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THE PERFORMANCE OF DIRECTIONAL FLOODING ROUTING PROTOCOL FOR UNDERWATER SENSOR NETWORKS

Nur Asfarina Idrus, Jiwa Abdullah*

Department of Communication Engineering, Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, Batu Pahat, Malaysia

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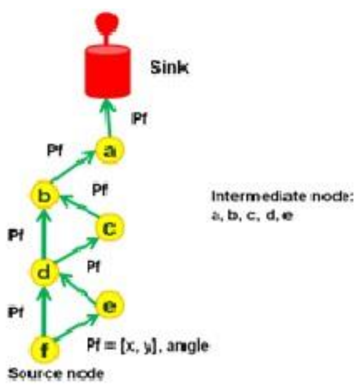
*Corresponding author
jiwa@uthm.edu.my

Graphical abstract



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 necessitate specialized new protocols for successful underwater communication. In this paper, a specialized protocol, known as Directional Flooding Routing Protocol is being chosen as the protocol to implement the routing mechanism for underwater sensor networks (UWSNs). The protocol is analyzed and evaluated. Simulation experiments have been carried out to find the suitability of various protocols for the sub aquatic transmission medium, whether in freshwater or seawater. The goal of this paper is to produce simulation results that would illustrate the performances of the protocol for a given metric such as end-to-end delay, packet delivery ratio and energy consumption. By analyzing the simulation results, DFR is considerably reliable for UWSN because this protocol is suitable for the sub aquatic transmission medium such as seawater.

Keywords: Underwater wireless sensor networks, end-to-end delay, packet delivery ratio, energy consumption

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, protocol tersebut adalah sangat sesuai untuk medium air.

Kata kunci: Rangkaian pengesan wayarles dalam air, penundaan dari hujung ke hujung, nisbah penghantaran paket, penggunaan tenaga

1.0 INTRODUCTION

Underwater sensor networks have many potential applications including seismic monitoring, equipment monitoring, leak detection and managing underwater robots [1]. There are multiple issues and various difficulties needed to be researched and resolved, especially in this area of underwater communications. The development of Underwater Wireless Sensor Networks (UWSNs) has never been more interesting than in the last few years. Table 1 shows the comparison between Terrestrial and Underwater Wireless Sensor Networks. In this paper, we attempt to analyze the behavior of UWSN based on the existing technologies developed during the last decade in the terrestrial wireless sensor networks (TWSNs). Although the network functionalities were similar, UWSNs exhibit several architectural differences with respect to the terrestrial ones. These are mainly due to the characteristics of the transmission medium (seawater) and the signal employed to transmit the data, which is the acoustic ultrasound signals[2]. The paper is organized as follows. Section 2 presents the review of UWSN. Section 3 explains the routing schemes in detail. Simulation and results are presented in Section 4. Finally, the paper concludes in Section 5.

2.0 UNDERWATER WIRELESS SENSOR NETWORKS THEORY

UWSN consists of densely deployed sensor nodes, which is the key characteristic of such networks. These networks can generally be classified into two categories depending on the type of applications: (1) long term non time critical aquatic monitoring applications; (2) short-term time critical aquatic exploration applications. The nodes that make up the UWSN are anchored to the sea bed and acoustically connected to each other with few of them acted as underwater gateways through clustering. Clusters contain sensors and sinks where sensors are connected to sinks within each cluster. These connections may be multiple hops or direct paths structure. The signals shared at each sink within the cluster sends the packets to the surface stations through a vertical link. The surface station will handle multiple parallel communications with the sinks by the acoustic transceivers [3].

Table 1 Comparison between terrestrial and UWSNs

Terrestrial Wireless Sensor Networks	Underwater Wireless Sensor Networks
Dense deployment due to cheap node price and small area which affects the network performance. Node movement almost fixed [4].	Sparse deployment due to expensive underwater equipment's and vast area [1, 3]. Nodes moves 1-3m/s by water currents [4].
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.

