THE PERFORMANCE OF DIRECTIONAL FLOODING ROUTING PROTOCOL FOR UNDERWATER SENSOR NETWORKS

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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.
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LIST OF SYMBOLS AND ABBREVIATIONS

\( f \) - Frequency
\( \% \) - Percentage
\( ^\circ C \) - Degree Celsius
\( a \) - Frequency-dependent parameter
\( A_n \) - The coefficients
\( \text{B(OH)}_3 \) - Boric acid
\( d_A \) - Sender’s depth
\( \text{dB} \) - 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
\( \text{Kbps} \) - Kilo bit per seconds
\( \text{kHz} \) - Kilo Hertz
\( \text{km} \) - Kilometers
\( \text{kW} \) - 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
\( \text{m/s} \) - Mile per seconds
MgSO4 - Magnesium sulphate

MHz - Mega Hertz

pH - Potential of hydrogen

PL(t) - The propagation loss from node A to B

RN - The random number from a Gaussian distribution

S - Euclidean distance between nodes A and B

Tw - 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

H²-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
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CHAPTER 1

INTRODUCTION

1.1 Background and History

Wireless sensor networks became popular research area at the end of 20th 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)

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

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)

<table>
<thead>
<tr>
<th>Terrestrial Wireless Sensor Networks</th>
<th>Underwater Wireless Sensor Networks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense deployment due to cheap node price and small area which affects the network performance.</td>
<td>Sparse deployment due to expensive underwater equipments and vast area (Akyildiz, Pompili et al. 2004) (Thumpi.R 2013).</td>
</tr>
<tr>
<td>Node movement almost fixed (Jun-Hong, Jiejun et al. 2006).</td>
<td>Nodes moves 1-3m/s by water currents (Jun-Hong, Jiejun et al. 2006).</td>
</tr>
<tr>
<td>A network with static nodes considered more stable especially in terms of communication links.</td>
<td>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.</td>
</tr>
<tr>
<td>More reliable due to a more matured understanding of the wireless link conditions.</td>
<td>Reliability is a major concern due to inhospitable conditions. Communication links face high bit error rate and seldom temporary losses.</td>
</tr>
<tr>
<td>Nodes are moving in 2D space even when deploy as ad hoc and as mobile sensor networks.</td>
<td>Nodes can move in a 3D volume without following any mobility pattern.</td>
</tr>
<tr>
<td>The destination is fixed and seldom changes its location but still these movements are predefined.</td>
<td>Sinks or destinations are placed on water surface and move with water current due to random water movement, predefined paths are difficult.</td>
</tr>
<tr>
<td>Deployment affects the performance of the network. Generally, deployment is deterministic as nodes are placed manually so data routed through pre-determined paths.</td>
<td>Non-uniform and random deployment is common with more self-configuring and self-organizing routing protocols are required to handle non-uniform deployment.</td>
</tr>
<tr>
<td>Nodes are assumed to be homogenous throughput the network which these types provide better efficiency in most of the circumstances.</td>
<td>Heterogeneous network is common where it set of sensor nodes raises multiple technical issues related to data routing.</td>
</tr>
</tbody>
</table>
Table 2.2 (continued): Comparison between terrestrial and UWSNs (Ayaz, Baig et al. 2011) (Kheirabadi and Mohamad 2013)

<table>
<thead>
<tr>
<th>Terrestrial Wireless Sensor Networks</th>
<th>Underwater Wireless Sensor Networks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radio waves are available by means nodes can communicate with low propagation delays at speed of light (3 x 10^8 m/s).</td>
<td>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.</td>
</tr>
<tr>
<td>High data rate (MHz)</td>
<td>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).</td>
</tr>
<tr>
<td>Increased number of hops during the routing process.</td>
<td>Number of hops depends on depth of the monitoring are normally 4 until 7 hops.</td>
</tr>
<tr>
<td>Low energy consumption.</td>
<td>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.</td>
</tr>
<tr>
<td>Large batteries can be used and can be replaced or recharged with ease.</td>
<td>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.</td>
</tr>
<tr>
<td>Nodes are less error prone and can continue to work for longer time.</td>
<td>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.</td>
</tr>
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### 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
interval of time that is caused by slow variations in the propagation medium (Soo Young and Soo Hyun 2008).

