Comparative Analysis of Routing Protocols for Under-Water Wireless Sensor Networks

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***Abstract*—Underwater Sensor Networks (UWSNs) are significantly different from terrestrial sensor networks in the following aspects: low bandwidth, high latency, node mobility, high error probability, and 3-dimensional space. These new features bring many challenges to the network protocol design of UWSNs. The communication range of underwater wireless sensor networks (UWSNs) is limited, and the nodes are equipped with limited power battery whose replacement is expensive due to underwater harsh environment. Moreover, the networks including small number of nodes have communication problems for long ranges. In this paper, we evaluate the performance of three location-based protocols (namely, VBF, HH-VBF, and VBVA) for underwater wireless sensor networks routing for dynamic network topology. Our comparison includes energy consumption, end-to-end delay, and packet delivery ratio.**

Keywords- Underwater Wireless Sensor Networks; Routing protocols; Location Based Routing Protocols; Vector Based Forwarding; Hop-by-Hop Vector Based Forwarding; Vector-Based Void Avoidance; energy consumption.

I. INTRODUCTION

Wireless sensor networks covers only terrestrial applications. However, with 70% of the surface of the earth is covered by water and with the increasing role of oceans in human life, discovering all of the ocean parts became of prime importance. Due to these reasons, many researchers cared about the Underwater Wireless Sensor Networks (UWSNs). UWSNs enable various applications i.e. gas spills monitoring, offshore exploration, disaster prevention, underwater natural resource discovery, water quality analysis, submarine detection, pollution detection etc. However, the routing protocols for terrestrial wireless sensor networks (TWSNs) cannot be used in UWSNs due to major challenges in the design of UWSNs like the limited bandwidth, high propagation delay, high energy consumption due to longer distances, battery power is limited and usually batteries cannot be recharged, also because solar energy cannot be exploited underwater and underwater sensor nodes are prone to failures due to fouling and corrosion [1], also the radio signals used in terrestrial networks are not suitable in UWSNs. The radio signals propagate long distances at extra low frequencies which require large antennas and high transmission power. Hence, acoustic signals are employed as an enabling communication medium in UWSN. This shift from radio signals to acoustic signals imposes many challenges on underwater communications. Therefore, enormous efforts have been made for designing efficient protocols while considering the characteristics of underwater communication [17][25][26].

Routing is one of the fundamental issues in UWSNs. Most of the studies on UWSNs focus on physical layers, while issues related to the network layer such as routing techniques are a new area. Thus, this paper the analyzes the efficiency of some of localization-based routing protocols in UWSNs.

The routing protocols for UWSNs can be classified into localization-based and localization-free routing protocols. In location-based routing protocols it is supposed that each node already has location information about itself and sinks. However, because of the mobility of sensor nodes and harsh environment the localization is not perfect, rather localization-free routing protocols are highly demanded by research communities [3]. In this paper we have focused on a energy consumption for some of localization-based routing protocols, the Vector-Based Forwarding, Hop-by-Hop Vector-Based Forwarding and Vector-Based Void Avoidance routing protocols. The Vector-Based Forwarding (VBF) protocol solve the problem of error probability in dense networks. In VBF the forwarding pipe is guided by a vector from the source to the target nodes, and all the flooding data packets are carried out through this pipe. To improve the robustness, packets are forwarded in redundant paths. Further, a localized and distributed self-adaptation algorithm allows the nodes to reduce energy consumption by discarding redundant packets, whereas no state information is required on the sensor nodes. VBF performs well in dense networks. For sparse networks, we introduced enhanced version of VBF called Hop-by-Hop Vector-Based Forwarding (HH-VBF), it the same of VBF, but instead of using a single pipe from source to destination, HH-VBF defines per hop virtual pipe for each forwarder. Another improvement of VBF protocol called Vector-Based Void Avoidance (VBVA) routing protocol which extends the VBF routing protocol, it addresses the routing void problem in UWSNs by two mechanism vector-shift and back-pressure, these routing protocols are based on the assumption of the localization of sensor nodes in UWSNs.

The rest of this paper is organized as follows. In Section II, the functionality and performance issues of VBF, HH-VBF and VBVA location-based routing protocols are introduced. Section III we show the performance results of VBF, HH-VBF and VBVA location-based routing protocols. Finally, the conclusions and layout some future work are in Section IV.

