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Original Article

Enhancing Underwater Wireless Sensor Networks: A Novel Energy-Harvesting Protocol

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Abstract *- Underwater Wireless Sensors Networks (UWSNs) are comprised of sensor nodes collaborating and connecting each other and different objects in the maritime and underwater environments, an emerging ecosystem for communication and observing the target environments. The applications of UWSNs include underwater exploration, intelligent monitoring for disaster prevention and monitoring, oil gas exploration, etc. The UWSNs impact a wide range of sizes, from a small scientific observatory to a medium-sized harbour to worldwide oceanic traffic. UWSNs network architecture is inherently heterogeneous and must be durable enough to operate in severe settings. This poses significant hurdles regarding underwater communications, especially given the limited energy supplies available. Furthermore, UWSNs face a number of inherent problems, including frequent node mobility due to water currents, a high error rate, limited bandwidth, significant latency, and energy constraints. A sensor node that does not have enough energy in its battery cannot contribute to network performance and is effectively worthless as a void hole. The battery in an underwater wireless sensor network cannot be recharged or replaced. As a result, in order to extend the network's life, we'll need a source that can harvest energy from the environment and replenish the sensor node's battery. The Extended Energy-Scaled and Expanded Vector-Based Forwarding Protocol (EESEVBF) uses the timer method to prevent duplicate packets. A proposed novel Mollies and Platies Bottom-Feeder Pods routing aided Energy Harvesting for (MPBFP-EH) Underwater Wireless Sensors Networks (UWSNs) protocol, which harvests energy from ambient sources and extends the network lifetime. The timer value is calculated based on the distance from the transmission area's boundary relative to the inverse energy of the potential forwarding node at the first and second hops, the distance from the virtual pipeline, the distance from the source to the potential forwarding nodes at the second hop, the distance from the first-hop PFN to its destination. Furthermore, it can be seen from the results that the proposed scheme outperformed compared to the banckmarker EESEVBF in terms of energy tax, PDR, and end-to-end delay with an average of 15%, 11% and 8%.*

Keywords *- Underwater Acoustic Wireless Sensors Networks (UAWSNs), Mollies and Platies Bottom-feeders pods routing protocol, Energy harvesting for underwater wireless sensors networks.*

1. Introduction

One of the most efficient ways to manage aquatic applications is using Underwater Acoustic Sensor Networks (UASNs). Underwater Wireless Sensor Network (UWSN) typically uses UASN as an application for environmental analysis (UWSNs). The data is gathered bythe acoustic sensors and sent to the sink via a routing mechanism. Researchers have given high importance to UWSN for years because of its significant and crucial role in oceanographic scientific study. Pollution testing, ocean current detection, submarine research and underwater habitat moni- toring are examples of UASN applications [1, 2]. Unlike terrestrial Wireless Sensor Networks (WSNs), UWSNs use entirely different communication protocols. Acoustic signals are used for routing in underwater wireless sensor networks.There are no radio frequencies that can be used for signalling in the water environment. There are many advantages of using radio frequencies to communicate between surface- mounted sensors and an offshore base station, such as low bit error rate and high bandwidth. A direct line of sight between nodes is also required for optical signal communication in UWSNs. In addition, because of the fluidity of the under- water channel, nodes are rarely in the direct line of sight, resulting in more frequent changes in the optical relationship.Acoustic signals are the most common method employed in UWSNs. Auditory signals can fly longer distances with less strong channel effects than electromagnetic and optical waves. In order to create a communication environment, a sensor network comprising a variety of smart devices is inter-connected. One of the key concepts behind a sensor network is that a device, node, or antenna equipped with various sensors can gather helpful and necessary data andsend it to a base station at a separate location for processing. Sensors of several types are included in a single sensing device for various purposes. Transmitting data from sensor nodes to the base station can be accomplished using a wired or wireless communication method. Data transfer between sensors and sink nodes or sink nodes and the base station is required in wired communication sensor networks. However, in wireless communication sensor networks, no physical connection is required. Different types of dispersed devices work together in a wireless sensor network via wire-less communication. As depicted, large numbers of connected wireless devices interact and collaborate with each sensordevice to boost sensing levels, detect the surroundings, and gather information from other devices. The wireless sensor network has many features, including mobilityand contact. In order to improve the network's performance, UWSN used various routing mechanisms in various protocols. The marine climate makes improving energy efficiency at the routing layer difficult. Path loss, noise power, propagation delays, and distance dependence on bandwidth and power are just a few of the key distinctions between terrestrial and underwater circumstances. As a result, the multimode energy consumption, idling, receiving, and trans-mitting (i.e., idle, receive and transmit) is distinct from its terrestrial WSN equivalent. To summarise, UWSN cannot use the routing technique designed for terrestrial sensor networks for the above reasons [3–6].

Acoustic signalsin UWSNs are significantly impacted by ambient factors androute loss. Even while underwater acoustic signals have a lower bandwidth and transmission speed than Radio Signals (RF), they are more suited for use. The data rate and range provided by radio signals are inadequate due to their quick attenuation. Various UWSN routing protocols have been created in response to the actual network challenges and problems. These issues include power consumption, stability, end-to-end delays, time-changing channels, throughput, lowbandwidth, and Quality of Services (QoS). In general, WSNshave a tiny energy budget due to their deployment in distant places and the difficulty or impossibility of recharging or replacing the batteries of the network's sensor nodes. Numerous approaches have been examined to alleviate the UWSN's energy shortage and extend its lifespan. In order to run applications on the nodes for months or even years, UWSNs require the longest life span possible. Mutual routing and harvesting energy from ambient sources are also considered in UWSNs. In order to keep the network running indefinitely, Energy Harvesting (EH) collects some of the ambient energy and feeds the sensor node regularly. In order to make effective use of EH, the harvesting mechanism must be included in the network's design. A number of issues with underwater wireless acoustic systems have been brought to light [11]. The term "underwater energy efficient routing protocols" refers to a variety of different routing approaches, such as localization-based Vector-Based Forwarding (VBF), Hop-by-Hop Vector-Based Forwarding (HHVBF), Forward Beam Routing (FBR), Directional Flooding Routing (DFR) and localization-free (Depth Based Routing (DBR), Hop-by-Hop Dynamic Addressing Based (H2-DAB) Routing). Unlike free nodes, which rely solely on the depth of localization of other nodes in their vicinity, nodes using localization- based routing protocols can grasp their own and surrounding nodes' geographical positions. UWSNs feature a dynamic topology because the nodes' placements are not fixed by the water flow [7–10]. In light of dynamic topology design, regional routing is more important than free localization routing. In addition to the above-mentioned advantages, it is also important because it allows for geo-opportunistic forwarding. As an alternative, a collection of nodes known as a "cluster" is formed, which collaborates to send the packet to the destination node. So, we may conclude that the cost of alternative routing techniques in UWSN is higher, but it is the responsibility of the nodes to route the data to its final destination.

Nodes in a UWSN require more energy to deliver data than they do to receive it. The number of transmissions must be reduced as well in order to reduce energy con- sumption and increase the network's lifespan. The researcher faces a huge issue balancing the energy consumption of nodes responsible for routing data from source to destination. Maximum end-to-end delay, multipath fading, and mobility issues are among the most challenging issues for UWSNs. Nodes utilized solely to transport data packets are referred to as "courier or relay nodes," the optimal cost function for weight computations is used to balance the energy consumption of sensor nodes. As an additional bene- fit, good coordination between nodes can help reduce energy use. Static or mobile sinks are options for data collection structures. When using static methods, nodes that are closest to the sink use up their energy more quickly, and as a result, a segment or the entire network may become disconnected [12]. Researchers are interested in UWSNs because of the enormous challenges they pose and because of the unpre- dictable and harsh nature of water. It is possible to improve the network's performance through a variety of protocols, including energy optimization, packet ratio, end-to-end delay and so on.

However, enhancing one network aspect can impact other factors because each factor is somehow linked. After further discussion, it is clear that if we wishto improve the packet delivery ratio, it impacts the energy tax of protocols and, hence, the network's through- put. So, we'll address some of the most pressing issues in underwater network protocols so that researchers can keep these trials in mind while they work on underwater network protocols. While acoustic communication is widely used for underwater network routing, there are a number of problemsthat must be overcome. Underwater sensor networks confront particular challenges since the acoustic signal speed is five times slower than the radio signal, resulting in significant packet distribution delays. To avoid packet loss and severe attenuation due to the restricted bandwidth of acoustic channels, most sensors transmit their packets to other nodes by flooding them in the local area. This allows every node within the transmission range to receive the packet and pass it on to the next forwarder nodes. Flooding causes numerous sensors in the transmission range to receive a packet and send it on to other nodes, which results in a lot of noise and an increased risk of bit errors in the packet. Because of these bit errors, the packet must be retransmitted to ensure a fair transmission, a time-consuming and energy-intensive process in an underwater environment. Sensor nodes in UWSNs move more horizontally than verti- cally due to the water's movement, which causes the nodes to move more horizontally. The additional energy needed to keep the network moving reduces its lifespan because each node is powered by a battery that can't be easily replaced or recharged in an underwater network. For routing, the source and destination addresses are critical for establishing links between sender and receiver. However, because nodes in an underwater network can freely move in horizontal and vertical directions, this movement makes linking underwater network nodes more difficult and necessitates special attention.

A network protocol's life can be significantly impacted if a net- work fails to establish and maintain a link between the packet and the designated path, resulting in a rise in network noise and error likelihood. Sensor nodes in UWSNs are randomly distributed, resulting in varying densities in some areas and void holes in others. This is another crucial issue to remember when routing, and it also causes imbalances in energy and the formation of void holes. In the underwater setting, balancing energy and avoiding the formation of void holes is a key challenge. Time-critical applications, for example, may necessitate keeping track of holding time to ensure equitable transmission and suppression of redundant packets; this is a key consideration for UWSN's communication. The following definitions are included in this section: In this section, we'll go over some of the key terms that appear throughout this article and the ones that follow so that the reader may get a better grasp on how networks work as a whole. The following is how we define these factors.

- Node - A node is a device that incorporates sensors for various functions and is used to receive and transmit the necessary packets. A node that generates or transfers a packet to other nodes within its transmission range is referred to as a source node or a forwarded node. This node receives the packet from the source node and forwards it to its final destination. It could be a sink node or not. If it is not a sink node, the received packet will be transmitted as if it were a source node because a node can both receive and transmit packets, as previously specified. Next, when referring to a node as a "forwarded node," it is important to remember that this is the same node as the final destination. This node is called the next-hop forwarded node in two-hop communication because it is assumed to transmit the packet to the forwarding node. One of the nodes that connects to a sink is a device that sits on the water's surface and uses an acoustic signal to connect with underwater sensor nodes and a radio signal to communicate with the base station. A packet is considered to have arrived at the sink node if it reaches it.
- Relay/Courier Nodes: To transfer the data from the Anchor nodes to the following forwarder nodes, these nodes are situated at various points in the water.
- An Anchor node: It is a node that sits at the bottom of a body of water and is responsible for gathering data from the environment and relaying it to other nodes. It is possible for them to move with the flow of water or any other disturbance in the surrounding environment, but they are usually held in place by the tether.
- Packet: A packet is a collection of bits carrying information about a particular issue or, in the case of UWSN, the environment. These packets are transferred from onenode to another during the routing process
- Packets of information: Packets of 64 bits or 128 bits are known as "data packets" because they con- tain all of the statistics related to a particular problem

Request Packets: Request packets are the same as data packets, except they are exclusively used by a source node to acquire information about the environment. When it comes to size, they're usually just two bits long

Acknowledgment Packet: As a response packet to a re- quest packet, the Acknowledgment Packet/Reply Packet is typically routed by neighbouring nodes. This packet carries information that the source node needs to know about its surroundings

Redundant Packet: When we send the same packet several times, it is referred to as a "redundant" packet. Many protocols attempt to limit the generation of redundant packets during the routing process

Topology: The topology of the nodes refers to the deployment technique or arrangement of the nodes in various circumstances for the purpose of gathering information about the surroundings.

