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Research Article

A Localization Based Cooperative Routing Protocol for Underwater Wireless Sensor Networks

Nadeem Javaid,[1] Hammad Maqsood,[1] Abdul Wadood,[2] Iftikhar Azim Niaz,[1] Ahmad Almogren,[2] Atif Alamri,[2] and Manzoor Ilahi[1]

[1]*COMSATS Institute of Information Technology, Islamabad 44000, Pakistan*
[2]*Research Chair of Pervasive and Mobile Computing, College of Computer and Information Sciences, King Saud University, Riyadh 11633, Saudi Arabia*

Correspondence should be addressed to Nadeem Javaid; nadeemjavaidqau@gmail.com

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Localization is one of the major aspects in underwater wireless sensor networks (UWSNs). Therefore, it is important to know the accurate position of the sensor node in large scale applications like disaster prevention, tactical surveillance, and monitoring. Due to the inefficiency of the global positioning system (GPS) in UWSN, it is very difficult to localize a node in underwater environment compared to terrestrial networks. To minimize the localization error and enhance the localization coverage of the network, two routing protocols are proposed; the first one is mobile autonomous underwater vehicle (MobiL-AUV) and the second one is cooperative MobiL (CO-MobiL). In MobiL-AUV, AUVs are deployed and equipped with GPS and act as reference nodes. These reference nodes are used to localize all the nonlocalized ordinary sensor nodes in order to reduce the localization error and maximize the network coverage. CO-MobiL is presented in order to improve the network throughput by using the maximal ratio combining (MRC) as diversity technique which combines both signals, received from the source and received from the relay at the destination. It uses amplify-and-forward (AF) mechanism to improve the signal between the source and the destination. To support our claims, extensive simulations are performed.

1. Introduction

In recent years, UWSNs are getting more attention due to useful applications such as military surveillance, oil exploration, and seismic and environmental monitoring. The UWSN consists of sensor nodes which are deployed inside the water. The main task of these sensor nodes is to sense the underwater environment and transmit the sensed data to the onshore sink by using acoustic signals. At the same time, localization is one of the major issues in UWSNs [1], especially in the design of the routing protocol. Due to harsh underwater environments, data must be gathered with the location information. Therefore, a sensor node must know its location at the time of deployment to recover the data from the exact locations. Although in manual deployment sensor nodes know their exact location, however, due to dynamic nature of underwater, manual deployment is not feasible. In this case, sensor nodes are randomly deployed in order to collect the information from the areas which are difficult to reach. Localization is very important in many applications like a battlefield area, catastrophic areas, and so on. Due to water currents, localization is a challenging task in UWSNs. Generally, acoustic waves are used in underwater communication; these waves have high propagation delay and extremely low bandwidth which lead to high probability of localization error. Unlike terrestrial WSNs, the underwater network does not support GPS for position estimation. Thus, efficient localization schemes are needed to estimate the position(s) of the node(s).

Nowadays, cooperative communication has gained much attention in UWSNs due to its unique ability of joining erroneous packets at the destination by using cooperative diversity techniques. While minimizing the energy consumption with fewer retransmissions, a cooperative process involves

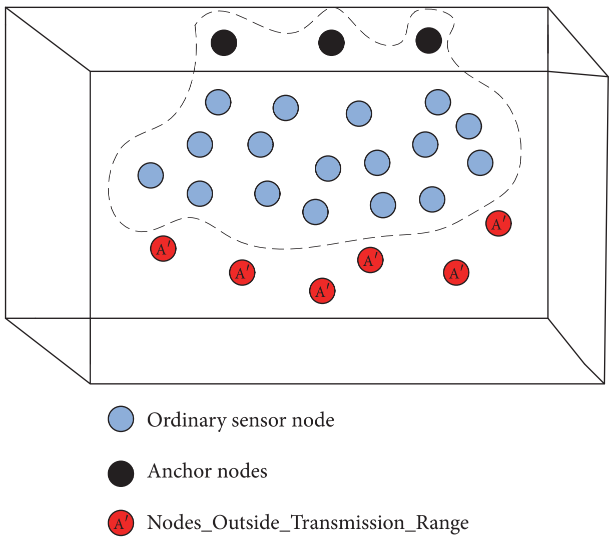

Figure 1: Anchor nodes coverage problem.

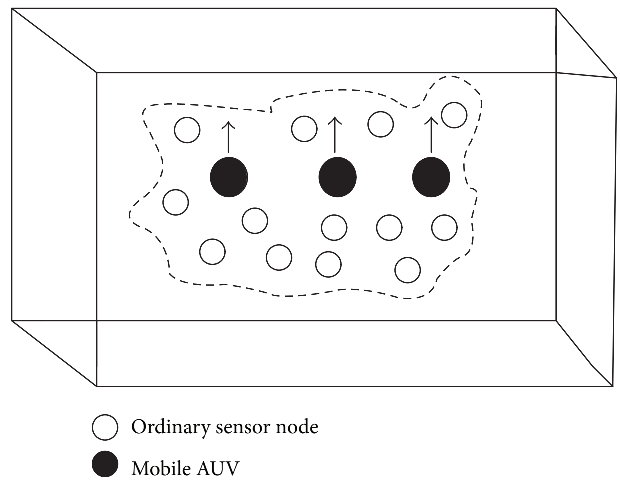

Figure 2: AUVs coverage area.

the neighboring nodes to relay the data of a particular source node to the destination. The main techniques used to relay data from the source node to the destination node are AF and decode-and-forward (DF). In the AF relaying technique, the relay node amplifies the received signal and then transmits the amplified version of the signal towards the destination, whereas in the DF scheme the relay node decodes the received signal and then transmits the signal to the intended destination.

After the localization, the next objective is data routing. For this purpose various attempts in the literature have been proposed. In MobiL [2], anchor nodes deployed on water surface are used as reference nodes for the localization of ordinary nodes. However, nodes that are not in the transmission range of these anchor nodes are localized as shown in Figure 1. The nodes with label A′ are not in the transmission range of anchor nodes which results in higher chance of the localization error. The anchor nodes do not provide enough coverage to localize the nodes. So, the remaining nonlocalized nodes will make reference to the other ordinary nodes resulting in a high localization error.

To encounter these problems, two localization routing schemes are proposed in this paper: (i) MobiL-AUV [3] and CO-MobiL. In MobiL-AUV, three mobile AUVs are deployed underwater at predefined depth (d). The mobile AUVs accelerate towards the surface to find their own three-dimensional coordinates via a GPS satellite and dive back to the underwater as shown in Figure 2. The mobile AUVs cover a large network volume and act as reference nodes for nonlocalized nodes, minimizing the localization error due to minimum distance between mobile AUVs and nodes.

We also present a region based cooperative routing mechanism as shown in Figure 3. The nodes closer to the onshore sink (nodes in transmission range of sink) are considered in region one, and the rest of the nodes are considered in region 2. Nodes in region 1 directly communicate with the sink consuming less energy. On the other hand, nodes in region 2 communicate via a cooperatively chosen best relay.

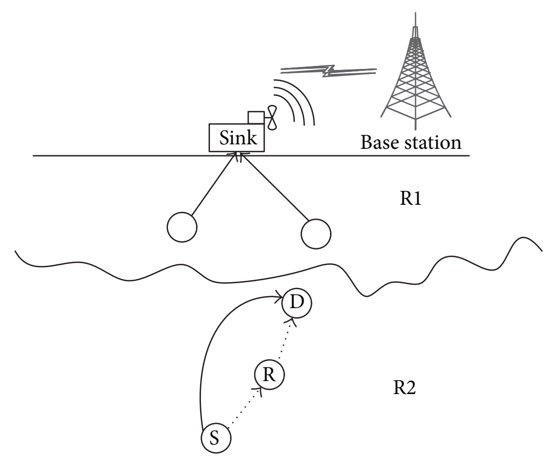

Figure 3: Region base cooperation.

The remainder of the paper is organized as follows. The related existing work is summarized in Section 2. Section 3 discusses our scheme in a detail. Then, simulation results are presented and discussed in Section 4 and finally Section 5 concludes our work by discussing the findings of our schemes.

2. Related Work

In this section, we discuss recent routing protocols for UWSNs in two categories: (i) nodes mobility and localization based and (ii) cooperation based.

2.1. Node Mobility and Localization. In [4], the authors propose a distributed localization technique for UWSNs. The authors introduce two types of nodes: anchor nodes and ordinary nodes. The anchor nodes are used as reference nodes which are localized, whereas the ordinary nodes do not know their location. The main focus is on the localization of ordinary nodes by using distributed localization techniques.

The authors in [5] propose a centralized localization technique in which each sensor node sends its location information to the onshore sink. The scheme results in a higher energy utilization as well as a high localization error. The centralized localization schemes are not suitable for a high level UWSN task.

Performance analysis of ranged base and distributed localization techniques and protocols are presented in [6]. The authors conclude that the existing protocols that are made for small scale networks cannot be used in large scale networks.

Received signal strength (RSS) and ad hoc on-demand distance vector protocol to detect the attacks on the localization mechanism is proposed in [7]. The authors choose the best and secured neighbors for data forwarding process, such that data is transmitted through the qualified secured neighbors.

