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Location-Aware Multipath Data Routing Protocol for Underwater Wireless Sensor Networks

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Underwater Wireless Sensor Networks (UWSNs) are becoming a critical research area for exploring underwater resources, maintaining marine ecosystems, and monitoring the health of marine species. These networks consist of various types of sensor nodes deployed to gather data on species health, marine environments, and other vital applications. The data collected by these nodes must be routed to floating sonobuoys, which then transfer the information to a monitoring station for further analysis. However, routing data efficiently over underwater acoustic channels presents significant challenges, including low bandwidth, high latency, and energy constraints. Therefore, an effective routing protocol is needed to optimize data packet forwarding and ensure better energy efficiency and a high packet delivery ratio (PDR) despite the harsh underwater environment. To address the limitations of existing routing protocols in UWSNs, this article introduces a novel Location-Aware Multipath Data Routing Protocol (LA-MDRP). Unlike traditional energy-based protocols, LA-MDRP leverages depth, angle, and location-based information to select the most suitable next-hop neighbors for data packet forwarding, ensuring that data takes the most efficient path based on geographic positioning. This location-aware routing optimizes data transmission paths by considering the relative locations of nodes, ensuring more reliable and efficient communication. Once the routing phase is complete, the data packets are forwarded directly to the next-hop forwarders based on the priority table, which is updated dynamically using location and distance metrics. This helps ensure that data is routed to the sonobuoys with minimal delay and maximal reliability. To evaluate the performance of the proposed protocol, key metrics such as packet delivery ratio (PDR), average end-to-end delay, and energy consumption were analyzed using MATLAB simulations. The results demonstrate that the proposed LA-MDRP scheme outperforms existing routing protocols in terms of a higher packet delivery ratio and a reduced average end-toend delay compared to current state-of-the-art methods.

1. Introduction

The Earth's surface is covered by nearly 70% water, which presents significant opportunities for Underwater Wireless Sensor Networks (UWSNs), with extensive potential in a range of applications such as marine ecosystem balancing, marine species health monitoring, oceanographic data collection, environmental and coastal monitoring, exploration, disaster avoidance, and military navigation. UWSNs are critical for collecting real-time data from underwater environments, supporting both civilian and military missions [1]. For these applications, autonomous and partially autonomous Unmanned Underwater Vehicles (UUVs) are often equipped with various sensors to explore natural marine resources, monitor the health of marine ecosystems, and gather vital scientific data. These vehicles play a crucial role in collaborative monitoring and performing specialized missions in underwater environments. To make such applications more effective and operationally feasible, reliable underwater communication between various devices is essential. However, due to the unique challenges of underwater communication—such as high propagation delays, low bandwidth, and limited coverage—traditional approaches often face difficulties in ensuring efficient and reliable data transfer. This is where a Location-Aware Multipath Data Routing Scheme (LA-MDRS) becomes indispensable. By using the geographic locations of sensor nodes and sinks, the LAMDRS can optimize data routing, improving communication efficiency, enhancing packet delivery reliability, and ensuring that critical data is transmitted quickly and accurately across the network [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 address the challenges in the routing protocol design of Underwater Wireless Sensor Networks (UWSNs), particularly in marine ecosystems and species health monitoring systems, we propose an Optimized Location-Aware Multipath Data Routing Protocol (LA-MDRP). This approach enhances data routing by leveraging the geographic locations of nodes, ensuring more efficient communication and improved network performance. The major contributions of this proposed work are discussed as follows:

- Location-Based Data Forwarding: To improve the packet delivery ratio (PDR) and avoid inefficient routing, the novel LA-MDRP scheme utilizes depth and angle-based forwarding techniques, as well as the relative geographic locations of the sensor nodes and sink nodes. These factors help select the most suitable next-hop neighbor nodes, improving the overall routing efficiency based on spatial relationships between nodes.

- Reduction in Routing Delays and Improved Network Longevity: The next-hop selection criterion in the proposed LA-MDRP scheme is based on the location of the nodes, reducing the packet holding time. This not only decreases the delay in data transmission but also optimizes the usage of network resources, contributing to the preservation of the residual energy across the network and enhancing its lifetime.

