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Energy Optimization using Swarm Intelligence for IoT-Authorized Underwater Wireless Sensor Networks

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Abstract: The technology advancement in the Internet of Things (IoT) enables a variety of smart monitoring applications assisted by networks like Wireless Sensor Networks (WSNs) and Underwater WSNs (UWSNs). The IoT-UWSNs supported a wide range of applications such as underwater data collection, underwater equipment monitoring, underwater imaging, etc. The acoustic signals have been utilized for communication in IoT-UWSNs over radio signals and optical signals. Data transmission using acoustic signals is suffering from lower throughput, excessive energy consumption, long transmission delay, and lower network lifetime. Several data forwarding and clustering algorithms have recently been proposed to enhance UWSN's performances. This paper proposed a novel routing solution for energy and QoS-efficient data transmission from the underwater sensor node to the surface sink using Swarm Intelligence (SI). This protocol called Energy Optimization using Routing Optimization (EORO) protocol. To optimize the UWSNs performance, we used Effective Fitness Function-based Particle Swarm Optimization (EFF-PSO) to select the best forwarder node for data transmission. In EORO, forwarding relay nodes discovered by the intended source node using location information firstly. Then EFF-PSO algorithm is applied to select the optimal relay node considering the rich set of parameters. Four parameters of each forwarder node used for fitness computation as residual energy, packet transmission ability, node connectivity, and distance. These parameters are intelligently selected to avoid packet collisions to achieve energy consumption and delay reduction with higher throughput. An experimental result shows that the EORO protocol outperformed underlying routing techniques using throughput, energy consumption, delay, and Packet Delivery Ratio (PDR).

Keywords: Acoustic signals, data forwarding, energy optimization, internet of things, swarm intelligence, underwater sensor network.

I. Introduction

The emergence of the Internet of Things (IoT) has bridges the gap between the physical world and cyber [1]. The IoT is a network that comprises a wide assortment of items like actuators, sensor hubs, versatile hubs, RFID labels, and so forth associated by means of wired and additionally wireless networks to the Internet as indicated by the application. Late advancement in the IoT has shown that it is driving toward another digital setting, which advances different novel applications and administrations [2]. To effectively execute the IoT, network framework and conventions assume pivotal parts in giving compelling and proficient correspondences among IoT goals. Consequently, the exhibition of the network fundamentally affects the assistance execution of IoT [3]. Since from last decade, the data transmissions in IoT gained significant research interests regardless of application area. The data communication tasks have mainly been handled by the routing protocols. The applications of IoT are traffic monitoring, security services, home automation, e-healthcare systems, precision agriculture, ocean monitoring, etc. [4-7]. In this work, our focus is IoT-enabled ocean monitoring applications assisted using Underwater Wireless Sensor Networks (UWSNs). The development in sensor technology makes it possible to build low-cost and small-size IoT-enabled wireless sensor networks (WSNs). Technology advancement motivated researchers to introduce large-scale UWSNs in IoT perspective for a variety of monitoring applications. The core applications are environmental data collection (pH, conductivity, dissolved oxygen, temperature, etc.), supervising geological processes on the ocean floor, underwater imaging, monitoring marine things associated with fuel or mineral extraction, etc. [8]. The design and deployment of IoT-enabled UWSNs enable a broad range of applications such as ocean sampling nets, disaster prevention, undersea explorations, assisted navigation, mine reconnaissance, and distributed tactical surveillance.

By and large, UWSNs comprise a variable number of sensors and vehicles conveyed to perform communitarian observing assignments over a given region. To accomplish this unbiased, sensors and vehicles self-coordinate in a self-sufficient network that adjusts to the attributes of the sea climate. Underwater networks can be described by their spatial inclusion and by the thickness of hubs. As an arising region, underwater wireless sensor network has pulled in quickly developing interests over the most recent quite a while [9]. From one perspective, UWSNs empower a wide scope of amphibian applications, for example, oceanographic information assortment, contamination checking, offshore investigation, debacle anticipation, and strategic observation applications, sea examining network, submarine location, calamity counteraction, and so on On the opposite side, the antagonistic underwater conditions present fabulous difficulties for proficient correspondence and networking. In underwater conditions, because of water assimilation. radio doesn't function admirably. Consequently, acoustic correspondence is typically utilized as a practical arrangement in underwater wireless sensor networks. In any case, because of the physical attributes of sound signs, acoustic channels are included with low accessible transmission capacity, exceptionally huge spread delay, and high blunder likelihood [9]. The uniqueness in underwater conditions is that most sensor hubs could be inactively versatile with water flows. The importance of UWSNs in human life gained significant attention on its performance optimization since from last decade.

