Optimized Energy-Aware Multipath Data Routing Framework for Underwater Wireless Sensor Networks in Marine Ecosystem and Species Health Monitoring Applications

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KEYWORDS

Marine Ecosystem; Species Health Monitoring; Sensor Data; Routing Protocols; Underwater Wireless Systems.

ABSTRACT:

Introduction: Underwater Wireless Sensor Networks (UWSNs) are becoming an increasingly important research area for exploring underwater resources, maintaining marine ecosystems, and monitoring species' health. Such UWSNs incorporate different types of sensor nodes deployed to monitor species' health, marine ecosystems, and other applications. The sensed data packets need to be directly routed to the floating sonobuoys for transferring the information to the monitoring station for further processing. Energy-efficient data routing with appropriate multipath in underwater acoustic channels is a challenging task. **Objectives**: To Design an effective routing protocol is required for efficient data packet routing and forwarding to overcome the challenges of underwater characteristics, providing better energy efficiency and a good packet delivery ratio. **Methods**: To overcome the challenges in existing routing protocols of UWSNs, this article proposes a novel Optimized Energy-Aware Multipath Data Routing Protocol (EA-MDRP). This proposed method considers depth, angle, and location-based information for selecting the most suitable next-hop neighbors for data packet forwarding and the routing phase. After completing the routing phase, the data packets are directly forwarded to the corresponding next-hop forwarders as per the priority table information. **Results**: For analysing the performance metrics, the packet delivery ratio (PDR), average end-to-end delay, and energy consumption are analyzed using MATLAB simulation. **Conclusions**: The proposed EEA-MDRP scheme achieves a better average end-to-end delay of 40 seconds, an improved packet delivery ratio of 57.5%, and 45.17 Joules of energy consumption compared to other existing state-of-the-art routing methods.

1. Introduction

The earth surface is covered almost 70% of the water. Underwater wireless sensor networks (UWSN) have more number of potential and military applications in Marine ecosystem balancing and marine species health monitoring such as collecting the oceanographic information's, environmental monitoring, coastal monitoring and exploration, disaster avoidance, and supported navigational and military monitoring applications [1]. A fully autonomous Unmanned underwater vehicles (UUVs) or partially autonomous UUVs are generally equipped with various different type of sensors which can be used to explore natural marine resources and collect significant scientific data during collaborative monitoring and performing designated missions. For performing such applications and make it to be viable and ease of operation, the underwater communication among devices is highly required and essential [2]. Sensor nodes are deployed in the underwater and floating sonobuoys or vehicles are used at the above the sea surfaces which are must have self-configuration capabilities for better signal reception and transmission. Such floating sonobuoys and sensor nodes are need to allowing them to coordinate their operations by exchanging configuration, location and position information's as well as relaying monitored data to an onshore station. Such acoustic networking has highly serves and used as a primary enabling technology that empowers and facilitates the wide array of applications which highly rely on it for effective functioning and performance.

Underwater acoustic sensor networks, commonly referred to as UASNs which composed of a highly diverse and different type of sensors nodes and vehicles, which all meticulously deployed in order to carry out collaborative monitoring tasks over a specified geographical area or marine environment [3]. In order to successfully achieve this complex synchronization task, the sensors and vehicles engage in a process of self-organization, forming an autonomous network that possesses the remarkable ability to adapt dynamically to the ever-changing characteristics and conditions of the ocean environment in which they can easily operate. Acoustic communications are the one of the important and primary physical layer technique in underwater networks [4]. The normal RF communications used in the typical wireless sensor networks are not suitable for acoustic communication because of its inherent signal characteristics.

Radio waves may traverse to a long distance in terrestrial networks over conductive sea water at extra low frequencies at the range of 30-300 Hz, here it is assuming that the large antennas with significant transmission power can be used. Optical waves are generally enduring more number of scattering effect rather than significant attenuation. Furthermore, transmitting optical signals needs precise targeting of small laser beams. Due to these problems in the signal propagation of RF and optical waves, the underwater networks rely on acoustic signal communications [5]. The ocean-bottom monitoring and ocean-column monitoring techniques are traditionally used which involves deploying of more number of underwater sensors, collecting data, and then retrieving by using the costlier instruments and systems for signal. Therefore, in light of the current advancements in technology and the increasing necessity for more effective oceanographic research, there is an exhaustive research is needed to deploy sophisticated underwater networks which will be expected to facilitate real-time monitoring of oceanic regions and transmit the sensed data from the deployed nodes [6]. Such regions are also allowing for remotely configured and gives a seamless interaction with human operators located onshore who are responsible for managing these operations.