2.1 Propagation Model

Propagation of acoustic waves in the frequency range of interest for communication can be described in several stages. Submarine radio communication propagation models were the subject of intense research in the years 1950 to 1970. Seawater is a conductive medium with large electromagnetic signal attenuations, as the operating frequencies are increased. [5]. There are several attempts to develop underwater Electromagnetic Wave (EM) signal propagation based communication models as shown in Table 2. Underwater communications simulation requires modeling the acoustic wave's propagation while a node tries to transmit data to another one. The acoustic communication channels are classified in according to different features, but it can hardly exceed 40 kbps with a range of 1 km. The speed of sound depends on water properties which is the temperature, pressure and salinity. The speed of sound near the ocean surface is 4 times faster than the speed of sound in air particularly with the increase of practical salinity unit (PSU), temperature and depth. Approximately, the increase of 1 PSU will cause the speed of sound to increase by 4m/s, 17m/s and 1.4m/s respectively.

Table 2 Theoretical comparison of acoustic and EM waves in seawater environments [6]

	Acoustic	Electromagnetic	Optical
Nominal speeds (m/s)	1.5×10^3	3×10^8	3×10^8
Power Loss	>0.1 dB/m/Hz	~28 dB/1km/100MHz	∞ turbidity
Bandwidth	~kHz	~MHz	~ 10 MHz–150 MHz
Frequency Band	~kHz	~MHz	~ 1014 Hz–1015 Hz
Antenna Size	0.1m	0.5m	0.1m
Antenna Complexity	Medium	High	Medium
Effective Range	~km	~10m-100m	~ 10m–100m
Data Rate	Up to 100kbps	Up to 10Mbps	Up to 1Gbps
Major Hurdles	Bandwidth and Interference – Limited	Power - Limited	Narrow beam – Limited

3.0 RELATED WORK

For the last few years many researchers have shown interest in the fields of underwater sensor network. There are several researches that contributed 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, illustrating the performances. Various simulation software's are shown, such as OPNET, Qualnet, NS2 and Omnet++.

3.1 Routing Schemes

Routing is a fundamental issue for all networks and consist of the route discovery and route maintenance. [7] Underwater environment is related to physical layer while the routing issues are concerned with the network layer of the OSI reference model. Researchers have proposed various types of routing protocols to improve the performances of the networks based on their choice of performance metrics, suitable to the applications in the underwater environment. Routing protocols of UWSN are developed based on various approaches such as flooding based, multipath based, cluster based and miscellaneous[7]. Figure 1 illustrates the taxonomy of protocols. In flooding approach, the transmitters send a packet to all nodes within the transmission range. This protocol is simple and provides network information, but the main disadvantage is that nodes may transmit duplicated packets and resulted in more energy been consumed. In multipath based approach, it establishes more than one path from source node towards a sink node. This formation augments the robustness and reliability. In the clustering based approach, the sensor nodes are grouped together in a cluster. The group consists of clusterhead and non-clusterhead. Clusterhead collects data from members of the cluster and generate transmission schedule. On the other hand, non-clusterhead nodes aggregate the sensed data and transmit data packets to the clusterhead. This paper focused only on flooding based protocols for UWSNs.

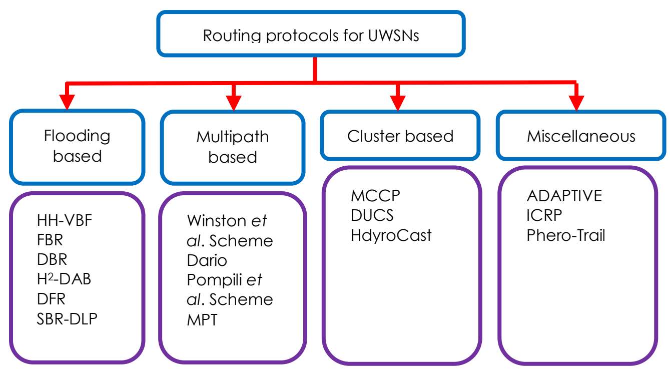


Figure 1 Taxonomy of the routing protocols for UWSNs [7]

