A Stable and Reliable Short-Path Routing Scheme for Efficient Acoustic Wireless Sensor Networks (AWSNs)

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ABSTRACT

Owing to the vital resources in a harsh and unforeseeable aqueous environment, the network stability and reliability in underwater acoustic wireless sensor networks (UAWSNs) have paramount significance. Stability guarantees the consistent performance of the network node’s energy consumption, avoids data loss, packets reception time and network lifetime. The reliability of packet ensures the selection of favorable channel and avoid adverse channel effects, and the vital information is easily obtained from data packets. This paper introduces two new routing schemes for UAWSNs; stable and reliable short-path routing (RSPR) scheme, and cooperative reliable short-path routing (CoRSPR). In RSPR routing, the destination node is selected by considering the weighting function parameters of the highest residual energy, highest SNR, lowest euclidean distance, and least number of neighbor nodes. The scheme reduces the energy consumption due to less number of nodes contribution in the packet advancement process. The RSPR protocol is a non-cooperative technique, where the packets are delivered using a single-path link, which may not be consistently reliable. To cope with this issue, the CoRSPR protocol is proposed, which takes cooperative routing into account, for stable and reliable data delivery. In cooperative routing, the reception of more than one copy of the data packet is involved by the destination node. This reduces the unfavorable channel effects during data delivery. The simulation results show that the proposed schemes achieve better performance in terms of dead nodes, energy left in the battery, packet acceptance ratio, successful receiving of packets at the sink and E-2-E delay.

INDEX TERMS

Acoustic wireless sensor networks, short-path routing, network reliability, RSPR, CoRSPR.

I. INTRODUCTION

In underwater communication, a stable network and reliable communications are the most prominent challenges. Both challenges need much attention when using underwater acoustic wireless sensor networks (UAWSNs for applications such as disaster provocations, marine detection and oceanographic information [1]. In addition, maximum correct packet reception and network stability are an essential part of a successful communication system. The acoustic channel has a very challenging environment, and the data reception at the final destination with good accuracy is a difficult task. The probability of the data loss is high because of multi-path fading, salinity, noise and attenuation [2]. Due to these challenges, acoustic waves are used for delivery of data packets instead of radio waves [3]. The speed of acoustic waves in water is much lower than the radio waves [4]. The problem of data latency is greater than the terrestrial network, as of the low speed [5]. In underwater communication, the nodes position change with the water current. So the changing of the position of the nodes makes the network dynamic and unstable. The stability of the network is a key parameter, because the underwater nodes have limited battery power,
and replacement or recharging of the node is difficult in underwater [6].

Cooperative routing overcomes the packet reliability problem by traveling the packet through multi-path. In cooperative routing, the source node broadcasts the information packets. The desired information follows multiple paths to reach the sink node. Due to the cooperation, the various number of relay and destination nodes are contributed during the packet forwarding process. This ensures maximum information to the sink node and reduces the probability of packet drop. Cooperative routing has two types: fixed relaying cooperation (FRC) and incremental relaying cooperation (IRC) [7]. In the FRC scheme, the relay node always used cooperation in data forwarding. Whereas in IRC, the relay node cooperates only when received a request from the destination node. The FRC scheme has further two sub-schemes, e.g. amplify and transmit (AT) and decode and transmit (DT) [8]. In AT, the relay node first amplifies the received information and then forward towards the destination node. While in DT scheme, the relay node decodes the received information and transmits it in the direction of the destination node.

In non-cooperative routing protocols [9], [10], the packets travel from the source node to the destination node over a single channel, which does not guarantee reliable data delivery, due to the high probability of error in the channel. Therefore, the cooperative routing overcomes challenges that exist in the non-cooperative routing. However, the cooperative routing consumes more energy than that of non-cooperative routing, as the maximum number of nodes involved in data delivery. This makes the network stability less than that of non-cooperative networks [11].

Several routing schemes [11]–[13] take only the information about the depth of nodes into account for data delivery instead of the coordinates of the sensor node. In such schemes, only the lowest depth node is considered as the best candidate for the delivery of the packets from the water bottom to the water surface. The uppermost nodes have low depth in the network. Therefore, these nodes are selected frequently which has a high burden and, hence, tend to die quickly than the rest of the nodes. The death of the uppermost creates holes that reduce the stability of the networks.

This work presents two routing schemes; (1) Reliable and short path routing (RSPR) scheme for network stability, and (2) cooperative reliable short path routing (CoRSPR) for network reliability. The RSPR is a non-cooperative scheme which forwards the information packet over a single path, while the CoRSPR is a cooperative based scheme. For the selection of optimal destination node, both schemes considered the weighting function of highest residual energy, highest SNR, lowest distance and bit error rate (BER). The network of the proposed schemes is region-based, where the two sub-sinks are placed at the middle of the network at equal distances and super-sinks are positioned at the upper water surface. In both the proposed schemes, the source node collects all the information in terms of weighting function parameters surrounding the neighbor nodes and forwards it towards the destination node. In the RSPR scheme, due to the single path routing, it consumes minimum energy and prolongs the node lifetime. However, in the CoRSPR scheme, the source node selects the destination node along with a single relay node for cooperation. The two copies of data packets are combined by using a fixed ratio combine (FRC) as a diversity technique at the destination, and forwards an optimal packet towards the super-sink by following the multi-hop path. For both the schemes, the selection parameters lowest distance and the network division reduces the path length, which ensures the quick delivery of information packet. In order to increase the accuracy, the source node checks each link SNR and forwards the packet over that link, which has the highest SNR. Moreover, due to the balance network, the proposed schemes avoid the early death of the lowest depth node and reduce the packet collision.

A. PROBLEM STATEMENT

In the DBR scheme [12], only depth information is considered for the data advancement node. This information is not enough to specify the position of the nodes. Moreover, the situation becomes more worst when two nodes are at the same depth (due to random deployment) and forwards the redundant information towards the sink node. The redundant data is received by the destination node in case of the same depth position. It increases the energy consumption and put an extra burden on the lowest depth nodes due to continuous usage. Secondly, the data packets are advanced from the bottom source node towards the upper surface sink node by following the long transmission path, which increases the latency. Moreover, the CoDBR [11] scheme also selects the best forwarder nodes (relay and destination) by considering the same criteria. The contribution of two relay nodes with destination increases the node contribution during the packet advancement, which also increases the energy consumption. The deployed sensor nodes are energy-constrained and are considered dead when drained its battery power. Unlike the DBR scheme, it also forwards the packet over a long transmission path and increases the burden on the lowest depth nodes. In short, the scheme also consumes high energy and render long latency during the packet advancement.

B. CONTRIBUTIONS

To cope up with the above problems in both the schemes, we have proposed two new schemes. The main features of the proposed schemes can be summarized as follows.

- To reduce energy consumption and prolong the network lifespan, the RSPR scheme is introduced. In this scheme, we split the network into two sub-regions. The sub-sinks is placed fixed at the mid of the network, while the two super-sinks are positioned at the top of the water surface. The source node considers the weighting function parameters (highest residual energy, SNR, lowest distance, and least number of hops) for the choice of data forwarding node. In addition, a $Dth$ is applied, which also reduces the energy consumption by making
an isolate queue among the neighbor within the communication range. The sub-sink placement at a particular position in the network reduces the path length, which minimizes the latency. The weighting function helps to select that node as the best forwarder node, which has maximum function value. By using such a technique, the scheme saves the network energy, retain maximum nodes alive for a long time, and minimize the latency. However, due to single-path routing, it decreases the network reliability and loss of the packet.