This essential capability of such UWSN is efficiently utilized by achieved by establishing a robust connection between various underwater instruments, utilizing wireless links that are fundamentally based on advanced acoustic communication techniques, which enable reliable data transmission even in the challenging underwater environment [7-8]. Many Researchers are currently exploring different type of network and routing solutions for terrestrial WSNs and UWSNs. Such underwater acoustic communication channels are employed with limited bandwidth utilization capacity and multiple delays, which is highly necessitates the data communications will be efficient and highly reliable, despite the availability of recently developed wireless sensor network protocols [9].

To overcome these challenges in routing protocol design of UWSN employed for marine eco-systems and species health monitoring systems, we have proposed an Optimized Energy Aware Multipath Data Routing Protocol (EA-MDRP) and discussed in this article. The major contributions of this proposed work is discussed here,

1. To avoid more energy consumption and improve the packet delivery ratio (PDR) of the existing routing protocols, the novel proposed EA-MDRP scheme utilizes the depth and angle based data forwarding techniques as factor for choosing the suitable best neighbour nodes.
2. Due to next hop selection criterion used in proposed EA-MDRF scheme, the packet holding time is also reduced which directly related to saving of the residual energy of the network.
3. This proposed EA-MDRF scheme effectively reduces the redundancy of message quantities to the sink node which will improves the network lifetime and reduces the delay of the UWSN.

The article is organized as follows: the section II explains the detailed literature survey and its related discussions. The proposed EA-MDRF scheme and its implementation is explained in the detail in the section III. The simulation results and its related discussion is given in the section IV. The article is concluded in the section V.

2. Related Work

Over the past decades, an extensive research works is done by many scholars through an investigation has been undertaken, specific findings aimed at the reduction of energy consumption in Underwater Wireless Sensor Networks (UWSNs).

The authors Khalid et al. [10] have proposed the novel multimedia cross-layer protocol for UWSN. This routing protocols gives novel routing design to for underwater communication framework, including forward error correction, signal modulation, MAC based data routing. This method also useful to predict the formulation of a distributed mechanism based cross-layer wireless communication, the deployed sensor nodes are enabled to optimize the allocation of network bandwidth effectively. The protocol validates that the energy efficiency and network throughput are improving based on experimental and validated results.

Khalid et al. presented an energy efficient and optimization path of the hierarchical routing protocol known as E-PULRP [11]. Such of the E-PULRP type of routing scheme is composed of a different layered and uses a communication phase which is based on the proposing a network-layered structure which utilizes a gathering node as the center and other sensor nodes are directly located as used on concentric circles. By, choosing into consideration layer width and transmission loss occurs at the sensor nodes will directly improves the likelihood of nodes successfully sending data and avoiding loss. During the communication phase of this routing protocol, an energy-efficient multiple relays node based algorithm will route the data packets to the sink node. Experiments comparing the E-PULRP protocol to other algorithms demonstrate its effectiveness in promoting energy efficiency.

The authors of [1] have proposed a novel network architecture of underwater acoustic wireless channel with analysing the fading characteristics of de-multiplexing types of an asymmetric communication protocol. Such proposed AMDC type of the protocol are having the uneven distribution of underwater channel noise and the actual undersea propagation environment with noise attenuated as given in the

WSN. Such underwater wireless communication region of this routing protocol is divided to create a tree-based channel signal transmission, which will give the improvement to the energy consumption and packet delivery ratio. Efficiency and multi-level of dependability of data transmission is also improved along with the UWSN.

Such type of routing protocols is generally divided into mainly two categories, they are Location-based routing (LBR) and location-free routing (LFR) [13]. This LFR type of the routing protocols do not depend on various number of the geographical based pre-network information. Such type of this routing protocols are able to perform the different operations with or without having any precise location information of other nodes in the network. Such LFR protocols are widely utilizing the flooding phenomenon for it enables rapid packet delivery ratio. The major limitation of the LBR uses the path calculation and the node's geographic information which will improve the network lifetime and delay.

Some VBF methods in [14] is a position-based method that involves only a few nodes for data forwarding of UWSN. When several nodes deliver data packets, they usually transit in a single path towards the sink. In every VBF type of the network, every node is hereby knowing the position of the other nodes and their information. VBF is based on the concept of establishing a virtual pipe during the routing process. Such type of virtual pipe, a few numbers of sensor nodes are used by the routing method, and their combination leads in a routing pipe. The improved version of VBF routing protocol is presented for Hop-by-Hop based strategies which will directly give the robustness to the network, improves the energy efficiency, reduces the path loss and having the higher data packet delivery. VBF routing protocol is also use a single virtual pipe for packet forwarding, while HH-VBF recommended several virtual pipes for data forwarding based on the various numerous number of sensor nodes in data-forwarding and creates virtual pipes to transmit packets to their final destination.

