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CR-NBEER: Cooperative-Relay Neighboring-Based Energy Efficient Routing Protocol for Marine Underwater Sensor Networks

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Abstract: This paper proposes a Cooperative-Relay Neighboring-Based Energy-Efficient Routing (CR-NBEER) protocol with advanced relay optimization for MUSN. The utilization of the relay nodes, among all other sensor nodes, makes it possible to achieve node-to-node deployment. The proposed method focuses only on cooperation and relay optimization schemes. Both schemes have previously been implemented, and thus the proposed method represents the extended version of the Neighboring-Based Energy-Efficient Routing (NBEER) protocol. Path loss, end-to-end delay, packet delivery ratio, and energy consumption parameters were considered as part of the performance evaluation. The average performance was revealed based on simulations, where the overall average EED of Co-UWSN was measured to be 35.5 ms, CEER was measured to be 26.7 ms, NBEER was measured to be 27.6 ms, and CR-NBEER was measured to be 19.3 ms. Similarly, the overall EC of Co-UWSN was measured to be 10.759 j, CEER was measured to be 8.694 j, NBEER was measured to be 8.309 j, and CR-NBEER was measured to be 7.644 j. The overall average PDR of Co-UWSN was calculated to be 79.227%, CEER was calculated to be 66.73.464%, NBEER was calculated to be 85.82%, and CR-NBEER was calculated to be 94.831%. The overall average PL of Co-UWSN was calculated at 137.5 dB, CEER was calculated at 230 dB, NBEER was calculated at 173.8 dB, and CR-NBEER was calculated at 79.9 dB. Based on the simulations and evaluations, it was observed that the cooperation and relay optimization scheme outperformed previous schemes.

Keywords: marine communication; cooperating routing; relay optimization; CR-NBEER; NBEER; CEER; Co-UWSN; autonomous underwater vehicles; underwater sensors; path loss

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1. Introduction

Marine Underwater Sensor Networks (MUSNs) present the possibility of communication underwater and on the water's surface [1]. Marine vehicles use this technology, known as the Underwater Wireless Sensor Network (UWSN) [2–5], for communication. The sensor nodes are deployed in and on the water's surface, forming a Wireless Sensor Network (WSN) in the water environment [6]. Over 70% of the surface of the earth is occupied by water, and communication is essential, especially in underwater environments, such those primarily used by marine vehicles [7]. There is no proper cabling, and there are no other centrally controlled internet facilities. Thus, marine vehicles use wireless communication with the help of ad hoc networks [8].

Cooperation is a scheme by which a network is enhanced and helped to improve its performance [9]. This scheme is based on relay optimization, in which different relay sensor nodes are deployed on the surface and in underwater environments [10]. Communication in water/underwater is different from in terrestrial areas; therefore, underwater communication uses acoustic channels to transfer data packets from one sensor node to another [11]. A limited frequency range is also used that is not able to effectively penetrate to a significant distance [12,13]. Therefore, relay optimization nodes are deployed, which are able to boost the transmission signal and shorten the distance among sensor nodes [14–20].

The proposed method is focused on marine communication and its utilization in ocean communications. Numerous Autonomous Underwater Vehicles (AUVs) have been deployed in underwater environments [21–23]. Numerous other sensor nodes have also been deployed as part of the underwater communication system, as shown in Figure 1. Multiple nodes are deployed in underwater communication, each with its own characteristics and features [24–27]. Pressure sensors, moving sensors, moving relay sensors, moving sink nodes, and AUVs are used in communication scenarios [28]. The ranges of nodes are increased underwater, creating massive problems for marine vehicles that are not able to effectively communicate and transfer data [29,30]. Relay and cooperation schemes can improve network performance and deliver data by means of advanced and fair mechanisms [31–34].

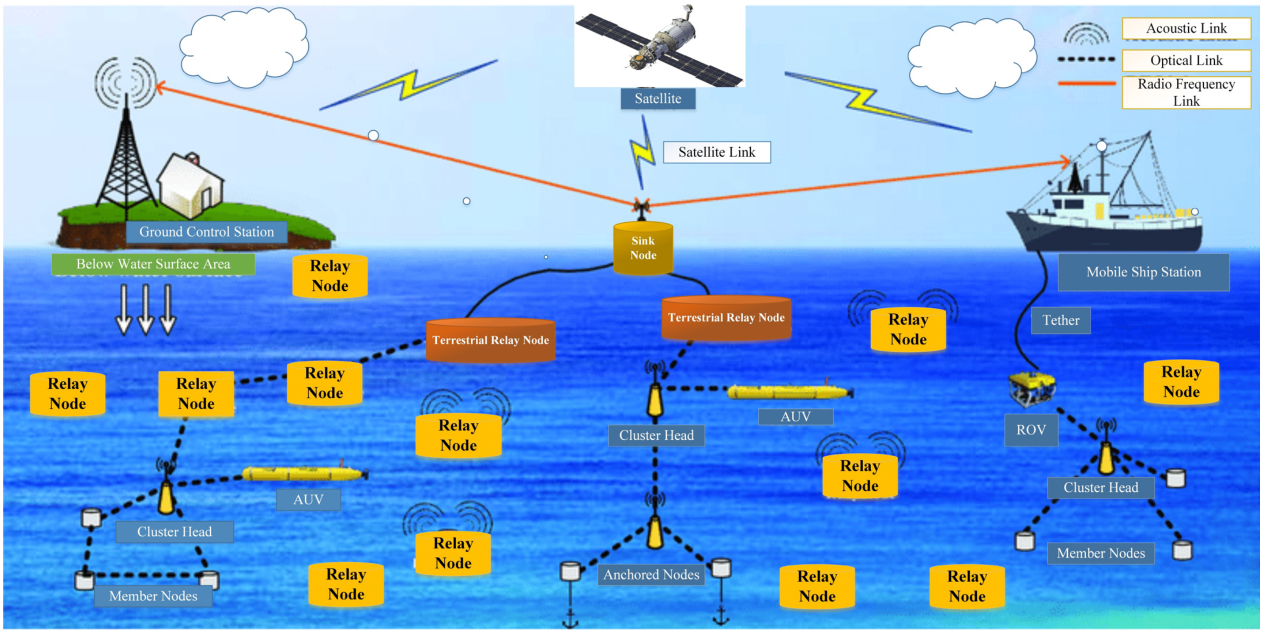

Figure 1. Illustration of cooperative relay-based scheme for MUSN.