II. REVIEW OF LOCATION-BASED ROUTING PROTOCOLS

In this section, we discuss in brief three location-based routing protocols, which we will evaluate them. These protocols are:

A. Vector-Based Forwarding (VBF) Routing Protocol

VBF is a location-based routing approach for UWSNs. In this protocol, state information of the sensor nodes is not required since only a small number of nodes are involved during packet forwarding. It utilizes the flooding based approach for routing. Where, flooding is performed in a constrained virtual routing pipe with a radius that covers the area around a vector is predetermined (a certain threshold), a vector is a virtual line from a source node towards the destination. Data packets are forwarded along redundant paths from the source to the sink, which helps handling the problem of packet losses and node failures. Each packet carries simple routing information. In a packet, there are three position fields, SP, TP, and FP, that are respectively; the location of the source, forwarding nodes, and final destination. Each packet also has a RADIUS field, which is a predefined threshold used by sensor nodes to determine if they are close enough to the routing vector and eligible for packet forwarding and a RANGE field in order to handle node mobility [5][7][8][20][21][24][26]. Thus, all the nodes receiving the packet compute their positions. If a node determines that it is close to the routing vector enough (less than RADIUS), it puts its own computed position in the packet and continues forwarding the packet; else, it discards the packet simply. As shown in Figure 1(a), only nodes that are located inside the pipeline, taking into account the threshold value, can be selected as forwarding nodes. The forwarding path is specified by the routing vector from the sender to the target.

VBF uses a self-adaptation algorithm to allow each node to estimate the density in its neighborhood and forward packets adaptively. The Self-Adaptation Algorithm in VBF introduces a measure the suitableness of a node to forward packets, it is an important notation desirableness factor. Upon receiving a packet, it first determines if it is eligible for packet forwarding (close enough to the routing vector). If yes, it holds the packet for a time period, T adaptation , which is computed based on its desirableness factor and other network parameters, otherwise, it will discard the packet [2][3][7][11][13][18][22][23][26].

Figure 1(a) illustrates an example of how to select the next forwarding nodes. Assume that nodes A, B, and C are source nodes. Therefore, they create a virtual pipeline toward the sink and then each source node embeds its sink location and its own location in the header of the data packet and broadcasts it.

- Advantages of VBF:
    - Because only the nodes along the forwarding path are concerned in packet forwarding, this will save the energy of the network.
- Disadvantages of VBF:
    - Sensitivity to the routing pipe's radius.
    - Small data delivery ratio in sparse networks.
    - In case of a void, VBF cannot find a path to forward the packet.
    - It suffers from the communication void problem in sparse networks, this problem occurs when the sender node does not find any neighbor node in its transmission range [1][2][7][13].

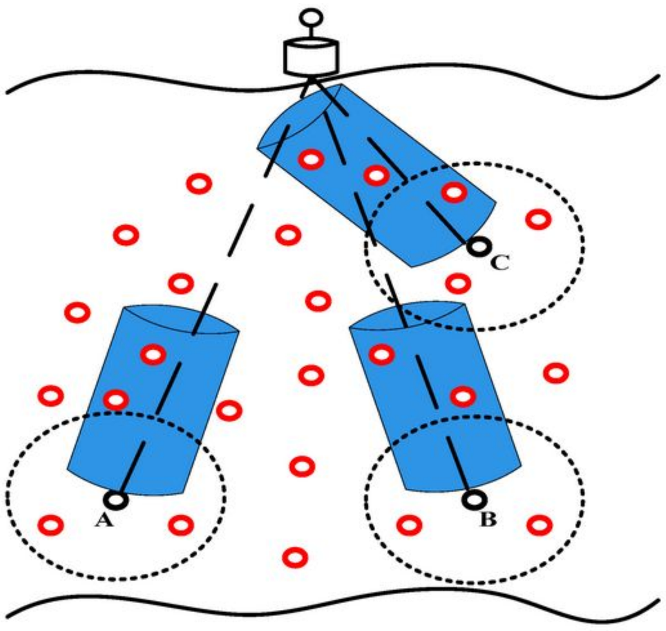

Figure 1(a). Single pipeline in VBF [5].

B. HH-VBF Routing Protocol

Hop-by-Hop Vector Based Forwarding (HH-VBF) is an improvement for a problems that encountered by the VBF like small data delivery ratio in sparse networks, and sensitivity to the routing pipe's radius [5], as in VBF, HH-VBF utilizes the flooding based approach for routing. In HH-VBF, it redefines the routing virtual pipe to be a per-hop virtual pipe creation, instead of a unique pipe from the source to the sink [3][4][11][15][23][26].

The difference of HH-VBF with VBF is that in VBF it considers a single routing vector from a source towards the destination, but, in HH-VBF it considers a routing vector from each forwarder/sender towards the destination [16]. Figure 1(b) illustrates an example of how nodes A, B, and C create their virtual pipeline. As shown in this figure, each source node creates its pipeline towards the sink individually to forward the data packet.

