VOID AVOIDANCE OPPORTUNISTIC ROUTING DENSITY RANK BASED FOR UNDERWATER SENSOR NETWORKS

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Computer Science)

School of Computing
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Universiti Teknologi Malaysia

APRIL 2021

Specially Dedicated to…

My lovely Wife, Son and Daughters

My Parents in Law

My dear Brothers and Sisters

My love to you will always remain and thank you for your

Support, Guidance, Patience, Joyfulness to make this experience complete.

ACKNOWLEDGEMENT

First and foremost, I would like to extend my gratitude to Allah (Subhanahu Wa Ta'ala), for granting me this opportunity and with His permission; I managed to complete my study and complete this thesis successfully.

Secondly, I also would like to express my sincere appreciation to my supervisor, **Associate Professor Dr Mohd Murtadha Mohamad**, for encouragement, guidance, critics, and friendship. Thanks also to all the lecturers who have taught me during my study in UTM.

Thanks also go to all my colleagues at **Pusat Teknologi Maklumat UTHM** who have really helped me doing this research. Without you all, I could not successfully complete this task in time.

Not to forget for all my family members, especially to my lovely **wife, son** and **daugthers** who have helped me during implementing this research study. You all gave me the passion and desire to continue this fight until I finish this thesis succesfully.

Finally, I would like to thank all my **friends** who have me helped directly or indirectly. Thanks you so much.

ABSTRACT

Currently, the Underwater Sensor Networks (UWSNs) is mainly an attractive area due to its technological ability to gather valuable data from underwater environments such as tsunami monitoring sensors, military tactical applications, and environmental monitoring. However, UWSNs are suffering from limited energy, high packet loss, and the use of acoustic communication which have very limited bandwidth and slow transmission. In UWSNs, the energy consumption used is 125 times more during the forwarding of the packet data from source to destination as compare to during receiving data. For this reason, many researchers are keen to design an energy-efficient routing protocol to minimize the energy consumption in UWSNs while at the same time provide adequate packet delivery ratio and less cumulative delay. As such, the opportunistic routing (OR) is the most promising method to be used in UWSNs due to its unique characteristics such as high path loss, dynamic topology, high energy consumption, and high propagation delay. However, the OR algorithm had also suffered from as higher traffic load for selection next forwarding nodes in the progression area, which suppressed the redundant forwarding packet and caused communication void. There are three new proposed algorithms introduced to address all three issues which resulted from using the OR approach in UWSNs. Firstly, the higher traffic load for selection next forwarding nodes in the problematic progression area problem was addressed by using the Opportunistic Routing Density Based (ORDB) algorithm to minimize the traffic load by introducing a beaconless routing to update the neighbor node information protocol. Secondly, the algorithm Opportunistic Routing Density Rank Based (ORDRB) was developed to deal with redundant packet forwarding by introducing a new method to reduce the redundant packet forwarding while in dense or sparse conditions to improve the energy consumption effectively. Finally, the algorithm Void Avoidance Opportunistic Routing Density Rank Based (ORDRB) was developed to deal with the communication void by introducing a simple method to detect a void node and avoid it during the forwarding process. Simulation results showed that ORDB has improved the network performance in terms of energy tax average (25%, 40%), packet delivery ratio (43%, 23%), and cumulative delay (67%, -42%) compared to DBR and UWFlooding routing protocols. While for ORDRB, the network performance improved in terms of energy tax average (0.9%, 53%, 62%), packet delivery ratio (100%, 83%, 58%) and cumulative delay (-270%, -94%, 55%) compared to WDFAD-DBR, DBR and UWFlooding. Lastly, for VAORDRB, the network performance improved in terms of energy tax average (3%, 8%), packet delivery ratio (167%, 261%), and cumulative delay (68%, 57%) compared to EVA-DBR and WDFAD-DBR. Based on the findings of this study, the protocol VAORDRB is a suitable total solution to reduce the cumulative delay and increase the packet delivery ratio in sparse and dense network deployment.

