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# OPPORTUNISTIC ROUTING USING RELAY NODE SELECTION IN ACOUSTIC WIRELESS SENSOR NETWORKS FOR EFFICIENT AND RELIABLE NETWORK PERFORMANCE

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## ABSTRACT

Underwater Sensor Networks (UWSNs) represent a critical component of modern oceanic exploration and monitoring systems. These networks enable real-time data collection and communication beneath the ocean's surface, facilitating scientific research, environmental monitoring, and underwater surveillance. However, the exceptional challenges caused by the underwater conditions, such as limited bandwidth, high latency, and sporadic connectivity, demand innovative routing strategies to ensure efficient and consistent data transmission. This work emphases on the exploration of Opportunistic Routing (OR) in underwater sensor networks, a promising approach that leverages transient communication opportunities to enhance network performance. Opportunistic routing adapts to the dynamic and unpredictable underwater channel conditions, making it well-suited for UWSNs. It enables nodes to exploit intermittent connectivity and choose the most favourable transmission paths, thereby improving data delivery efficiency. Based on this concept of opportunistic routing, we have introduced a novel opportunistic routing protocol to improve the overall performance of UWSNs. The main aim of OR is to select the best suitable forwarding node which is chosen based on energy, node connectivity, and link quality. The link quality is estimated based on power; node connectivity analysis is done based on distance parameter. By evaluating these parameters, the final scheduling is assigned to accomplish the transmission task. The efficacy of proposed solution is validated through simulations where we have measured the performance in terms of throughput, packed delivery, packet loss and energy consumption. The comparison analysis shows that the proposed approach brought significant improvement when evaluated against with state-of-art schemes.

**Keywords:** *Underwater Sensor Networks, Opportunistic Routing, Relay Node Selection, Reliable Communication*

## 1. INTRODUCTION

Approximately seventy percent of the Earth's outer surface is enveloped by the waters of oceans, seas, rivers, and lakes [1]. It is worth noting that less than ten percent of our oceans have been meticulously studied, and numerous regions remain un-investigated to this day [2]. In recent times, ocean exploration has been gaining increasing prominence. Nevertheless, conventional methods employed in oceanic investigations are affected by various constraints, including exorbitant costs, protracted turnaround times for results, and the formidable challenges associated with human presence in this demanding environment. To mitigate this issue, researchers have introduced the concept of underwater sensor networks (UWSNs) which is inspired from the traditional sensor networks [3].

UWSNs represent a specialized category within the broader domain of WSNs, specifically tailored for operation beneath the water's surface. UWSNs are tasked with monitoring diverse underwater phenomena, including seismic events, pollution controllers, and submarine movements, among others [4]. These networks can be established using one of three deployment models: static sensor nodes, mobile sensor nodes, or sensor nodes integrated with

Autonomous Underwater Vehicles (AUVs) [5]. It is worth noting that regardless of the chosen deployment model, UWSN nodes operate with limited energy resources typically supplied by non-rechargeable batteries. Furthermore, the uneven distribution of energy utilization significantly impacts the overall performance of UWSNs. Below figure 1 illustrates the overall system of UWSN.

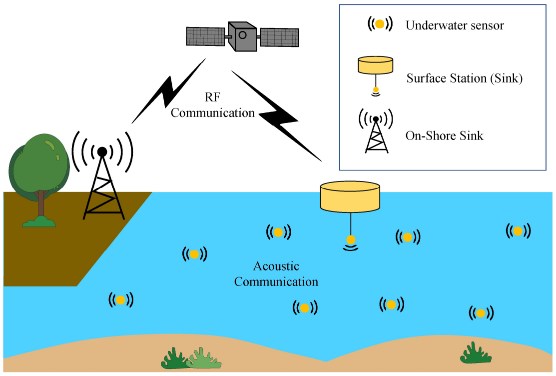

*Figure 1: UWSN deployment*

UWSNs favor acoustic communications primarily because of their ability to support extended propagation distances [6]. Nevertheless, underwater acoustic waves travel at a relatively slow speed of approximately 1500 meters per second [7], leading to significant propagation delays when deploying networking services underwater. Furthermore, energy efficiency represents a critical design consideration for UWSNs, given the substantial energy consumption associated with communication [8] and the constraints imposed by limited available energy resources [9].