The authors in [8] propose correction received signal strength index (RSSI) localization scheme for UWSNs. The reference nodes send beacon message; on receiving a message, the nodes use median mean filtering to process the information and by the help of weighted centroid technique, the unknown node finds its three-dimensional coordinates.

Optimization and minimum cost factor is briefly explained in [9]. The authors focus on localizing the nonlocalized nodes by utilizing lower number of anchored nodes. To efficiently use the anchor nodes, the authors propose the greedy mechanism to select the anchor nodes pair. This scheme also introduces the confidence interval methodology to handle the localization error issues.

In [10], multihop localization process is proposed. This scheme has two phases: in the first phase, the nodes find the shortest link between anchored nodes and ordinary nodes by using a greedy algorithm. In the second phase, the nonlocalized nodes find their positions by using trilateration scheme.

The time difference of arrival (TDOA) based localization technique for a heterogeneous network is proposed in [11]. In this scheme, there are three types of nodes: the target nodes, the anchored nodes, and the reference nodes. In the first step, the TDOA of minimum four nodes sets is calculated and in the second step the values with position information of localized nodes are used to find the position of the target nodes.

The authors in [12] propose a scalable localization technique. The protocol has two phases: anchored node localization and nonlocalized node localization. On the basis of node's past mobility, the nodes predict their future position. During anchor nodes localization, the anchor nodes use the lateration technique to find their respective coordinates.

In [13], the authors present three different deployment strategies and briefly explain their effects on localization. The authors conclude that tetrahedron deployment strategy shows good results as compared to other deployment strategies in terms of the localization error.

An analysis of localization process is proposed in [14]. The authors make use of asynchronous clock to make anchor nodes asynchronous. The asynchronous anchor nodes help other nodes to find their position in an effective way with less localization error.

Localization mechanism for nonlocalized nodes is discussed in [15]. The protocol consists of two parts: in the first part, sensor nodes estimate their distance from the anchored reference node and in the second part sensor nodes utilize their estimated distance to find their coordinates with a trilateration mathematical technique.

The authors [16] propose a hybrid localization scheme for ocean sensor networks. This localization scheme is divided into three steps; in the first step, the group nodes are localized to act as anchor nodes, in the second step with the help of anchor nodes, the nonlocalized nodes find their coordinates to become localized, and in the final step, the free drifting nodes find their location by applying floating node localization algorithm (FLAP).

In [26], a network access mechanism is presented in three phases: (i) network discovery, (ii) finding of a relay path, and (iii) association for multihop underwater acoustic local area network. It achieved the network lifetime, high packet delivery ration with the balanced energy consumption.

Wu et al. [27] propose a network coding based routing protocol for UWSNs. In this scheme, the authors present three algorithms: (i) time-slot based routing (TSR) to reduce the sensor nodes conflict due to underwater dynamic nature, (ii) time-slot based balanced routing (TSBR) in order to minimize the energy consumption, and (iii) time-slot based balanced network coding algorithm to balance the energy consumption over long routing paths.

An energy efficient depth based routing protocol is proposed in [28]. It considers a low depth sensor node that has high residual energy to transmit a data packet to maximize the network lifetime. It performs better in dense deployment; however in sparse conditions, it consumes more energy resulting in low network lifetime and lower packet delivery ratio.

Authors in [29] propose an energy efficient routing protocol based on a physical distance and a residual energy (ERP^2R) for UWSNs. ERP^2R uses physical addresses of nodes to minimize the location error. It also enhanced the network lifetime with balanced energy consumption.

An energy efficient routing algorithm for UWSN inspired by ultrasonic frog mechanism is presented in [30]. In order to improve the network lifetime, it utilizes the gravity function to indicate the attractiveness of network nodes for each other. This scheme achieves comparatively a high network lifetime and more packet acceptance ratio.

Cao et al. propose a balanced transmission algorithm for UWSNs [31]. Authors divide the transmission into two phases: (i) an energy efficient algorithm based on the optimal distance to optimize the energy consumption of the network and (ii) data load algorithm which balances the data load on the sensor nodes. This protocol achieves the energy efficiency by balancing the data load. The comparison of the discussed routing protocols (Node Mobility and Localization) is given in Table 1.

Table 1: State-of-the-art related work: Node Mobility and Localization.

Technique	Features	Achievements	Limitations
MobiL: a 3-dimensional localization scheme for mobile UWSNs [2]	Handles nodes mobility and nodes localization	Mobility model for mobile nodes, efficient node localization with less error	Large distance between ordinary nodes and reference nodes resulting in localization error
Design and implementation of a time synchronization-free distributed localization [4]	Event-driven time synchronization-free distributed localization scheme	Successful efficient nodes localization	ToA based distance estimation method is used, which causes error if delay occurs
A survey of architectures and localization techniques for UASNs [5]	Survey of UASNs and localization techniques	Briefly explaining the existing localization techniques and their drawbacks	Performance analysis of different localization methods with different mobility models is neglected
Performance evaluation of localization algorithms in large scale underwater sensor networks [6]	Comparison of ranged base and distributed localization schemes	Analysing different schemes and explaining briefly their advantages and disadvantages	Analysis of different localization methods is not performed
Localization using multilateration with RSS based random transmission directed localization [7]	RSS based efficient random transmission directed localization is introduced	RSS is used for distance estimation, multilateration technique is used for efficient nodes localization	RSS greatly is affected by channel conditions
A distance measurement wireless localization correction algorithm based on RSSI [8]	Node localization mechanism based on RSSI	Efficient correction of estimated RSSI values, efficient measuring of the coordinates of nodes, minimizing error during localization process	RSSI does not accurately localize nodes due to multipath propagation and fading effects
Minimum cost localization problem in three-dimensional ocean sensor networks [9]	Minimum localization cost and handles distance problem	Finding best anchor set to measure each node coordinate efficiently	If confidence interval threshold increases the anchor nodes selection will be affected
A multihop localization algorithm in UWSNs [10]	Multihop localization algorithm to handle the void node localization problem	Efficient mechanism for nodes localization	Not suitable for large scale applications
TDOA based target localization in inhomogeneous UWSNs [11]	TDOA based localization scheme, introduced for inhomogeneous WSNs	Achieving improved localization coverage area	Affected by channel conditions, time synchronization is very important
Scalable localization with mobility prediction for UWSNs [12]	Localization scheme for large scale applications with mobility forecasting	Efficient node mobility prediction and improved localization	High energy consumption
Impacts of deployment strategies on localization performance in UASNs [13]	Efficient node deployment strategies and their effects on localization coverage area and error are introduced	Successfully achieving larger coverage area and less error because of efficient node deployment mechanism	Localization is not very accurate
On-demand asynchronous localization for UWSNs [14]	On-demand nodes localization scheme using asynchronous anchor nodes	Successfully localizing both types of nodes passive and active	Passive nodes localization accuracy is less than the active nodes
A three-dimensional localization algorithm for UASNs [15]	Iterative and distributed nodes localization algorithm	Improved coverage area with less error	When node mobility increases the localization error increases
Localization for drifting restricted floating ocean sensor networks [16]	Efficient nodes localization scheme	Large number of nodes finding their three-dimensional coordinates successfully	Higher network deployment cost

In the discussed existing routing protocols, the impact of nodes mobility is not taken into account, which results in high localization error and degrades the performance of the network. Therefore, to mitigate the localization error due to water currents, in our proposed work, the speed of the node is computed in order to estimate the coordinates of the sensor node deployed in the network field. The details of procedure are given in Section 3.1.

2.2. Cooperative Routing. The authors in [17] propose an energy efficient cooperative routing protocol. It is a cross layer protocol for cooperative communication where if the destination node fails to receive the data packet successfully then the nearby relay node retransmits the data packet to the destination node. This protocol achieves energy efficiency compared to its counterpart schemes.

A cross layer cooperative communication protocol is proposed in [18]. The authors utilize the power allocation and route selection information during the route selection phase; a link with minimum chances of collision is selected for the data transmission. This protocol achieves high network throughput; however, the mechanism of forwarder selection is not reliable.

An incremental qualified relay selection for the cooperative communication is presented in [19]. When the destination node fails to receive the data via direct transmission, the relay node was used to retransmit the same data packet. The authors computed closed form expressions for bit error rate (BER) and outage probability. It achieves less probability of error and high network throughput at the cost of high energy consumption.

In [20], the authors propose an efficient cooperative routing protocol. In this technique, the selection of the best relay depends on the channel conditions and distance between the source node and the neighbor node. The best relay is selected from the set of qualified neighboring nodes. The acknowledgement mechanism helps to reduce the redundant packets resulting in high reliability; however, the relay selection mechanism is not energy efficient.

Authors in [32] propose an energy efficient routing protocol for cooperative transmission. Two problems are tackled in this proposed scheme; the first one is the energy consumption and the other one is the power allocation for cooperative transmissions. This scheme mainly focuses on the distance between different nodes for efficient power allocation.

A cooperative routing protocol for UWSNs is proposed in [33]. There are three types of nodes: the source nodes, the relay nodes, and the destination nodes. When the data is transmitted from the source to the destination, if the destination node fails to receive error-free data then the relay node has to retransmit the data towards the destination. There are two scenarios; in the first scenario single relay node is selected whereas in the second scenario two relay nodes participate in the data retransmission.