Protocols: For routing packets in networking, protocols are used, such as vector-based forwarding, depth-based forwarding, and others. Address: The addresses of the source and destination nodes are contained in the pack-ets generated by the source. Through the request packet or through the network deployment, we can find the destination address.

- Throughput: The number of packets that travel from the source node to the destination/sink node in a unit of time is known as the throughput. Bits per unit of time or packetsper unit of time are used to measure it.
- Latency: Latency refers to the length of time it takes for a packet to travel from its source node to its destination node.

Smart coastlines, also known as SCs, are quickly becoming increasingly important as a major aspect that contributes to sustainable communities. Monitoring water quality, water pollution, seismic activity, ecosystems, and the overall management of coastal zones are essential components of SCs [13]. In order to put these aspects into effect efficiently, it is necessary to have continuous collection, monitoring, detection, and management of a variety of aquatic factors. Employing Underwater Wireless Sensor Networks (UWSNs), which have become the technology underpinning of SCs, is the only way to make such continuous monitoring of oceanographic parameters conceivable. UWSNs are the technological underpinning of SCs [14]. In order to create UWSNs, a number of sensor nodes powered by batteries are placed in areas dominated by water. These types of nodes are outfitted with the ability to sense, communicate, and store data regarding various physical and aquatic factors. A sink floating on the surface of the water collects the data that is felt and then transmits it to a monitoring station located on land. When applied in an underwater setting, each method of communication presents its own distinct set of obstacles [8]. Waves of different types, including optical waves, electromagnetic waves, and acoustic waves, can be used to carry out the communication process between sensor nodes [16–20].

In contrast to underwater communication, terrestrial communication typically makes use of electromagnetic signals at radio frequencies. This is due to the fact that electromagnetic signals at radio frequencies have a wider bandwidth, require less energy per bit to transmit, and have shorter propagation delays. As a result, this method is utilized for the communication that takes place between the floating sinks and the onshore monitoring stations. On the other hand, the high conductivity of salt- water causes severe attenuation and large absorption losses, making it an unfavourable option for use in underwater communications. Similarly, for optical communications between parties to take place, there must be a sightline, which is not always attainable. Additionally, the distance over which optical communication may properly take place is dramatically reduced by the turbidity of the water, which renders it unviable for use as a method of underwater communication.

The acoustic communication modality is the preferred one for underwater networks, and as a result, it is the one that is utilized the most frequently; the network itself is sometimes referred to as an Underwater Acoustic Sensor Network (UASN). In addition, UASNs are subject to a variety of problems, such as fading, which can lead to high error rates and bandwidth constraints as a result of multipath. Compared to radio signals in a terrestrial setting, the speed at which acoustic signals move through an aquatic environment is significantly slower. As a direct consequence of these issues, synchronization, data routing, and information regarding the network state are all subject to restrictions. This helps to explain why conventional communication methods, which are otherwise effective for terrestrial sensor networks, are not suited for usage in an environment that is submerged in water [2]. Most of the difficulties that UASNs confront, which are stated above, are interrelated, making it much more difficult to create optimal solutions. In vector-based routing protocols [21], each node calculates the holding time based on the node/network parameters, such as the distance to the sink, the middle of the virtual pipeline, and the receiving node's distance from the sender of the previous hop. For example, the distance to the sink determines the holding time. Only when a node has checked and verified that it is situated within the virtual pipeline is holding time taken into account in the estimation process.

Following the acquisition of the initial duplicate copy of a packet from downstream nodes, this step is carried out. The timer is established based on the (estimated) amount of time that the item will be held. When the timer for the node runs out, the node will forward the packet if it has not received another copy from any of its neighbours. At the same time, the remaining nodes will suppress their packet forwarding protocols in favour of the node with the smallest holding time in all of the surrounding nodes. This will happen in favour of the node with the lowest possible timer value. These protocols (which are vector-based) determine the timer value based on the proximity of the nodes, which allows for faster propagation. When making an estimate, we also take into account how close we are to the pipeline's centre and how far away we are from the sink. While packets are being routed through these nodes, end-to-end delay can be reduced; nevertheless, this causes energy depletion, which in turn results in an issue known as a void energy hole.

Because of this, it is necessary to have an equitable distri- bution of energy between the nodes contained within the vector and throughout the entire network. As a result, estimates of timer value take into account the energy factor in order to extend the lifetime of the network. However, when each node in the network is updated with the network state information, the shortest path between the sender and the sink does not guarantee that accurate timer calculations will be attained. This is because the sender and sink are not on the same node (complete or partial network). This information on the state of the network can be accessed through the exchange of control packets; however, this traffic places an additional burden on bandwidth, energy consumption, and error rates. As a result, it is necessary for proposed forwarding algorithms for UASNs to take into account these constraints and provide a satisfactory compromise.

Suppose the immediate neighbours estimate their timer durations are longer than the propagation delays. In that case, there is room for further improvement in the process of reducing the number of duplicate packets. In aquatic environments, there are a number of well-known problems, including higher levels of energy consumption, channel defects, and lengthy delays in the propagation of acoustic signals [22]. When a node in the network that is further distant than the sink node delivers packets to the sink node, there is a remarkable rise in both energy consumption and propagation delays (fixed at a particular point). Several models described in the research literature recommend mobile sinks as the most effective method for collecting data. Mobile Sinks, sometimes known as mobile stations, are nodes that have the ability to move both independently and in conjunction with other nodes using attached ropes and vessels. Autonomous underwater vehicles, or AUVs for short, are a good example of anything that can change positions on their own [23]. To ensure that the mobile sink may wander freely within the network, it is anticipated that it has ready access to regular refilling and charging facilities. As a result, the proposed routing algo- rithms for UASNs might also take into consideration how useful it is to make use of a mobile sink. Using the holding time method, the Extended Energy-Scaled and Expanded Vector-Based Forwarding (EESEVBF) protocol is able to suppress duplicate packets [24]. In addition, the protocol addresses the issue of hidden terminals, which results in a significant reduction in the number of duplicate packets that are started by reproducing nodes. A Wireless Sensors Network (WSN) comprises sensor nodes collaborating to perform specific tasks under observation. One of the major challenges in an Underwater Wireless Sensor Network (UWSN) is that each individual node has very limited energy in the battery, which degrades with time. Without energy in the battery, a sensor node cannot contribute to network performance and is essentially useless as a void hole.

In an underwater wireless sensor network, the battery can neither be recharged nor replaced. Therefore, to extend the network's lifetime, we must have a source that harvests energy from the environment and recharges the sensor node battery. This article proposed a novel technique Mollies and Platies Bottom-Feeders Pods routing protocol aided Energy Harvesting (MPBFP-EH) UWSNs by considering the EESEVEBF and an energy harvesting source for UWSNS. Recent researchers have developed many energy harvesters, and a few of them are listed in Table 1. Piezoelectric material converts mechanical energy into electrical energy and generates vibration, and piezoelectric material converts it into low-level power density. Piezoelectric energy transducers are characterized by a high impedance output, unlike conventional voltage sources, so an appropriate electric circuit will be required for that correct interface. The Piezoelectric output can be presented to a half-wave synchronous rectifier with voltage, a full-wave synchronous rectifier, and a passive full-wave rectifier [35]. Plucked-driven piezoelectric improves the performance of piezoelectric. There are two beams in plucked-driven piezoelectric; one is called the generating beam, and the other is a short-driven beam called plectra. When the plectra strikes the generating beam, it vibrates the system and produces a power density 350μWm^{-3} [27]. Piezoelectric bimorph produces a power of 250μWcm^{-3} form the vibration source at the acceleration rate of 2.5ms^{-2} at 120Hz. A Microbial Fuel Cell (MFC) is a bio-electrochemical system that produces electric power by using bacteria and there metabolic reaction. MFCs are categorized into two groups: mediated and unmedi- ated. The MFC in mediated bacteria transfer electrons directly to the anode, while in unmediated bacteria have in outer membrane electrochemically redox protein, e.g. Cytochromes, which transfer electrons to the anode. A microbial fuel cell comprises from two electrodes (Anode and Cathode), and one external resister is attached on which we give the power to the sensor node. The anode is placed where oxygen is in less amount, and the cathode is immersed in a higher oxygen density, in b/w there is a proton permeable membrane. Corbon dioxide (CO_2, H+, and electron is produced in Anolyte due to the metabolic activity of bacteria and electric power is generated. The Microbial Fuel Cell is also called bio- electrochemical system. The power is increased by increasing the PH value as microbial is in favor of alkaline condition.

[26] and also by using different substrates, as shown in Table 1. The Benthic Microbial Fuel Cell uses the same principle as the microbial fuel cell here, and the anode is a nutrient-rich media that uses ocean sediment, which contains electro genic microbes. The Benthic Microbial Fuel Cell produces a power density of 44 mWm^{-2} [28]. The underwater wireless sensor network is gaining importance due to its wide range of applications. The major obstacle in UWSNs is continues power supply to the network, so some technique uses the combination of both Piezoelectric and MFC for power supply, as in multi-source energy harvesting systems [34]. Electrodes of Platinum are used for power generation. The anode is immersed in marine sediment, while the cathode is placed in seawater. The power generated depends on electrode design, sediment composition and temperature. The anode and cathode configuration constitutes a microbial fuel cell and generates a power of 0.01 Wm^{-2} [29].

A Galvanic Cell produces electric energy by using a redox reaction within the cell. It comprises from a sufficient amount of power density, i.e. 330μW [25]. The two metal plates connected by a salt bridge or individual most common piezoelectric materials are quartz, Rochelle salt, ceramics, and different other solids that have the piezoelectric effect. A piezoelectric transducer comprises two plates, and a piezoelectric material is placed b/w the two plates. When a sound wave strikes one or both plates, it generates a half-cell separated by a porous membrane. Oxidation means releasing electrons occurs in one half-cell, and reduction occurs in another half-cell. The chemical reaction at the electrode produces an electric potential difference. The anode comprises Zn, and the Cathode is made of an alloy of Zn and Cu. Half effect Sensor small radios and microcontroller is packed in 'Backpack', which are then glued by a mussel shell [31]. The Galvanic Cell produces the required 25μWm^3 for the 'Backpack'. Self-Powered Ocean monitoring contains an Acoustic modem, a Smart battery charge controller, a Marine energy harvesting module, Actuators with thruster and blaster, a wireless power module, and a Solar energy harvesting module [33]. Solar Energy harvesting module charges the external battery from the sun- light. Microcontroller periodically checks the battery level and compares it with the threshold; if it is less than the threshold, then it sends an alarm command to the user and with the help of a thruster, the sensor goes up near to the gateway, which means near to Solar energy harvesting module from where the battery of the sensor node is wirelessly charged by using induction rule. According to the induction rule, the two coils can transfer energy if they have the same resonating frequency. By setting the resonating frequency of the coil in the solar energy harvesting module and the sensor node, one can charge the battery of the sensor node. The system requires 19.4W [33], and the solar energy harvesting module provides 20W per day.

