RECEIVED SIGNAL STRENGTH INDICATION BASED DISTANCE MEASUREMENT USING LAMBERT FUNCTION FOR UNDERWATER WIRELESS SENSOR NETWORK LOCALIZATION

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I dedicate this thesis in honor of my wife, HOMA, and my daughter, YOUKABOD.

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ABSTRACT

Localization issue is a crucial part of Wireless Sensor Networks (WSNs) including Underwater WSNs (UWSNs). Unlike in Terrestrial WSNs where the localization techniques are well established, localization for UWSNs is still at the infancy stage. Most of the existing localizations proposed are based on Time of Arrival (ToA) and many of them assume an ideal environment and precise synchronization among sensor nodes. This research has proposed a new localization technique for UWSN based on Received Signal Strength Indication (RSSI). Extensive study has been carried out on the application of Lambert W function for an accurate distance measurement within five iterations. The technique that utilizes Lambert W function and RSS has been developed. The technique is divided into three separate steps including initialization, distance measurement and position estimation. This new localization technique has a two-level computation approach that allows sensor nodes to have coarse estimations of their locations, while the sink, which has more resources, calculates accurate positions. The new RSS-based localization is compared to ToA-based localization using MATLAB with variety of oceanographic properties considered. The simulation results showed that the new localization technique can achieve far better accuracy in all conditions. Besides, the proposed technique is less susceptible to errors caused by the environment factors as compared to ToA-based methods. It is also power-efficient, as the main part of the localization computations is computed at the sink rather than sensor nodes.

ABSTRAK

Isu penempatan adalah kritikal kepada semua Rangkaian Penderia Tanpa Wayar (RPTW) termasuk Rangkaian Penderia Tanpa Wayar Dalam Air (RPTWDA). Berbeza dengan teknik penempatan RPTW Atas Tanah yang telah banyak dibangunkan, teknik penempatan RPTWDA masih agak baru. Hampir kesemua teknik yang dicadangkan adalah berdasarkan teknik Masa-Tiba (MT) dan kebanyakannya pula mengandaikan persekitaran ideal dan ketepatan kesegerakan nod deria. Penyelidikan ini mencadangkan satu teknik penempatan baru berdasarkan Petunjuk Kekuatan Isyarat Terima (PKIT). Kajian terperinci telah dijalankan dengan mengaplikasikan fungsi W Lambert untuk pengukuran jarak yang tepat dengan lima iterasi. Teknik ini yang menggunakan fungsi W Lambert dan teknik MT telah dibangunkan. Teknik ini melibatkan tiga langkah berbeza termasuk penilaiawalan, pengukuran jarak dan penganggaran kedudukan. Teknik penempatan baru ini menggunakan pendekatan pengiraan dua peringkat yang membolehkan pengukuran kasar dilakukan di nod deria sementara kedudukan yang tepat dikira di sinki yang mempunyai sumber yang lebih. Teknik penempatan PKIT baru ini telah dibandingkan dengan MT menggunakan MATLAB dengan mempertimbangkan pelbagai sifat air lautan. Hasil simulasi menunjukkan teknik penempatan baru ini telah mencapai ketepatan yang jauh lebih baik dalam pelbagai keadaan berbanding dengan kaedah berdasarkan MT. Teknik yang dicadangkan ini juga mempunyai kuasa yang cekap, kerana sebahagian besar pengiraan dilaksanakan di sinki dan bukan di nod deria.

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LIST OF ABBREVIATIONS

2D	-	2 Dimensional
3D	-	3 Dimensional
ALS	-	Area Location Scheme
AM	-	Ainslie and McColm
AoA	-	Angle of Arrival
AUV	-	Autonomous Underwater Vehicle
CPBL	-	Centroid-based Preplaced Beacon Localization
CRB	-	Cramer Rao Bound
CSNL	-	Centroid-based Scalable Node Localization
DET	-	Detachable Elavator Transceiver
DNR	-	Dive aNd Rise
DSML	-	Dual Merit Signal of Localization
DV-Hop	-	Distance Vector-Hop
DV-Loc	-	Distributed Voronoi Localization
FG	-	Francois and Garisson
GPS	-	Global Positioning System
LaMSM	-	Localization Algorithm with Merging Segmented Maps
LOS	-	Line-Of-Sight
MCL	-	Monte Carlo Localization
MDS	-	Multi Dimensional Scaling
MLE	-	Maximum Likelihood Estimation
MMSE	-	Minimum Mean Square Error
MWSN	-	Mobile Wireless Sensor Network