The underwater environment presents a distinct set of challenges compared to terrestrial settings, primarily attributed to the unique properties of water. These characteristics encompass ambient noise, signal attenuation, temperature fluctuations, salinity variations, low acoustic wave speed (approximately 1500 m/s), and multipath signal propagation [10]. These factors collectively contribute to several noteworthy implications, including limited data rates (typically in the order of Kbps), substantial propagation delays, intermittent communication, constrained bandwidth (typically in the MHz range), increased deployment expenses, suboptimal network connectivity, increased energy consumption, and more [11]. Consequently, these challenges significantly impact the data forwarding mechanisms within UWSNs. Furthermore, the dynamic nature of water tides prevents underwater nodes from maintaining stable static positions for pre-configuration. Additionally, underwater nodes lack awareness of their depth coordinates, posing difficulties in estimating their depths even with embedded pressure sensors [1]. The conventional Global Positioning System (GPS) also proves unsuitable as a localization system in underwater settings because of the inevitable conditions like water waves and rapid attenuation of signals. Similarly, routing for packet relaying also plays crucial role in UWSN communication. During routing process, the congestion and packet collision scenario occurs which impacts the overall network performance [12, 13].

- **Problem statement**

In UWSNs, routing data efficiently poses significant challenges due to the unique characteristics of the underwater environment, such as limited bandwidth, high propagation delay, variable channel conditions, and energy constraints. Traditional routing protocols designed for terrestrial networks may not be suitable for UWSNs due to these distinctive challenges. Opportunistic routing has emerged as a promising approach to address these challenges by leveraging the dynamic nature of underwater environments to improve routing efficiency. However, designing effective opportunistic routing protocols for UWSNs requires a deep understanding of the underwater environment and its impact on data transmission. As discussed before, these networks are widely used in various applications but suffer from many constraints such as delay, energy consumption. moreover, due to high dynamic nature, the node connectivity also remains a challenging aspect. Therefore, developing a routing approach to address all these challenges is essential.

To overcome these issues, several researches have been carried out which are mainly focused on routing mechanism which are mainly categorized as acoustic, opportunistic, QoS based, cross layer, location based, clustering based and hierarchal routing. Some of the latest routing schemes are discussed in literature section. However, these routing techniques face several challenges as mentioned before therefore efficient routing mechanism is required to improve the performance of UWSN. Therefore, we have focused on minimizing the congestion, and packet collision by using adaptive opportunistic routing protocol.

The main objectives of this research work are as follows:

- To present a mathematical model for underwater energy consumption for receiving and transmitting the data.

- To present an opportunistic routing model by incorporating link quality estimation, and node connectivity analysis for underwater scenario.
- To identify the most efficient candidate node as forwarder node of opportunistic routing

In order to accomplish this, the main research contribution of this work are as follows: in first phase, we present a mathematical model to characterize the energy consumption for under water scenarios. For this scenario, we focus on development of energy aware opportunistic routing protocol where link quality estimation, node connectivity, residual energy, and priority analysis are performed to find the most suitable forwarding node. The link quality estimation uses power as main parameter to estimate the link quality, node connectivity analysis considers distance between nodes. finally, node priority is computed and scheduling is done for packet transmission

The remainder of this paper is structured as follows: Section II provides a brief review of the literature., section III presents proposed routing protocol for QoS management, section IV discusses about the experimental setup, the results of the suggested methodology and their comparative evaluation, and Section V comprises the work's future scope and conclusion remarks.

## 2. LITERATURE REVIEW

This section briefs an overview of existing routing techniques for UWSN. Several methods have been developed for this purpose but the performance of these systems is affected due to several constraints such as speed, delay, bandwidth and excessive energy consumption. Subramani et al. [14] suggested that clustering and multi-hop routing can play pivotal role in reducing the energy consumption in WSN. However, the prevalent clustering mechanisms are not suitable for underwater scenarios due to bandwidth, delay and attenuation etc. issues. To overcome this issue, authors introduced a metaheuristic based clustering mechanism which uses cultural emperor penguin optimization strategy to find the optimal cluster head. Moreover, it uses grasshopper optimization approach to derive the optimal input parameters. Similarly, Mohan et al. [15] also used the concept of metaheuristic optimization approach because the clustering problem is considered as NP hard optimization problem which can be solved by employing optimization schemes. Therefore, authors introduced improved meta heuristic based clustering approach for CH selection. This approach comprises two key processes: the utilization of the Chaotic Krill Head Algorithm (CKHA) for cluster formation and the implementation of the Self-Adaptive Glow Worm Swarm Optimization algorithm (SA-GSO) for multi-hop data transmission. In the CKHA method, Cluster Heads (CHs) are selected and clusters are formed through various criteria, including residual energy, intra-cluster distance, and inter-cluster distance. Likewise, the SA-GSO algorithm defines a fitness function that takes into account four parameters: residual energy, delay, distance, and trust.