Upon the receipt of a packet, a node computes a vector starting from the transmitter of the packet towards the destination. Then the node calculates the distance between the computed vector and itself. In case, the distance between the vector and the node is smaller than the radius of virtual routing pipe, this node becomes eligible for forwarding and becomes a candidate forwarder, otherwise, it simply discards the packet. The node be eligible for forwarding the packets based on self-adaption algorithm. The self-adaption algorithm in HH-VBF is different from that in the original VBF. To enhance the packet delivery ratio in sparse networks in VBF, HH-VBF assumes some redundancy control in the self-adaption procedure for HH-VBF [3][4][16][18][23].

Each node in the vicinity may hear the same packet multiple times, and calculates its distances to the various vectors from the packet forwards to the sink, so the nodes are hold the packet for some period of time. This time will be proportional to its desirableness factor and, the node having the smallest value of desirableness factor will be the first one to send the packet. As in VBF, the candidate forwarder holds the packet for a particular time (holding time) before forwarding it. The holding time is based on a desirableness factor which illustrates the suitableness of a node for forwarding. Therefore, the node with the smallest desirableness factor will send the packet first [14][16][22].

- Advantages of HH-VBF:
    - Less sensitive to the routing pipe radius than VBF.
    - Provide more paths to deliver data than VBF, which increased the packet delivery ratio in sparse networks.
- Disadvantages of HH-VBF:
    - More traffic compared to VBF due to its hop-by-hop nature.
    - High energy consumption in dense network.
    - It suffers from the communication void problem [1][19].

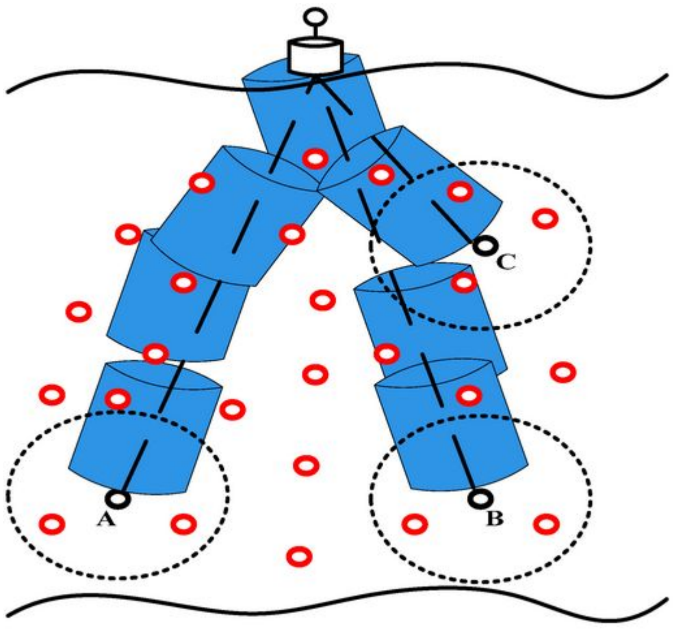

Figure 1(b). Virtual pipelines in HH-VBF [5].

C. VBVA Routing Protocol

Vector-Based Void Avoidance (VBVA) routing protocol, which extends the VBF routing protocol to handle the routing void problem (the sender node does not find any neighbor node in its transmission range) in UWSNs. If there is no presence of void in the forwarding path, VBVA behaves the same as VBF. VBVA uses a location information metric to select the next forwarding nodes. It assumes two mechanisms, **vector-shift** and **back-pressure**. The vector-shift mechanism is used to route data packets along the boundary of a void to select the next forwarding node in the boundary of the void area, when a node determines that it is a void node for a packet, it will try to bypass the void by shifting the forwarding vector of the packet first. To do the vector shifting, the node broadcasts a vector-shift packet to all its neighbors. Upon receiving this control packet, all the nodes outside the current forwarding pipe will try to forward the corresponding data packet following a new forwarding vector from themselves to the target. This process is called vector-shift and we say the void node shifts the forwarding vector.

If the void area is concave, the vector-shift method cannot work efficiently. Therefore, the back-pressure mechanism routes data packets backward to another node that can apply the vector-shift mechanism, it can handle the end-node problem and the concave void. With its void avoidance mechanism, VBVA can potentially find multiple forwarding vectors for a data packet, thus improving the robustness of the network [5][6][10][11][13].

As shown in Figure 2(a), node S is the sender and node T is the sink node, the void area represents by dashed area. At the beginning, node S forwards the packet along the forwarding vector ST, which represents the arrowed line in Figure 2(a), then it keeps listening the channel for some time period. Since the neighboring node D and A of node S are not within the forwarding pipe, they will not forward this packet. Thus node S cannot overhear any transmission of the same packet and concludes that it sits at the edge of a network void. It then broadcasts a vector-shift control packet, asking its neighbors to change the current forwarding vector to DT and AT as shown in Figure 2(a). Nodes D and A repeat the same process. From this figure, we can see that if the void area is convex, it can be bypassed by the vector-shift mechanism [10].