MMWSN	-	MultiMedia Wireless Sensor Network
NNSS	-	Nearest Neighbor in Signal Space
RBF	-	Radial Basis Function
ppt	-	part per thousand
RF	-	Radio Frequency
RSSI	-	Received Signal Strength Indication
TDoA	-	Time Difference of Arrival
TL	-	Transmission Loss
ToA	-	Time of Arrival
TWSN	-	Terrestrial Wireless Sensor Network
UGWSN	-	UnderGround Wireless Sensor Network
UUV	-	Unmanned Underwater Vehicle
UWSN	-	Underwater Wireless Sensor Network
WAF	-	Wall Attenuation Factor
WCL	-	Weighted Centroid Localization
WSN	-	Wireless Sensor Network

LIST OF SYMBOLS

R	-	Range (distance)
α	-	Attenuation absorption coefficient
f	-	Frequency
TL	-	Transmission loss
C	-	Velocity
θ	-	Temperature in Kelvin
T	-	Temperature in Celsius
S	-	Salinity
D	-	Depth
pH	-	Acidity
z	-	Complex number
W	-	Lambert Weight function
$Dist$	-	Distance
C	-	Complex numbers set
R	-	Real numbers set

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CHAPTER 1

INTRODUCTION

Nowadays, Wireless Sensor Networks (WSNs) and their applications have caught the interest of many researchers. The significance of the state-of-the-art sensors are manifested more by their wonderful and crucial applications. The applications allow users to monitor, track, and observe variety of objects and phenomena in different environments. Habitat monitoring, animals movement tracking, health monitoring, environment exploration, and natural disaster prediction, are examples of such applications. Many of these applications were not implementable, or environments were not accessible for human before the development of this new technology. A WSN is normally designed based on its especial 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). However, the sensor node has its own specifications and resource constraints including unreplenished energy supply, limited communication range, low bandwidth, and limited processing ability and storage. Typically, there are two types of sensor nodes available in the market - generic sensor, and gateway (bridge) nodes (Yick *et al.*, 2008). The generic sensor could have different measurement abilities to detect phenomenon in different environment but their resources are limited. The gateway has higher capabilities and act like an access-point to relay the received information from generic nodes to a server or an end-user.

In sensor networks, the network topology can be either structured or unstructured. Furthermore, the operational field is considered to be large in terms of size and the number of sensors that work in an ad-hoc manner. Therefore, designing proper protocols for WSN is a critically challenging task when the deployment is random, the field is large, the nodes communicate in ad-hoc manner, and considering the existing sensor nodes constraints. Among different protocols in WSN and apart from sensor constraints, environments, and applications; there is a unique trans-prerequisite requirement for all WSN applications which is the origin of information. It is essential in sensor networks to be aware about the location of information, otherwise knowing about phenomenon without location-knowledge is less meaningful. The procedure to find the location of sensor, which has emitted the signal, is called localization.

As the localization is vital in WSNs, numerous efforts are taken to develop a general and efficient localization techniques. Nodes have distinct definitions within localization techniques- generic sensors, beacon nodes, and sink nodes. Besides, there are manipulated variety of techniques to derive location information. According to the sensor constraints, it is accepted that all designed position estimation schemes must keep the costs as low as possible, however, there are always some exceptions.

Localization techniques have been extensively investigated for Terrestrial WSNs. Among the WSN categories, Terrestrial WSN has a common property with Multimedia WSN, Mobile WSN, and Underground WSN (inside caves and mines); i.e. the communication medium is the air. In contrast to such networks, Underwater WSN uses the water as communication medium, thus, yields a fundamental challenge.

1.1 Background and Motivation

Wireless Sensor Network has expanded a range of novel vital applications, however, it has its own unique challenges. In such network, the data represents a phenomenon like pressure, temperature, and pollution. It can be collected from operational terrain where the scale of the terrain could be large. Thus, it is crucial to know where the phenomenon has occurred. Obviously, the information is more meaningful when the location-knowledge is available. The procedure of position estimation is called localization in wireless sensor network.