Depth based routing is also an LUR technique does not have any require pre-network node position information of UWSN [15]. Such proposed DBR will directly analyses sensor along its depth when sending data packets to floating sonobuoys. In data packet forwarding, nodes compare their depth to that of the proposed receiver node. Such data packets are forwarded directly from the UWSN for transmitting the receiver node has a lower depth than the sender. It initiates the transmission of data to all nodes exhibiting a depth inferior to that of the originating node. On one hand, this approach is advantageous in terms of reducing end-to-end latency; however, conversely, it results in a flooding phenomenon that increases energy consumption. This flooding mechanism within the Dynamic Beacon Routing (DBR) protocol persists until the aforementioned package is acquired by any of the sinks deployed onshore. DBR analyses just depth information during data forwarding operations. DBR having drawbacks such as shorter network life, floods, and higher consumption energy. It mostly provides a data to numerous nodes at the same depth level. DBR lacks a path selection mechanism, which leads to a random number of the path for each data packet generated from the sender node of UWSN.

The modified Energy Efficient DBR (EE-DBR) is proposed in [16] which will help to enhance, processes and gives more number of the functionalities in contrast to DBR. This EE-DBR framework will transmits and route the data packets, it considers the depth of the recipient node, RE as well as the distance from the sink. In the initial phase, the depths are evaluated, similar to the procedure observed in DBR. In general, each node of the network carries information on depth information and RE of his neighbor nodes. The main disadvantage of EE-DBR routing protocol is not that much flexible for data transmission in the long term and it will also arise the data flooding.

Hop-by-Hop-Dynamic Address-Based Routing (H2-DAB) scheme is also proposed by some authors which will helps to assigns addresses to nodes dynamically [17]. This node with lower address is considered nearer to the sink while nodes with higher values are far away from the sink. Node-ID is a permanent physical address, while Hop-ID is temporary and changes as the node moves, starting from the top level or sink. It moves downwards in an increasing way. Finding a node with an appropriate hop-ID is sometimes impossible because to the node's unpredictable movement. In this case, the sender node must either deliver the data packet backwards or wait for the appropriate next hop-ID which will leads to more time delay in data packet transmission.

In [18] routing scheme that has been devised for efficient data transmission and network management, every single node that participates in the network is provided with two distinct kinds of basic identification numbers, which serve critical roles in the functioning of the network. The first type of identification number, which is referred to as the s-ID, is characterized by its stability and consistency, remaining unchanged and fixed for a node throughout the entire duration of the network's operational lifetime, thereby ensuring that the node can be reliably identified. On the other hand, the second type of identification number is known as the C-ID, which is also commonly referred to as the next-hop ID; this ID serves a different purpose and is crucial for routing decisions. Both of these two types of identification numbers, the S-ID and the C-ID, are composed of a total of two digits, which allows for a simplified yet effective method of identification within the network.

Some authors have proposed a novel protocol scheme as presented in [19-20] which uses a delay-tolerant based on the bio mimic nature of dolphin for delay tolerant applications in UWSN. In this protocol, all the deployed sensing nodes are relatively considered as a fully static and it will transmit the sensed data to the floating sonobuoys via data dolphin which acts a courier node. In this approach, communication that consumes high energy at each hop is minimized. Data dolphins, serving as courier nodes, receive a steady supply of energy. In the architectural framework, all static nodes are positioned on the seabed. These static sensors enter a dormant state when there is an absence of data to detect and subsequently reactivates periodically upon the detection of relevant data. Following the acquisition of pertinent data, it promptly transmits this information to intermediary nodes, which are alternatively referred to as data dolphins. These data dolphins transfer the data to a sink or base station. The type of network, its intended use, and the quantity of nodes deployed within the network all influence the number of dolphin nodes.

The primary challenges that have been identified and discussed concerning the literature survey section of this article, there are various types of routing protocols that have already been proposed in various studies are significantly high energy consumption at different rounds, a very few number of nodes are participating in the network actively, and a reduced operational lifetime of those nodes in the network. A considerable number of the routing schemes are currently utilized by the UWSN which is fundamentally rely on the flooding phenomenon as their core mechanism for operation. This particular approach involves the transmission of multiple messages that are sent out to various nodes within the network simultaneously, thereby increasing the communication traffic significantly [21]. This routing strategy is always inefficient in any network, particularly in marine eco-system and species health monitoring of UWSNs, where the available energy is significantly limited due to the multiple number of data transmission to its table based approach. Such a strategy results in high energy consumption for both the forwarder and receiver nodes, and it ultimately reduces the overall performance of the network.