Submarine radio communication propagation models were subject of intense research in the years 1950 to 1970. Seawater is a conductive medium with large electromagnetic signal attenuations, which increase with frequency (Balanis 2012). There have been several attempts to develop underwater Electromagnetic wave (EM) signal propagation based communication models as shown in Table 2.3. Underwater communications simulation requires modeling the acoustic wave’s propagation while a node tries to transmit data to another one. An acoustic communications are classified by different features but it can hardly exceed 40kbps at a range of 1km. The speed of sound generally depends on water properties which is temperature, pressure and salinity. The speed of sound near the ocean surface is 4 times faster than the speed of sound in air with the increase of practical salinity unit (PSU), temperature and depth. Hence, the ocean salinity in seawater is defined as ionic salt concentration with 35.5 PSU in average salinity.

Table 2.3: Theoretical comparison of acoustic, EM and optical waves in seawater environments (Uribe and Grote 2009)

<table>
<thead>
<tr>
<th></th>
<th>Acoustic</th>
<th>Electromagnetic</th>
<th>Optical</th>
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<tbody>
<tr>
<td>Nominal speeds (m/s)</td>
<td>$1.5 \times 10^3$</td>
<td>$3 \times 10^8$</td>
<td>$3 \times 10^8$</td>
</tr>
<tr>
<td>Power Loss (dB/m/Hz)</td>
<td>$&gt;0.1$</td>
<td>$\sim 2.8 \times 10^{10}$</td>
<td>$\infty$ turbidity</td>
</tr>
<tr>
<td>Bandwidth (Hz)</td>
<td>$\sim 10^3$</td>
<td>$\sim 10^6$</td>
<td>$\sim 10 \times 10^6 - 150 \times 10^6$</td>
</tr>
<tr>
<td>Frequency Band (Hz)</td>
<td>$\sim 10^3$</td>
<td>$\sim 10^6$</td>
<td>$\sim 1014 – 1015$</td>
</tr>
<tr>
<td>Antenna Size (m)</td>
<td>0.1</td>
<td>0.5</td>
<td>0.1</td>
</tr>
<tr>
<td>Antenna Complexity</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Effective Range (m)</td>
<td>$\sim 1000$</td>
<td>$\sim 10$</td>
<td>$\sim 10 – 100$</td>
</tr>
<tr>
<td>Data Rate (kbps)</td>
<td>100</td>
<td>$10 \times 10^6$</td>
<td>$1 \times 10^9$</td>
</tr>
<tr>
<td>Major Hurdles</td>
<td>Bandwidth and Interference – Limited</td>
<td>Power - Limited</td>
<td>Narrow beam – Limited</td>
</tr>
</tbody>
</table>
2.2.3 Network Architecture

The network architecture of UWSN can be described in the form of two dimensional and three dimensional structures. Static two dimensional UWSNs for ocean bottom monitoring consist of sensor nodes that are anchored to the bottom of the ocean. Typical applications may be environmental monitoring or underwater tectonic plates monitoring. Static three dimensional UWSNs for ocean column monitoring including networks of sensors whose depth can be controlled and may be used for surveillance applications or ocean phenomena monitoring (Akyildiz, Pompili et al. 2004) (Zhang, Xiao et al. 2009). Underwater sensors may be organized in cluster based architecture and be interconnected to one or more underwater gateways (uw-gateways) by means of wireless acoustic links. Underwater gateways introduce devices in charge of relaying data from the ocean bottom network to a surface station. They are equipped with a long range vertical transceiver used to relay data to a surface station and with a horizontal transceiver used to communicate with the sensor nodes for sending commands signals and collecting and aggregating the data. The surface station is equipped with an acoustic transceiver that is able to handle multiple parallel communications with the deployed uw-gateways, and with a long-range radio transmitter and/or satellite transmitter that needed to communicate with an onshore sink and/or to a surface sink (Akyildiz, Pompili et al. 2004) (Pompili, Melodia et al. 2009).

