Strata Adaptation-Based Energy Efficient Routing Protocol for Underwater Wireless Sensor Networks

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***Abstract*— Underwater wireless sensor network (UWSN) is a wireless system that distributes tiny sensors with constrained energy, memory, and bandwidth at varying water depths for a range of monitoring tasks, including acquiring data, environmental monitoring, and surveillance. This research tackles the issues of excessive energy consumption and end-to-end latency in UWSN transmission brought on by changes in the underwater environment's depth and turbidity. Current routing techniques, including the Neighboring-Based Energy-Efficient Routing Protocol (NBEER) for UWSN, strive to implement a routing protocol underwater to handle energy constraints, but fall short in addressing variables like dynamic depth and turbidity that negatively impact network performance as a whole. This led to the development of the strata adaptation-based energy efficient routing protocol (SABEERP) for UWSN. The SABEERP utilized a strata adaptation scheme for intra- and inter-cluster communication and a distributed underwater clustering scheme (DUCS) for cluster formation, the proposed SABEERP re-clusters the displaced nodes to the closest cluster head (CH) following changes in the underwater environment's depth or turbidity. SABEERP was simulated using MATLAB (R2023b). The simulation result shows that the SABEERP achieved 9.68 TEC, 46.42 E2ED, and 35191 NPR outperforming the NBEER with 12.60 TEC, 53.00 E2ED, and 22500 NPR respectively. These findings show significant enhancements in overall performance, energy efficiency, and network reliability.**

***Index Terms*— Depth, Energy, Sensor nodes, Sensor Network.**

I. INTRODUCTION

THE underwater wireless sensor network (UWSN) is a system of sensor nodes placed underwater for data collection and environmental monitoring that are outfitted with processing units, antennas, and non-rechargeable and replaceable batteries. Applications for UWSN include monitoring, disaster risk prediction, and exploration [1],[2].

The characteristics and capabilities of UWSN and terrestrial wireless sensor networks (TWSN) differ. To transmit and receive data between the source and the destination, TWSN uses radio frequency (RF) transmission. RF is not used for communication in underwater environments due to its attenuation. UWSN communicates by means of acoustic transmissions. In water, acoustic signals move at a speed of about 1500 m/s, that is five times slower than radio waves [3].

The changes in underwater turbidity and depth of affects the acoustic signals [4].

The limitations and challenges of UWSN include high ocean interference, low bandwidth, dynamic network architecture, high propagation latency, noise, and sensor nodes' limited battery life. Data can be transferred efficiently from the source to the destination using an efficient routing protocol [5],[6]. Energy efficiency is an important element that needs to be taken into account while designing routing protocols for UWSNs. Cluster formation strategies are one of the techniques that many researchers have looked at to reduce node energy consumption [7],[8]. Clustering techniques are frequently employed to address sensor node energy limitations and deployment challenges in both TWSN and UWSN. The clustering method groups sensor nodes into clusters, and in each cluster, a leading node known as a Cluster Head (CH) is selected to gather and transmit data [9],[10].

II. RELATED WORK

Several routing methods, including depth-controlled routing, cooperative energy-efficient routing, and adaptive circular spinning routing, have been developed to assure data

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transmission reliability and handle energy constraint in UWSNs. When routing packets from source to destination, these methods usually overlook environmental factors like water depth and turbidity fluctuations, which uses energy inefficiently and impairs network performance. The NBEER protocol was developed to address these issues. It divides sensor nodes into layers using a cooperative transmission technique and nearest neighbor scheme (NNS), then chooses NHNs based on high residual energy. This approach fared better in simulations than CEER and Co-UWSN, particularly in terms of end-to-end latency, packet delivery ratio, and energy consumption. Nevertheless, the NBEER procedure still ignores environmental elements, that decreases its overall efficiency. An Energy Balanced Efficient and Reliable Routing (EBER2) was proposed in [11]. The reliability and energy balancing among neighbors were accomplished by the EBER2 by taking into consideration the forwarder node's number of Potential Forwarding Nodes (PFNs) and residual energy, respectively. Through the division of the transmission range into power levels and adaptive modification of the forwarder's transmission power according to the neighbor list node that is farthest away, the protocol improved energy efficiency. However, the power level partition process may be impacted by the dynamic depth environment, which could impact its overall performance. Moreover, in [12], a delay-sensitive cooperative strategy for UWSNs that is cognizant of depth and dependability was presented. To reduce energy consumption and improve routing efficiency, the protocol used the depth and reliability-aware delay sensitive (DRADS) to determine the minimum number of hops between the source and the destination; interference-aware DRADS (iDRADS) to reduce interference by choosing a receiver node with a minimum number of neighbors; and cooperative iDRADS (CoiDRADS) routing protocols to reduce the number of retransmissions by taking into account the mechanism of relay cooperation. The protocol restricted the number of hops between the source and the destination while ensuring effective packet delivery by introducing a new metric called the depth threshold. Although Co-iDRADS used a static depth threshold, variations in turbidity and depth threshold may have an impact on its overall performance. Furthermore, an energy-efficient routing system algorithm for an underwater acoustic sensor network was proposed in [13]. The protocol used genetic algorithms (GA) to determine the optimal path to forward packets from source to destination; the path is encoded as chromosomes and the nodes as genes by the use of GA operators; each sensor node uses its location information to determine its position and potential forwarder node, resulting in increased routing efficiency. Nevertheless, the protocol is designed for a static underwater environment and is therefore vulnerable to changes in underwater turbidity.