This article proposed a novel scheme utilizing marine sediment as energy harvesting. The calculation of the holding time takes into account the following four parameters: the distance from the boundary of the transmission area relative to the PFNs' inverse energy at the 1st and 2nd hop, the distance from the virtual pipeline, the distance from the source to the PFN at the second hop, and the distance from the first-hop PFN to its destination, harvesting energy and its residual energy in its transmission locality. As a consequence of this, the suggested protocol will prolong the network's lifetime by energy harvesting. It will result in lower energy consumption, a reduced number of dead nodes, overcoming the hidden terminal problem, decreased end-to-end delay, and an increased packet delivery ratio.

1.1. Motivations and Contributions

Vector-based routing protocols employ the pipeline to determine directionality, and the positional information of the node is utilized for the purpose of deter- mining holding time. When examining the normalized energy of the Potential Forwarding Nodes (PFNs) from the first and second hop, the node's proximity to the destination point (upward packet advancement) reduces the end-to-end delay. This also results in a reduction in the amount of energy that is consumed by the network overall. Based on these considerations, we implemented the MPBFP-EH protocol by embedding an energy-harvesting source through marine sediment. In the process of constructing the timer value mechanism for the PFNs, MPBFP-EH takes into consideration the following points:

- The amount of time that a PFN is allowed to keep data is determined depending on the average energy of its nearby nodes. This helps solve the problem of void holes. The timer value between two PFNs of a source node is dependent on the propagation distance between them. This means that a higher timer difference results in fewer duplicate packets, which leads to less network overhead. The difference in timer values between the nodes can be affected by even a minute variance in the energy levels of the nodes that are adjacent.
- The importance of the nodes is determined by where they are located in relation to the virtual pipeline. The holding time system considers the distance that separates the sender and the forwarder, which helps to keep the total delay from beginning to end to a minimum. In most cases, this element helps the movement of packets across a considerable distance and towards a particular direction in the direction of the sink.
- The source node and the other nodes in the network collaborate to represent the network as a real-time system by manipulating the timer information of the nodes in the network with which they have common neighbours. Within a relatively short amount of time, the packet is sent by the node with the shortest average holding time over all the PFNs of the originating node.

Table 1. Energy harvesting sources in underwater wireless sensor network

Harvesting Source	Power Generated
Piezoelectric	$330\mu Wcm^{-3}$ [25]
Vibration	$116\mu Wm^{-3}$ [25]
Plucked-Driven Piezoelectric	$350\mu Wm^{-3}$ [27]
Marine Sediment	$0.01\mu Wm^{-2}$ [29]
Benthic Microbial Fuel Cell	$44mWm{-}^{2}$ [30]
Galvanic Cell	$25\ \mu Wm{-}^{3}$ for Small Back- Pack (Hall Effect Sensor, Small Radios and Microcontrollers) [31]
Piezoelectric Bimorph	$250\mu Wcm{-}^{3}$ [32]
Self-Powered Wireless Ocean Monitoring Systems	20W [33]
Acoustic Wave	$0.96\ \mu W\,cm^{-3}$1001 [35]
Piezoelectric with Active Syn-Chronous Rectifier	$16\mu W$ [35]
Piezoelectric with Passive Syn-Chronous Rectifier	$22\mu W$ [35]

Table 2. Energy harvesting sources in underwater wireless sensornetwork [26]

MFC Configuration	PH	Current Density (Anolyte)	Power Density
Yogurt Waste Water	Single Chamber Air Cathode MFC	10.5	$100mWm^{-2}$
Acetate	Single Chamber Air Cathode MFC	9.5	$833mWm^{-2}$
Diary Waste Water	Single Chamber Air Cathode MFC with Spiral Node	10	$161mWm^{-3}$
Diary Industry Waste Water	Dual Chamber MFC	7	$621mWm^{-2}$
Glucose + Yeast Ex-Tract	Single Chamber Air Cathode MFC	10	$213mWm^{-2}$
Brewery Waste Water		6.5	$669mWm^{-2}$

- Energy balancing is achieved by using the residual normalized energy information of the candidate nodes to estimate the timer value. The packet is then forwarded further by the nodes in the second hop using the same technique. The goal of this operationis to ensure that all of the nodes within the transmission range of the source node have the same energy level. An energy-harvesting marine sediment source is embedded in the sensor nodes to extent the network lifetime. As a result, there won't be a single node that enters the dead state all by itself.

The upward packet advancement is achieved by considering the depth information of the first two hopsfrom the current source node in the packet's path. Because the forwarder nodes are given higher priority, more progress is made in the first two hops of the network after the source node than in the succeeding hops.

Additional reduction in the amount of energy tax paid is accomplished by inhibiting the process of packet forwarding that is launched from replicating regions.

The proposed protocol makes use of control packets, also known as announcement packets, to suppress duplicate data packets coming from areas to which the forwarder nodes do not have access.

Compared to EESEVBF, the results of the simulation show that MPBFP-EH is superior in lowering the energy tax, reducing the number of dead nodes by embedding a marine sediment source, decreasing the time from beginning to end, and ensuring reliability.

The remaining sections of this work are organized as follows: Section 2 presents the related work in the field of UWSNs, while section 3 discusses the network architecture.

Section 4 discusses the timer value calculation. In section 5, simulation results and analysis are briefly explained. Section 6concludes the proposed work.

2. Related Work

A basic routing protocol for underwater wireless sensor networks is covered in this section (UWSNs). Underwater Wireless Sensors Networks are the focus of this part, which examines various fundamental routing protocols (UWSNs). As a result, the protocol is broken down into three distinct sections: Local Routing, Depth Routing, and Energy Routing. All of these divisions result from the diverse ways that different protocols persuade to route traffic. Each sensor node routes data based on the local distribution of sensors and the timer information required for broadcasting in local-based routing. By utilizing local-based routing schemes, protocols transmit packets to sink nodes while considering the location and distribution of nodes and redundant packets, residual nodes' energy requirements for packet transmission, and where the sources are from the sink nodes, amongst other considerations. In the following session, we briefly examined some of the most essential protocols that follow the Local Based Routing scheme.

An approach called Vector-Based Forwarding (VBF), which relies on the network's sensor nodes to direct traffic, was presented in [21]. Each sender node in VBF creates a fixed routing-vector/virtual-pipeline that shows the path to the forwarder node during the transmission of packets. The sensor nodes' routing decisions are based on their relative position in relation to the pipeline when using this method. The packet is being forwarded by the sensor nodes placed inside or close enough to the predefined threshold distance of the pipe but not by the node positioned outside. Nodes are allowed and given authorization to execute advantageous routing through evaluating the density of neighbour nodes and adjusting the transmission method in line with local node distribution in VBF, which also uses the self-adoption algorithm. In this way, the forwarding/Source node's packet transmission energy consumption is minimized via the routing-vector and self-adoption method. VBF has various shortcomings, such as the inability to locate the next forwarder node in a network with a minimal sensor node density and the routing pipe remaining constant throughout the routing process between the source and target nodes. Hope-by-Hope Vector-Based Forwarding (HH-VBF) is presented as a solution to this problem. Like VBF, routing pipes are redefined here, but the distinction is that in HH-VBF, a unique pipe is constructed at each hope rather than generating a single pipeline as in VBF. Because we're going hope by hope, the pipe is built and routed in accordance with how a network's sensors and nodes are distributed across the network. Here in HH-VBF, the likelihood of identifying a routing path is higher than in VBF when compared. HH-VBF increased its transmission power level in low sensor node density zones in accordance with its transmission range, allowing the packet to travel as far as possible. They are able to prevent the production of void holes in this manner. In addition, HH-self-adoption VBF's algorithms differ from VBF's. Since packets are effectively suppressed in VBF, it's possible that this causes issues in areas with few sensors.

The source node in HH-VBF stores the packet for a while before forwarding it and then calculates the desirableness factors for each forwarder based on network information. A specified threshold is used to compare the desirability of each node, and the one with the highest desirability is chosen to forward the forwarded packet over the others. Due to other nodes being more desirable than me, packets from other nodes with lower desirableness factors are dropped. For low node density networks, VBF is inadequate; hence, HH-VBF covers this gap. There is no equitable distribution of energy in HH-VBF since the pipelines constructed at each hop have the same radius and expansions, and the sensor nodes in a network are not taken into account. With AHH-VBF [36], the limitations of Hope-by-Hope Vector-Based Forwarding are addressed. While the HH-VBF is the foundation of AHH-VBF, it also creates a virtual pipeline at each hop.

However, as we know, in UASN, sensor nodes are distributed randomly, resulting in low sensor density in sparse sensor regions and high sensor density in dense network locations. As a result of the unevendistribution of sensor nodes within a given area, AHH-VBF stands out from the HH-VBF under discussion right now. AHH-VBF uses an adaptive transmission range at each hop and a sensor node-oriented pipeline to achieve this first goal.Thus, hop-by-hop, the transmission power of each forwardernode is likewise changed to overcome the energy distribution and increase the lifetime of all networks. To further ensure that duplicate packets are not sent, the virtual pipeline's radius varies adaptively at each hop, allowing thetransmission to be controlled and limited. It also improved the source node's transmission reliability and, as a result, thewhole sensor network's reliability. It is also possible to routein a limited forwarding area and well-measured forwardernodes inside the source node's pipeline because of AHH- adaptive VBF's method. In this way, the end-to-end delay is minimized since the forwarder node is chosen depending on the distance from the current source node to the destination node in the pipe.

On pipeline radius, as in AHH-VBF, all focus is on transmission areas, which successfully improves essential network parameters such as reducing the number of duplicate packets, improving energy distribution, and increasing the end-to-end delay. In AHH-VBF, on the other hand, the for- warding zone is covered by more dense sensor regions than required, which impacts the network's performance, leading to the development of AHHC-VBF [37]. In AHHC- VBF, the next forwarded node is selected for transmission based on its position relative to the virtual pipe and the angle of the cone at the next hop. Each node's angles are measured in relation to the cone's predefined angle, and the distances of each node from a virtual vector are also provided. If a node makes an angle less than the predefined angle of the cone, it will be inside the cone. There are some nodes inside the cone and some outside of it. At each hop, the cone angles increase/decrease based on the distribution of local sensor nodes, which is hard-programmed into the algorithm.