3. Proposed EA-MDRP Scheme

This section discusses about proposed Energy-Aware Multipath Data Routing Framework (EAMRF) of Underwater Wireless Sensor Networks.

Deployed sensor node architecture for marine ecosystem and species health monitoring:

The overall structural design and configuration of a typical underwater acoustic sensor nodes are consisting of five different and fundamental components as depicted in the Figure 1. These include the energy management unit, which oversees power distribution; the data sensing unit, responsible for gathering environmental parameters; the depth measuring unit, dedicated to assessing underwater depth accurately; the communication unit, which facilitates data transmission; and the central processing unit, which coordinates all functions and processes. The processing unit executes various forms of data processing, while the energy management unit monitors the node's residual energy. The data sensing unit detects data and relays relevant information to the next node, remaining active even in sleep mode. The depth measuring device assesses the water's depth, and the communication unit manages data transfer when deployed in the underwater environment.

Importance of this proposed Network protocol architecture:

The proposed EA-MDRP scheme has been carefully designed to effectively prevent unnecessary flooding of data and the generation of redundant copies of data packets in the networks. Additionally, it will leverage the advantages of an UWSN architecture along with multiple floating sink nodes which will improving the efficiency of data transmission and management. The network will consist of several sinks equipped both the radio-frequency (RF) signal and acoustic signal transmission modems, placed above the water's surface. Some sensor nodes are kept as static which is permanently located in the designated underwater region, are capable of gathering sensed data from the sensor nodes and forwarding it to intermediate courier nodes or floating sinks using a multi-hop method as referred in the Figure 2. The courier nodes, which are continuously powered intermediate nodes, which can only receive data packets from static sensor nodes and forward it to floating sinks. Communication in underwater is highly achieved by only the sink nodes is facilitated via acoustic channels. This assumption is supported by the fact that sound travels at approximately 1.5×10^3 m/s in water, but the sound waves are significantly slower than radio waves, which travel at 3×10^8 m/s in air. In the context of UWSN transmission, we assume that a data packet will be directly reaches to its destination nodes or monitoring station immediately upon being delivered to any of the sinks.