The conventional methods exploited for underwater monitoring applications lead to various limitations. Additionally, such ungracious conditions are not possible for human presence as erratic underwater exercises, high water pressure, and immense regions are the purposes behind the automated investigation. In this manner, UWSNs are drawing in light of a legitimate concern for some scientists recently, particularly those dealing with terrestrial sensor networks [10-15]. Sensor networks utilized for underwater interchanges are diverse in numerous perspectives from conventional wired or even terrestrial sensor networks. Right off the bat, energy utilization is diverse because some significant applications require a lot of information, yet rarely. Also, these networks typically work on a typical undertaking as opposed to addressing autonomous clients. A definitive objective is to amplify the throughput as opposed to reasonableness among the hubs. Thirdly, for these networks, there is a significant connection between the connection distance, number of bounces, and

dependability [16]. For energy concerns, parcels over multiple short jumps are liked rather than long connections, as multi-bounce information conveyances have been demonstrated more energy effective for underwater networks than the single-bounce [17]. Simultaneously, it was seen that bundle steering over more jumps, at last, corrupts the start to finish dependability work, particularly for the cruel underwater climate. In short, the existing methods failed to address all the challenges of UWSNs [17].

To end this, we sum up that the UWSNs face many plan difficulties like high way misfortune, restricted accessible transfer speed, restricted battery limit, high weakening, high piece blunder rate, and so forth As the underwater sensor hubs are asset compelled, the extreme energy utilization abbreviates the network lifetime of the general network. The routing tasks such as route discovery and data forwarding mainly responsible for the energy-efficiency of UWSNs with network throughput and communication delay. The clustering and routing algorithms of WSNs cannot directly apply to UWSNs due to acoustic signals and different layers of communications. Thus, designing either clustering-based or route formation algorithms by considering the ocean properties of UWSNs gained significant attention from researchers [18-21]. But UWSNs challenges mainly related achieve trade-off among energy-efficient, higher PDR, and minimum communication delay parameters. In this paper, we focused on link establishment from source sensor to the surface sink through the opportunistic routing for both small and large-scale networks by considering the objectives of energy and QoS-efficiency. Energy Optimization using Routing Optimization (EORO) Algorithm proposed in this paper using Swarm Intelligence (SI). To the best of our knowledge, this is the first attempt at applying SI for UWSNs performance enhancement. Various SI techniques have already been proven effective for WSNs [22] [23]. The Particle Swarm Optimization (PSO) based route formation and data transmission algorithm designed with Effective Fitness Function (EFF) using the different properties of underwater sensor nodes. The EFF-PSO iteratively selects the optimal relay node for data transmission to reduce the packet collisions, energy consumption, transmission delay, and improving PDR. Section 2 presents the various routing solutions of UWNSs with motivation and contributions of EORO protocol. Section 3 presents the EORO

protocol design in terms of architecture and algorithm. Section 4 presents the simulation results and comparative study with similar methods. Finally, section 5 deals with the paper conclusion followed by suggestions for future work.

2. Related Works

Since from decade, various routing protocols have been designed for UWSNs to address the challenges related to energy-efficiency, data loss, collisions, high latency, etc. These problems are mainly related to data transmission from underwater sensor nodes to surface sinks. In this section, some recent works of energy-efficient data transmission techniques in UWSNs are reviewed.

A. State-of-Art Methods

The novel void recovery approach was proposed in [26] using geographical routing according to the concept of packet advance. It was the topology-based approach in which the topology information had been available with the autonomous underwater vehicle. When a node was struck with communication void topological changes are made by the winch-based apparatus or a floating buoy to overcome it. Then anycast routing where it can find a neighbor node nearest to the void node has been used. The adjusted information then was available to all of the nodes with replay messages in a distributed topology structure. The AURP (Autonomous Underwater Vehicleaided Underwater Routing Protocol) was proposed in [27]. In AURP, autonomous underwater devices have been used as a relay for huge value and short-range data transmission over the underwater channel. The communication among underwater source nodes and sink depends on relay nodes. The data forwarding algorithm was designed in [28] for energy-efficient routing in UWSNs using the various parameters of relay selection as optimal distance, residual energy, and depth. The flexibility provided by the source node in transmission energy had based on the surface sinks such that the signal received with similar transmitted energy. The optimal hop position-based energy-efficient routing had divided into two phases. In the first initialization phase it checks the node identity, position of forwarders then priority has been assigned with residual energy value. In the second data forwarding phase, it checked the availability of packets for forwarding and forwards checking their