4.0 METHODOLOGY

4.1 Underwater Acoustic Channel

There are various realistic simulations of underwater acoustic communication, modeling sound behavior in seawater, which in effect corresponds to the electromagnetic waves propagation through the atmosphere. Propagation delay, interferences and signal attenuations are characterized in this study. Basically, an underwater networking environment is formed with the cooperation of network sensor nodes that established and maintained the network through bidirectional acoustic links. Every node is able to send or receive messages to/from intermediate nodes in the network, and also forward messages to the remote sink in the case of multi-hop networking scenario. The main characteristics of acoustic signals in UWSNs are: (1) acoustic wave velocity which is close to 1500 m/s, thus causing the communication links to suffer from large and variable propagation delays, additionally may cause large motion-induced Doppler effects; (2) phase and magnitude fluctuations lead to higher bit error rates; (3) the attenuation observed in the acoustic channel increased as the frequency being increased, resulting in a serious bandwidth constraint; (4) multipath interference in underwater acoustic channels is severe due to the surface waves or vessel activity, considered as being a serious problem [8]. Simulating underwater medium requires modeling the acoustic signal in which a node tries to transmit data to another node. In these subsections, several underwater acoustic channels are described which can be considered in the UWSN simulations.

A. Urick Description and Thorps Formula

The theory of the sound propagation is properly described by Urick [9], 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 sea water, attenuation is due to the viscosity of pure water, the relaxation of magnesium sulphate (MgS04) molecules above 100 kHz and boric acid (B(OH)3) molecules above 1 kHz. The empirical formula presented by Thorp [8] is defined as the sound intensity which decreases through the path between the source and destination nodes. The absorption coefficient factor a depends on the sound frequency *f*. The proposed acoustic attenuation expression is represented as follows:

$$A(d,f) = dk\,\alpha(f)d \qquad (4.1)$$

where *k* is the spreading factor (1 for cylindrical, 1.5 for practical spreading and 2 for spherical), α is a frequency-dependent parameter [10].

$$10\,log\,A\,(d,f) = \frac{0.11f^2}{1+f^2} + \frac{44f^2}{4100+f^2} + 2.75 \times 10^{-4} \times f^2 + 0.003 \qquad (4.2)$$

where *a(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.

B. Monterrey Miami Parabolic Equation (MMPE)

The Monterey-Miami Parabolic Equation model [8] 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 shown below,

$$PL(t) = m(f,s,d\_A,d\_B\,) + w(t) + e() \qquad (4.3)$$

where, *PL(t)* is the propagation loss while transmitting from node A to node B; $m(f, s, d_A, d_B)$ is the propagation loss without random and periodic components which were obtained from regression of MMPE data; *f* is frequency of transmitted acoustic signals (in kHz); d_A is sender's depth (in meters); d_B is receiver's depth (in meters); s is Euclidean distance between nodes A and B (in meters); *w(t)* is periodic function to approximate signal loss due to wave movement; and *e()* is signal loss due to random noise or error. The $m(f, s, d_A, d_B)$ function represents the propagation loss defined by the MMPE model. According to the logarithmic nature of the data, a nonlinear regression is the best option to provide an approach to the model based on the coefficients, A_n. The proposed expression to determine this function is as follows,

$$m(f,s,d_A,d_B) = log\left(\left|\frac{\left(\frac{s}{0.9}\right)^{A_0} {d_A}^{A_9} s^{A_7}((d_A-d_B)^2)^{A_{10}}}{(s*\,d_B)^{10\,A_5}}\right|\right) + \left(f^2\left(\frac{A_1}{1+f^2}+\frac{41}{4100+f^2}+0.002\right)+0.003\right)*\left(\frac{s}{914}\right) + A_6*d_B + A_8*s \qquad (4.4)$$

The *w()* function in Equation (4.3) approximates the signal loss due to the wave movement. It considers the movement of a particle that will oscillate around its location in a sinusoidal way. The movement is represented as circular oscillations that reduce their radius as the depth of the particle increases. The length of that radius is dependent of the energy of the wave and is related to its height. The common waves consist of hundreds of meters of wavelength and have an effect up to 50 m of depth. It can be mathematically expressed as,

$$w(t) = h(l_w,t,d_B,h_w,T_w)E(t,T_w) \qquad (4.5)$$

where, *h(s)* is the scale factor function; l_w is the ocean wavelength in meters; h_w is the wave height in meters; d_B the receivers depth in meters; T_w is the wave period in seconds; and *E()* the function of wave effects in nodes. This function consists of elements that resemble the node movement and can then be expressed mathematically. Hence the effect of the wave in particular phase of wave motion can be expressed by calculating the scale factor *h()* which is given as in [8]. The calculation of the scale factor is as follows,

$$h(T_w, l_w, t, h_w, d_B) = \left(\frac{\left(h_w\left(1-\left(\frac{2\,d_B}{l_w}\right)\right)\right)}{0.5}\right) * \left|sin\left(\frac{2\pi(mod(T_w))}{T_w}\right)\right| \quad (4.6)$$