A Genetic Algorithm-Based Energy-Efficient Routing Protocols for UWSNs (GAER-UWSN) was proposed in [14]. The protocol used a genetic algorithm (GA) to determine the best next hop from a group of neighboring nodes for routing the message to its destination. The method used multipath routing based on GA, and the fitness function of GA is based on the following five variables: distance, average energy, aggregation energy, residual energy, and total potential path. This improved network lifetime by allowing transmitting nodes to choose the best route for forwarding packets from source to destination, minimizing excessive energy consumption and end-to-end latency. However, GAER-UWSN's overall performance is impacted by its susceptibility to a dynamic underwater depth threshold during potential path determination. Furthermore, in order to optimize energy usage and establish cooperative routes, a cooperative energy efficient routing (CEER) mechanism for UWSNs was designed in [15] using clusters. In terms of end-to-end latency and total energy usage, CEER outperformed LEACH and Co-UWSN when MATLAB was used to model it. The CEER packet delivery ratio, however, was inadequate and has to be improved. The protocol for the marine underwater sensor network (MUSN) known as cooperative-relay neighboring-based energy-efficient routing (CR-NBEER) was presented in [16]. The CR-NBEER protocol, uses several relays between the NHN, is an improvement on NBEER. The relay nodes shortened the distance between NHNs that were in communication, which decreased the NHN's energy usage. The forwarding NHN and the sink nodes at the water's surface experience attenuation due to long-distance communication, which is addressed by the relay nodes. Consequently, network performance tends to improve. Although, the CR-NBEER operates in a static underwater environment, changes in underwater parameters like depth and turbidity affects its overall performance. To address these challenges, the SABEERP protocol is an enhanced energy-based efficient routing protocol that takes into consideration changes in water depth and turbidity was developed. The goal of the SABEERP protocol is to reduce high-energy consumption, increase network lifetime, and guarantee dependable data transfer from source to destination in an underwater environment with dynamic depth and turbidity.

III. METHODOLOGY

This section is structured into following parts: the first explains the design of a strata underwater environment, the second covers the development of a strata adaptation-based energy efficient routing protocol for UWSN, use a distributed underwater clustering scheme for cluster formation, and a strata adaptation scheme for data transmission considering underwater depth and turbidity variations, and the third part is the performance evaluation of the developed SABEERP.

A. Design of a strata underwater environment

At this point, the following specifications are used to design a strata underwater environment: The transmission range was set to 250 meters, the water turbidity was set to less than 10 nephelometric turbidity units (NTU), the normal water depth was set to 450 meters, and the network area was set to 550 meters by 450 meters by 350 meters. To replicate a dynamic underwater environment, the turbidity variation range was set between 1 and 15 NTU, the depth variation range was set between 1 and 500m, the channel frequency was set between 2.412GHz and 2.472GHz, and the transmission frequency was set between 10KHz and 50KHz.

B. Development of a Strata Adaptation based Energy efficient Routing Protocol for UWSN

The SABEERP protocol was developed during this stage. In underwater, 250 sensor nodes were arranged in ten clusters, with one Cluster Head Node (CHN) chosen for each cluster. The nodes were distributed at random. The CHN gets the nodes' current energy level, depth, and turbidity information. The CHN re-adjusts the displaced nodes to maintain communication with the neighboring cluster when the turbidity or depth of the sensor nodes changes. The lower-energy sensor nodes were placed on hold, the higher-energy sensor nodes sent the packets to the CHN. The CHN removes redundancy, the packets are sent to the nearest shallower depth CHN and to the next available sink node at the water's surface. The packets are subsequently sent to the base station offshore by the sink nodes. The CHNs is computed using eq. 1.

$$CH_{\text{prob}} = \frac{C_{\text{i}}}{C_{MAX}} \times C_{\text{prob}} \quad (1)$$

Where C_{i} represents the node's battery level, or residual energy, and C_{MAX} represents the maximum battery capacity. A tiny constant fraction known as C_{prob}, which is used to set the initial proportion of CH, limits the number of initial cluster-head announcements. It is necessary to increase the probability that certain nodes will choose to become CHs by keeping CH_{prob} from falling below a tiny probability, p_{min}, to guarantee the routing protocol will continue to operate even if sensor battery levels across the network are low.