packet history buffer to avoid redundant packet forwarding and provides the correct priority based on the residual energy and distance. The local maximum routing recovery had proposed in [29] uses a network energy consumption model based on the communication range and carrier sensing range, where the carrier sensing range had greater than the communication range. When a node is struck with voids, it increases its communication range by adjusting its transmission power to overcome voids. Initially, each node tries to route towards a node with minimal hops and energy consumption. The RMTG (Routing & Multicast Tree-based Geo-casting) protocol had proposed in [30] as the handshake method. In RMTG, nodes transfer data packets to a particular group according to their geographical locations. They used GPS (Global Positioning System) to estimate the geographical coordinates. The WDFAD-DBR (Weighting Depth & Forwarding Area Division-Depth Based Routing) had designed in [31]. They designed WDFAD-DBR with anchor nodes, relay nodes, and multiple sink nodes. The relative coordinates of nodes were available based on the RSSI (received signal strength indicator). They used the criteria of the depth of the present forwarder and then anticipate the depth of the adjoining hop of the forwarding node with a lower depth. Efficient use of energy consumption was optimized by dividing the forwarding area that has been classified as primary forwarding area and auxiliary forwarding area using nodal density and channel state to avoid duplicate packet transmission.

Recently more works were introduced on opportunistic data forwarding for UWSNs [32-46]. The energy-efficient chain-based routing method had introduced in [32] for UWSNs. They considered the unpredictable highlights of underwater elements like powerful network geography and node versatility, the energy of the cluster heads (CHs), relay nodes (RNs), and cluster coordinators (CCOs) during the transmission of information and the job of the CHs, CCOs, and RNs is updated after some time term to keep up the heap on the nodes. Another routing mechanism had designed in [33] for underwater communications using the voracious routing techniques. They accomplished new routing by improving the VBF calculation, which is subject to the span of the climate's measurements and the reach and the density of the nodes. The routing method to enhance the energy-efficiency using the removal technique on

physical routing space had designed in [34] for UWSNs. The routing protocol had based on vector-based forwarding routing protocol and spherical divisions that were spherical division-based vector-based forwarding. The LF-IEHM named (Localization Free-Interference & Energy Holes Minimization) protocol had proposed in [35]. This protocol overcomes interference during data packet forwarding by defining a unique packet holding time for every sensor node. The energy hole formation was mitigated by a variable transmission range of the sensor nodes. An event-driven energy-efficient routing approach called CBEER (Clustering-Based Energy-Efficient Routing) was proposed in [36] to enhance the lifetime of UWSNs. They evaluated performance through extensive simulations. Another location-free technique for UWSNs routing was proposed in [37] called EERBLC (Energy-Efficient Routing protocol Based on Layers & unequal Clusters). EERBLC was designed in three phases as a layer and unequal cluster formation, transmission routing, maintenance, and update of clusters. The opportunistic routing designed for UWSNs in [38] was called EECOR (Energy-Efficient Cooperative Opportunistic Routing). They designed EECOR to transfer packets from source sensor nodes to the surface sink via the best relay nodes. They applied the fully logic method to select the relay node using two parameters such as packet delivery probability and energy consumption rate. Fully logic rules were applied to these two parameters to select the best relay node to forward the packet. The TORA (Totally Opportunistic Routing Algorithm) had introduced in [39] for UWSNs. They designed TORA to prevent horizontal transmission, minimize end-to-end delay, address the problem of void nodes, minimize energy consumption, and enhance throughput. The SORP (Stateless Opportunistic Routing Protocol) was designed in [40] in that traffic and void sensor nodes detected locally in the various regions of the network topology of UWSNs. They excluded such nodes from the routing phase according to the passive participation technique. They designed adaptive forwarding in SORP protocol for efficient data transmission from under sensor nodes to the surface sink nodes. Another opportunistic data forwarding mechanism was proposed in [41] for IoT-UWSNs with aim of reducing the energy-consumption called BEAR (Balanced Energy Adaptive Routing). As the name indicates, BEAR had designed to enhance the network lifetime of IoT-authorized UWSNs. They designed BEAR in