After shifting the forwarding vector of a packet, a node keeps listening the channel to check if there is a neighboring node forwarding the packet with the new forwarding vector. If the node does not hear the packet being forwarded even if it shifts the current forwarding vector, the node is defined as an end node. For an end node, the vector-shift mechanism cannot find an alternative routing path and we have to use a new back-pressure mechanism.

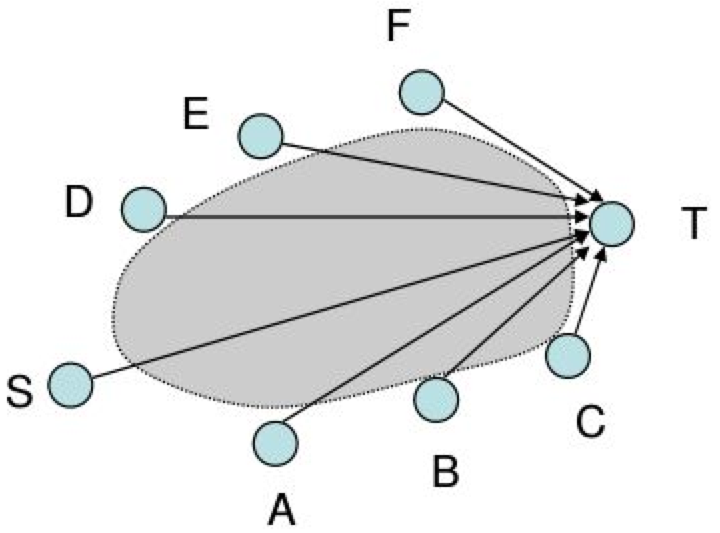

Figure 2(a). An example of vector-shift mechanism [10].

When a node finds out that it is an end node, it broadcasts a control packet, called Back Pressure (BP) packet. Upon receiving a BP packet, if every neighboring node has never shifted the forwarding vector of this packet before, it tries to shift the forwarding vector of the corresponding packet. Otherwise, the node broadcasts the BP packet again. This process of repetitively broadcasting the BP packet call back-pressure process . The BP packet will be routed back in the direction moving away from the target until it reaches a node which can do vector shifting to forward the packet toward the target.

In Figure 2(b), the shadowed area is a concave void, the node S is the sender and node T is the sink. When node S forwards the packet to node C with forwarding vector ST , since node C cannot forward the packet along the vector ST, it will first use vector-shift mechanism to find alternative routes for the data packet. Since node C is an end node, it cannot overhear the transmission of the packet. Node C then broadcasts a Back Pressure (BP) packet. Upon receiving the BP packet, node B first tries to shift the forwarding vector but fails to find routes for the data packet. Then node B broadcasts BP packet to node A and so on. Finally, a BP packet is routed from node A to the source S. Node S then shifts the forwarding vector to HT and DT. The data packet is then forwarded to the sink by the vector-shift method from nodes H and D [13].

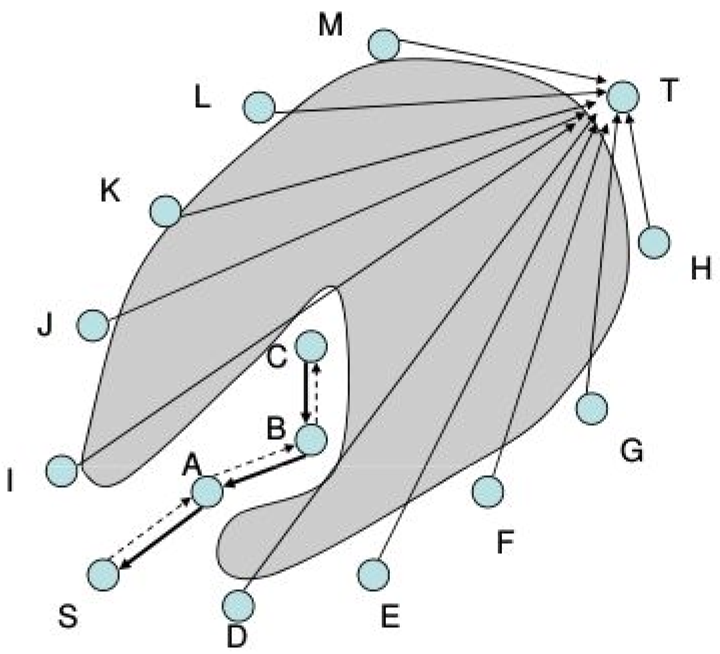

Figure 2(b). An example of back-pressure mechanism [10].

- Advantages of VBVA:
  - Solve the void problem.
  - Void avoidance mechanism generates multiple forwarding vectors, which improve the packet delivery and robustness of the network.
- Disadvantages of VBVA:
  - VBVA void avoidance mechanism introduces more energy consumption.
  - More overhead generated by void avoidance mechanism.