The *e()* function represents a random term modeling background noise. As the number of sound sources increased and undetermined, this random noise follows a Gaussian distribution and is modeled to have a maximum of 20 dB at the furthest distance. It formulates the function on the basis of the proportion between the distances from communicating nodes to the source transmitter. The background noise is modeled as,

$$e(s) = 20\left(\frac{s}{s_{max}}\right) R_N \quad (4.7)$$

where; *e()* is the random noise function; *s* is the Euclidean distance between node A and node B in meters; s_{max} is the transmission range in meters; and R_N is the random number from a Gaussian distribution centered in 0 and with variance 1.

4.2 Simulation Scenarios

The simulation of UWSN is implemented using OMNET++. The simulation scenario consists of 39 nodes deployed in the area of 3000 m x 4000 m with triangular grid. The distance between nodes is 300m, 400m and 500 m with one source node, 38 intermediate nodes and one sink node. Source nodes generate each packet sizes with 64 bytes per 30 seconds. The transmitter frequencies associated with underwater communication are typically between 10 Hz and 1M Hz. The bandwidth of 30 kHz is used in this scenario broadcasting at data rate of 2 kbps that related with 0.136 s time interval. On average, the seawater density is approximately p=1030 kgm$^{(-3)}$. Underwater acoustic frequency is set at 30 kHz with a velocity of 1500 m/s and wavelength of 0.05m. The acoustic wave propagation in seawater behaves differently due to its inherent physical characteristic.

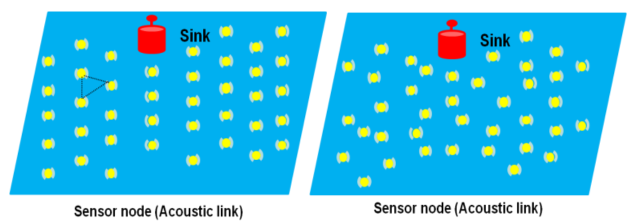
Since the acoustic signal is used in UWSNs, the acoustic propagation model is implemented in OMNeT simulator. Thorp formula [4.1] is useful in estimating the optimal frequency while MMPE [4.3] offers a better description of the attenuation calculation by including the effects of ocean waves, the depth of nodes and the sea floor multipath. Both wave propagation models can be incorporate into OMNeT to get better performance results within the DFR protocols. The acoustic wave's absorption characteristic in seawater is 7.609 dB/km using Thorps formula. UDP was located at transport layer because DFR are flooding routing protocols. IEEE 802.11 MAC protocol is implemented to generate MAC layer traffic [11]. The 802.11 also assumed that the amount of data transmitted is short and transmit infrequently in order to keep a low duty-cycle. In the simulation, the RTS/CTS messages are not use to access a channel. The node broadcasts a packet without the control messages if the channel is free because DFR depends on broadcasting capability of each node. The simulation parameters are given in Table 3.

Table 3 Parameter used in simulations

Parameter	Value
Propagation models	Thorp and MMPE
Network area	3000m x 4000m
Number of sinks	1
Total number of nodes	39
Packet size	64 bytes
Frequency	30 kHz
Simulation time	600s
Time interval	0.136s

4.3 Network Architecture

Simulating in UWSN architecture can be modelled as in Figure 2 where all the deployed sensor nodes are anchored to the bottom of the ocean. The architecture is organized in triangular topology and random topology which interconnects one sink and 39 nodes based on their acoustic link quality. The total number of nodes used is based on the previous research [11].



