IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received 21 September 2023, accepted 13 October 2023, date of publication 17 October 2023, date of current version 26 October 2023.

Digital Object Identifier 10.1109/ACCESS.2023.3325311

RESEARCH ARTICLE

Reliable and Delay Aware Routing Protocol for Underwater Wireless Sensor Networks

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The authors acknowledge the Researchers Supporting Project number (RSP2023R34), King Saud University, Riyadh, Saudi Arabia.

ABSTRACT The reliability of Underwater Wireless Sensor Networks (UWSNs) is measured in terms of energy consumption (EC), end-to-end delay(E2E), and packet delivery ratio (PDR). The adverse effects of a channel may cause data loss. Reducing delay up to the possible extent improves the reliability of the network, also increasing the number of nodes in a particular network increases reliability. Besides, increasing the number of nodes improves reliability but also increases power consumption. In order to overcome these shortcomings, the two routing protocols are proposed in this paper, namely the Delay and Reliability Aware Routing (DRAR) protocol and the Cooperative Delay and Reliability Aware Routing (Co-DRAR) protocol for UWSNs. In the DRAR protocol, the network is divided into two equal regions where two sink nodes(SNs) are positioned at the upper region of the network and two SNs are placed at the mid-region of the network. The protocol chooses the relay node based on residual energy (RE), distance, and Bit Error Rate (BER). These parameters protect the data packets from corruption and also provide a stable path (where nodes remain active for longer periods and do not die quickly). The protocol uses a single link and may get worse sometimes while changing channel circumstances. To address this problem, a cooperative routing scheme is added to the DRAR protocol in order to develop its enhanced version known as the Co-DRAR protocol. The protocol works by allowing the destination to receive multiple copies of data packets in order to decide the quality of packets. The proposed protocols DRAR and Co-DRAR perform routing irrespective of the geographical position of sensor nodes conversely to some conventional routing protocols. This is why our proposed protocols perform better than the well-known protocol i.e. Depth base routing (DBR) in terms of EC, E2E, PDR, dead nodes, packet drop ratio, and number of alive nodes.

INDEX TERMS DRAR, Co-DRAR, relay nodes, cooperation, energy efficiency, routing protocol.

I. INTRODUCTION

Researchers and businesses alike have begun to take an interest in underwater wireless sensor networks (UWSN) because of their potential as a burgeoning sector. Seventy percent of Earth's surface is made up of water in the form of seas, oceans, and rivers, all of which can potentially be explored [1]. The UWSN is of great importance in monitoring, disaster prevention, tactical surveillance, environmental monitoring, and ocean sampling [2]. However, replacing the battery and swapping out the node of a UWSN is a challenging task in a marine setting. The battery life of UWSN is therefore restricted [3]. Moreover, the acoustic channel has low bandwidth and long propagation delay [4].

The associate editor coordinating the review of this manuscript and approving it for publication was Fang Yang.

In turn, the aquatic signal suffers from path loss, reflection, refraction, multi-path fading, and aquatic noise [5].

E2E reduction is a critical design parameter in UWSNs since it enhances system dependability [6], [7]. Due to channel behavior, the reliability of the UWSNs decreases which in turn decreases the PDR of the network [8]. Due to the higher packet overhead in a crowded network, dependability suffers and error rates rise. Three routing techniques were described by Nadeem et al. that use delay minimization as a cost function by adjusting either the depth threshold the lowest depth or the holding duration. While the proposed protocols were successful in reducing latency, they did not boost the network's throughput [9].

The authors developed a cooperative approach, in which the cost function is determined using depth and RE. The protocol, however, causes a significant amount of latency while forwarding data to the target destination node [10]. In turn, Nasir et.al introduced a cooperative routing system in which the forwarder node is picked based on the lowest depth. Higher latency is introduced by the protocol [11]. In the literature, many researchers presented cooperative-based algorithms [12], [13], [14], [15], [16]. They attempted to improve the reliability of UWSNs [11], [17], [18]. However, they compromise stability, network longevity, and energy. Because cooperative algorithms' network architecture model is poorly constructed, stability is further reduced. These algorithms also struggled with synchronizing time and data. Most data is transferred between the nodes closest to the sink. This volume of traffic results in problems including data collision, higher energy costs, and increased time consumption. Due to the node's proximity to the sink node, there was a significant volume of data transmission.

In order to overcome these shortcomings and difficulties, We proposed two carefully designed routing protocols for UWSNs. The first protocol is termed DRAR, in which a network is divided into two equal regions to reduce delay. We deploy two SNs for the upper and two for the lower region i.e. an upper region of the network. The sink node(SN) in both regions of the network is free of the geographical position of sensor nodes. When data is transmitted through a single link, the reliability of the network may be disturbed whenever the link is influenced by a noisy channel. Therefore, cooperation is one of the optimal solutions to set up a reliable operation. In order to ensure reliable operation, a cooperative routing protocol is added to the DRAR protocol known as the Co-DRAR protocol. In the case of Co-DRAR, the sensor nodes in both regions of the network send their data packets directly toward SN. Whenever SN is not available in the range of transmission of the source node, information is sent to the SN through a single relay node. Similarly, in each region, sensor nodes having the shortest distance with regard to SN is taken as destination node (DesN). An SN lying in the lower region of the network forwards their information to an SN situated in the upper region of the network. Consequently, data are forwarded to the destination. The motivation of the proposed Protocol is that: the UWSNs adopt Ad hoc network therefore, it is important to define a protocol that performs routing on the basis of energy efficiency, end-to-end delay, throughput, and ability to sustain a network alive. Dividing the network into sections made the network efficient and reliable.