- To cope with the reliability problem in RSPR schemes, cooperation is utilized in the CoRSPR scheme. For the same network, the selection of relay and destination nodes are planted over the function parameters. Where the destination is the first highest priority node, while the relay is the second highest function value node. Besides this, a $Dth$ is also applied in the forwarding mechanism among the neighbor nodes. A single relay node cooperates with destination, which decreases the energy of nodes due to the small number of nodes contributing to the packet advancement. Due to multi-path routing and the selection of a robust function by considering the weighting function, the source node selects the best nodes as a relay and destination. The nodes in the communication range of sub-sink or super-sink send directly packet towards it. Multi-hoping phenomena is utilized due to the limited transmission range of the deployed nodes.

- For end-to-end delay minimization, the broadcast time is assumed into three stages. The first stage is the transmitting and receiving time, which is the time seized by the whole packet from the transmitter to the receiver over the channel. It is the function of the transmission rate and packet size. The second stage deals with the propagation time, which is dependent on the speed of the acoustic wave in the acoustic background while the third one is the alignment time, which is considered the time taken of a node when it waits for particular condition in the network. The delay among the source $s$ and destination node $d$ is denoted by $\tau_{s,d}$ and can be calculated as,

$$\tau_{s,d} = T_s + P_{s,d} + A_s$$

(1)

The transmitting and receiving time is denoted by $T_s$, the propagation time is $P_{s,d}$ and the alignment time is presented by $A_s$. Therefore, As the transmitting and receiving time consider the function of packet size $PS$, and the transmission rate $R_t$, then,

$$T_s = \frac{PS}{R_t}$$

(2)

Moreover, the propagation time $P_{s,d}$ from source $s$ towards the destination $d$ depends on the distance $D_{s,d}$ among the source node and the destination, while $V$ is the speed of the acoustic wave in the ocean environment.

$$P_{s,d} = \frac{D_{s,d}}{V}$$

(3)

In order to minimize the propagation delay, the distance $D_{s,d}$ is reduced by dividing the network into two sub-regions and placed the sub-sink nodes in the middle of the network. Secondly, the selection parameter lowers distance and reduces the path length, which results in small latency.

II. LITERATURE REVIEW

In UWSNs, for efficient energy and delay minimization, the authors proposed a new scheme in [14]. This scheme aims to enhance the performance of the vector base forwarding (VBF) by using the fuzzy logic interference technique (FLIT). The scheme considers the position of the node and the information of the highest residual energy for the choice of the best relay node. In addition, the FLIT reduces the interference between the nodes, where the packet follows the shortest path to reach the desire sink node. The selection parameter residual energy helps to find the robust node for data forwarding, which transfers maximum information over the low cost of energy. The scheme loses the network reliability due to single-path routing, and also loss maximum information packets. However, it reduces per node energy, maximizes the network lifespan and reduces the latency between the sender and receiver.

The reduction of the energy consumption and forwarding maximum information along with the small latency are the benefits of the scheme [15]. To analyze the under-sea parameters, e.g, dissolved oxygen, PH level and water salinity, the scheme uses two techniques during packet transmission. The nodes in the communication range use the regular packet, while the nodes outside the communication range use emergency packets. The best relay node is selected by considering the source identifier and the least number of hops. The parameter source identifier helps to hold the receiver node address. The scheme saves the network energy and reduces the latency, while drops maximum packet due to the single path routing.

The authors in [16] presents a method to avoid the void spaces occupancy and reduced the network energy along with a small delay. The scheme considers the robust function for efficient energy by ignoring the non-contributed node in the network. The data forwarding nodes are selected by taking the function of nodes ID and lowest distance. The selection parameter, smallest distance concerning the sink node, reduces the path length and the latency, while node ID distinguished the node location among the neighbor nodes. Moreover, due to the multi-layered scheme, it enhances the function and helps to discover the efficient route for data advancement. The use of the splice function enables the source node to select the node having the greatest energy, which improves the network life span. The scheme saves the energy along with a small latency but loses the reliability and drops maximum information.

Another cooperative scheme for UWSNs is presented in [17]. The scheme uses two techniques for routing, i.e, effective routing, and reactive routing. The effective routing is a non-cooperative routing, which forwards the packets
over a single path. Such routing decreases the network reliability, while increases the latency due to the early death of the lowest depth nodes. To address this issue the scheme uses the reactive technique, where packet advancement involves multi-path routing. In the scheme, each node creates a routing table which holds the multiple routes information in the direction of the destination, the table is updated after some time. The source node broadcasts the packet and examines the channel link if one path is busy, it immediately chooses the alternate path for the packet. The scheme reduces the latency due to this mechanism and consumes low energy. However, it has no mechanism to check the accuracy of the received information.

A non-cooperative routing algorithm in [18] for underwater WSNs aims to avoid the interference between neighbors. The scheme sounds good, only having the information of the lowest depth and minimum neighbor nodes information, instead of full-dimensional channel information. The selection of the best destination node is based on function parameters, which reduces energy consumption and avoid collision between the nodes. The parameter minimum number of neighbor nodes minimizes the ratio of nodes contribution in data advancement, which decreases the energy consumption. The scheme reduces network energy consumption, and retain the maximum nodes alive for a longer time and improves network reliability. However, it renders high delay during the packet forwarding due to following the long transmission path and loss the information accuracy.

Wang et al. [19] proposed an energy-efficient compressive sensing-based clustering routing (EECSR) for wireless sensor networks (WSN). In this algorithm, the overall network is divided into k-layers, whereas the sink node is deployed at the center of each layer. The sink node obtains the clusters in each layer in which the optimal cluster is targeted. Furthermore, the sink node transmits the cluster-head information among all members of the network. Furthermore, compressive sensing theory data collecting is divided into two types which are intra-cluster and inter-cluster data collections. The simulation demonstrated that this approach achieves good results in improving energy efficiency and network lifespan.

In [20], a game theory-based clustering scheme for wireless sensor networks is proposed. This approach is based on localization in which each all the nodes initially transmit the hello message to the sink node which is deployed at the center of the network. The hello message contains the information: node ID and residual energy. A sink node defined a threshold by which the residual energy of all the nodes is sorted out. Also, it acknowledges all the nodes in response to residual energy. Furthermore, to rotate the role of cluster head (CH), a sink node defined a circle T in the message. All the nodes are classified into different classes as per their residual energy. This approach achieves good results for energy balancing and energy conservation.

The authors in [21] proposed a clustering algorithm for wireless sensor networks (WSNs) to improve energy efficiency and energy balance in a network. In this approach, a sector-shaped network is considered in which a sink node is deployed at the mid of each layer. Each layer is shaped like a ring and with a constant width. This sink node is capable of finding the optimal distribution of the cluster head by using the criterion. The rotation of cluster heads as distributed by the sink consume more energy. Therefore, the ECGD algorithm is designed to improve the energy efficiency of the network. The simulations reveal that this approach achieves good results for energy efficiency and network lifespan.