(a) (b)

Figure 2(a) The illustration model of triangular topology in UWSN (b) The illustration model of random topology in UWSN

4.4 Directional Flooding Routing Operation

Directional flooding protocol, shown in Figure 3 enhances transmission reliability using flooding techniques. The source node will start transmitting the packets directionally towards sink through intermediate node. Source nodes forward the packet to any intermediate node that is close to it so that the probability of finding the shortest path is high. Additionally it is robust against each node failure and positional inaccuracy. Each node will decide its current angle to determine whether to forward the data packet based on their link quality. Initially, the source node starts broadcasting the packet by their location and base angle with a minimum value of angle according to a network density. DFR allows more nodes to participate in forwarding the packet when a forwarding node has poor link quality to its intermediate nodes geographically, advancing toward the sink. It allows at least one other intermediate node to participate in flooding the packet. If the route is correct, the node will transmit the data packet, otherwise it will discard the packet because it is considered out of flooding zone. However, it can be solved by adjusting the base angle of each node based on average link quality. There have two conditions to reflect the precise acoustic link in which current angle of each node is larger than the forwarder current angle and distance between nodes to sink is smaller than the distance from forwarder to the sink. The simulation is done using OMNeT++ simulator and thus proved that DFR is more suitable for UWSNs, especially when acoustic links are prone to packet loss.

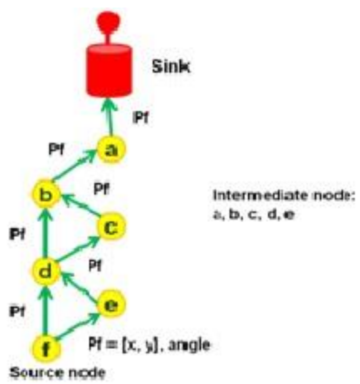


Figure 3 The illustration model of DFR protocol

5.0 RESULTS

OMNeT++ is a general purpose object oriented tool and not specifically designed for network simulations. Components for network simulations are provided by MiXiM framework. Firstly, the underwater wireless sensor networks modules and network topology are defined in network description file (.ned) with suitable network module setting. Next, the flooding modules (flood.cc) are included and compiled. A specific sensor is known as sink, collects data of interest from sensor nodes. Source node will start transmitting data packets to intermediate node after which it sends the packet according to the flooding scheme. One of the important aspects of discrete event simulation is the initial startup values. All the necessary parameters for UWSN need to be initialized in OMNeT++. It is done through file, omnetpp.ini, and the initialization file.

5.1 Triangular Topology Results

5.1.1 Static Sink and Number of Nodes Scenario

Packet delivery ratio is an important metric related to the network reliability. In static scenarios, the sensor nodes produced negligible movement where they are relatively anchored after deployment. The packet delivery ratio with various numbers of nodes in triangular topology is investigated. Figure 4 shows the performance of packet delivery ratio against the number of nodes from 6 to 39 stationary nodes, while using three different transmission ranges. Transmission range is broadcast between one nodes to another node. As the number of nodes increases, the packet delivery ratio tends to increase also in all three different transmission ranges of DFR. In these scenarios, the transmission ranges considered are 500m, 400m and 300m. Previous researcher only used 500m. Transmission range of 300m has higher packet delivery ratio than other ranges due to the number of nodes which play a role in forwarding the packets according to the average link quality. The range of 400m and 500m have lower packet ratio because of the possible occurrence for wide range by allowing node to participate in forwarding a packet.

The effect of static nodes on the energy consumption is shown in Figure 5. It is defined as the total energy consumed throughout the network during all the routing processes. The energy metric is one of the major constraints of the wireless sensor network. It is observed that in each range there is an increased in the average energy from starting up to the last node. The energy consumed is considered by a node per round when a packet has reached the destination successfully. This energy consumption tends to increase when network density had increased since more nodes are qualified for packet forwarding. Average energy consumption of DFR at the range of 500 m is higher than 400 m and 300 m due to excessive number of nodes and paths involved in the forwarding process. Nodes typically used limited energy sources such as batteries, thus required the implementation of energy saving techniques.