In places where sensors are scarce, the cone angle is increased so that the next forwarding node can be found. Because of this, the AHHC-VBF are adjusting the cone angle so that the packet is sent at a low energy level. As discussed above, AHHC-VBF guides the transmission of packets to the sink nodes, as stated. AHHC-VBF enhances the network's critical parameters and performance. The most important one, as we say it, offers direction to the transmission of packets and changes its angle depending on the distribution of local nodes, which boosts the network's resilience in low-density nodes. Smart selection of forwarded nodes also decreases the formation of duplicate packets and the end-to-end delay owing to adaptively changing source node angles. Routing protocols that consider the sensors' distance from the sinks when determining a path are known as "depth-based routing protocols." Sensor nodes fitted with depth sensors can measure their depth from the sink node.

The protocols that follow the depth-based routing method are listed below. Every UWSN aims to transmit data from sensors to sinks with little loss and low energy usage. Similar issues arise in every routing protocol, including VBF, HH-VBF, AHH-VBF, and so on. Here, too, in Depth-Based Routing (DBR) [38], a packet is routed by its relative depth to the other nodes. Consider a case in which a sensor node receives a packet from another node after it has been transmitted in all directions by the sensor node. Using the depth sensor encoded in the transmitted packet, this receiver node may determine how far it is from the sender node. Forwarded packets at a greater depth than the present receiving node (sanded by another node) indicate that the receiving node is located closer to the water's surface or the sink node. When a packet is received and embedded in its own depth, the receiver node sends the packet to the next forwarder. Forwarded packets with more depth than the current receiving node are closer to the surface or the sink nodes, whereas packets with less depth than the current receiving node are farther away. In this case, the packet will be discarded by the receiver node. The best next forwarder node to forward the packet was scheduled using holding time computation in DBR. That's exactly what happens in DBR, as well. When a packet arrives, the node keeps the packet for a while so that it can take appropriate action, such as calculating its position using depth differences and also calculating its timer value.

The sensor nodes in the water are constantly moving as a result of the water currents. Therefore, they will be at various locations. In this way, the amount of time they may be held will likewise differ. As a result, the nodes that are closest to the sink nodes or the surface nodes have a shorter timer value. Hence, the sink or close-to-surface nodes are better forwarded than other nodes in the network. It also prevents other nodes in the same local area from sending identical packets, which reduces energy usage and improves packet transmission. WDFAD-DBR [39] is another unique protocol that considers the void hole creation for the following forwarder node, which has a negative impact on overall network performance. For example, DBR only considers one-hop local node distribution through its depth differences, which may lead to void holes in the projected next-hop forwarding. WDFAD-DBR, on the other hand, takes into account a feature known as "second hop forwarding," which improves the network's overall stability.

DBR will send the packet directly to the current forwarder node if the source node forwarded the packet to this node, which is in an optimal position (i.e., its depth difference is the smallest among all other nodes; hence, it is the best forwarder node for the next forwarding) in this scenario. This node will be the best forwarder node because it is situated in an ideal location and can support DBR. However, DBR is not considering this forwarder node because it does not have a second hop. This optimal forwarder node can't forward its packet to the next forwarder if it has a void hole in its transmission zone, meaning there are no other forwarder nodes in its range. While this is true for WDFAD, the expected next hop forwarding node is also considered while transmitting the packet. As a result, WDFAD- DBR will consider not just the optimal node that DBR had in mind but also any nodes with a subsequent forwarder node on the second hop, which may or may not be in an optimal location. WDFAD-DBR, on the other hand, works on the next hope forwarder nodes and avoids the generation of void holes, effectively reducing energy usage and eliminating packet losses. When there are void holes at the second hop, WDFAD-DBR doesn't know what to do with the packets it receives; thus, it can't forward them. So, a new method, DOW-PR, for UWSN is intended to address some of the issues that WDFAD-DBR faces [40]. Suppressed nodes and prospective forwarding nodes are just a few of the parameters that DOW-PR has defined (PFNs). In DOW-PR, the authors evaluate not just two-hop communication but also the number of PFNs and the number of suppressed nodes during transmission. WDFAD-DBR considers the path with nodes on the second hop and their optimal position, while DOW-PR considers the number of PFNs present at the forwarded node. As more PFNs are transmitted, the likelihood of making more duplicate packets rises, as more transmission equals more packets being transmitted, which leads to greater packet duplication. As a result, DOW-PR considers only those paths for two-hop communication with a low number of PFNs at both the first and second hop to enhance the network's resilience and decrease the production of redundant packets. DOW-PR will evaluate the node from those suppressed links with sufficient PFNs other than the source node if a void hole occurs at the second hop, as we described earlier. As WDFAD-DBR does not evaluate this method, the packets will not be lost in DOW-PR in this manner. DOW-PR also divides the transmission range into several energy levels. The flooding of request packets and the reply of the acknowledgement packet provide the source node with information about the transmission energy level. This allowed the source node to tune its transmission power level to the optimal level so that no packets were lost during transmission while WDFAD-DBR flooded the packet with random power.

At the water's surface, sink nodes collect data from sensor nodes and send it to a central station. Nonetheless, with DOW-PR, there is an embedded sink that is connected to the surface sink via a high-bandwidth high-speed connection. As a result, nodes that are both remote from the surface sink and close to the embedded sink can communicate with each other directly over the latter. While the packets are being delivered to the surface sink, the rest of the network will not suffer any loss of power. Compared to WDFAD-DBR networks, the DOW-PR networks consume substantially less energy, deliver more packets to the sink node, and have a longer lifespan. Energy is the lifeblood of every sensor network, whether on land or in the water. The underwater routing, on the other hand, necessitates special consideration because batteries are used as a source of power in underwater sensor networks and cannot be simply recharged or replaced during data transmission. UWSNs are additionally hindered by variables such as the narrow bandwidth of acoustic signals, the higher power consumption for transmission, and the increased de- lay rate. When the batteries in the sensor nodes fail, we face a major threat, such as packet transmission failure or even network failure. The protocols covered here focus on energy-based routing and maintenance to extend the networks' life and avoid the formation of holes in the network's energy supply. Other network parameters, such as packet delivery ratio and end-to-end delay, are also affected by focusing on the network's energy, which will be explained in each routing protocol correspondingly. Energy-based routing requires the use of the following protocols. The authors in [41] suggested a Directional Routing Protocol (DRP) protocol that considered the likelihood of packet collisions between sender and recipient nodes and the energy consumed by such packets. The greater the distance between the source and destination nodes, the greater the likelihood of a collision. Increasing the distance between the source and destination nodes increases the likelihood of packet collisions; hence, this DRP route data should be used to select the shortest path between the source and destination nodes, which requires the least amount of energy for transmission. In order to keep the network going, DRP is always looking for ways to send packets with a low collision probability and a high amount of residual energy. Since power allocation to each sensor node remains nearly optimal, packet throughput increases. Another routing system, Shortest Path Routing (SPR), also works to find the shortest path for transmitting packets from the sensor node to the sink node to keep the network alive and increase its life span [42].

An Energy-Aware and Avoidable Routing Protocol (EAVARP) [28] is a new protocol that discusses two phases: the layering phase and the data collection phase. As a part of the layering phase, each layer of the distance between the sink node and the source node is divided into layers, each of which is separated from the previous layer by a fixed distance. The sink node shell covers a large number of source nodes because sensing nodes are randomly distributed around the sink nodes. Second-phase nodes direct their data to sink nodes based on their placement at the layer of the sink node. Data transmission and the remaining energy of all nodes in a shell were taken into account by EAVARP in order to avoid redundant transmission and an empty energy hole. Prior to transmitting data, these phases are taken into consideration, and their primary goal is to direct the routing toward the sink node. A limited number of nodes with more energy and proximity to the sink will participate in the communication process as a result of this shell method so that the network's lifespan is maximized.

That's why there's DB-EBH [29], an alternative routing protocol that relies on direct and multi-hop communication of the network to keep things running smoothly. Using depth sensors installed in each sensor node, this protocol prioritizes a node based on its location and uses that information to select the best nodes for communicating with. To improve one parameter, you'll impact others because they all interact. Another unique protocol Region, aware proactive routing approaches exploiting energy efficient paths for void hole avoidance in underwater WSNs (PA-EPS) [43], is presented to address this issue, which takes into account all of these parameters and examines each one's impact on the network as a whole in order to boost the network's overall performance. When it comes to dense sensor networks and sparse sensor networks, a proactive routing technique is offered. To avoid generating void holes in a sparse network, a clustering technique is presented in which each sensor node knows its own location and the location of all other nodes present in the same cluster. Different nodes in a network are used to gather information and scale the network as needed.

Accordingly, PA-EPS adaptively increases or decreases the number of nodes between 100 and 500 to improve the network's scalability and performance. Adaptive modifications to routing algorithms based on the distribution of local nodes reduce packet-dropping rates and the time it takes for packets to reach their sink nodes. The ESEVBF protocol [24] proposes a different approach to this problem to increase the routing's efficiency. Here are some examples of ESEVBF's work: To begin, they use the energy data from all of the sensors located across the local area to adjust the timer duration of the forwarder nodes. The distance from the source node to the sink node and the timer computation is used to select the next forwarding node to determine which forwarding node to use. To reduce the end-to-end latency for the next forwarding, sensor nodes gather information from all nearby nodes and reduce timer value as nodes are spread out across the local area; for a third point in our discussion of how water currents and sensor node movement cause an uneven distribution of energy in various transmission scenarios. The remaining energy levels at each node in ESEVBF are considered when rescheduling the timer value of each node in the local region. If necessary, extra packets are suppressed to balance the energy. There are no hard numbers in ESEVBF when it comes to holding times; rather, varied routing and energy balancing are considered when customizing the hold times.