In [21], a cooperative routing protocol is presented to minimize the collision in the network. Authors formulated the problem with the use of mixed integer nonlinear programming (MINLP). They used branch-and-bound algorithm to reduce the search space and save the energy for solving mixed integer nonlinear programming problems.

To achieve energy efficiency, the authors in [22] propose a scheme which allocates a power at each hop between the sender and the receiver/sink. Based on the allocated power, each sensor node computes its signal-to-noise ratio (SNR) of the link (between the source and the destination) and distance between the source and the destination. It performs better in terms of network lifetime and end-to-end delay.

In [23], the authors present a cooperative strategy for data transmission in a clustered network. They divided the scheme hello packet transmission into two phases: (i) intercluster and (ii) intracluster. In intercluster, the cluster head (CH) broadcasts the data packet directly to the neighbor CHs and via potential relay nodes only if any CH is not in its transmission range. Similarly, in intracluster, the CH forwards its data packets to all sensor nodes within the cluster, the nodes which receive hello packet successfully, selected as potential relay nodes. However, it consumes more energy when the nodes density is high in a cluster.

Authors propose a cooperative routing algorithm in [24]. This algorithm considers a propagational delay and BER of the link to select the best incremental relay for data forwarding between the source and the destination. However, it achieves high performance of the network at the cost of more end-to-end delay.

To improve the network throughput, a cooperative scheme is presented [25]. This scheme uses partner nodes mechanism for cooperation and for the selection of each node, SNR of the link and propagational is checked; if the link met the criteria then a node is elected as a partner node to perform cooperation. However, this scheme enhanced the packet delivery ratio with higher stability period at the cost of high energy consumption. Summary of the cooperative routing schemes is presented in Table 2.

In this subsection, numerous cooperative routing algorithms are stated. The energy consumption is high due to duplicate packets at the destination in the discussed schemes, due to energy constraint of sensors; in this paper, we have proposed a CO-MobiL, in which relay node only transmits data packet towards the respective destination, when the received packet is erroneous or not received by the destination. The working mechanism of the proposed work is given in Section 3.2.

3. Proposed Work

In this paper, two contributions are presented: (i) an AUV based node localization scheme (MobiL-AUV) and (ii) a cooperative routing protocol (CO-MobiL). In the first, nonlocalized nodes are localized by using an efficient AUV aided localization mechanism. In the second scheme, after the successful localization of node regions based cooperative data routing is carried out. Details are as follows.

3.1. MobiL-AUV. We consider a three-dimensional underwater network, where n numbers of sensor nodes are randomly deployed. With the help of onboard pressure sensors, sensor nodes are capable of determining their depth. All nodes can communicate with mobile AUV as well as with other deployed nodes. We assume that N is the number of mobile AUVs that are deployed inside the water at depth d. These mobile AUVs periodically accelerate towards the water surface to get their own three-dimensional coordinates information by using the GPS [34, 35]. After getting the required information, these dive back into the water and broadcast localization beacon messages. These mobile AUVs act as reference nodes for all other underwater nodes.

TABLE 2: State-of-the-art related work: cooperative routing.

Technique	Features	Achievements	Limitations
Joint cooperative routing and power allocation for collision minimization in WSNs with multiple flows [17]	Cooperative routing protocol, optimal power allocation to sensor nodes	Collision probability is minimized	High computational cost
Energy efficient cooperative communication for data transmission in WSNs [18]	Reliable and efficient data communication cooperative routing protocol	High throughput and reliable data delivery	Mobility of sensor node is neglected; qualified forwarder node selection mechanism is not accurate
Performance analysis of cooperative diversity with incremental-best-relay technique over Rayleigh fading channels [19]	Incremental relaying cooperation is implemented	Less probability of error, higher throughput, and reliability	High energy consumption
Exploiting cooperative relay for reliable communications in UASNs [20]	Cooperative scheme that increases the throughput and reliability of the network	High network throughput	Nonefficient relay node selection mechanism
Optimal and near-optimal cooperative routing and power allocation for collision minimization in WSNs [21]	MINLP problems are solved with branch-and-bound algorithms	Minimizing the end-to-end delay by reducing the search space	Only efficient for predefined network topologies
Co-UWSN: cooperative energy efficient protocol for UWSNs [22]	Incremental relay is selected on the basis of distance and SNR of the link	Comparatively less energy consumption	ACK on each packet resulted in high end to delay
EECCC (energy efficient cooperative communication in clustered WSNs) [23]	Clustering and cooperative communication in the network	Comparatively less energy consumption with direct communication	High energy consumption in dense deployment due to redundant transmissions
Relay selection and optimization algorithm of power allocation based on channel delay for UWSNs [24]	Relay is selected on the basis of BER and propagational delay	Improving the network lifetime	High end-to-end delay
Cooperative partner nodes selection criteria for cooperative routing in UWSNs [25]	Partner node selection on the basis of depth threshold and propagational delay	Comparatively high packet acceptance ratio	High energy consumption

All the ordinary sensor nodes have a communication link with mobile AUVs and also with other sensor nodes deployed underwater. The mobile AUVs form a link with GPS satellite via radio waves and the use acoustic waves to establish a link with underwater nodes. There are two phases in the MobiL-AUV localization scheme.

(1) Mobility forecasting

(2) Localization process

(1) Mobility Forecasting. In mobile UWSN, water currents have a strong impact on the mobility of sensor nodes. For the sake of simplicity we only focus on x and y coordinates. We ignore the z coordinate because two distinct coordinates (points) always compute a straight line between the source and the destination in the given transmission range. In this case, a straight data path must be established between the sender and the receiver node to avoid the use of extra energy. Considering an underwater scenario, the node k at depth d experienced underwater current velocity $v_k = (v_k^x(d), v_k^y(d), 0)$, where v_k^x and v_k^y are the velocities of the node in x and y directions, respectively. Due to spatial correlation in underwater networks, mobile sensor nodes show a group-like behavior [2]. So, by using the group movement property as shown in (1), we can find the velocity of the node.

$$v_k^x(d) = \sum_{m=1}^{n_{\text{neigh}}} R_{m,k} v_m^x(d)$$
$$v_k^y(d) = \sum_{m=1}^{n_{\text{neigh}}} R_{m,k} v_m^y(d) \quad (1)$$

In (1), n_{neigh} represents the number of neighbors of sensor node k. The Euclidean distance between node m and node k is presented as r_{mk} and $R_{m,k} = (1/r_{m,k})/\sum_{m=1}^{n_{\text{neigh}}}(1/r_{m,k})$ represent the interpolation coefficient.

After the velocity estimation, each ordinary node in the network interchanges the speed beacon message periodically with other nodes. These special beacon messages carry the speed information of respective node. By utilizing the speed information of a neighboring node, every ordinary node in the network can predict its mobility pattern.

(2) Localization Process. After the mobility prediction of ordinary nodes, the process of localization starts. During this localization process the mobile AUVs broadcast localization

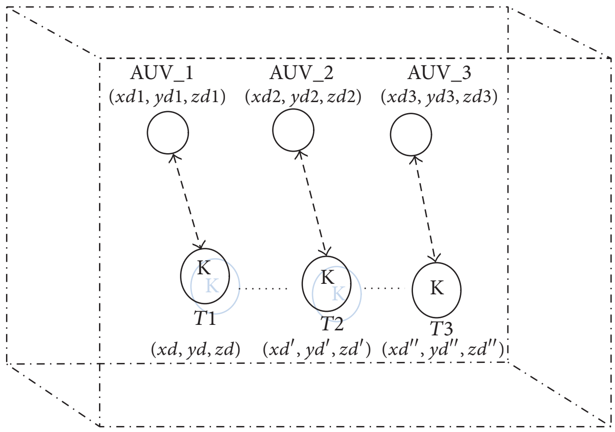

FIGURE 4: MobiL-AUV localization process.

beacon message to the ordinary nodes. The ordinary sensor nodes listen to these beacon messages. On receiving the beacon messages all the nodes estimate their distance from the mobile AUV by using an efficient measurement technique. As shown in Figure 4, the ordinary sensor node k initially at position (xd, yd, zd) listens to the localization beacon message. At $T1$ from a mobile AUV located at $(xd1, yd1, zd1)$ the ordinary node calculates the distance with respect to the mobile AUV by using the following equation [9].

$$\text{Distance } (d_k) = (T_{\text{send}} - T_{\text{recv}}) \times V, \quad (2)$$

where T_{send} is the time when the mobile AUV broadcasts the localization beacon message, T_{recv} is the time when the sensor node receives the beacon message, and V is the speed of sound in an underwater environment. The above process is repeated at $T2$ and $T3$, until the ordinary nodes receive beacon messages from n_{AUV} different mobile AUVs. The flow of localization process is shown in Figure 5.