Sensors are used in computing due to their easy installation and deployment. Different types of sensor are used, including underground sensors, terrestrial sensors, pressure sensors, etc. [35–37]. Another sensor type is the underwater sensor, which has the unique ability to communicate underwater using acoustic signals [38]. Marine vehicles use these sensors for communication in underwater environments, and this technology is referred to as Marine Underwater Sensor Networks (MUSNs) [39–47]. These networks are established by marine forces and other parties for whom the acquisition of information and knowledge regarding the sea and life in the sea is of interest [48–53]. These sensor nodes have a limited communication range, and are equipped with batteries with limited charge, thus limiting computation. Due to the high pressure and continuous resistance in the water, communication becomes difficult. Relay optimization and cooperation are processes that can boost and enhance underwater communication. Path and packet loss often occurs in this scenario, thus requiring a robust and reliable routing scheme.

To address the described issues and to avoid path and communication loss in marine communication systems, in this article, we propose a cooperation and relay optimization approach to boost the network performance. The proposed protocol will make it possible to transfer data across the minimum distance and to avoid any path loss occurring while using the marine communication system. The Marines devote their lives to the oceans, where they serve and are stationed, and it is essential to effectively implement a communication system that can deliver data with a high packet delivery ratio while achieving the lowest delays during transmission. The significant contributions of the proposed method are as follows:

- To thoroughly study the major routing protocols for marine communication and sensor networks.
- To identify the problems and issues that arise when using the existing methods.
- To propose a cooperating scheme for marine sensor networks named Cooperative-Relay Neighboring-Based Energy-Efficient Routing (CR-NBEER).
- To deploy the proposed relay optimization scheme and to balance the possibilities with the help of advanced relay sensor nodes, both underwater and terrestrial.
- To enhance the network performance by applying nearest neighbor node identification.
- To perform simulations and illustrate the results of the proposed method.
- To evaluate the proposed method with existing routing protocols for underwater communication: Cooperative Underwater Wireless Sensor Network (Co-UWSN), Cooperative Energy-Efficient Routing (CEER), and Neighboring-Based Energy-Efficient (NBEER).
- To determine the performance of the proposed method via an evaluation based on packet delivery ratio, path loss, end-to-end delay, and energy consumption.

This manuscript is organized in the manner described below. Section 1 introduces the proposed method, along with problem statements and critical contributions. Section 2 provides a detailed literature review. Section 3 presents the details of the proposed methodology and the mathematical implementation model. Section 4 presents an evaluation and discussion of the results. Finally, Section 5 presents the conclusion of the article.

2. Literature Review

Bharany et al. [5] presented a novel routing scheme for underwater communication. Further work was reported by Bosi et al. focusing on energy consumption [6]. Cao et al. [7] suggested ways of improving the quality-of-service optimization approaches in underwater communication systems for marine networks. In a study by Hu et al. [11], the sensor nodes were implemented to achieve this task. In the study by Kaidarova et al. [20], the authors focused on privacy and security in underwater communication systems. Kumar [29] proposed work focusing purely on sensor node communication, and used NS3 to perform simulations. The results revealed that their proposed scheme was able to cope with the conditions of the environment. Richard et al. [37] introduced an energy-efficient routing protocol for underwater marine network improvements. They used PDR, EED, PL, Jitter, Throughput, Alive and Dead Nodes, and Frequency of Probability as the core evaluation parameters [38–41].

Similarly, Shah et al. [42] proposed a novel nature-inspired routing protocol that takes the idea of ants and acts like them in order to deliver data from one source to another. This method focuses on beam technology, which has improved over time. The authors suggested that sensors can acquire a lot from nature by using an AI enabling approach, and can adapt accordingly. Shovon et al. [43] proposed a UWSN communication-based scheme targeting radio propagation and acoustic channels. The authors presented the idea of ocean-based communication incorporating a next-generation 5G network. This would allow satellites and other terrestrial networks to communicate.

Sreeraj et al. [44] implemented a secure and reliable communication scheme for marine communication. Their proposed method focused on link stability and link quality. The simulations revealed that improving the link quality and stability could ultimately improve the network by avoiding the occurrence of path loss during transmission. Subramani et al. [45] and Khan et al. [46] improved network performance by focusing on underwater acoustic channel communication. Vignesh et al. [47] targeted the acoustic and channel utilization in their proposed method. Neighboring-based approach have been applied, whereby the nearest nodes take part in underwater communication (Zaman et al. [50], Zhang et al. [51], Zhao et al. [52], Zhu et al. [53].

Different approaches have been introduced to enhance and improve the service quality, and achieve energy optimization, void hole avoidance, underwater localization, link stability, etc. In these cases, a number of authors have presented works aiming to solve or avoid the existing problems. Based on the previous works, the proposed method focuses on cooperation with relay optimization, with a further focus on energy optimization. Cooperation, relay optimization, energy optimization, energy consumption, neighbor node identification, and head node selection are the core research gaps addressed in the proposed method. Table 1 provides a tabular summary of the previous literature.

Table 1. Summary of the existing literature.