3. Types of Packets in the MPBFP-EH

The proposed protocol distinguishes between five distinct kinds of packets: Neighbor Request, Acknowledgment, Container, Announcement, and Data Packet. The sensor nodes are set up in various locations. When the packet is ready to be forwarded, the timer mechanism chooses the next forwarder. The packet is transmitted by the source node to all of the Potential Forwarding Nodes (PFNs), which then receive it. In the event that the PFN does not change its position at any point in the locality, then, if we are talking about real life in the simulation, a single node will be chosen every time the source broadcasts the packet. Because of the repeated selection, the currently chosen node will enter a dead state after a certain amount of time has passed. Therefore, the sensor nodes move around, changing their positions randomly. These nodes are qualified to act as forwarding nodes if the current source node is shallower and the distance between them is closer together than the transmission distance. The Neighbor Request Packet is broadcast by the source node in order to locate the forwarding nodes that it needs. The Neighbor Request Packet has the format Nreq (id, d, Typepacket), where id is an unchanging integer number that is specific to the sensors nodes, d is a field that was initially assigned to each node during the initialization phase, and it stores information regarding the depth while Typepacket is a number in a binary format that is used to distinguish each of the packets. As soon as when a neighbor's Neighbor Request Packet is received, the neighbour sends a Neighbor Acknowledgment Packet in response. The configuration of an Ackpacket (id, d, residualenergy, Typepacket) where an id is a unique number that is given to each node, d is the data packet type, residualenergy is residual energy or energy status, and Typepacket denotes the packet type, i.e., in the current case, it will be denoting an Acknowledgement Packet. At the first hop, the PFNs of the source node communicate with one another using packets through Container Packets, also known as CPs, to exchange their priorities. Whenever a data packet is delivered to a neighbour node from the source node, the neighbour node immediately calculates its own timer value in addition to determining the bare minimum required timer for the second hop. The structure of a Container Packet can be described as Can (id, TimerHop1, TimerHop1, Typepacket), where id is the unique number of the sending node, TimerHop1 is the timer value at first hop, and TimerHop2 is the timer value at the second hop (the minimum timer value among the second hop forwarder of the applicant adding TimerHop1 and Typepacket represents the packet type, i.e., in this case, the container packet. When the source node is in pos- session of the Container packets sent by each of the Announcement Packets, which it broadcasts to the neighbours (AC). This particular kind of packet is utilized in the process of determining the concealed, ultimately fatal problem, which will be covered later in this section. The Announcement Packet follows this format for its contents:

$$Announcement_{packet} = (id_{(highestpriority)}, x, y, z, Type_{packet})$$

In which $id_{(highestpriority)}$, x,y, and z stands for the id and coordinates of the node with the highest priority; $Type_{packet}$ represents the type of packet, i.e. announcement packet in the current case; The final type of packet is called a Data Packet, and it contains the actual data or information that must be transmitted to the centralized station. Data Packet refers to the format that Data Packet uses Data packet = (Header, Payload, $Type_{packet}$). The packet's header includes information regarding the node that generated the packet and the centralized station. The data packet's payload is the most important component, as it contains the data that pertains to the environment and the $Type_{packet}$ representing the packet type. In the event that the preceding packets are data transmitted at frequent but brief intervals, then increased network overhead and power consumption can be anticipated. Because of this, in order to circumvent this issue, every node maintains its own corresponding neighbour table, which is for the purpose of keeping a record of their fellow community members: $Neighbor_{table}$ = (id, $residual_{energy}$, d, $Timer_{value}$, $Update_{time}$) where id is neighbour node unique number, $residual_{energy}$ is the residual energy of the node, d representing the Depth in- formation, $Timer_{value}$ is the timer value of the node, and $Update_{time}$ stands for the time required to update the neighbour entry. In the meantime, when there is sufficient time for neighbouring nodes to be updated, the source node will send out and receive the second packet. Then, the sourcewill immediately broadcast the Data Packet as well as the Announcement Packet that was contained in the prior table.

4. Network Diagram of the Proposed Work

The changes in pressure and temperature are the primary factors that determine how quickly acoustic waves travel, as well as the salinity of the water in its various layers. Let us assume that the letter C denotes the speed of the acoustic sound, T denotes the temperature of the water at various depths, S refers to the salinity of the water, and D stands for the depth of the water. Therefore, in terms of mathematics, the speed of an acoustic signal, denoted by the letter C, can be expressed as [44]:

$$\begin{aligned} C = & 1448.96 + 4.591 \times T - 5.304 \times 10^{-2} \times T^2 + \\ & 2.374 \times 10^{-4} \times T^3 + 1.340(S - 35) \\ & + 1.63 \times 10^{-2} D + 1.675 \times 10^{-7} D^2 \\ & - 1.025 \times 10^{-2} T (S - 35) - 7.139 \times 10^{-13} D^3 \end{aligned} \quad (1)$$

5. Timer Value Calculation

Sensor nodes are used to gather data packets and send them across forwarder nodes to sink nodes or centralized nodes. As a result, many overhead packets are being created that have a negative impact on the energy consumption of nodes and networks. In order to prevent the creation of duplicate packets, a timer value technique is employed, and the nodes that are most favourable with respect to residual energy and in the best possible position with respect to the pipeline can only send the packets. The unfairness of the timer value, on the other hand, causes issues for routing since it adds latency, which influences routing performance, particularly for time-critical application protocols, and hence consumes network energy. The proposed work extends the timer mech- anism of the first-hop to the second-hop forwarder.

The second hop is used to determine which node provides the most optimal level of service in relation to the progression of the network packet cover between the two jumps. In addition, it prevents the formation of void holes, which can happen for several reasons, including an energy hole, also known as an insufficient number of potential forwarding nodes with an energy status higher than the threshold in the transmission range. Two distinct varieties of nodes are neighbours to a source node. The nodes located in the source node's upper hemisphere and having a residual energy higher than the threshold are referred to as Potential Forwarder Nodes (PFNs). Suppressed nodes, on the other hand, are those that are nested deeper than the source node.

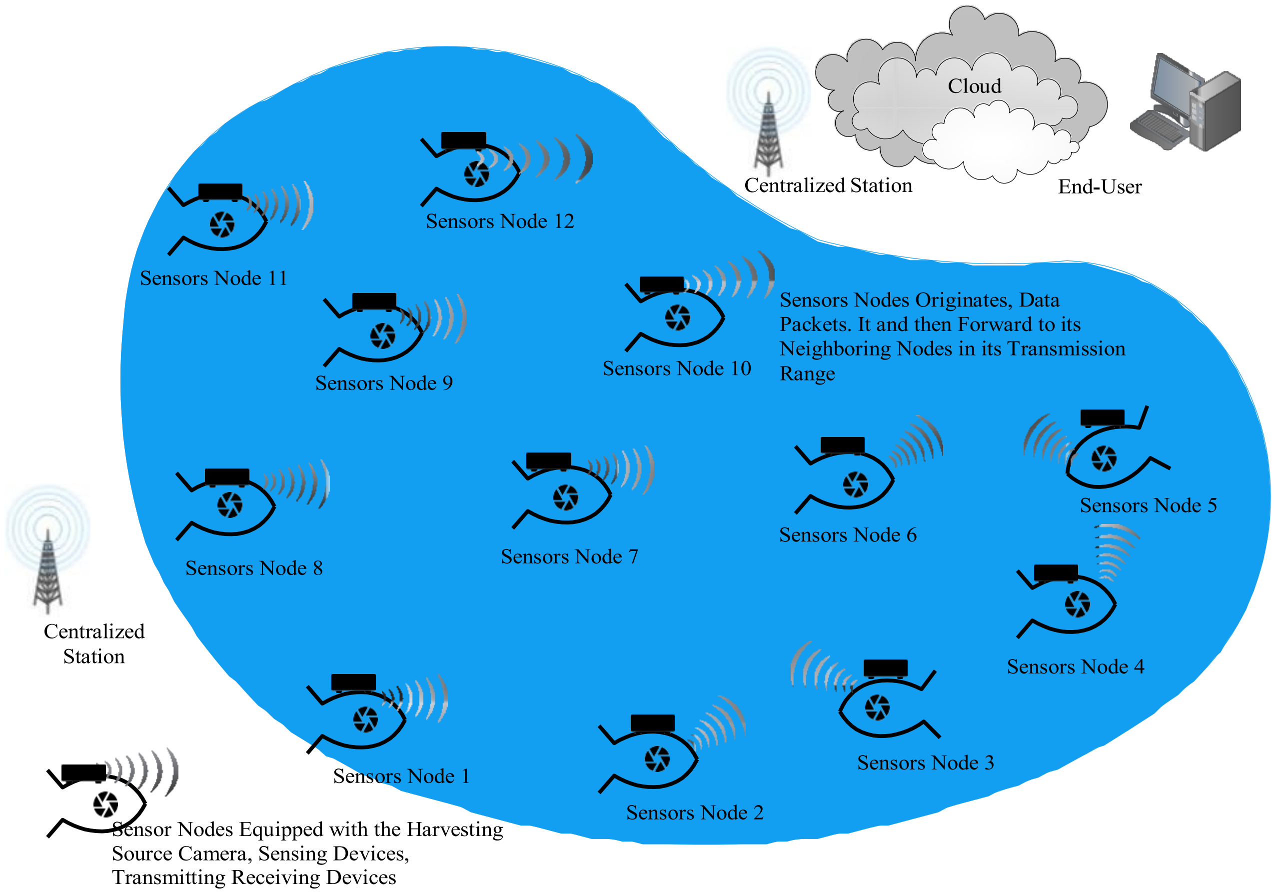

Fig. 1 Network architecture of the proposed work

In the event that a packet that was broadcast by the source node is received by a qualified node, the receiving node consults the neighbour table to determine the energy levels of its neighbours to determine its timer value during the first hop. Additionally, the qualified node of the source node is taken into consideration. That of the PFN subsequently computes both its own timer value.

The preceding equation has solid foundations for the val- ues 0^C, Temp 30^C, 30^{Si}, 40PPT, as well as 0^C and depth 8000 m. It is possible to observe the effects that temperature and salinity have on the acoustic sound velocity.

The network architecture of the MPBFP protocol is composedof anchored nodes, relay nodes and sink nodes, as depicted in Figure 1. The sensor nodes are equipped with the energy harvesting resource, which generates a specific amount of energy in due time. The terminus nodes/sink nodes are centralized stations consisting of acoustic and radio modems.They communicate with each other and the external network through the radio links. Sink nodes are fixed atthe water surface. The data received by any sink node is considered a successful delivery to its destination.

On the other hand, relay nodes are movable with the water current, while anchored nodes are fixed at the bottom. The sensor nodes communicate with each other through an acoustic link.The speed of acoustic signals (1500 m/s) is much smaller than that of electromagnetic signals and the expected nodes at the second hop. To discover the $Timer_{Hop2}$ of the PFN refers to the amount of time that thenode has been holding for, and it is the node with the highestpriority among the second hop PFNs, is added, each with itsown storage duration, as shown in Algorithm 1. The qualifiednodes have two different priorities: one at the first hop and one further down the tree. According to its own timer value, and both its own timer value and the anticipated next PFNat the second hop in the chain, the nodes then communicate about the priorities of the PFNs by exchanging the containerpacket.