This paper contributes in the following ways;

- In the *DRAR* protocol, the best DesN is selected using the parameters of *RE*, distance, and *BER*. In this protocol, the source node selects one destination from the set of neighbor nodes. The protocol consumes less energy, increasing the sensors' battery life.
- Since the network is divided into two regions i.e. upper and lower regions and deployed sub-sink nodes in both regions, which reduces the physical distance for each sensor node. As a result, end-2-end is reduced.
- On the other hand, the Co-DRAR protocol considers a single relay. Here relay and destination nodes (DesNs) are selected using the parameters of maximum RE, shortest distance, and low BER. Those nodes which obtained efficient values of these parameters are considered relay nodes. They further forward the data packets to the final destination. The procedure for relay node selection and DesN selection are the same. PDR of the data packet is improved due to the shortest distance and low BER value.
- By deploying the relay node in the network, we increase the probability of *PDR* and reduce total energy consumption.

The paper is categorized in such a way. Related work is introduced in Section II. In Section III, we introduce our proposed algorithm. Simulation results are introduced in section IV. We conclude the work in section V.

II. RELATED WORK

In this section, we review some of the corporation-based protocols and non-corporation-based protocols. Anwar et.al presented direct and relay forwarding techniques to carry a packet from the source node toward DesN. The protocol selects the relay node having a minimum distance between a source node and DesN. However, fewer neighbor nodes ensure the selection of the best relay node. The protocol divides the network into three zones i.e., source, relay, and destination zones. The protocol ensures energy efficiency by nominating the best route selection. There are two ways to select the best route through which data packets are sent from source to destination. The first way is to choose the best relay in the entire relay region. In the second way, the packet is delivered through the relay node if the relay node is not found, then a direct path is chosen to send packets towards the destination. A maximum number of packets is reached in the protocol compared to DBR. Less energy is consumed in this scheme. The drawback of the protocol is that the delay increases due to a single sink [19].

Junaid et.al improved the work presented in [19] by considering low depth along with channel noise for routing criteria.

Higher energy is assigned to those sensor nodes that have depth levels less than 150 meters. This scheme aims to avoid high noise intensity at the receiver end. Consequently, those sensor nodes that lie near the surface sink have high transmission potential and do not die soon. Information on dimensional locations is also not required. The protocol improves in terms of PDR EN network lifetime, however, the protocol introduces higher latency [20].

Moreover, Anwar et.al chooses the best relay node based on the lowest depth and a minimum number of neighbors. The two routing parameters like lowest depth and minimum number of neighbors ensure that data is transmitted to the final destination with minimum interference on its path. The network is free of dimensional location information of nodes. Similarly, the total depth of the network is split into different parts to differentiate between the relay, neighbor, and source node. The interference of the path is reduced whenever selecting a forwarder node that has less number of neighbors. The merit of this protocol is that it has low latency and high energy efficiency. However, the nodes lying close to the surface expire fast as a result of the constant selection of the shortest path [21].

Chao et.al chooses the distance-varied probability of collision along with each node's RE. The technique selects the path that can have more data flow and high RE. The parameter used for route selection depends on the distance covered between the sender node and the destination. Similarly, the residual power of every node in the network is used for route selection. It is important to know that among all UWSNs, DRP is the first routing protocol that uses transmission collision probability in finding the best path selection. In this scheme, it is proved via theoretical analysis that a long network lifetime is achieved. The SN broadcasts the hello packet repeatedly in DRP. DRP has a long network lifetime, low latency, and increased network throughput [22].

Renfei et.al Presented fuzzy logic vector base forwarding (FVBF), during the selection of the forwarder node, the position information of the sensor node does not fulfill the condition to choose the best forwarder node. The reason is that the underwater environment is harsh and nodes move from one position to another position which causes a reduction in battery power. Position Information and energy information both are important FVBF. Moreover, the real distance towards SN, battery level of all nodes, and projection are taken into account in the fuzzy logic system. The proper distance in protocol observes the actual length between the source and SN. The technique achieves high throughput and efficient delay, however, forwarder nodes die quickly because the extra burden of data utilizes the power as they are continuously nominated for forwarding of data packets [23].

Isofi et.al Presented an advanced flooding-based routing protocol to improve the performance and energy efficiency of a network. Two ideas are employed in the protocol. The first idea involves information about the node position to reduce the number of relay nodes that implement overflooding. The second idea consists of a network coding-based protocol which is used for duplicate packet transmission. The advantage of the protocol is high throughput and EC. However, the demerit of the protocol is its high latency [24].

Anwar et.al, consider the lowest depth and lowest location of sensor nodes in order to select the DesN. The extraction of information from the received packet is difficult if BER and signal-to-noise ratio (SNR) do not lie in the range of acceptable threshold. In this technique, cooperative routing protects the channel from the attack of unfavorable links. This ensures the reliable transmission of data packets toward the water surface. The beacon signal is continuously sent to individual nodes in the network which further uses information to find its location. The location value in the network calculates the distance nodes situated from the SN. Similarly, the relay nodes forward the information packets to the final destination on the spot when the relay node receives it. The relay node is selected in a network on the basis of a node near DesN. In the protocol, the ratio of packet drop and packet received is improved while it introduces high latency and high EC [17].

Sahar et.al presented two routing protocols that select DesN on the basis of its optimal RE, number of hops, and BER of the channel through which nodes are forwarded. The first protocol is based upon the cooperative while the second one is based upon the non-cooperative scheme. The node will be set as DesN which has high RE, least number of hops, and low BER. However, in the case of cooperative protocol, destination, and relay nodes are chosen using the same parameters as used by non-cooperative protocol. In cooperative protocol, only one relay node is selected, unlike other protocols. Those nodes are used to forward important messages that have high RE, less number of hops, and low BER. The protocol has high PDR, high RE, and optimal EC, while the protocol depicts high latency [25].