ABSTRAK

Pada masa ini, Rangkaian Sensor Dalam Air (UWSNs) adalah bidang yang menarik kerana kemampuam teknologinya untuk mengumpulkan data bernilai dari persekitaran bawah air seperti pemantauan tsunami, aplikasi taktikal tentera dan pemantauan alam sekitar. Walau bagaimanapun, UWSNs menghadapi masalah tenaga yang terhad, kehilangan paket yang tinggi, dan menggunakan komunikasi akustik yang mempunyai masalah jalur lebar yang terhad dan masa penghantaran yang perlahan. Dalam UWSNs, penggunaan tenaga yang digunakan adalah 125 kali lebih tinggi semasa penghantaran data paket dari sumber ke destinasi dibandingkan dengan semasa menerima data. Oleh itu, ramai penyelidik berminat menghasilkan protocol penghala tenaga yang cekap untuk meminimumkan penggunaan tenaga dalam UWSNs dan pada masa yang sama memberikan nisbah penghantaran paket yang memuaskan dan mengurangkan masa kelewatan kumulatif. Oleh itu, penghala secara oportunis (OR) adalah kaedah yang paling sesuai untuk digunakan dalam UWSNs kerana ciri-ciri uniknya seperti kehilangan laluan yang tinggi, topologi dinamik, penggunaan tenaga yang tinggi, dan kelewatan penyebaran yang tinggi. Walau bagaimanapun, algoritma OR juga mempunyai masalahnya tersendiri seperti beban lalu lintas yang lebih tinggi untuk pemilihan nod pemajuan seterusnya dalam kawasan kemajuan, penghantaran paket yang berlebihan dankomunikasi yang terhalang. Terdapat tiga algoritma baru yang diperkenalkan untuk menangani ketiga-tiga isu yang timbul dengan menggunakan pendekatan OR dalam UWSNs. Pertama, beban lalu lintas yang tinggi untuk pemilihan nod pemajuan seterusnya ditangani dengan menggunakan algoritma Penghala Secara Oportunis Berdasarkan Ketumpatan (ORDB) untuk meminimumkan beban lalu lintas dengan memperkenalkan protokol penghalaan tanpa seruan untuk kemaskini senarai jiran nod. Kedua,algoritma Penghala Secara Oportunis Berdasarkan Darjat Ketumpatan (ORDRB) dibangunkan untuk berurusan dengan isu penghantaran paket berlebihan dengan memperkenalkan kaedah baru untuk mengurangkan penyebaran paket berlebihan semasa berada dalam keadaan yang padat atau jarang untuk meningkatkan penggunaan tenaga secara efektif. Akhirnya, algoritma Penghindaran Tidak Sah Penghala Secara Oportunis Berdasarkan Darjat (VAORDRB) dibangunkan untuk menangani komunikasi terhalang dengan memperkenalkan kaedah mudah untuk mengesan nod tanpa jiran dan mengelakkannya semasa proses penghantaran. Hasil simulasi menunjukkan bahawa ORDB meningkatkan prestasi rangkaian dari segi purata tenaga (25%, 40%), nisbah penghantaran paket (43%, 23%) dan kelewatan kumulatif (67%, -42%) berbanding dengan DBR dan penghalaan UWFlooding protokol. Sementara untuk ORDRB, prestasi rangkaian bertambah baik dari segi purata tenaga (0.9%, 53%, 62%), nisbah penghantaran paket (100%, 83%, 58%) dan kelewatan kumulatif (-270%, -94% 55%) berbanding dengan WDFADDBR, DBR dan UWFlooding. Akhir sekali untuk VAORDRB, prestasi rangkaian bertambah baik dari segi purata tenaga (3%, 8%), nisbah penghantaran paket (167%, 261%) dan kelewatan kumulatif (68%, 57%) berbanding dengan EVA-DBR danWDFAD-DBR. Berdasarkan penemuan kajian, protokol VAORDRB adalah penyelesaian menyeluruh yang sesuai untuk mengurangkan kelewatan kumulatif dan meningkatkan nisbah penghantaran paket dalam penempatan rangkaian yang jarang dan padat.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AHH-VBF	-	Adaptive Hop by Hop Vector Based Forwarding Routing
AODV	-	Ad-Hoc On Demand Vector
AUV	-	Autonomous Underwater Vehicles
CARP	-	Channel Aware Routing Protocol
CBR	-	Constant Bit Rate
Co-UWSN	-	Cooperative UWSN
CSC	-	Candidate Set Coordination
CSS	-	Candidate Set Selection
CSSR	-	Candidate Selection Set and Ranking
CV	-	Communication Void
DCEER	-	The Dynamic Control Energy Efficient and Reliable Algorithm
DBMR	-	Depth Based Multi-Hop Routing
DBR	-	Depth Based Routing
DFR	-	Directional Flooding Based Routing Protocol
DREE	-	Distance Based Reliable and Energy Efficient
DSDV	-	Destination-Sequenced Distance Vector
E-CARP	-	Enhanced CARP
EEDBR	-	Energy Efficient Depth Based Routing
EEF	-	Energy Efficient Fitness Based Routing
ERP2R	-	Energy Efficient Routing Protocol Based on Physical Distance and Residual Energy
EVA-DBR	-	Energy-efficient and Void Avoidance Depth Based Routing
FBR	-	Focus Beam Routing Protocol
GPS	-	Global Position System
H2-DAB	-	Hop by Hop dynamic addressing based
HH-VBF	-	Hop by Hop Vector Based Forwarding
Hydrocast	-	Reliable Pressure Based Opportunistic Routing
iAMCTD	-	Improved Adaptive Mobility of Courier Nodes in Threshold Optimized DBR