III. PERFORMANCE EVALUATION

Performance is evaluated through measures of energy consumption, average end-to-end delay and packet delivery ratio. The energy consumption is the total energy consumed by the sensor network nodes. The average delay is the average end-to-end delay for each packet received by the sink. And the packet delivery ratio is the rate of the number of packets successfully received by the sink to the number of packets generated by the source.

Analyzing energy consumption, end-to end delay, and packet delivery ratio are very useful in each communication. Because the node in UWSNs are big in size and thus, need more energy for its process, so this will represent the transmitting, receiving, and ideal energy consumption of a node. Also because of large propagation delay, and to define the successful transmission of packets from source to destination.

Simulation is performed by the underwater package Aqua-Sim of ns-2 [9][10], aqua-Sim can effectively simulate acoustic signal attenuation and packet level in underwater sensor networks, In all our simulations, we set the parameters as in Table 1.

Table 1. Simulation Parameters

Simulation Software	NS2 version 2.30(Aqua-sim)
Topology size	600m x 600m x 600m
Number of nodes	20, 40, 60, …, 180, 200
Transmission range	20 meters
Packet size	50 bytes
Simulation time	1000 Seconds
Initial Energy	1000J
Idle power	0.01J
Width	20

Figure 3. depicts the total energy consumption as the number of sensor nodes varies. The energy consumption increases with increase the number of nodes since more nodes are involved in packet forwarding. On the other hand, this figure shows that the energy consumption for the VBF is less than that in HH-VBF and VBVA routing protocols, indicating that the VBF can save more energy with high node density, in VBF only the nodes close to the routing vector are involved in packet forwarding, and all other nodes are in idle state. Moreover, in data forwarding process limited number of nodes are participated, so it is the most energy efficient among these three protocols, since VBF never attempts to consume more energy to overcome the voids in the networks, while VBVA is not energy efficient compared with VBF and HH-VBF due to a large number of generated control packets (Back Pressure packet) and because of the vector-shift mechanism and back-pressure mechanism, which possibly can generate several forwarding vectors and more number of nodes are participate in data forwarding in the networks, this can improve the network's robustness, but they also result in more energy consumption, but regarding to HH-VBF, the routing virtual pipe is redefined to be a per-hop virtual pipe, instead of a unique pipe from the source, so more number of nodes are participate in data forwarding which result in more energy consumption, as shown in Table 2, extracted from Figure 3.

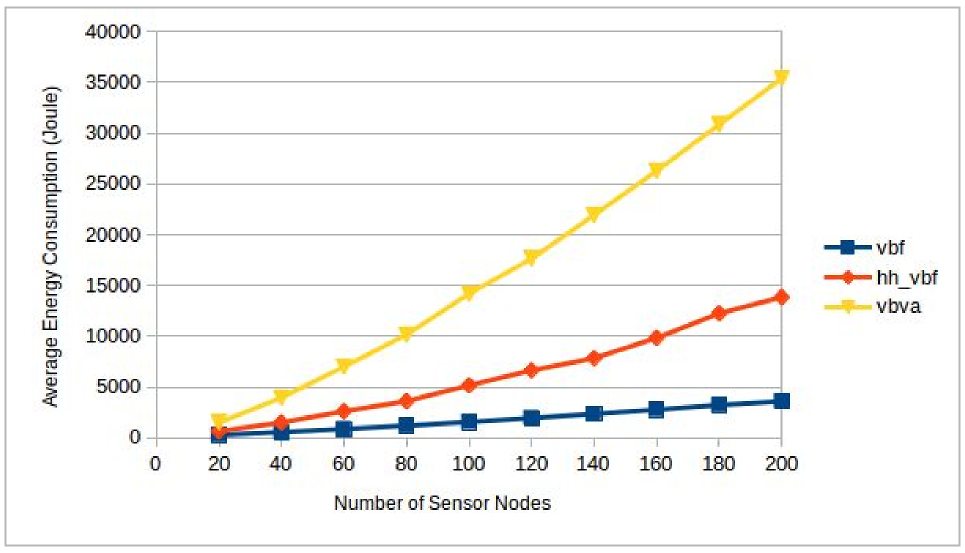

Figure 3. Energy consumption vs. number of sensor nodes.