RAHMAN et al. introduced a cooperative routing algorithm for efficient energy and network reliability for UWSNs [22]. In the scheme, the source node initially selects a bent of data forwarder nodes in the communication range instead of a single data forwarder node. The local information of the node in terms of lowest depth and the residual energy of each node is used for the selection of data forwarder nodes. By considering the technique of the packet delivery probability (PDP) and the ratio of energy consumption, a fuzzy logic-based technique is used to find the optimal relay from the set of relay nodes. In addition, the scheme described, that most of the energy is lost due to the collision between the nodes. To avoid such issues, the scheme used a timer base schedule for data forwarding towards the sink node, which also reduces the network energy. At the destination, the multiple packets are combined through a diversity scheme and forward an optimal packet in the direction of the sink. The scheme improves the link quality, minimize the ratio of packet drops. However, it loses information accuracy and consumes high energy due to cooperation.

For localization and network reliability, the authors proposed both the cooperative and non-cooperative routing schemes in [8]. For the network coverage, the scheme used the mobile sink nodes, which are responsible to receive the packet from the deployed sensor nodes. In the non-cooperative scheme, to localize the un-localized nodes in the network, the mobile sink uses a global positioning system (GPS). This technique increases the network coverage and minimizes the localization error in the network. Moreover, for network reliability, a cooperative scheme is applied, which improves the link quality. For both the schemes, the nomination of the best data carrier node is based on the function of residual energy, SNR, and the lowest depth information. The cooperative scheme travels the packet over the multi-path instead of a single path, which enhances the link quality. The scheme prolongs the network lifetime, improves reliability and throughput. However, it renders high latency and reduces the data accuracy.

To enhance the network reliability and reduce the energy consumption the authors proposed a cooperative routing algorithm for UWSNs [23]. In the scheme, the selection of data forwarder nodes is based on the weighting function in terms of maximum remaining energy, maximum SNR and the lowest depth information. A single relay node is considered with the destination for the sack of multi-path routing. The whole network is splitted into four equal sub-zones and deployed nodes randomly in the ocean environment. The source node...
transmits the information toward both the relay and the destination node simultaneously. In the case of the high BER, the destination node sends a REQ towards the relay node, while the relay node responds over the destination REQ with an ACK. The multiple packets are received by the destination node and are merged through the FRC technique, and forwards an optimal packet towards the sink node. The constraint that the sensor nodes have limited communication range, the scheme uses multi-hoping. The scheme increases the reliability, reduces the ratio of packet drop and minimizes the latency with the loss of maximum energy consumption.

The authors in [24] aim to enhance the performance of the energy-efficient depth base routing scheme (EEDBR). The scheme deals with the lowest depth and the maximum residual energy for the choice of the best forwarder nodes. In order, to improve the network reliability, it forwards the packets into multi-path routing. The re-transmission phenomena are utilized, in case of best forwarder node received the corrupted data packet. The source node transmits the packet to the relay and destination node simultaneously due to the broadcast nature. The reason for the relay node nearest to the destination node reduces the distance, which results to reduce the network energy. The destination node combines the multiple packets by using the diversity technique (MRC) and advance an optimal packet towards the sink node. The scheme maximizes the throughput and reduces the ratio of packet drops. However, due to multiple nodes involving in the packet advancement, it consumes high energy and nodes die quickly.

In [25] the authors proposed a new scheme for underwater WSNs. The scheme reduces the latency and saves energy by forwarding the packet in the network diagonally. Due to such an assumption, it reduces the contribution of the nodes, which results in the reduction of energy consumption. The data forwarder node is selected by considering the lowest depth information. The scheme defines the flooding zone in the network by setting the criteria $\theta = 90 \pm 10K$, which helps to prevent the flooding region in the network. In order to broadcast the information in the direction of the sink, the scheme increases the $\pm K$ value which increases

### TABLE 1. Overview of the existing non-cooperative schemes.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Features</th>
<th>Advantages</th>
<th>Limitations</th>
<th>Publishing years</th>
</tr>
</thead>
<tbody>
<tr>
<td>[20]</td>
<td>Game theory-based clustering scheme, nodes initially transmit the hello message to the sink. The hello message contains the information: node ID and residual energy.</td>
<td>This approach achieves good results for energy balancing and energy conservation.</td>
<td>Unbalanced data reception at the sink node</td>
<td>2017</td>
</tr>
<tr>
<td>[14]</td>
<td>Non-cooperative scheme, chooses the best data forwarder node by considering the node position and highest remaining energy, used the FLJT to enhance the packet advancement.</td>
<td>Reduced the latency between the sender and receiver, balance energy consumption, and prolong the network life span.</td>
<td>Loss the network reliability, drop maximum information, and loss data accuracy.</td>
<td>2018</td>
</tr>
<tr>
<td>[15]</td>
<td>Non-cooperative routing scheme, set the criteria of regular packet and emergency packet for packets advancement, considers the minimum number of neighbor for the best forwarder node selection.</td>
<td>Balance energy consumption, reduces the latency, prolong the node battery life.</td>
<td>Due to single path routing, it lost the reliability and maximum packets are dropped.</td>
<td>2018</td>
</tr>
<tr>
<td>[16]</td>
<td>Multi-layered network routing scheme, the selection of data forwarder node is based over the node ID and the lowest distance.</td>
<td>Avoid the void zone occurrence in the network, consumes less energy, reduces the delay.</td>
<td>Lack of cooperation, loss the reliability, drop maximum information.</td>
<td>2018</td>
</tr>
<tr>
<td>[17]</td>
<td>Multi-path routing scheme, it used two techniques for data forwarding, i.e. effective routing and reactive routing, checking the channel condition before the packet transmission.</td>
<td>Reduced the latency during the packet transmission, consumes a relatively small energy and ensured the improvement in the PDR.</td>
<td>Increases the ratio of erroneous packet, nodes are died at quicker a rate.</td>
<td>2018</td>
</tr>
<tr>
<td>[18]</td>
<td>Uni-path routing algorithm, the best destination node is chosen by considering the lowest depth and the information of least neighbor of nodes, a cluster based network scheme.</td>
<td>Avoids the collision between the nodes, reduces the energy consumption, increases the network life span.</td>
<td>Rendered high delay due to long transmission path, lost the data accuracy.</td>
<td>2018</td>
</tr>
<tr>
<td>[19]</td>
<td>Sensing-based clustering routing, the overall network is divided into k-layers, finding optimal cluster.</td>
<td>Achieve good results in improving energy efficiency and network lifespan.</td>
<td>High network complexity</td>
<td>2019</td>
</tr>
<tr>
<td>[21]</td>
<td>A sector-shaped network is considered in which a sink node is deployed at the mid of each layer, the sink node is capable of finding the optimal distribution of the cluster head by using the criterion.</td>
<td>This approach achieves good results for energy efficiency and network lifespan.</td>
<td>It has low packet delivery ratio</td>
<td>2019</td>
</tr>
</tbody>
</table>