By substituting values of velocity $(v_k^x(d), v_k^y(d))$ in (3), we can estimate the values of (xd', yd') and (xd'', yd'').

$$\begin{aligned} xd' &= xd + (T2 - T1) \times v_k^x(d) \\ xd'' &= xd' + (T2 - T1) \times v_k^x(d) \\ yd' &= yd + (T2 - T1) \times v_k^y(d) \\ yd'' &= yd' + (T2 - T1) \times v_k^y(d). \end{aligned} \quad (3)$$

Here, in (3), (xd, yd, zd), (xd', yd', zd'), and (xd'', yd'', zd'') are the coordinates of node k and $(xd1, yd1, zd1)$, $(xd2, yd2, zd2)$, and $(xd3, yd3, zd3)$ are the coordinates of mobile AUVs at times $T1$, $T2$, and $T3$, respectively. By substituting values in (4), a node can estimate its position.

$$\begin{aligned} (xd - xd1)^2 + (yd - yd1)^2 + (zd - zd1)^2 &= d_1^2 \\ (xd' - xd2)^2 + (yd' - yd2)^2 + (zd' - zd2)^2 &= d_2^2 \\ (xd'' - xd3)^2 + (yd'' - yd3)^2 + (zd'' - zd3)^2 &= d_3^2. \end{aligned} \quad (4)$$

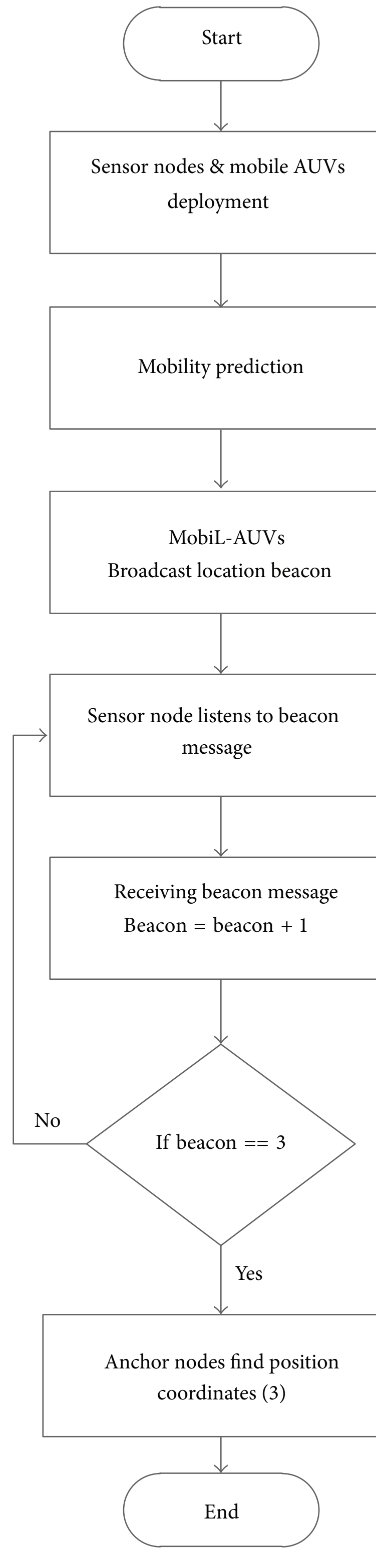

FIGURE 5: Flow chart of complete localization process.

3.2. CO-MobiL. After the process of mobility and localization, the process of data routing starts. For routing purposes, researchers have proposed different routing protocols [17–20]. In our proposed scheme, the source nodes broadcast

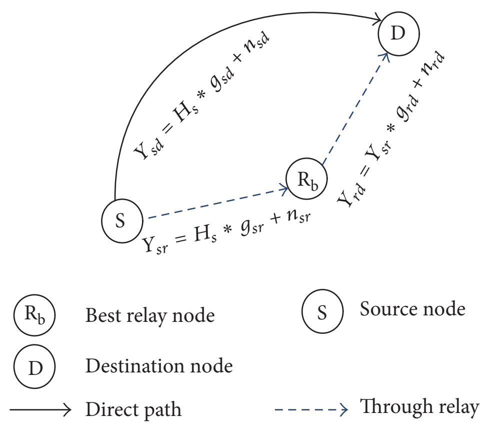

Figure 6: Network model.

data packets towards the destination. If the destination fails to receive the error-free packet then the best selected relay node will transmit data packet to the destination. At the destination, the MRC is used as a diversity combining technique. The relaying technique we used in our scheme is amplify-and-forward.

The underwater environment is harsh due to which the transmitted signals experience the noise, the multipath fading, and the interference. Every link from the source to the destination and from the relay to the destination is affected by the Rayleigh fading and additive white Gaussian noise (AWGN). The Rayleigh fading scatters the acoustic signal before its arrival at the destination because of less dominant propagation towards the destination and AWGN is used to simulate the background ambient noise of the channel.

The signal transmitted from the source node to the destination and the relay node to the destination is shown in Figure 6. The data packets are transmitted to both the destination and the relay node. If the source node fails to receive an error-free packet then the relay node transmits the same data packet from the alternative path to the destination, where the MRC diversity technique is used to combine the data packets to get the error-free packet. Its mathematical expression is given in (5), (6), and (7).

$$Y_{sd} = H_s \times g_{sd} + n_{sd}, \tag{5}$$

where Y_{sd} is the directly transmitted signal from the source to the destination, H_s denotes the channel from the source node to the destination node/sink, g_{sd} represents the broadcast information between the source and the destination, and n_{sd} shows the ambient noise added to channel H_s.

$$Y_{sr} = H_s \times g_{sr} + n_{sr}. \tag{6}$$

Y_{sr} denotes the transmitted signal between the source and the relay as shown in Figure 6; g_{sr} shows the information transmitted by the source to the relay. Similarly, n_{sr} is the ambient noise added to channel H_s.

$$Y_{rd} = Y_{sr} \times g_{rd} + n_{rd}. \tag{7}$$

When the destination fails to receive data packets from the source node then relays transmit data packets according to (7), where Y_{rd} is the transmitted data from the relay to the destination, g_{rd} denotes the information forwarded by the relay to the destination, and n_{rd} represents the noise added to the information Y_{sr} on the channel H_s.

There are two phases in CO-MobiL protocol.

(1) Initialization phase

(2) Data forwarding phase

In the first phase, nodes are deployed and each node finds its qualified relay and destination. This information is used in the second phase to transmit data from source to destination. The flow chart of CO-MobiL is shown in Figure 7.

(1) Initialization Phase. In this phase, nodes are randomly deployed underwater. Each node in the network finds a qualified relay node and destination for data transmission.

(i) Relay Selection. The relay selection mechanism is shown in Algorithm 1. All nodes in the network broadcast hello packet within their transmission range; the hello packet format is shown in Figure 8. On receiving the packet, each node sends a response packet to the nodes from which they receive a hello packet. A response packet is shown in Figure 9; it contains information about the node ID, depth, residual energy, and SNR of each node in the network. On receiving the response message, each node computes the weight function to find the qualified relay node in the network. The relay is selected based on the following parameters: SNR, residual energy (RE), depth of a node (D_i), and delay (T_{delay}) between the source node and the relay node. Each node maintains its neighbor information to gather data from the source node and then from these neighbors, a relay node is selected on the basis of a maximum weight function. The weight function of each node is computed as given in

$$W_{\text{weight}} = \frac{\text{RE} \times \text{SNR}}{D_{\text{depth}} \times T_{\text{delay}}} \tag{8}$$

(ii) Destination Selection. The destination node is selected on the basis of depth and residual energy. A node with higher residual energy which lies outside the depth threshold ($D_{d\text{th}}$) but within the transmission range (T_{range}) of the source node is a qualified destination ((T_{range}) $\geq d_i \geq D_{d\text{th}}$). Figure 10 shows the destination node selection mechanism. $D_{d\text{th}}$ is computed according to $D_{d\text{th}} = d_i - 1$, where d_i is the depth of any node of the network. The objective of $D_{d\text{th}}$ is to minimize the number of hops to reduce the energy consumption. The weight function presented in (9) has been used to find the destination for a particular source node.

$$W_{\text{weight}} = \frac{\text{RE}}{d_i} \tag{9}$$

(2) Data Forwarding Phase. In this phase, the source node generates data packets and forwards these towards the destination and the relay node. At the destination node, a decision is made on the basis of instantaneous SNR between the source and the destination, whether the data received from the direct path is acceptable or a relay will be used for the data

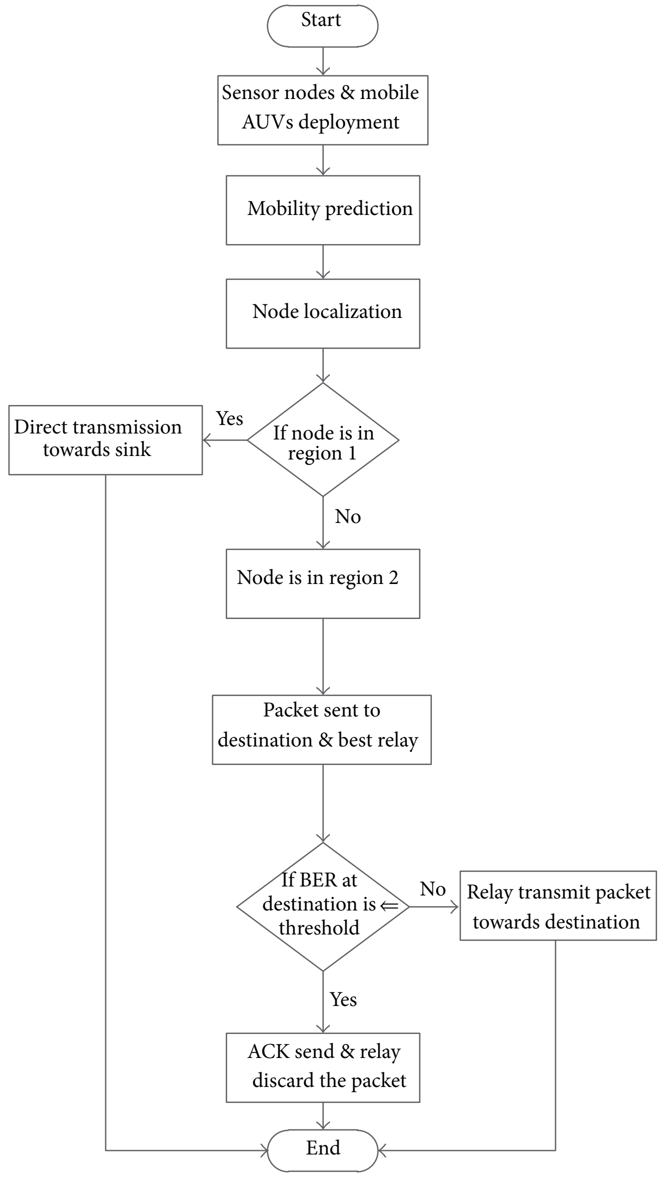

Figure 7: Complete cooperation process.