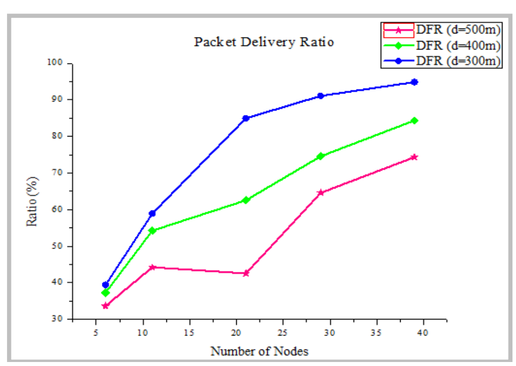


Figure 4 Packet delivery ratio with different transmission range in DFR

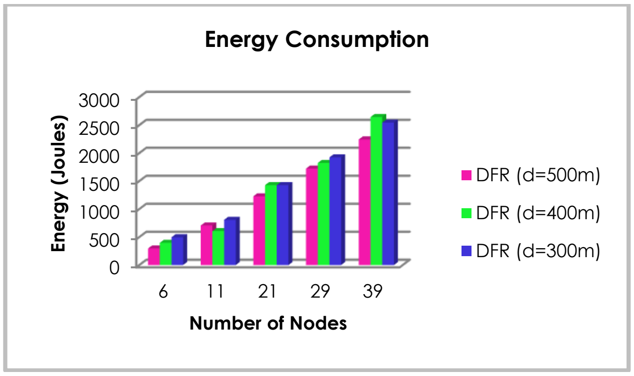


Figure 5 Energy consumption with different transmission range in DFR

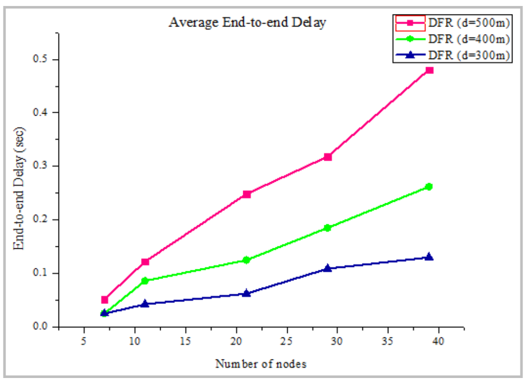


Figure 6 End-to-end delay with different transmission range in DFR

End to end delay should always be significantly low for a better quality of service. In general acoustic link quality is enhanced when the end to end delay is small and the actual comparison is shown in Figure 6. The transmission range of 300m is slightly lower than other ranges. The higher delay is observed to transmission range of 500m and followed by 400m. In shortest path, it will cause less delay in packet transmission between nodes and sink. Generally, static node has no serious effect on the packet delivery ratio; energy consumption and end-to-end delay due to no complex routing tables are going to be maintained according to the location information of the sensor nodes. All simulations were set to run for 600 seconds.

5.2 Random Topology Results

5.2.1 Node Speed Scenario

The random waypoint mobility model is used to simulate node movement. Node movement is referred to the water current even though the distance is small in underwater acoustic channel. The 39 nodes are considered in random motion except sink node. The nodes movement speeds are set at 20 mps, 40 mps and 60 mps to evaluate how mobile node affects the performance of DFR. A node will randomly choose the destination with node velocity selected from a uniform distribution. The node stops for a duration after reaching its destinations. During this duration, the node again chooses a random destination and repeat the whole process until the simulation ends. All simulations are run for 600 seconds. This node mobility speeds network scenarios for packet delivery ratio are shown in Figure 7. Observed that at 60 mps the packet delivery ratio dropped sharply when the number of nodes from 30 to 39. In contrast, mobility speeds at 40 mps have 20% higher ratio than 60 mps, hence at this speed, it will be more reliable in packet forwarding.

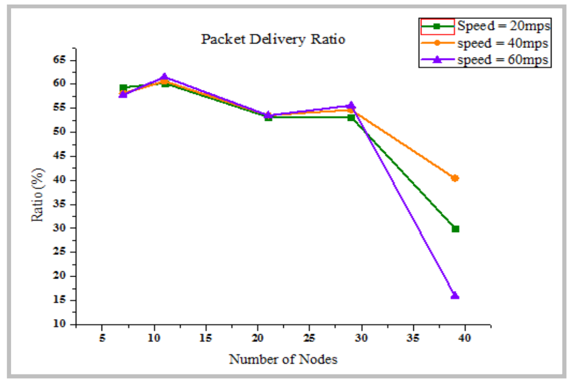


Figure 7 Packet delivery ratio for node mobility speed in DFR

Meanwhile, Figure 8 depicts packet delay due to variations of speed and the number of nodes. As the number of nodes is increased, the delay becomes very large. The higher the speed, the longer is the delay. Additionally, as the number of nodes is increased the amount of delay becomes longer. The data deliveries in DFR schemes are largely to minimize the end-to-end delay along with the lower speeds of the deployed sensor nodes but within a limited flooding zone.