table 2. overview of the existing cooperative schemes.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Features</th>
<th>Advantages</th>
<th>Limitations</th>
<th>Publishing years</th>
</tr>
</thead>
<tbody>
<tr>
<td>[24]</td>
<td>Cooperative based multi-path algorithm, considered the highest energy and lowest depth information for the selection of data forwarder nodes, for diversity used MRC technique.</td>
<td>The scheme maximizes the throughput, reduces the ratio of packets drop and ensures maximum information towards the sink node.</td>
<td>Due to the maximum nodes involving in the packet advancement, it consumes high energy and nodes die quicker.</td>
<td>2014</td>
</tr>
<tr>
<td>[25]</td>
<td>Single path routing scheme, forwards the information packet in the specific zone, assume the incident angle criteria for the packet forwarding.</td>
<td>Reduced the un-contributed nodes ratio during the routing, saves the energy consumption, reduced the latency.</td>
<td>Reduced the link quality, loss the throughput.</td>
<td>2014</td>
</tr>
<tr>
<td>[23]</td>
<td>A cooperative based routing scheme, divided the network into four sub-regions, consider each node remaining energy, the SNR and the depth information is used for the relay and destination node nomination. Multi-path opportunistic routing scheme, used a set of relay nodes instead of single relay, data carrier nodes are selected by considering the function of depth and remaining energy information.</td>
<td>It maximizes the throughput and the reliability, while minimizes the packet drop and the latency.</td>
<td>Consumes maximum energy, unbalanced network, nodes die quickly.</td>
<td>2015</td>
</tr>
<tr>
<td>[22]</td>
<td>A localization based mobile-sink multi-path routing scheme, the information of maximum remaining energy, maximum SNR and the lowest depth are used for the selection of best forwarder nodes.</td>
<td>The scheme improves the link quality, minimize the ratio of packet drops and maximize the throughput.</td>
<td>Loss the data accuracy and consumes high energy due to cooperation.</td>
<td>2017</td>
</tr>
</tbody>
</table>

the flooding area and packet reached to the sink node. The random variable \( K \) defines energy consumption and latency during the packet forwarding. The scheme decreases energy consumption and latency. However, it reduces the link quality and drops maximum information.

### III. CHANNEL MODEL

Consider two sensor nodes communicating with each other through the acoustic link by using the non-coherent binary frequency shift keying (BFSK). To assume that, the trains of \( M \) packets are encoded into \( N \geq M \) packets and forward over the acoustics link using fountain codes. The group of the packets is subjected to path loss and path noise. Besides, the model of fading is involved by considering the K-distributions. In the acoustic channel, the channel model deals with the transmission of one-bit information by considering, the energy consumption, the transmission rate, the attenuation, noise, and fading.

#### A. ATTENUATION, NOISE, AND FAADING

The path loss in the acoustic WSNs communication depends on the energy loss. The parameters, distance, frequency and the available bandwidth of the acoustic communication increase the path loss. The attenuation in \( dB \) is calculated by using the Thorp’s formula [26].

\[
10 \log A(d, f) = 10 \log(d) + 10 \log(a(f))
\]  

(4)

The above equation shows that the combination of the absorption loss and the spreading loss creates the underwater attenuation, where the absorption coefficient is denoted by \( \log(a(f)) \). Moreover, when the acoustic signal moves away from the source it increases the spreading loss, which reduces its energy. The spreading geometry is denoted by \( k \), and it’s values are calculated for spherical spreading \( k = 1 \) and for cylindrical spreading \( k = 2 \). By using the empirical relationship in [26], the absorption coefficient in \( dB/Km \) can be calculated as.

\[
10 \log A(f) = 0.11f^2 + 44f^2 + 2.75f^2 + 0.003[dB/Km]
\]

(5)

The above equation describes the attenuation of the acoustic wave in the acoustic channel. The absorption and the transmission losses are the fundamental losses associated with the acoustic channel, causing attenuation. The reflection of the acoustic wave from the water surface or bottom also loss the acoustic energy. The amount of energy loss due to the reflection of water surface at incident angle \( \theta \) towards horizontally is denoted by \( ER_s \) and can be modeled empirically as [27].

\[
ER_s = 10 \log \left[ \frac{1 + (f/f_1^2)}{1 + (f/f_2^2)} \right] - \left( 1 + (90 - \omega)/60 \right)(\theta/30)^2
\]

(6)

The subscripts \( s \) in the above equation indicates the water surface, where the value of \( f_1 = \sqrt{10f_2} \) and \( f_2 = 378/\omega^2 \). Similarly the energy loss due to the reflection of water bottom is denoted as \( ER_b \) and is modeled as [28].

\[
ER_b = \frac{m}{\rho_1 \rho_2} \left[ \frac{(m \sin \theta_1 - (n^2 - \cos^2 \theta_1)^{1/2})^2}{m \sin \theta_1 - (n^2 - \cos^2 \theta_1)^{1/2}} \right] (7)
\]

\[
m = \frac{\rho_1}{\rho_2} \quad n = \frac{c_1}{c_2}
\]

(8)
In above model the subscripts $b$ indicates the water bottom, where $ho_1$ is the water density before the reflection and $ho_2$ is the water sediment density after reflection. While $c_1$ is the speed of the acoustic wave before reflection from the water surface and $c_2$ denoted the speed of the wave after reflection.

In addition to model the K-distribution fading of the acoustic channel, whose probability distribution function (PDF) is given by [29].

$$f_x = \frac{4}{\sqrt{\pi \alpha \Gamma(v)}} \left( \frac{x}{\sqrt{\alpha}} \right)^v I_{v-1} \left( \frac{2x}{\sqrt{\alpha}} \right)$$

The parameters $v$ and $\alpha$ denotes the shape and the scale respectively, $I_{v-1}$ shows the improved Bessel function of the $\nu - 1$ order and $\Gamma(v)$ is the Gamma function.

In order to calculate the K-distribution fading for a non-coding transmitted signal, while considering the non-coherent BFSK modulation is given in [30] and model as.

$$P_b(\tilde{y}) = \frac{\nu}{\Gamma(v)} \int_0^\infty \frac{e^{-u}}{2v + e^{uE_b/\nu}} du$$

where energy per bit is denoted by $E_b = \tilde{y}/R_b$, while $R_b$ is the bit rate.

B. ACOUSTIC WAVE ENERGY CONSUMPTION

In underwater communication, the transmission of information is set among the transmitter and the receiver by using the acoustic wave. The passive sonar equation is utilized to characterize the energy consumption of such modems. The equation of energy consumption for modeling the SNR in $dB$ is given below [28].

$$\text{SNR} = S_L - T_s L - N_I + D I \geq D T_h$$

In the above equation $S_L$ indicates the source level, and $T_s L$ is considered the transmission loss. While $DI$ and $N_I$ shows the directivity index (in the case of omnidirectional, it is considered zero) and the noise level, while $DT_h$ shows the specified threshold. The above equation shows that at the receiver, the transmitted signal can be detected by the acoustic modems, and the SNR of the acoustic signal should be equal or higher than the specified threshold. At the receiver, the acoustic wave intensity is presented by the source level. The noise level and the transmission loss bend the acoustic signal intensity when it moves away from the source. The source level $S_L$ in terms of signal intensity $SI$, when it is $1m$ away with respect to the source can be calculated as [31].

$$S_L = 10 \log \frac{SI}{5 \mu Pa}$$

where $\mu Pa$ considers the standard reference in the acoustic communication and it’s value is $0.67 \times 10^{-18} \text{ Watt/m}^2$. The signal intensity of $SI$ can be written as.

$$SI = 10^{S_L/10} \times 0.67 \times 10^{-18}$$

The above equation shows that in shallow water, when the $SI$ is positioned at 1 m distance away from the source node, it needs the source node transmitted power. Which can be calculated as.

$$PT_s = 2\pi \times 1m \times H \times SI$$

In deep water for the same SI the source transmitted energy is given as below.

$$PT_s = 2\pi \times (1m)^2 \times H \times SI$$

where $s$ presents the distance values with respect to the source, and $H$ shows the the sea depth.

