dan 37.08% berbanding dengan 3D SCAN. Selain itu, EDMPP mengurangkan 47.36% berbanding 3D Hilbert dan 10.48% berbanding 3D SCAN bagi masa lokalisasi. Seterusnya, HybMPP mengurangkan 56.27% overhed komunikasi untuk penemuan nod sensor berbanding EDMPP bagi persekitaran air dalam. Ini membuktikan bahawa algoritma yang dicadangkan menunjukkan prestasi yang lebih baik dalam proses lokalisasi berbanding dengan algoritma sedia ada.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ACK	-	Acknowledgement
ADV	-	Advertisement
AoA	-	Angle of Arrival
AUC	-	Adaptive Underwater Cluster
AUV	-	Autonomous Underwater Vehicles
AquaSim	-	Aquatic Simulation
Aqua3D	-	Aquatic 3D Simulation
CDS	-	Connected Dominating Set
CH	-	Cluster Head
CHs	-	Cluster Heads
CPU	-	Central Processing Unit
DET	-	Detachable Elevator Transceiver
DNR	-	Dive and Rise
DV-hop	-	Distance Vector-Hop
EDMPP	-	Efficient Dynamic Mobile beacon Path Planning
FBL-VSS	-	Floating Beacon-assisted 3D Localization for Variable Sound Speed
GWs	-	Gateway Nodes
GPS	-	Global Positioning Systems
LLCM	-	Lightweight Localization Coverage Maintenance
LRH	-	Largest Regular Hexagon
LEACH	-	Low-Energy Adaptive Clustering Hierarchy
MAC	-	Medium Access Control
MANETs	-	Mobile Ad Hoc Networks
MBL-ndc	-	Mobile Beacon-assisted Localization-node density clustering

MDS	-	Multidimensional Scaling
MDS-MAP	-	Multidimensional Scaling-Map
MRP	-	Message Report Package
MS-DNR	-	Multi-stage Dive and Rise scheme
MS-AUV	-	Multi-stage Autonomous Underwater Vehicles scheme
NAM	-	Network Animator
Non-CH	-	Non-Cluster head
NS-2	-	Network Simulator-2
OMNeT++	-	Objective Modular Network Testbed in C++
OTcl	-	Object-oriented Tools Command Language
QoS	-	Quality of service
ROV	-	Remotely Operated Vehicles
RSSI	-	Received Signal Strength Indicator
RWP	-	Random Way Point
SUML	-	Scalable Underwater Mobile beacon-assisted Localization scheme
SCTP	-	Stream Control Transmission Protocol
TCP	-	Transmission Control Protocol
ToA	-	Time of Arrival
TDoA	-	Time Difference of Arrival
TinyOS	-	Tiny Operating System
UDP	-	User Datagram Protocol
UASN	-	Underwater Acoustic Sensor Network
UWSN	-	Underwater Wireless Sensor Network
WSNs	-	Wireless Sensor Networks

LIST OF SYMBOLS

d	-	Distance
t_i	-	Time Stamp
L_e	-	Localization Error
L_c	-	Localization Coverage
L_t	-	Localization Time
dx_{ij}	-	Distance between two point of mobile beacon trajectory
ntp	-	Total number of trajectory point
MB_{path}	-	Mobile Beacon trajectory step
n	-	Number of Unknown Node
m	-	Total Number of Localized Sensors
$t_{loc(i)}$	-	Complete time of localization
$t_{rec(i)}$	-	Received Time
$R_{cluster}$	-	Communication Range for Clustering
CR_{signal}	-	Cluster Region Signal
CH_{signal}	-	Cluster Head Signal
C_m	-	Master Cluster
C_s	-	Slave Cluster
d_{ij}	-	Distance between any pair of node i and j
$D(X)$	-	Distance Matrix
A_H	-	The height value of the deployment area
A_W	-	The width value of the deployment area
S_H	-	The height value of the sector area
S_W	-	The width value of the sector area
R_H	-	The height value of the sub-sector area
R_W	-	The width value of the sub-sector area
$S(i)x_{start}$	-	x coordinate for the starting point of Sector i

$S(i)y_{start}$	-	y coordinate for the starting point of Sector i
$S(i)x_{end}$	-	x coordinate for the ending point of Sector i
$S(i)y_{end}$	-	y coordinate for the ending point of Sector i
$R_{S(i)}$	-	Row number of Sector i
$C_{S(i)}$	-	Column number of Sector i

