THE PERFORMANCE OF DIRECTIONAL FLOODING ROUTING PROTOCOL FOR UNDERWATER SENSOR NETWORKS

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A special dedication to:

“My father, my mother”

IDRUS BIN HANAPIAH & NORLIDA BINTI JAFAR

“My beloved siblings”

MUHAMMAD IZZUL AKMAL BIN IDRUS

NUR ANIS NADHIRA BINTI IDRUS

And

All my beloved friends,

Thank you for giving me support and chance to be what I can be. Finally, this thesis is dedicated to all those who believe in the richness of learning.

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ABSTRACT

The specific characteristic of underwater environment introduces new challenges for the networking protocols. Underwater Wireless Sensor Networks (UWSN) and terrestrial Wireless Sensor Networks (WSN) share some common properties but their differences too. These differences necessitate specialized new protocols for successful underwater communication. In this thesis, a specialized architecture for underwater sensor networks (UWSNs) is proposed and evaluated. Simulation experiments have been carrying out to analyze the suitability of various protocols for the sub aquatic transmission medium, whether in freshwater or seawater. Additionally various scheduling techniques maybe applied to the architecture in order to study their performances. Furthermore, for a given the harsh conditions of the underwater medium, different retransmission methods are combined with the scheduling techniques. The goal of this thesis is to produce simulation results that would illustrate the performances of the proposed protocol for a given metric such as end-to-end delay, packet delivery ratio and energy consumption. From the results, some protocols can be very suitable for the underwater medium.

ABSTRAK

Ciri-ciri khusus persekitaran dalam air menghasilkan permasalahan baru bagi protokol rangkaian. Rangkaian pengesan wayarles dalam air (UWSN) dan rangkaian pengesan wayarles di daratan (WSN) berkongsi beberapa ciri-ciri yang sama tetapi memerlukan beberapa perbezaan protokol baru juga yang khusus untuk komunikasi dalam air. Dalam tesis ini, seni bina khusus untuk rangkaian pengesan wayarles dalam air (UWSNs) dicadangkan dan dinilai. Eksperimen simulasi telah dijalankan untuk dianalisis mengikut kesesuaian pelbagai protokol sebagai media penghantaran air kecil, sama ada di air tawar atau air laut. Selain itu pelbagai teknik penjadualan mungkin digunakan untuk seni bina bagi mempelajari persembahan yang diperoleh. Tambahan pula, suatu keadaan yang teruk sederhana di dalam air, kaedah penghantaran semula yang berlainan digabungkan dengan teknik penjadualan. Matlamat projek ini adalah untuk menghasilkan hasil simulasi yang akan menggambarkan prestasi protokol yang dicadangkan untuk metrik tertentu seperti penundaan dari hujung ke hujung, nisbah penghantaran paket dan penggunaan tenaga. Dari hasil yang diperoleh, beberapa protokol boleh menjadi sangat sesuai untuk medium air.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

f	-	Frequency
%	-	Percentage
°C	-	Degree Celsius
a	-	Frequency-dependent parameter
A_n	-	The coefficients
B(OH)3	-	Boric acid
d_A	-	Sender's depth
dB	-	Decibels
d_B	-	Receiver's depth
$e()$	-	Signal loss due to random noise or error
$E()$	-	The function of wave effects in nodes
$h(s)$	-	The scale factor function
h_w	-	The wave height in meters
k	-	The spreading factor
Kbps	-	Kilo bit per seconds
kHz	-	Kilo Hertz
km	-	Kilometers
kW	-	Kilo Watt
l_w	-	The ocean wavelength in meters
m	-	Meters
$m(f, s, d_A, d_B)$	-	The propagation loss without random and periodic
m/s	-	Mile per seconds

$MgSO_4$	-	Magnesium sulphate
MHz	-	Mega Hertz
pH	-	Potential of hydrogen
$PL(t)$	-	The propagation loss from node A to B
R_N	-	The random number from a Gaussian distribution
S	-	Euclidean distance between nodes A and B
T_w	-	The wave period in seconds
$w(t)$	-	Periodic function to approximate signal due to wave
α	-	The absorption coefficient factor
2D	-	Two dimension architecture
3D	-	Three dimension architecture
DBR	-	Depth Based Routing
DFR	-	Directional Flooding Based Routing
EM	-	Electromagnetic wave
EUROP	-	Energy Efficient Routing Protocol
FBR	-	Focused Beam Routing
H^2-DAB	-	Hop-by-hop Dynamic Addressing Based Routing
HH-VBF	-	Hop-by-hop vector based forwarding
HTML	-	Hyper Text Markup Language
IDE	-	Integrated Development Environment
MAC	-	Medium Access Control
MMPE	-	Monterrey Miami Parabolic Equation
NED	-	Network Description Language
OMNeT++	-	Objective Modular Network Testbed in C++
OSI	-	Open Systems Interconnection
PSU	-	Practical Salinity Unit
RREP	-	Route Request
RREQ	-	Route Reply
RTS	-	Request to Send
TKENV	-	The graphical runtime environment
UWSNs	-	Underwater Wireless Sensor Networks
VBF	-	Vector Based Forwarding