C. ACOUSTIC WAVE SPEED

In the underwater acoustic channel, the contrary channel effects (fading, noise, and attenuation) reduces the speed of the acoustic wave. Especially the water temperature $T_w$, water salinity $S_w$ and the water depth $D_w$ varies the speed of the acoustic wave $v$. The acoustic wave speed is emphatically derived by using these parameters as below [32].

$$v = 1449 + 4.591T_w - 5.304 \times 10^{-2}T_w^2 + 2.374 \times 10^{-4}T_w^3 + 1.34(S_w - 35) + 1.63 \times 10^{-2}D_w + 1.675 \times 10^{-7}D_w + 1.025 \times 10^{-2}T_w(S_w - 35) + 7.139 \times 10^{-3}T_wD_w$$

The underwater acoustic signal is affected by the higher propagation delay as compared to terrestrial communication. The reason is the slow propagation speed of the acoustic signal in the acoustic channel than the radio wave. By using the above empirical equation, the acoustic speed can be calculated in such condition when the temperature is 0 to 30 $^\circ$C range, the depth between the 0 and 8000 m, and salinity in the range of 30 to 40 ppt.

D. BANDWIDTH AND TRANSMISSION RANGE

For long-distance of hundreds of k/M coverage range having a small bandwidth of few kHz, while for short-range of several meters may need a high bandwidth of hundred kHz. In a given time slot, the bandwidth is considered the maximum data which can be broadcasted in the channel. For various applications and different transmission ranges, the limits of the bandwidth are different. In general, the 100m or less than 100m transmission range uses the maximum available bandwidth. And for long-distance transmission range, such as mining detection and ocean, smaller bandwidth is used.

IV. PROPOSED SCHEMES

This section contains the complete description of the both proposed RSPR and CoRSPR schemes for acoustic WSNs.
A. RELIABLE SHORT-PATH ROUTING (RSPR) SCHEME

1) NETWORK MODEL

The network model depends on node capacity, network reliability, and network energy consumption. For the proposed schemes, the network is branched into two sub-regions, where the cross-sectional area is considered 500 meter in each direction. The deployment of the sensor nodes is considered randomly in each sub-region and each node has the sensing capability. The position of the two super-sinks is accomplished at the upper water surface, while the two sub-sink are placed at the mid-region with the same distance. The sensor node communicates with each other, sub-sinks and the upper super-sinks by using an acoustic wave. The super-sink nodes are considered the hybrid, which has the capability to communicate with the sensor node by using the acoustic link and with the offshore data center through the radio link. As the sensor nodes have a short transmission range, multi-hoping is used to cover the whole network. To save energy, it is assumed that the nodes nearest with respect to the super-sink send direct information. The sensed data is first gathered by the sub-sink transmission. The function value is calculated for each node the nodes nearest with respect to the super-sink send direct queue of neighbor and finds an optimal node for packet cover the whole network. To save energy, it is assumed that nodes have a short transmission range, multi-hoping is used to threshold (Dth) is applied, where each node retains its isolate queue of neighbor and finds an optimal node for packet transmission. The function value is calculated for each node using the equation given below.

$$
W_f = \frac{\max\left(\rho(d_{s,dsn}, f), \rho(d_{dsn,sk}, f)\right) \times \max(RE)}{\min\left(d_{s,dsn}^2, |d_{dsn,sk}|^2\right) \times \min(NH)}
$$

where the subscript $s$, $dsn$ and $sk$ indicates the source node, destination node, and sink node respectively. $\rho(d_{s,dsn}, f)$ and $\rho(d_{dsn,sk}, f)$ are the SNR of the identical source to destination and destination to sink node, while $NH$ is the number of hops. For simplicity, residual energy of each node is presented as $RE$ and the corresponding path distances are denoted as $|d_{s,dsn}|^2$ and $|d_{dsn,sk}|^2$ respectively. The Euclidean distance of each path can be calculated as,

$$
\begin{align*}
    d_{s,dsn} &= \sqrt{(x_s - x_{dsn})^2 + (y_s - y_{dsn})^2 + (z_s - z_{dsn})^2} \\
    d_{dsn,sk} &= \sqrt{(x_{dsn} - x_{sk})^2 + (y_{dsn} - y_{sk})^2 + (z_{dsn} - z_{sk})^2}
\end{align*}
$$

In above $x$, $y$ and $z$ shows the spatial coordinates. By considering the above weighting function each node creates a routing table and broadcasts it among the neighbor nodes in the transmission range. The nodes which receive a packet, wait for a certain interval of time (which is proportional to the processing and propagation delay in acoustic WSNs communication) to receive a reply. During the specified interval of time, if the desired node does not receive any reply, it sends the control packet again. The size of the control packet is specified 10 bytes which is broadcasted after some time for the sake of neighbor updating about the changing condition of the network.

2) NEIGHBOR IDENTIFICATION

After the random deployment of the sensor nodes, the nodes do not have any information about the neighbors in the transmission range. A control packet is broadcasted by each node among the neighbor nodes to make the entire network sensor node aware. The exchange of control packet keeps the nodes updated about the information of the highest residual energy, highest SNR, lowest distance and the minimum number of hops. Due to the exchange of control packet nodes identified its neighbor in the communication range. A depth threshold (Dth) is applied, where each node retains its isolate queue of neighbor and finds an optimal node for packet transmission. The function value is calculated for each node

FIGURE 1. The proposed network model of RSPR.

3) OPTIMAL RELAY CHOSEN AND DATA TRANSITION

This phase describes the selection of data forwarder node and information transition towards the sub-sink and then the super-sink. In the proposed RSPR scheme, the selection of best forwarder nodes is based on the weighting function parameters, i.e., highest residual energy, SNR, and lowest distance and the number of hops. After the control packet exchanging among the neighbor nodes, the source node stored all the neighbor nodes information in the routing table. The source senses the desired information and forwards it towards the data forwarder node. In the transmission range, the node which has the highest residual energy, maximum SNR value, lowest distance and the minimum number of hops is considered the destination nodes. In addition, a $Dth$ as shown in Figure 2 is applied in the transmission range forwarding mechanism to choose the finest data forwarder node for packet transition. The weighting function parameters help to select the robust node and the improved link for packet transition. Moreover, the distance and least number of neighbors reduce the path length and packet congestion, which minimizes the interference. The destination node received the information packet and checks the associated BER. In the case of BER exceeds the threshold value,
it discards the packet and waits for a certain interval of time to receive the second packet. The source node selects the second route, if one route is busy, having low SNR or maximum neighbor nodes exist. However, if the BER is less than the threshold, the destination accepts the packet and checks the sub-sink vicinity. It directly transmits the information packet towards the sub-sink, contingent upon the sub-sink lie in the destination node communication range. Multi-hoping is used due to the limited range of the destination node. The sub-sink nodes accept the information packet and forward it towards the upper super-sink node, which processes the packet further towards the offshore data center.

The scenario of the proposed RSPR single link scheme is shown in Figure 3, wherein each sub-region the robust data forwarder node is selected by considering the weighting function parameters. The scheme minimizes the network energy by using a $D_{th}$ in parallel with the highest residual energy, which keeps maximum nodes alive for a long time. The selection parameter maximum SNR helps for the best link selection, while the lowest distance reduces the packet transmission path and renders a small latency. The data forwarder node, by considering the minimal neighbor nodes, avoids the collision and interference and also saves the network energy.