(1) S_{source}: Source node
(2) $\text{RE}_{\text{energy}}$: Residual energy of node
(3) SNR_{sr}: Signal to Noise ratio between source and expected relay
(4) D_{depth}: Depth of the node
(5) T_{delay}: Delay between source and expected relay
(6) S_{source} broadcast control packet
(7) Neighboring nodes send response message
(8) **if** Response message received = True, **then**;
(9) Compute W_{weight} function using equation (8).
(10) **end if**
(11) Node with maximum value of W_{weight} function is considered best relay

Algorithm 1: Relay node selection.

Node ID	Residual energy	Depth

Figure 8: Control packet format.

Node ID	Residual energy	Depth	$SNR_{(Link)}$

Figure 9: Response packet format.

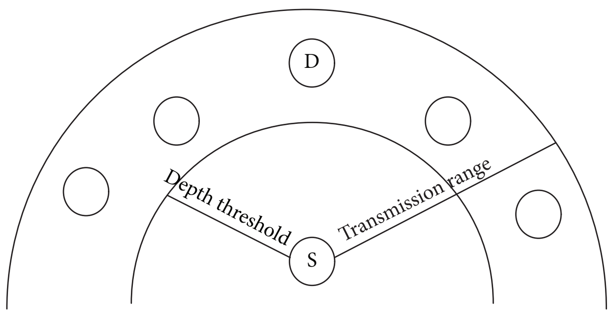

Figure 10: Destination node selection.

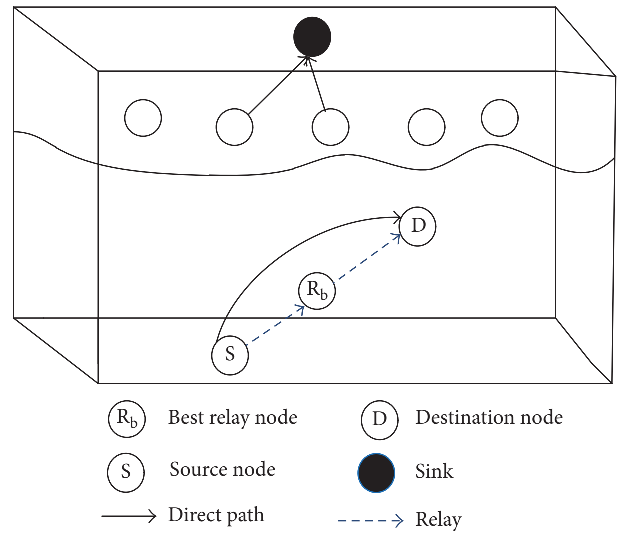

Figure 11: Data forwarding scenario.

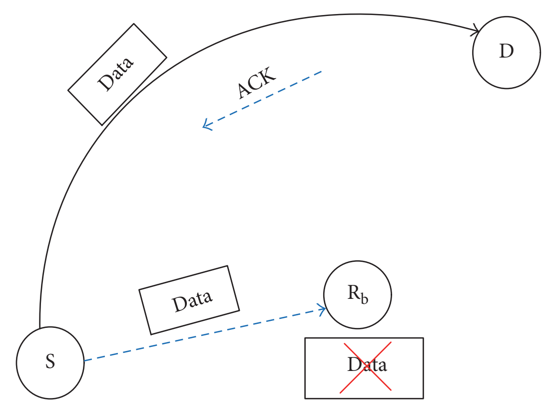

Figure 12: Data forwarding mechanism (ACK).

retransmission. The instantaneous SNR [36] is computed according to

$$\gamma_{AF} = \gamma_{s,r,d} + \gamma_{s,d}, \tag{10}$$

where γ_{AF} denotes amplify-and-forward signal, $\gamma_{s,d}$ is the channel instantaneous SNR between the sender and the receiver, and $\gamma_{s,r,d}$ is the equivalent instantaneous SNR between the source and the destination through the relay node. The equivalent instantaneous SNR of the relayed data/signal is computed as given in

$$\gamma_{s,r,d} = \frac{\gamma_{s,r}\gamma_{r,d}}{\gamma_{s,r} + \gamma_{r,d} + 1}. \tag{11}$$

The network is divided into two regions as shown in Figure 11. The division reduces the energy consumption on the sensor nodes deployed near the sink. Due to the cooperation, the number of retransmissions increases at the destination resulting in more energy consumption. In order to mitigate the energy consumption and to prolong the network lifetime, we have limited the cooperation process in one region and in the second region direct data transmission is carried out. The working mechanism of both regions is discussed in the following subsections.

(i) Direct Transmission Region. The nodes closer to the onshore sink (nodes in transmission range of sink) are considered in region one, whereas the nodes that are not in the transmission range of onshore sink are considered in second region. Nodes that belong to region one forward their data packets towards the sink via direct transmission. As the distance between the source node and the sink in region one is not very large, lower amount of energy is consumed during direct transmissions and moreover the bit error rate (BER) in direct transmission is less compared to multihoping. In case there is no direct communication link between the nodes of region 1 and the sink then data forwarding is carried out via cooperation.

(ii) Cooperative Region. In region two, nodes transmit a data packet towards the destination via cooperation. During the cooperation process, the source node transmits data packets towards the destination and the best relay node. On receiving the data packet, the relay node waits for the acknowledgement (ACK) or negative acknowledgement (NACK) from the destination node. At the destination node BER is computed; if the BER is less than the BER threshold, the packet is accepted at the destination and ACK is sent. The relay node overhears ACK and discards the packet. This scenario is shown in Figure 12.

If the BER at destination is greater than the defined BER threshold, then NACK is sent and the relay node amplifies the received data and transmits the amplified data packets

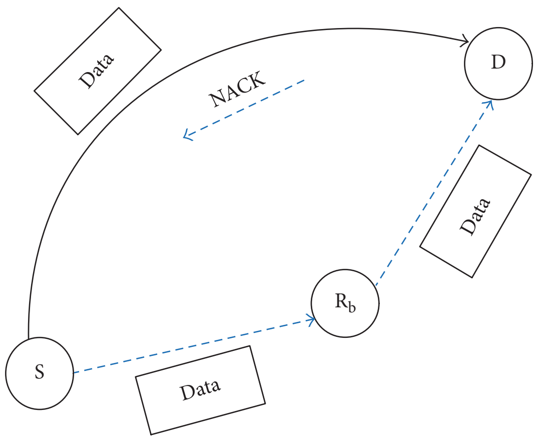

Figure 13: Data forwarding mechanism (NACK).

towards the destination. This scenario is shown in Figure 13. At the destination, MRC technique is used as a diversity combining technique. The signals from all links from the source to the destination and from the relay to the destination are added together to generate an original data packet.

Amplify-and-Forward. The relaying technique used in the proposed scheme is AF. In this technique, the source node sends data packets to the destination using a direct link; if the destination is unable to detect the packets using the direct link, the relay forwards the data to the destination. The relay amplifies the data and transmits the amplified data to destination.

4. Experiments and Discussions

The performance of our proposed schemes (MobiL-AUV and CO-MobiL) is validated via simulations. We have claimed that region based cooperative routing minimizes the localization error and improves the data delivery ratio compared to existing traditional localization schemes (e.g., multihop localization, three-dimensional localization). Through simulation results we have showed that our schemes perform better than the existing compared schemes (MobiL and UDB).

The network field is considered of size 500 m × 500 m × 500 m, number of nodes vary from 50 to 200 with transmission energy 2 joules (J) and receiving energy of 0.1 J, and three AUVs are deployed to localize the ordinary nodes. The simulation parameters are given in Table 3 [2].

4.1. Performance Metrics

(i) Alive nodes: they are nodes that have a sufficient amount of energy to transmit a data packet from the source to the destination.

(ii) Dead nodes: they are nodes that do not have a sufficient energy to transmit data from the source to the destination.

Table 3: Simulation setting parameters.