Ref.	Year	Techniques Utilized	Benefits	Limitations
[39]	2023	To decrease the distance, a distance-based evaluation scheme was utilized	Improved PDR and minimized EED	Due to the decreased network distance, overhead occurred in this work
[40]	2022	A protocol for multipath routing was utilized	Decreased Jitter, EED, and PL	Latency was still not minimized due to the network load
[41]	2022	A multichannel routing path for energy efficiency was established	Improved PDR and decreased EC	Energy consumption did not decrease
[42]	2022	Network performance was improved using a clustering approach	Improved network lifetime	The path loss increased due to not stable clusters
[43]	2023	Energy optimization was implemented	Minimized EED and maximized throughput	Lower integrity and reliability
[44]	2023	Improved quality of service optimization for marine sensor networks.	Increased PDR, decreased Jitter	Occurrence of overhead routing
[47]	2023	Network performance was improved using a clustering approach	Lower energy consumption	The PDR was ultimately decreased
[50]	2023	Focused on quality of service and security while maintaining privacy	Improved integrity, trust, reliability	Non repudiate occurred
[51,52]	2022	A cooperation scheme was introduced	Improved overall network performance	The latency increased due to the non-stable clustering approach
[53]	2023	A neighboring scheme was used to recognize the nearest possible sensor node for communication	Less energy consumption and minimal delay	No cooperation and relay scheme was applied

3. Methodology

In this section, the implementation and methodology of the proposed method are described. The proposed protocol introduces advanced cooperation and relay optimization. The CR-NBEER protocol represents an improved version of the NBEER protocol. In NBEER, there are no cooperation and relay optimization approaches. Only the Nearest Neighbor Scheme (NNS) and Neighbor Head Node (NNH) are applied in its core methodology. The network is divided into three steps, each representing the NNS process. Initially, cooperation and relay optimization occur, followed by the routing, energy consumption, and optimization phases.

The proposed scheme is graphically illustrated in Figure 2, which shows the implementation of the relay and cooperation optimization schemes. As shown in the figure, multiple relay nodes are installed underwater. It is clear that these relay nodes improve the network performance and decrease the distance among the nodes, resulting in less delay and less path loss. This scheme is able to preserve path loss in nature and improve the overall performance of marine communication systems. Acoustic, optical, and Radio Frequency (RF) links are significant aspects of communication.

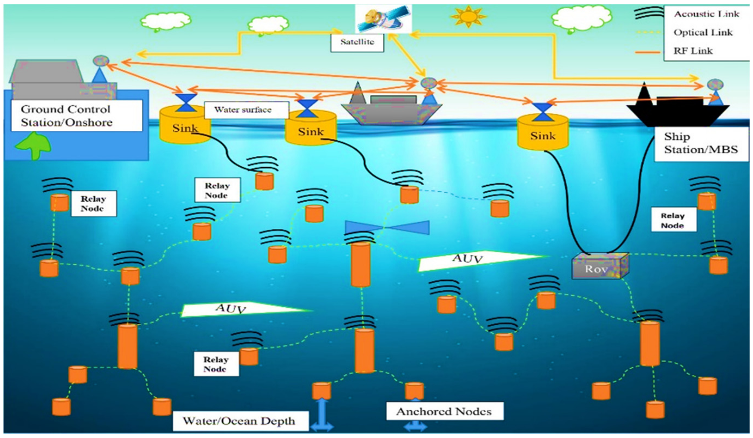

Figure 2. Schematic diagram of the proposed cooperative-relay optimization protocol.

The surface of the water and the underwater environment represent different communication scenarios; thus, each scenario uses different communication standards. The working procedure for the proposed protocol is illustrated in Figure 3. Each step and phase is implemented, from the first stage to the last stage, by moving further with simulation time and the passage stipulated by the methodology. A cooperation phase is implemented in the CR-NBEER methodology that begins at the beginning. The main reason for this is that the protocol focuses on cooperative routing, followed by a relay optimization phase, which represents the second main concern of the proposed protocol. The Residual Energy (RE) scheme has also been incorporated.

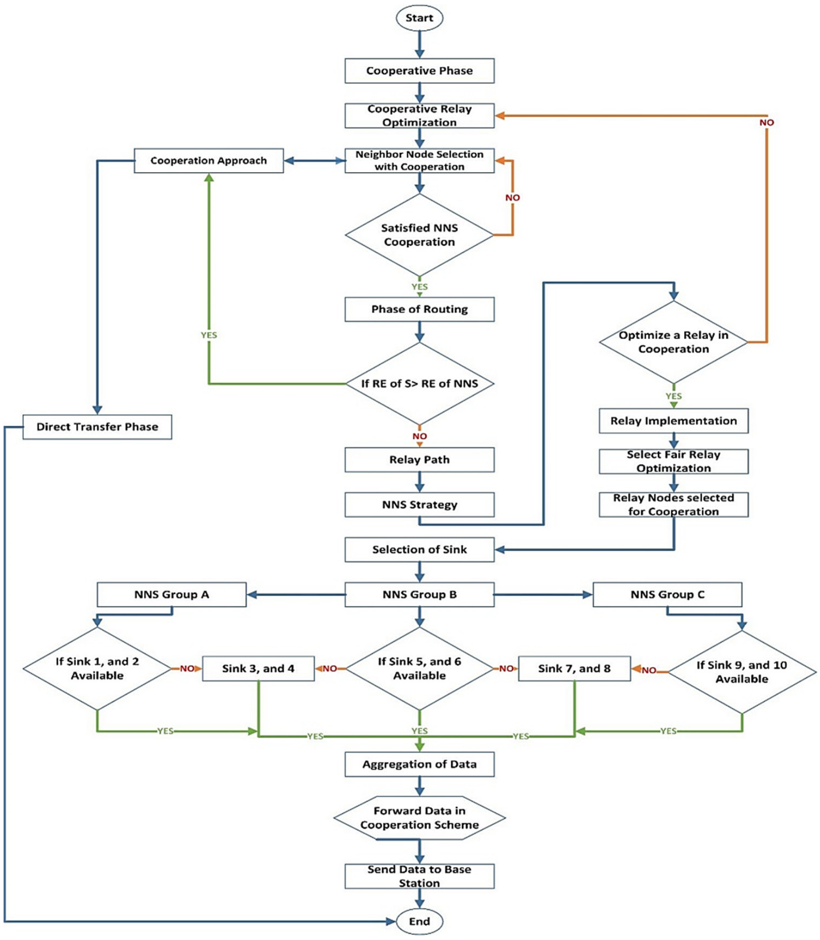

Figure 3. Functionality flowchart of the proposed CR-NBEER protocol.