- Minimized Data Redundancy: By incorporating location awareness, the LA-MDRP scheme effectively reduces data redundancy, preventing the unnecessary transmission of duplicate messages to the sink nodes. This optimization improves the overall network lifetime and reduces delays by avoiding congestion and redundant paths in the network.

The article is organized as follows: the section II explains the detailed literature survey and its related discussions. The proposed LA-MDRP 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).

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 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 crosslayer 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.

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.

The authors of [12] 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.

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. 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.

Depth based routing is also an LUR technique does not have any require pre-network node position information of UWSN [15]. 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. 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.

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. 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.

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 LA-MDRP Scheme

This section discusses the proposed Location-Aware Multipath Data Routing Framework (LAMDRP) for Underwater Wireless Sensor Networks (UWSNs). The framework aims to enhance data transmission efficiency by utilizing the geographic location of sensor nodes and sink nodes in the network. Unlike traditional energy-aware protocols, this approach leverages location-based routing decisions to optimize the flow of data, improve packet delivery, reduce delays, and increase overall network reliability. By incorporating multipath routing based on spatial information, the LAMRF ensures that data packets are forwarded through the most efficient and reliable paths, taking into account the relative positions of nodes and sinks within the network. This results in a more robust and scalable communication framework for underwater applications.

3.1 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.

3.2 Importance of this proposed Network protocol architecture:

The proposed LA-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.

