A REVERSE LOCALIZATION SCHEME FOR UNDERWATER ACOUSTIC SENSOR NETWORKS

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A REVERSE LOCALIZATION SCHEME FOR UNDERWATER ACOUSTIC SENSOR NETWORKS

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requirements for the award of the degree of
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To my husband Javad, for his endless suport, love and encouragement and to my lovely son Barbod, for his patience.

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ABSTRACT

Underwater Wireless Sensor Networks (UWSNs) offer new opportunities to observe and predict the behavior of aquatic environments. A vital service in UWSNs is localization used in many underwater applications such as warning systems for natural disaster, ecological applications and military surveillance. In these applications, the locations of sensors need to be determined for meaningful interpretation of the sensed data. Localization for underwater is challenging as compared to terrestrial because the latter has stabilized in WSNs. In underwater networks, acoustic communication is a typical physical layer technology which has limitations and challenges. Moreover, there is a need for a large amount of sensor nodes to cover wide and deep (three dimensional) oceanographic regions. Consequently, it is essential to develop a localization protocol specifically for Underwater Acoustic Sensor Networks (UASNs). Unfortunately, many of the existing underwater localization schemes suffer limitations such as long localization time, low location accuracy, excessive messaging and limited power. Therefore, the aim of this research is to develop a faster localization scheme for UASN to reduce energy consumption and communication overhead, and to be adaptable to the mobility of water current and location changes. The proposed scheme is named Reverse Localization Scheme (RLS). The developed localization scheme is mathematically compared with seven efficient methods in terms of communication cost. Besides that, the RLS results are compared with the benchmark method Dive'N'Rise Localization using MATLAB. Simulation results showed that the developed scheme achieved faster localization time with the least possible message transfers. In addition, the scheme offers a real time localization and it is less susceptible to errors caused by mobile underwater currents. RLS has been proven to be power-efficient as all parts of the localization computations are computed at the onshore sink.

ABSTRAK

Rangkaian Penderia Tanpa Wayar Dalam Air (RPTWDA) memberi peluang baru untuk mencerap dan meramal keadaan persekitaran akuatik. Satu perkhidmatan penting dalam RPTWDA ialah penyetempatan yang digunakan oleh banyak aplikasi dalam air seperti sistem amaran bencana alam, aplikasi ekologi dan pengawasan ketenteraan. Dalam aplikasi ini, kedudukan penderia perlu ditentukan untuk mendapat tafsiran berguna kepada data yang diperolehi. Penyetempatan dalam air adalah mencabar berbanding dengan daratan kerana penyetempatan daratan dalam RPTW telah mencapai kestabilan. Untuk rangkaian dalam air, komunikasi akustik adalah teknologi lapisan fizikal biasa yang mempunyai keterbatasan dan cabaran. Tambahan pula terdapat keperluan untuk menempatkan bilangan besar nod penderia untuk meliputi kawasan lautan yang luas dan dalam (tiga dimensi). Oleh yang demikian, adalah satu keperluan untuk membangunkan protocol penyetempatan khususnya untuk Rangkaian Penderia Akustik Dalam Air (RPADA). Malangnya kebanyakan skema penyetempatan terbatas dengan masa penyetempatan yang panjang, ketepatan kedudukan yang rendah, mesej yang berlebihan dan had kuasa penderia. Oleh itu, kajian ini bertujuan untuk membangunkan satu skema penyetempatan yang pantas untuk RPADA supaya penggunaan kuasa tenaga dan overhed komunikasi dikurangkan, serta boleh beradaptasi dengan pergerakan arus air dan perubahan kedudukan. Skema yang dicadangkan dikenali sebagai Skema Penyetempatan Balikan (SPB). Skema penyetempatan yang dicadangkan ini dibanding secara matematik dengan tujuh kaedah yang cekap dari segi kos komunikasi. Keputusan SPB dibanding juga dengan kaedah penandaarasan penyetempatan *Dive'N'Rise* menggunakan MATLAB. Hasil simulasi menunjukkan skema yang dicadangkan mencapai masa penyetempatan yang lebih pantas dengan penghantaran mesej yang kurang. Selain daripada itu, skema ini juga memberikan penyetempatan masa nyata dan kurang terdedah kepada ralat disebabkan oleh pergerakan arus air. SPB terbukti cekap-kuasa kerana pengiraan penyetempatan dilakukan di sink pantai.