The values used for the simulation and evaluation processes are given in Tables 2–6 respectively. Each table represents a different category of the data used and the simulation requirements. Four protocols are compared in total, with CR-NBEER being the proposed method, and NBEER, CEER, and Co-UWSN being existing approaches.

Table 2. Simulation setup and basic assumptions.

Parameter(s)	Value(s)
Total NNS Schemes Deployed	15
NHNS/Sink Nodes	15/10
Initial Energy Level of the Nodes	23 joules
Range of Transmission	200 m
Evaluation-Based Metrics	1. EED (ms) 2. EC (j) 3. PDR (%) 4. PL (dB)
Underwater Channel/Frequency Type	Acoustic Channels VLF radio waves (in the range of 3–30 kHz)
Terrestrial/Water Surface Channel Type	IEEE 802.11s
Frequency Range	2.411 GHz to 2.471 GHz
Number of Relay/Cooperation Nodes	50
Packet Size	512 kb

Table 3. Simulation assumptions and parameters.

Parameter(s)	Value(s)
Simulation Tools	Matrix Laboratory
Network Area	$500 \times 400 \times 300$ m
Nodes Deployments Number	300
NNS Schemes Deployed	15
Time of Simulation(s)	1000 s

Table 4. Parameters for node information.

Parameter(s)	Value(s)
Initial Node Energy (E)	232 joules
Range of Transmission	200 m
Relay and NNS Nodes	15/50

Table 5. Parameters for communication.

Parameter(s)	Value(s)
Range of Frequency (f)	The frequency range of the channel spans 2.411 GHz to 2.471 GHz.
Size of Packet(s)	512 kb

Table 6. Parameters for acoustic underwater communication.

Parameter(s)	Value(s)
Propagation Models of Acoustic	Ray Tracing Models/Bellhop
Profile of Sound's Speed	Custom/Empirical
Frequency of Transmission	3 kHz to 30 kHz
Path Loss/Transmission Power	161 dB R.E 1 μPa @ 1 m

The proposed CR-NBEER protocol was implemented using the MATLAB simulation environment. All of the relevant parameters were introduced, and the cooperation and relay optimization scheme was performed. Based on sink and relay mobility, the proposed approach focuses on cooperation and relay optimization. Now, the sink is able to gather all of the information sensed from underwater nodes, including relay nodes. We deployed 15 neighbor identification, 15 neighbor head node selection, and 50 relay optimization nodes. With the help of these nodes, significant contributions were achieved with the introduction of the CR-NBEER protocol. A 10-sink approach was implemented, as illustrated in Figure 2. The simulations were carried out, and the values of all relevant parameters obtained via the simulations are given in the tables below.

3.1. Implementation of Mathematical Model of CR-NBEER

The mathematical model that represents the overall execution and deployments of the proposed algorithm is the system model. In mathematical equations, each step is described with equations and notations. There are several steps involved in the design of the proposed CR-NBEER protocol.

3.1.1. System Configuration & Node Deployment (SC&ND)

In this phase, the system configures all the requirements for the simulations to be started from the right direction and to proceed further by taking each step with process and condition statements. Plus, node deployment also takes place in this phase.

3.1.2. Node Relay Phase (NRP)

The significant and critical phase of the CR-NBEER is in which the advanced relay optimization nodes are implemented and deployed.

3.1.3. Cooperation and Relay Optimization Phase

The cooperation and relay optimization approach has been implanted in the last stage to guarantee that data must be derived in the boost-up approach. The combined cooperation and relay scheme is given in Equation (1).

$$Cooperative\ Routing_{CR} = Ph1_{CR}1Ph2y_{RO}2 + Combined_{CO+RO}3 \tag{1}$$

CR denotes cooperative routing, *Ph* denotes phase, and *RO* denotes Relay optimization. Three phases are used in total with the summation of 1 + 2.

3.1.4. Neighbor Head Node Phase (NHNP)

The *NHHP* step takes place by using Equation (2), where the *NHN* (*Ri*) multiply the acknowledgments signals from *Si*, from the starting of transmissions to the destinations (*Di*), by a (gain) improvement factors $G + G$, is denoted by Equations (2) and (3) as:

$$NHNP\,1 - Y - rd = G(Y - sr) \tag{2}$$

$$NHNP\,2 - SNR\ = (|h_{SR}|_2 + \frac{1}{y_{AF}})^{-1} \tag{3}$$

whereas $y_o = p_{s/N_o}$ is the mutual SNR value of every link with no fading and is denoted by Equations (4) and (5) as:

$$Y - rd = G(Y - sr) \tag{4}$$

$$y_{RD} = h_{RD}Gy_{SR} + N_{RD} \tag{5}$$

The notations $h, n \in (S_D, S_R,\ R_D)$ represents the magnitude of channel fading.

3.1.5. System Integration Phase (SIP)

Equation (6) is applied with a three-step approach, cooperating with any disruption or lack of noise in the sensor communication.

$$SIP = y_{SD}1 + y_{RD}2 \tag{6}$$

3.1.6. Node Path Loss Phase (NPLP)

The nodes are embedded with functionalities to calculate the path loss in dB and transfer the data to the nearest possible node.

3.1.7. Node Cooperation Phase (NCP)

To cooperatively route the data from one sensor node to another, the NCP step can occur where normal nodes are deployed for cooperation.