Meanwhile, 3D underwater networks are used to detect and observe phenomena that are not adequately observable by means of ocean bottom uw-sensor nodes. In this architecture, sensors float at different depths to observe a given phenomenon. One possible solution would be to attach each sensor node to a surface buoy, by means of wires whose length can be regulated to adjust the depth of each sensor node. However, this solution enables quick deployment of the sensor network; multiple floating buoys may obstruct ships navigating on the surface. These floating buoys are vulnerable to weather and tampering or pilfering. Alternatively, this is to anchor winch based sensor devices to the bottom of the ocean. Each sensor is anchored to the ocean bottom and equipped with a floating buoy that can be inflated by a pump. The buoy pushes the sensor towards the ocean surface. The depth of the sensor can then be regulated by adjusting the length of the wire that connects the sensor to the anchor, by means of an electronically controlled engine that resides on

### 2.3 Description of Previous Research

For the last few years many researchers have shown interest in the fields of underwater sensor network. There are several previous researches that contribute to this area specifically in the subtopic of routing, end-to-end delay, energy efficiency and packet delivery ratio. Each contributed paper used different routing protocols, show the performance results and software that was used to solve the problem in underwater sensor networks.

#### 2.3.1 Routing Schemes

Routing protocol is a fundamental issue for any network and considered to be in charge for discovering and maintaining the routes (Wahid 2010). Underwater environment is related to physical layer while the routing techniques issue is related to network layer of the OSI (Open Systems Interconnection) reference model as shown in Fig.2.2. Most researchers have proposed various types of routing protocol to get the performance metrics in network layer according to the requirement with different applications in underwater environment.

![Figure 2.2: The OSI reference model](image_url)
Routing layer of underwater sensor networks employ in various approaches by means flooding based, multipath based, cluster based and miscellaneous (Wahid 2010). Fig. 2.3 shows the classification of the selected protocols. The selection of the protocols follows the criterion of the most citation and recently proposed approaches. In flooding approach, the transmitters send a packet to all nodes within the transmission range. This protocol is simple and provides network knowledge while the main disadvantage is that nodes many transmit duplicate packet and resulted in more energy been consumed. In multipath based approach, it established more than one path from a source node towards a sink node. This formation augments the robustness and reliability. Clustering based approach means, the sensor nodes are grouped together in a cluster. The group consists of clusterhead and non-clusterhead. Clusterhead collects data from members of the clusterhead and generate transmission schedule. On the other hand, non-clusterhead nodes aggregate the sensed data and transmit data packets to the clusterhead. This thesis focused only on flooding based protocols for UWSNs.

![Routing protocols for UWSNs](image)

**Figure 2.3: Classification of the routing protocols for UWSNs (Wahid 2010)**

### 2.3.1.1 VBR (Vector based forwarding)

In VBF (Xie, Zhou et al. 2010), data packets are forwarded along redundant and interleaved paths from the source to sink where it mitigate the problems of packet losses and node failures. Forwarding path from sender to target is nominated by the routing vector. All nodes which received the packet compute their positions by
measuring the distance from the forwarder. It is assumed that every node already
knows its location and each packet carries involve all nodes location. VBF works
well for dense networks, as the ideas of virtual routing pipes establish between the
source and the destination nodes and packet delivery is occurred along this pipe.

Figure 2.4: VBF routing protocol which uses single pipeline for each node
(Kheirabadi and Mohamad 2013)

Figure 2.5: A virtual pipelines for each forwarder by HH-VBF (Kheirabadi and
Mohamad 2013)

The enhanced version of VBF, is the HH-VBF (Hop-by-hop vector based
forwarding) (Min, Cho et al. 2012) offer an extra robustness feature and an improved
on link quality. The protocol used the same concept as VBF but using a single pipe
from source to destination where defines by per hop virtual pipe in each forwarder.
Every intermediate node makes decision about the direction of pipe with reference to
its current location and HH-VBF can find a data delivery path even if the number of
nodes available in the forwarding path is very limited. HH-VBF produces more
signaling overhead than VBF. Simultaneously, it faces the problem of routing pipe
radius threshold where its affect the performance metrics.
2.3.1.2 FBR (Focused beam routing)

FBR (Jornet, Stojanovic et al. 2008) protocols for acoustic sensor networks are intended to avoid unnecessary flooding of broadcast queries. Overall expected throughput is significantly reduced by overburdened networks due to uncertain location information of nodes. Other than that, the location of intermediate nodes is not required. Routes are established dynamically during the traverse data packet for its destination and the decision about the next hop is made at each step on the path after the appropriate nodes have proposed themselves.