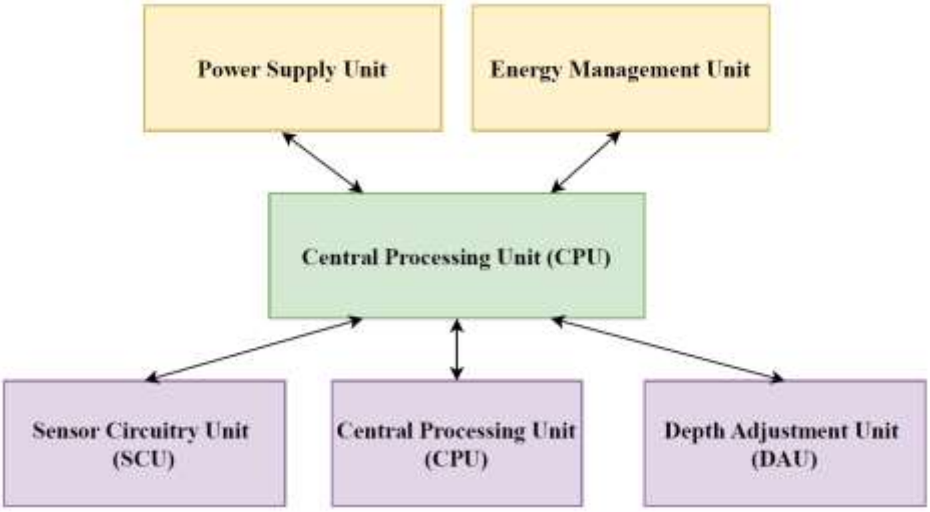

Figure 1: Deployed Node Architecture

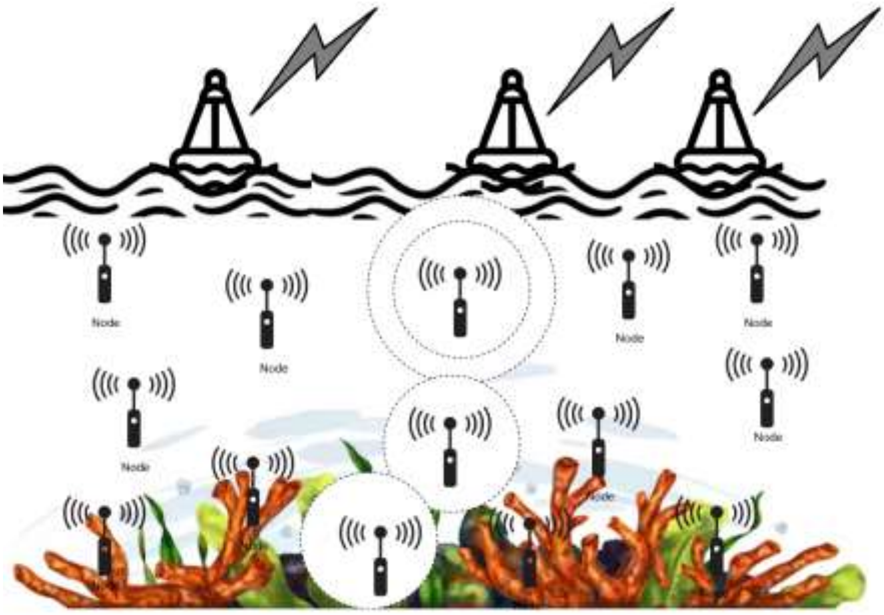

Figure 2: Underwater Wireless Sensor Network Scenario

EA-MDRP Scheme

This paper proposed an Energy- Aware Multipath Data Routing Framework (EA-MDRP) scheme is implemented and analysed for UWSN. The primary objective is that this sophisticated routing algorithm seeks to achieve is not only energy efficiency but also an increased packet delivery ratio, alongside the aspiration for a significantly prolonged network lifetime which is essential for sustainable operation. The innovative scheme that has been put forth has resulted in a notable enhancement of energy consumption metrics while simultaneously contributing to the improvement of the overall network lifetime, thereby ensuring that the network operates optimally for an extended period. Furthermore, this advanced approach strategically avoids the redundant transmission of multiple packets to the subsequent node within the network, thereby streamlining the communication process and conserving valuable resources. The proposed routing algorithm have an advantages of Multiple sink architecture in UWSN. Multiple sinks are randomly deployed in a specific location for underwater environment and then they operate by using the acoustic frequency communication modem. A sink node communicates to the information for other sink node via the acoustic communication model.

The routing algorithm proposed in this article will assumes that the sensor nodes will directly forward packets to sink node by using multipath routing, the data packets are delivery is considered successful as soon as the packet is successfully received by any of the sinks. The idea of this proposed EA-MDRP scheme is to improve the energy efficiency Communication and it will run a node for a longer lifetime. The proposed EA-MDRP scheme will also contribute to extend the lifetime of the UWSN. This schemes will prevent flooding of data by sending unnecessary data packets to a pre-selected node. This proposed EA-MDRF is having a multiple sink node of architecture in underwater wireless sensor network but they are avoid generating multiple copies. Deploying multiple number of underwater sensor nodes inside the water in the desired area of interest based on the applications. These nodes are widely used to collect the sensed data, but also assist propagate the data to multiple sinks through acoustic transmission. A floating sink node or sonobuoys can easily communicate with another floating sink through acoustic communication channels. In this scenario, assumes packets reach their destination once they are successfully received by sinks deployed on the underwater surface area.

Transmitter Sender Node ID	Transmitter Receiver Node ID	Residual Energy(RE)	Depth (D)	Distance from receiver node to sender node

Figure 3: Hello packet format

Transmitter Node ID	Receiver Node ID	Packet sequence number	Data Packet

Figure 4: Senor data packet format

In the initial phase of the setup process, every single node is strategically and randomly deployed throughout the vast expanse of the ocean, ensuring a diverse distribution across the aquatic environment. In the first step of this intricate procedure, the nodes engage in the initial action of broadcasting a specific control message to their neighboring nodes; within the context of this scholarly paper, this particular control message is referred to as a hello packet, which serves as a foundational communication element. There exist two distinct scenarios that outline the modes of communication utilized by the nodes within the Underwater Wireless Sensor Network (UWSN), which are categorized as soft communication, characterized by its flexible and adaptive nature, and hard communication, which is marked by its more rigid and definitive parameters. Nodes, which serve as important components in the network, proceed to transmit the hello packet to those specific nodes that are situated within a distance of 25 meters, an interaction that is commonly referred to as soft communication to its less direct nature.

Setup initialization phase:

In the realm of hard communication, nodes that fall within the designated range are capable of establishing a direct line of communication with the sink nodes, thereby facilitating a more robust exchange of information. When the receiver nodes successfully detect and obtain the control message, which is known as the hello packet, that has been dispatched by the sender, they will subsequently generate and send back their own response hello packets as a means of acknowledging receipt and maintaining the communication flow. Receiver nodes reply with the parameters requested by the sender (as previously discussed in this paper). The sender node's distance will be estimated using received signal strength indication (RSSI). The hello packet and data packet format are depicted in the Figure 3 and 4 respectively.