LIST OF APPENDICES

LIST OF PUBLICATIONS

Proceedings:

(i) Nur Asfarina Idrus, Jiwa Abdullah (2014) "Performance of Routing Protocol for Underwater Sensor Networks." The 5th International Conference on Underwater System Technology: Theory and Applications (USYS 2014), pp. 80-87, City Bayview Hotel Melaka, 3rd – 4th December 2014.

CHAPTER 1

INTRODUCTION

1.1 Background and History

Wireless sensor networks became popular research area at the end of 20^{th} century and covers only terrestrial applications. The deep oceans are harsh environments for human to explore and the existing sensing technologies do not meet the need for easy deployable low cost equipments. The underwater world has always fascinated human beings and almost two third of the Earth is covered by the largely unexplored vastness of the seas and has attracted human's attention.

The traditional approach to ocean monitoring is to deploy oceanographic sensors, record the data, and recover the instruments which spend lots of time receiving the recorded information. Additionally, if failure occurs before recovery, all the data would be lost. The ideal solution is to establish real-time communication between the underwater instruments and a control center within a network configuration (Sozer, Stojanovic et al. 2000, Xiao 2009). Also, the concept of an ad-hoc and sensor networks for underwater is very attractive, because it can be helpful and easily extend the range of current acoustic modems. It also offers distributed communications with less deployment time.

Underwater sensor networks have many potential applications including oceanographic data collection, oil and gas spills monitoring, offshore exploration, disaster prevention, submarine detection, assisted navigation and tactical surveillance applications (Akyildiz, Pompili et al. 2004). There are still difficulties needed to be researched and solved. The development of Underwater Wireless Sensor Networks (UWSNs) has never been more interesting than in the last few years. Here, we attempt to analyze behaviour of UWSN based on the technology developed during the last decade in terrestrial wireless sensor networks (TWSNs). Although it has a very similar functionality, UWSNs exhibit several architectural differences with respect to the terrestrial ones, which are mainly due to the characteristic of transmission medium (seawater) and the signal employed to transmit the data, which is the acoustic ultrasound signals (Akyildiz, Pompili et al. 2007).

The underwater acoustic channel differs from radio channels in many aspects. The available bandwidth of the underwater acoustic channel is limited and also dependent on both range and frequency. In acoustic communications, shorter links have access to a wider bandwidth due to the specific features of acoustic propagation and noise. The sensors are battery powered so power efficiency is a critical issue for underwater sensor networks as well. In addition, extremely long delay in the underwater acoustic channel could lead to collapse of traditional terrestrial routing protocols because of limited response waiting time. According to circumstances, designing a suitable network routing protocol in underwater environment is urgent. Sensor nodes with wireless communication can be deployed under the sea level. The sensors detect and transfer the data from the bottom level to the top level (Chun-Hao and Kuo-Feng 2008).

1.2 Motivation/Problem Statements of the Study

The specific characteristics of underwater environments introduce new challenges for networking protocols. First, radio waves are strongly attenuated in salt water using acoustic. The speed of sound underwater is lower than the speed of light and it severely limited bandwidth. Second, the channel it is severely impaired either multipath or fading. Third, long and variable propagation delays problems. Fourth, High bit error rates and temporary losses of communication links. Lastly, underwater sensors are prone to failures because of fouling and corrosion.

1.3 Aim of the Study

The aims of this study are examine specialized a protocol and architecture for Underwater Wireless Sensor Networks (UWSNs). Study aims are typically identified in relation between performance achievements of the protocol in end-to-end delay, packet delivery ratio and energy consumption can be suitable for the underwater medium.

1.4 Objectives of the Study

The objectives of the study are:

(i) Investigate the architecture and performances of routing protocol for UWSN.

(ii) Analyze the suitability of the protocol for the sub aquatic transmission medium in fresh water or seawater.

(iii) Evaluate the performances of the protocol by considering the following metric; end-to-end delay, packet delivery ratio and energy consumption.