JSIM	-	Java Simulator
LPL	-	Low Power Listening
LPP	-	Low Power Probing
MAC	-	Media Access Control
NEI	-	Node Exchange Information
NNT	-	Neighborhood Network Table
NS2	-	Network Simulator 2
NS3	-	Network Simulator 3
OEER	-	The Optimize Energy Efficient and Reliable Algorithm
OMNET	-	Objective Modular Network Testbed in C++
OPNET	-	Optimized Network Engineering Tools
OR	-	Opportunistic Routing
ORDB	-	Opportunistic Routing Density Based
ORDRB	-	Opportunistic Routing Density Rank Based
OTcl	-	Object-Oriented Tool Command Language
OVAR	-	Opportunistic Void Avoidance Routing
PER	-	Power Efficient Routing
QUALNET	-	QUALNET Network Simulator
RERP2R	-	Reliable Energy Efficient Routing Protocol Based on Physical Distance and Residual Energy
RF	-	Radio Frequency
RPFA	-	Redundant Packet Forwarding Avoidance
RSB	-	Receiver Side Based
SEANAR	-	Energy Efficient and Topology Aware Routing
SSB	-	Sender Side Based
SUNSET	-	Sapienza University Networking framework for underwater Simulation Emulation and real-life Testing
TWSN	-	Terrestrial Wireless Sensor Networks
UWSNs	-	Underwater Wireless Sensor Networks
VAEER	-	Void Avoidance Energy Efficient and Reliable Algorithm
VAORDRB	-	Void Avoidance Opportunistic Routing Density Rank Based

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Overview

Although the Earth's surface is covered by water over 70% compared to the land, human knowledge regarding the underwater environment is still very limited as compared to the land. Due to technological advances in wireless sensor networks (WSNs) nowadays, exploration of knowledge about the land and its structure are able to grow successfully. This remarkably exploration encourages researcher to venture with the same technology to be used in the underwater environment which is called Underwater Wireless Sensors Networks (UWSNs) (Akyildiz, Pompili and Melodia, 2005). According to Ayaz *et al.* (2011), the use of UWSNs is more appropriate for un-manned exploration since the underwater environment are harsh, vast and has high water pressure.

UWSNs consist of autonomous vehicles and individual sensor nodes that implement monitoring operations as well as sensing, storing and forwarding the data that has been collected to a sink node. Acoustic communications are the typical physical layer technology in UWSNs as other mediums are not feasible to use at the underwater environment such as radio waves and optical waves (Akyildiz, Pompili and Melodia, 2005). Each of these sensor nodes is equipped with acoustic modem and being deployed manually or randomly in deep or shallow water based on their requirement application.