![Figure 2.6: (a) Procedure of finding next hop node in the FBR, (b) The region of forwarder node selection in the FBR (Kheirabadi and Mohamad 2013)](image)

However, FBR acts as suitable routing protocol for both mobile and static underwater acoustic networks without the need of clock synchronization. This idea is to restrain the flooding by the transmission power so that the energy consumption is reduced. Nodes can become sparse resulting in a situation that node cannot lie within the forwarding cone of the angle due to water movements. Then, if some nodes are positioned outside the forwarding area, it is forced to retransmit the RTS eventually resulting in the increase in communication overhead. It will subsequently affect the data delivery in the sparse areas. Lower flexibility of network is also a drawback of FBR concept (Thumpi.R 2013).
2.3.1.3 DBR (Depth based routing)

The DBR (Yan, Shi et al. 2008) requires only the depth information of sensor node which is use depth sensors. It senses own relative current position from the surface and place its value in the header and then broadcasts when a node wants to send a data packet. The receiving node calculates its own depth position and compares this value with the value embedded in the packet. The packet is forwarded if it is smaller and otherwise the packet will be discarded. The process is repeated until the packet reaches the destination. The main disadvantage of this protocol is that in sparse and high density areas, the performance is affected by packet loss and inefficient memory usage.

2.3.1.4 $H^2$-DAB (Hop-by-hop dynamic addressing based routing)

These protocols are assumes that are multiple buoys on the water surface which collect data of nodes anchored at the bottom of the sea and deployed at different depths. Sensor data is sent towards the water surface in a greedy fashion. The flooding based approach is employed along with the utilization of unique IDs to each sensor nodes. A hop ID illustrates the distance of hop count from a sink node towards the sensor node. In $H^2$-DAB protocol, multi sink architecture is taken into account where consider the transmitted packets delivered to the destination if any of the sinks receives the packet correctly.

![Diagram](image)

Figure 2.7: Assigning HopIDs with the help of Hello packets in $H^2$-DAB (Kheirabadi and Mohamad 2013)
Furthermore, H²-DAB (Ayaz and Abdullah 2009) has many advantages by means it does not require any specialized hardware, require no dimensional location information and handle node movements easily without maintaining complex routing tables. The multi-hop routing problems still exists as it is based on multi-hop architecture, where nodes near the sinks drain more energy because they are used more frequently.

2.3.1.5 DFR (Directional Flooding based routing)

The DFR (Daeyoup and Dongkyun 2008) (Shin, Hwang et al. 2012) protocol enhances reliability by packet flooding technique. The packets are transmitted in a restricted flooding zone where the zone area is selected based on an angle formed by the vectors. The vector between the receiver and the sender of the packet and another formed is the vector between the receiver and the destination node. The assumption is that all nodes know about its own location, location of one next hop and destination. Link quality is the foundation for deciding the forwarding nodes. This protocol rectifies the void problem by the selection of at least one node to transmit the data packet towards the sink but it can still exist if the sending node cannot find a next hop closer to the sink as reverse transmission of data packet is impossible.

Figure 2.8: Packet forwarding in DFR Protocol (Wahid 2010)
2.3.1.6 EUROP (Energy efficient routing protocol)

A EUROP (Chun-Hao and Kuo-Feng 2008) protocol is designed to reduce a large amount of energy consumption by reducing broadcast hello messages. The depth sensor will eliminate the requirement of hello messages for control position, which can be helpful for increasing the energy efficiency. These sensor nodes are deployed at different depths in order to observe the events occurring at different locations in the network. Further, every node is anchored at the bottom of the ocean and equipped with a floating module that can be inflated by a pump. This electronic module that resides on the node helps push the node towards the surface and return back to its initial position.

The depth of the sensor node can be regulated by adjusting the length of wire that connects the sensor to the anchor. All sensor nodes located at different depths will form layers, while the amount of layers depends on depth. The sink on the surface can communicate only with the sensors that belong to shallow water. Each sensor node on all the layers communicate through an acoustic channel after deciding to which layer it belongs by detecting the value of pressure by using RREQ and RREP packets. The performances of different routing protocols for underwater sensor networks are shown in Table 2.4.
Table 2.4: Performance comparison of UWSN protocols (Wahid 2010, Ayaz, Baig et al. 2011)