1.5 Scope and Limitations of the Study

The study examines the designing underwater wireless sensor networks with suitable underwater medium, propagation delay and the network architecture. OMNeT++ software will be used to run the simulation process according to suitable parameter of underwater environment. However, flooding based routing protocol will be used as a baseline results to understand the performance in terms of end-to-end delay, packet delivery ratio and energy consumption throughout simulation process. The DFR protocol is proposed in different scenarios to the baseline performance.

1.6 Outlines of the thesis

The outlines of this thesis are organized as follows:

Chapter 1: This chapter covers the background and history of underwater wireless sensor networks, motivation or problem statements, aims, objectives, scope and limitations and outlines of the thesis.

Chapter 2: This chapter deals with review related literature of others research or previous studies which conclude theoretical and results. It also clarified, justified and compared to results based on related research.

Chapter 3: In this chapter comprises the methodology or approaches in order to achieve the aims of the study. It shows procedure or protocols used in completion of this study.

Chapter 4: The simulation implementation and setup are described in this chapter. Metrics and parameters are also discussed and explained during simulation process.

Chapter 5: Results and data analysis are addressed through simulation using OMNeT++. Simulation output and the results of comparative study are shown and explained in this chapter.

Chapter 6: Finally, all results and conclusions will be summarized and the chapter is concluded with contributions, significant of findings and the recommendations for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides a survey of an existing routing protocol that is used for underwater sensor networks. The surveys include the basic underwater sensor network theory, the comparison between terrestrial and UWSN characteristics, propagation model and suitable network architecture. The surveys then focus to the various routing protocols, metrics and their performances. Comparative analysis are done base on various metrics such as the packet delivery ratio, end-to-end delay and energy consumption. The rest of the chapter is organized as follows. Section 2.2 describes underwater wireless sensor networks theory. Section 2.3 outlines the description of previous research. Section 2.4 provides a brief performance metrics of the existing protocols. The chapter is summarized in section 2.5.

2.2 Underwater Wireless Sensor Networks Theory

The UWSNs is densely populated sensor nodes, the key characteristic of which is that the nodes are strictly in the water be it fresh water or sea water. These networks can generally be classified into two categories depending on the type of applications: (1) UWSNs for long term non-time critical aquatic monitoring applications; (2) UWSNs for short-term time critical aquatic exploration applications. The former category of UWSNs can be either mobile or static depending on the deployment of sensor nodes (buoyancy controlled or fixed at sea floor) (Jun-Hong, Jiejun et al. 2006). The later usually mobile since the cost of deploying or recovering fixed sensor nodes is typically prohibitive for short term time critical applications (Lanbo, Shengli et al. 2008). Obviously, different types of UWSNs have different communication requirements as summarized in Table 2.1.

Table 2.1: Communication requirements of UWSNs (Lanbo, Shengli et al. 2008)

Requirements	M-LT-UWSNs	S-LT-UWSNs	M-ST-UWSNs
Data rate	Various	Various	Various
Transmission Range	Short (10m – 1km)	Short (10m – 1km)	Short (10m – 1km)
Deployment Depth	Shallow water	Shallow or Deep	Shallow water
Energy efficiency	Major concern	Major concern	Minor concern
Antenna size	Small	Small	Small
Real-time Delivery	Minor Concern	Minor Concern	Major Concern

Underwater sensor networks consist of a group of sensor nodes anchored to the sea bed that are acoustically connected together and to other underwater gateways through clustering or cell. Clusters contain sensors and sinks where sensors are connected to sinks within each cluster. These connections may be multiple hops or direct paths. The signals shared at each sink within a cluster are transmitted to the surface stations through a vertical link. The surface station will handle multiple parallel communications with the sinks deployed underwater by acoustic transceivers (Thumpi.R 2013).