Furthermore in order to reduce the span of routing, Nadeem et.al split the network area into three specific regions. Next, every region is split into three more sub-regions of low medium, and high depth. When a neighbor is identified a route is created between source and DesN, which is further used in selecting the relay node. Depth, RE, and SNR are the parameters used for the selection of the relay node. BER is calculated at the destination end through which positive or negative acknowledgment is received by both source and relay nodes. Four mobile SNs are deployed randomly in the whole network. In this scheme, mobile sinks (MSs) are used instead of stationary sinks. The purpose of MSs in the network is to control the packet drop rate. To protect the network from flooding, the depth threshold is fixed. The protocol sets a threshold level for the desired level in the network. Also, nodes that are situated above the threshold level are set to be relay nodes, while the nodes that are outside the threshold are set to be DesNs. The DesNs send data to the surface through multi-hops or MSs. Similarly at DesNs MRC technique is applied. The protocol improves throughput, and network lifetime and increases the packet acceptance ratio. The drawback of the protocol is its increased EC [26].

The depth is controlled with energy balanced routing protocol presented by [27]. The technique enables bringing the lower energy depth nodes in order to swap low-energy nodes. The high energy nodes for the purpose that both nodes use the same amount of energy, lying at different depths underwater. The different lying on different depth positions cause irregular utilization of power. This leads to a limited lifetime of the network and degrades its performance. The technique used by the author is an enhanced genetic algorithm and data fusion. During simulation, the proposed model perform well in terms of RDR 86.7, EC 12.6, and packet drop ratio 10.5. The network did not perform well in E-2-E.

Xiao et.al presented a routing protocol based on ant colony optimization (ACO). The network is split into several clusters. Similarly, every cluster consists of one cluster head node (CHN) and many cluster member nodes (CMNS). The parameters used for the selection of CHN depend on nodes RE and the distance factor. The CHN collects the data forwarded by CMNS and then back sends it to SN through multiple hops. The optimal path is selected from source to destination by ACO for the sake of utilizing less energy and increasing network lifetime. The protocol optimizes EC, network lifetime, and packet drop ratio while E-2-E is not improved [28]. Munsif et.al presented two approaches i.e. multilayer sink and reliable (MuLSi) and MuLSi-Co. The MuLSi is further improved to MuLSi-Co by using the cooperation technique. The first algorithm is a multi-layered network design of a solid single structure and sink placement at that position, which optimizes multiple hops communication [29]. In the aforementioned literature, some of the existing algorithms presented are based on cooperative and some are based on non-cooperative schemes, to address some of the shortcomings. In our proposed algorithm we proposed both cooperative and non-cooperative based protocols to investigate these shortcomings. Therefore, the proposed algorithm well performs in terms of EC, E2E, PDR, dead nodes, packet drop ratio, EC, and the number of alive nodes (ANs).

III. PROPOSED ALGORITHM EXPLANATION

We present the steps of our proposed algorithm as follows:

A. NETWORK ARCHITECTURE

In the proposed algorithm we deploy the network in $3D$ space. Each dimension is equal to $500m$, and consists of randomly deployed 200 nodes. Each node has a finite amount of energy. The network is divided into two equal regions in order to reduce energy consumption. Two super SNs are located at the upper surface of the network, while two sub SNs are placed in the middle region of the network i.e. at the length of ($x = 250$, $y = 250$ and $z = 250$) in $3D$. The upper region in the network is called the destination region, as it is near the sink. Nodes that are lying in the lowest depth are called source nodes.

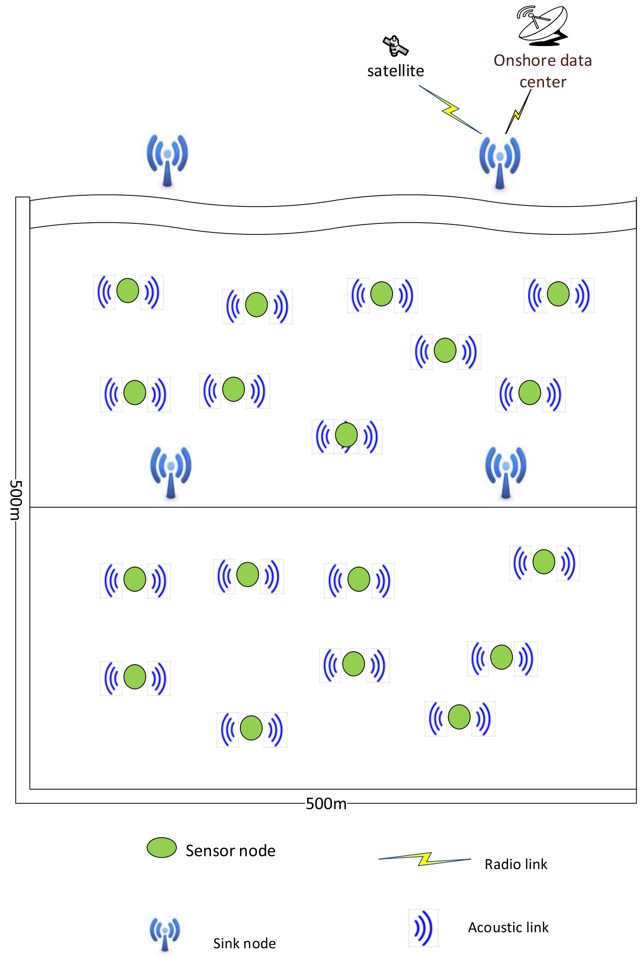

FIGURE 1. **Network model.**

All nodes have the ability to transmit data packets to the destination. Moreover, SNs are placed in such a way that the two super SNs are placed above the surface of the network and two sub SNs are available in the middle of the network as shown in Figure 1. The design of this deployment refers to collecting the data packets from all nodes. SNs in the network are equipped with both acoustic and radio modes at a time. However, SNs exchange data packets with each other through acoustic waves. SNs in the network are equipped with both acoustic and radio modes at a time. However, sensor nodes exchange data packets with each other through acoustic waves. The absorption rate of a radio wave is higher than acoustic waves underwater therefore, in underwater the node communicates through acoustic waves. The SN at the upper region of the network uses radio waves for the exchange of information with the onshore data center.