Table 2. Total Energy Consumption (Joule)

No. of Nodes	**Total Energy Consumption (Joule)**				
	20	**60**	**120**	**160**	**200**
VBF	256.65	849.32	1931.15	2748.61	3580.29
HH-VBF	633.53	2600.35	6627.52	9828.61	13840.82
VBVA	1479.15	6989.97	17641.71	26300.87	35402.99

Figure 4. depicts the end-to-end delay as the number of sensor nodes varies. The average delay decreases as there are more nodes in the network. This trend is attributed to the self-adaptation algorithm. When the number of nodes increases, the path from the sender to the receiver, selected by the self-adaptation algorithm, are closer to the optimal path and since more neighbours nodes, the sender node can find many neighbor node in its transmission range; therefore, the end-to-end delay decreases. On the other hand, this figure shows that the end-to-end delay for the HH-VBF is less than that in VBF and VBVA routing protocols, indicating that the HH-VBF redefines the routing virtual pipe to be a per-hop virtual pipe creation, which has a greater possibility to find an optimal path for data forwarding, while in VBVA, it assumes two mechanisms to handle the routing void problem this result in more end-to-end delay, but in VBF, it is the highest end-to-end delay than HH-VBF and VBVA, because VBF suffers from void problem, so it can't find a path to forward the packet, as shown in Table 3, extracted from Figure 4.

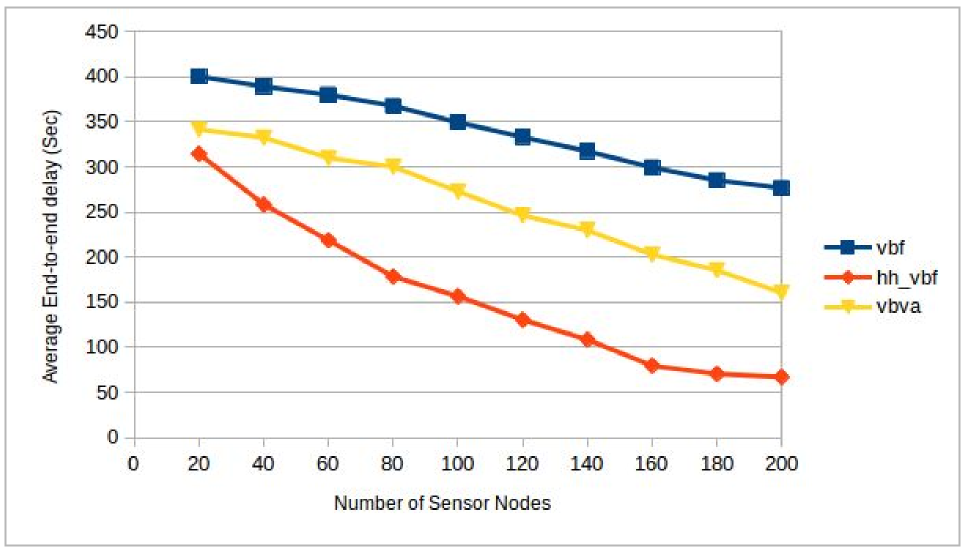

Figure 4. End-to-end delay vs. number of sensor nodes.

Table 3. Total End-to-End Delay (Sec)

No. of Nodes	**Total End-to-End Delay (Sec)**				
	20	**60**	**120**	**160**	**200**
VBF	400.347	379.944	333.112	299.507	276.755
HH-VBF	314.528	218.655	130.557	79.5284	67.0699
VBVA	341.621	310.067	246.109	202.857	160.608

Figure 5. depicts the Packet Delivery Ratio as the number of sensor nodes varies. The packet delivery ratio increases with increase the number of nodes since more neighbours nodes. On the other hand, this figure shows that the packet delivery ratio for the VBVA is high than that in HH-VBF and VBF routing protocols, indicating that the VBVA handles the routing void problem by assumes two mechanisms and it can potentially find multiple forwarding vectors for a data packet, thus improving the packet delivery and robustness of the network, also we noticed that the HH-VBF has a good packet delivery than the VBF because in HH-VBF, each node forms a new routing pipe for each forwarding node, this mechanism is not too sensitive to a predefined virtual routing pipe radius and hence find more path for data delivery, while in VBF, it is too sensitive to the routing pipe radius threshold, because of the use of the unique source-to-sink vector, the creation of a single virtual pipe may significantly affect the routing efficiency in different node density areas. If nodes in one area are too sparsely distributed, then it is quite possible that very few or even no nodes lie within the virtual pipe eligible for data forwarding, hence data delivery ratio is degraded, as shown in Table 4, extracted from Figure 5.