5.2.2 Number of Sinks Scenario

In this scenario, various number of sinks is used. In each experiment the number of sinks is set to 1, 2 and 3. In Figure 9, the variation of packet delivery ratio with is compared with different number of sinks. DFR with multiple sink is better than DFR with one sink. Since DFR is trying to deliver data packets to the water surface, the number of sinks at the water surface will definitely increase the chance that a packet is received by a sink. This explains why the higher delivery ratio when multiple sinks are deployed. However, the 2 sink have a maximum dropped because this sink is not reliable in receiving the packets from nodes. On average, the packet delivery ratio, single sinks have 11% higher ratio than multiple sink because single sink is more reliable adopt a concept of flooding based packet transmissions.

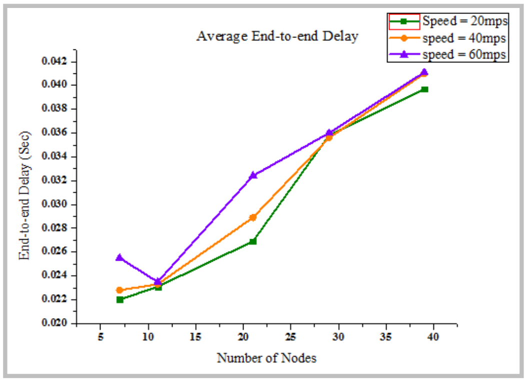


Figure 8 End-to-end delay for node mobility speed in DFR

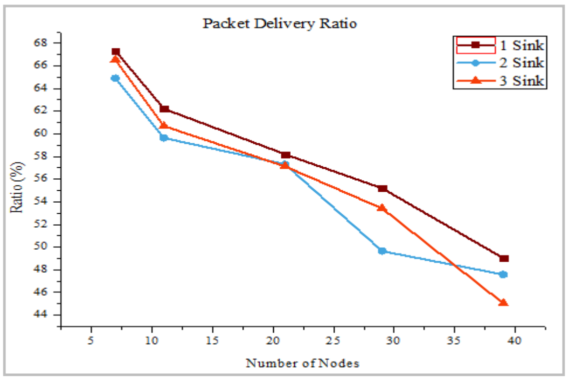


Figure 9 Packet delivery ratio with different number of sinks in DFR protocols

Additionally, Figure 10 illustrates that the DFR with single sinks has a slightly better end-to-end delay than DFR with multiple sink. This happened because in the single sink case, a packet is considered successfully delivered whenever it reaches any of the sinks. Single sink have a better performance of receiving the packet in underwater medium. The average end-to-end delay in multiple sinks is very high due to the nodes have to forward a packet to many sinks.

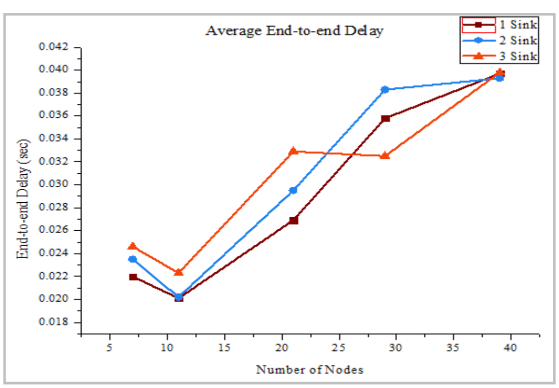


Figure 10 End-to-end delay with different number of sinks in DFR protocols

5.2.3 Depth Scenario

In the third scenarios, Figure 11 and Figure 12 illustrate how the depth affects the packet delivery ratio and end-to-end delay. For this set of simulations, the number of sinks is set to 1 while the number of nodes is set to 7 and varies up to 39. The depth is defined as the vertical distance in meters from source node to sea floor. Figure 11 shows that the depths of 10 m, 25 m and 50 m produced an approximate and almost similar packet delivery ratio performances. Similar results can be seen for packet delay as shown in Figure 12. From both figures, it can show that as the depth increases, the packet delivery ratio decreases and the end-to-end delay increases. The main reason is that by increasing the depth, it has similar effect to reducing the number of available nodes in the network. Consequently, the packet delivery ratio starts to decrease as well. As expected, the end-to-end delay for all depths shows the increasing trends as the number of nodes increases. DFR have better performance with low depth where nodes delivered the packets to the sinks in shortest path possible.

