An Efficient Routing Scheme Based on Node Density for Underwater Acoustic Sensors Networks

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Abstract

Underwater Wireless Sensors Networks (UWSNs) are deployed in remotely monitored environment such as water level monitoring, ocean current identification, oil detection, habitat monitoring and numerous military applications. Providing scalable and efficient routing is very challenging in UWSNs due to the harsh underwater environment. The biggest difficulties are the nodes inherent movement due to water current, long delay in data transmission, low bandwidth of the acoustic signal, high error rate and energy scarcity in battery powered nodes. Many routing protocols have been proposed to solve the aforementioned problems. There are three broad categories of routing protocols namely depth based, energy based and vector-based routing. Vector Based Forwarding protocols perform routing through virtual pipeline by defining their radius which give proper direction to packets communication. We proposed a routing protocol termed as Path-Oriented Energy Scaled Expanded Vector Based Forwarding (PESEVBF). PESEVBF takes into account all parameters; holding time, the source nodes packets routing path and void holes creation on the second hop; PESEVBF not only considers the packet upward advancement but also focus on density of the forwarded nodes in terms of number of potential forwarding and suppressed nodes for path selection. Node selection in resultant holding time is based on minimum Path Factor (PF) value. Moreover, the suppressed node will be selected for packet forwarding to avoid the void holes occurrences on the second hop. Performance of PESEVBF is compared with other routing protocols using matrices such as energy consumption, packet delivery ratio, packets dropping ratio and duplicate packets creation indicating considerable performance improvement.

Keywords: Vector Based Forwarding Protocol, Path-Oriented Energy Scaled Expanded Vector Based Forwarding (PESEVBF), throughput, Path Factor, Underwater Wireless Sensors Networks

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1. Introduction

The word communication is derived from Latin which literally means "to share" and it depicts purposeful exchange of the information between peoples and devices," in Proc. of today's world, there are numerous ways of communication and different mediums are introduced to achieve the target. Different devices communicate with each other, making a network of communication," in Proc. of order to create a communication environment, sensor networks comprising of heterogeneous intelligent devices interconnect with one another. The primary concept behind a sensor network is that a sensor-equipped devices, node or antenna sense relevant and necessary data and transmits it to base station(s) dispersed throughout the network for further processing. From the sensor nodes to the base station, data is transferred using either a wired or wireless communication route," in Proc. of a wired communication sensor network, a physical link is required for data transfer between sensor nodes and targeted sink nodes or between sink nodes and data processing base station; this is not necessary in wireless communication.

Different kinds of sensors devices collaborate among themselves in Wireless Sensor Networks (WSNs) via wireless communication. WSNs are made up a large number of wireless devices that are connected to one another, communicate and work together to improve sensing and detect the environment. The wireless sensor network has a wide range of features, including interactive bandwidth, data switching, and limited battery power. WSNs come in various flavors; worth mentioning terrestrial wireless communication and underwater wireless communication. The Radio Frequency (RF) signal is used in wireless communication on the ground; however, it performs poorly and degrades in numerous ways when used for underwater communication. First, the RF signal is not detectable in underwater due to its significant attenuation. Second, Underwater Wireless Sensor Networks (UWSNs) have a highly dynamic network structure since most nodes can passively move with water currents (with the exception of a few fixed nodes). With land-based routing protocols, sensor networks must routinely update routing information in order to operate complex networks, adding a significant overhead to the routing process. Hence, acoustic communication is commonly used for routing underwater. **Table 1** displays the salient characteristics of acoustic and radio waves.

When compared to terrestrial Wireless sensor Networks, UWSN communication techniques are completely different. A UWSN uses an audio signal for routing and similar to radio signal we cannot use optical signaling for transmission because optical transmissions require a direct line of sight between nodes, they cannot be used for communication in UWSNs. Additionally, because underwater channels and nodes move quickly, they are rarely in the direct line of sight, which cause the optical connection to change more frequently. The most practical method is typically chosen, and it is the acoustic signal in UWSNs. The acoustic signal can travel with less severe channel effects than electromagnetic and optical waves.

Acoustic wireless sensors nodes are placed underwater and sink node(s) situated on the water surface form the basic structure of UWSNs. Unlike sink nodes, the sensor nodes are constrained by energy and other factors [1]. Sink node often has less power restrictions, but the acoustic sensors battery life is more constrained [2]. A sink on the ocean surface has the responsibility of gathering information (valuable data) and transmitting it to the fusion centers for additional processing over a radio connection. Sound and radio modems are installed in the sinks and GPS modules. Each sensor node deployed in underwater equipped data to the sink node utilizing multi hop routing. UWSNs additionally contains tiny, antenna-mounted nodes equipped with a pressure gauge, bladder gadgets, and depth controller [3],” in Proc. of the UWSN architecture, sensor nodes are deployed underwater, whereas sink nodes are placed near the water surface. Sink nodes use radio signals to communicate with one another and the base station, whereas sensor node uses acoustic signals. Using Underwater Acoustic Sensor Networks (UASNs) is a dependable way to manage aquatic application, from environmental screening to the detection of intrusion [4]. Underwater Wireless Sensor Networks (UWSNs) use UASN as a tool to investigate the oceanic environment. The routing system is used by the acoustic sensors to collect the data and transmit it to the sink. UWSNs has been focus for researchers because of the significant and vital application in oceanic science. Testing for pollutants, locating ocean currents, submersible research, habitat monitoring, oil findings, underwater surveys, and seabed management are just a few examples of application for UASNs [5].

Table 1. Properties of Radio and Acoustic Signal

Serial	Properties	Radio Signal	Acoustic signal
1	Waves	Electromagnetic waves	Mechanical Waves
2	Nature	Transverse	Longitudinal
3	Polarization	Polarize	cannot Polarize
4	Propagation	Very fast, Speed of light	Very slow, 1500m/s
5	Production	Produces from moving charge particles	Produces from vibration of objects
6	Medium	No need	Needed
7	Bandwidth	3kHz-300GHz	5kHz-15kHz
8	Deployment Cost	Less Expensive	More Expensive

2. Literature Review

In this section we briefly discuss some important routing protocols, which are related to UWSNs. A comprehensive review of the previous work is discussed. Also, focusing on some of the pertinent and most recent protocols about routing in different scenario are elaborated. The research challenges, shortcoming and achievement of the literature reviewed are highlighted.