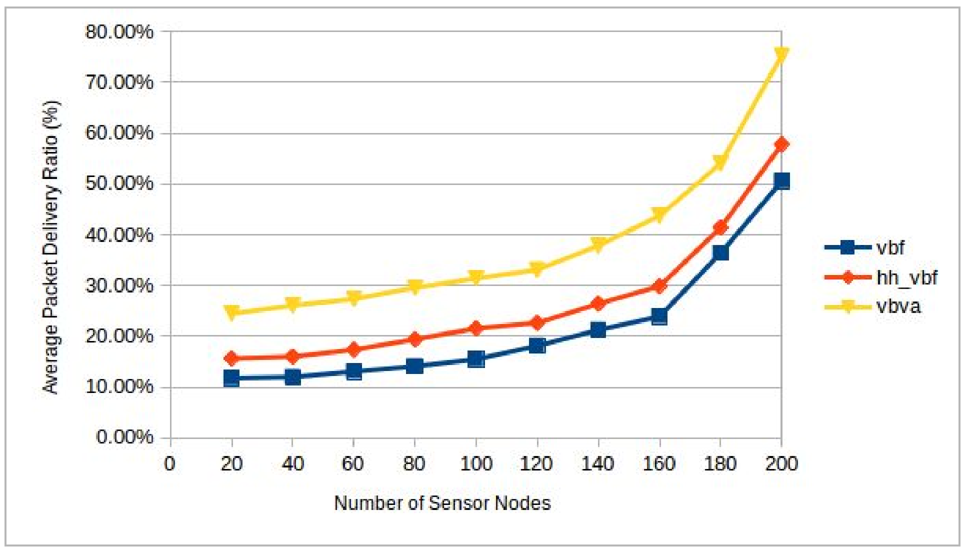

Figure 5. Packet delivery ratio vs. number of sensor nodes.

Table 4. Packet Delivery Ratio (%)

No. of Nodes	Packet Delivery Ratio (%)				
	20	60	120	160	200
VBF	11.714%	13.026%	18.087%	23.883%	50.553%
HH-VBF	15.585%	17.329%	22.606%	29.828%	57.795%
VBVA	24.454%	27.328%	33.073%	43.735%	75.342%

IV. CONCLUSIONS

In this paper we evaluated routing protocols that were discovered for underwater sensor networking. Nowadays Because of the vital role of the ocean in the humanity's life. Underwater observation coming into a seat of attention. We compared three routing protocols based on energy consumption, end-to-end delay, and packet delivery ratio for underwater sensor networks and based on the results obtained, the VBF is mostly and highly recommended protocol in term of energy consumption due to a limited number of nodes are participated in packet forwarding, which are close to the routing vector, while all other nodes are in idle state. Also VBVA can achieve the highest packet delivery ratio compared with VBF and HH-VBF, because in VBVA, two mechanisms are assumed to handle the routing void problem, it can find multiple forwarding vectors, which improve the packet delivery and robustness of the network. While in term of end-to-end delay, HH-VBF has a lowest end-to-end delay because it redefines the routing virtual pipe to be a per-hop virtual pipe creation, which has a greater possibility to find an optimal path with less delay compared with VBF and VBVA.

However, the routing pipe radius threshold significantly affects the routing performance. However, the radius of the pipe in VBF, HH-VBF, and VBVA has a great impact on the total energy consumption and packet delivery ratio and end-to-end delay. Selecting a large radius can involve more nodes in packet forwarding; which leads to more energy consumption and a less end-to end delay. Moreover, a lower radius causes more packet failures. On the other hand, when the network gets denser, VBF shows its advantage over HH-VBF. But in sparse networks HH-VBF yields much better performance than VBF, it can significantly improve the robustness and enhancing the data delivery ratio in sparse networks. Also the packet delivery ratio, the total energy consumption, and the average end-to-end delay do not change much with node speed. Therefore, VBF, HH-VBF and VBVA can handle node mobility effectively.

FUTURE WORK

In future work we plan to manipulate the architecture of VBVA protocol to achieve less end-to-end delay by implementing a hop-by-hop routing vector and hence find more path for data delivery.

REFERENCES

[1] Haitao Yu, Nianmin Yao, and Jun Liu "An Adaptive Routing Protocol in Underwater Sparse Acoustic Sensor Networks", 2014 Published by Elsevier B.V.

[2] Y. Bayrakdar, N. Meratnia, and A. Kantarci "A Comparative View of Routing Protocols for Underwater Wireless Sensor Networks", IEEE, OCEANS, 2011 IEEE - Spain, 6-9 June 2011.

[3] D. Ibrahim, T. Eltobely, M. Fahmy, and E. Sallam "Enhancing the Vector-Based Forwarding Routing Protocol for Underwater Wireless Sensor Networks: A Clustering Approach", ICWMC 2014 : The Tenth International Conference on Wireless and Mobile Communications.

[4] N. Nicolaou, A. See, P. Xie, J. Cui, and D. Maggiorini "Improving the Robustness of Location-Based Routing for Underwater Sensor Networks", Published: 17 September 2007.

[5] A. Khasawneh, M. Shafie Bin Abd Latiff, O. Kaiwartya, and H. Chizari "Next Forwarding Node Selection in Underwater Wireless Sensor Networks (UWSNs): Techniques and Challenges", Published: 25 December 2016.