CHAPTER 1

INTRODUCTION

1.1 General Overview

Sensor networks are becoming common-place for real-time information since they have ability to gather the information from their deployed area during the monitoring task. New achievements in wireless communications brought forth the recent generation of sensors with low cost, low power and multi functional properties. Whereas the sensors enable to communicate in short distances and deployed in large numbers, networking them through wireless links promise a wide range of applications for monitoring homes or controlling cities. Moreover, the wireless networked sensors have enabled opportunities in the defense areas and surveillance as well as other tactical applications (Mao *et al.*, 2007).

A Wireless Sensor Network (WSN) is normally designed based on its special application's objectives and operational environments. It can be classified into five main categories: Terrestrial WSN, Mobile WSN, Underground WSN, Underwater WSN, and Multimedia WSN (Yick *et al.*, 2008).

During the last decades, a growing interest in Underwater Wireless Sensor Network (UWSN) has been observed, while it is integrated with some different challenges. The major challenge in UWSN comes from its propagation medium. There is only one choice for underwater communications which is acoustic link. In fact, radio waves suffer from high attenuation at long distances. On the other hand, optical waves are seriously affected by scattering. Hence, underwater acoustic networking is the enabling technology for the UWSN applications, and it successfully provides some opportunities of ocean environment monitoring such as the life of the ocean animals and target tracking as well as mine recognition. Additionally, the underwater warfare capabilities of the naval forces can benefit from the UASNs. As one of the humanism applications of UASN technology, the Earthquake and tsunami forewarning systems can also be addressed (Erol *et al.*, 2011a).

Localization is a crucial issue in WSN both terrestrial and underwater, while the collected data will be meaningful with corresponding location information. Availability of location information of the gathered data can enhance the capability of the network. The issue also plays a key role in other services such as geographical routing protocols (Isik and Akan, 2009).

1.2 Problem Background and Motivation

A broad spectrum of applications and opportunities in ocean exploration and sampling such as oceanographic data collection, early warning system for natural disasters like tsunami, military underwater surveillance and warfare capabilities are growing interest in Underwater Wireless Sensor Network (UWSN) (Tan *et al.*, 2011).

Localization is known as location estimation of ordinary sensor nodes in a network. Most localization schemes rely on some nodes that their locations are known. These location-aware nodes are known as anchor or beacon nodes (Chandrasekhar and Seah, 2006). There are different methods to prepare location information for the beacons such as placed at fix location or using special hardware like Global Positioning System (GPS) (Erol *et al.*, 2011a). A typical localization process comprises the following steps (Tan *et al.*, 2011), namely range measurement, location estimation, and calibration.

With regard to range measurement, the localization schemes are broadly divided into two main groups, i.e., range-based and range-free. In range-based schemes, precise estimations of distance or angle are made to estimate the location of nodes (Erol *et al.*, 2011a). Different techniques are available to calculate distances to other nodes, e.g., Time of Arrival (TOA), Time Difference of Arrival (TDOA), Angle of Arrival (AOA) or Received Signal Strength Indicator (RSSI). Range-free localization schemes do not use range or bearing information. The location estimation methods are based on connectivity information instead of distance or angle measurements.

In location estimation, two well-known range-based localization techniques include angulation and lateration utilizing bearing and distance information. Range-based methods provide fine-grained location estimation. Range-based localization is a proper choice for underwater environments, while acoustic channels are employed by such an aquatic area. Acoustic channels provide range-measurement much more accurate than radio channels (Cui *et al.*, 2006; Xie *et al.*, 2005). Although range-free schemes are less accurate and achieve only a coarse-grained localization but their simplicity to implement is considerable. Range-free localization techniques are classified into hop count-based and area-based methods (Chandrasekhar and Seah, 2006). In callibration step, the estimated location is further refined via various iterations, measurement error models and mobility models (Tan *et al.*, 2011).

Localization in terrestrial wireless sensor networks (TWSN) is mature enough, while it is still challenging for UWSN due to some major technical differences. Radio waves propagation through conductive water has some various constraints such as the requirement of large antenna and high transmission power which make it infeasible. Optical waves as another propagation media, requires high precision in pointing the narrow laser beam to travel through the water. It also is impossible to implement. So, it is implied that links in underwater environment cannot be substantiate without using acoustic communications (Stojanovic, 2003). Using acoustic communication among UWSN compared to radio links in TWSN presents different challenges and constraints in underwater localization. Employing Global Positioning System (GPS) as the well-known solution for localization is impossible through long distance in water because RF waves are heavily attenuated (Chandrasekhar and Seah, 2006). The acoustic channels are characterized by severely limited bandwidth, high propagation delays and high bit error rates.