B. HELLO PACKET FORWARDING AND NEIGHBOR IDENTIFICATION

Nodes are placed underwater in a random manner. After node deployment, sensor nodes are unfamiliar with their neighbors' depth, the shortest distance from source to destination,

Lowest Depth	Shortest Distance	Bit Error Rate

FIGURE 2. Hello packet information.

and BER. The format of a hello message consists of sender ID, depth of sensor node, shortest distance from source to destination, and BER. Initially, the nodes in the underwater sensor network have no knowledge of their neighbor for routing. The lowest depth, shortest distance, and BER are necessary in the proposed scheme. In order to get information of each sensor node a hello message is transmitted by the final DesN to sensor nodes. The structure of the hello packet is shown in Figure 2. The capacity of the hello packet is assumed to be 8 bytes which is essential for the exchange of information among all the sensor nodes [30]. The presence of a particular ID of SN helps differentiate the hello packet that it sends. However, only those nodes respond to the hello packet that exists within the transmission range. Every node in the network gains information about its nearby node due to the broadcast nature of the hello packet. The information of depth, shortest distance, and BER of nodes are essential for the selection of the best forwarder node. This process continues until all the nodes share their information with one another. To determine the BER, a node sends a test packet to all neighbors. The test packet carries a specific number of bits. This arrangement of bits is by default known to all the nodes. Whenever a test packet is received, every node in the network checks the amount of corrupted bits in a test packet due to channel behavior. Each node in the network then informs all the sensor nodes about the presence of corrupted bits in test packets. We present a very simple formula for a hello packet overhead as follows:

$$Overhead = N \times H \tag{1}$$

where N is the number of nodes in the network and H is the depth of the network. In the proposed approach N is the same as used in literature, however, H is 500. In the proposed approach we divide the network into two regions, which dramatically reduces the overhead because the virtual span of the network becomes half. However, In the case of our network, after each 30 cycle transmits the hello packet, they gain updated knowledge and information. To find out the position of each sensor node, its residual energy, and multi hops. After 30 cycles of the periods, they update the results for us and show us how much residual energy there is now, what the SNR value is, the position of the sensor nodes in both regions of the network, and the number of multi-hops.

C. DATA FORWARDING

In the data forwarding section, the source node chooses a forwarding node based on the depth of the sensor node and the shortest distance from the source to DesN and BER. At first, the source node investigates the best DesN on the

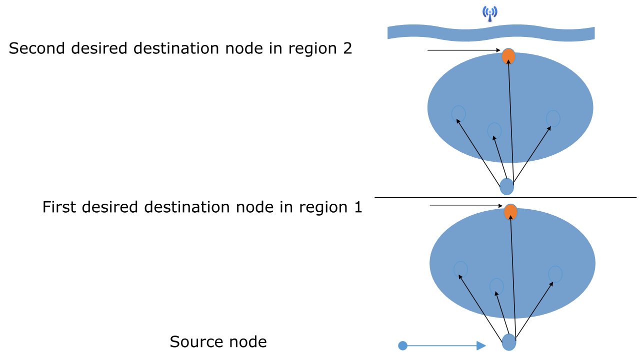

FIGURE 3. Data forwarding using best destination node in both regions of network.

basis of the parameters' lowest depth, the shortest distance from source to destination, and BER in the group of neighbor nodes. Whenever the BER of DesN is high, the packet is dropped. Similarly, another DesN is selected using the same parameters within the transmission range. This process of selection of DesN is continued until data has reached SNs as shown in Figure 3. The selected DesN forwards the information packets to the next DesN by multi-hopping till the data packet is received by the final DesN. Whenever the final DesN lies within the transmission range of the source node it directly sends information to the final DesN. The weighting or cost function that is used for the selection of the best forwarder node among all the neighbors is written as:

$$f = \frac{1}{depth \times shortestdistance \times BER} \tag{2}$$

Whenever the BER threshold value is less than 0.5, the packet is gained and directed toward the next suitable node. But if the BER of the information packet is higher than 0.5 the DesN drops the packet. If the information packet received at the DesN satisfies the BER threshold value, then it is accepted by the DesN and forwarded to the final DesN.

D. COOPERATIVE ROUTING PROTOCOL

We proposed a cooperative routing protocol in addition to the DRAR protocol called CO-DRAR. This routing protocol ensures reliability in the transfer of valuable information through a channel with successful relaying between source and DesN. The mechanism of CO-DRAR is further explained as under:

In the Co-DRAR protocol, the data packet is forwarded towards the final DesN in two different ways i.e. direct path transfer and relay or cooperative path transfer as illustrated in Figure 5. In direct communication, when a source node is within the communication range of SN, it sends data packets directly towards the SN. However, if the SN is far away from the communication range of the source node then cooperative routing is adopted which makes DRAR as Co-DRAR. In order to achieve reliable data packets during transmission, the source node in Co-DRAR selects the DesN from neighbor nodes that lie near the SN. A node possesses

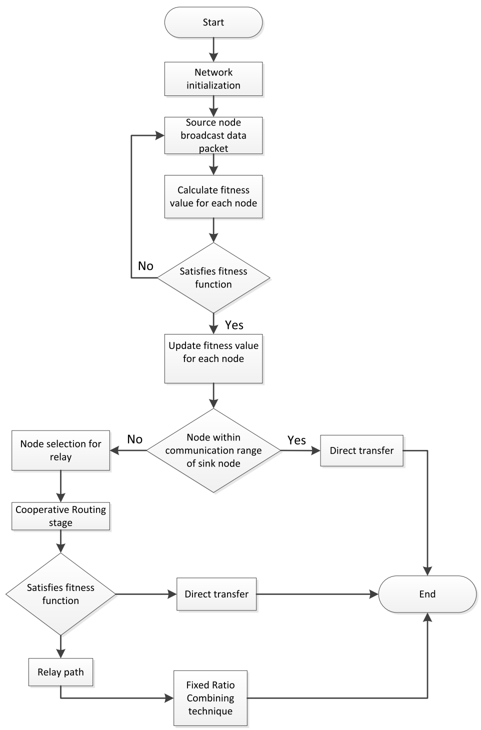

FIGURE 4. Flow chart of the proposed protocol.