3.1.8. Neighbor Node Identification Phase (NNIP)

To identify the nearest node and to calculate the Signal Noise Ratio (*SNR*), the Equations (7)–(9) are used respectively.

$$NNIP(1) + W_g = \frac{\min\,(PL_{SiRi},\ PL_{Ri,Di}) + \min((SNR_{Si,Ri}, SNR_{RiDi}))}{\max(R.E_{Ri}, R.E_{Di})} \tag{7}$$

$$NNIP(2)PL = 10nLog_{10}\ (d\ max - min) + c \tag{8}$$

$$NNIP(3) + SNR = \frac{P_{signal}}{P_{Power}},\ SNR_{db} = 10log_{10}(SNR(3)) \tag{9}$$

3.1.9. Node Energy Efficiency Phase (NEEP)

The *NEEP* representations have been given in Equation (10), which denotes the energy optimization approach. Here the four parameters are presented by *A*, *B*, *C*, and *D*, respectively.

$$NEEP = \left[\frac{1 - W(AMax) - B(Qa - Bs)}{CMax - DMin} - G\left(1 - \frac{I_{remaning}}{I_{maximum}}\right)\right]NEEP^0 \tag{10}$$

Equation (11) represents the overall cooperation and relay optimization ratio, where *k* denotes the values in the *n*th range.

$$CR + RO = \begin{pmatrix} CR_{12}^K, \ldots, CR1_n^K \\ CR + RO_{ab}^k \\ RO_{12}^K, \ldots, RO2_{n1}^K. \end{pmatrix} \tag{11}$$

3.1.10. Depth Optimization Phase (DOP)

Equations (12) and (13) represents the DOP in which the direct and relay path takes place with energy level measurements, denoted by the residual energy level.

$$DOP = E_{CR}(S_i > E_{re}\ (R_i)\ Then\ direct\ transfer \tag{12}$$

$$Else\ E_{RO}\ (S_i)\ \le\ E_{re}\ (R_i\ then\ relay\ (Co - RO))\ Path \tag{13}$$

4. Results Evaluation and Discussion

In this section, the simulation results are presented, analyzed, and discussed. Each parameter is discussed in detail, with reference to tabular and graphical representations. For the proposed CR-NBEER protocol, four evaluation parameters were taken for analysis and evaluation. All of these parameters were tested under diverse settings, and three existing protocols were considered for comparison. The results are portrayed in the following subsections. The end-to-end delay, energy consumption, packet delivery ratio, and path loss parameters were taken for evaluation purposes. Each protocol was compared the others based on the mentioned parameters.

To give each protocol a fair chance, all protocols started the simulation from the same point, corresponding to zero seconds in the simulation. Each protocol started its simulation at zero seconds, corresponding to the essential system initialization time. After that, each protocol followed its own method, and continued until the last second of the simulation time.

4.1. End-to-End Delay (EED) Analysis

Tabular and graphical representations of the EED results are presented in Table 7 and Figure 4, respectively. When a data packet takes more time than anticipated, a delay is declared to have occurred. The delay represents latency in the data packet when it travels from one sensor node to another. The simulations for EED were executed for 1000 s, divided into ten slices. Each slice represents 100 s. The data analysis was performed by focusing on each simulation cycle. The average values determined for EED are presented in Figure 5. It can be observed from the graphical illustrations that the proposed CR-NBEER protocol performed well compared to the existing Co-UWSN, CEER, and NBEER protocols.

Table 7. EED evaluation of all protocols with respect to simulation time.

Protocol(s) Name	EED at 0	EED at 100	EED at 200	EED at 300	EED at 400	EED at 500	EED at 600	EED at 700	EED at 800	EED at 900	EED at 1000
Co-UWSN	0	50	50	48	40	27	22	18	20	50	30
CEER	0	45	33	26	23	21	18	11	25	40	25
NBEER	0	50	33	34	40	20	15	18	16	20	30
CR-NBEER	**0**	**52**	**40**	**30**	**15**	**12**	**10**	**4**	**15**	**10**	**5**

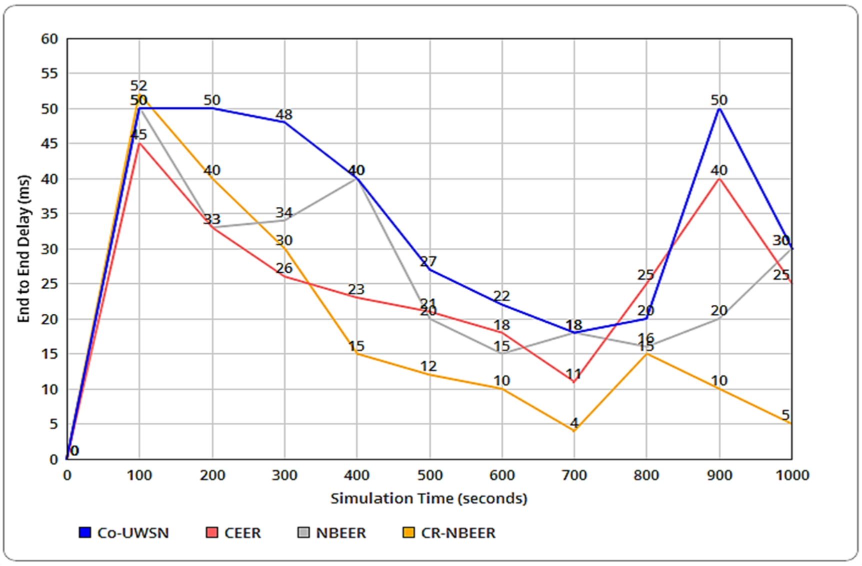

Figure 4. EED of existing and proposed methods vs. simulation time.

It can be seen that, over time, the values of EED decreased to below those of the other protocols. It is a crucial factor and focus that the proposed protocol should be able to decrease the EED as much as possible in order to improve network performance.