Chenthil et al. [16] focused on establishing the communication link for underwater sensors with reduced delay and minimized energy consumption. Therefore, authors introduced energy aware clustering mechanism. The complete approach is carried out into various steps such as initialization of network, CH formation, and transmission of data. According to this approach, the network is divided into two areas as near and far dense areas. In next phase, the rectangle mobility transmission method is adopted to reach to the surface of sink. In next phase, the CH handles the data collection process to manage the energy consumption. Finally, the data transmission is performed when the coverage area is in the range of transmission.

Noorbakhsh et al. [17] developed energy-efficient grid-based routing protocol with the help of TOPSIS mechanism and introduced a 3-dimensional approach for cell division. In the first stage, the network is split into 3 dimensional cells, in next stage, cluster head or gateway nodes are chosen and finally, the data transmission is performed in communication phase. Bhattacharjya et al. [18] introduced energy efficient approach for UWSN which is based on cluster formation, CH selection and multihop transmission. The selection of CH is accomplished by considering residual energy of the node.

Di Valerio et al. [19] discussed the performance related issues in these networks caused due to high dynamic nature of the UWSNs. To overcome these issues, authors introduced an innovative data forwarding strategy in their work, one that rapidly adjusts to the dynamic conditions encountered within the underwater channel. This novel protocol, named CARMA, intelligently transitions between single-path and multi-path routing. This transition is facilitated through a distributed reinforcement learning framework, which effectively optimizes both the energy consumption over the entire route and the packet delivery ratio, thereby enhancing the overall efficiency of data transmission in underwater communication scenarios.

Xiao et al. [20] introduced an energy-efficient clustering routing algorithm that relies on an enhanced Ant Colony Optimization (ACO) technique. In clustering routing schemes, the network is partitioned into multiple clusters, each comprising a Cluster Head Node (CHN) and several Cluster Member Nodes (CMNs). This research focuses on optimizing the selection of CHNs by considering factors like the residual energy levels of nodes and their distances. The chosen CHNs are accountable for collecting data from CMNs and forwarding it to the sink node through multiple intermediate hops. The identification of optimal multi-hop routes from CHNs to the sink node is achieved using an improved ACO algorithm.

## 3. PROPOSED MODEL

This section describes the proposed approach for underwater sensor routing by using the opportunistic routing concept. Opportunistic routing is a promising approach for improving data delivery in UWSNs. Unlike traditional routing protocols that rely on predetermined paths, opportunistic routing takes advantage of the dynamic and unpredictable nature of underwater communication channels. It enables nodes to opportunistically forward packets to maximize the chances of successful delivery, even in the presence of intermittent connectivity and unreliable links. It uses two main concepts which are as follows:

- Opportunistic routing relies on the store-carry-forward mechanism, where nodes store data packets until an optimal forwarding opportunity arises. This mechanism ensures that data is not discarded when a direct transmission fails.
- Nodes in opportunistic routing may have multiple candidates for forwarding data packets. The selection of the best candidate depends on various factors such as link quality, node mobility, and energy constraints.

We use this concept of opportunistic routing and presented a novel routing for UWSNs. A basic system model is considered where total $N$ no. of nodes are present in the underwater region. This model uses a symmetric wireless channel and nodes follow the random mobility model. Moreover, these nodes are enabled with sleep-awake mechanism to minimize the overall energy consumption. In order to transmit the $b_i$ bits over distance $d$, the energy used by power amplifiers can be defined as:

$$E_{TX}(b_i, d) = \begin{cases} b_i \times E_{elec} + b_i \times \epsilon_{mp} \times d^4, d > d_0 \\ b_i \times E_{elec} + b_i \times \epsilon_{fs} \times d^2, d \leq d_0 \end{cases} \quad (1)$$

Where $E_{elec}$ represents the energy dissipation per bit of transmission or receiving circuit, $\epsilon_{fs}$ is the energy consumption in free space and $\epsilon_{mp}$ denotes the energy consumption in multipath scenario where $d_0 = \left(\frac{\epsilon_{fs}}{\epsilon_{mp}}\right)^{\frac{1}{2}}$. Similarly, the energy consumed to receive the same size of data can be calculated as:

$$E_{RX}(n_i) = b_i \times E_{elec} \quad (2)$$

### 3.1. Opportunistic Routing

Opportunistic routing in Underwater Sensor Networks is a promising approach to enhance data transmission reliability and efficiency in challenging underwater environments. By leveraging the dynamic nature of underwater communication channels, opportunistic routing protocols have the potential to overcome connectivity issues and improve data delivery rates. The sole objective of this approach is to find the optimal relay node to ensure the reliable transmission. In order to obtain this, we use link quality prediction, node connectivity, residual energy, priority assignment and scheduling of candidate forwarding nodes to generate the final solution for relay node selection.