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Overview

Wireless Sensor Network (WSN) is one of the microchip technologies, created with the combination of technological advances such as Micro-Electro-Mechanical Systems (MEMS) technology, computation, and communication technologies. WSN is composed of many sensor nodes, where each node is able to sense the environmental conditions such as humidity level, temperature, pressure, etc. The information or data received in WSN will be sent to a data processing center called a sink node for the data to be processed the data according to the desired needs. Due to this ability, WSN technology becomes important and has been implemented in various applications such as habitat monitoring, healthcare application, underwater ocean monitoring, etc. However, WSN technology has several limitations that should be considered.

The limitations of WSN technology are insufficient amount of energy, low bandwidth, limited communication range, minimal processing, and storage. Due to these limitations, WSN technology has become an interesting area for researchers around the world to participate in solving the issues from a different point of view. There are various aspects that the researchers are interested in, particularly in the development of WSN technology such as security, routing protocols, localization, data aggregation, time synchronization, etc. The type of WSN may be divided into several environments such as terrestrial, underwater, underground, body sensor, etc. Each environment has distinct characteristics and challenges.

The Underwater Wireless Sensor Network (UWSN) or Underwater Acoustic Sensor Network (UASN) is one of the most common WSN. In UWSN, the radio frequency channel does not function accordingly due to the propagation of the channel in an underwater environment. In addition, acoustic channels need to have a high level of accuracy compared to radio frequency channels (Cui *et al.*, 2006). Moreover, localization in UWSN is one of the challenging issue. As the Global Positioning System (GPS) that used to locate the sensor nodes on the water surface. It cannot be used in underwater networks because GPS signals cannot propagate through the water. The acoustic channels become an alternative choice for underwater communication is due to the capability in transmitting the signal in underwater environment. However, the characteristics of acoustic channels make the task of designing underwater localization scheme more challenging. Moreover, the good localization scheme need to consider high localization accuracy, fast convergence, and wide coverage issues (Tan *et al.*, 2011). For wide coverage issue it also included the scalability for underwater localization scheme, which it should be scalable to cover the sensor node in term of changing the number of node of deployment and the change of deployment area size. Therefore, a new localization scheme should be proposed for UWSN.

1.2 Problem Background

Localization is one of the main tasks that play an important role in many applications, especially for UWSN. Localization is the process of determining the location of on sensor node in the network environment. Besides, localization can help to avoid the received information becomes inconsequential if the original location of the information is unknown. In terrestrial environment, the use of GPS technology is a popular choice in determining the location of sensor nodes. However, in UWSN direct use of GPS technology is limited due to the inability of GPS signals to propagate through underwater.

Based on the limitations, PARADIGM (Austin *et al.*, 2000) and GPS Intelligent Buoys or GIB (Bechaz and Thomas, 2000) have been proposed to detect underwater objects and then obtain the absolute position. These GPS schemes have adopted the use of surface buoys that act as satellites, which are commonly used in GPS technology. All nodes within the communication range of surface buoys will calculate their absolute position based on the estimation distance with surface buoys, which requires at least three beacon messages from the surface buoys. However, these schemes are not suitable to be implemented in the large-scale underwater environment. This is because the surface buoys cannot guarantee that all sensor nodes can receive their beacon message. To make this happen; surface buoys need a large transmission power to ensure that all nodes can receive the beacon message sent. As a result, it will shorten the lifetime of surface buoys, since in most cases buoys are powered by the battery.

Localization scheme based on surface buoys was proposed by Austin *et al.* (2000) where the buoys are moored to the seafloor. This scheme is proposed for small underwater vehicle networks and is used to perceive the absolute position of the underwater vehicle whereby it must communicate directly with surface buoys. This type of communication is called a single-stage reference method (Tan *et al.*, 2011). However, this method is not suitable for large-scale UWSN because it will burden the surface buoys, having to send a beacon messages to all nodes. Therefore, a multi-stage reference method is required to reduce the large power transmission faced by surface buoys.