2.1. Depth Based Routing Protocols

Here, we are mainly focusing on Depth-Based Routing protocols. The protocol knows as Depth-Based Routing (DBR) [6] uses a depth-based routing technique that routes based on the depth difference between nodes. Sensor node directed the packet to the nodes located at the surface that is sink nodes, in order to decide which node will be the best next forwarder for the packet, utilizes a holding time computation in which a node must hold the received packet for that amount of time. Additionally, it prevents nodes in the same local regions from delivering the same packets to each other, which effectively lowers energy utilization and reduce packets redundancy," in Proc. of [7], time-critical routing schemes are proposed that are primarily concerned with lowering End to End delay. These include Dynamic Source Depth Based Routing (DSDBR), Delay-Sensitive Energy Efficient Depth Based Routing (DSEEDBR), and Delay-Sensitive Adaptive Mobility of Courier Nodes in Threshold-optimized Depth-based Routing (DSAMCTD). DSDBR, DSEEDBR, and DSAMCTD collaborate to handle this through active signaling, delay-sensitive holding time, and weight function, minimizing End to End delay and accelerating packet transmission, affecting the routing energy of the network. Weighting Depth and Forwarding Area Division (WDFAD-DBR) [8] is another novel technique that considers how the performance of the entire network is impacted by the development of the void holes for succeeding forwarder node," in Proc. of order to reduce packet loss, WDFAD-DBR takes into account the second hop forwarding technique, which significantly improves network dependability. Choosing which node to utilize as the packet relay, if there are void holes at the second hop is one of the downsides of WDFAD-DBR. Another unique protocol called Dolphin and Whale Pods Routing Protocol (DOW-PR) [9] for UWNS is suggested to overcome some of the pertinent problems with WDFAD-DBR," in Proc. of addition to two-hop communication, like in WDFAD-DBR, the developers of DOW-PR also considered the number of Potential Forwarding Nodes (PFNs) and the number of Suppressed Nodes (SUPs)," in Proc. of order to take it simple to understand and compute the local node information, it is also advised to divide network transmission into multiple phases in the Adaptive Mobility of Courier Nodes in Threshold-optimized Depth-Base Routing Protocols (AMCTD-DBR) [10]. This will increase the life time of the network," in Proc. of order to improve the performance of AMCTD-DBR in terms of holding time calculation, path loss factor due to remote transmission, flooding of packets, and energy limit, improved Adaptive Mobility of Courier Nodes in Threshold-optimized Depth-Based Routing AMCTD-DBR (iAMCTD-DBR) was proposed [11]. The author of iAMCTD-DBR made use of the already-existing AMCTD phases while adding a few new ones," in Proc. of [26], the authors worked on finding the best network in a fully interconnected wireless medium which are desirable and useful for the end user based on integrated Fuzzy AHP-TOPSIS, so that to minimize the traffic congestion issue and slow services.

2.2. Energy Based Routing Protocols

The energy-based routing which acts as a route life force in terrestrial and underwater sensor network. But here, we talked about underwater routing, which requires special consideration in this context, because in the sensor network, the battery serves as a source of power that is housed in a node, and we are unable to quickly recharge or replace it while the data is being transmitted.

The protocols which are under the jurisdiction of energy-based routing are discussed next. The authors of [12] presented a Dynamic Routing Protocol (DRP) protocol that took into account both the energy remaining in the sender and receiver nodes as well as the likelihood that packets between those nodes would collide," in Proc. of order to maintain the network, DRP seeks a channel for packet transmission that has low probability of collision and more remaining energy. Similarly, another routing technique, Stateless P2P Routing protocol (SPR) [13] also focuses on the communication path, choosing the shortest route for packet transmission between nodes in order to keep the network active and lengthen its lifespan. While in [27], the uncovering and classification approach of malicious traffic are discussed by using Fuzzy AHP, MCDM methodologies and implemented TOPSIS for order assessment," in Proc. of [28], the authors summarize how to protect and secure the physical devices that is the concept of IoT connected to the world of non-secure internet. Moreover, the application, challenges and the concept of IoT are also discussed in details. The author of Energy-Aware and Void-Avoidable Routing Protocol (EAVARP) [14], proposed another innovative protocol having two phases: the layer phase and the data gathering phase. The distance between a source and target node separated into layers during the layering phase, and during the data collection phase, nodes direct their data toward the sink node based on where they are located on the layer of the sink node. There stages are taken into consideration prior to data transmission, and their major objective is to guide the path toward the sink node. The largest problem with UWSNs is the uneven energy distribution of the source nodes, which causes gaps in packet transmission, as previously described," in Proc. of order to maintain the network operational, a different routing scheme called Depth-Based Energy-Balanced Hybrid (DB-EBH) [15] based on direct and multi-hop network connections is proposed. Localization data is gathered from depth sensors installed at each sensor nodes; In order to improve network performance as a whole, Proactive routing Approach with Energy efficient Path Selection (PA-EPS) [16] is proposed, which consider all network affecting characteristics and provides an in-depth analysis of each factor impact on the network. This protocol suggests a proactive routing strategy for both sparse and dense sensor networks.

2.3. Vector Based Routing Protocols

Focusing on Vector Based Routing Protocols required special attention here, as the whole concept of our manuscript are surrounding mainly around vector-based routing. So, starting from the very beginning where Vector Based Forwarding (VBF) [17] protocol is proposed, in which routing is carried out based on the position of the nodes and virtual vectors," in Proc. of VBF, a virtual pipeline or fixed routing vector is created, emerging from source to sink node. Routing decisions are made using this virtual pipeline. To reduce the amount of energy used during packet transmission, a self-adoption algorithm is proposed. Another protocol, Hop by Hop-VBF (HH-VBF) [18], based on VBF, was suggested," in Proc. of this protocol, a direct virtual pipe was established at each hop in accordance with the network's node distribution. The author's major goal with HH-VBF was, to fix VBF shortcomings in low node density networks. Another protocol Adaptive HH-VBF (AHH-VBF) [19] based on HH-VBF was proposed, focuses on adaptively modifying pipelines in sparse and dense sensor networks. Also, in [29], a Point Multiplication (PM) is presented and mainly focusing on the optimization and latency of the hardware resources by using bit-serial method and on the reduction of the pipeline registers. The efficacy of the route was increased by Energy Scaled and Expended VBF (ESEVBF) [20]; through rescheduling the holding duration of the nodes in accordance with the remaining energy and, if necessary, suppressing more packets. The normalization process is carried out by obtaining data on the remaining energy at each node dispersed over the local area so that, ESEVBF balances the energy. This indicates that the holding time estimation in ESEVBF does not have a fixed number, but rather, depending on the energy routing and balancing, while customizing the holding time accordingly. By extending the holding period to the second hop, Extended ESEVBF (EESEVBF) [21] improves ESEVBF while also decreasing packet losses and suppressing duplicate transmission. Also, another novel approached based on the block chain are proposed in [30] for enhancing the privacy and security of the data placed in the cloud. The proposed scheme works on the encryption of data before outsourcing it the cloud. While in [31], a design for increasing the scalability and throughput called Block Trail are proposed based on block chain and used for the efficiency in audit trails. As the block chains are equipped in audit trails for transparent and secure processing of data in enterprise business.