Currently, many localization algorithms have been proposed for UWSNs. Erol *et al.* (2011a) surveyed many localization algorithms and classified them into two categories, i.e., distributed and centralized localization algorithms, based on where the location of unknown node is determined. These two categories are further divided into subcategories of estimation-based and prediction-based algorithms. Meanwhile, underwater sensor networks if not anchored, are mobile networks with locations change continuously. Another recent survey paper is proposed by Han *et al.* (2012)

and reclassifies the localization algorithms based on the mobility of sensor nodes. This research has proposed a new localization scheme for mobile underwater acoustic sensor networks.

1.3 Problem Statement

Since acoustic communication is employed as convenient choice for underwater links, the localization schemes suffer from many constraints of acoustic channel. The limited bandwidth and low data rates are two closely related features which put some requirements on designing the localization protocols such as avoiding extensive messaging and huge communication overhead. A practical solution for achieving more data rate is using short-range communications which is required more sensor nodes to attain a certain level of connectivity and coverage. So, the existing small-scale localization schemes are not proper for large-scale UWSNs (Heidemann *et al.*, 2006). In addition, the mobility feature of water currents may create the lower accuracy. Since almost often existing underwater localization techniques achieve low accuracy, highly precise localization is desired for a localization protocol. Beside the stringent resource limitation of underwater wireless sensor networks, high accurate localization scheme is specially challenging. Moreover, the speed of sound is slow (approximately 1500 m/s) yielding large propagation delay. Last, collecting beacons information required for localization is a time consuming process which is most likely the movement of underwater sensor nodes to new places during the collection time.

The statement of the problem can be stated as follows:

The development of a novel localization scheme is essential which avoid excessive overhead and establish localization with minimum number of message exchange and smaller transmitted message size. This is also dictated by the limited battery power of the underwater sensor nodes. High accuracy and fast convergence are desirable properties for the localization scheme.

1.4 Research Questions

The open issues in the previous section leads to investigation of some research questions which are addressed in this research as follows:

(i) How can the scheme be developed to reduce average localization time and achieve a fast localization?

(ii) What are the main factors that contribute to overhead and how the proposed scheme would avoid excessive overhead?

(iii) How can the proposed scheme deal with 3D underwater localization problem?

(iv) How can the method deal with the beacon deployment problem in deep ocean environment?

(v) What are the main factors that contribute to energy consumption?

(vi) How higher accuracy can be achieved in real-time environment?

1.5 Research Aim

The main goal of this study is to design and develop a novel localization scheme for determining the location of an event-triggered sensor in deep water. The developed localization scheme aims to localize sensors with energy efficiently, highly precise and utilizing minimum number of transferred messages. The proposed scheme also aims to establish a fast localization.

1.6 Research Objectives

To achieve the research aims, the following objectives are specified:

(i) To design and develop an event-driven and reverse message transfer mechanism in order to reduce the overhead and improve the average localization time.

(ii) To develop a centralized and projection-based localization algorithm that enable nodes to be localized in an accurate and energy-efficiently manner.

(iii) To test and verify the effectiveness and efficiency of the proposed scheme through simulation.

1.7 Research Scopes

The scopes of this research are defined as follows:

(i) Sensor nodes are to be deployed in deep sea water.

(ii) Beacons are location-aware and deployed on water surface.

(iii) Sink is established above the sea surface.

(iv) Three dimensional deployment is utilized.

(v) Mobility of sensor nodes due to underwater currents is allowed.

(vi) Underwater sensors are synchronized with each other.

(vii) Underwater sensors are equipped with pressure sensor.

1.8 Significance of the Research

Inhomogeneous aquatic environment, harsh mobility of water currents and relative motion of distributed underwater sensor nodes and large network scale, pose several challenges towards developing localization for mobile UWSN. Moreover, various constraints are arisen by employed acoustic channel to fulfill the following desirable properties:

(i) Highly precise

(ii) Fast convergence

(iii) Energy efficiency

(iv) Low communication cost

The purpose of this research is to develop an underwater localization scheme which reduce the energy consumption and communication cost. The developed scheme consists two phases, transmission and localization. The research finding leads to a fast and highly precise localization and improve energy efficiency.

1.9 Research Contributions

The main contribution of this research is the development of an event-driven message transfer mechanism which can significantly reduce the number of transferred messages. The design of the proposed message transfer mechanism is based on the event-driven report. Underwater detector sensors will change their mode from sleep to transmit only if they detect phenomena. So, energy consumption of underwater sensors will be saved. Moreover, the event-driven method establishes a message transfer mechanism with minimum number of transmitted message compared with periodic localizations. Other supportive contribution lies in reverse projection-based localization. In contrast to all existing localization works, the proposed scheme is reverse and underwater detector sensors launch localization process, while it minimizes the negative impact of mobility of water currents and improve a fast localization algorithm. The method is projection-based and geometrical projection of underwater detector sensors' location is completed in sink. Unlike the existing projection-based localization methods, underwater node's location is projected into water surface by sink. The reverse projection-based method helps the scheme to successfully reduce the transmitted message and also energy consumption.