Zhou *et al.* (2010), had proposed a large-scale localization algorithm that uses multi-stage reference with static anchor nodes. Three types of nodes are involved in this scheme, namely, anchor nodes, surface buoys, and ordinary nodes. The localization processes are split into two phases namely localization of anchor node and localization of ordinary node. For localization of the anchor node, the phase uses the current localization approach such as GPS based. Meanwhile, for the localization of ordinary nodes, it is divided into two types of nodes, namely, reference node and un-localized nodes. In this scheme, the anchor node will communicate directly with surface buoys to obtain a position. Then, the anchor node will send the beacon message to the ordinary node where the ordinary node will estimate their distance based on the received beacon message. When the node is localized, it becomes a reference node by achieving selected criteria; in this case, the confident value. Next, reference node will broadcast the beacon message to localize another ordinary node. This scheme achieves a high coverage and small localization error but its localization performance depends on network density. If node density is low, then the localization error will increase and wastage of beacon message will increase the communication cost. Hence, to expend the localization coverage and localize deep-water sensor nodes, this scheme requires more anchor nodes. To overcome this issue, the use of static anchor will be replaced with a mobile beacon node to cover larger localization area.

Based on the strategy of multi-stage reference, Kulkarni *et al.* (2016) has proposed localization algorith that based on Machine Learning (ML) solution using artificial bee colony in improving the localization accuracy and localization coverage. The algorithm delivers an improvement in localization accuracy for multi-stage reference. However, the result show that the proposed algorithm need a longer time to converge in the large number of sensor node deploy due to the optimisation strategy. Moreover, this research work are not focus for underwater environment. The result show that the proposed algorithm need a longer time to converge in the large number of sensor node deploy due to the optimization strategy. This shows that the use of ML-based algorithm is less suitable for underwater environment because the location information for a sensor needs to be known quickly and involves a large number of nodes. The next underwater multi-stage reference algorithm has been proposed by Islam and Lee (2019b) with the aim to achieve high localization coverage while minimizing the communication overhead. In the proposed algorithm underwater sensor are divided into two type which is reference node and ordinary node. The reference node is assumed as a powerful node with three non-collinear antenna and have higher capabilities in term of computational power communication range and energy. The result show that, the algorithm reduce the communication overhead in overall energy consumption. However, in this research work the deployment of sensor node is consider in two dimensional and the communication between reference node and surface node are communicate directly with high communication range. With this type of communication, the algorithm prune to the estimation error due to long distance estimate.

1.2.1 Accumulative estimation error in Multi-stage localization scheme

Multi-stage localization strategy is used to address the problem of localization coverage for the large-scale area of UWSN. In this strategy, all nodes have been localized to expand the localization coverage. The main challenge faced by this strategy is the decrease of localization accuracy due to the accumulative error. This is because the accumulative error comes from the localization error that exists in the localized node that acts as a reference. The localization accuracy of each node that is localized by the localize reference node will also deteriorate. To improve the distance measurement, Stojkoska (2014) proposed the Improvement Multi-Dimensional Scaling (IMDS) algorithm. The proposed algorithm is based on MDS. The main target of this algorithm is to reduce the distance estimation error between non-neighboring nodes in the network presented by MDS. To achieve this target, this algorithm uses a heuristic approach for distance matrix calculation. In the heuristic approach, the author assumes two possible positions from the far node based on the maximum communication range that lies in the curve of the communication range. Then, the angle information of two assumption position has been used to calculate the distance matrix. The result shows that this algorithm has the ability to reduce the distance estimation error with better accuracy. However, the algorithm required high computation when the number of nodes is increase.

On the other hand, Chen *et al.* (2013) proposed the cluster-based structure of MDS-MAP. This algorithm is based on a traditional MDS-MAP algorithm but rather than using a centralized location algorithm, the algorithm uses a distributed approach by dividing the nodes into the clusters. The main target of this algorithm is to reduce the computational complexity and improve the positioning accuracy and scalability through clustering and the Euclidean algorithm. Futhermore, in this algorithm, the UWSN is divided into several clusters, whereby each cluster is referred to as a local network. Each local network is represented by local CH, which is responsible to calculate the distance between the nodes in the local network. Then, the algorithm introduces the Euclidean Algorithm to generate a more accurate distance of two-hop range than the shortest distance of the traditional MDS-MAP algorithm, resulting in reduced localization error; thereby improving the whole network positioning. The proposed algorithm has the ability to reduce the computational complexity and improve the localization accuracy compared to the traditional MDS-MAP algorithm. However, this algorithm does not cover three-dimensional environments due to the assumption that the UWSN is deployed on the seabed as the two-dimensional sensor networks. This does not reflect on the realistic nature of the underwater environment. Moreover, in cluster construction, these algorithms do not take into account the variable speed of sound for different depths, where it affects the quality of acoustic signal which is a very important element in measuring the distance of a node. This makes this algorithm unsuitable for localizing three-dimensional UWSN. Saeed and Stojkoska (2016) has proposed three dimensional localization algorithm based on Multi-Dimensional Scaling (MDS). The algorithm aim to improve the localization accuracy in MDS based algorithm in 3D environment. The improvement are divide by two part in MDS which is distance matrix calculation using heuristic approach and absolute map refinement using Levenberg-Marquardt (LM) method. The result show that the algorithm reduce the estimation error in position computation. However, this algorithm are not consider to deploy in three dimensional underwater environment which are more challenging in term of mobility and underwater communication parameter that use acoustic signal (sound speed) as communication medium.