![FIGURE 3. RSPR scheme data forwarding.](image)

B. COOPERATIVE RELIABLE SHORT-PATH ROUTING (CoRSPR) SCHEME

1) RELAY AND DESTINATION NODE SELECTION

The source node in the CoRSPR scheme forwards the data packet after knowing the desired information among the neighbor nodes. The source node at each region transmits the information packet directly to the nearest sub-sink node if it lies inside the communication range. Moreover, if the sub-sink does not exist in the communication range, then the source node chose the most optimal nodes, which transmits further the information toward the sub-sink node. The selection of best destination nodes is based on the highest residual energy, highest SNR, lowest distance and the minimum number of the neighbor in the transmission range. In the communication range, each node calculates the following function for the control packet which is exchanged among the neighbor (18), shown at the bottom of this page, where $\rho(d_{s,r,f})$ is the corresponding path SNR from the source towards the relay, while $|d_{s,r}|^2$ shows the distance between the source and the relay node. The source node collects the information in terms of weighted function and stores it into the routing table. The neighbor node in the communication range, which has the highest function value is considered as the destination node. It is also given the highest priority node for packet transition. For cooperation, the second-highest function values node is known as the relay node.

In the proposed scheme a single relay node is considered with the destination. Instead of multiple relay nodes, the single relay node reduces the ratio of nodes contribution during the packet advancement, which reduces the energy consumption.

$$W_f = \frac{\max \left( \rho(d_{s,dtn,f}), \rho(d_{s,r,f}), \rho(d_{r,sk,f}) \right) \times \left( \max(\text{RE}) \right)}{\min \left( |d_{s,dtn}|^2, |d_{s,r}|^2, |d_{r,sk}|^2 \right) \times \min(\text{NH})}$$

(18)
The nodes in each zone having the same value of the function but have unique IDs discriminates the destination node position. Besides this, a $D_{th}$ is applied in the packet advancement during the cooperation, which helps to hold a separate link among the neighbor nodes.

As displayed in Figure 5, the source node selects the node 4 is a destination and node 3 is a relay node instead of node 5 and 6. By using such a mechanism, it minimizes energy consumption and improves the network life span. When the relay node received the information packet it waits for specified holding time before forwarding the packet further. During the holding time, it discards the other packet received from the neighbor nodes or through a direct link from the source node. In the proposed Cooperative RSPR scheme the delay is minimized by dividing the network into two sub-regions. The selection parameter minimum distance also ensures quick communication. The selection parameter highest SNR improves the link quality and the minimum neighbor nodes reduce the interference and packet congestion as shown in Figure 6.

2) DATA ADVANCEMENT AND COOPERATION
In this phase, the destination and the relay node receives the information packet simultaneously form the source node. At the destination, it checks the associated BER and accept the packet and acknowledge (ACK) the source node, if BER is less than the threshold value. However, if the BER exceeds the threshold value, the destination node sends a request (REQ) towards the relay node. The relay node responds over the
destination REQ and sends an ACK also towards the destination node. The relay node does not send the packet to the destination node without receiving any REQ from the destination. The scenario of ACK and REQ is shown in Figure 7. The relay cooperates in such a case, in which it receives the REQ signal from the destination node. After securing the two packets, the destination node combines these two packets through a diversity technique. An optimal packet is received by the sub-sink, in case it lies inside the communication range of the destination. Otherwise, multi-hoping is used to forward the packets first towards the sub-sink and then the super-sink at the water surface.

A single relay cooperation scheme is shown in Figure 8, where two state scheme is considered for data advancement among the source, the relay, and the destination node. The scheme ensures non-overlapping transmission in the queue, which is done in two states. In-state first, the source node forwards the packet towards the relay and the destination node simultaneously due to the broadcast nature. While in the second state, the relay node advances the packet towards the destination node in a certain condition. In the first state, the packet received by the destination and the relay node can be calculated as [33],

\[ y_{sd} = \sqrt{T_s h_{sd}} + n_{sd}(f) \]  \hspace{1cm} (19)  
\[ y_{sr} = \sqrt{T_s h_{sr}} + n_{sr}(f) \]  \hspace{1cm} (20)

In the above equations, \( y_{sd} \) and \( y_{sr} \) are the received packet at the relay and the destination nodes respectively. \( T_s \) is the original transmitted signal, while \( h_{sd} \) and \( h_{sr} \) are the corresponding link gain. The noise of certain paths is denoted by \( n_{sd} \) and \( n_{sr} \) which are considered the channel coefficient. These channel coefficients are modeled as a Gaussian random variable having \( \sigma^2 \) variance and zero mean. The \( \sigma^2 \) can be modeled in [34],

\[ \sigma^2 = \eta d_{sd}^{-\alpha} \]  \hspace{1cm} (21)

where \( d_{sd} \) denoted the distance between the source and the destination node, \( \eta \) is a constant factor which is dependent on the propagation, while \( \alpha \) is denoted the propagation loss.

In the second state, the relay node responds over the destination REQ and amplifies the packet by multiplying a constant term \( \beta \) with the signal. The \( \beta \) can be modeled as [34],

\[ \beta = \sqrt{\frac{T_r}{T_s \vert h_{sr} \vert^2 + \sigma^2}} \]  \hspace{1cm} (22)

In above \( T_s \) is the source signal and \( T_r \) is the receiver signal, while \( h_{sr} \) considers the path characteristic from the source towards the relay node. The received signal at destination forwarded by the source node can be modeled as [33],

\[ y_{rd} = \beta \sqrt{T_r h_{rd}} + n_{rd}(f) \]  \hspace{1cm} (23)

where \( h_{rd} \) is the source to the destination link gain and \( n_{rd} \) is the associated noise of the desired path. The two received packets are combined by using a diversity scheme and forwards an optimal packet towards the sub-sink and then the super-sink towards the water surface. The super-sink extracts the desire information and forwards the packet in the
direction of the offshore data center for further processing. The Flow chart is shown in Figure 4 defines the complete routing process for both RSPR and CoRSPR schemes.

3) DIVERSITY TECHNIQUES
In the proposed CoRSPR scheme, instead of MRC, the fixed ratio combine (FRC) is used as a diversity strategy. In order, to enhance the channel aspects and reduce the effects of the shadow zone and other adverse channel characteristics, the FRC is just weighted with a constant ratio adding with the incoming signal. Moreover, the MRC needs full channel state information (CSI). The FRC can be expressed as below in case of a single relay with the destination.

\[ y_d = m_1y_{sd} + m_2y_{rd} \]  \hspace{1cm} (24)

In the above \( y_d \) is the merged output packet of the destination node, while \( m_1 \) and \( m_2 \) are the constant weights of the two paths. These constant weights can be extended, in case of the number of relay nodes extending, which are considered as the ratio of channel coefficient and power function and can be modeled in [35],

\[ m_1 = \frac{\sqrt{T_s|h_{sd}|^2}}{\sigma_o^2} \]  \hspace{1cm} (25)
\[ m_2 = \frac{\sqrt{T_s|h_{rd}|^2}}{\sigma_o^2} \]  \hspace{1cm} (26)

In case of amplifying and forwarding an optimal ratio of the weights constant are considered 2 : 1 and expressed as [33],

\[ m_1 = \frac{\sqrt{T_s|h_{sd}|^2}}{\sigma_o^2} \]  \hspace{1cm} (27)
\[ m_2 = \frac{\sqrt{T_s|h_{rd}|^2}}{\sigma_o^2} \]  \hspace{1cm} (28)