However, localization is matured in cellular networks as well as robotics, but it is a challenging and complicated task in WSNs (Sun *et al.*, 2005). Additionally, mobile phones and robots in their respected area are more powerful and flexible than sensor nodes because the power is rechargeable, size is immaterial compared to sensors, and processing ability is much higher. As mentioned in last section, Terrestrial WSN protocols are widely investigated as well as localization is being extensively studied. Recently, Underwater WSNs get more attentions from researchers due to their applications. Underwater environment is less accessible and it is unexplored especially in deep water. Therefore, location-knowledge could be more crucial in such networks as compared to Terrestrials. There are some fundamental differences between terrestrial and underwater networks that makes the underwater study inevitable even though there is possibility to extend the terrestrial techniques to the underwater. So it is necessary to review the existing works in both categories.

There are two important issues in sensor localization - accuracy and cost. The considerations are how accurate the location information is required for a particular application and what the cost of getting such accurate location information is. The costs in sensor network can be considered as sensor size, price, processing, and power consumption. The accuracy directly affect on the localization cost. Based on granularity of location information, Bulusu *et al.* (2000) defines two different localization categories including fine-grained and coarse-grained. The fine-grained techniques use range measurement metrics which are more accurate, of course with higher cost. Range measurement metrics consist of: Time of Arrival (ToA), Time Difference of Arrival (TDoA), Angle of Arrival (AoA), and Received Signal Strength

Indication (RSSI). However, these metrics are matured enough in signal processing field, but they are mostly challenging in sensor networks. Despite the high accuracy, ToA and TDoA are highly dependent on precise synchronization among nodes. AoA demands special antenna arrays which are very costly for sensor networks and furthermore needs a distance measurement technique (typically TDoA is used). RSSI is the only solution that does not need any extra hardware (Bahl and Padmanabhan, 2000) and processing ability but vulnerable to environment noises like reflections and interferences. On the other hand, when precise accuracy is not needed, there are few well-known methods such as connectivity and hop-counting that can provide a coarse-grained estimation. They rely on existing resources of sensor nodes and normally the schemes are low-cost and power-efficient. Applications such as disaster prevention and environment monitoring that do not need precise location can employ this type of low-cost techniques. During the last few years, numerous efforts have been done to develop efficient localization techniques either low-cost with a coarse estimation or precise but costly mechanisms. However, the main barriers are the sensor network characteristics which are variable and they are typically dependent on the environments and application objectives.

As mentioned above, most techniques in localization studies focus on terrestrial WSN. This could be understood based on several reasons such the number of feasible applications, possibility of commercialization, and easy access to variety of simulators and real equipments for experimental and evaluation. Recently, the significance of Aquatic or Underwater WSN applications has attracted the attention of many researchers. It is believed that remote sensing for coastal management and surveillance tasks, or ocean monitoring for disaster prevention and recovery applications can be supported by deployment of underwater sensor networks (Garcia, 2007). In the presence of numerous literatures and while many of terrestrial protocols may be applicable in Underwater WSN, the aquatic environment must be researched carefully because of three fundamental differences (Heidemann *et al.*, 2006) which are:

(i) Radio is not suitable for aquatic communication because of highly limited propagation (50 - 100 cm (Heidemann *et al.*, 2006)).

(ii) The shift from radio frequency (RF) to acoustics change the physics of communication from speed of light ($3x10^8$m/s) to the sound velocity ($1.5x10^3$m/s).

(iii) Energy consumption of Underwater WSN will be different from the Terrestrial WSN because the sensors will be larger and some applications require large amounts of data at irregular interval (once per week or less).