There are a few hurdles that need to be overcome with the use of UWSNs technology. First, by using the acoustic wave in the communication channel the available bandwidth are limited, higher propagation delay which acoustic speed slower than in radio frequency (RF) channel a difference of five orders of magnitude, high packet loss and consume more energy (Akyildiz, Pompili and Melodia, 2005). Second, a very costly underwater equipment compared to terrestrial equipment, limited computational power and memory storage (Akyildiz, Pompili and Melodia, 2005; Ovaliadis, Savage and Kanakaris, 2010). Third, due to the continuous motion of the nodes with water flow currents makes underwater is a dynamic network topology and unreliable communication (Li *et al.*, 2016). Lastly, the location information of node for underwater environment cannot use the Global Position System (GPS) because high frequencies face the problem of quick absorption in water environment (Ayaz *et al.*, 2011; Melodia *et al.*, 2013).

However due to the characteristic differences between UWSNs and Terrestrial Wireless Sensor Network (TWSNs), many existing established hardware and software developed for TWSNs could not directly adapt to UWSNs. Because of the above reason, there have been many current research in different field of UWSNs and it is slowly getting much attention from the researchers around the world to solve many issues in UWSNs field. Routing protocol design is one of the hot topics of research in UWSNs which can guarantee the reliability and effective packet transmission from source node to the destination node in UWSNs. This routing protocol design is one of the crucial problems in UWSNs (Melodia *et al.*, 2013; Climent *et al.*, 2014; Li *et al.*, 2016).

Since the research in the physical and the data link layer is already in the maturity stage in UWSNs, then researchers have shifted toward more exploration of network layer issues. As a result, recently many new routing protocols in UWSNs have been proposed by researchers. Many researchers have already carried out research on routing protocol but all of them have their own advantages and disadvantage since each of the research tackles different problem and requirement. So there are greater chances to develop a suitable routing protocol that can achieve at least reliable communication, less energy consumption and prolong network life with packet delivery ratio of the UWSNs.

1.2 Problem Background

In UWSNs, sensor nodes are powered by battery which had limited capacity and very difficult to recharge and replace (Akyildiz, Pompili and Melodia, 2005). Sensor nodes in UWSNs consume high energy compared to TWSNs sensor due to the use of acoustic wave for communication which experience high latency, low bandwidth and high error probability (Zenia *et al.*, 2016). Therefore to prolong the network lifetime in UWSNs it is important to consider an energy efficient protocol design without sacrificing the network performance such as by reducing the energy consumption during communication (Ovaliadis, Savage and Kanakaris, 2010; Zenia *et al.*, 2016). Communication in UWSNs is mostly to transmit and receive the packet either data packet or control packet, routing protocol in network layer is the key player to deliver a packet from the source towards destination. There are several techniques used in UWSNs routing protocol to reduce energy consumption such as reducing flooding transmission, clustering, limited retransmission, mobicast and intelligent algorithm like reinforcement learning to preserve the battery power in sensor node (Zenia *et al.*, 2016).

Opportunistic Routing (OR) approach is the promising routing approach to be used in UWSNs due to high dynamic network topology in UWSNs compared to traditional routing approach in TWSNs using end-to-end routing (Darehshoorzadeh and Boukerche, 2015; Ghoreyshi, Shahrabi and Boutaleb, 2016; Coutinho, Boukerche and Guercin, 2019). However, OR are suffered from high network traffic with redundant packets which can lead to higher energy consumption (Darehshoorzadeh and Boukerche, 2015; Coutinho *et al.*, 2016; Rahman *et al.*, 2020). OR algorithm in UWSNs can be divided into two categories, location-based and location-free (Kheirabadi and Mohamad, 2013). For location-based, each of the protocol is using the costly location information of sensor during the network communication. In contrast, location-free does not require the full location information of sensor node. Furthermore, based on candidate selection set approach, the location-based and location-free can be divided into three more subcategories namely as sender-side-based, receiver-side-based and hybrid approach (Coutinho *et al.*, 2016).