#### 3.1.1. Link quality estimation

The inherent dynamic nature of UWSNs can lead to routing failures, primarily due to the frequent disruptions in communication links. Consequently, this section introduces an effective method for predicting link quality, aimed at assessing the likelihood of such interruptions. Furthermore, we will explore the concept of the update period, which involves the broadcasting of 'Hello' messages. This approach ensures the real-time renewal of link connectivity metrics, ultimately bolstering the reliability of the established routing paths. According to the path loss model, the received power can be computed as:

$$P_R(d) = P_t - PL\ (d_0) - 10\alpha \log_{10}\left(\frac{d}{d_0}\right) + X_\sigma \quad (3)$$

Where $P_t$ denotes the transmit power of node, $PL(d_0)$ is the loss in signal strength for $d_0 = 1m$, $\alpha$ represents the path loss exponent, and $X_\sigma$ represents the wave shadow factor. Given that the nodes' communication radius is denoted as '$r$,' the requisite received signal strength threshold for a node to effectively obtain data packets can be expressed as follows:

$$P_{R_{Th}} = P_t - PL(d_0) - 10\alpha \log_{10}\left(\frac{0.9054r}{d_0}\right) \quad (4)$$

The received strength threshold, denoted as $P_{R_{Th}}$, signifies the minimum signal strength required for a node to receive messages from its neighboring nodes. To assess the link connectivity between the node and its neighbors, we introduce a metric referred to as LC. This metric quantifies the relationship between the threshold $P_{R_{Th}}$ and the received signal strength and can be expressed as follows:

$$LC_{i_j} = \begin{cases} 0, if\ \Pr(d) \le P_{R_{Th}} \\ 1 - e^{1 - \frac{P_{R_{Th}}}{\Pr(d)}}, if\ \Pr(d) > P_{R_{Th}} \end{cases} \quad (5)$$

Where $LC_{ij}$ denotes the likelihood of link connection between node and $i$ and neighbouring node $j$. A higher $LC_{i_j}$ value indicates a more dependable link. Conversely, when $LC_{i_j}$ equals 0, it signifies that the link is either disconnected or prone to interruption. In UWSNs, the network topology undergoes frequent changes due to its high dynamism, causing established, reliable communication links among nodes to have a limited duration. Consequently, there arises a need for periodic updates of $LC_{i_j}$. To illustrate this, let's examine a scenario where two nodes are presumed to be moving in opposite directions at their maximum speeds. In such a case, we can calculate the min. time required for the direct link between the nodes to uphold seamless connectivity as follows:

$$t_m = \frac{r - 09054r}{2v_{max}} \quad (6)$$

Where $v_m$ is the maximum speed of uwsn node.

### 3.1.2. Node connectivity analysis

The distance between source and sink node is denoted by $Y_i^t$ at a time $t$. The forwarding path is depicted in below given figure 2. According to the data transmission mechanism, data packets are produced by the node $i$ and transmitted to the corresponding sink node by using multihop random route. The consideration of the next-hop forwarding node relies on two factors: the priority assigned to candidate nodes and the sleep/active method. The avg. count of forwarding nodes for any node $i$ is given as $N_i = \rho A_i^t$ where $\rho$ represents the node density and $A_i^t$ represents the region where candidate forwarding nodes are placed which can be expressed as:

$$A_i^t(\gamma_i^t, \theta) = \int_\theta^r 2(\gamma_i^t - x) \arccos\left(\frac{(\gamma_i^t)^2 + (\gamma_i^t - x)^2 - r^2}{2\gamma_i^t(\gamma_i^t - x)}\right) dx \quad (7)$$