three phases such as initialization phase, the tree-building phase, and the data transmission phase. Cooperative communication had exploited in [42] to propose an energy-efficient algorithm for UWSNs. Each node had equipped with multiple node coordinates and an Omni directional antenna in the network. They designed AF (Amplify & Forward) at the relay and FRC (Fixed Ratio Combining) method at the receiver. The IEBR (Improved Energy Balanced Routing) had designed in [43] for energy-efficient UWSNs. They designed IEBR in two phases such as route discovery and data transmission. The relay nodes were selected using the neighbor's depth and depth threshold. The energy level differences were utilized in the second phase of data transmission. The energy-efficient techniques were introduced recently in [44] for smart city applications called IoT-authorized UWSNs. They considered different cases for routing mechanisms and proposed various variants for UWSNs. Another recent protocol had proposed in [45] for UWSNs that focused on joint optimization of hold and forwarding technique, sink mobility, data aggregation, adoptive depth threshold with pattern matching. They aimed to reduce energy consumption, propagation delay, and maximize throughput and network lifetime. The LEER (Layer-based Energy-Efficient Routing) method was designed in [46] to overcome the problems of route failure, long delay, and excessive energy consumption for UWSNs. Each node fetches the layer information from the received HELLO packets and updates its layer to prevent the void area packet routing. In this way, all nodes forwarded packets towards the sink without requiring location information.

B. Motivation and Contributions

Different types of UWSNs methods have been reviewed in the above section, but still, it is challenging to address the said concerns of UWSNs. The solutions [27] designed of AUV-based cannot be suitable for UWSNs as excess energy cost rather than focusing on internetworking with sensors. The GPS-based location estimation [30] failed in an underwater environment, thus, discovering relay nodes becomes difficult. Similarly, the distance computation techniques may lead to void in the network [31-36]. Some other recently presented methods [37-46] were based on efficient route formation and data transmission via selecting the best relay nodes suffering from various challenges related to network scalability and performance

reliability. Most of these protocols used a maximum of two parameters for forwarding relay selection like residual energy (commonly used) and either packet delivering probability or distance to sink. For UWSNs, relying on just energy level parameters commonly does not solve the problem of packet collisions, void communications, and higher delay. Thus lack of a rich set of parameters for relay selection via the optimizations motivates us to propose the EORO protocol in this paper. The key contributions of EORO are:

- Initially each underwater source discovering the possible set of forwarding relay nodes via local information in EORO protocol.
- To select the optimal relay node for data forwarding, the EFF-PSO technique is applied to all the available particles. The EEF of each particle has been computed by using the parameters such as residual energy, packet delivery ability, node connectivity, and acoustic distance. This process has been repeated until the surface sink.
- Once the route establishes, the data forwarding begins with the provision of checking the void communications in water along and periodically updated EEF values of each relay to ensure the energy level and network QoS.
- The performance of the EORO protocol has investigated using different types of UWSNs scenarios and compared them with recent protocols.

3. EORO Design

According to the research challenges of existing works and contributions defined in this paper, this section presents the methodology of the EORO protocol. The overall functionality of the EORO protocol is showing in figure 1 consist of the deployment phase, route formation phase, and data transmission phase. In the deployment phase, we deploy the IoT-UWSN to monitor the underwater environment by designing underwater sensor nodes using different parameters like energy model, acoustic frequency, MAC layer, etc. Define and deploy the surface sink position in the network. After the design and deployment of acoustic signal propagation-based UWSN, next to the underwater sensors at different layers periodically sense the underwater data, initiates its transmission towards the intended surface sink. In the second phase, the main focus is on optimal relay selection using EFF-PSO via opportunistic routing to improve the network lifetime and reliability. The process of route formation performed according to opportunistic routing using SI. The SI is technically designed to address the problem of maximization of network lifetime and throughput. The EFF-PSO selects the forwarding relay nodes according to EFF evaluation of each neighboring node. The EFF evaluation considers a rich set of parameters such as Residual Energy Level (REL), Packet Transmission Ability (PTA), Node Connectivity Ratio (NCR), and Node Distance Ratio (NDR). These parameters have been selected mainly to reduce the energy consumption and data loss caused by the problems like packet collisions, void communications, and unreliable relays. During the data transmission phase, each forwarding relay has periodically monitored to prevent void communications and packet collisions. In the next sections, we elaborate on the design of the system model and SI-based route formation and data transmission for IoT-UWSNs.