Simulation parameter	Value
Sensor nodes	50–200
Network dimension	500 m × 500 m × 500 m
Localization threshold	1 m
Transmission energy	2 J
Reception energy	0.1 J
Transmission range	100 m
Transmission frequency	22 KHz
Node mobility	1–5 m/s

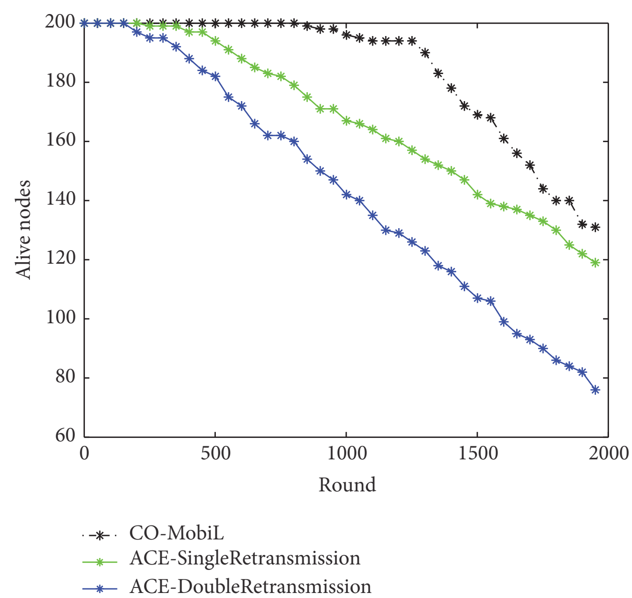

Figure 14: Alive nodes.

(iii) Throughput: it means the successfully delivered data packets at the sink.

(iv) Energy consumption: it is the total amount of energy consumed in the network by all nodes.

(v) Localization error: it is the Euclidean distance between the original position of a sensor node (xd, yd, zd) and the estimated position of a sensor node (xd', yd', zd').

(vi) Localization coverage: It is the ratio of the number of successfully localized nodes to the total number of deployed nodes in the whole network. A node is successfully localized if its localization error is less than a predefined localization error threshold.

4.2. Performance Discussion. The alive nodes of all schemes are shown in Figure 14. The results show that our scheme outperforms the existing techniques; there are more alive nodes in our than others as shown in Figure 14. In ACE-DoubleRetransmission scheme [33], two relay nodes are used for a data transmission which increase the energy cost. More nodes are involved in a data transmission from the source to the destination which results in rapid energy depletion

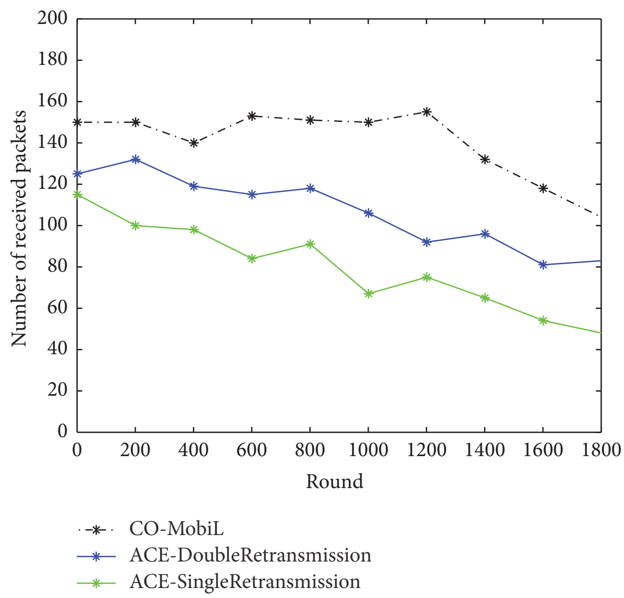

Figure 15: Throughput.

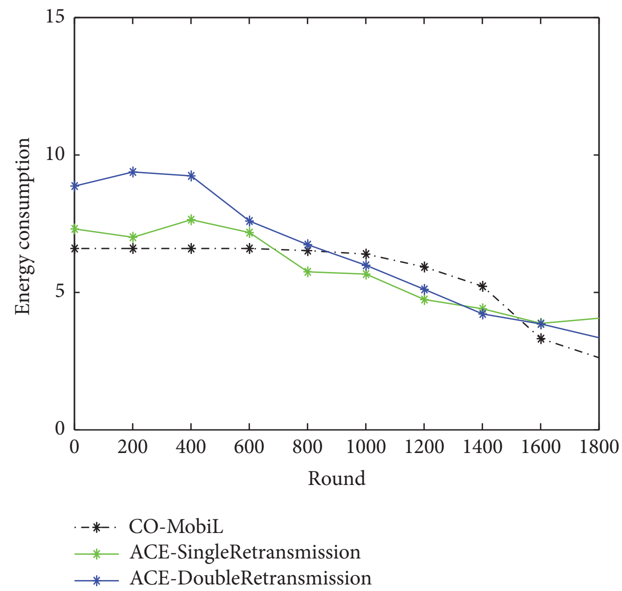

Figure 16: Energy consumption.

of nodes and the network lifetime is decreased. In ACE-SingleRetransmission, all nodes are involved in cooperation process; thus the energy consumption of the protocol is greater, whereas in our protocol due to efficient relay selection there is no need for the second relay to retransmit data to the destination. The nodes nearer to the sink directly transmit data to the sink, as the distance between the sink and these nodes is not so large; thus avoiding cooperation in the vicinity of the sink is to balance the energy consumption of the network.

Figure 15 represents the throughput for all the simulated schemes. The throughput of our scheme is more as compared to the other schemes. Due to the efficient selection of a relay node, a large number of data packets reached their destination successfully. If the destination fails to receive an error-free packet from the source, then the relay forwards data to the destination. In the other two schemes the relay is selected on the basis of depth and residual energy. The link between the source and the relay is ignored due to which the existing schemes experience packet drop and result in decreased throughput, whereas in the proposed scheme the relay is selected on the basis of depth, residual energy, and SNR of the link between the source and the relay. Due to the best selection of the relay, a greater number of data packets are successfully received at the destination. By using direct transmission in region 1 (i.e., closer to the sink), the probability of the BER decreases. As a result, high throughput is achieved.

In Figure 16, the energy consumption for all simulated schemes is shown. In ACE-DoubleRetransmission scheme, due to the selection of two relays, more energy is consumed. Whenever multiple relay nodes are used for retransmissions it results in high energy consumption. In ACE-SingleRetransmission scheme, all nodes are involved in the cooperation process which increases the energy consumption, whereas in our proposed scheme the region based cooperation is introduced. Nodes that are far from the onshore

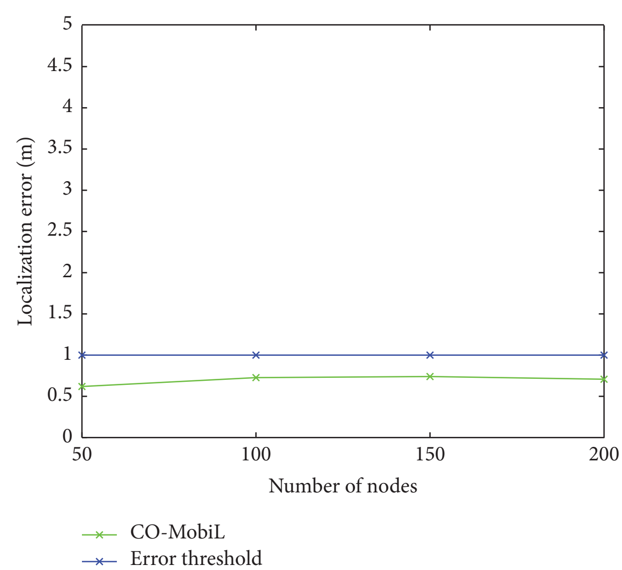

Figure 17: Localization error.

sink transmit data packets to the destination by cooperative routing and the other nodes that are part of region one (in the transmission of sink) directly transmit the data packets to the sink. Due to division of the field, the distance between the nodes of region one and the sink is reduced which results in less energy consumption.

The effects of localization error are shown in Figure 17. During simulations, we kept localization threshold 1 m. The localization error parameter is plotted by varying the number of sensor nodes from 50 to 200. During the computation of localization error, the mobile AUV nodes are kept aside because these nodes are already localized. With the increase in the communication distance between ordinary nonlocalized nodes and mobile AUVs, the localization error increases. To reduce the localization error, in proposed scheme mobile

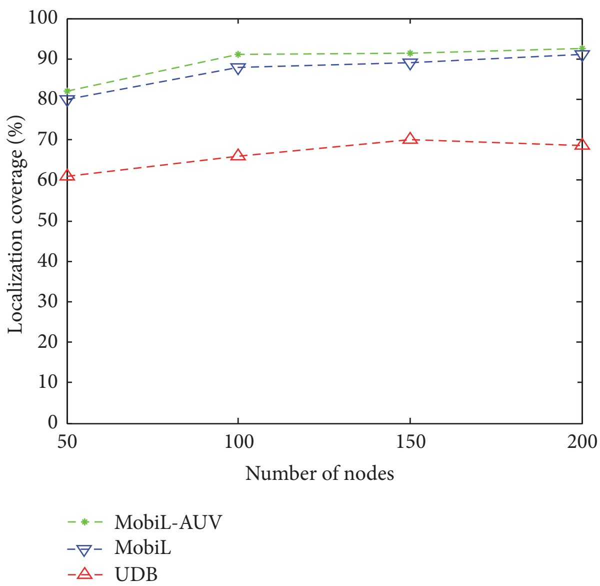

Figure 18: Localization coverage.