One base station was located offshore, and ten sink nodes were placed on the water's surface to gather data from CHNs. CHNs retrieves the depth, distance, turbidity, and energy levels of each member node every 30 seconds. This information was used to organize clusters, and the closest accessible sink node to the forwarder nodes was taken into consideration while choosing the optimum path to forward packets to the destination. Data is aggregated and transmit to the base station by the selected sink node.

C. Performance Evaluation of the Developed SABEERP

The performance of the proposed SABEERP protocol was evaluated total energy consumption (TEC), end-to-end delay (E2ED), and number of packets received (NPR).

IV. RESULTS AND DISCUSSION

The simulation results of the suggested SABEERP are shown in this section along with a discussion. Graphical and chart representations are used to analyze each measure and compare the SABEERP protocol's performance to those of other protocols, such as CEER, Co-UWSN, and NBEER. The main goal is to assess these protocols using key metrics including NPR, E2ED, and TEC.

Fig. 1. shows the TEC results graphically. The developed SABEERP's overall energy usage of 9.86% is a notable improvement over the existing Co-UWSN, CEER, and NBEER, with respective values of 13.29, 13.15, and 12.60%. This is due to SABEERP's capacity to balance energy between the sensor nodes.

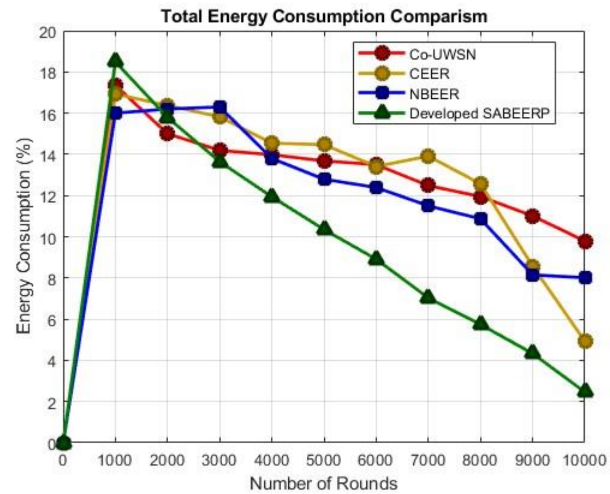

Fig. 1. Total Energy Consumption of SABEERP

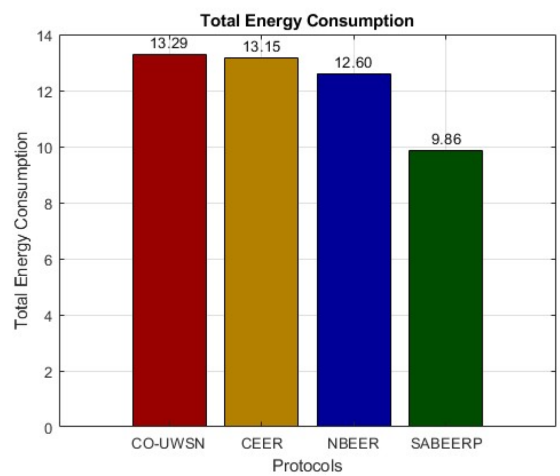

Fig. 2. Average Energy Consumption of all Protocols

The ability of the suggested SABEERP to efficiently handle intra and inter-cluster communication allowed it to achieve a high average of the number of packets received (NPR). This reduces collisions throughout the network by lowering the number of sensors actively participating in packet transmission at any given time. Fig. 3. illustrate that the developed SABEERP achieved 35191 NPR after 10000s simulation time, outperforming Co-UWSN, CEER and NBEER with 21000, 11171 and 25000.