4.2. Energy Consumption (EC) Analysis

In sensor networks, energy consumption and energy efficiency are primary concerns. Because of the limited power of the tiny sensors used, energy is consumed rapidly. Meanwhile, in underwater settings, the water resistance and density can cause them to consume more energy than the nodes. Protocols that consume less energy can be regarded as energy-efficient protocols. Table 8 and Figure 6 represent the energy consumption of the Co-UWSN, CEER, NBEER, and CR-NBEER protocols. These four protocols were tested every 100 s during the simulation. The simulation was carried out for a total of 1000 s. It can be observed from the figure that, in every 100 simulation slice, the proposed CR-NBEER protocol achieved the best performance, consuming less energy than the other protocols. The primary and critical factor is the cooperation and relay optimization sensor nodes. These nodes are able to improve network performance by calculating efficient path routing. The average values determined for these protocols are illustrated in Figure 7, where it can be seen that the proposed protocol achieved the best performance.

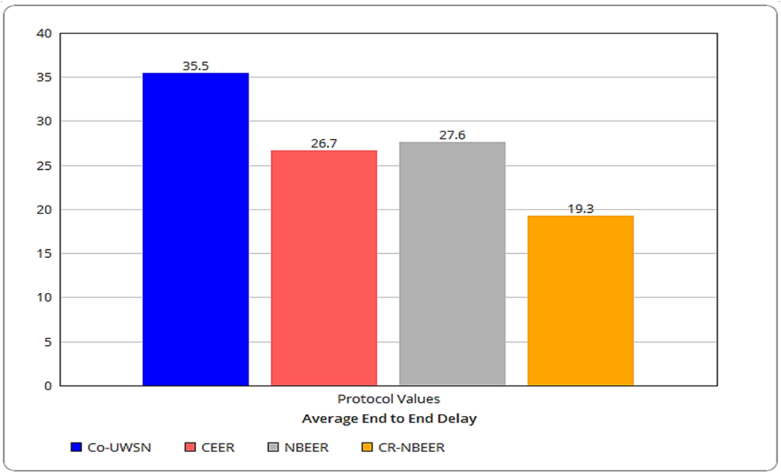

Figure 5. Average evaluation of end-to-end delay of all protocols.

Table 8. EC of all protocols with respect to simulation time.

Protocol(s) Name	EC at 0	EC at 100	EC at 200	EC at 300	EC at 400	EC at 500	EC at 600	EC at 700	EC at 800	EC at 900	EC at 1000
Co-UWSN	0	9.19	10.53	10.65	10.9	10.99	11.27	11.24	10.79	10.99	11.04
CEER	0	9.17	9.35	9.23	9.15	8.68	8.35	8.46	8.2	8.25	8.1
NBEER	0	8.63	8.08	8.58	8.08	8.75	8.08	8.41	8.06	8.38	8.04
CR-NBEER	**0**	**7.98**	**7.12**	**8.19**	**8.05**	**8.23**	**7.65**	**7.22**	**7.88**	**7.11**	**7.01**

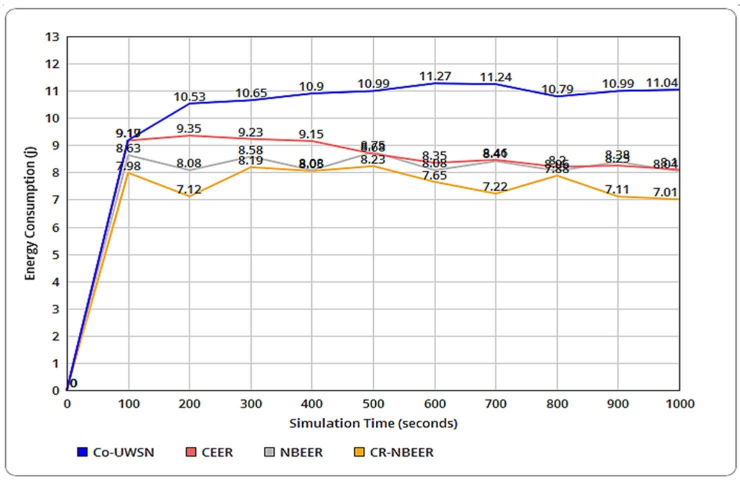

Figure 6. EC evaluation for all protocols vs. simulation time.

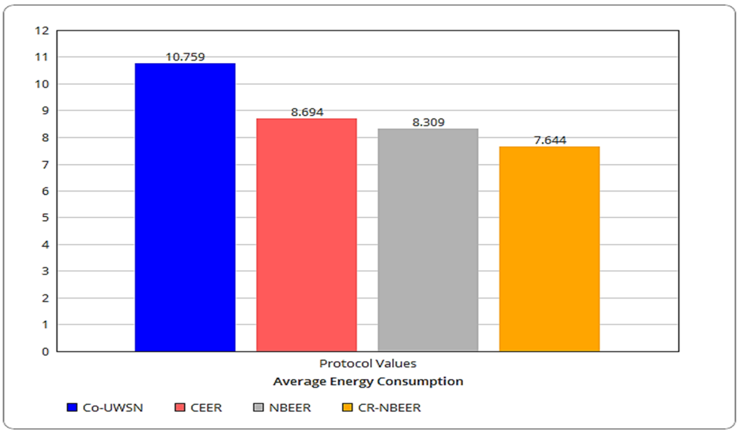

Figure 7. Average evaluations of EC of all protocols.

4.3. Packet Delivery Ratio (PDR) Analysis

The ratio of an entity can be measured as a percentage. In sensor networks, the PDR is the ratio of the number of packets successfully delivered to their destination to the total number of packets constituting the delivery, expressed as percentage. When the distance between the sensor nodes is increased, the ratio of PDR decreases, as these two parameters have a direct relation to each other, whereby an increase in one will result in a decrease in the other. This ultimately has an impact on the distance. In the proposed method, a cooperation and relay optimization approach was implemented, which is the crucial factor in proposed CR-NBEER protocol performing well in terms of PDR, as shown in Table 9 and Figure 8, respectively. On the other hand, in Figure 9, the overall average PDR determined for the proposed method is compared to those of existing methods. It was found, and can be observed from the figure, that the proposed protocol was able to achieve the best PDR due to having the smallest distance among sensor nodes.