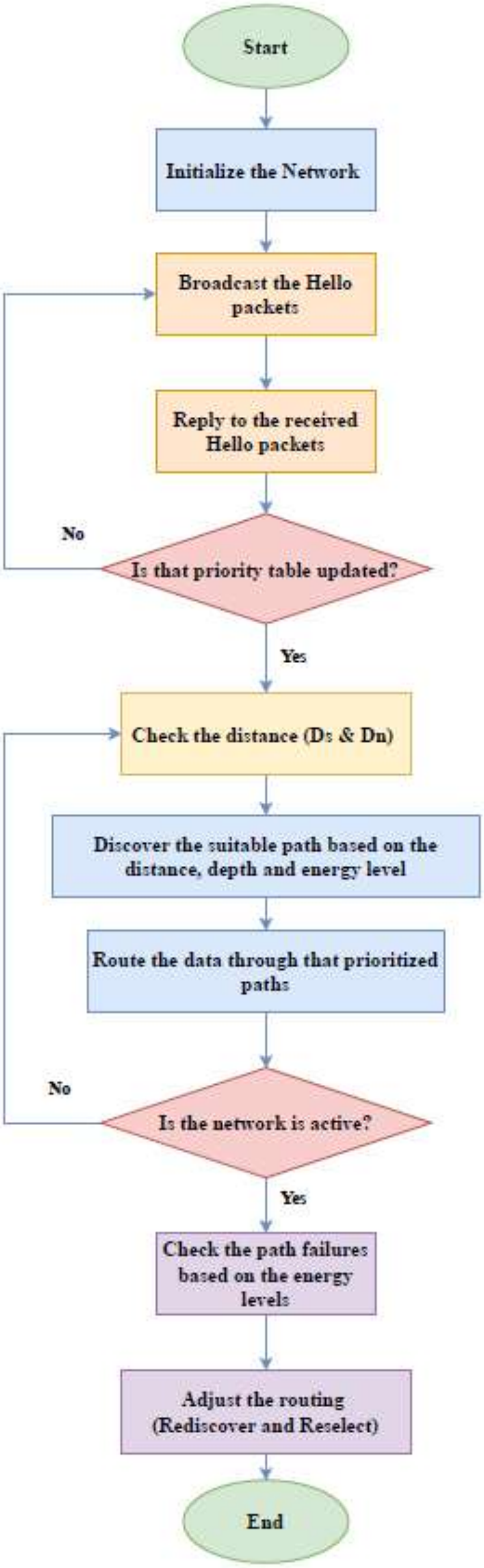

Figure 5: Proposed EA-MDRF Algorithm Flow

In marine ecosystems and species monitoring of this underwater environment, each node disseminates a hello packets to all other sensor nodes which is located within their designated soft communication range, which is established at 100 meters, whereas within the void communication range, a node is capable of directly interfacing with the sink. When a deployed sender node receives a hello packet, it first compares its depth to the nodes from with whom it received the response. The table will not include entries from nodes with a depth greater than the sender's node.

This paper EA-MDRF scheme will first sends the hello packet which contains Transmitter Sender Node ID, Transmitter Receiver Node ID, TSI and TRI messages will helps to identify the respective sender and receiver nodes. Residual Energy (RE) is the remaining energy of node, Depth (D) and Distance (ds) from sender to receiver is the energy of table is measured to distance between the receiver and sender to the base station. Within this table, a sender identifier is designated for the originator of each packet, a receiver identifier is allocated to the recipient of every packet, and an exclusive numerical designation is attributed to each data packet, referred to as the packet sequence number. When this condition has been satisfied, the packet will be picked up for further processing. The algorithm for propose EA-MDRF scheme is explained in Figure 5.

Forwarding and priority table formation phase:

The value of RE will be measured in joules, while the depth and distance between nodes will be expressed in meters. After calculation, the resulting value will be added to the priority table. A higher value of Pv signifies a greater priority for being selected as a forwarding node, while a lower value results in fewer chances of selection. After forming the priority table, every node is set and forward that data packets to the respective sonobuoys. Every node will choose a best next hop neighbour nodes which is having the highest priority value from their priority table. After some t secs, the RE of forwarding nodes will start decreasing due to the data transmission and if any alternate path is not chosen, the node will obviously run out of RE.

This protocol is proposed and designed in such a way to update the priority table of each and every sensor node after a fixed interval of time. After the threshold value reaches, each deployed sensor node will automatically send a hello packet to its neighboring node and the entire procedure of constructing the priority table will be repeated in the underwater environment.