In order to keep an eye on the conditions of the ocean floor,acoustic sensor nodes have been set up to monitor an area under observation. Data packets are continually generatedby nodes and sent to the centralized station as soon as every node within the transmission range of the source nodereceives the data packets after the source node has broadcasted them. If all of the forwarder nodes are involvedin the process of forwarding the packets, it will lead to an increase in overhead and an increased amount of consumed energy. We propose a timer mechanism as a means of extending equation as shown in Figure 2.

$$Timer\_value^{NodeA} = Energy\_Factor + Harvesting\ Energy + Pipeline\_Factor + Net\_depth\_difference \quad (2)$$

```
Algorithm 1: Proposed Algorithm for MPBFP-EH
Define total nodes and transmission ranges
for Avg_factor ←1 to Avg by 1 do
    Define Nodes in the network for the current avg factor;
    for Cnoade ← 1 to Sensor_Nodes by 1 do
        Deploy Sensor Nodes in 3D Space
        for C_transmission ← 0 to Total_Transmission ranges by 1 do
            for i ←1 to Sensor_Nodes by 1 do
                for j ← 1 to Sensor_Nodes by 1 do
                    Based on the Euclidean distance b/w i and j
                    Find Potential Forwarding Nodes

                _
            _
            for i ← 1 to Packets by 1 do
                Source node S ID =i
                while Forwarding nodes of S exist AND sink_recieved == False do
                    Find if centralized station is reached
                    S1=source(x.y.z), D=Destination(x.y.z), Find Emin and Emax at Ist hop
                    for P ← 1 to number of Forwarder of S by 1 do
                        Get the location of PFN (P), Find Emin and Emax at 2nd hop
                        for K←1 to number of PFNs of P by 1, do
                            S1(S1(ID).neighbor(K)).E=S1 (S1(ID).neighbor(K)).E+Harvesting Energy;
                            E_hopz=Get the energy of the second hop PFN
                            Energy_factor = E_hop2 -Emin_hp2/Emax_hp2-Emin_hp2
                            Timer_Hop2=Find minimum timer value at the second hop

                        _
                        Timer_Hop1=Find timer of node P at the First hop
                        Record Hop 1 and Hop 2 IDs and corresponding timer values

                    _
                    Prioritized Record of Hop 1 and Hop 2 with respect to the timer
                    value for m 1 to nodes in Record_Hop2 by 1 do
                        m element of Record_Hopz. Timer = m element of Record_Hop.Timer:

                    _
                    S=Find The node Having minimum Timer value
                    for t 1 ← to nodes in Record_Hop2 by 1 do
                        Check the propagation distance between the current node and
                        node having minimum timer value

                    _
                    if number of nodes in Record_Hopz==1 then
                        Record_Hopz. Timer = 0

                    _
                _
            _
            Measured Performance Parameters
        _
    _
_
```

The parameter known as the energy factor indicates the distance separating the PFN from the perimeter of the transmission range scaling with the inverse normalized energy of the PFN both at the first and second hop. The energy factor can be defined as:

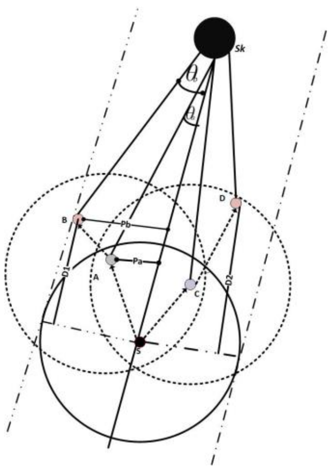

Fig. 2 Timer value calculation

$$\text{Energy}' - \text{Energy} - T^{S} - D^{F-\text{Node}} \quad (3)$$

$$\text{Factor} = e \quad F_{\text{Node}} \quad r\ S\ vS$$

The lifespan of the network. The timer value for a node A forwarding a packet P can be calculated with the following.

The neighbouring nodes of the source node are used to normalize the energy of the node. The energy adjusted for normalization is between 0 and 1. The node that has the highest amount of residual energy will have a higher absolutevalue of normalized energy. Energy in a forwarder node at the firstand second hop can be calculated with the following equation.

$$\text{EnergyFN ode} = \frac{(e_{hp1}+e_{hp2})-(emin_{hp1}+emin_{hp2})}{(emax_{hp1}+emax_{hp2})-(emin_{hp1}+emin_{hp2})} \quad (4)$$

The values ehp1 and ehp2 represent the amount of energyleft over from nodes A and B, respectively. The minimum energy of the PFN at the first and second hops is denoted by eminhp1 and eminhp2, respectively; the opposite is also true. The normalized energy value is greater for the node with higher residual energy for itself and its anticipated PFN at the second hop. The energy harvesting factor is the amount of energy generated by the ambient generated harvester source at a specific time. The pipeline factor in the timer value calculation provides directionality and demonstrates the positioning of a forwarder node regarding the virtual pipeline. The sensor nodes A in Figure 2 have a distance of Pa from the virtual pipeline. The node located closer to the vector that connects thesender and the sink has a higher value of the pipeline factor. The last factor *Net_depth_defference,* is the overall distancecovered at the 1st two hops from the source node by selectingnode A, as briefly explained in [24].

6. Simulation Results and Analysis

UWSNs face a major problem when transmitting packets due to the inequities in the energy allocation among the source nodes. Some nodes are involved in the communicationprocess while others are not, which is why this happens. To monitor the environment and route different data packets the sensor nodes with restricted energy sources are put in various locations to the sink nodes. Also, a randomly deployed network is monitored to maintain a healthy energy balance and extend the network's life. There arethree main goals of the UWSNs protocols: to ensure reliable communication, improve throughput, and extend the network's life by making it easier for data to be routed from source to sink and back to the base station. We comparethe performance of the proposed work MPBFP and the conventional EESEVBF in our simulations. We use a three- dimensional volumetric model region with dimensions of length (10 km), width (10 km), and depth (10 km).

The size of the data packet's header is 11 bytes, and the payload consists of 72 bytes; the neighbour request and acknowledgement eachtake up 50 bits, and the container packet is 70 bits. The speedof sound as it travels through the water is approximately 1,500 metres per second. To demonstrate the performancein both the sparse and dense configurations, the number of nodes used ranges from 200 to 450 in the networks, andthe range of transmission can be anywhere from 500 to 900 metres in length. The nodes can move at a consistent speed of 2 metres per second.

The initial energy of the node is set to 80J, and its sendingenergy, receiving energy, and idle energy are all set to 4.5J, respectively. The background wireless environment that exists underwater and the acoustic channel parameters (ambient noise, site-specific noise, central acoustic signal frequency) are set for simulation, as stated in reference [33]. The performance parameters are evaluated as a result of the proposed protocol. The deployment of the underwater network is to monitor certain localized regions on the top of the ocean. Packet Delivery Ratio (PDR)is defined as the data packets that are invariably created by the source nodes, and then those nodes transmit the packets to the destination. The packet delivery ratio, abbreviated as PDR, is the ratio of the number of packets received at the destination to the total number of packets created. There is a possibility that we could have received more than one copy of a particular packet, but only one copy will be considered on the receiving end.

The PDR performance parameter for the proposed work MPBFP-EH is plotted in Figure 3 with varying transmission ranges available. For both protocols, the PDR rises as the number of nodes in the network increases. It satisfies the fact that when the number of nodes andtransmission range increases, then in the transmission range of each node, there will be a greater number of nodes, whichwill result in a decrease in the number of packet drops whilesimultaneously increasing the reliability.

When the network shifts away from the traditional topology, there is a lower chance of void holes developing, i.e., from a sparse state to a more dense one. There are two scenarios in which void holes could occur; the first is when there is no PFN and the second is when there is a PFN within range of the source node but does not have enough energy to forward the signal.