3. Motivation and Contribution

The objective of UWSNs is to successfully transport of packets to the target regions with least amount of overhead. Hence, to reach this goal, researcher have explored many routings protocol paying special focus to optimize the energy, minimize the End-to-End delay and enhance the packet delivery ratio. Based on the ESEVBF and EESEVBF protocol design considerations, we propose PESEVBF routing protocol for UASNs. The novelty of our proposed protocol is described as follows.

- Investigation of efficient routing paths for different scenarios of the network such as sparse and dense sensor networks.
- Paths selection for routing which are efficient and have less traffic congestion, so that the energy and time delay of the network is conserved.
- To achieve the above two points, we in PESEVBF, introduce the Path Factor (PF) in holding time setup, functioning to select the best route at different hop of the potential forwarding nodes.
- Minimizing the packets dropping ratio above the second hop, by selecting the suppressed nodes when there is a void hole.

This paper is further prepared as follow: Section 4 details the problem statement; section 5 contains the proposed work, main architecture, algorithm, parameters description and performance measures calculations," in Proc. of section 6, the simulation results are described and lastly the conclusion and upcoming direction are given in section 7 and section 8 respectively.

4. Problem Statement

Energy conservation, End to End delay and multipath routing are the major issues with UWSNs. Researcher worked on many routing strategies such as VBF, ESEVBF and EESEVBF for finding the efficient solution to it. Enhanced Energy Scaled and Expended Vector Based Forwarding (EESEVBF) protocol extended the holding time of Energy Scaled and Expended Vector Based Forwarding (ESEVBF) protocol to the second hop Potential Forwarding Nodes (PFN) in order to increase the net packet advancement and enhanced the network life time. Additionally, EESEVBF uses the Hidden Terminal Problem to prevent the production of duplicate packets. The node distance from the pipeline; the distance to the second hop PFN from the source; the distance from the first hop PFN to its destination; and the distance from the transmission boundary in relation to the inverse energies of the first and second hop PFNs are all taken into consideration when calculation the holing time of EESEVBF. EESEVBF takes in account related factor of holding time, but it ignores the network density, or the quantity of forwarders and suppressed nodes of the source node, which use more energy while routing data. Moreover, EESEVBF considers two hop distance from the source node for packet advancement but not considering if there is a void hole above the second hop.

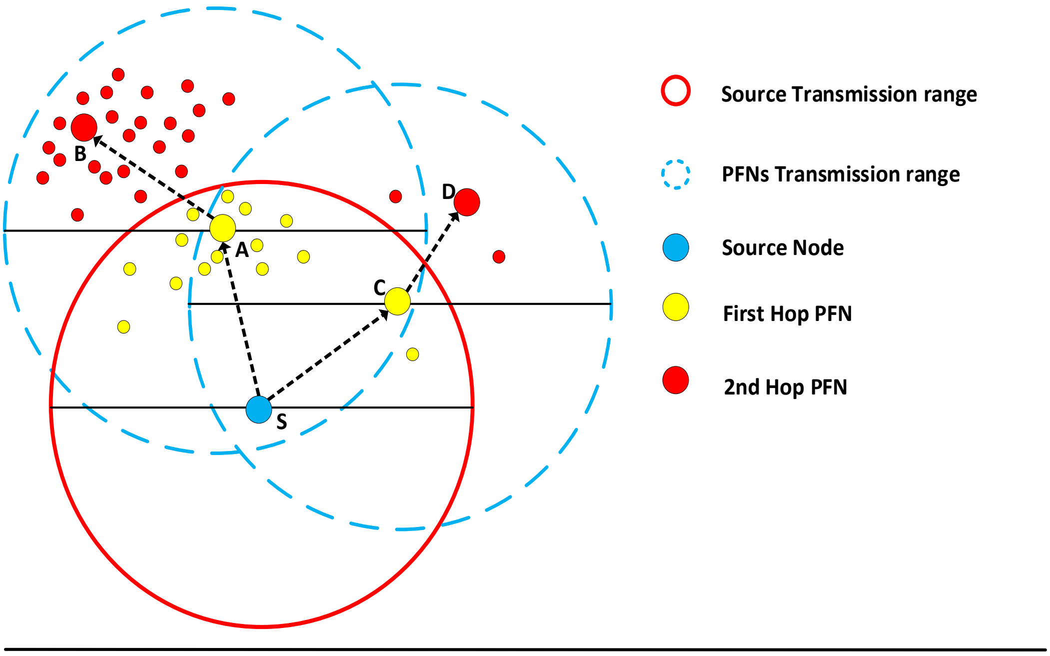

Fig. 1. Problem Statement Explanation

Consider we have two scenarios for forwarding of packet from node S as shown in **Fig. 1**. According to the EESEVBF the node S will select node A and B at first and second hop respectively, containing more energy and covering more distance at the second hop, so node A and B will be selected for forwarding to the next forwarder. As in EESEVBF, we are not considering the path selection, as there are numerous nodes in the same transmission range for receiving and forwarding the same packets which will lead us to energy scarcity. So, considering these problems we have another scenario in which we select node C and D shown in **Fig. 1**, for forwarding the packet having same energies and each node covering small distance for forwarding the packets but there is a smaller number of nodes are takes part in receiving and transmitting the data. So, by comparing EESEVBF and our proposed protocol PESEVBF, EESEVBF considering energies and distance covered for transmitting the packets at first and second hop but not the number of nodes; But in PESEVBF, we are focusing on the path selection, that is we selected those paths for data forwarding which are less traffic as shown in **Fig. 1**, to overcome the energy losses and collision of packets.

5. Proposed Work

In this section our proposed work is discussed in detail which contains basic architecture, the preliminaries, notation used for the definition of the basic parameters, the holding time calculation and packet forwarding strategies.

5.1. Basic Architecture

Acoustic wireless sensors placed underwater and one or more sinks placed on the water surface make up the basic structure of the UWSN. Unlike sink nodes, the sensor nodes are constrained by energy, battery life, harsh underwater environment while the sink has less restriction [22] [4]. A sink on the ocean surface has the responsibility of gathering information (valuable data) and transmitting it to the fusion/base centers via RF signal for additional processing. Sound and radio modems are installed in the sinks and GPS module.