Next-hop node selection phase:

In this specific protocol that has been established, it is determined that any data packet that arrives at either the sea level or the shore level will be officially regarded as successfully delivered to the designated sink. As referenced in source [18], it is important to note that all the sinks within this network are interconnected with one another through various wireless communication methods, while the nodes within the system maintain their connections through means of acoustic communication technology. Therefore, when a packet is received at any designated sink within the network, it will be unequivocally regarded as having been successfully delivered to that particular location. Upon its arrival at the sink, the packet will be identified and acknowledged by its unique sequence number, and subsequently, it will be positioned accurately at the specified location where it is intended to reside

Data transmission after node selection

By establishing the priority table, a mechanism will be in place to determine which node to transmit data onward. The higher a node's priority value, the greater the probability it will be selected as a forwarding node. When a priority node is first selected for data forwarding, its status will be checked through the ‘ready to send, clear to send’ mechanism, and if found available, the data will be forwarded; otherwise, another node in the queue will be selected and the same process will be carried out. In the network set-up phase, when all the network nodes are deployed, all nodes begin broadcasting a hello packet to its surrounding nodes. When the reply is received by the sender node, it includes the Transmitter sender node ID, Transmitter receiver node ID, depth of the receiver node which is denoted by DRn, RE of the receiver node denoted by Er and the distance from the sender towards the receiver node which is denoted by $s \rightarrow r$. When a hello packet is received, the sender node compares its depth to that of the receiving node. If the depth of the sender node exceeds that of the one receiving node, the priority value is calculated using the formula $Pv \propto Er/(Ds{\rightarrow}r)$. A higher priority improves the chances of selection as a forwarding node. The priority value is updated after a set interval of time.

4. Simulation Results and discussions

The proposed EA-MDRF routing protocol is simulated by using the MATLAB software for various sparse and dense environments. This proposed EA-MDRP routing schemes has been compared with recently proposed state or art protocols such as DBR, EE-DBR and E2MR schemes. This performance metrics measures such as packet delivery ratio (PDR), Average end to end delay (Delay) and Energy consumption are analysed through the simulation. The simulation setup parameters considered for evaluation this UWSN is givens in the table 1.

Simulation Parameters	Values
Network size	500 m × 500 m
total deployed sensor nodes	322
Initial residual energy of the nodes	25 J
Data packet size	1000 bits
Operating Frequency	30 Hz
No. of sinks considered	5
Transmission or Communication range	100 m
Total no. of rounds for simulation	2000

Table 1: Simulation Parameters

Packet delivery ratio

The packet delivery ratio, which is one of the most important performance metric for analysing the network, refers to the proportion of data packets that have been successfully reached or delivered to their intended destinations when compared to the total number of packets that were originally created and transmitted within the network.

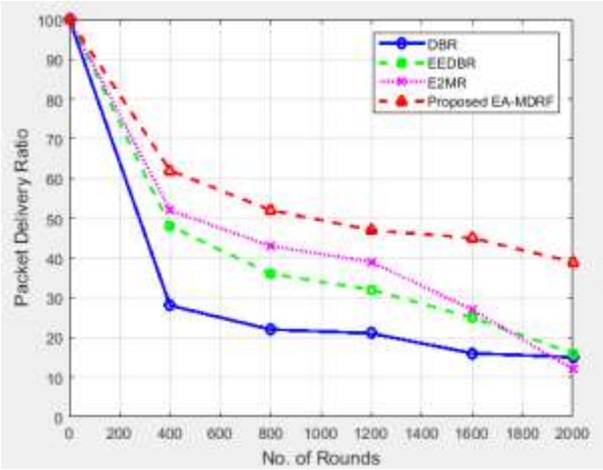

Figure 6: Packet delivery Ratio

This packet delivery ratio holds significant importance and plays a significant role for determining the network efficiency and reliability by ensuring that data is accurately and consistently communicated between devices. The figure 3 represents the total amount of data packets transmitted during forwarding in the network from source to the destination sonobuoys is analysed for all the four techniques. The packet delivery ratio is calculated after running the specific rounds of simulation after data transmission. The proposed EA-MDRF method exceeds all previous protocols in terms of packet delivery ratio as depicted in the above figure. Simulation results for DBR, EEDBR, and H2-DAB indicate low packet delivery ratio.

Average End-to-end delay

The average end to end delay is also an another important performance metric for evaluating the underwater wireless sensor networks. The average end to end delay represents the average duration of time required for the effective and successful transmission of a data packet from the designated forwarder node to the intended receiver node is known as the end-to-end delay. In underwater acoustic scenarios, that are critically dependent on time sensitivity, it is essential to achieve a smaller end-to-end delay, whereas in circumstances where long-term monitoring and assessment are of greater importance, a slightly more relaxed approach to the end-to-end delay can be acceptable.