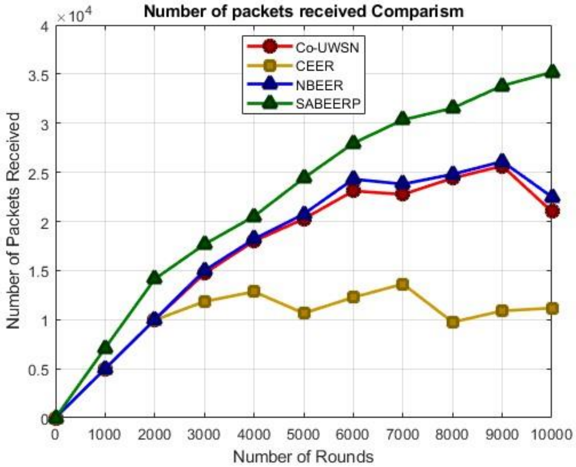

Fig. 3. Number of Packet Received of SABEERP

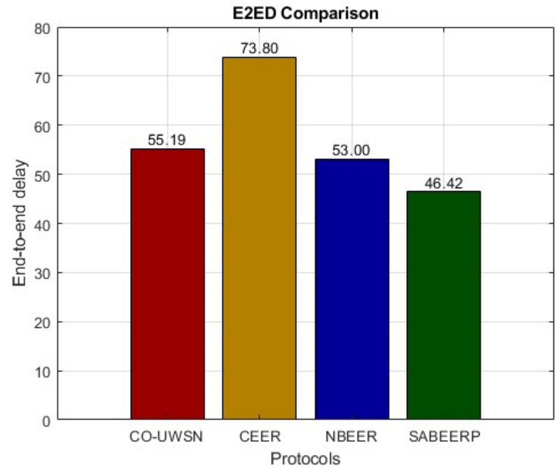

Fig. 6. Average End-to-End Delay of all Protocols

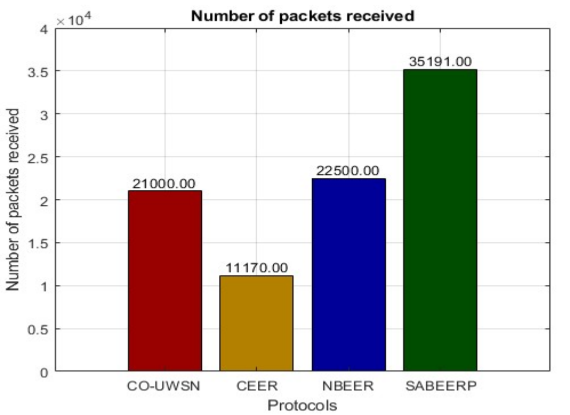

Fig. 4. Average NPR of all Protocols

Since the distance between the source and the destination changes as the depth of the underwater environment increases, the SABEERP was able to adapt to the dynamic depth and turbidity of the environment, resulting in a reduced end-to-end delay (E2ED). Fig. 5. shows the E2ED for the Co-UWSN, NBEER, CEER, and SABEERP, respectively.

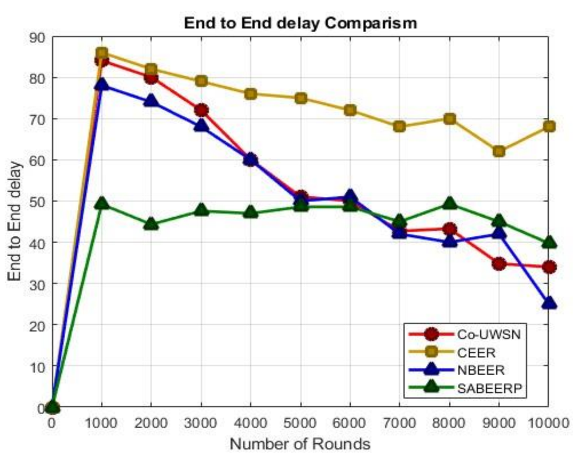

Fig. 5: End-to-End Delay of the Developed SABEERP

V. Conclusion

Underwater wireless sensor networks (UWSNs) are sensor networks positioned underwater to gather information from specific river or ocean regions for research purposes. UWSN consist of anchoring sensors throughout a field for exploration and deploying a variable number of sink nodes. The challenges of UWSN are end-to-end delay (E2ED), high-energy consumption, poor performance due to dynamic turbidity and depth threshold of underwater environment. To address these challenges, this work proposed a strata adaptation based energy efficient routing protocol (SABEERP) for UWSN. SABEERP will utilize distributed underwater clustering scheme (DUCS), and strata adaptation scheme to improve the routing efficiency of the UWSN. The developed SABEERP protocol achieved 9.86 TEC, 46.42 E2ED, and 35191.00 NPR outperforming the NBEER with 12.60 TEC, 53.00 E2ED, and 22500 NPR. Future work can consider introducing relay nodes between the clusters for an improved routing efficiency

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