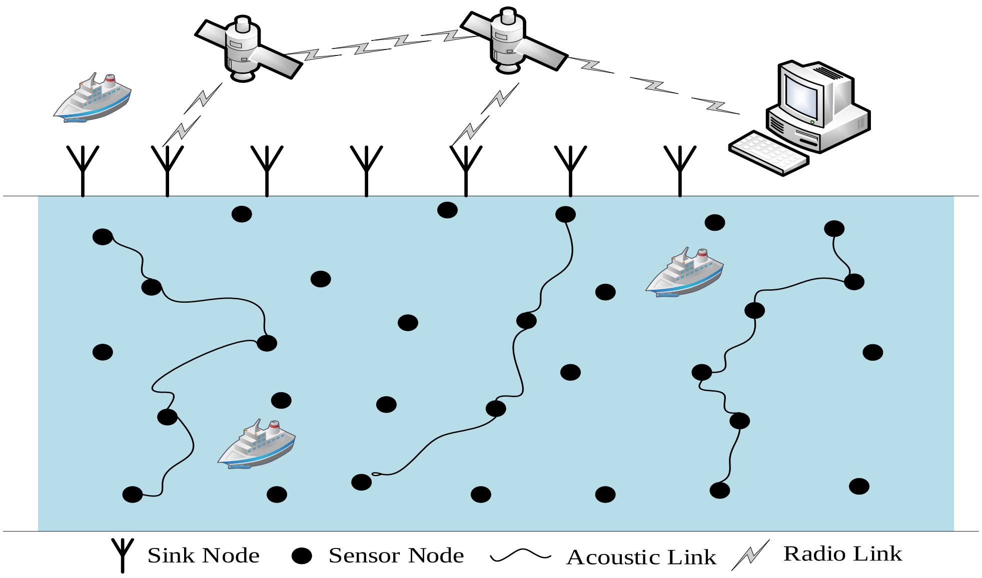

Fig. 2. Basic Architecture of UASN

Each sensor node in the sensor-equipped aquatic architecture analyses the nearby underwater activities and uses multi-hop routing to transfer the pertinent data to the sink node. Utilizing a pressure sensor, communication devices and a depth controller, UWSNs also has tiny antenna mounted node [23]. The general architecture of UWSNs is shown in **Fig. 2**, where sink nodes located at the top of the ocean and nodes for each sensor are distributed underwater. Sink nodes use radio signal to communicate with one another and the base station, whereas sensor nodes use acoustic singles.

Preliminaries

First, we define some of the important parameter, which is used throughout in our proposed scheme in order to establish the basic terminology regarding the discussions mentioned ahead.

5.1.1. Sink Node:

The node located at the surface of water and considered in our protocol as the most prominent destination node is called sink node. Let set S is the sink nodes set in the whole network deployment scenario then we can express S in Equation (1), as:

$$S = (S1, S2, S3, \dots \dots, Sn) \quad (1)$$

Where S1, S2 up to S_n in (1), are the sink nodes located at the sea surface.

5.1.2. Transmission range T_r^D:

The range allocated for the flooding to every node according to the transmission power level and node distribution in the local region. A source node $D(x_D, y_D, z_D,)$ located in a three-dimensional space having a transmission range r can be represented as T_r^D.

5.1.3. Eligible Neighbor Nodes ENN:

When nodes are located inside the transmission range of other node, then these nodes are called Eligible Neighbor Nodes (ENNs). Consider a node j located inside the transmission range of node i, so mathematically this expression can be written in Equation (2), as:

$$ENN_i = i \epsilon S_N \wedge D_j^i \leq T_r^i \quad (2)$$

Where the number of sensor nodes in a network is denoted by S_N in (2) and D_j^i is the three-dimensional Euclidean distance between node i and j located in x, y and z planes respectively. This distance mathematically can be represented and shown in Equation (3):

$$D_j^i = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2 + (z_i - z_j)^2} \quad (3)$$

5.1.4. Potential Forwarding Nodes PFN:

Those nodes which are located inside the transmission range of other node but their depth $Depth_x$ is smaller than the other nodes then all these nodes are called Potential Forwarding Nodes (PFNs). Consider a node j will be a PFN of node i if it is satisfied the inequalities shown in Equation (4):

$$PFN_j \subseteq ENN_i \wedge Depth_j < Depth_i \quad (4)$$

5.1.5. Suppressed Nodes SUP:

Those nodes which are located inside the transmission range of other node but their depth is more than the other nodes then all these nodes are called Suppressed Nodes (SUPs). Consider a node j will be a suppressed node of node i if it is satisfied the inequalities shown in Equation (5):

$$SUP_j \subseteq ENN_i \wedge Depth_j > Depth_i \quad (5)$$

5.2. Holding Time (HT_P^i) Calculation

In this section we will discuss about the holding time of the packet for a node that is what should be the policy for a node to hold or forward the received packet to the forwarded nodes or PFN located in its range. Each node has an internal depth sensor, which allows it to readily determine its depth. When a node receives a packet, it first determines if its depth is greater than the depth of the packet it has just received. If it is, the node drops the packet immediately; otherwise, it calculates it’s holding time.

The general trends of the packet transmission are that, node received packet, then they compute their holding time according to their depth. When a node located at more depth, then it will drop the packet and other nodes located at smaller depth and inside the range of the forwarded node will ultimately start to forward the packet. Consider a node i for packet p, the holding time Equation (6), derived from Stretching Holding time Paper [21] is:

$$HT_P^i = \alpha + \beta + \gamma \tag{6}$$

The first factor α, also referred to as the energy factor, in which the normalized energies of the first and second-hop PFN inversely with the distance of the PFN from the edge of the transmission range as shown in Equation (7).

$$\alpha = e^{(-Ei)} \left(\frac{T_r^S - D_S^i}{v_s}\right) \tag{7}$$

where

$$E_i = \frac{\left(e_i + e_j\right) - \left(emin_{hpi} + emin_{hpj}\right)}{\left(emax_{hpi} + emax_{hpj}\right) - \left(emin_{hpi} + emin_{hpj}\right)}$$

$$emin_{hpi} = min(e_i \mid \forall i \in X_i)$$

$$emax_{hpi} = max(e_i \mid \forall i \in X_i)$$

$$E_i \in [0,1]$$

Where E_i represents the total energy and e_i and e_j represents energy at a specific node located at first and second hop difference the addition of maximum and minim energy of the nodes located at first and second hop which is further divided by their normalization. From (7), we ensure two parameter performance. First, those nodes will participate in forwarding the packet which have the most energy compared to the other nodes at the first and second hops of the source node. Second, those nodes will participate in forwarded the packets which are located at more proximity to the sink node.