<table>
<thead>
<tr>
<th>Protocol Scheme</th>
<th>Mobility</th>
<th>Packet delivery ratio</th>
<th>End-to-end delay</th>
<th>Energy consumption</th>
<th>Network dimension</th>
<th>Number of nodes</th>
<th>Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>VBF (Xie, Zhou et al. 2010)</td>
<td>Sink fixed and node mobile (0-3m/s)</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
<td>1000m x 1000m x 500m (3D area)</td>
<td>From 500 to 4000</td>
<td>500m</td>
</tr>
<tr>
<td>HH-VBF (Xie and Connecticut 2008)</td>
<td>Sink and node fixed</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>1000m x 1000m x 500m (3D area)</td>
<td>500 to 3000 nodes</td>
<td>500m</td>
</tr>
<tr>
<td>FBR (Jornet, Stojanovic et al. 2008)</td>
<td>Sink fixed and node mobile (0-3m/s)</td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
<td>200km² (square area)</td>
<td>100 active nodes</td>
<td>n/a</td>
</tr>
<tr>
<td>DBR (Yan, Shi et al. 2008)</td>
<td>Sink (RF) and node mobile (1m/s, 5m/s and 10 m/s)</td>
<td>High</td>
<td>Low</td>
<td>Medium</td>
<td>500m x 500m x 500m (3D area)</td>
<td>200 nodes</td>
<td>500m</td>
</tr>
<tr>
<td>H²-DAB (Ayaz and Abdullah 2009)</td>
<td>Sink and node fixed</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>1500m x 1500m x 1500m (3D area)</td>
<td>300 (anchor &amp; floating)</td>
<td>1500 m</td>
</tr>
<tr>
<td>DFR (Shin, Hwang et al. 2012)</td>
<td>Sink and node fixed</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>3000m x 4000m (2D area)</td>
<td>41 nodes</td>
<td>n/a</td>
</tr>
<tr>
<td>EUROP (Chun-Hao and Kuo-Feng 2008)</td>
<td>Sink and node fixed</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
<td>150m x 150m x 150m (3D area)</td>
<td>1000 nodes</td>
<td>150m</td>
</tr>
</tbody>
</table>

2.4 Performance Evaluation

The performance of the UWSN is evaluated by considering the following metrics; mean packet delivery ratio, end-to-end delay and energy consumption. The outcomes of the evaluation will ultimately indicate the most suitable protocol that should be used.
2.4.1 Packet Delivery Ratio

This performance is defined as the ratio of data packet that is successfully delivered to the destination (sender) compared to the number of packets that have been sent out by the sender. These redundant packets are considered as only one distinct packet whether a packet may reach the sinks multiple times. Illustrates the level of delivered data to the destination:

$$\frac{\sum \text{Number of packet receiver}}{\sum \text{Number of packet send}}$$

The greater value of packet delivery ratio means the better performance of the protocols.

2.4.2 End-to-end Delay

This time delays are an average time taken by a data packet to arrive in the destination. It also includes the delay caused by route discovery process and the queue in the data packet transmitter. Only the data packets that successfully delivered to destinations that counted.

$$\frac{\sum (\text{Receive time} - \text{Send time})}{\sum \text{Number of connections}}$$

The lower value of it means the better performance of the protocol.

Packet Lost = the total number of packets dropped during the simulation

Packet Lost = Number of packet send – Number of packet receiver

However, the lower value of the packet lost means the better performance of the protocol.

2.4.3 Energy Consumption

Underwater wireless sensor network sensor cannot use solar energy to recharge the battery and difficult to replaces because underwater communications are severely
affected by network dynamics, large propagation delays and high error probability of acoustic channels. The direct way to resolve this problem is to generate energy by the sensors themselves. The probably method we can used is current movement or chemistry method to generate power to recharge battery. Efficient routing protocol and communication method can contribute to these issues. Energy consumption is the one of the biggest constraints of the wireless. Sensor nodes often use limited energy sources such as batteries. Therefore, the implementation of energy saving techniques is needed.

2.5 Summary of Chapter

This chapter defines the important parameters for the fundamental for underwater wireless sensor networks which is includes propagation models, communication architecture and routing protocols. There are three important performance of routing protocols that must use in UWSNs simulation process by means packet delivery ratio, end-to-end delay and energy consumption.
CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter is described about the methodology that will be used in this research. The overview for all stages is discussed in flowchart form to summarize the progress of this project.

3.2 Design Procedure

The procedure of designing this study represented the flowchart shown in Fig. 3.1. In the earlier stages, the problems, objectives and scopes of the study identified where are related with title of project by approval from supervisor. After that, there will be lot information by reviewing the previous projects and references such as journal, thesis, survey or review papers that very useful for this research done. While understanding the fundamental and theory background by means underwater wireless sensor networks, routing protocol and performance metrics also will be involved.