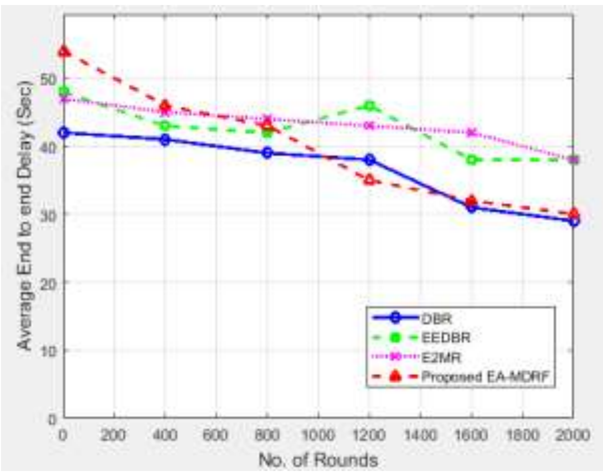

Figure 7: Average end-to-end delay

When performing data forwarding operations, dynamic addresses and other parameter, such as RE, are compared, resulting in end-to-end delays. Similarly, when nodes are moving from its original position to another due to the water movement and other environmental factors caused by the sea water surface will directly leads to cause for the delay. The proposed EA-MDRF schemes gives less end-to-end delay compared to DBR and EEDBR, as shown in the above figure. DBR and EEDBR focus on flooding, which leads to reduced end-to-end delays due to this routing schemes access the most appropriate next hop neighbours for long-term network monitoring with low energy consumption and battery usage.

Energy Consumption

The energy consumption metric indicates the total amount of energy utilized or consumed by all nodes in a network over a specific period of time. Energy consumption is essential for UWSN. If a node consumes too much energy, it could close down the entire network. Being unable to replace batteries in UWSN has led to issues with measuring the consumption of energy.

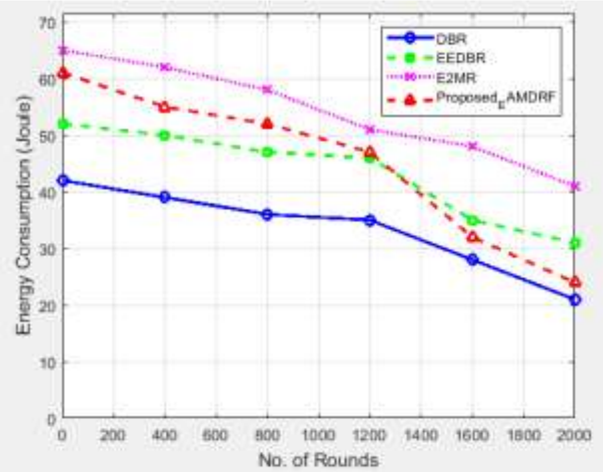

Figure 8: Average Energy Consumption

The total energy utilized by the four routing methods during simulation is displayed in Figure 9. As the DBR protocol delivers data packets to all nodes, whether they are close by or far away, the previously mentioned illustration shows how a node's battery goes out earlier. All nodes are given dynamic addresses via H2-DAB, and only a subset of nodes get data each round. Additionally, EEDBR improves DBR and E2MR in terms of operating time by comparing RE during data forwarding. The proposed EA-MDRF scheme utilizes the depth and angle based measurement for finding the suitable next hop neighbours for the initial deployment stands to lose more energy of nodes and network setup. Later, such routing operation will be kept and remains stable for a longer time due to the priority table formation using the depth and angle factors. This proposed RA-MDRF routing protocol scheme consumes less amount of energy compared to others existing routing protocols.

5. Conclusion and Future Work

This article proposes the novel Energy-Aware Multipath Data Routing Protocol (EA-MDRP) to improve data delivery and reduce energy consumption, addressing the challenges and characteristics of underwater acoustics. In this protocol, the priority table is optimized using depth, distance, and angle-based measurements along with RSSI values. This priority table is updated based on higher priority, considering residual nodes and the top neighboring nodes. The proposed EA-MDRP algorithm improves the packet delivery ratio, reduces end-to-end delay, and minimizes energy consumption compared to other existing methods. This routing protocol overcomes the challenges of UWSNs' lower bandwidth and is easily adaptable to any type of topology under sparse and dense characteristics. In future work, this multipath routing may be optimized through effective clustering or chain-based data forwarding, which can help improve network reliability and extend the lifetime of UWSNs.

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