The second factor β in (6), ensure that the path selection and direction by a source node for packets upward transmission must be an efficient one and shown in Equation (8), i.e.

$$\beta = (PF_i) \times \tan\left(\frac{P_i}{W}\right) \tag{8}$$

where

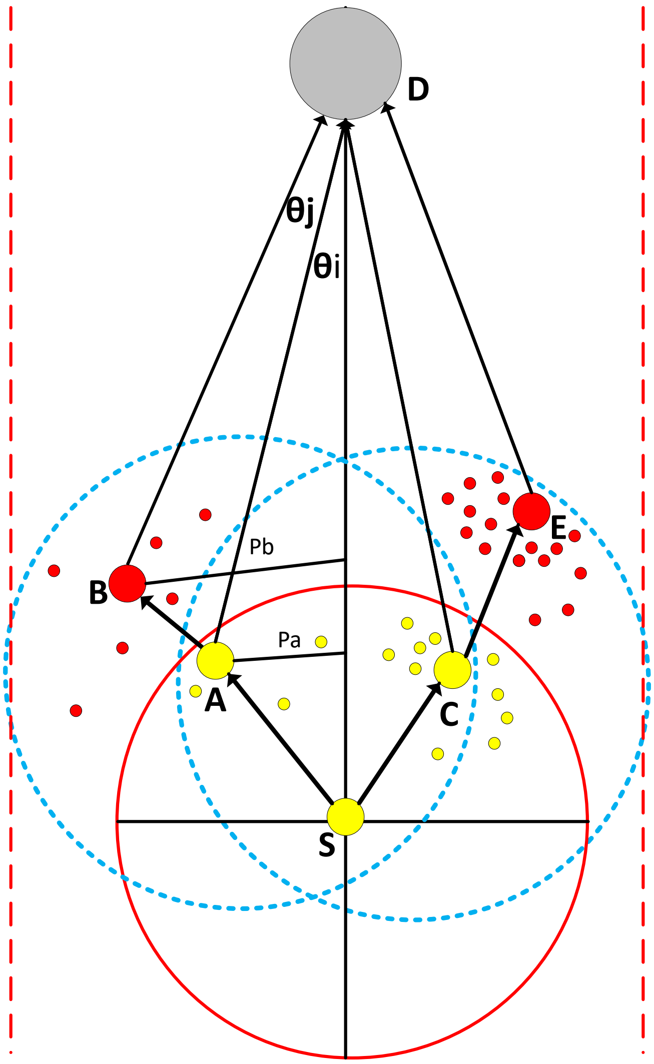

Fig. 3. Holding Time Scenario

$$PF_i = \frac{1 + PFN_i}{2 + (PFN_i + SUP_i)}$$

and P_i is estimated as:

$$P_i = \left(\frac{D_D^S + D_D^i + D_S^i}{2}\right)$$

The Path Factor (PF) of any forwarding node are normalized to all the potential forwarding and suppressed node located in the neighbor of the source node. The node which has low PF means the path has less traffic and a smaller number of nodes will be involved in communication, which results in enhancing the network life time and energy optimization.

While the ratio of P_i and W in (8), deals with the node distance from the centerline of sink and source nodes. P_i is the path distance of the PFN from the source and sink nodes and it is further divided so that we got a minimum of it for normalization. The node which are nearer to the centerline will be the desirable node to forward the packet than the one which are farthest from the centerline.

By using factor γ, we insure how much the node is nearer to the target node that is sink node; we choose those nodes located at the first and second hop of the source node which are nearer to the sink node. Here γ is represented in Equation (9) as:

$$\gamma = 2 - \left(\frac{D_D^S - D_D^i \cos(\theta_i)}{v_s}\right) + \left(\frac{D_D^S - D_D^j \cos(\theta_j)}{v_s}\right) \quad (9)$$

While $D_D^i \cos(\theta_i)$ and $D_D^j \cos(\theta_j)$ in (9), give the projection points of node i and j respectively on the centerline of the virtual pipe located between source and sink node. Where θ_i and θ_j can be easily calculated using cosine rules as shown in Equation (10) and Equation (11) respectively. i.e.

$$\theta_i = cos^{-1}\left(\frac{{D_D^S}^2 + {D_D^i}^2 - {D_S^i}^2}{2 \times D_D^S \times D_D^i}\right) \quad (10)$$

$$\theta_j = cos^{-1}\left(\frac{{D_D^i}^2 + {D_D^j}^2 - {D_i^j}^2}{2 \times D_D^i \times D_D^j}\right) \quad (11)$$

Consider the node as shown in **Fig. 3**, EESEVBF will select the node C and E for forwarded transmission because it fulfills all the requirement it needed compare to node A and B respectively. However, node C and E contains more numbers of forwarded node compared to node A and B, so PESEVBF prefer to node A and B for forwarding the packet, resulting in lower energy consumption and lower End to End delay.

5.3. Packets forwarding Mechanism

The proposed PESEVBF similar to EESEVBF worked on two hop holding time mechanism to transmit the data satisfactorily to the target sink node while covering the net packets advancement of two hop," in Proc. of addition, PESEVBF avoid the 'void hole' by selecting the best path through Path Factor (PF) parameter or through selecting the suppressed node which can route the packet through other paths so that to effectively minimize the packets dropping ratio of the whole network. As we have Potential Forwarding Nodes (PFNs) and Suppressed Nodes (SUPs) of the source node and each time when node forwarded the received packets then two types of holding time are calculated for effective node selection and for forwarding the packets according to the holding time (6). According to **Table 2**, the source node calculated the first holding time HT1st, which is from the closest neighbor nodes at the first hop, and the second holding time HT2nd, which is calculated by qualified source node that has enough knowledge of the nodes in it transmission range to select the next-best node: The first holding time HT1st as shown in **Table 2** calculated by source node is from the nearest neighbor nodes at first hop; and the second holding time HT2nd is calculated by the qualified node of the source node which have the sufficient information of the nodes in its transmission range about the next best node selection; while resultant holding time HTr is the timer value calculated for final packet holding by a node based on HT1st, HT2nd and PF values. So, as we follow two hop packets forwarding mechanism, the two-node priority of the qualified node are exchanged between forwarding nodes through special packets, termed as 'Carrier Packet', whose parameters are shown in **Table 2**.