Figure 1. Architecture of EORO protocol for IoT-UWSNs

A. System Model



Figure 2. System model for IoT-authorized UWSN application

Figure 2 shows the design system model in this work for monitoring the underwater environment. The model consists of a single destination node called Surface Sink (SS) that collects the data from the different underwater sensor nodes called Underwater Source (US). Let underwater network of size $X \times Y \times Z$ deployed with N number of underwater senor nodes $S = \{s^1, s^2, ..., s^3\}$. The SS node is designed using the acoustic model to receive the acoustic information from the $US \in S$ via the neighboring relay sensor nodes. The SS node is deployed outside of the ocean and sensor nodes are deployed in the ocean. The data received at SS can be transmitted to a remote monitoring center called an application monitor via a radio communication channel. The core focus of the EORO protocol is on efficient data transmissions from any US to SS via an optimal relay selection strategy. As showing in figure 2, the red-colored US nodes transmitting the ocean data to SS via a routing path connected by different forwarding relays. The process to discover the routing paths has initiated by the US node in the underwater environment towards SS. The Thorp propagation model is utilized for the acoustic channel. The SS and relay nodes used these acoustic signals to transfer their data. The design of the proposed protocol has based on some assumptions such as:

- Underwater sensor node discovers its current depth with an embedded depth sensor [47]. It computes the perpendicular distance from the underwater sensor to SS.
- The residual energy of sensor node computed by distributed beaconing approach [48].
- The relative distance among the underwater sensor nodes computed by using the RSSI [49].
- The underwater sensor nodes perform the random movement in a horizontal direction because of water currents with negligible horizontal movements.
- All underwater sensors are resource-constrained with homogenous considering the transmission range and energy model [50-52].
- SS node is unconstrained and located at a fixed position.

B. Optimal Route Formation

As described above, UWSNs deployed with one sink called SS which collects the periodic underwater information from different US nodes. To discover the data transmission path from US nodes to SS, every US required the depth information of corresponding sensor nodes with the energy level. The SS node broadcasts the beacon packets to the underwater sensor nodes containing residual energy of sensor nodes and depth information. Based on this information, each US builds the routing path by selecting the optimal relay nodes for data transmission. However, selecting the optimal relay in UWSNs is a challenging research problem by considering the challenges like excessive energy consumption, packet collision, void communications, etc. In the EORO protocol, we formulate this problem as an optimal relay selection problem that subjects to minimize energy consumption, minimize communication delay, and maximum network throughput. To solve this problem, we designed an SI technique called EFF-based PSO for optimal relay selection and reliable route formation in the EORO. To satisfy all requirements of the proposed objective function, we applied PSO to solve this problem with objective function as:

$$f(r) = \max \sum_{i=1}^{n} EEF(i)$$
(1)

Subject to,

$$\max \sum_{i=1}^{n} REL(i), \tag{2}$$

$$\max\sum_{i=1}^{n} PTA(i), \tag{3}$$

$$\max\sum_{i=1}^{n} NCR(i),\tag{4}$$

$$\max \sum_{i=1}^{n} NDR(i), \tag{5}$$

Where f(r) is the selection of next forwarding relay r for current pair of US and SS by maximizing the EEF value subject to multiple constraints such as REL, PDA, NCR, and, NDR. The n represents the total number of nodes discovered in forwarding relay set. The PSO selects the optimal forwarding relay by considering the above problem definition. Figure 3 and algorithm 1 shows the functionality of the proposed SI-based optimal relay selection to form the routing path.



Figure 3. Efficient route formation using SI-based optimal relay selection

As showing the figure 3 and algorithm 1, any US first discovers its neighboring nodes using local information, and then among all neighboring nodes, we have to select the best relay node according to an objective function defined above. The EFF-PSO is applied to select optimal relay by evaluating all the neighboring nodes by satisfying the objective function. This process repeated until the SS node. The PSO iteratively evaluate the each particle in set of available particles that belongs to current forwarding relay set NR. At the beginning of PSO, the random particle selected as Gbest solution followed by evaluate it using proposed objective function f (Gbest). At each iteration, the each particle \in Particles is evaluated as Pbest solution. If the current objective function evaluation of Pbest is greater than Gbest, then the *Pbest* position assigned to *Gbest*. After that, position of particles updated along with its objective function values in routing tables for periodic analysis. This process repeated until the criteria of convergence met. In convergence, we set maximum number of iterations or no more particles left for evaluations. This criterion minimizes the computation burden as well as produces the fast solutions than existing conventional SI methods. This ensures not only the optimal relay selection but also the reliability of route formation. The algorithm 1 is responsible for returning the most reliable and stable route R^{US-SS} to begin data transmission from current *US* to the intended *SS* node.