If a signal is broadcasted and considered its average energy of unity, then the SNR of the signal can be computed as [35],

\[ \rho = \frac{T_s|h_{sd}|^2 + T_r|h_{rd}|^2}{\sigma_o^2} \]  \hspace{1cm} (29)

V. SIMULATION RESULTS AND DISCUSSIONS
The realization of the proposed schemes RSPR and CoRSPR is accomplished by using the MATLAB 2018b. The total network area is considered 500-m in all directions, while the total number of 250 nodes are deployed randomly at different distances. The communication between the sensor node is accomplished by using the acoustic Link Quest UWM 2000 modem [36]. Such a modem has a working depth of 200 m to 400 m, which is suitable for the proposed depth of 500 m. The data rate is considered 9.6 kbps, while the transmission power is 2 W, the reception power is 0.8 W and the idle power of the modem is 8 mW. The network is split into two sub-regions, where each node has a limited communication range of 100 m in all directions. Initially, the sensor nodes in the network are energized with 10-J energy. The capacity of the control packet is 50 bits while the data packet size is considered 1600 bits. The total allowable bandwidth is 30 kHz. In a certain interval of time, if the channel is busy, the sensor node drops the packet. The proposed RSPR and the CoRSPR schemes are compared with the DBR, CoDBR and ODBR [37] schemes. The reason behind this comparison is that DBR, ODBR and RSPR schemes forward the data in a non-cooperative manner. In order, for reliability, the CoDBR and the CoRSPR schemes used multi-path routing for data advancement. To average the simulation results, 100 rounds are considered due to the fluctuating in each scheme after 100 rounds. The parameters used for simulation are given in the Table 4.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acoustic wave speed</td>
<td>1500 m/s</td>
</tr>
<tr>
<td>Control packet size</td>
<td>50 bits</td>
</tr>
<tr>
<td>Data packet size</td>
<td>1600 bits</td>
</tr>
<tr>
<td>Data rate</td>
<td>9600 bits/second</td>
</tr>
<tr>
<td>Deployment area depth</td>
<td>500 m</td>
</tr>
<tr>
<td>Deployment area width</td>
<td>500 m</td>
</tr>
<tr>
<td>Depth threshold</td>
<td>60 m</td>
</tr>
<tr>
<td>Initial energy</td>
<td>10 J</td>
</tr>
<tr>
<td>Network depth</td>
<td>500 m</td>
</tr>
<tr>
<td>Network height</td>
<td>500 m</td>
</tr>
<tr>
<td>Network width</td>
<td>500 m</td>
</tr>
<tr>
<td>Number of sub-sinks</td>
<td>2</td>
</tr>
<tr>
<td>Number of super-sinks</td>
<td>2</td>
</tr>
<tr>
<td>Reception power</td>
<td>0.8 W</td>
</tr>
<tr>
<td>Transmission power</td>
<td>2 W</td>
</tr>
<tr>
<td>Transmission range</td>
<td>100 m</td>
</tr>
<tr>
<td>Total available bandwidth</td>
<td>30000 Hz</td>
</tr>
<tr>
<td>Total sensor nodes</td>
<td>250</td>
</tr>
<tr>
<td>Wind speed</td>
<td>10 m/s</td>
</tr>
</tbody>
</table>

A. TOTAL NUMBER OF DEAD NODES
The nodes which drain their battery power are considered dead nodes. The comparison of all the schemes in terms of dead nodes is plotted in Figure 9. The ratio of the dead nodes in the proposed RSPR scheme is lower than the rest of all the schemes. The reason behind this achievement is the minimum energy consumption in the RSPR scheme. Moreover, the network of the RSPR scheme is split into two regions and the placement of sub-sinks into the middle of the network reduces the path length, which results in reducing energy consumption. In addition, the scheme uses the weighting function parameters of the highest residual energy for the choice of the destination node, which also helps to choose the robust node for packet advancement. The CoRSPR scheme also reduces the dead ratio due to assigning more energy to the lowest depth node as compare to the DBR, CoDBR and ODBR schemes. Moreover, the proposed CoRSPR scheme is a multi-path routing scheme, where data forwarder nodes cooperate with each other for packet advancement. Due to region-based networks and the utilization of weighting function, the CoRSPR also consumes low energy and reduces the ratio of dead nodes. The DBR and ODBR is a single-path routing scheme, which considers only depth information and reduces the ratio of dead nodes due to low energy consumption. In the CoDBR scheme, two relay nodes are selected with the destination by considering only depth information, which
forwards the packet from the bottom to the upper sink node by following the long transmission path. Thus the scheme consumes more energy and nodes die quickly.

**B. ENERGY LEFT IN THE BATTERY**

Energy left in the battery is also known as residual energy. The Figure 10 shows the plot of energy left in the battery of all the schemes. The residual energy of the proposed RSPR and CoRSPR schemes is much high than the DBR, CoDBR and ODBR schemes. The reason for the saving high energy in the RSPR scheme is the selection of an optimal destination node by considering the weighing function parameter highest residual energy. Secondly, the scheme also reduces the interference and collision of the neighbor nodes, which also saves the node battery power. The division of the network into two sub-regions keeps balancing the entire network energy and nodes uniformly consume its battery power during the routing. In the CoRSPR scheme, for the same network as the RSPR scheme, and the usage of the robust function parameters for the relay and the destination node selection are key techniques to minimize the network energy. The contribution of cooperation among the single relay and the destination node ensures maximum information at the super-sink node with the cost of low energy consumption. The DBR and ODBR schemes follow the long transmission path from the bottom source to the upper sink node for packet advancement. Due to the unbalanced network in these two schemes, the nodes collide with each other and drain their battery power quickly. The CoDBR scheme uses the cooperation of two relay nodes with the destination which consume high energy. Moreover, the multi-path routing by considering only the lowest depth criteria in CoDBR scheme, it increases the node interference and results in small energy left in the node battery.

**C. PACKETS ACCEPTANCE RATIO**

The packet acceptance ratio (PAR) is the total number of packets secured by the super-sink node. Figure 11 demonstrates the comparison of all schemes in terms of PAR. The proposed scheme CoRSPR achieves the highest value of PAR due to single relay cooperation with destination and short transmission path. In addition, the selection of data forwarder nodes by considering the function parameters, the highest SNR also selects the robust link for data transmission. In the scheme, the source node selects the link which has the highest SNR and lowest distance from the sub-sink node, which ensures maximum information and quick delivery of the packet to the desired sink nodes. Moreover, from round 0 to till round 200 the CoDBR scheme hold a maximum PAR value than the RSPR, ODBR, and DBR schemes but lower than the CoRSPR scheme. The reason is that the CoDBR scheme forwards the data using the cooperation of two relay nodes with the destination, which ensures maximum packet...
transmission towards the super-sink nodes. However, after such rounds, the lowest depth nodes of the CoDBR scheme die quickly due to the burden of continuous data transmission to the super-sink nodes. In such a scenario, the RSPR scheme copes the lowest depth node early dead by keeping the network balance and secure the uniform data advancement to the final destination. The DBR and ODBR schemes are single-path routing schemes that reduce the reliability and drop maximum information.