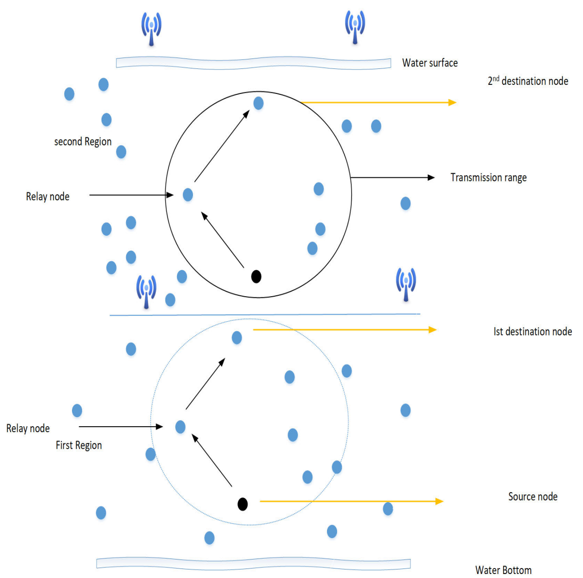

FIGURE 5. Co-DRAR scheme.

the shortest distance with respect to SN as taken as DesN. A node having the second nearest distance to the SN is considered a relay node. Similarly, the source node broadcasts its data packet to the destination and relay nodes respectively. Since the BER of information packets is checked by DesN, if the BER of the packet is lower than the specified threshold, it will forward information directly to SN. But, if BER becomes more than its threshold, then a request is sent to a relay node to send the same information again. After this, the relay forwards its information together with acknowledgment to DesN. The data packets from both the source and relay node are recombined at each DesN using a Fixed Ratio Combined (FRC). This technique is preferred instead of the Maximal Ratio Combine (MRC) technique that requires complete channel information which is a challenging task underwater. Finally, the information is merged together at the destination point, this information is further evaluated to extract desired valuable information. Next, the information is forwarded from the destination point to SNs located at both regions of the network. In the end, the information is broadcasted from the lower region to the upper region SNs of the network. The flow chart of both protocols is shown in Figure 4, at first the network is initialized. The source node broadcasts the data packet in the network. After this, the source node calculates the fitness value of each sensor node in the network. If one of the source nodes satisfies the fitness function then the remaining will also update their fitness function value. If the fitness function is not satisfied then again source node broadcasts the data packet. If the source node lies within the transmission range of a sink node then data is directly forwarded to the sink node. Otherwise, the source node selects a relay node, and cooperation routing using a fixed ratio combine technique is entertained. In the case of satisfying the fitness function data is forwarded directly. The detail of our proposed algorithm is shown in 1.

IV. SIMULATION RESULTS

In this section, we compare the simulation results of both DRAR and Co-DRAR protocols with existing DBR [31] protocol. The techniques presented in [20] and [32] also use DBR as a reference. The simulations are performed using Matlab R2019a as the simulation tool on a PC with a processor Intel(R) Core(TM) i5 CPU 661 @ 3.33GHz,8GB, and RAM, the proposed approach average running time is 2044.673654(s). The network contains 200 nodes distributed randomly in $3D$ area having length, width, and height of $500m$, respectively. Two super SNs are placed at the upper region of the network, while two sub-SNs are fixed at the mid-region of the network. In the proposed protocol the depth threshold for all the nodes in the network remains fixed. A protocol known as Medium Access Control (MAC) is used in the proposed scheme [19]. In MAC, the nodes first check and identify the condition of the channel, through which data is to be forwarded. If the channel is free then they start broadcasting. Or if a channel is busy then the nodes wait. But if the channel is not vacant up to a specific time, then the data is dropped. The SNs in both regions of the network are positioned in stationery mode. The sensor nodes can move easily from one position to another position with no restriction due to water flow. Due to water currents, the speed of sensor nodes nearly reaches up to $5m/s$ [20]. The nodes in the network use the acoustic modem of LinkQuest UWM 1000 in order to communicate with each other. The transmission range of each node in the network

Algorithm 1 Proposed

1) **Z**: Number of nodes
2) **TBER**: Threshold of bit error rate
3) **SN**: Sink Node
4) **RN**: Rely node
5) **RE** : Residual energy
6) **BET**: Bit error rate
7) **i**: Nodes starting number
8) **for**: **i**= 1: Z Perform
9) **Data received**
10) **D**= Distance between the sink node and the source node
11) **if** SN is in transmission range
12) **Data received = true**
13) **else if** SN is not in transmission range select the nearest relay node
14) Also find the DesN in the nearest region
15) DesN can be found by cost function Calculate as in **Eq2**; we calculate the distance between two nodes using the Euclidian distance formula.
16) **Data forwarded**
17) **if BER** $\leq$ 0.5=**then**
18) Find the relay node
19) **if** RN found=**true**
20) Packet sent to **RN**
21) **While**
22) **check SN**
23) data reached to mid-sink node
24) data transfer upper sink node=**true**
25) **end if**
26) **end if**
27) **end While**
28) **break**

TABLE 1. Parameters for simulation.

Operations	Values
Network height	500m
Network depth	500m
Network width	500m
Initial energy	10J
Frequency	30KHz
Packet size	50 bytes
Transmission range	100m
Bandwidth	30KHz
Sensor nodes	200
Depth threshold	60m
Sink nodes	4

is assumed 100m in all directions and consumes power of 0.1W, 2w, and 10mW power for receive, transmit, and idle states, respectively. Initially, the nodes carry energy of 10J and the packet size of each sensor is 50 bytes with 10 kbps data rate. The parameter of the network for simulation is depicted in table 1.