Therefore, the promising transmission media in the water is the acoustic wave. Due to slow propagation speed of acoustic wave in sea water compared to RF, the existing localization techniques are mostly inclined to use time-based methods particularly Time of Arrival. However, they are highly dependent on synchronization. Furthermore, the inhomogeneity of sea water causes sound velocity variation which is significant in terms of time based methods. In such conditions, synchronization is very challenging in underwater networks. AoA metric may not be good choice as it requires special expensive devices like antenna arrays, besides the technique needs another distance measurement metric like ToA or TDoA. Ironically, the existing works are based on many assumptions that make them less practical. Assumptions like ideal environment and constant velocity. Since RSSI is not considered as a possible solution for UWSN, this research has developed a RSSI-based localization algorithm as a new measurement metric to solve UWSN localization problem.

1.2 Problem Statement

Although the WSN is a specific application, localization requirement is considered a general need. Despite the fact that many localization techniques in Terrestrial WSN are available, localization for Underwater WSN is still at its infancy. For Terrestrial WSN, medium of signal transmission is the air, while for Underwater WSN the medium is water. Regarding underwater WSN localization, time base distance measurement techniques are widely used while the methods are vulnerable to synchronization errors. Moreover, adapting the existing RSSI-based localization techniques directly would be inappropriate due to three fundamental differences and affective parameters mentioned in Section 1.1.

The statement of the problem can be stated as follows:

"The existing localization techniques for UWSNs are less effective, less accurate, and power hungry. A new localization that utilizes more appropriate technique coupled with more efficient calculation strategy is needed."

Therefore, an algorithm that can extend network lifetime is needed to reduce power consumption of nodes. Furthermore, accurate distance measurement model based on received signal strength is needed to produce accurate localization.

1.3 Research Goal

The main goal of this research is to develop an efficient underwater localization scheme for determining the location of a sensor in deep water. The designed localization scheme is based on Received Signal Strength Indication of acoustic wave. The calculation strategy uses the highly efficient Lambert W function. The desired characteristics of the scheme are: accurate and energy efficient.

1.4 Research Objectives

To fulfill the research goals, the following objectives are specified:

(i) To develop a signal-strength-based distance measurement technique using Lambert function for Underwater WSN which can estimate the distance accurately.

(ii) To develop a localization algorithm for Underwater WSN that enable nodes to be localized in an accurate and energy-efficiently manner.

(iii) To test and verify the effectiveness and the efficiency of the proposed method using simulation.

1.5 Research Scopes

The scopes of this research were defined as follows:

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

(ii) Beacons are location-aware

(iii) Number of beacons are set to four

(iv) Sink is established above the sea surface

(v) Signal strength is measurable by sensors

(vi) Two dimensional architecture is installed

(vii) Sensor nodes are static

(viii) Underwater current is not considered

1.6 Significance of the Research

The purpose of this research is to develop an accurate and energy efficient aquatic localization scheme through the signal ranging parameters. The development of accurate positioning method is based on the Received Signal Strength Indication modeling concept. Accuracy is a crucial property within Underwater WSN applications like offshore-engineering and construction activities because the environment is not accessible and observable. Furthermore, the state-of-the-art sensors appear as promising technology to reduce the cost of such networks. The main advantage of this method is that there is no need to install any extra hardware and it uses the available resources of the sensor node. To obtain the energy efficiency, a new localization algorithm is developed that fulfills the localization in three separate steps including initialization, distance calculation, and position estimation. In initialization, sensor nodes store received signal strength of beacons. Sensors send those information back to sink where the distances are measured. Finally, the sink calculates the position of sensors utilizing the efficient method of Lambert W function. The developed localization helps sensor nodes to have a coarse location estimation and it extracts the accurate position by using the sink as a powerful node. This algorithm uses two-level computational approach as it employes both distributed and centralized calculations. This research is created a general adaptive scheme regarding the changes of affective aquatic parameters.

1.7 Thesis Organization

The organization of this thesis is as follow: Chapter 1 presents a general discussion on the topic of the thesis and the issues that need to be solved by introducing statement of problems, set of objectives, and the scopes of research. The related available literatures are reviewed and discussed to achieve the necessary knowledge for developing the research objectives is in Chapter 2. Chapter 3 discusses the research methodology that is employed to achieve the objectives of this research. The developed RSS-based measurement and localization algorithm are presented in Chapter 4. This chapter also discusses simulation techniques in details. Chapter 5 represents simulation results along with a comprehensive analysis over the results. Finally, this thesis is concluded by highlighting the contributions of this work and introducing the possible future works.