1.10 Thesis Organization

This thesis is organized as follow:

Chapter 1: It presents a general overview on the topic of the study which includes problem background and the issues that require to be considered by introducing statement of problems, the objectives, and the scopes of the research.

Chapter 2: It provides extensive literature review of the research domain and the related available researches are reviewed and discussed to gather the necessary knowledge for developing the research objectives. A survey on underwater localization is proposed and followed by discussion of existing methods is presented along with a comparison table of the algorithms.

Chapter 3: It presents a general overview of research methodology and provides research operational framework flowchart. It discusses problem situation, solution concept and the scheme design used in this research. The overall research methodology plan is described in details. In the end it presents evaluation metrics and simulation setup.

Chapter 4: An overview of the proposed scheme, named RLS, is presented. It also illustrates a target underwater sensor network model. It continues by discussing different phases of the algorithm in details and the mobility model and also employed physical layer. Error analysis of the proposed scheme is also described.

Chapter 5: The main contribution of this research is presented in this chapter. It provides a broad range of mathematical comparison to validate the first objective. It also discusses the results of RLS in terms of defined metrics. Finally in this chapter a comparison with one highlighted method and the new proposed localization scheme in terms of all simulation metrics are presented.

Chapter 6: It concludes the discussion and highlights the achievements of all the objectives. Research questions and their solutions are reviewed while they represent the contributions of this research. In the end, assumptions of the research and future works are listed.

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LIST OF ABBREVIATIONS

2D	–	2-Dimensional
3D	–	3-Dimensional
3D-MALS	–	3 Dimensional Multi-power Area Localization Scheme
3DUL	–	Three Dimensional Underwater localization
AAL	–	AUV-Aided Localization
ALS	–	Area-based Localization Scheme
AOA	–	Angle Of Arrival
ARTL	–	Asymmetrical Round Trip based Localization
AUV	–	Autonomous Underwater Vehicle
BPR	–	Bottom Pressure Recorder
CTD	–	Conductivity, Temperature, Depth
DET	–	Detachable Elevator Transceiver
DNRL	–	Dive’N’Rise Localization
GPS	–	Global Positioning System
LDB	–	Localization with Directional Beacon
MEMS	–	Micro-Electro-Mechanical System
ML	–	Maximum Likelihood
MSL	–	Multi-Stage Localization
QOS	–	Quality Of Service
RF	–	Radio Frequency
RLS	–	Reverse Localization Scheme
RSS	–	Received Signal Strength
RSSI	–	Received Signal Strength Indicator
SLMP	–	Scalable Localization with Mobility Prediction
SNR	–	Signal-to-Noise Ratio
TDOA	–	Time Difference Of Arrival

TOA	–	Time Of Arrival
UASN	–	Underwater Acoustic Sensor Network
UPS	–	Underwater Positioning Scheme
USN	–	Underwater Sensor Network
USP	–	Underwater Sensor Positioning
UTM	–	Universal Transverse Mercator
UUV	–	Unmanned Underwater Vehicle
UWSN	–	Underwater Wireless Sensor Network
WSN	–	Wireless Sensor Network
	–	

LIST OF SYMBOLS

A	–	Anomaly of Acoustic Propagation
Avg_{LS}	–	Average Localization Success
d	–	Distance
e	–	Occured Event
E_{Tx}	–	Energy Consumption for Sending
E_{Rx}	–	Energy Consumption for Receiving
f	–	Frequency
$g(r)$	–	Geometrical Spreading
G_t	–	Transmitting Antenna Gain
G_r	–	Receiving Antenna Gain
I_s	–	Acoustic Intensity at the Source
I	–	Intensity
K	–	Spreading Coefficient
LS_a	–	Lateral Surface Area
N_t	–	Total Number of Sensors
N_L	–	Total Number of Localized Nodes
N_d	–	Total Number of Detector Sensors
P_a	–	Acoustic Power of Source
P_r	–	Received Power
P_t	–	Transmission Power
r	–	Radius of Circular Base of Cone Shape
R	–	Range
S	–	Salinity
T	–	Temperature in Celcius
TL	–	Transmission Loss
T_R	–	Receive Time

T_s	–	Sending Time
v	–	Signal Velocity
z	–	Depth
α	–	Absorption Coefficient
$\alpha(f)$	–	Absorption Loss
δ	–	Time Delay
	–	

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