Where θ represents the control parameter

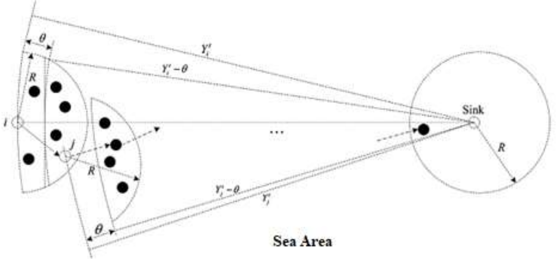

*Figure 2: Node connectivity analysis*

In this context, nodes with a stronger connectivity have a greater likelihood of being selected as candidate forwarders. The expected advancement prediction can be expressed as:

$$h(\gamma_i^t, \theta) = \int_{x=\theta}^{x=r} \frac{2(\gamma_i^t - x) \arccos\left(\frac{(\gamma_i^t)^2 + (\gamma_i^t - x)^2 - r^2}{2\gamma_i^t(\gamma_i^t - x)}\right)}{A_i^t} . x . dx \quad (8)$$

### 3.1.3. Residual energy analysis

We also use residual information to determine the priority of candidate node for forwarder node selection. For any sending node i the energy probability distribution $\zeta_i = \left(\zeta_{1_i}, \zeta_{1_2}, .., \zeta_{1_j}\right)$ is characterized based on a regularized random variable $\overline{\zeta_\iota} = \left(\overline{\zeta_{1_\iota}}, \overline{\zeta_{1_2}}, .., \overline{\zeta_{1_J}}\right)$. The energy distribution and energy variable can be expressed as:

$$\zeta ij{=}1{+}\zeta je0,\forall j{\in}Fij \quad (9)$$

$$\overline{\zeta_{1_J}} = \frac{e^{(\zeta_{i_j})\gamma^\phi}}{e^{(\bar{\zeta}_{i_j})\gamma^\phi}}, j \in F_{ij}\ and\ \gamma_\phi \ge 0 \quad (10)$$

Where $\gamma^\phi$ represents the control parameter for energy distribution, $\tilde{\zeta}_j$ denotes the remaining energy in node $j$, $e_0$ is the initial energy and $F_{ij}$ represents the set of candidate nodes.

### 3.1.4. Priority computation and scheduling

Based on aforementioned parameters, link quality, node connectivity, residual energy and distance between nodes, we compute the final priority of node $j$ at time $t$ as:

$$P_{i_j}(t) = \ln\left(1 + \frac{LC_{i_j}(t).h(\Upsilon_i^t).\tilde{\zeta}_{i_j}(t)}{d_{j-sink}(t)}\right) \quad (11)$$

With the help of this, the optimal next hop can be expressed as:

$$j^* = \underset{j}{argmax}\, P_{i_j}(t) \quad (12)$$

The process of scheduling of the selected forwarding node is demonstrated in algorithm 1:

**Algorithm: 1: Forwarding candidate node selection for UWSNs**

```
Step 1: when underwater node $i$ receives $ack$ message packets then $do$
Step 2: compute the priority of node as $P_{i_j}(t) = \ln\left(1 + \frac{LC_{i_j}(t).h(\Upsilon_i^t).\tilde{\zeta}_{i_j}(t)}{d_{j-sink}(t)}\right)$
Step 3: for each $P_{i_j}(t)$ do
Step 4: if $P_{i_j}(t) \geq \frac{1}{1+q_{i_j}}$ //$q$ is the no. of neighbouring nodes
Step 5 Add neighbour node $j$ to $F_{i_j}$
Step 6: End if
Step 7: End for
Step 8 For each $j \in F_{i_j}$ do
Step 9: if candidate node is able to forward data packet successfully then
Step 10: other node is kept as dormant
Step 11: else
Step 12: a low-priority node will be considered for activation and it will attempt to forward the packet until the packets are transmitted successfully
Step 13: End if
Step 14: End for
```

Utilizing $P_{i_j}(t)$, we derive the priority ranking of candidate forwarding nodes. Subsequently, we implemented a packet forwarding coordination mechanism using timers. While the other candidate forwarders stay inert, the candidate nodes with the greatest priority take the lead in delivering data packets. A lower-priority candidate node becomes active and tries to forward the data packet if the high-priority candidate node is unable to do so within the allotted time limit. Until the sensor data from the maritime node is correctly transferred, this repeated procedure is continued.

## 4. RESULTS AND DISCUSSION

This section briefs the results of proposed solution and demonstrates comparative analysis of it with state-of-art algorithms. In simulation, we have considered varied no. of nodes from 50 to 400 which are deployed in a region whose dimensions are 300m X 300m X 600m. The ideal power and transmission power are considered as 8mW and 2W, respectively. The maximum transmission range is considered as 100m for 1000 bits of data packet size. The size of control packet is fixed as 60 bits. Below given table shows the simulation parameters used in this work.