Algorithm 1: Reliable Route Discovery		
Inputs		
US: Source node		
SS: Sink node		
Gen = 100, number of iterations		
j = 1: initialize the hop count parameter in route		
Outputs		
R ^{US-SS} : Path established from US to SS		
1. US broadcast message to discover neighboring relays		
2. Let $NR = \{r^1, r^2,, r^n\}, NR \in S$		
3. Initialize $particles = NR, NR \ge 2$		
4. Initialize $Gbest = random(NR)$		
5. $f(Gbest) = EFF(Gbest)$		
6. $G = 1$		
7. For each particle evaluate $Pbest \in particles$		
8. $f(Pbest) = EFF(Pbest)$		
9. If $((f(Pbest) > f(Gbest))$		
10. $Gbest = Pbest$		
11. Else		
12. Update <i>Pbest</i> value in its routing table entries		
13. End If		
14. Update particle position		

15. Check for convergence If $(G \ge Gen || All particles evaluated)$ 16. $R^{US-SS}(j) = R^{US-SS}(j) + Gbest$ 17. 18. Else 19. G + +, go to step 720. End If 21. End For 22. If (Gbest == SS)Return R^{US-SS} 23. 24. Else 25. i + +26. US = Gbest, go to step 127. End If

The core part of this algorithm is the objective function EEF () which is applied to evaluate each particle while selecting the optimal forwarding relay node. The f(r) for node r is computed using EEF (r) as:

$$f(r) = f1 \times REL(r) + f2 \times PTA(r) + f3 \times NCR(r) + f4 \times NDR(r)$$
(6)

Where, f1, f2, f3, and f4 represents the control parameters in range of 0 to 1 with f1 + f2 + f3 + f4 = 1. In EORO protocol, we set this parameters value as f1 > f2 && f2 > (f3, f4). This ensures the maximum network lifetime with minimum data loss in IoT-UWSNs. The *EEF* () computation depends on four parameters such as REL, PTA, NCR, and NDR computations.

REL: It is commonly used parameter to balance the energy consumption among the underwater sensor nodes and enhance the network lifetime. The node with higher residual energy is considered as the best candidate for forwarding relay. The REL(r) computes the remaining energy level of node r at time t as:

$$REL(r) = \frac{residual(r,t)}{initial(r)}$$
(7)

Where, *residual* (r, t) represents residual energy of node r at time t. *initial* (r) represents initial energy of node r. Node with higher *REL* (r) is reliable to become next forwarding relay in route.

PTA: This parameter used to maximize the network throughput and Packet Delivery Ratio (PDR). In this regards, node r forwards data packets any one randomly selected node . During this time, node r collects such ACK packets of node p to estimate the number of sensing packets. The *PTA* (r) in time interval t - 1 to t is computed as:

$$PTA(r) = \frac{receievedACK(t,t-1)}{generated(t,t-1)}$$
(8)

This parameter addresses the problems of void communications and packet collisions in network. Node with higher PTA(r) is reliable to become next forwarding relay in route.

NCR: The void communication problem mainly caused by the lack of sufficient connectivity to the forwarding relay nodes. The NCR parameter computed to prevent this problem by estimating the connectivity ratio of node r for optimal forwarding relay selection. The NCR (r) of node r at time t is computed as:

$$NCR(r) = 1 - \left(\frac{1}{NR(r)}\right) \tag{9}$$

Where NR(r) represents the number of neighbours discovered using RSSI communication range. Node with higher NCR(r) is reliable to become next forwarding relay in route.

NDR: For UWSNs, this parameter is received less attention, but it is also vital to maximize the network throughput by minimizing the transmission distance between the US to the intended SS. The depth information periodically shared by the SS node, which is used during this parameter to compute the oceanographic distance between node r to SS. The NDR (r) of node r at time t is computed as:

$$NDR(r) = 1 - \left(\frac{1}{depth(r,SS)}\right)$$
(10)

Where depth(r) represents the communication distance between node r to SS. Node with higher NDR (r) is reliable to become next forwarding relay in route.