A. PACKET DELIVERY RATIO

The comparison of proposed protocols and the DBR in terms of PDR is depicted in Figure 6. The Co-DRAR performance is

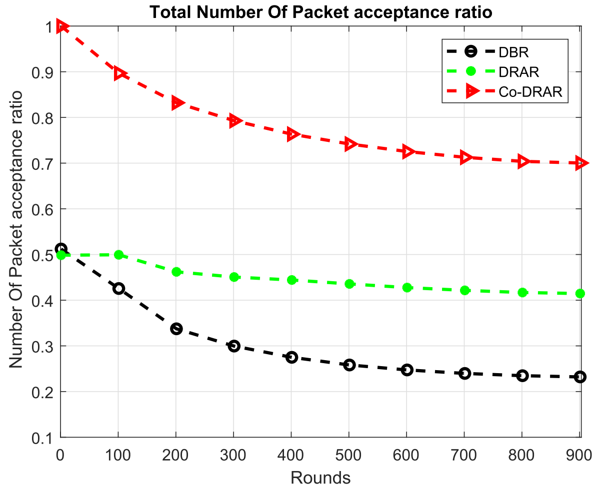

FIGURE 6. Packet delivery ratio.

compared to the rest of the protocols because the PDR of the Co-DRAR protocol is the cooperation of a single relay node and putting SN at both regions of the network. In the case of the Co-DRAR scheme every sensor node in the network forwards its information to the desired SN and as a result, more data packets are reached successfully. This mechanism increases the PDR of the proposed scheme. Similarly, nodes that lie near the SNs in both regions of the network send their information directly. While that node which is situated far away from the SN forwards its valuable information through a single relay node using the method of cooperation. Due to this mechanism, the packet drop ratio decreases as compared to the DBR scheme and gains the highest PDR. Also, the PDR of the DBR scheme is better than DRAR, because the DRAR scheme shows a better result on the lowest depth node faced by the DBR scheme. The PDR value of the Co-DRAR scheme starts from a value of 1 because of cooperation, while the value of DRAR and DBR scheme start from 0.5 due to non-cooperation while the presence of cooperation in scheme brings the reliability in forwarding the information. The long transmission path degraded the PDR of the DBR scheme as compared to the DRAR scheme. The more detail of PDR performance is shown in Table 2.

B. END-TO-END DELAY

The E2E delay of the proposed protocol is shown in Figure 7. The proposed protocol has less latency because of the absence of cooperation in data transmission. The delay of the DBR scheme is greater than DRAR and Co-DRAR because, in the DBR protocol, the source node forwards the information packet from the highest depth to the lowest depth DesN. Similarly, DBR protocol follows a long transmission path which utilizes more time to reach the data packet to the desired DesN. In the case of the Co-DRAR protocol, the presence of a single relay node and positioned of SN at both regions of the network decrease the path length which in turn reduces the delay during transmission of data packet.

TABLE 2. Comparison of PDR at each round R.

Protocol	R_1	R_{100}	R_{200}	R_{300}	R_{400}	R_{500}	R_{600}	R_{700}	R_{800}	R_{900}
DRAR	0.4985	0.4995	0.4618	0.4505	0.4441	0.4356	0.4276	0.4215	0.4168	0.4145
Co-DRAR	1	0.8959	0.8315	0.7926	00.7634	0.7420	0.7255	0.7128	0.7039	0.7003
DBR	0.5120	0.4249	0.3372	0.2997	0.2751	0.2583	0.2474	0.2397	0.2397	0.2321

TABLE 3. Comparison of end-to-end delay of proposed scheme at each round R.

Protocol	R_1	R_{200}	R_{400}	R_{600}	R_{800}	R_{900}
DRAR	319.031	11554781.2	31748657.7	47093826.0	54171802.4	55275609.6
Co-DRAR	692.47	21978704.0	54876150.3	72650259.4	81570788.7	83381889.1
DBR	2430.765	61761169.3	123536575.5	154932835.6	171872966.7	176257397.9

TABLE 4. Comparison of the packet received of proposed scheme at each round R.

Protocol	R_1	R_{100}	R_{200}	R_{300}	R_{400}	R_{500}	R_{600}	R_{700}	R_{800}	R_{900}
DRAR	104.3	9804	17790	23825	27973	30565	31759	32213	32395	32427
Co-DRAR	200	17516	30782	39780	44576	46825	47843	88372	48650	88728
DBR	98	8374	11562	13203	14036	14476	14775	14978	15085	15114

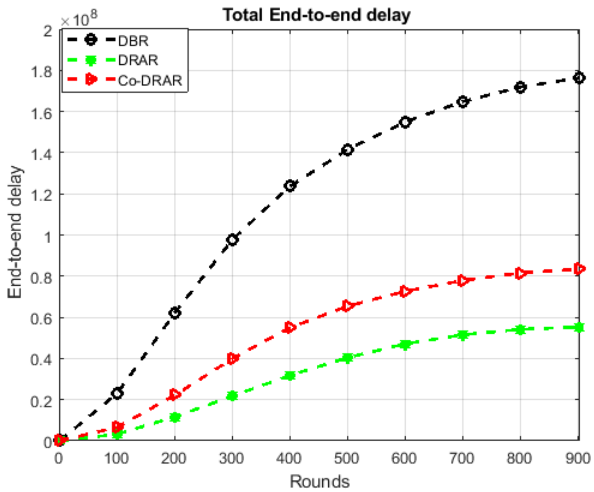

FIGURE 7. End-to-end delay.