*Table 1: Parameters simulated.*

| Parameter name | Considered value |
|---|---|
| Node count | 50-400 |
| Network deployment region | 300m X 300m X 600m |
| Transmission Power | 2 W |
| Idle Power | 8 mW |
| Receive Power | 0.75 W |
| Maximum Transmission Range | 100 m |
| Data Packet size | 1000 bits |
| Mobility Model | Random Walk |
| Control packet size | 60 bits |

The efficacy of proposed approach is measured in terms of throughput, packet delivery rate, packet loss rate and energy consumption. The computation formula for these parameters are described below:

- Throughput

$$\begin{aligned} &Throughput \\ &= (Successfully\ received\ packets \\ &* duration\ of\ data\ transmission) \\ &/Simulation\ time \end{aligned} \quad (13)$$

- Packet delivery rate

$$Packet\ delivery\ rate = \frac{\sum packets\ received\ by\ the\ all\ destination\ node}{\sum total\ packets\ sent\ by\ all\ source\ nodes} \quad (14)$$

- Packet loss

$$\begin{aligned} &Packet\ Loss \\ &= (Total\ no.of\ transmitted\ packet \\ &- Total\ no.of\ received\ packet) \\ &/\ Total\ transmitted\ packet \times 100 \end{aligned} \quad (15)$$

Based on these parameters, we measure the performance of proposed approach for varied simulation parameters. Below given section describes the outcome of proposed approach and its comparative analysis.

### 4.1. Comparative analysis

This section describes the outcome of proposed approach and compares its performance with existing schemes such as UWAN-MAC, TLohi, ED-MAC, and DL-MAC. The complete experimental study is carried out into two phases: the first phase measures the performance for varied number of nodes and second phase measures the performance in terms of varied packet rate.

### 4.1.1. Experiment 1: Performance analysis for varied number of nodes

In this experiment, we varied the number of nodes and packet rate is fixed at 0.1 packets per second to monitor the performance of proposed model. Below given figure 3 depicts the obtained throughput for different algorithms.

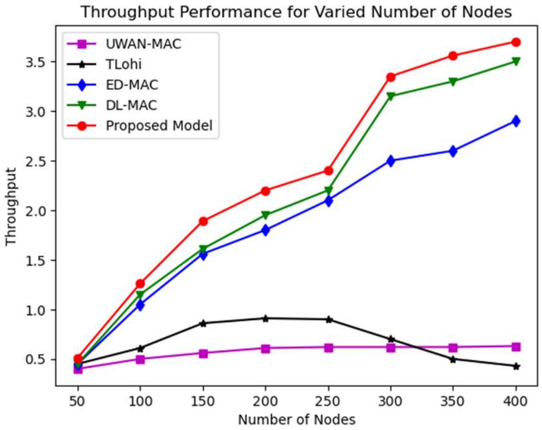

*Figure 3: Throughput performance for varied number of nodes*

Figure 14 illustrates the relationship between the number of nodes and the throughput of the routing protocols. As the number of nodes in the network increases, there is a proportional increase in network throughput, eventually levelling off at a saturation point in TLohi and UWAN-MAC protocols. However, the proposed approach reported an overall increase of 7.8% when compared with recent DL-MAC protocol. This is achieved because of proposed opportunistic model which helps to tackle the congestion problem efficiently. Similarly, we measured the performance in terms of packet delivery for varied number of nodes. The obtained performance analysis is presented in below given figure 4.

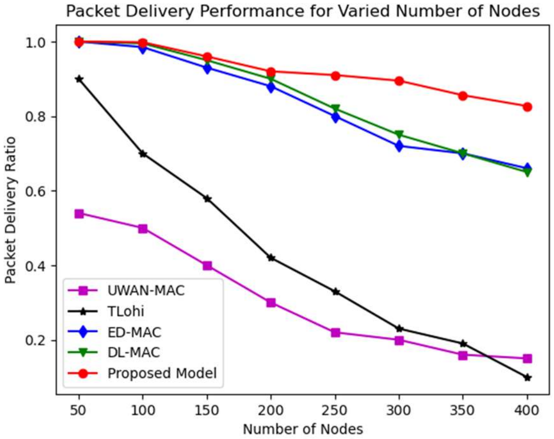

*Figure 4: Packet delivery performance*

Average packet delivery performance is obtained 0.3087, 0.4312, 0.8343, 0.8456, and 0.92 by using UWAN-MAC, TLohi, ED-MAC, DL-MAC, and proposed approach, respectively. Similarly, the average energy consumption reported as 11.23, 11.16, 2.16, 1.99 and 1.51 by using UWAN-MAC, TLohi, ED-MAC, DL-MAC, and proposed approach, respectively. However, the increased number of nodes lead to increase the collision resulting in packet drop therefore the existing schemes UWAN-MAC, TLohi, ED-MAC, DL-MAC reported the average packet loss performance as 0.69, 0.56, 0.165, 0.154 whereas proposed approach outperforms these methods by achieving the average packet loss as 0.079.