However, in the recent year there are several OR algorithms being proposed to increase the energy efficiency by reducing the redundant packets travel by suppressing it which can reduce the traffic load in network (Yan, Shi and Cui, 2008; Ahmed *et al.*, 2015; Ghoreyshi, Shahrabi and Boutaleb, 2016; Noh *et al.*, 2016; Yu *et al.*, 2016). Each of this OR protocol such as VBF (Xie, Cui and Lao, 2006), HH-VBF (Nicolaou, See, P. Xie, *et al.*, 2007), DBR (Yan, Shi and Cui, 2008), DBMR (Liu and Li, 2010), HydroCast (Noh *et al.*, 2016), WDFAD-DBR (Yu *et al.*, 2016), EVA-DBR (Ghoreyshi, Shahrabi and Boutaleb, 2017a) and SORP (Ghoreyshi, Shahrabi and Boutaleb, 2018) is also using different technique to reduce the traffic load and to identify the progressing area for forwarding the packet. In addition, each of this OR approach has their own advantages and disadvantages. Nevertheless, there is still a need to design an energy efficient OR algorithm for UWSNs.

Redundant packet forwarding is one of the common issues in OR algorithms either in TWSNs or UWSNs, which can increase network traffic load that would lead to higher energy consumptions (Bayrakdar, Meratnia, & Kantarci, 2011; Coutinho et al., 2016; Darehshoorzadeh & Boukerche, 2015, Khan, Hua, Ayaz, Shahid Anwar, & Ahmad, 2020). The mechanism to handle this issues in OR is commonly by using overhear and suppression algorithm which can suppress the packet after overhear the same packet that already being transmit. However in UWSNs, the progressing area for packet is so wide open which can affect the efficiency on performance of overhearing and suppression algorithms especially in the large area as compared to a small area. Therefore, selecting a suitable size progressing area for OR algorithms in UWSNs is a big task. Thus, in the several existing proposed solutions especially for location-based approach, the each forwarder candidate node is chosen in progressing area based on the average link quality of its next hop node in progressing area (Shin, Hwang and Kim, 2012).

While for location-free approach OR, mostly existing proposed is suffered from the wide area progressing area. Nevertheless, some of them are using the costly two-hop neighboring information to overcome that issues which are very complex and costly solution with limited computing and energy (Noh *et al.*, 2016; Yu *et al.*, 2016; Hussain *et al.*, 2020; Zhang and Cai, 2020). Therefore, the improving of overhearing and suppression algorithm in location-free OR routing algorithms for UWSNs is necessary to reduce the high load network traffic due to redundant packet forwarding and at the same time reduce the energy consumption to prolong the network lifetime but still have a sensible packet delivery ratio.

Communication void or routing void is one of the critical problems in OR, which happens when a sender node cannot forward the data packet if there is no neighbors node reside in its progression area (P. Xie *et al.*, 2009; Khasawneh, Abualigah and Al Shinwan, 2020). There are several proposed OR algorithms have been introduced to handle the communication void in UWSNs either propose a solution to handle the communication void after it happens (Jornet, Stojanovic and Zorzi, 2008; P. Xie *et al.*, 2009; Shin, Hwang and Kim, 2012; Noh *et al.*, 2016) or solution to detect the void nodes in the packet forwarding process (Javaid *et al.*, 2014; Ghoreyshi, Shahrabi and Boutaleb, 2016) or solution to avoid trapped nodes which lead to void communication (Ghoreyshi, Shahrabi and Boutaleb, 2017a, 2018). As most of the existing solution are either using the full location of node or topology information which involve a complex algorithm. As a result, it is still needed to design and develop a heuristic energy efficient communication void handling algorithm that does not need full location information node and complex algorithm in location free OR in UWSNs in order to improve the packet delivery ratio in sparse UWSNs with realistic energy consumption, especially in sparse networks.

1.3 Problem Statement

In UWSNs, sensor nodes spend mostly their limited energy to transmit and relay the data packets during communication. As OR algorithm is more suitable to use in UWSNs environment due to its high dynamic topology network. However, OR approach is suffered from high energy consumption due to the greedy technique which redundant the packet into network to provide more probability for packet delivery success. Thus, the energy efficient OR is proposed based on location-based and location-free approach. However, in location-based approach, there is a need to use costly full location information which is not suitable in UWSNs due to unable to use

GPS signal in underwater environment because of highly absorb GPS signal in water. Therefore, the location-free OR algorithm is more promising than location based OR for applying in UWSNs to get an energy efficient OR.