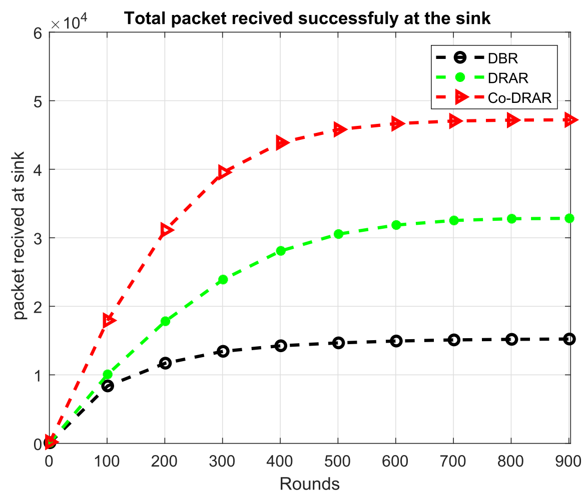

FIGURE 8. Packet received.

As in both network regions, the sensor nodes near SN send their data packets directly to SN. However, node far away from the SN forwarded their data packet to the desired destination through cooperation using the single relay and considering less physical distance. This mechanism decreases the transmission path and reduces the delay. The more detail of E2E delay performance is shown in Table 3.

C. PACKET RECEIVED AT SINK

Figure 8 shows the number of packets reached successfully to the final DesN. The ratio of the packet received by the SN of DRAR is better than DBR, further, Co-DRAR achieves better performance than DRAR and DBR. The reason for this high number of packets received at SN in the Co-DRAR scheme is due to the reason of cost function parameters i.e. highest RE, lowest BER, and shortest distance. The cost function ensures the maximum number of packets reach the final DesN. The Co-DRAR scheme uses the single relay node during cooperation with DesN. The contribution of more nodes in the Co-DRAR scheme utilizes maximum energy and those nodes that lie near to the surface die quickly due to that data loss occurred. The more detail of packet received performance is shown in Table 4.

D. TOTAL ENERGY CONSUMPTION

Figure 9 shows the comparison of three protocols in terms of total EC. The EC of Co-DRAR and DRAR protocols is less than DBR protocol. The low consumption of energy in

TABLE 5. Comparison of total energy consumption (EC) of proposed scheme at each round R.

Protocol	R_1	R_{100}	R_{200}	R_{300}	R_{400}	R_{500}	R_{600}	R_{700}	R_{800}	R_{900}
DRAR	7.112	702.0	1307	1782	2112	2330	2459	2534	2573	2589
Co-DRAR	9.135	830.9	1399	1720	1867	1932	1964	1984	1995	2000
DBR	11.32	1033	1667	2063	2305	2461	2565	2635	2679	2703

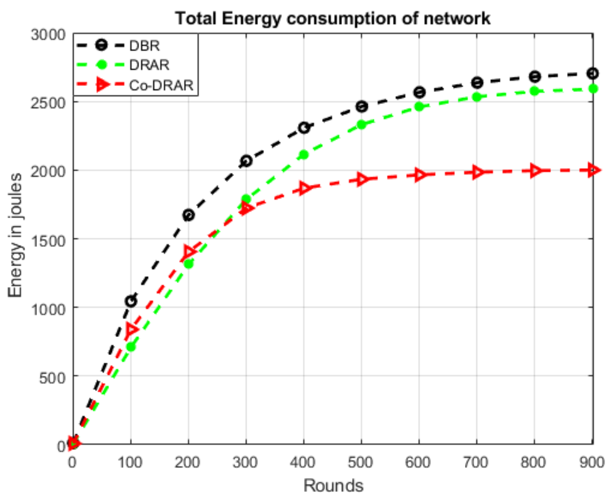

FIGURE 9. Total energy consumption.

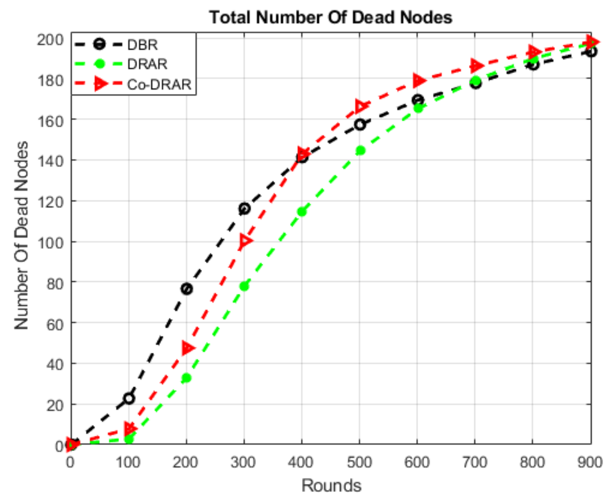

FIGURE 10. Total number of dead node.

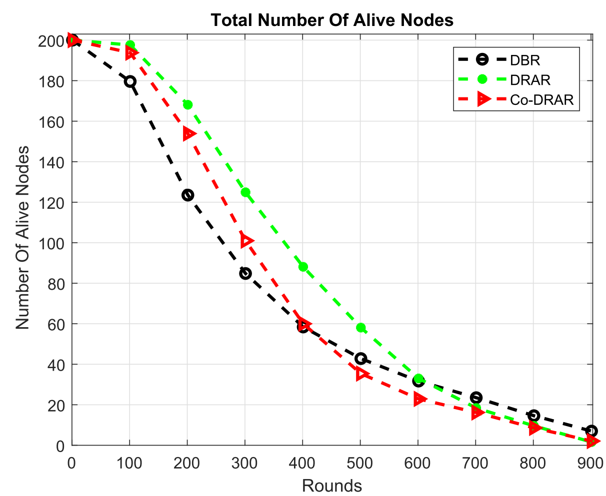

FIGURE 11. Total number of alive node.

the Co-DRAR protocol is due to the cooperation technique. Consequently, nodes away from the SN in both regions of the network forward their information in a cooperative manner. Moreover, the Co-DRAR protocol uses SNs in both regions of the network that help to reduce the congestion of data packets due to long multi-path routing. Secondly, the EC of the DRAR protocol is less than the DBR scheme. This is because of the balance EC in the network which permits the nodes to transmit more information at the rate of minimum energy cost. In the case of the DBR protocol, more energy is consumed in the transmission of the packet from the highest depth source node towards the sink which in turn increases the energy consumption. More details EC performances as given in Table 5.