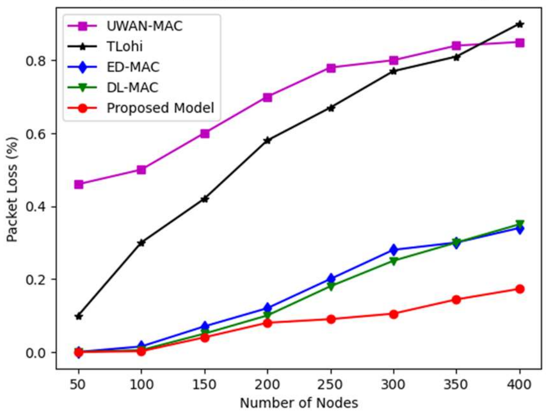

*Figure 5: packet loss performance for varied number of nodes*

These experiments demonstrate the performance for diverse no. of nodes ranging from 50 to 400 nodes. According to this experiment, for a smaller number of nodes, traditional and proposed approaches obtain similar performance because of less congestion and packet collision. As the number of nodes are increased, the existing schemes suffer from packet collision and continuous packet generation leads to increase the waiting period. The average throughput performance is obtained as 0.57, 0.67, 1.87, 2.17, and 2.35 by using UWAN-MAC, TLohi, ED-MAC, DL-MAC, and proposed approach, respectively.

### 4.1.2. Experiment 2: Performance analysis for varied traffic rate

In this experimental configuration, we have considered varied traffic rate to evaluate the performance for underwater scenarios. First of all, we evaluated the throughput performance as depicted in below given figure 6:

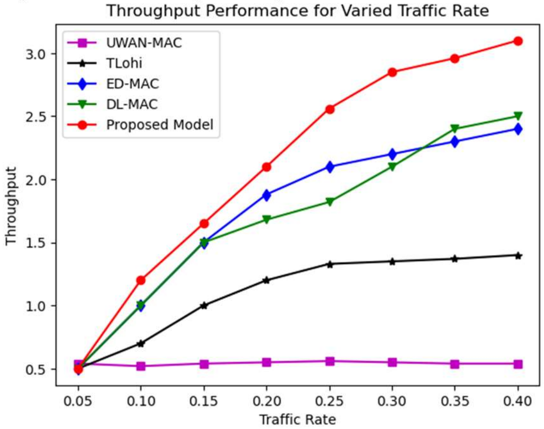

*Figure 6: Throughput performance for varied traffic rate*

According to this experiment the increased traffic rate leads to increase the overall throughput of proposed approach whereas the UWAN-MAC and TLohi reported the saturated results after 0.15 traffic rate. The average throughput for this experiment is obtained as 0.542, 1.10, 1.73, 1.6875, and 2.115. Further, we measured the packet delivery rate performance for varied traffic rate. The obtained performance is reported in figure 7.

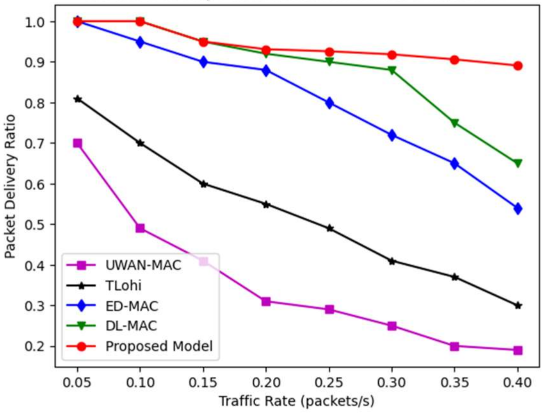

*Figure 7: Packet delivery performance*

This experiment, shows that the increased traffic rate reduced packet delivery because of collision and node failure. For this experiment, the average packet delivery ratio is obtained as 0.355, 0.528, 0.804, 0.881, and 0.940.