AUVs cover the large network volume that results in less localization error.

The localization coverage is shown in Figure 18. The result shows that our scheme MobiL-AUV outperforms MobiL [2] and UDB [37], in terms of localization coverage. With the increase in the number of nodes in proposed scheme, the localization coverage increases up to 80%. Our proposed scheme results in less localization error due to which a large number of nodes get localized. The localization coverage depends on the transmission range of the reference nodes. With the increase in the transmission range of reference nodes, more numbers of nodes get their position coordinates. Due to mobile AUVs, the greater number of ordinary non-localized nodes exists in the transmission range that results in the successful localization of large number of the ordinary nodes. In MobiL, reference nodes at the water surface are used to localize the network nodes, due to which a minimum number of nodes get localized, whereas, in UDB, directional beacons are broadcasted which are bounded by angle which varies from 10 to 90 degrees. Due to the involvement of angle, area of the beacon message is restricted due to which a lower number of nodes receive beacon messages resulting in less localization as compared to our proposed localization scheme (MobiL-AUV).

In Figure 19, the localization of the proposed scheme (MobiL-AUV) is presented at numerous time intervals with respect to node mobility. When the node mobility is 1 meter per second (m/s) as shown in Figure 19(a), MobiL-AUV broadcasts beacon message after every 1 second over a predefined path to localize the sensor nodes. The normalized values are shown in Figure 19(a); the success ratio increases with the increase in the nodes density from 50 to 200. It can be clearly seen that when beacon message interval is 1 s (1 second), the localization ratio increases as the node density changes from 50 to 200. The success ratio at lower interval (1 s) is more because nodes receive beacon messages more often to localize themselves, whereas, at high intervals (2 s, 3 s), nodes receive fewer beacons resulting in fewer localized nodes in the network. Therefore, the success ratio is lower when the value of the time interval is high. As it can be seen from Figure 19(b), at 1 s the success ratio is 92% and for 2 s and 3 s, the localization success ratio is 89% and 86%, respectively. When the node mobility is 3 m/s, the localization success slightly decreases because nodes move out of the range from MobiL-AUV. As it is shown in Figure 19(b), with the increase in the node speed, the success ratio is affected. Similarly, From Figure 19(c), it further decreases as the node moves with the speed of 5 m/s. Therefore, we have used (2), to acquire the coordinates of the nodes by considering the speed of the nodes which gave us high success in estimating the coordinates of the nodes.

5. Performance Trade-Offs

Trade-offs made in our proposed protocol are given in Table 4. CO-MobiL achieves high network throughput at the cost of energy due to cooperation as shown in Figures 15 and 16, respectively. Figures 17 and 18 show that our proposed scheme MobiL-AUV minimized the localization error and enhanced the network localization coverage up to 80%, however, at the cost of energy consumption due to the localization of each node. In ACE-SingleRetransmission, all the nodes in the network take part in the cooperation process due to which packet delivery ratio increases at the cost of high energy consumption. Similarly, in ACE-DoubleRetransmission, two relays participate in the cooperation process to achieve network throughput by compromising on energy.

6. Conclusion

To minimize the localization and enhance the network throughput with efficient energy consumption, two routing protocols are proposed in this paper: MobiL-AUV is proposed for the localization of the network. In this scheme, three mobile AUVs are deployed and equipped with GPS and act as reference nodes. With the help of these reference nodes, all the ordinary sensor nodes in the network are localized. It achieved comparatively low localization error and high network coverage because of less distance between mobile AUVs and nodes. On the other hand, CO-MobiL is presented to utilize the localization done by the MobiL-AUV. In this scheme, the network is divided into two regions that minimized the data load and reduced the energy consumption of sensor nodes deployed near the sink. The use of MRC as diversity technique enhanced the network throughput, however, at the cost of energy. Extensive simulation results showed that MobiL-AUV performs better in terms of network coverage and localization success ratio than MobiL and UDB, whereas CO-MobiL outperformed its compared existing schemes (ACE-SingleRetransmission and ACE-DoubleRetransmission) in terms of throughput and energy consumption.

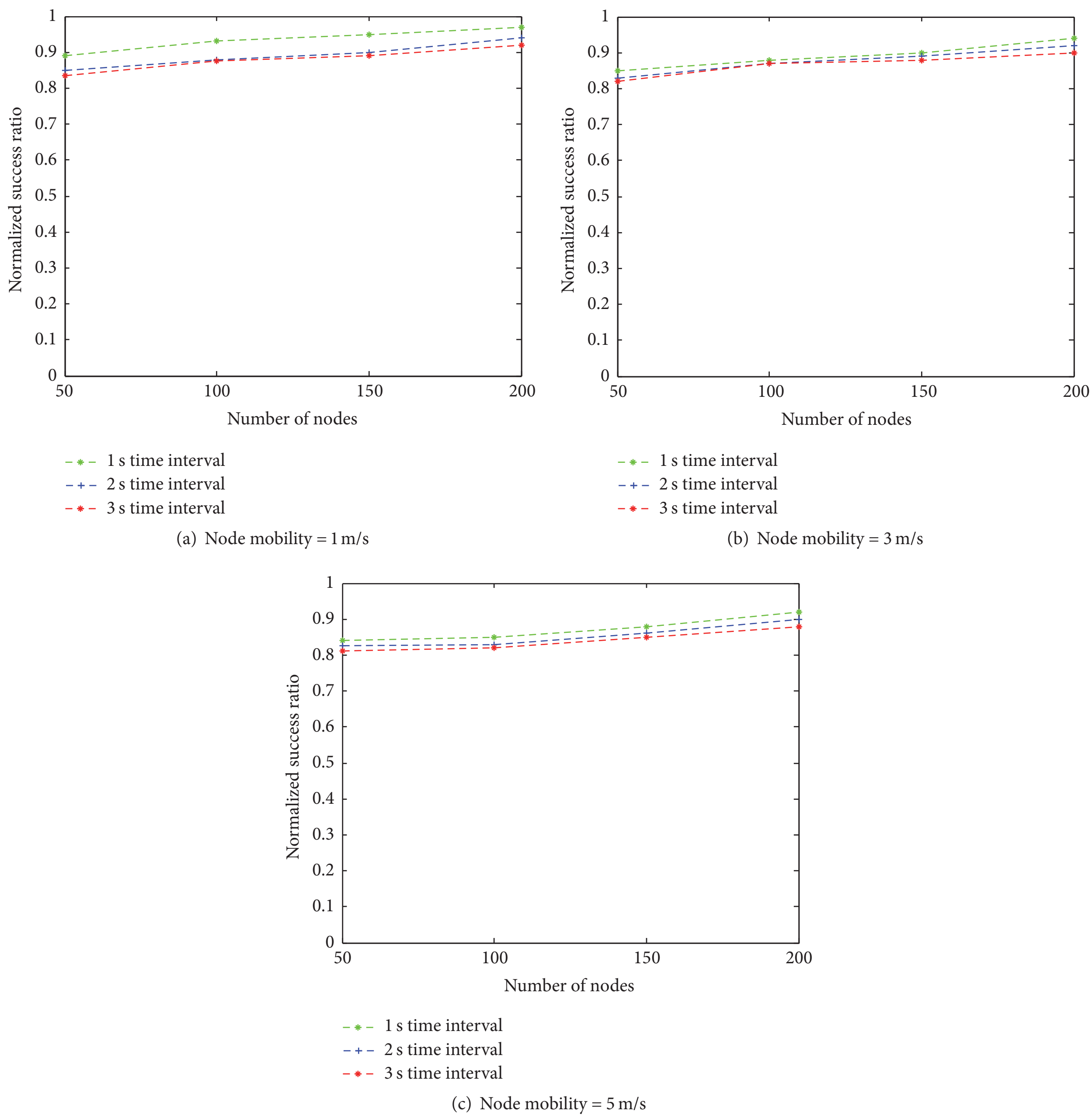

FIGURE 19: Normalized localization success ratio with respect to node mobility at various time intervals.

TABLE 4: Performance trade-off.

Protocol	Achieved parameters	Figure	Compromised parameter	Figure
CO-MobiL	Network lifetime and throughput	Figures 14 and 16	Energy consumption	Figure 17
MobiL-AUV	High localization coverage and low localization error	Figure 18	Energy consumption	Figure 17
ACE-SingleRetransmission	Throughput	Figure 16	Energy consumption	Figure 17
ACE-DoubleRetransmission	Throughput	Figure 16	Energy consumption	Figure 17

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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References

[1] P. Kirci and H. Chaouchi, "Recursive and ad hoc routing based localization in wireless sensor networks," *Computer Standards and Interfaces*, vol. 44, pp. 258–263, 2016.

[2] T. Ojha and S. Misra, "MobiL: a 3-dimensional localization scheme for Mobile Underwater Sensor Networks," in *Proceedings of 2013 National Conference on Communications, NCC 2013*, ind, February 2013.