Based on variable sound speed, Kim *et al.* (2010) have proposed a scheme named Floating Beacon-assisted 3-D Localization for Variable Sound Speed in UWSN (FBL-VSS). The main target of this algorithm is to tackle the issue of the variable of sound speed in the underwater environment. To handle the variable sound speed in underwater at the different depths, at first, FBL-VSS uses few beacons that have a transmitter on the surface of the water and a receiver on the seabed. Based on the beacons, FBL-VSS computes the actual sound speed from the surface to the seabed. Then, with the speed, a node computes the actual distance to beacons and estimates its position using Multi-Dimensional Scaling (MDS) and linear transformation method. By considering the variable sound speed, the proposed algorithm has stable performance for summer and winter profiles with better accuracy. Nevertheless, this algorithm can only be implemented in shallow water due to high range of beacon transmission between the water surface and the seabed. Moreover, with the high beacon transmission, the localization error will also be affected due to water interference.

Another algorithm has been proposed by Islam and Lee (2019a) for reducing the accumulative error in multi-stage localization scheme, the author has proposed Cluster based localization scheme with partition handling for underwater acoustic sensor network. The aim of the algorithm is to maximize the localization coverage and reduce the communication overhead at a minimum level. In this algorithm, the author use two type of nodes which is GPS-enabled nodes as a reference node and ordinary nodes as node to be localize. As a backup to GPS-enabled node, some extra GPS-enabled node been deploy to react as ordinary node. The node been partition based on the neighbouring information and the cluster head are randomly select based on the higher random value. In this algorithm, CH will initial a request to be localize by the GPS nodes (reference node). if the CH do get a response from the reference node. CH node will increase the communication range to discover the reference node. Once get the response from reference node the value of communication range will be store as reference in retransmission strategy and calculate the range to other node. The result show this algorithm reduce the accumulative error because only GPS-enable node can send the localization beacon and all node are equipped with three non-collinear antenna. Moreover, this algorithm reduce the communication overheads and energy consumption. However, this algorithm required high cost of deployment for large-scale environment due to the used of three non-collinear located antenna for all sensor node and many GPS-enable node to discover the large-scale monitoring area. Most of the existing large-scale localization algorithms focus on mitigating the impact of localization coverage to make sure that all the sensor nodes have been localized. However, most of these algorithms lack a mechanism to ensure that all the sensor nodes received an optimum beacon message for localization process. Additionally, most of these algorithms disregard the characteristics of underwater environment like water pressure, depth, salinity and distance of receiver which affects the strength and quality of acoustic signal in terms of sound speed.

1.2.2 Mobile beacon Path Planning

In large-scale UWSN, localization with a mobile beacon is inherently more accurate than localization using static beacons, because one mobile beacon can play the role of many static beacons and a sensor node can receive the beacon messages from a mobile beacon with a single-hop connection. This advantage, however, does not come for free, but in exchange for increased localization delay. It is because sensors can be localized only when they are in direct contact with the mobile beacons and receive sufficient beacon messages. The trajectories of mobile beacons, thus, have to be properly planned so as to be shortest in length and meanwhile covers every sensor for quick, full, and accurate localization. The problem of path planning for the mobile beacon is to design the trajectory satisfying the following properties; it should pass closely to as many potential node positions as possible, aiming to localize as many unknown nodes as possible (Sichitiu and Ramadurai, 2004), and it should provide each unknown node with at least four non-coplanar beacon points to achieve the unique estimation of unknown nodes position (Sichitiu and Ramadurai, 2004) with the shortest trajectory as possible to save the energy consumption of mobile anchor and time of localization (Li *et al.*, 2008, 2009).