Table 9. PDR evaluation of all protocols with respect to simulation time.

Protocol(s) Name	PDR at 0	PDR at 100	PDR at 200	PDR at 300	PDR at 400	PDR at 500	PDR at 600	PDR at 700	PDR at 800	PDR at 900	PDR at 1000
Co-UWSN	0	96.39	93.01	88.47	86.09	80.04	78.87	78.57	67.37	62.84	60.62
CEER	0	93.57	91.77	86.13	77.38	75.46	72.73	68.84	59.08	55.8	53.88
NBEER	0	99.32	95.27	93.28	90.09	89.78	86.88	82.09	76.19	74.4	70.9
CR-NBEER	**0**	**99.9**	**97.24**	**95.69**	**94.99**	**99.65**	**95.57**	**90.1**	**90.02**	**93.58**	**91.57**

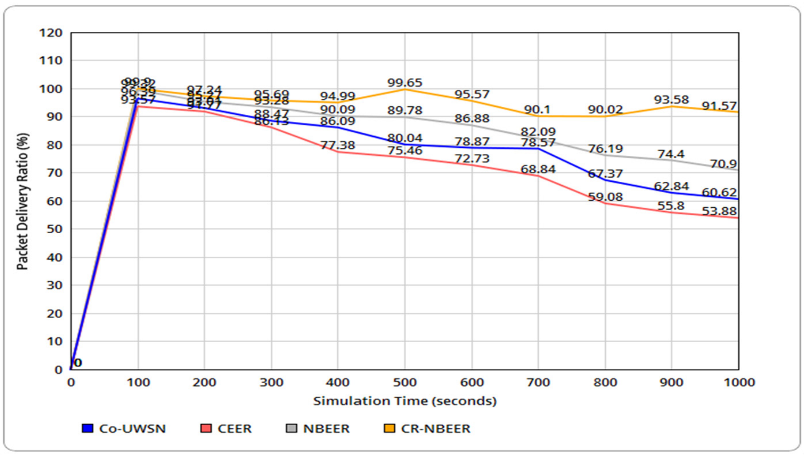

Figure 8. PDR of all protocols vs. simulation time.

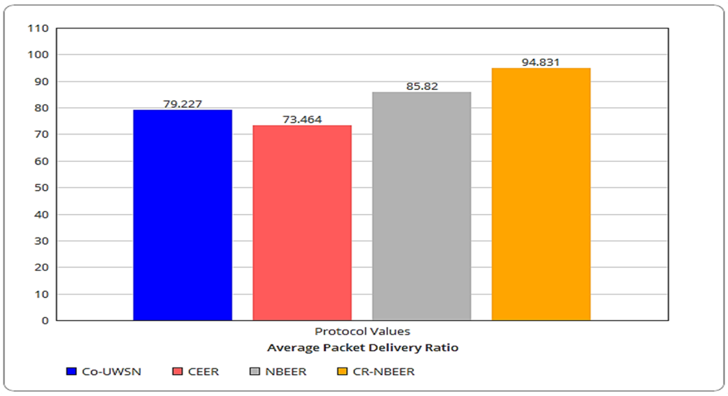

Figure 9. Average PDR evaluations of all four protocols.

4.4. Path Loss (PL) Analysis

When discontinuities occur in communication, and the sensor nodes are no longer in communication, the results include a vast path loss, the signal not being able to be delivered from the source to the destination, and so on. The cooperation and relay optimization scheme can work in such situations in order to avoid path loss or communication disruption. The relay nodes can move from one side to another in order to fill the gaps in which the nodes become dull and are not able to communicate further. Figure 10 and Table 10 illustrate the PL evaluations of the Co-UWSN, CEER, NBEER, and CR-NBEER protocols in terms of a total simulation time of 1000 s. From the given illustrations, it can be concluded that, due to the cooperation and relay optimization, the proposed CR-NBEER protocol has a lower path loss value in dB than the other routing protocols (Co-UWSN, CEER, and NBEER). The critical factors are cooperative routing and advancements in relay optimization. On the other hand, in Figure 11, the total average evaluations of the four routing protocols are depicted, and it can be seen that the proposed protocol achieved better performance than the other three.

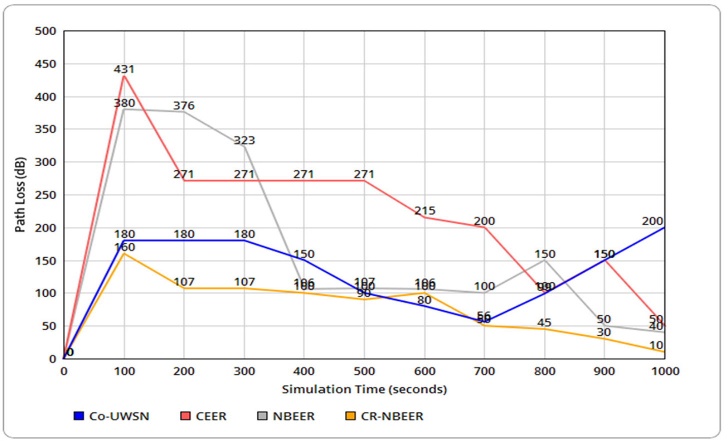

Figure 10. Evaluation of the path loss (dB) vs. simulation time (seconds).