E. DEAD AND ALIVE NODES

The number of dead nodes is lower in DRAR and Co-DRAR protocol as shown in Figure 10. The DRAR protocol possesses a minimum number of DN than Co-DRAR and DBR protocols. In the Co-DRAR protocol, cooperation is performed by selecting only one DesN to forward information towards the final destination. Co-DRAR has less number of dead nodes because it consumes less energy than the DBR scheme. Figure 11 shows the number of ANs in all protocols. The rate of AN in the DRAR protocol is higher in comparison with Co-DRAR and DBR protocols. In the DRAR protocol, only one DesN can transmit the data packets to the final DesN. Due to this reason minimum energy is consumed and there are more ANs. The Co-DRAR protocol has a maximum number of ANs than the DBR protocol. This is due Co-DRAR protocol only one destination and relay node are contributed to transfer the information towards the desired nodes. As DBR consumes more energy due to multi-hopping and possesses less number of ANs. The analysis of DN and ANs is shown in Tables 6 and 7.

F. NUMBER OF PACKET DROPS

The comparison of our proposed protocols DRAR and CO-DRAR with DBR in terms of packet drop ratio is shown in Figure 12. In CO-DRAR less number of information

TABLE 6. Comparison of dead nodes of proposed scheme at each round R.

Protocol	R_1	R_{100}	R_{200}	R_{300}	R_{400}	R_{500}	R_{600}	R_{700}	R_{800}	R_{900}
DRAR	0	2.70	32.40	77.70	114.1	144.1	165	179.2	190.1	197.3
Co-DRAR	0	7.300	47.10	99.70	142.6	166.1	178.7	186.1	193.1	198
DBR	0	21.80	76	115.6	141.1	157	169.3	177.8	186.9	193.3

TABLE 7. Comparison of alive node of the proposed scheme for each round R.

Protocol	R_1	R_{100}	R_{200}	R_{300}	R_{400}	R_{500}	R_{600}	R_{700}	R_{800}	R_{900}
DRAR	200	197.3	167.6	122.3	85.90	55.90	35	20.80	10.20	2.700
Co-DRAR	200	192.7	152.9	100.3	57.40	33.90	21.30	13.90	6.900	2
DBR	200	178.2	124	84.40	58.90	43	30.70	22.20	13.10	6.700

TABLE 8. Number of packet drops at each round R.

Protocol	R_1	R_{100}	R_{200}	R_{300}	R_{400}	R_{500}	R_{600}	R_{700}	R_{800}	R_{900}
DRAR	100.30	9993.2	20661	29100	35155	39627	42772	44802	46070	46625
Co-DRAR	0	2061	6275.1	10318	13582	15943	17719	19053	19962	20337
DBR	97.60	11218	31205	13203	37344	41957	45311	47799	49456	50423

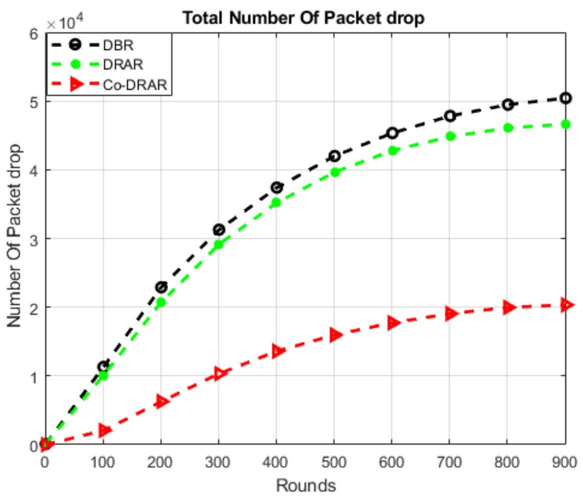

FIGURE 12. Number of packet drops.

packets are dropped, and more packets reach to final DesN due to the cooperation involved in CO-DRAR. The packet drop ratio is comparatively high in DRAR while DBR depicts more number of packets drop as compared to DRAR and CO-DRAR schemes. More details number of packet drop ratios are given in Table 8.

V. CONCLUSION

We propose two routing protocols known as (DRAR) protocol and Cooperative Delay (Co-DRAR) protocol for UWSNs. In DRAR protocol the network is divided into two equal regions to reduce delay. Two super SN are located at the upper surface of the network while two sub SN are placed in the middle region of the network. The proposed framework is used to ensure low EC in order to reliably forward data packets towards SNs. The Co-DRAR scheme ensures reliability in the transfer of valuable information through a channel with successful reliance between the source and DesN. Due to network division in two regions, data load is reduced and the EC of sensor nodes decreases. In Co-DRAR, the sensor nodes in both regions of the network send their data packet directly towards SN. In the proposed Co-DRAR framework, the best forwarder node is chosen using the value of cost function i.e. lowest depth, shortest distance, and BER. The lowest depth and shortest distance make sure that the data packet reaches successfully to the final destination. The protocols shows improved performance in term of EC, PDR, ANs, PDR, total number of packets dropped and total number of packet received successfully to SN. The proposed techniques are applicable for underwater wireless sensor networks by considering the underwater attenuation

TABLE 9. Tale of abbreviations.

Keyword	Expanded form
PDR	Packet delivery ratio
BET	Bit error rate
E2E	End-to-end delay
RE	Residual energy
DBR	Depth base routing
SNs	Sink nodes
SN	Sink node
MRC	Maimal ratio combine
MAC	Medium access control
UWSNs	Underwater wireless sensor networks
EC	Energy consumption
AN	Alive Node
ANs	Alive Nodes
DesN	Destination Node
DesNs	Destination Nodes

coefficient constant. However, there are many types of water i.e. coastal water, turbid water etc. These are the limitations of our proposed technique.

In future work, we can implement the energy harvesting techniques on the proposed model to further decrease the energy consumption which in turn increases the lifetime of the network.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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