Most of the existing proposed location-free OR algorithms either beacon-based or pressure-based is using hello message to exchange their neighbor nodes information to choose the candidate selection set and their progression area of UWSNs (Yu *et al.*, 2016; Khasawneh *et al.*, 2017; Ghoreyshi, Shahrabi and Boutaleb, 2018; Hussain *et al.*, 2020). This technique needs interval update which could lead to higher traffic load resulting to more energy consumption to operate the network which could lead to shorten network lifetime. Therefore the existing location-free OR protocols in UWSNs is still suffered from an unnecessary traffic load just for updating their neighbor information to select the best candidate selection set or their progression area especially for sender-based algorithm. Therefore, designing a technique to collect their neighbor nodes information for choosing the candidate next forwarder node or progression area is essential for location-free OR in UWSNs to minimize the traffic load and reduce the energy consumption while still maintaining a reasonable packet delivery ratio.

Even though, it is known that current overhear and suppression algorithms do not efficiently suppress the redundant packet forwarding in OR algorithms in large progressing area, however the existing proposed OR algorithms do not find the suitable solution upon this matter (Lee *et al.*, 2010; Darehshoorzadeh and Boukerche, 2015; Khasawneh *et al.*, 2015; Bouabdallah, 2019). On the other hand, the existing solutions for this issue in OR algorithms are mostly using location information to control the size of progressing area and improve the efficiency of overhear and suppression algorithm, while finding this location information could lead to higher energy consumption of nodes respectively. Consequently, it is necessary to design and develop a new novel algorithm to increase the efficiency of overhear and suppression algorithms to reduce the unnecessary load network traffic and decrease the total energy consumption without any location information and topology-less especially in dense area.

Existing proposed OR algorithm handling communication void, either using the location information, network topology control, void avoidance, transmission power adjustment, or special mechanism to overcome this problem like using courier node or AUV(Ghoreyshi, Shahrabi and Boutaleb, 2017b; Ali *et al.*, 2018; Coutinho, Boukerche and Loureiro, 2020). Therefore, most of the existing proposed algorithms are still using costly and complex algorithm solution to overcome this issues on OR implementation in UWSNs which could lead to extra energy consumption. As a result, it is still needed to design and develop a heuristic energy efficient communication void handling algorithm that does not need full location information node and complex algorithm in location free OR in UWSNs in order to improve the packet delivery ratio in dense or sparse UWSNs with realistic energy consumption.

1.4 Research Question

Based on the aforementioned issues and problems, the research questions are developed as the followings:

i. How to design a location-free OR algorithm that uses low network overhead for selecting next forwarding nodes which can reduce the energy consumption while still providing an improve packet delivery ratio in UWSNs?

ii. How to design and develop a dynamic location-free OR algorithm which performs sufficiently in dense and sparse deployment without wasting so much energy and improve packet delivery ratio generally?

   a. How to identify the sensor node are in sparse or dense deployment in advancement area?

   b. How to optimize the selecting next forwarding nodes algorithm without the location information and topology-less while each of selected nodes can still overhear each other either in sparse or dense deployment?

iii. How to design and develop a void avoidance OR density rank based algorithm which can identify and avoid the communication hole in UWSNs especially in sparse deployment to improve the packet delivery ratio and end to end delay?

   a. How to identify the void node during routing process?

   b. How to avoid the void node during routing process without sacrificing the network performance and consume more energy?

1.5 Research Goal

The main goal of this study is to propose a novel design of a void avoidance opportunistic routing density rank based algorithm in order to deal with three main issues in opportunistic routing algorithms. The three main issues are; a higher traffic load for selection next forwarding nodes in progression area, suppressing the redundant forwarding packet and the communication void issue while concerning saving the energy of nodes, improve the packet delivery ratio and reduce the overhead network especially during dense deployment sensor nodes which could consume more energy.