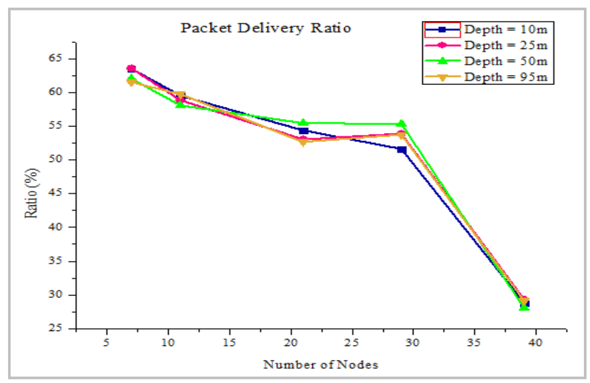


Figure 11 Packet delivery ratio with different depth in DFR

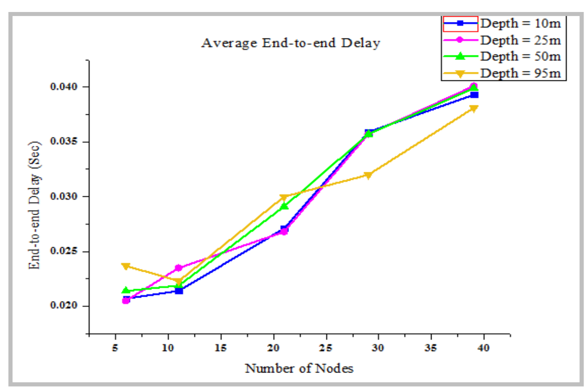


Figure 12 End-to-end delay with different depth in DFR

6.0 DISCUSSION

Four scenarios had been simulated using DFR protocol where one scenario covers triangular topology and the other three scenarios cover random topology. DFR performs packet flooding techniques in order to achieve the reliable packet delivery. The experiment varies the number of nodes in forwarding the packets based on their link quality. This routing schemes rectifies the void problem by the selection of at least one node to transmit the data packet towards the sink. Furthermore, in the multiple sink scenarios, the network settings considered some simple cases in which the sinks are randomly and uniformly deployed on the water surface. It may find better deployment locations to achieve better performance using DFR protocol and the node deployment model. Besides the depth information, such as the residual energy level and estimated distance to neighboring nodes, could also be useful in making routing decisions that can further reduce energy consumption and extend the networks life time. The results thus far, showed that the packet delivery ratio and energy consumption decreases as the number of nodes increases. In contrast, the delay increases with the number of node. This means that the protocol is suitable to be deployed in the scenario with smaller number of nodes.

7.0 CONCLUSION

The research covered more on theory and concept of underwater environment. For underwater acoustic channel, DFR (Directional Flooding Routing) had been chosen because this routing scheme works by forwarding the multicast packets from one source node to many specific intermediate nodes in network. This category of restricted directional flooding in which the sender broadcast the packet to all single hop neighbors towards the destination. The sender also broadcast the packets whether they are data packets or route request packet. The node which received the packet checks whether it is within the set of nodes that should forward the packet. If the route is correct, it will continue transmitting data packets. Otherwise the packet will be dropped. In restricted directional flooding, instead of selecting a single node as the next hop, several nodes participate in forwarding the packet in order to increase the probability of finding the shortest path. The protocol is also robust against the failure of individual nodes and position inaccuracy. This scheme distributes routing information updates quickly to every node in a large network. The proposed performance was evaluated through OMNeT++ simulator in terms of Packet Delivery Ratio, Energy Consumption and End-to-end Delay. By analyzing the simulation results, DFR is considerably reliable for UWSN because this protocol is suitable for the sub aquatic transmission medium such as seawater. Hence, all objectives of this research are achieved and produced an improvement from previous researches.

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