From the overall illustrations and representations, and their discussion, it can be concluded that the sensor relay nodes operating in a cooperative manner have the best performance in terms of boosting the network function. The proposed CR-NBEER protocol achieved the best results in all considered scenarios. Due to advancements in the relay optimization schemes, the proposed protocol positively impacts the considered settings. Representations in graphical and tabular form are given in Table 11 and Figure 12, respectively. The overall average EED of Co-UWSN was measured to be 35.5 ms, CEER was 26.7 ms, and NBEER was measured to be 27.6 ms, whereas CR-NBEER was measured to be 19.3 ms. Likewise, the overall EC of Co-UWSN was measured to be 10.759 j, CEER was measured to be 8.694 j, and NBEER was measured to be 8.309 j, whereas CR-NBEER was measured to be 7.644 j. The overall average PDR of Co-UWSN was calculated at 79.227%, CEER at 66.73.464%, and NBEER was calculated at 85.82%, whereas CR-NBEER was calculated at 94.831%. The overall average PL of Co-UWSN was calculated at 137.5 dB, CEER at 230 dB, and NBEER at 173.8 dB, whereas CR-NBEER was calculated at 79.9 dB.

Table 10. PL comparison of all protocols with respect to simulation time.

Protocol(s) Name	PL at 0	PL at 100	PL at 200	PL at 300	PL at 400	PL at 500	PL at 600 s	PL at 700	PL at 800	PL at 900	PL at 1000
Co-UWSN	0	180	180	180	150	100	80	56	99	150	200
CEER	0	431	271	271	271	271	215	200	100	150	50
NBEER	0	380	376	323	106	107	106	100	150	50	40
CR-NBEER	**0**	**160**	**107**	**107**	**100**	**90**	**100**	**50**	**45**	**30**	**10**

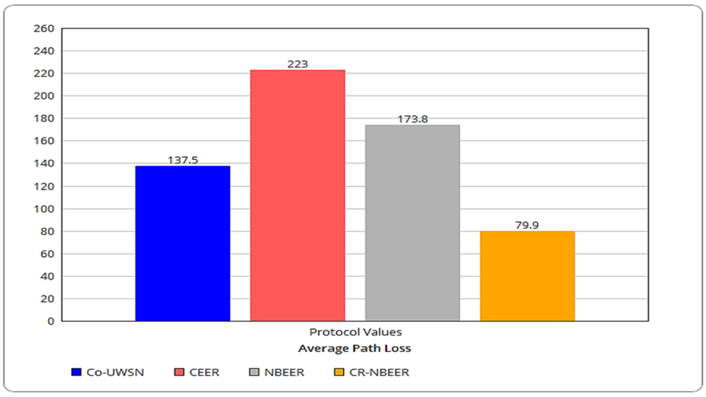

Figure 11. Average path loss evaluations for all protocols.

Table 11. Average evaluations of each protocol with respect to each parameter.

Protocol(s) Name	Average EED	Average EC	Average PDR	Average PL
Co-UWSN	35.5	10.759	79.227	137.5
CEER	26.7	8.694	73.464	230.0
NBEER	27.6	8.309	85.82	173.8
CR-NBEER *(Proposed)*	19.3	7.644	94.831	79.9

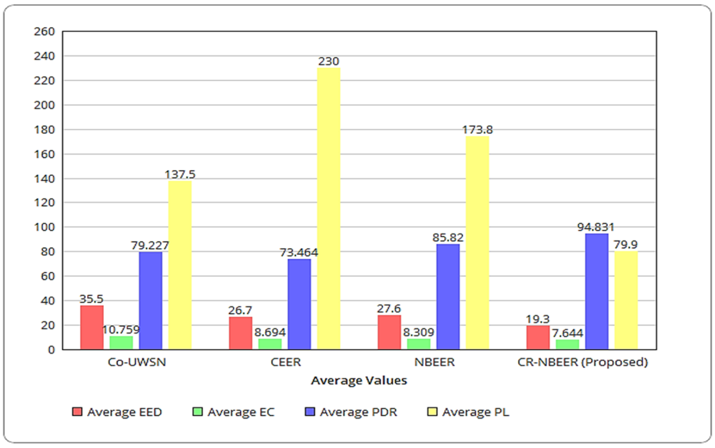

Figure 12. Average evaluations of each protocol with respect to each parameter.

5. Conclusions

Marine vehicles use ad hoc network technology, and sensor networks have been implemented both on the surface of the water and in underwater environments. These networks can suffer from energy consumption, path loss, delay, etc. Introducing a cooperation and relay optimization scheme can avoid such problems and deliver an energy-efficient, path-loss-aware routing approach. In this article, a path loss avoidance scheme was proposed, focusing on energy consumption. For use in such cases, the cooperation and relay optimization scheme was introduced. The proposed CR-NBEER protocol was tested under different simulation settings. Additionally, the performance of the protocol was evaluated in comparison with the existing Co-UWSN, CEER, and NBEER approaches for routing in the MUSN. The simulation were carried out in MATLAB, where the performance of the proposed method was evaluated in comparison with existing approaches. Four performance evaluation parameters, EED, PDR, EC, and PL, were considered. From the results and discussion, it was found that the proposed CR-NBEER protocol performed well due to the advanced relay optimization with fair possibilities in the network. The proposed protocol was demonstrated to be efficient for use in future marine communication systems in which the ad hoc network is composed of sensor nodes.

The proposed method was developed in consideration of the following points.

- The proposed method was focused on the cooperation scheme. Furthermore, a relay optimization scheme was developed.
- In terms of effective operation, the proposed CR-NBEER protocol achieved better results and performance than the previous protocols.
- The neighbor node identification approach was implemented.
- The presented protocol was tested while employing different simulation parameters.
- The results and evaluations show that the proposed method had a dramatic impact on cooperation and relay optimization with respect to energy consumption.

The marine sensor network is still in its infancy, and requires robust and efficient routing and other localization and relay approaches. However, the proposed method can effectively be deployed for marine communications. The work performed in this article will have a dramatic impact on sensor network performance in underwater regions. This could be further improved by effectively implementing quality-of-service, energy, void hole avoidance, node scalability, geographic scalability, and localization approaches.

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