In (Mondal *et al.*, 2015) a dynamic path planning based on the hexagonal movement strategy is proposed for the mobile beacon to provide a cost-effective movement strategy. To achieve the target, this algorithm uses connectivity information of the connected network. In the initial stage, a Mobile anchor randomly moves over the deployment area. Once signal is received from the localized node, the mobile anchor computes the Largest Regular Hexagon (LRH) and draft the path within the communication circle with that point as a vertex. At the same time, all the other vertices of LRH are also computed by the mobile anchor. Then the mobile anchor starts the trajectory by moving along the draft path of LRH and broadcast the beacons message with its current position along with all vertices of the LRH at regular interval. Any sensor that received the beacon message knows the beacon point of LRH that represent as vertex of LRH draft path. At the same time, all the neighbours of the localized sensor mark at least two beacon points which help them to compute two probable positions of themselves according to the scheme. The algorithm has abilities to reduce the requirement of three beacon points for localization to two beacon points. Moreover, the algorithm able to localize all its neighbours with one hexagonal movement around the sensor. However, this algorithm is based on two-dimensional environments and not suitable for the underwater environment due to three-dimensional space in underwater. Furthermore, this algorithm prone to redundant broadcast beacon range due to random movement strategies.

Another dynamic path planning algorithm proposed by Erdemir and Tuncer (2018) that based on search and decide strategy. The author uses Perpendicular Bisector

Strategy (PBS) as a strategy to transmit the non-collinear anchor position and discover all deployment sensor node by allowing the mobile beacon move freely in circular grid. The result show that this algorithm improve the localization coverage with shorter path of mobile beacon in two dimensional environment. However, in this algorithm the mobile beacon prune to revisit the virtual beacon point and overlapping coverage. The revisiting and overlapping issue in sensor node discovery may increase the path length of mobile beacon if this algorithm be implement in three dimensional environment due the search and decide strategy. In underwater mobile path planning, Xu *et al.* (2019) has proposed mobile path planning algorithm that discover regional sensor node for broadcast the beacon message to the targeted area. The algorithm is divide into two stages with is region determination stage and location positioning stage. In region determination stage, the deployment area are divide in sub-region with pentagon shape, the movement of mobile beacon move to the center of pentagon to discover the nearest available sensor. When the nearest sensor is detected, the next stage mobile beacon will move using HILBERT trajectory and broadcast the beacon message or virtual anchor node to cover the detected region sensor node, then continue the discovery path. The result show that this algorithm improve the localization accuracy and reduce the energy consumption. However this algorithm are not considering irregular deployment due to the effect of underwater current. This algorithm will revisit the previous location at least one time when they complete the location positioning stage to continue the discovery process. Therefore, the need of dynamic mobile path planning for underwater wireless sensor network which consider the irregular deployment of sensor due to water current effect for underwater is necessary.

1.3 Problem Statement

This thesis addresses the problem faced by the existing mobile beacon assisted localization scheme for large-scale UWSN in pursuit of providing an accurate position of underwater sensor node which limits the localization accuracy, communication cost, and localization coverage stability. However, the impact of accumulative error is due to multi-stage localization strategies whereby each node that has been localized will help another node to be localized. The localization error of the localized node helps others to localize and affects the location estimation of the next localized node. Subsequently, the overall performance of the localization scheme in terms of localization accuracy will be affected.

In localization with a mobile beacon, the movement of the mobile beacon plays an important role in the deployment of beacons messages for localization process and the deployment influences the performance of localization schemes in terms of localization accuracy. Moreover, the performance of localization will be affected if the deployment beacon message (beacon point) is not non-collinear point and the deployment is too far from the estimation node. To ensure that the transmitted beacon message is not wasteful and useless, mobile beacon needs to identify the pattern of node deployment, which helps the mobile beacon to plan the trajectory and identify the appropriate beacon point for beacon message deployment. Negligence of node deployment information will lead to the ineffective design of a mobile beacon trajectory. Consequently, the performance of the localization scheme will also be affected due to the waste of beacon message (communication overhead) and decrease of localization accuracy.