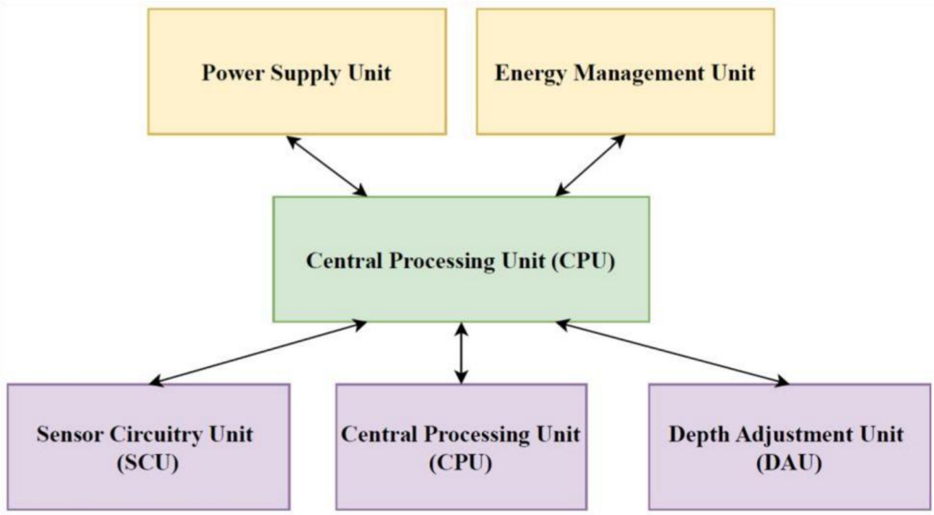

Figure 1: Deployed Node Architecture

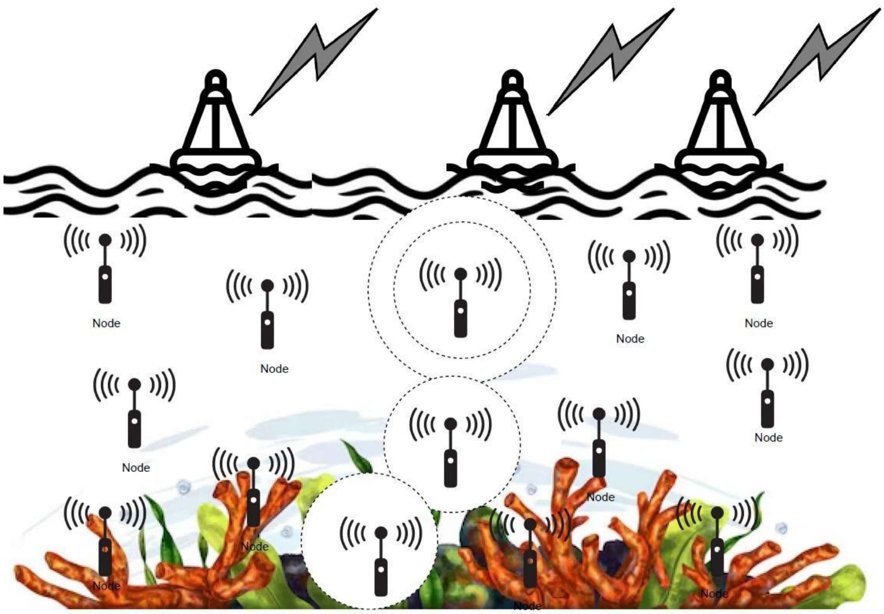

Figure 2: Underwater Wireless Sensor Network Scenario

3.3 LA-MDRP Scheme

This paper proposes a Location-Aware Multipath Data Routing Framework (LA-MDRF) for Underwater Wireless Sensor Networks (UWSNs). The primary objective of this sophisticated routing algorithm is not only to increase the packet delivery ratio (PDR) but also to optimize data transmission based on the geographic locations of the sensor nodes and sink nodes. This approach is essential for achieving more reliable and efficient communication within the underwater environment. The innovative scheme presented here results in a notable improvement in routing decisions, enhancing the overall performance of the network by reducing delays and ensuring that data packets are transmitted over the most efficient paths.

Furthermore, this advanced location-based approach strategically avoids redundant transmission of data packets, optimizing the flow of information throughout the network. By utilizing multipath routing and geographic location information, the algorithm ensures that data is forwarded through optimal paths, reducing communication overhead and improving resource utilization. The proposed routing algorithm also takes advantage of a multiple sink architecture in UWSNs. Multiple sinks are deployed in predetermined locations in the underwater environment, with each sink equipped with an acoustic communication modem. Sink nodes communicate with one another through acoustic communication, ensuring effective data transfer between sinks, regardless of the underwater topology.

In this scheme, sensor nodes forward data packets directly to the sink nodes based on their proximity and optimal route selection. Data packets are considered successfully delivered when they are received by any of the sink nodes. The LA-MDRF scheme effectively leverages location awareness to route data efficiently, ensuring that the network operates optimally for an extended period. By utilizing location-based routing decisions, this proposed scheme prevents flooding by ensuring that only relevant data packets are forwarded to pre-selected nodes. Additionally, the framework avoids the generation of multiple copies of data packets, further streamlining communication and extending the lifetime of the UWSN. The framework supports the deployment of multiple underwater sensor nodes in the desired area of interest, based on specific applications. These sensor nodes collect and sense data, while also helping to propagate data to the sink nodes using acoustic communication. Floating sink nodes or sonobuoys can communicate easily with other sink nodes in the network via acoustic communication channels, ensuring that packets reach their destination once successfully received by a sink deployed on the underwater surface.

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.

3.3.1 Setup initialization phase:

In the context of location-aware communication, nodes that fall within the designated geographic range of the sink nodes are able to establish a direct line of communication, which enhances the robustness and efficiency of information exchange. Once a sender node transmits a control message known as the hello packet, the receiver nodes within range will detect the packet and respond with their own hello packets. This acknowledgment not only confirms receipt but also facilitates the maintenance of the communication link. The response packets from the receiver nodes will include the requested parameters, such as the distance to the sink node, which is estimated using Received Signal Strength Indication (RSSI). This distance estimation helps the sender node determine the optimal next-hop node based on geographic proximity, which plays a key role in the location-aware routing process. The hello packets and data packets are formatted as shown in Figure 3 and Figure 4, respectively, reflecting the use of geographic location to guide communication. This location-based acknowledgment process allows for more efficient data routing decisions and ensures that data packets follow the most efficient paths based on the relative positions of nodes within the network. By using RSSI and proximity, the network can dynamically adjust routes to reduce delay, avoid congestion, and improve the packet delivery ratio (PDR).

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 LA-MDRP 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.