In EESEVBF, the priority of a node to send the packets are exchanged and resultant holding time HTr are established according to HT1st and HT2nd value. When a node has minimum holding time at first hop but has large holding time at second hop; then priority of resultant holding time is exchanged with minimum holding time node at second hop as discussed in EESEVBF. But in PESEVBF, we give priority to those nodes on the first and second hop which have minimum Path Factor (PF) value. For instance, assume we have PFN nodes A, B, C, and D and their respective holding time at first and second hop which is calculated through the 'Carrier Packets' while transfer among different nodes are shown in **Table 2**. Now according to EESEVBF, node C is the most favorable node to forward the packet because it has the minimum holding time value at second hop and their resultant HTr will set with the node B holding time and their priority will exchange with node B but according to the PF value calculation (let the number of SUP nodes = 10 for all nodes and number of PFN for A, B, C and D are 25, 15, 20 and 10 respectively), node C is located at dense route then node D and B and communication through this route will lead towards more energy consumption. So according to the PF value, the priority of forwarding nodes will exchange and each node will set their HTr value accordingly as shown in **Table 2**," in Proc. of this respect Node D is smallest PF value, so HTr of node D will exchange with node A and similarly all other nodes also set their HTr values as shown in **Table 2**," in Proc. of this way, each node forwards their packets to the forwarded nodes.

Table 2. Packets Forwarding Strategy

Carrier	Node A	Node B	Node C	Node D
ID	1	2	3	4
HT_{1st} [msec]	17	10	15	30
HT_{2nd} [msec]	70	55	35	45
PF value	0.8	0.6	0.7	0.5
HT_r [msec]	30	15	17	10

6. Simulation Analysis

For simulation purpose and analysis, we use MATLAB and compare the performance of our work with AHH-VBF [19], ESEVBF [20] and EESEVBF [21]. For this we have tested our proposed work PESEVBF in a similar scenario as AHH-VBF, ESEVBF and EESEVBF are tested. We deploy from 100-500 source node in three-dimensional space having length, width and height of $10\ Km \times 10\ Km \times 10Km$; the volumetric region of each node is changing according to the network deployment that is sparse or dense network from $2Km^3$ to $10Km^3$ respectively; we deploy total of nine sink nodes and fixed it at the surface of the water. The structure of the packets and their purpose of transferring and receiving are similar to the one used in [21], while the simulation and experimental setup are similar to the [20].

6.1. Performance metrics

The simulation has been carried out and the performance matrices i.e. Packet Delivery Ratio, End to End Delay, Total Energy Consumption, Total Forwarded Copies of data and Number of Packets Dropped were drawn after the extensive simulation. We will discuss, analyze and compare each performance matric with their respective results in details in the next sessions.

6.2. Packet Delivery Ratio (PDR)

The ratio of successfully transmitted packets from a source node to the target sink node is known as the packet delivery ratio. **Fig. 4**. displays the PDR result. It is evident that as the number of nodes increase from left to right, the PDR also rises. Due to this, as the number of nodes rises, more live nodes are present, increasing the likelihood that a packet will be successfully received at the destination node.

As we observe at Node number = 100, in **Fig. 4**, PDR of the PESEVBF is lower than the EESEVBF and its energy-tax is higher than EESEVBF as shown in **Fig. 6**, it is due to the fact that, smaller number of nodes are involved in packets transmission which consumed moreidle and sending energy while selecting a favorable path for routing of packets. On the other hand, when the number of node increases, the PDR of PESEVBF becomes higher than EESEVBF while the energy expenditure becomes low as shown in **Fig. 4** and **Fig. 6**. respectively. It is due to the fact that it became easier for PESEVBF to forward the packet to the next hop nodes without losing and with low sending and receiving energy. As in PESEVBF, we select those paths to forward the packet which have less traffic and leads the network to reach more packets to the destination and as a result the PDR of the whole network enhanced as shown in **Fig. 4**.

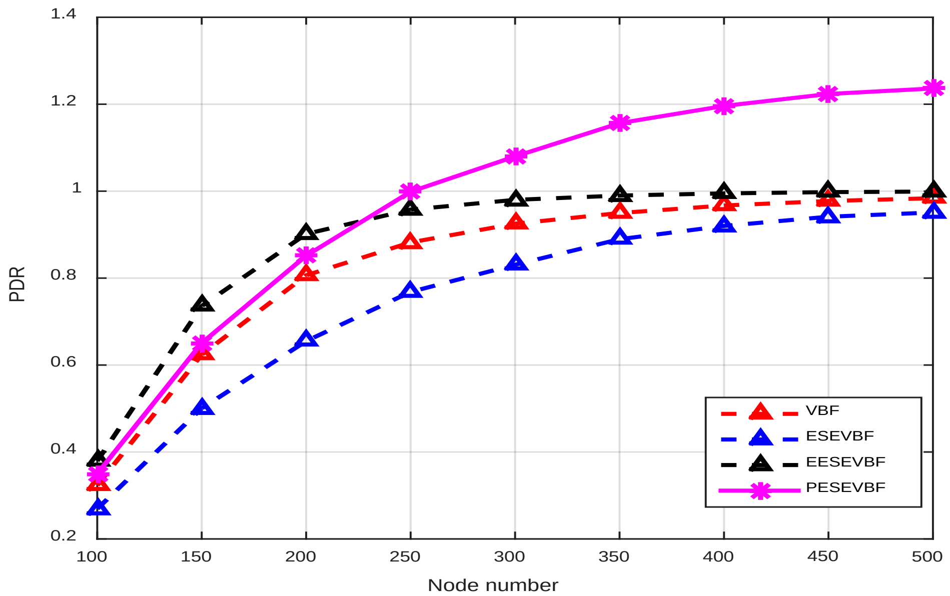

Fig. 4. Packet Delivery Ratio

6.3. End to End Delay

The overall amount of time takes by a packet to reach from source node to target sink node is known as an End-to-End delay. It comprises holding and propagation time delays as well as transmission time delays. **Fig. 5**, illustrates, how the End-to-End delay changes depending on the number of nodes. However, as the number of nodes gradually increases as shown in **Fig. 1**, it becomes easier for each node to send the packet quickly to the next forwarder node, which is why End to End delay first rises and then fall as a general trend. When there are few nodes, each node struggle to send the packet to the next forwarder nodes, which causes more propagation and transmission delay.