Then, OMNeT++ software will explore by doing all tictocs tutorial and attend any workshop for make more understands by solving these projects. Last part in Master’s project 1, there will be enough by focused until searching any related research. In second stages for Master’s project 2, selecting the best routing protocols in UWSNs with getting a better performance evaluation packet delivery ratio, end-to-
end delay and energy consumption. This part is designed and simulates using OMNeT++ software and analyzes the simulation results. Finally, conclude the enhanced results to achieve the objectives of this project.

Figure 3.1: Flowchart of overall project
3.2.1 Underwater Acoustic Channel

There exist realistic simulations of underwater acoustic communication as compared to electromagnetic propagation through the atmosphere modeling sound behaviour in dissipative transmission medium, such as seawater. Propagation delay, interferences and signal attenuations are characterized in this study. Basically, an underwater environment is formed with the cooperation of several network sensor nodes that establish and maintain the network through bidirectional acoustic links. Every node is able to send or receive messages from/to intermediate nodes in the network, and also forward messages to remote sink in case of multi-hop networks.

The main aspects of acoustic signals in UWSNs are given by: (1) the acoustic wave velocity is close to 1500m/s and so the communication links will suffer from large and variable propagation delays and relatively large motion-induced Doppler effects; (2) phase and magnitude fluctuations lead to higher bit error rates by using the forward error correction codes (FEC); (3) the attenuation observed in the acoustic channel increases when the frequency increases, thus produced a serious bandwidth constraint; (4) multipath interference in underwater acoustic communications is severe due mainly to the surface waves or vessel activity, being a serious problem to attain good bandwidth efficiency (Hwee-Xian and Seah 2007, Llor and Malumbres 2012). Simulating underwater medium requires modeling the acoustic signal while a node tries to transmit data to another node. In these subsections, several underwater acoustic channels represent in UWSNs.

A. Urick Description and Thorps Formula

The theory of the sound propagation is properly described by Urick (Urick 1983), as a regular molecular movement in an elastic substance that propagates to adjacent particles. A sound wave can be considered as the mechanical energy that is transmitted by the source from particle to particle, being propagated through the ocean at the speed of sound. The attenuation is often the most limiting factor in acoustic propagation where the amount depends on propagation medium and frequency. In seawater, attenuation comes from the viscosity of pure water, the relaxation of magnesium sulphate (MgSO₄) molecules above 10 - 500kHz and boric acid (B(OH)₃) molecules above 1kW, kHz. The empirical formula presented by
Thorpe (Llor and Malumbres 2012) is defined as the sound intensity decrease through the path between the source and destination nodes. The absorption coefficient factor $\alpha$ depends on the sound frequency $f$. The proposed acoustic attenuation expression is represented as follows (Lucani, Médard et al. 2008):

$$A(d, f) = d^k \alpha(f)^d$$  \hspace{1cm} (3.1)

where $k$ is the spreading factor (1 for cylindrical, 1.5 for practical spreading and 2 for spherical), $\alpha$ is a frequency-dependent parameter (Lurton 2002)

$$10 \log \alpha(f) = \frac{0.11f^2}{1+f^2} + \frac{44f^2}{4100+f^2} + 2.75 \times 10^{-4}xf^2 + 0.003$$  \hspace{1cm} (3.2)

where $\alpha(f)$ is given in dB/km and $f$ is in kHz. The absorption coefficient is the major factor that limits the maximum usable bandwidth at a given distance as it increases very rapidly with frequency. This formula is under a temperature of 4 °C, a salinity of 35 %, a pH of 8.0 and a depth of about 50m. It is suitable for low frequency 30 kHz region and approximate 7.609dB/km measurement results for proposed frequency.

**B. Monterey Miami Parabolic Equation (MMPE)**

The Monterey-Miami Parabolic Equation model (Llor and Malumbres 2012) is used to predict underwater acoustic propagation using a parabolic equation which is closer to the Helmholtz equation (wave equation); this equation is based on Fourier analysis. The sound pressure is calculated in small incremental changes in range and depth, forming a grid. It incorporates randomness and wave motion to the approximation, using a dynamic propagation loss calculation. The authors show that small changes in depth and node distances can drive to big differences in the path loss as a result of the ocean wave’s motion impact on acoustic propagation. The propagation loss formula based on the MMPE model is the following one:

$$PL(t) = m(f, s, d_A, d_B) + w(t) + e(s)$$  \hspace{1cm} (3.3)
REFERENCES