[3] H. Maqsood, N. Javaid, A. Yahya, B. Ali, Z. A. Khan, and U. Qasim, "MobiL-AUV: AUV-aided localization scheme for underwater wireless sensor networks," in *Proceedings of 2016 10th International Conference on Innovative Mobile and Internet Services in Ubiquitous Computing (IMIS)*, pp. 170–175, Fukuoka, Japan, July 2016.

[4] S. Kundu and P. Sadhukhan, "Design and implementation of a time synchronization-free distributed localization scheme for underwater acoustic sensor network," in *Proceedings of 2015 2nd International Conference on Applications and Innovations in Mobile Computing, AIMoC 2015*, pp. 74–80, ind, February 2015.

[5] M. Erol-Kantarci, H. T. Mouftah, and S. Oktug, "A survey of architectures and localization techniques for underwater acoustic sensor networks," *IEEE Communications Surveys and Tutorials*, vol. 13, no. 3, pp. 487–502, 2011.

[6] G. Han, A. Qian, X. Li, J. Jiang, and L. Shu, "Performance evaluation of localization algorithms in large-scale Underwater Sensor Networks," in *Proceedings of 2013 8th International ICST Conference on Communications and Networking in China, CHINACOM 2013*, pp. 493–498, chn, August 2013.

[7] D. Sivakumar and B. Sivakumar, "Localization using multilateration with RSS based random transmission directed localization," *Middle-East Journal of Scientific Research*, vol. 22, no. 1, pp. 45–50, 2014.

[8] J. Xiong, Q. Qin, and K. Zeng, "A distance measurement wireless localization correction algorithm based on RSSI," in *Proceedings of 7th International Symposium on Computational Intelligence and Design, ISCID 2014*, pp. 276–278, chn, December 2014.

[9] C. Zhang, Y. Liu, Z. Guo, G. Sun, and Y. Wang, "Minimum cost localization problem in three-dimensional ocean sensor networks," in *Proceedings of 2014 1st IEEE International Conference on Communications, ICC 2014*, pp. 496–501, aus, June 2014.

[10] Z. Zhu, W. Guan, L. Liu, S. Li, S. Kong, and Y. Yan, "A multi-hop localization algorithm in underwater wireless sensor networks," in *Proceedings of the 6th International Conference on Wireless Communications and Signal Processing (WCSP' 14)*, pp. 1–6, Hefei, China, October 2014.

[11] S. Poursheikhali and H. Zamiri-Jafarian, "TDOA based target localization in inhomogenous underwater wireless sensor network," in *Proceedings of 5th International Conference on Computer and Knowledge Engineering, ICCKE 2015*, pp. 1–6, irn.

[12] Z. Zhou, Z. Peng, J.-H. Cui, Z. Shi, and A. Bagtzoglou, "Scalable localization with mobility prediction for underwater sensor networks," *IEEE Transactions on Mobile Computing*, vol. 10, no. 3, pp. 335–348, 2011.

[13] G. Han, C. Zhang, L. Shu, and J. J. P. C. Rodrigues, "Impacts of deployment strategies on localization performance in underwater acoustic sensor networks," *IEEE Transactions on Industrial Electronics*, vol. 62, no. 3, pp. 1725–1733, 2015.

[14] P. Carroll, S. Zhou, K. Mahmood, H. Zhou, X. Xu, and J.-H. Cui, "On-demand asynchronous localization for underwater sensor networks," in *Proceedings of OCEANS 2012 MTS/IEEE Hampton Roads Conference: Harnessing the Power of the Ocean*, usa, October 2012.

[15] M. T. Isik and O. B. Akan, "A three dimensional localization algorithm for underwater acoustic sensor networks," *IEEE Transactions on Wireless Communications*, vol. 8, no. 9, pp. 4457–4463, 2009.

[16] H. Luo, K. Wu, Y. Gong, and L. M. Ni, "Localization for drifting restricted floating ocean sensor networks," *IEEE Transactions on Vehicular Technology*, vol. 65, no. 12, pp. 9968–9981, 2016.

[17] F. Mansourkiaie and M. H. Ahmed, "Joint cooperative routing and power allocation for collision minimization in wireless sensor networks with multiple flows," *IEEE Wireless Communications Letters*, vol. 4, no. 1, 2015.

[18] W. Fang, F. Liu, F. Yang, L. Shu, and S. Nishio, "Energy-efficient cooperative communication for data transmission in wireless sensor networks," *IEEE Transactions on Consumer Electronics*, vol. 56, no. 4, pp. 2185–2192, 2010.

[19] S. S. Ikki and M. H. Ahmed, "Performance analysis of cooperative diversity with incremental-best-relay technique over rayleigh fading channels," *IEEE Transactions on Communications*, vol. 59, no. 8, pp. 2152–2161, 2011.

[20] Y. Wei and D.-S. Kim, "Exploiting cooperative relay for reliable communications in underwater acoustic sensor networks," in *Proceedings of 33rd Annual IEEE Military Communications Conference, MILCOM 2014*, pp. 518–524, usa, October 2014.

[21] F. Mansourkiaie and M. H. Ahmed, "Optimal and near-optimal cooperative routing and power allocation for collision minimization in wireless sensor networks," *IEEE Sensors Journal*, vol. 16, no. 5, pp. 1398–1411, 2016.

[22] S. Ahmed, N. Javaid, F. A. Khan et al., "Co-UWSN: Cooperative energy-efficient protocol for underwater WSNs," *International Journal of Distributed Sensor Networks*, vol. 2015, Article ID 891410, 2015.

[23] Z. Zhou, S. Zhou, S. Cui, and J. Cui, "Energy-efficient cooperative communication in a clustered wireless sensor network," *IEEE Transactions on Vehicular Technology*, vol. 57, no. 6, pp. 3618–3628, 2008.

[24] Y. Li, Z. Jin, X. Wang, and Z. Liu, "Relay selection and optimization algorithm of power allocation based on channel delay for UWSN," *International Journal of Future Generation Communication and Networking*, vol. 9, no. 2, pp. 103–112, 2016.

[25] A. Umar, M. Akbar, Z. Iqbal, Z. A. Khan, U. Qasim, and N. Javaid, "Cooperative partner nodes selection criteria for cooperative routing in underwater WSNs," in *Proceedings of 5th National Symposium on Information Technology: Towards New Smart World, NSITNSW 2015*, sau, February 2015.

[26] Z. Liao, D. Li, and J. Chen, "A network access mechanism for multihop underwater acoustic local area networks," *IEEE Sensors Journal*, vol. 16, no. 10, pp. 3914–3926, 2016.

[27] H. Wu, M. Chen, and X. Guan, "A network coding based routing protocol for underwater sensor networks," *Sensors*, vol. 12, no. 4, pp. 4559–4577, 2012.

[28] A. Wahid and D. Kim, "An energy efficient localization-free routing protocol for underwater wireless sensor networks," *International Journal of Distributed Sensor Networks*, vol. 2012, Article ID 307246, 11 pages, 2012.

[29] A. Wahid, S. Lee, and D. Kim, "An energy-efficient routing protocol for UWSNs using physical distance and residual energy," in *Proceedings of the OCEANS '11*, pp. 1–6, Santander, Spain, June 2011.

[30] M. Xu, G. Z. Liu, and H. F. Wu, "An energy-efficient routing algorithm for underwater wireless sensor networks inspired by ultrasonic frogs," *International Journal of Distributed Sensor Networks*, vol. 2014, Article ID 351520, 12 pages, 2014.

[31] J. Cao, J. Dou, and S. Dong, "Balance transmission mechanism in underwater acoustic sensor networks," *International Journal of Distributed Sensor Networks*, vol. 2015, Article ID 429340, 12 pages, 2015.

[32] H. Yang, F. Ren, C. Lin, and B. Liu, "Energy efficient cooperation in underwater sensor networks," in *Proceedings of 2010 IEEE 18th International Workshop on Quality of Service, IWQoS 2010*, chn, June 2010.

[33] H. Nasir, N. Javaid, M. Murtaza et al., "ACE: Adaptive cooperation in EEDBR for underwater wireless sensor networks," in *Proceedings of 9th IEEE International Conference on Broadband and Wireless Computing, Communication and Applications, BWCCA 2014*, pp. 8–14, chn, November 2014.

[34] M. Erol, L. F. M. Vieira, and M. Gerla, "AUV-aided localization for underwater sensor networks," in *Proceedings of Proceeding of the 2nd Annual International Conference on Wireless Algorithms, Systems, and Applications (WASA '07)*, pp. 44–54, Chicago, Ill, USA, August 2007.

[35] A. K. Othman, A. E. Adams, and C. C. Tsimenidis, "Node discovery protocol and localization for distributed underwater acoustic networks," in *Proceedings of the Advanced International Conference on Telecommunications and International Conference on Internet and Web Applications and Services*, Guadeloupe, France, February 2006.

[36] S. S. Ikki and M. H. Ahmed, "Performance analysis of incremental-relaying cooperative-diversity networks over Rayleigh fading channels," *IET Communications*, vol. 5, no. 3, pp. 337–349, 2011.

[37] H. Luo, Y. Zhao, Z. Guo, S. Liu, P. Chen, and L. M. Ni, "UDB: using directional beacons for localization in underwater sensor networks," in *Proceedings of 2008 14th IEEE International Conference on Parallel and Distributed Systems, ICPADS'08*, pp. 551–558, aus, December 2008.


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