In comparison with EESEVBF, the End-to-End delay of PESEVBF is higher; it is because of the transmission of routing path selection. As during forwarding of the packets to next forwarder, we select next forwarder node based on holding time calculation; so, in PESEVBF, we divert the holding time through Path Factor to select less traffic path for next forwarding, due to which its propagation and holding time delay increases, only the transmission time delay is decreased, so that's why End to End delay of PESEVBF are more than EESEVBF as shown in **Fig. 5**.

6.4. Total Energy Consumption

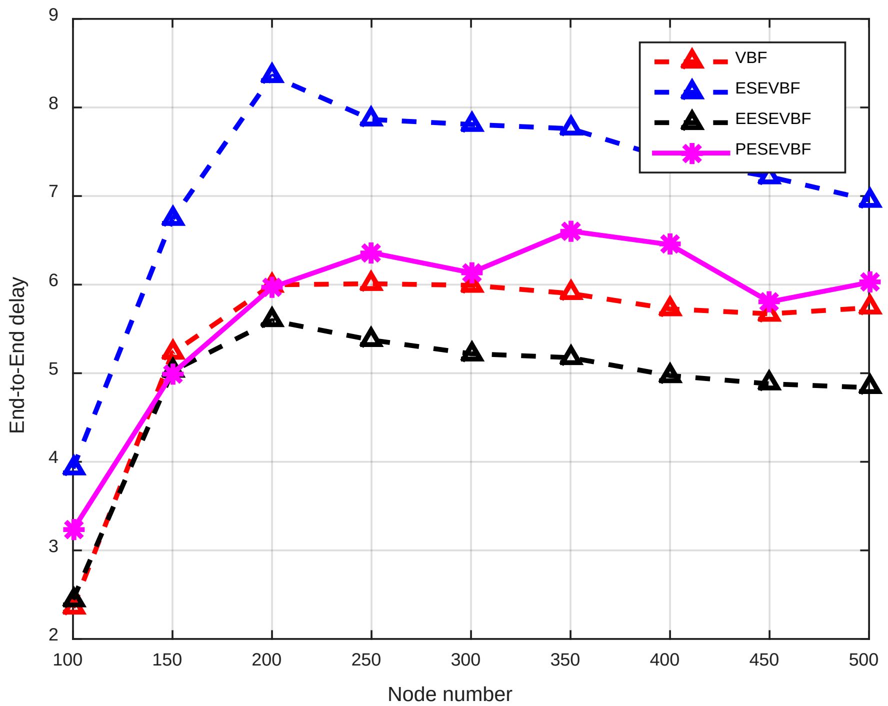

Fig. 5. End to End Delay

The average amount of energy used by each node during a successful packet transfer from the origin to the target sink node is known as the total energy consumption. It consists of energy used for transmission, receiving, and standby. We can calculate energy consumption using Equation (12) as:

$$EnergyConsum = \frac{E_{total}}{Nodes \times Packets} \tag{12}$$

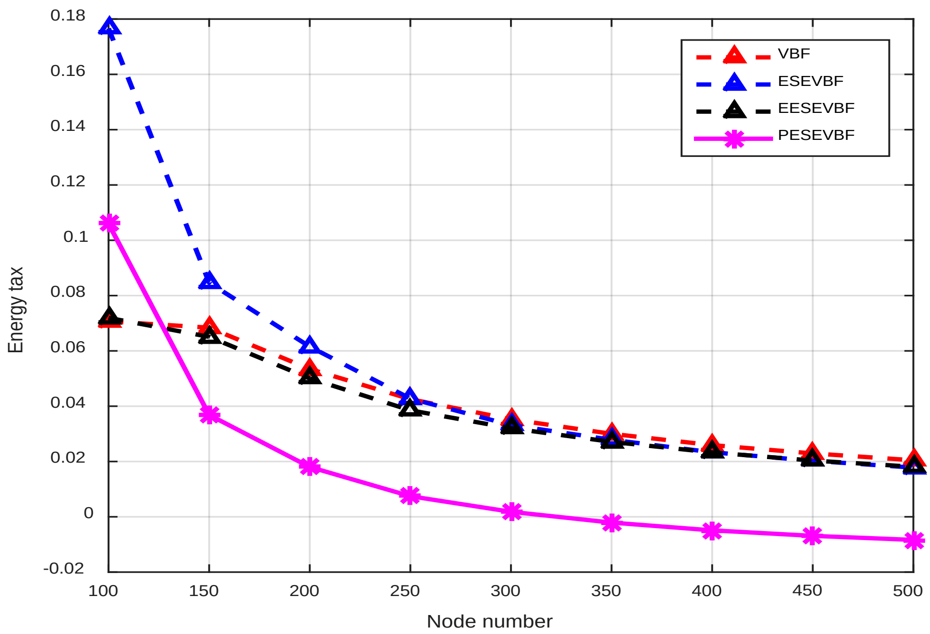

Fig. 6. Energy Consumption

Nodes and packets in (12), represent the number of nodes and received packets respectively, whilst E_total represents the energy of the entire networks. **Fig. 6** depicts the energy consumption results. The general trend of the energy expenditure is that it decreases as the number of nodes increases, when we plot it against the varying number of nodes; it is due to the fact that in low nodes region there are chances of void holes creation and in most cases for the transmission of packet the forwarder node is not available in the range or available at the most distant region, so the forwarder node used their ultimate power to transmit the packet which result increases in the energy consumption; secondly as shown in the (12) when the number of nodes is less, as nodes are inversely proportional then it will increases the total energy consumption.

In comparison the energy consumption of the ESEVBF and EESEVBF are more than PESEVBF; as in PESEVBF, there is a strategy for the selection of favorable path, due to which a smaller number of nodes are involved in packets transmission, resulting less receiving and transmitting energy consumption as shown in **Fig. 6**, Also due to selection of the most favorable path for packet forwarding, result energy saving and fair reduction in duplicate packets creation as shown in **Fig. 7**.