### D. TOTAL END-TO-END DELAY

The comparison of all schemes in terms of end-to-end delay in seconds is depicted in Figure 12. The plot shows that the proposed RSPR scheme yields a small delay as compared to all the schemes. The DBR scheme is the second smallest latency scheme, while CoRSPR is the third scheme having a small delay. In the RSPR scheme, the nodes forward the data packet through single-path routing, which decreases the latency due to the placement of sub-sinks in the middle of the network. In the scheme, the nodes close to the sub-sink and super-sink directly send the information towards it. In addition, the propagation time is reduced by considering the lowest distance as the selection criteria for the data forwarder nodes, which also reduced the latency. Moreover, the DBR scheme also renders the smallest latency, because it considers only the lowest information for the selection of data forwarder node. Secondly in DBR due to single-path routing latency is reduced. The reason of small latency produced by the CoRSPR scheme is due to the cooperation of single relay node with the destination. Moreover, the selection parameter lowest distance and dividing the network into two sub-regions also reduce the latency in the CoRSPR scheme. The placement of sub-sink nodes also ensures quick transmission of packets toward the sub-sink node. In CoDBR scheme the reason for long propagation delay is due to the cooperation of two relay nodes with the destination node. Secondly, the communication of data packets from the bottom toward the upper offshore data center also increases the latency. All the nodes in ODBR scheme follows a single path for data transmission, due to this the delay of the ODBR is high as compared to the proposed schemes.

### E. SUCCESSFULLY RECEIVED PACKETS AT THE SINK

The plot of the packets received successfully at the sink node of all the schemes is presented in Figure 13. In CoRSPR scheme, the ratio of successful packets secured by the sink node are maximum than the rest of all the schemes. The reason is that the CoRSPR scheme deals with the link quality by checking the SNR value for the sack of the relay and the destination choice. In addition, the replacement of two sub-sink nodes at the middle of the network also ensures maximum packets delivery to the sub-sink and then super-sink nodes. During the routing, the robust function parameters for the selection of data forwarder nodes help to chose those nodes as the data forwarder nodes, which are good in all aspects and delivers maximum packets towards the super-sink nodes.

---

**TABLE 5.** Dead nodes after equal interval of time.

<table>
<thead>
<tr>
<th>S.No</th>
<th>Protocol Name</th>
<th>Dead nodes at 200 rounds</th>
<th>Dead nodes at 400 rounds</th>
<th>Dead nodes at 600 rounds</th>
<th>Dead nodes at 800 rounds</th>
<th>Dead nodes at 1000 rounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DBR</td>
<td>40</td>
<td>120</td>
<td>160</td>
<td>210</td>
<td>250</td>
</tr>
<tr>
<td>2</td>
<td>CoDBR</td>
<td>80</td>
<td>170</td>
<td>240</td>
<td>220</td>
<td>250</td>
</tr>
<tr>
<td>3</td>
<td>RSPR</td>
<td>0</td>
<td>40</td>
<td>130</td>
<td>180</td>
<td>220</td>
</tr>
<tr>
<td>4</td>
<td>CoRSPR</td>
<td>40</td>
<td>150</td>
<td>190</td>
<td>210</td>
<td>240</td>
</tr>
<tr>
<td>5</td>
<td>ODBR</td>
<td>50</td>
<td>150</td>
<td>190</td>
<td>220</td>
<td>235</td>
</tr>
</tbody>
</table>

**TABLE 6.** Energy left after equal interval of time.

<table>
<thead>
<tr>
<th>S.No</th>
<th>Protocol Name</th>
<th>Energy left at 200 rounds</th>
<th>Energy left at 400 rounds</th>
<th>Energy left at 600 rounds</th>
<th>Energy left at 800 rounds</th>
<th>Energy left at 1000 rounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DBR</td>
<td>1250 J</td>
<td>550 J</td>
<td>200 J</td>
<td>100 J</td>
<td>0 J</td>
</tr>
<tr>
<td>2</td>
<td>CoDBR</td>
<td>800 J</td>
<td>300 J</td>
<td>150 J</td>
<td>0 J</td>
<td>0 J</td>
</tr>
<tr>
<td>3</td>
<td>RSPR</td>
<td>1800 J</td>
<td>1000 J</td>
<td>500 J</td>
<td>250 J</td>
<td>100 J</td>
</tr>
<tr>
<td>4</td>
<td>CoRSPR</td>
<td>1500 J</td>
<td>600 J</td>
<td>300 J</td>
<td>100 J</td>
<td>100 J</td>
</tr>
<tr>
<td>5</td>
<td>ODBR</td>
<td>1450 J</td>
<td>600 J</td>
<td>300 J</td>
<td>100 J</td>
<td>0 J</td>
</tr>
</tbody>
</table>

**FIGURE 12.** End-to-end delay in second.
Moreover, in the RSPR scheme, the same weighting function parameter for the selection of destination node increases the ratio of packet transmission. In RSPR scheme, maximum information is secured by the sub-sink node in behalf of the short transmission path. While in CoDBR scheme, the reason of minimum packet transmission is due to the long transmission path and the early death of the lowest depth nodes, where maximum packets are dropped when there is no neighbor exist in the communication range. The DBR and ODBR schemes consider only depth criteria for destination node selection, which is not enough to decide the link quality during the routing. This results in increasing the ratio of erroneous packets and discard maximum packets.

VI. CONCLUSION AND FUTURE WORK

In UWSNs, the attenuation and channel noise are the two major constraints which affect the reliable delivery of data,
packets from the water bottom to the water surface. The underwater nodes possess very limited energy which dies quickly due to unbalanced load during data exchanging, which in turn reduces the network stability. This paper presents two routing techniques: RSPR and CoRSPR. First technique makes reliable communication, while second technique improves network stability. The RSPR technique is a single-path routing algorithm, which minimizes the energy consumption during the routing. The destination node is chosen by considering the weighting function parameters highest residual energy, highest SNR, lowest distance and the least number of hops. The destination node receives the packet and forwards it toward the sub-sink directly, if it lies inside the communication range. Otherwise, uses multi-hoping if sub-sink does not exist in the communication range. In such a way the scheme, reduces the energy consumption, avoids the interference between the nodes and ensure quick transmission of packets towards the super-sink nodes. In addition, the division of the network into two sub-regions also reduces the path length and avoid the collision. The CoRSPR technique is the multi-path routing algorithm, which increases the network reliability. For the same network and the same weighting function, the CoRSPR scheme uses a single relay node with the destination. The source sends the packet towards the relay and destination simultaneously, where the destination checks the packet BER and sends a REQ to the relay in case of high BER than the threshold. The received two packets at the destination node are combined by using the FRC technique and forwards an optimal packet toward the sub-sink node. Like the RSPR scheme, the CoRSPR scheme also consumes minimum energy and avoids the collision due to balance network. The accuracy and quick transmission of packets are ensured due to the consideration of the highest SNR and lowest distance as the selection parameters. The schemes are analyzed with the DBR and the CoDBR schemes and validate the enhancement of dead nodes, energy left in the battery, PAR, E-2-E delay and packet received at the sink node.

In the future, it will be interesting to see how opportunistic routing can be used with cooperative RSPR routing scheme. The opportunistic routing sends the information with a set of relay nodes instead of a single relay. The scheme prolongs the network lifetime, retain nodes alive for a long time and reduces the early death of the nodes by saving each node energy consumption. We believe that the proposed schemes have significant potential for providing opportunistic routing in under water wireless sensor networks.

VII. DATA AVAILABILITY
The simulation codes are available from the first author upon reasonable request.

REFERENCES


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