C. Data Transmission

Once algorithm 1 returns the R^{US-SS} as optimal route to transmit data from intended US to the SS node, the US begins transmissions of underwater data through relays in selected path. The process of data transmission periodically monitors each relay node against the pre-defined threshold value 0.4 to ensure the network reliability by avoiding the node failure, packet collision, and void communications. Let set R^{US-SS} consists of $R^{US-SS} = \{US, R^1, R^2, ..., SS\}$. EORO checks k^{th} relay node R^k as below:

$$stat = EFF(R^k) > 0.4 \tag{11}$$

If stat is 1, then relay R^k is optimum and continue in use for current transmission. Otherwise if it is 0, then node R^k is critical and current route discarded and new route will be established using the algorithm 1. This process is applicable to all simultaneous communication pairs in IoT-UWSNs.

4. Simulation Results

The performance of the EORO protocol is analyzed in this section by considering the different network scenarios. The EORO protocol is implemented in the NS2 tool using the Aqua-sim underwater network simulator module. The EORO protocol performance compared with state-of-art similar methods such as BEAR [41], IEBA [43], and LEER [46]. We selected these methods for comparative analysis with EORO as they recently proposed optimal relay selection protocols for data transmission in UWSNs. The comparative analysis among BEAR, IEBA, LEER, and EORO protocol is presented by considering two different network scenarios such as network radius variations (table 1) and the number of underwater sensor nodes variations (table 2). Table 1 and 2 shows the details about simulation parameters used to design these networks. For each network using each protocol, we computed the four performance parameters such as average throughput, PDR, average energy consumption, and communication delay as per the formulas mentioned in [38]. The upcoming sections present the simulation results for each network scenario.

Underwater Sensor Nodes	80
Sink	1
Number of sources	5
Initial Energy	300 J
Frequency	20 kHz
Network Radius (R)	1-5 Km
Network 3D Area	$R \times R \times 1000m$
Horizontal movement	1 m/s

Table 1. List of simulation parameters for network radius variations

Table 2. List of simulation parameters for varying underwater sensor nodes

Underwater Sensor Nodes	80-160
Sink	1
	-
Number of sources	5
Initial Energy	300 J
Frequency	20 kHz
Network Radius (R)	1 Km
Network 3D Area	$R \times R \times 1000m$
Horizontal movement	1 m/s

A. Investigation of Varying Network Radius

This section presents the outcome of varying the network radius of UWSNs to verify the scalability and reliability of protocols investigated. Figures 4-7 demonstrate the outcome of average throughput, PDR, communication delay, and average energy consumption respectively. As observed in figure 4, the average throughput performance of all protocols compared with varying network radius. This result, first, shows the increasing network radius having a significant negative impact on network throughput performance. For EORO protocol the average throughput was 369 Kbps for a 1Km radius which has then reduced to 330 Kbps for a 5Km radius. This is because increasing routing operations to establish the routes using different algorithms with increasing network radius leads to transmission loss. The transmission loss then resulted in lower throughput and PDR (figure 5) performances. It can observe that the EORO protocol causes less throughput loss with increasing network radius compared to existing protocols. The EORO protocol able to maximize the network throughput compared to all existing protocols as network connectivity and distance parameters is computed for optimal relay selection along with residual energy and packet transmission ability. The throughput performance has improved by an average of 13 Kbps compared to the second-best protocol IEBR.



Figure 4. Comparative analysis of throughput with varying network radius

Figure 5 shows the outcome of PDR which is similar to average throughput performance. The increasing network radius results in increasing packet loss in the network due to transmission loss. The PDR of the EORO, the LEER, the DBR, and the IEBR protocol has analyzed in figure 5. Among all the protocols, EORO has higher PDR compared to other protocols as it discards the forwarding relay nodes that are below UB or at the same depth, which can avoid packet collision and void communication problems. Additionally, the forwarding relay has been selected in the

EORO according to the maximum PTA parameter that resulted in higher PDR. EORO protocol has improved the average PDR performance by 2.5 %.



Figure 5. Comparative analysis of PDR with varying network radius

The average communication delay performance using each protocol is showing in figure 6 according to increasing network radius. The communication delay has increased as the network radius increases because the increasing transmission loss with increasing network radius leads to increasing retransmissions in the network. The increasing retransmissions with increased network radius then increased communication delay as well. The average communication delay performance of the EORO protocol is lower than exiting protocols. As the source nodes focused on the selection of the best relay using EFF-PSO by considering four parameters, it reduces packet collisions and retransmissions compared to other protocols.