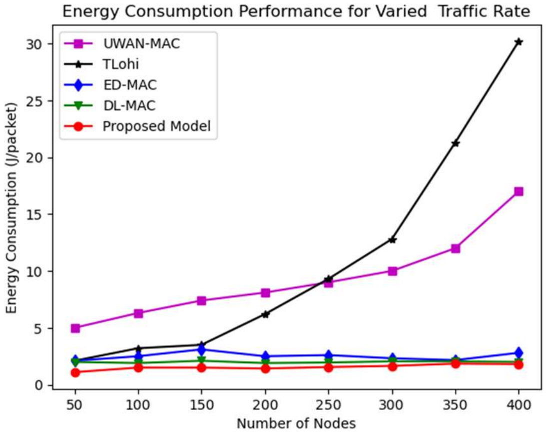

*Figure 8: Energy consumption performance*

Similarly, we measured the energy consumption and packet loss performance for varied number of nodes and traffic rate, respectively. The obtained output is depicted in figure 8 and 9. This experiment shows that the average energy consumption is obtained as 9.5, 11.10, 2.4, 1.85, and 1.44 by using UWAN-MAC, TLohi, ED-MAC, DL-MAC, and proposed approach, respectively whereas the average packet loss 0.645, 0.47125, 0.20625, 0.14125, and 0.0821875 by using UWAN-MAC, TLohi, ED-MAC, DL-MAC, and proposed approach, respectively.

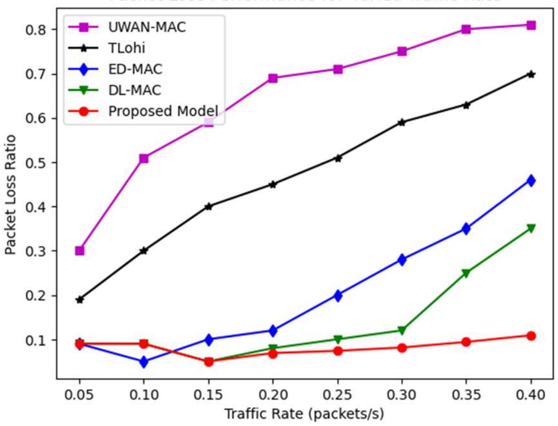

*Figure 9: Packet loss performance*

According to the energy consumption analysis that total energy consumption increases due to increased density of nodes. However, the proposed approach consumes less energy than other protocols because of its feature to detect the hidden terminal problem resulting in minimizing the packet Collison whereas the existing methods fail to detect the hidden terminals.

- **Difference from prior works**

Previous works in the field of underwater sensor networks have explored various routing techniques, including clustering-based approaches, metaheuristic optimization, and energy-efficient protocols. The performance of existing models is affected due to dynamic underwater scenarios. However, the specific focus on opportunistic routing considering link quality, energy, and node connectivity parameters is relatively less explored. Therefore, we have integrated these models in opportunistic routing models. This comprehensive consideration enables more informed decision-making in selecting the next hop for data transmission. Many existing routing protocols in underwater sensor networks follow predetermined paths or rely on static routing tables. In contrast to this, the proposed approach introduces opportunistic routing, which dynamically selects the next hop based on real-time conditions, such as the quality of the link and the energy status of neighboring nodes. This adaptive routing approach potentially improve network performance under dynamic underwater conditions. The proposed work addresses a critical gap in the existing literature by presenting an opportunistic routing approach tailored to the underwater sensor network environment. By integrating multiple parameters and emphasizing adaptability to dynamic conditions, your approach offers potential benefits in terms of network performance, energy efficiency, and robustness to environmental changes. The novelty lies in the comprehensive consideration of link quality, energy, and node connectivity in the routing decision process, which has not been extensively explored in previous studies.

## 5. CONCLUSION

This work has focused on underwater wireless sensor networks and improving the overall throughput of the network. Therefore, the proposed underwater routing through the utilization of opportunistic schemes represents a promising frontier in underwater communication and networking. The unique challenges posed by the underwater environment, such as limited bandwidth, high latency, and variable conditions, make it imperative to develop innovative approaches. Opportunistic routing, with its ability to adapt to changing conditions and exploit transient network connectivity, offers a compelling solution. Through our exploration of underwater routing with opportunistic schemes, we have demonstrated a novel approach for relay selection as forwarder node which uses several parameters to ensure the robustness of the forwarder node. The proposed work introduces a novel approach by using residual energy analysis, link quality estimation, and priority of transmission which require power, and distance information to select the most suitable next node for packet forwarding. Moreover, by intelligently leveraging fleeting communication opportunities, opportunistic schemes can mitigate the adverse effects of signal attenuation and improve the overall reliability of data delivery.

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