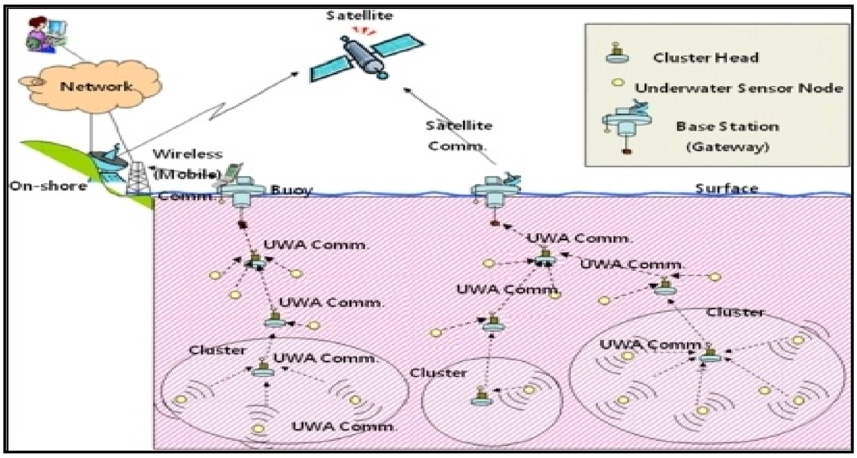

Figure 2.1: Cluster-based underwater acoustic sensor network model (Kim and Park 2011)

2.2.1 Different between terrestrial and underwater wireless sensor networks

Most of the research in wireless sensor networks has been done for terrestrial applications. But in last several years, an underwater sensor network has found an increasing use in a wide range of networks. Table 2.2 is shown the comparison between both applications.

Table 2.2: Comparison between terrestrial and UWSNs (Ayaz, Baig et al. 2011) (Kheirabadi and Mohamad 2013)

Terrestrial Wireless Sensor Networks	Underwater Wireless Sensor Networks
Dense deployment due to cheap node price and small area which affects the network performance.	Sparse deployment due to expensive underwater equipments and vast area (Akyildiz, Pompili et al. 2004) (Thumpi.R 2013).
Node movement almost fixed (Jun-Hong, Jiejun et al. 2006).	Nodes moves 1-3m/s by water currents (Jun-Hong, Jiejun et al. 2006).
A network with static nodes considered more stable especially in terms of communication links.	Routing messages from or to moving nodes is more challenging not only in terms of route optimization but also link stability becomes an important issue.
More reliable due to a more matured understanding of the wireless link conditions.	Reliability is a major concern due to inhospitable conditions. Communication links face high bit error rate and seldom temporary losses.
Nodes are moving in 2D space even when deploy as ad hoc and as mobile sensor networks.	Nodes can move in a 3D volume without following any mobility pattern.
The destination is fixed and seldom changes its location but still these movements are predefined.	Sinks or destinations are placed on water surface and move with water current due to random water movement, predefined paths are difficult.
Deployment affects the performance of the network. Generally, deployment is deterministic as nodes are placed manually so data routed through pre-determined paths.	Non-uniform and random deployment is common with more self-configuring and self-organizing routing protocols are required to handle non-uniform deployment.
Nodes are assumed to be homogenous throughput the network which these types provide better efficiency in most of the circumstances.	Heterogeneous network is common where it set of sensor nodes raises multiple technical issues related to data routing.

Table 2.2 (continued): Comparison between terrestrial and UWSNs (Ayaz, Baig et al. 2011) (Kheirabadi and Mohamad 2013)

Terrestrial Wireless Sensor Networks	Underwater Wireless Sensor Networks
Radio waves are available by means nodes can communicate with low propagation delays at speed of light ($3\ x\ 10^8$m/s).	Acoustic waves replace radio waves (speed $1.5x10^3$m/s). Communication speed is decreased from speed of light to speed of sound, results in high propagation delays (five orders of magnitude). It can be problematic for real time applications.
High data rate (MHz)	Low data rate (kHz) exceeds 40kbps at 1 km distance. Moreover, the attenuation of acoustic signal increases with frequency and range (Ayaz and Abdullah 2009).
Increased number of hops during the routing process.	Number of hops depends on depth of the monitoring are normally 4 until 7 hops.
Low energy consumption.	High energy consumption due to longer distances (consequence of sparse nodes deployment) and complex signal processing. The power required to transmit may decay with powers greater than two of the distance.
Large batteries can be used and can be replaced or recharged with ease.	Battery power is limited and usually cannot be easily replaced or recharged. The routing protocols should adopt a mechanism of power down during the communication and use minimum retransmission.
Nodes are less error prone and can continue to work for longer time.	Nodes are more error prone and can die due to fouling or corrosion or leave the working area. More reliable and self recovering routing algorithms are required.

2.2.2 Propagation Model

Propagation of acoustic waves in the frequency range of interest for communication can be described in several stages. The basic stage takes into account this fundamental loss that occurs over a transmission distance. Next, the site specific loss due to surface bottom reflections and refraction that occurs as sound speed changes with depth, and provides a more detailed prediction of the acoustic field around a given transmitter. Last stage addresses the acoustic wave speed in underwater condition as average of 1500m/s, which is 5 times slower than in air over some local

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