1.6 Research Objectives

The objective of this study are as follow:

i. To design and develop a location-free OR algorithm which uses low network overhead in selecting next forwarder node.

ii. To design and develop a dynamic location-free OR algorithm which performs efficiently in dense and sparse deployment.

iii. To design and develop a void avoidance OR density based rank algorithm which can identify and avoid the communication hole in UWSNs especially in sparse deployment.

1.7 Scope of the Study

In this study, the scope of study are as follow:

i. Acoustic obstacles such as fishes, which alter the transmitted acoustic signal, are not taken into account.
ii. Source nodes in this research apply a Constant Bit Rate (CBR) traffic generation.
iii. All underwater nodes are standardized in terms of sensing, communication range, initial energy, memory size, and energy consumption in transmission and receiving per bit.
iv. Since the salinity, temperature, and depth have negligible impact on sound speed in the underwater environment, the effects of these parameters on the speed of sound will be ignored in this study.
v. The performance of the proposed algorithms are evaluated and validated by Underwater Package called as Aqua-Sim based in NS2.

1.8 Significant of Research

In this study, the problem of OR algorithms in three-dimensional mobile UWSNs is addressing, designing and developing a novel void avoidance opportunistic routing density based rank in UWSNs and issues pertaining to them.

i. The Opportunistic Routing Density Based Forwarding (ORDB) location free OR algorithm is introduced a simple information exchange among the neighbor node without using so much traffic load in order to reduce the energy consumption while still improving packet delivery ratio.

ii. The Opportunistic Routing Density Rank Based Forwarding (ORDRB) location free OR algorithm is introduced with enhance the suppression of redundant packets forwarding especially in dense deployment network to perform efficiently in dense and sparse deployment without wasting so much energy and improve packet delivery ratio generally.

iii. The Void Avoidance Opportunistic Routing Density Rank Based Forwarding (VAORDRB) location free OR algorithm incorporating detection and avoidance of communication void locally during the data packet forwarding phase in order to identify and avoid the communication hole in UWSNs especially in sparse deployment to improve the packet delivery ratio and communication delay.

1.9 Organization of the Thesis

The remaining chapters of this study are arranged as follows. In Chapter 2, a comprehensive literature review related to research field is done in order to formulate the research problem. The research methodology, which is conducted in this research, is provided in Chapter 3. Chapter 4 introduces the design, development and evaluation performance of the proposed algorithms ORDB. Chapter 5 presents the design, development and evaluation performance of the second proposed algorithms ORDRB. Chapter 6 presents the design, development and evaluation of the third proposed algorithms VAORDRB. Finally, Chapter 7 concludes this research, extracts the research contribution and then discusses some future works.

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APPENDIX B

LIST OF PUBLICATIONS

1. Ismail, N., & Mohamad, M. M. (2018). REVIEW ON ENERGY EFFICIENT OPPORTUNISTIC ROUTING PROTOCOL FOR UNDERWATER WIRELESS SENSOR NETWORKS. *KSII Transactions on Internet and Information Systems*, *12*(7), 3064–3094. https://doi.org/10.3837/tiis.2018.07.006 (**Scopus Indexed, ISI, IF - 0.611**)

2. Ismail, N., Mohamad, M. M., & Salamat, M. A. (2019). Simulation and visualization of acoustic underwater sensor networks using aqua-sim and aqua-3d: An evaluation. *International Journal of Advanced Trends in Computer Science and Engineering*, *8*(3), 943–948. https://doi.org/10.30534/ijatcse/2019/93832019 (**Scopus Indexed**)

3. Ismail N., Mohamad M.M. (2020) An Evaluation of Performance of Location-Based and Location-Free Routing Protocols in Underwater Sensor Networks. In: Saeed F., Mohammed F., Gazem N. (eds) Emerging Trends in Intelligent Computing and Informatics. IRICT 2019. Advances in Intelligent Systems and Computing, vol 1073. Springer, Cham (**Scopus Indexed**)

4. Ismail, N., & Mohamad, M. M. (2019). Evaluation of the Performance of Underwater Wireless Sensor Networks Routing Protocols under High-density Network, 9(2), 65–70 (**Non-Indexed**)