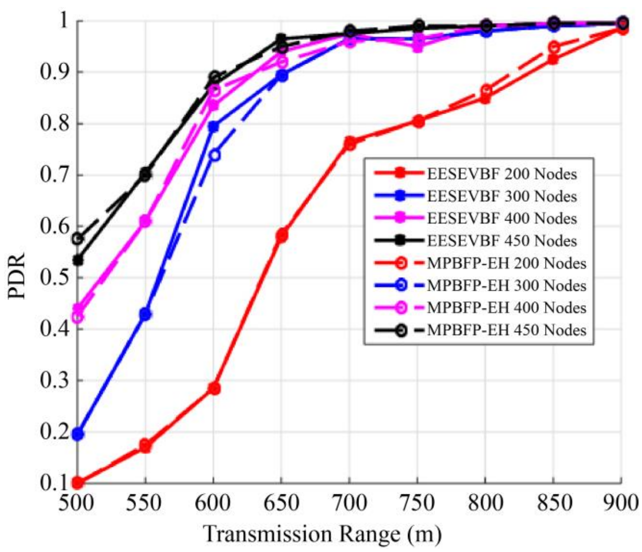

Fig. 3 Transmission range Vs PDR

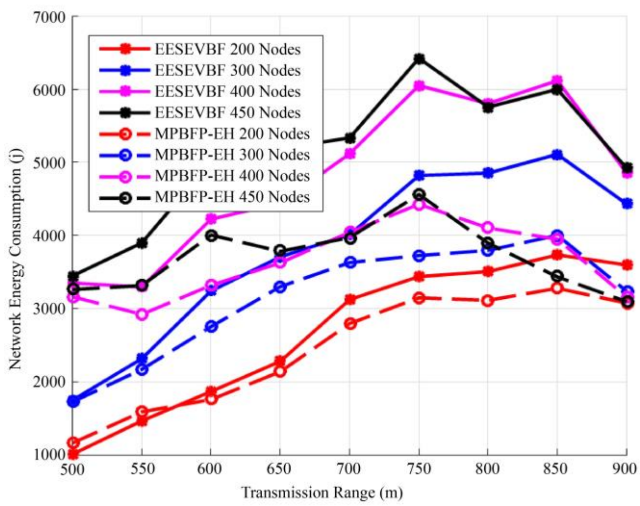

Fig. 4 Transmission range Vs Network energy consumption

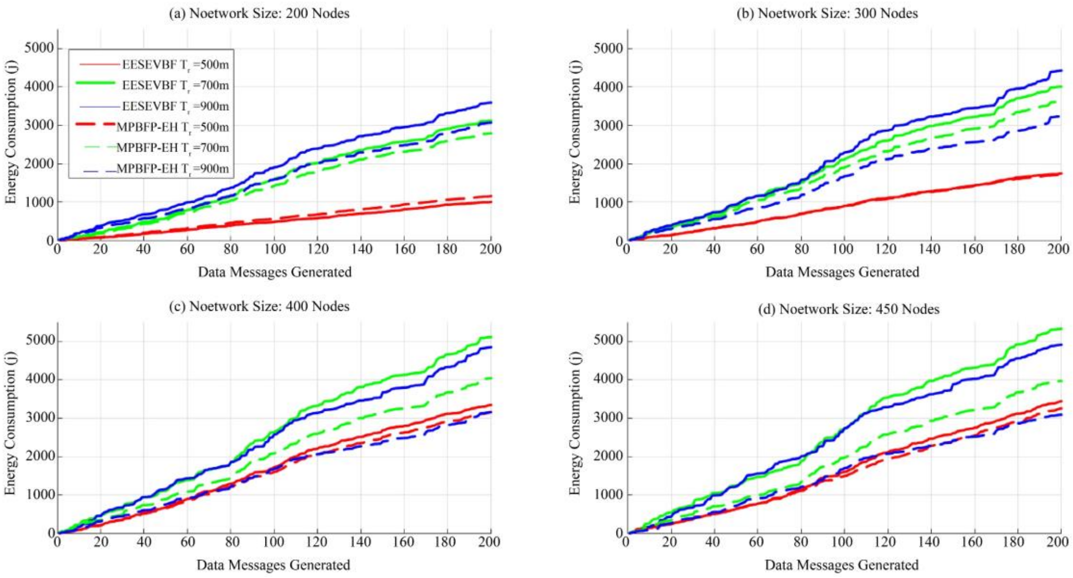

Fig. 5 Data messages generated Vs Energy consumption

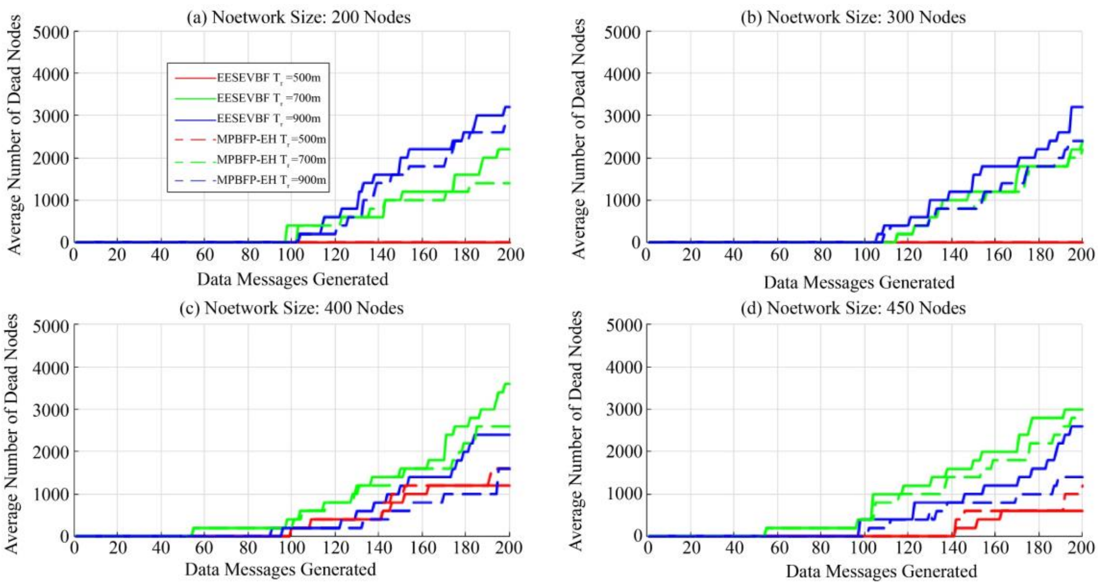

Fig. 6 Data messages generated Vs Average number of dead nodes

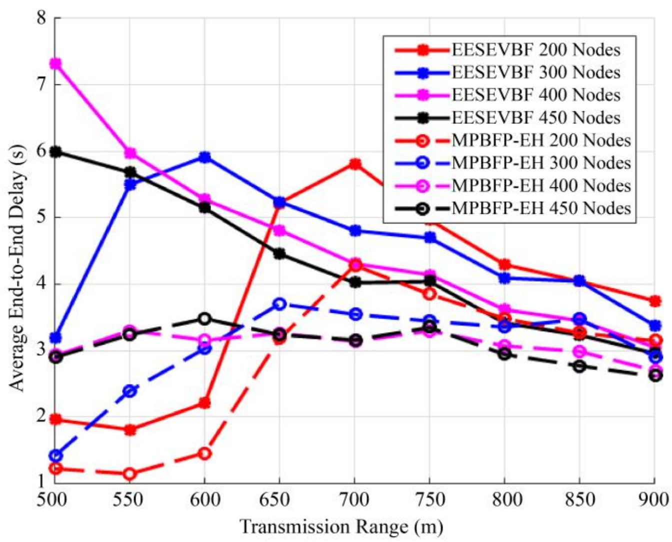

Fig. 7 Transmission range Vs Average end-to-end delay

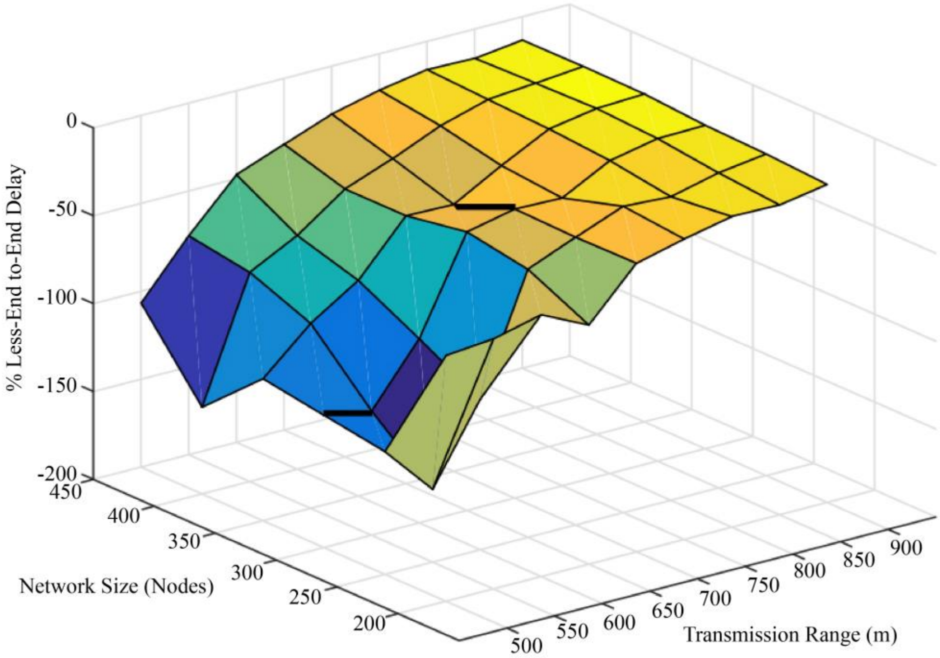

Fig. 8 Transmission range Vs % less end-to-end delay

The PDR of MPBFP-EH is marginally greater than that ofEESEVBF for a transmission range of 800 metres. Nevertheless, there is not much of a distinction when comparedto the transmission range of 700 metres, as shown in Figure 3, as the proposed work, MPBFP-EH is working to increase the network lifetime by embedding an ambient energy sourceequipped within the sensor nodes. When the scope of the transmission increases for a given number of nodes, thePDR also shows an increase as a result. In this particular scenario, there is a higher probability of discovering a more appropriate node in relation to timer value; on the other hand, for lower probabilities, transmission range, it is difficult to find the next PFN, and the more packets are not reached to the final destination or sink nodes.

The total amount of energy consumed in the network as a whole is referred to as the energy consumption. It is common knowledge that the amount of energy required rises in proportion to the number of nodes when the network increases because of the increase in the generation and transmission of duplicate packets 4. The energy simulation results are plotted in Figures 4 and 6. The energy consumption is plotted with the adjustments to both the number of nodes and the number of transmission ranges.As can be seen in Figures 4 and 5, the consumption of the proposed work MBPFP-EH is significantly lower than thatof the conventional EESEVBF. This is because duplicate packets are created in their initial state. The replicating nodes in EESEVBF are the ones that produce the duplicate copies. The total number of packets is increased as a result of the consumption of duplicate packets on the path from the reproducing node to the sink; in contrast, our suggested protocol not only chooses the best possible route but also takes into account any regard to the progression of the packet and the residual energy at the firstand second hop but also in terms of the harvesting energy generated from the ambient source embedded in the sensor nodes, which has led to a significant reduction in energy consumption and extending the network lifetime by reducing the number of dead nodes in the network as depicted in Figure 6.

The time it takes for a packet to travel from itssource node to its destination node is known as end-to-end delay. It considers both the delay in transmission and the propagation delay, as well as any necessary processingtime for the sensor node to send a packet in the next direction.The result of end-to-end delay with different values, the amount of transmission range, and the number of nodesis plotted in Figure 7. The delay from beginning to end of MPBFP-EH is significantly less than that of, according to ESEVBF, as presented in Figures 7 and 8, respectively. This is due to the following two factors: When a node forwards a packet, the timer value determines which subsequent forwarder should receive and forward the packet to the next hop. Only the advanced distance that was covered in the first hop was taken into consideration by the EESEVBF protocol, i.e., the distance from the source to the forwarder in the process of selecting the subsequent PFN rather than the one in the second hop of the route.

On the other hand, the proposed protocol MPBFP-EH extends network life by embedding an energy harvesting source through which the protocol finds the most favourable nodes in terms of residual energy. The proposed work with energy harvesting source included the distance between the source node and the forwarder is measured from the edge of the transmission range to the the distance between the sink and the next node, as well as the distance between the source node and the second hop forwarder forwarder, as well as how far away they are from the virtual pipeline, in the calculation of the timer value for a forwarder node. The MPBFP-EH also uses a container packet in which the nodes trade their respective timer values at both the initial and secondary transitions.

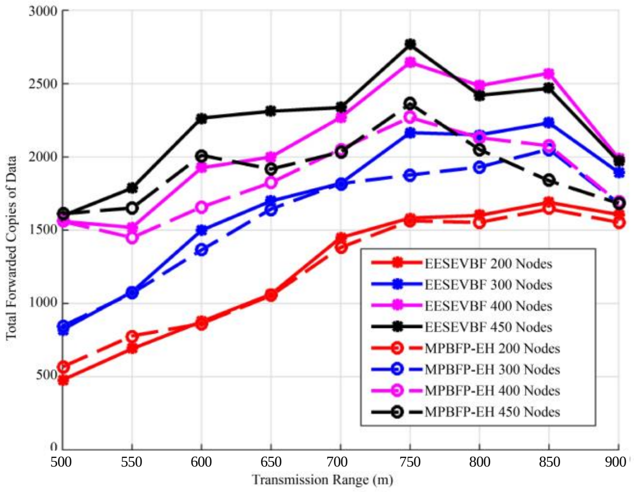

Fig. 9 Transmission range Vs Total forwarded copies of data

The priorities of the nodes were determined based on the amount of timer value they have for a specific packet for forwarding to the destination nodes. The nodes analyzing the announcement packet, the nodes with higher priority, will directly forward the packet while the rest drop the packet.

The total number of duplicate packets transmitted throughout the network by varying the nodes and the transmission range is plotted in Figure 9. The total number of copies that were forwarded in the sparser network are less than those travelled in the denser network. The reason being is that the vast majority of the packets do not arrive at their intended locations because they are abandoned earlier while travelling. A large number of forwarded copies of the packets are forwarded for larger networks and longer transmission ranges because of an increase in the pipeline radius, an increased number of duplicate packets transmitted throughout the network and an increase in the total number of PFNs present in the potential forwarding zone. The reason for the difference between the numbers of copies forwarded in MPBFP-EH and those in EESEVBF is that it prevents the creation of duplicate packets by preventing their instantiation due to using an announcement packet efficiently while providing favourable forwarder nodes for each instance of transmission.

7. Conclusion

Underwater Wireless Sensor Networks (UWSNs) are characterized by the sparse deployment of their sensor nodes to deployment and high manufacturing costs in regions where large deployments are required. In order to reduce the amount of energy and extend the network lifetime, we came up with a novel Mollies and Platies Bottom-Feeders Pods routing aided Energy Harvesting for (MPBFP-EH) Underwater Wireless Sensors Networks (UWSNs) protocol is proposed, which harvests energy from ambient sources and extends the network lifetime. The proposed work, along with the energy harvesting source, also included the distance between the source node and the forwarder, which is measured from the edge of the transmission range to the distance between the sink and the next node, as well as the distance between the source node and the second hop forwarder, as well as how far away they are from the virtual pipeline, in the calculation of the timer value for a forwarder node. The simulation findings indicate that the proposed work MPBFP-EH reduces energy consumption and extends the network lifetime by incorporating an ambient energy harvesting source embedded in the sensor nodes. Moreover, the number of void holes due to the dead nodes or the nodes with insufficient energy decreases.