[6] P. Xie, Z. Zhou, Z. Peng, J.-H. Cui, and Z. Shi, "Void Avoidance in Three-dimensional Mobile Underwater Sensor Networks," Proc of the 4th international conference of wireless algorithms, system, and applications (WASA 2009).

[7] P. Xie, J.-H. Cui, and L Lao, "VBF: Vector-based Forwarding Protocol for Underwater Sensor Networks," International conference on networking (IFIP networking), 2006.

[8] C. Namesh, and Dr. B. Ramakrishnan, "Analysis of VBF protocol in Underwater Sensor Network for Static and Moving Nodes", January - February (2015).

[9] NS-2 : Network Simulator, http://www.isi.edu/nsnam/ns.

[10] P. Xie, and et al., "Aqua-sim: A Ns-2 based Simulator for Underwater Sensor Networks," Proc of IEEE/MTS OCEANS, 2009, pp. 1-7.

[11] M. NAJM, and A. DINAR, "Comparative Study of Routing Protocols in Pollution Monitoring System Based on Underwater Wireless Sensor Networks", University of Technology, Baghdad, (Iraq), June 2013, Pgs.85-91.

[13] P. Xie, Z. Zhou, Z. Peng, J. Cui, and Z. Shi, "Void Avoidance in Mobile Underwater Sensor Networks", University of Connecticut, Storrs, CT 06269, 2009.

[14] S. Ahmed, I. U. Khan, M. B. Rasheed, M. Ilahi, R. D. Khan, S. H. Bouk, and N. Javaid, "Comparative Analysis of Routing Protocols for UnderWater Wireless Sensor Networks", COMSATS Institute of Information Technology, Islamabad, Pakistan, 3(6)130-147, 2013.

[15] S. Andrabi, M. Kumar, and M. Scholar, "A Comparative Study of Routing Protocols for Underwater Wireless Sensor Network", Department of Comp. Sc. &Engg.Shri Mata Vaishno Devi University, Katra (J&K), India, Sept 2016 - March 2017 pp. 27-29.

[16] A. Wahid, and K. Dongkyun, "Analyzing Routing Protocols for Underwater Wireless Sensor Networks", Kyungpook National University, 1370 Sankyuk-dong, Book-gu, Daegu 702-701, Korea, Vol. 2, No. 3, December 2010.

[17] S. Ghoreyshi, A. Shahrabi, and T. Boutaleb, "A Novel Cooperative Opportunistic Routing Scheme for Underwater Sensor Networks"

[18] Z. Wadud, S. Hussain, N. Javaid, S. Bouk, N. Alrajeh, M. Alabed, and N. Guizani, "An Energy Scaled and Expanded Vector-Based Forwarding Scheme for Industrial Underwater Acoustic Sensor Networks with Sink Mobility", September 2017.

[19] M. Sunhaloo, and R. Subramanian, "A study of the performance of vector based forwarding in underwater acoustic sensor network" ,2011.

[20] A. Das, K. V. Kumar, and M. Rao, "Current State of Art Techniques in Underwater Wireless Sensor Network", Department of Computer Science & Engineering, ITER, Siksha 'O' Anusandhan University, India, 751030, May-June 2017.

[21] R. Bu, Sh. Wang, and H. Wang, "Fuzzy logic vector–based forwarding routing protocol for underwater acoustic sensor networks", 17 January 2018.

[22] M. Khalid, Z. Ullah, N. Ahmad, M. Arshad, B. Jan, Y. Cao, and A. Adnan, "A Survey of Routing Issues and Associated Protocols in Underwater Wireless Sensor Networks", Northumbria University, Newcastle upon Tyne, UK, 2017.

[23] P. Xie, Z. Zhou, N. Nicolaou, A. See, J. Cui, and Z. Shi, "Efficient Vector-Based Forwarding for Underwater Sensor Networks", University of Connecticut, Storrs, CT 06269, USA, 25 February 2010.

[24] M. Pouryazdanpanah, M. Anjomshoa, A. Salehi, A. Afroozeh, and M. Moshfegh, "DS-VBF: Dual Sink Vector-Based Routing Protocol for Underwater Wireless Sensor Network", IEEE 5th Control and System Graduate Research Colloquium (ICSGRC), IEEE, Shah Alam, Malaysia, 2014, pp. 227-232.

[25] M.ChinnaDurai, S.MohanKumar, Dr.S. Sharmila, " Underwater Wireless Sensor Networks ", COMPUSOFT, An international journal of advanced computer technology, 4 (7), July-2015.

[26] Comparison of Routing Protocols for Underwater Sensor Networks: A Survey, GIANTSIS CHRIS, Department of Information Systems, University of Macedonia, Economic and Social Sciences, 156 Egnatia str. GREECE.