The average energy consumption performance is showing in figure 7 for each protocol according to network radius variations. The energy consumption parameter considers the total energy consumed for successful packet transmission that includes packet transmission consumption, the packet receiving consumption, packet forwarding consumption, etc. As demonstrated in figure 7, the EORO protocol consumes significantly less energy to deliver the packets from the intended US to SS. The EORO has been designed to minimize energy consumption with higher

network performance using novel fitness parameters. The route was established in EORO by considering the maximum connectivity, minimum distance, maximum energy level, and higher PDR. It prevents packet collisions, void communications, and hence retransmissions compared to existing protocols. Therefore, the EORO protocol achieved minimum energy consumption than other protocols.



Figure 6. Comparative analysis of communication delay with varying network radius



Figure 7. Comparative analysis of energy consumption with varying network radius

B. Investigation of Density Variations

This is the second scenario that varying numbers of underwater sensor nodes to investigate the scalability performance of protocols. The sensor nodes from 80 to 160 with other parameters the same as mentioned in table 2. Figures 8 demonstrate the average throughput of the EORO, the LEER, the BEAR, and the IEBR protocols according to the number of underwater sensor nodes. As the number of sensor nodes increased, the average throughput decreased. Because more sensor nodes lead to more computing time for relay selection and long routing path (in terms of hops) to transmit data from the intended source to the SS node. The EORO protocol achieved higher average throughput performance compared to all other protocols because of the consideration of trade-off parameters like energy, PTA, connectivity, and distance for optimal relay selection. The use of the SI method optimized the route establishment of EORO delivered the more reliable and stable paths for data transmission.



Figure 8. Comparative analysis of throughput with varying sensor nodes

The PDR performances according to the number of underwater sensor nodes observed in figure 9 using each protocol. The increasing number of nodes decreases the PDR performance because of the possibility of packet collisions and retransmissions. The EORO protocol utilized depth information and energy level appropriately along with maximum PTA and connectivity parameters while evaluating and selecting the best relay from the available sensor nodes. This results in packet loss reduction using EORO than the other existing protocols.



Figure 9. Comparative analysis of PDR with varying sensor nodes

Finally, figures 10 and 11 demonstrate the outcome of average communication delay and energy consumption. The communication delay has increased with increasing sensor nodes because long-hop routes were discovered for data transmissions with increased retransmissions. The EORO protocol shows a lower communication delay performance compared to the other protocols, because of the reduction of packet collision and retransmissions. The average energy consumption performance in figure 11 shows the contrast results compared to the average communication delay. The average energy consumption has reduced with an increased number of sensor nodes, because the more underwater sensor nodes may idle in the network. The average energy consumption of EORO has lower compared to all other protocols due to the prevention of packet collision and retransmissions.



Figure 10. Comparative analysis of communication delay with varying sensor nodes



Figure 11. Comparative analysis of consumed energy with varying sensor nodes

Table 3 shows the average performances of PDR and network lifetime for all four protocols. These performances have been computed considering both network scenarios. It shows that the EORO protocol enhanced the network lifetime by 15 rounds with 4.26 % PDR performance compared to recent techniques.

Table 3. Comparative analysis of network lifetime and PDR

Protocols	Network Lifetime (Rounds)	PDR (%)
LEER	2742	86.6
BEAR	2752	88.12
IEBR	2762	90.92
EORO	2777	95.18
Efficiency By	+15	+4.26

5. Conclusion and Future Works

This paper proposed the novel EORO protocol for IoT-authorized UWSNs intending to improve the energy-efficiency and route performance. The EORO protocol had designed to address the challenges like void communication, packet collision, the energy consumption of existing route establishment protocols. We formulate the problem of selecting the best forwarding relay subject to network lifetime enhancement, throughput maximization, and packet loss reduction. This optimization problem had solved by applying the PSO technique using EEF as the fitness function. Each particle of PSO had evaluated according to EEF value. The EEF had computed by considering the four parameters such as REL, PTA, NCR, and NDR to minimize the energy consumption, packet collisions, and retransmissions. Simulation results confirm that the EORO protocol improved the performances in terms of average throughput, average communication delay, PDR, and average energy consumption compared to recent routing solutions. For future work, we suggest applying other SI techniques for best relay selection and investigate their performances. Security provisions in EORO will be another interesting research direction.

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