1.4 Research Questions

Based on the discussion in Section 1.3, the research questions can be formulated as follows:

i) How to improve localization scalability and reducing localization error for non-uniform deployment in large-scale UWSN?

ii) How to improve the mobile beacon path planning in terms of minimizing the number of broadcast beacon and path length for large-scale localization scheme?

iii) How to improve the mobile beacon discovery trajectory towards the depth changes while reducing communication overhead of dynamic mobile path planning?

1.5 Research Goal

The aim of this research is to develop an underwater mobile beacon assisted localization scheme that improves the localization scalability in large-scale UWSN for maximizing the localization coverage and accuracy while minimizing the communication overhead and localization time.

1.6 Research Objectives

The objectives of this research are formulated as follows:-

i) To develop an adaptive cluster-based algorithm for large scale UWSN in reducing the distance estimation error.

ii) To develop an efficient dynamic mobile beacon path planning algorithm for beaconing distribution in UWSN mobile assistant localization scheme.

iii) To develop the hybrid mobile beacon path planning algorithm for reducing the communication overhead while maintaining the localization coverage in large-scale UWSN.

1.7 Research Contributions

Based on the research objectives, the contributions of this research are listed as follows:

i) The Adaptive Underwater Cluster-based (AUC) algorithm based on communication range control for underwater sensor networks to improve localization coverage and reduce the estimation error due to variable speed of sound for an acoustic signal.

ii) The Efficient Dynamic Mobile beacon Path Planning (EDMPP) algorithm to improve the placement virtual beacon point and reduce the communication overhead in the process of beaconing for sensor node localization.

iii) The Hybrid Mobile Path Planning (HybMPP) algorithm to reduce the communication overhead in dynamic mobile path planning for sensor node discovery process in large-scale UWSN.

1.8 Scope of the Research

To achieve the research goals, there are some limitations that must be considered. The scope of this research is as follows:-

i) This research only focuses on the scalability of localization for UWSN.

ii) All resources of the sensor nodes are homogeneous in terms of initial energy, communication range, and communication energy consumption.

iii) All sensor nodes consider the acoustic channels for communication.

iv) Ordinary nodes are randomly deployed in a three-dimensional underwater environment.

1.9 Significance of the Research

Localization, with a high degree of precision, is an essential service for UWSN and demands a significant improvement since it is a critical requirement for different applications and services. Employing a single mobile beacon to assist localization is promising while it is both energy-efficient and cost-effective. The beacon traverses around the network field and transmits its location information to cover the area and help to localize the unknown underwater sensors. However, the main problem is how to find an optimum movement trajectory to benefit from the mobile beacon location information to successfully and precisely localize the unknown sensors. A carefully designed trajectory ensures all unknown sensors are able to receive sufficient, highly precise and non-collinear beacon messages while keeping a shorter time for location estimation. In this thesis, the proposed localization scheme help to provide the unknown underwater sensor nodes with an optimum and efficient position of beacon messages for the sensors to be localized.

1.10 Research Outline

This thesis is divided into seven Chapters which are organized as follows:

Chapter 2 provides an intensive literature review in the area of study. This includes the background, problem and potential solution for wireless sensor node localization in an underwater environment. Furthermore, the recent localization schemes (in large-scale UWSN) with their shortcomings and advantages are also highlighted in this Chapter.

Chapter 3 describes the research methodology, design and experimental setup that have been used to obtain the research objectives. The design, implementation, and verification of the proposed scalable large-scale mobile-beacon assisted localization scheme that is applied in this research are also highlighted in this chapter.

Chapter 4 presents the details of the proposed Adaptive Underwater Cluster-based (AUC) algorithm. This includes the design and implementation for mitigating the localization coverage issue and minimizing the estimation error due to variable speed of sound for an acoustic signal.

Chapter 5 presents the details of the design and implementation of the proposed Efficient Dynamic Mobile beacon Path Planning (EDMPP) algorithm. The EDMPP is developed to improve the placement of the virtual beacon point and reduce the communication overhead on the process of beaconing for sensor node localization.

Chapter 6 presents the detailed description of the design and implementation of the proposed Hybrid Mobile Path Planning (HybMPP) algorithm. This algorithm is developed to tackle the communication overhead for sensor node discovery process in dynamic mobile path planning and improve the localization accuracy for large-scale UWSN.

Chapter 7 summarizes the contribution and achievement of the study. Furthermore, the future work directions for this study are also described in detail in this chapter.

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LIST OF PUBLICATIONS

Indexed Journal (SCOPUS)

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