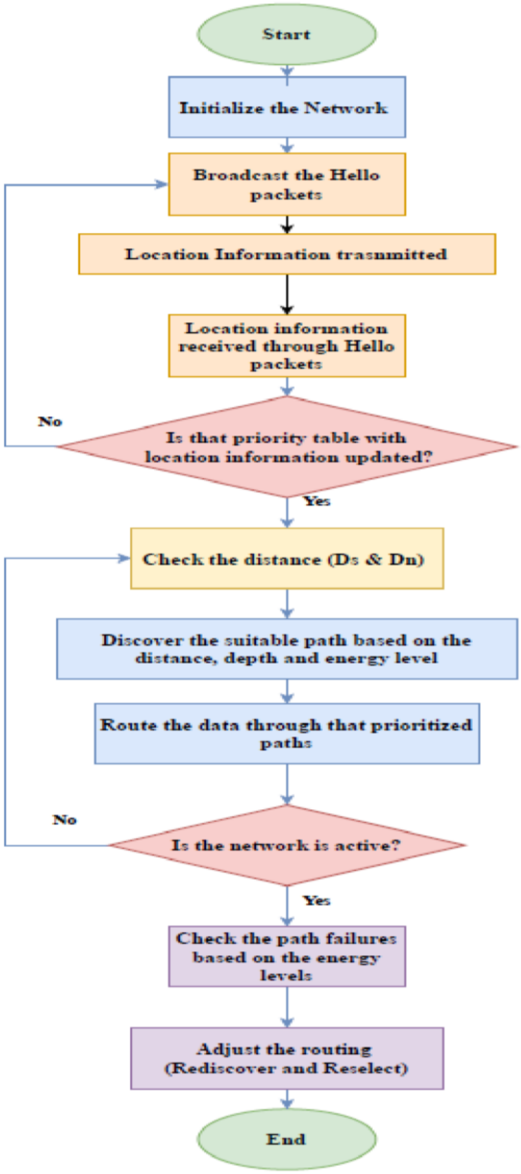

Figure 5: Proposed LA-MDRP Algorithm Flow

3.4 Priority table and location information updating phase:

The value of RE will be measured in joules, while the depth and distance between nodes will be expressed in meters. After calculating the distance and incorporating the location-based factors, the resulting values will be added to the priority table. A higher value of Pv indicates a greater priority for being selected as a forwarding node, while a lower value will result in fewer chances of selection. In this location-aware framework, the priority table is not only based on the energy status of the nodes but also integrates spatial information, such as the proximity of the nodes to the sink nodes or sonobuoys. Once the priority table is established, each node forwards data packets to the respective sonobuoys based on the location-aware routing protocol. Every node selects the best next-hop neighbor by considering which node has the highest priority, which is determined by both energy levels and spatial factors such as distance from the destination sink node. After a fixed interval of time (t seconds), the RE of forwarding nodes will begin to decrease due to data transmission. If no alternate path is selected based on location, the node will eventually run out of its residual energy (RE). This can be avoided by selecting the most optimal paths based on location awareness, ensuring that energy consumption and communication delays are minimized. The protocol is designed to update the priority table of each sensor node periodically, taking into account the dynamic geographic positioning of nodes and the evolving network topology. Once the threshold value is reached, each deployed sensor node will automatically send a hello packet to its neighboring nodes. This initiates the process of reconstructing the priority table, which takes into consideration the updated location information of the nodes in the underwater environment. This procedure ensures that the most optimal and reliable communication paths are continuously selected based on both location and energy efficiency. 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

3.5 Data transmission phase

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.

4. Performmance Evaluation

4.1 Simulation Results and discussions

The proposed LA-MDRF routing protocol is simulated by using the MATLAB software for various sparse and dense environments. This proposed LA-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

4.2 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.