References

[1] Youngtae Noh et al., "VAPR: Void-Aware Pressure Routing for Underwater Sensor Networks," *IEEE Transactions on Mobile Computing*, vol. 12, no. 5, pp. 895-908, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[2] Ian F. Akyildiz, Dario Pompili, and Tommaso Melodia, "Underwater Acoustic Sensor Networks: Research Challenges," *Ad Hoc Networks*, vol. 3, no. 3, pp. 257-279, 2005. [CrossRef] [Google Scholar] [Publisher Link]

[3] Huafeng Wu et al., "An ACOA-AFSA Fusion Routing Algorithm for Underwater Wireless Sensor Network," *International Journal of Distributed Sensor Networks*, vol. 8, no. 5, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[4] Salmah Fattah et al., "A Survey on Underwater Wireless Sensor Networks: Requirements, Taxonomy, Recent Advances, and Open Research Challenges," *Sensors*, vol. 20, no. 18, pp. 1-30, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[5] Khalid Mahmood Awan et al., "Underwater Wireless Sensor Networks: A Review of Recent Issues and Challenges," *Wireless Communications and Mobile Computing*, vol. 2019, no. 1, pp. 1-20, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[6] Khandaker Foysal Haque, K. Habibul Kabir, and Ahmed Abdelgawad, "Advancement of Routing Protocols and Applications of Underwater Wireless Sensor Network (UWSN)-A Survey," *Journal of Sensor and Actuator Networks*, vol. 9, no. 2, pp. 1-31, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[7] Kishor Patil et al., "Stochastic Modeling of Depth Based Routing in Underwater Sensor Networks," *Ad Hoc Networks*, vol. 89, pp. 132-141, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[8] Sarang Karim et al., "Anchor Nodes Assisted Cluster-Based Routing Protocol for Reliable Data Transfer in Underwater Wireless Sensor Networks," *IEEE Access*, vol. 9, pp. 36730-36747, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[9] Prakash Mohan et al., "Improved Metaheuristics-Based Clustering with Multihop Routing Protocol for Underwater Wireless Sensor Networks," *Sensors*, vol. 22, no. 4, pp. 1-16, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[10] Junhai Luo et al., "A Survey of Routing Protocols for Underwater Wireless Sensor Networks," *IEEE Communications Surveys Tutorials*, vol. 23, no. 1, pp. 137-160, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[11] Addisalem, K.P. Porkodi, and I.Karthika, "Comparative Analysis of Routing Protocols for Under Water Wireless Sensor Networks: A Survey," *EPRA International Journal of Multidisciplinary Research*, vol. 3, no. 5, pp. 40-47, 2017. [Publisher Link]

[12] Salvador Climent et al., "Underwater Acoustic Wireless Sensor Networks: Advances and Future Trends in Physical, MAC and Routing Layers," *Sensors*, vol. 14, no. 1, pp. 795-833, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[13] M.S. Garcia et al., "An Agent-Based Wireless Sensor Network Forwater Quality Data Collection," *International Conference on Ubiquitous Computing and Ambient Intelligence*, Springer, Berlin, Heidelberg, pp. 454-461, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[14] Ethem M. Sozer, Milica Stojanovic, and John G. Proakis, "Underwater Acoustic Networks," *IEEE Journal of Oceanic Engineering*, vol. 25, no. 1, pp. 72-83, 2000. [CrossRef] [Google Scholar] [Publisher Link]

[15] John Heidemann et al., "Research challenges and Applications for Underwater Sensor Networking," *IEEE Wireless Communications and Networking Conference*, Las Vegas, NV, pp. 228-235, 2006. [CrossRef] [Google Scholar] [Publisher Link]

[16] Frank Hanson, and Stojan Radic, "High Bandwidth Underwater Optical Communication," *Applied Optics*, vol. 47, no. 2, pp. 277-283, 2008. [CrossRef] [Google Scholar] [Publisher Link]

[17] Hemani Kaushal, and Georges Kaddoum "Underwater Optical Wireless Communication," *IEEE Access*, vol. 4, pp. 1518-1547, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[18] Umberto M. Cella, Ron Johnstone, and Nicholas Shuley, "Electromagnetic Wave Wireless Communication in Shallow Water Coastal Environment: Theoretical Analysis and Experimental Results," *Proceedings of the 4th International Workshop on Underwater Networks*, New York, United States, pp. 1-8.2009. [CrossRef] [Google Scholar] [Publisher Link]

[19] Xianhui Che et al., "Re-Evaluation of RF Electromagnetic Communication in Underwater Sensor Networks," *IEEE Communications Magazine*, vol. 48, no. 12, pp. 143-151, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[20] Milica Stojanovic, and James Preisig, "Underwater Acoustic Communication Channels: Propagation Models and Statistical Characterization," *IEEE Communications Magazine*, vol. 47, no. 1, pp. 84-89, 2009. [CrossRef] [Google Scholar] [Publisher Link]

[21] Peng Xie, Jun-Hong Cui, and Li Lao, "VBF: Vector-Based Forwarding Protocol for Underwater Sensor Networks," *International Conference on Research in Networking*, Springer, Berlin, Heidelberg, pp. 1216-1221, 2006. [CrossRef] [Google Scholar] [Publisher Link]

[22] Paolo Casari, Milica Stojanovic, and Michele Zorzi, "Exploiting the Bandwidth – Distance Relationship in Underwater Acoustic Networks," *OCEANS 2007*, Vancouver, BC, Canada, pp. 1-6, 2007. [CrossRef] [Google Scholar] [Publisher Link]

[23] Daniel Walker, "Micro Autonomous Underwater Vehicle Concept for Distributed Data Collection," *OCEANS 2006*, Boston, MA, USA, pp. 1-4, 2006. [CrossRef] [Google Scholar] [Publisher Link]

[24] Zahid Wadud et al., "An Efficient Routing Protocol Based on Stretched Holding Time Difference for Underwater Wireless Sensor Networks," *Sensors*, vol. 19, no. 24, pp. 1-30, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[25] Sravanthi Chalasani, and James M. Conrad, "A Survey of Energy Harvesting Sources for Embedded Systems," *IEEE SoutheastCon*, pp. 442-447, 2008. [CrossRef] [Google Scholar] [Publisher Link]

[26] Haiping Luo et al., "Electricity Generation in a Microbial Fuel Cell Using Yogurt Wastewater under Alkaline Conditions," *RSC Advances*, vol. 7, no. 52, pp. 32826-32832, 2017. [CrossRef] [Google Scholar] [Publisher Link]

[27] Daniel M. Toma et al., "Underwater Energy Harvesting System based on plucked-Driven Piezoelectrics," *OCEANS 2015-Genova*, Genova, Italy, pp. 1-5, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[28] Clare E. Reimers et al., "Harvesting Energy from the Marine Sediment Water Interface," *Environmental Science Technology*, vol. 35, no. 1, pp. 192-195, 2001. [CrossRef] [Google Scholar] [Publisher Link]

[29] Yanming Gong et al., "Benthic Microbial Fuel Cell as Direct Power Source for an Acoustic Modem and Seawater Oxygen/Temperature Sensor System," *Environmental Science Technology*, vol. 45, no. 11, pp. 5047-5053, 2011. [CrossRef] [Google Scholar] [Publisher Link]

[30] Hamid Fahim Rezaei, Anton Kruger, and Craig Just, "An Energy Harvesting Scheme for Underwater Sensor Applications," *IEEE International Conference on Electro/Information Technology*, Indianapolis, IN, USA, pp. 1-4, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[31] Shad Roundy, Paul K. Wright, and Jan Rabaey, "A Study of Low Level Vibrations as a Power Source for Wireless Sensor Nodes," *Computer Communications*, vol. 26, no. 11, pp. 1131-1144, 2003. [CrossRef] [Google Scholar] [Publisher Link]

[32] Sea-Hee Hwangbo, Jun-Ho Jeon, and Sung-Joon Park, "Self-Powered Wireless Ocean Monitoring Systems," *SENSORCOMM 2012: The Sixth International Conferenceon Sensor Technologies and Applications*, pp. 334-337, 2012. [Google Scholar] [Publisher Link]

[33] B. Sai Srujana, Princy Mathews, and V.P. Harigovindan, "Multi-Source Energy Harvesting System for Underwater Wireless Sensor Networks," *Procedia Computer Science*, vol. 46, pp. 1041-1048, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[34] Triet T. Le, *Efficient Power Conversion Interface Circuits for Energy Harvesting Applications*, Oregon State University, 2008. [Google Scholar] [Publisher Link]

[35] Triet T. Le et al., "Piezoelectric Micro-Power Generation Interface Circuits," *IEEE Journal of Solid-State Circuits*, vol. 41, no. 6, pp. 1411-1420, 2006. [CrossRef] [Google Scholar] [Publisher Link]

[36] Haitao Yu, Nianmin Yao, and Jun Liu, "An Adaptive Routing Protocol in Underwater Sparse Acoustic Sensor Networks," *Ad Hoc Networks*, vol. 34, pp. 121-143, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[37] Imran Ullah Khan et al., "Adaptive Hop-by-Hop Cone Vector-Based Forwarding Protocol for Underwater Wireless Sensor Networks," *International Journal of Distributed Sensor Networks*, vol. 16, no. 9, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[38] Hai Yan, Zhijie Jerry Shi, and Jun-Hong Cui, "DBR: Depth-Based Routing for Underwater Sensor Networks," *Networking 2008 Ad Hoc and Sensor Networks, Wireless Networks, Next Generation Internet*, *Lecture Notes in Computer Science*, vol. 4982, pp. 72-86, 2008. [CrossRef] [Google Scholar] [Publisher Link]

[39] Haitao Yu et al., "WDFAD-DBR: Weighting Depth and Forwarding Area Division DBR Routing Protocol for UASNs," *Ad Hoc Networks*, vol. 37, pp. 256-282, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[40] Zahid Wadud et al., "DOW-PR Dolphin and Whale Pods Routing Protocol for Underwater Wireless Sensor Networks (UWSNs)," *Sensors*, vol. 18, no. 5, pp. 1-34, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[41] Hrishikesh Gossain et al., "DRP: An Efficient Directional Routing Protocol for Mobile Ad Hoc Networks," *IEEE Transactions on Parallel and Distributed Systems*, vol. 17, no. 12, pp. 1438-1541, 2006. [CrossRef] [Google Scholar] [Publisher Link]

[42] R.M. Gomathi, and J. Martin Leo Manickam, "Energy Efficient Shortest Path Routing Protocol for Underwater Acoustic Wireless Sensor Network," Wireless Personal Communications, vol. 98, no. 1, pp. 843-856, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[43] Zahoor Ali Khan et al., "Region Aware Proactive Routing Approaches Exploiting Energy Efficient Paths for Void Hole avoidance in underwater WSNs," *IEEE Access*, vol. 7, pp. 140703-140722, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[44] Salvador Climent et al., "Underwater Acoustic Wireless Sensor Net-Works: Advances and Future Trends in Physical, MAC and Routing Layers," *Sensors*, vol. 14, no. 1, pp. 795-833, 2014. [CrossRef] [Google Scholar] [Publisher Link]