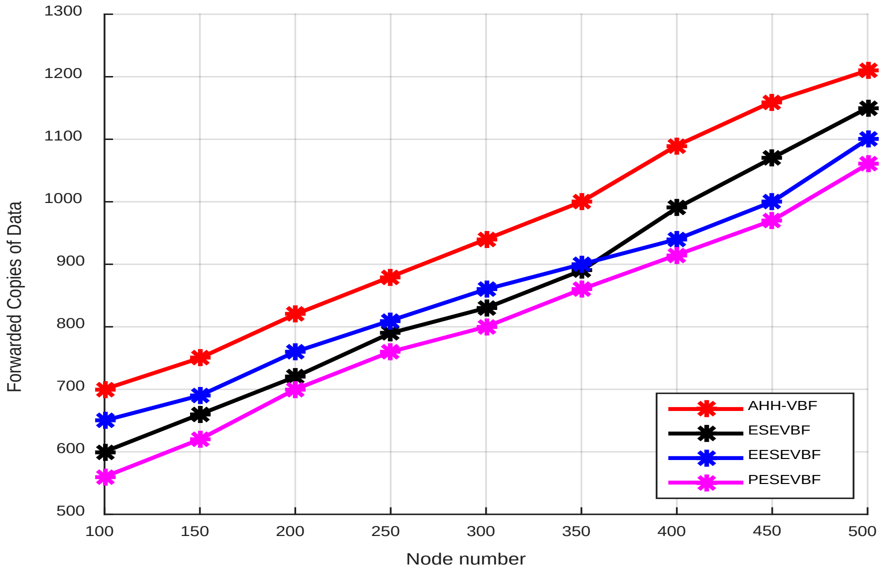

Fig. 7. Total Forwarded Copies of Data

6.5. Average Accumulated Propagation Distance (APD)

Each packet travels a certain distance from hop to hop during transmission from source to destination node, which is known as the average accumulated propagation distance. The hop distance is actually what is measured as the ultimate accumulated propagation distance because there are numerous sink nodes in a network. The definition of the APD is shown in Equation (13), as

$$APD = \frac{1}{s} \sum_{j=1}^{s} \sum_{i=1}^{k} dist_i^j \times Payload \tag{13}$$

where $dist_i^j$ in (13) is the propagation distance of the ith hop of the jth packet, where s and k are the amount of packet reached effectively and number of hops coming along the path of packet delivery, respectively while payload is the data in a packet. The general trend as shown in **Fig. 8** of the APD is similar to the End-to-End delay; firstly, the APD of the packet got increased and then it decreased; it is because when the node density of the region is lower than each packet is reached to the sink node and at each hop the packet covered more distance so that to minimize the packet drop. On the other hand, when the number of the node increases than it is obvious for the packet to reach to the sink node by covering a small distance at each hop. As we seen in **Fig. 8**, the APD of the PESEVBF is more than ESEVBF and EESEVBF, it is due to the fact that, PESEVBF transmit its packets through low traffic region, resulted less hops to cover for a packet to reach to destination or sink node, while in EESEVBF and ESEVBF there is no such phenomena of routing path selection.

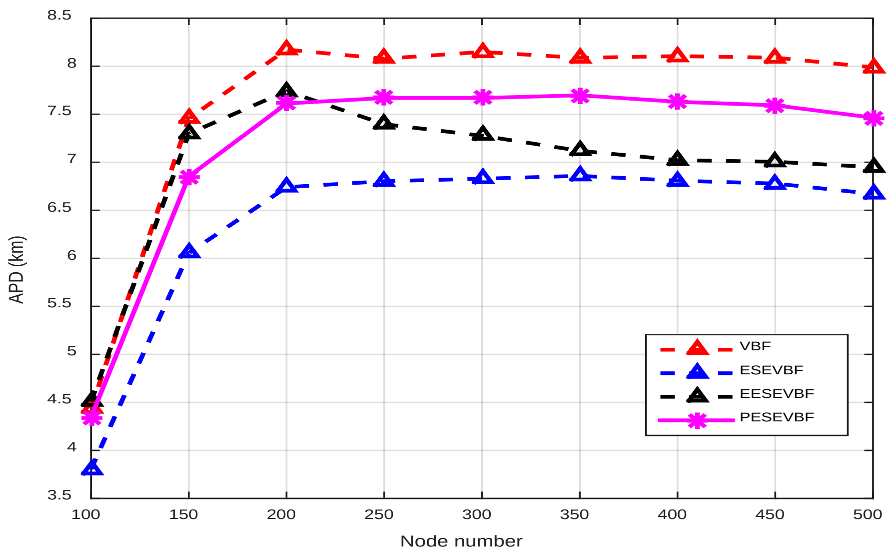

Fig. 8. Accumulated Propagation Distance

7. Future Work

The routing protocols for Underwater Wireless Sensors Network have been extensively explored as it has numerous real-world applications. We proposed PESEVBF in an attempt to improve routing path selection using Path Factor (PF), so that to select efficient path for packets routing. However, there is always room for further improvement and enhancement. Hence the following directions may be followed to enhance this research work further.

- Sensor nodes shift with water current, therefore continuously changing their locations. As a consequence, there are also changes in their job detail. This makes it a difficult job to localize the sensor nodes. Node movement often include regular updates on the fresh positions. As nodes have to share such information, this inherently adds delay and power consumption.
- The underwater medium is extremely unstable and demanding, thus in the future, protocols based on the dependability of data transfer from the bottom of the surface of the sea are worth investigating.
- In all current routing protocol, nodes close to the water surface are frequently selected as forwarders, since their nodes are near the sink surface. As a result, these nodes are under increased data demand and quickly exhaust their batteries. When one of these nodes dies, data traffic from the sea bottom to its surface is cut off, putting the network’s steady operation in jeopardy. The early demise of sensor nodes must be accommodated by taking appropriate measures.
- The acoustic waves can travel along curved routes because their velocity adapts to changes in water density, salinity and temperature. So, in some areas, where some

nearby sensor nodes cannot communicate with other nodes. This is a challenging problem for the design of next routing systems.

- Artificial intelligence and data science and deep learning technique, ML [24] [25] and given the cyber security to the data [4][10] will be implemented in the future in order to further improve efficiency. These techniques will assist the UWSN in predicting sudden failures in the environment of the underwater network," in Proc. of addition, our future study directions will be optimum throughput [32] and high network lifespan.

8. Conclusion

In this work, the authors focused on routing protocol improvement specific to Underwater Wireless Sensors Networks (UWSNs). The Protocols which are highlighting different aspect and challenges of the UWSNs such as DBR, VBF, HH-VBF, EESEVBF and many more are discussed in this manuscript providing useful insights.

The EESEVBF is the base protocol specifying the energy constraints and void holes issue in ESEVBF and advance holding time calculation to the second hop. While in our proposed PESEVBF we focused on the routing path traffic and void holes issue on the second hop," in Proc. of EESEVBF the void nodes are avoided by extending the holding time calculation to the second hop node, while we selecting the suppressed node in case of void hole on second hop having forwarding nodes other than the source node for next forwarding. An extensive simulation has been carried out which enhanced the PDR and throughput and reduces the energy consumption providing evidence that PESEVBF can be useful in selecting efficient forwarding path for data packets.

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