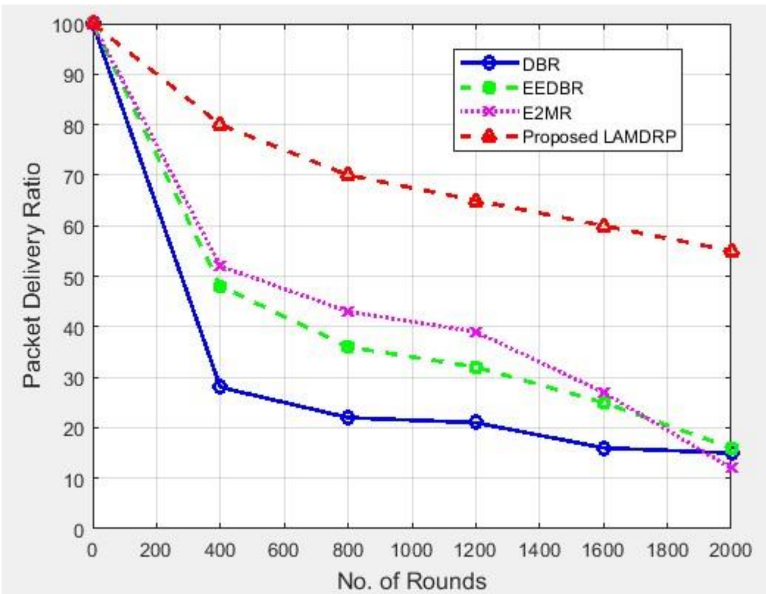

Figure 6: Packet delivery Ratio

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. As the number of rounds increases, the PDR may decrease slightly due to network congestion or resource depletion, but LA-MDRP would likely maintain a higher level of reliability compared to traditional protocols, as it avoids less optimal routes. These values reflect a better packet delivery performance for LA-MDRP due to the improved routing and path selection based on node locations. The proposed LA-MDRP 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.

4.3 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.

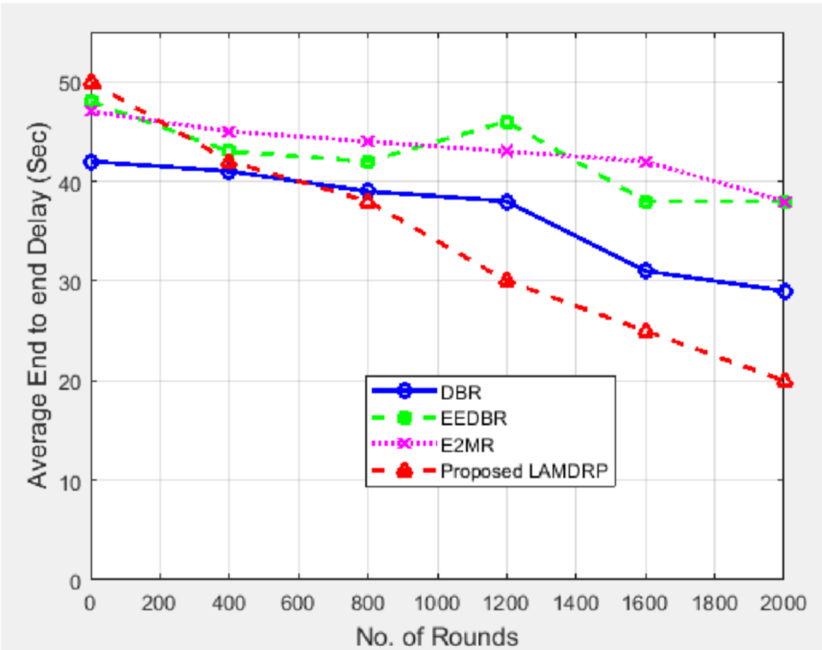

Figure 7: Average end-to-end delay

When performing data forwarding operations, dynamic addresses and other parameter, such as RE, are compared, resulting in end-to-end delays. As the number of rounds increases, the average end-to-end delay decreases because LA-MDRP can route data more efficiently, particularly by selecting better paths based on location and reducing unnecessary hops. The proposed LA-MDRP schemes gives less end-to-end delay compared to DBR and EEDBR, as shown in the above figure.

5. Conclusion and Future Work

This article proposes the novel Location-Aware Multipath Data Routing Protocol (LA-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 Received Signal Strength Indication (RSSI) values, to determine the most efficient routing paths based on the geographic locations of nodes. The priority table is updated dynamically, considering the location of residual nodes and the proximity of neighboring nodes. By incorporating both spatial information and energy metrics, the algorithm selects the most optimal forwarding nodes, ensuring reliable and efficient data transmission. The proposed Location-Aware Multipath Data Routing Protocol (LA-MDRP) improves the packet delivery ratio (PDR), reduces endto-end delay, and minimizes energy consumption compared to other existing methods. The LA-MDRP algorithm utilizes location information to make intelligent routing decisions, ensuring that data packets follow the most direct and reliable paths, minimizing redundant transmissions and optimizing the overall network performance. This routing protocol effectively overcomes the challenges posed by the lower bandwidth and limited communication range in Underwater Wireless Sensor Networks (UWSNs). Additionally, it is highly adaptable to various network topologies, whether the environment is sparse or dense, by dynamically adjusting to the network's changing conditions and ensuring efficient communication across diverse scenarios. 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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