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Research Article

Link Expiration Time-Aware Routing Protocol for UWSNs

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We propose a link expiration time-aware routing protocol for UWSNs. In this protocol, a sending node forwards a data packet after being sure that the packet reaches the forwarding node, and acknowledgment is returned to the sending node after receiving the data packet. Node mobility is handled in the protocol through the calculation of the link expiration time and sending the packet based on the link expiration time. Although the protocol employs two types of control packet, it provides less energy consumption and at the same time is providing better reliability of packets reaching to the destination because of using acknowledgement packet. The forwarding decision of node is taken by applying Bayes' uncertainty theorem. We use depth, residual energy, and distance from the forwarding node to the sending node as evidence in Bayes' theorem. In this protocol, we use the concept of expert systems ranking potentially true hypothesis. Extensive simulation has been executed to endorse better performance of the proposed protocol.

1. Introduction

About seventy percentage of the Earth is covered by water. This huge area is continuously being explored with a view to discover hidden knowledge and unknown resources. The research under water is being accomplished for the purpose of many kinds of application such as ocean sampling networks, environmental monitoring, undersea explorations, disaster prevention, and mine reconnaissance [1–3]. Underwater sensor network has appeared as a new dimension that helps in investigating the vast area under water and provides vital information to the surface. One of the imperative sections of underwater sensor network is to mature the routing protocols that are already existent and to revamp the routing protocol for UWSNs. In order to develop the routing protocol for UWSNs, some concerns pertaining to sensor networks have to be considered. UWSNs have to face some challenges such as node mobility, limited battery, limited bandwidth, and multipath noise. In UWSNs, the node moves with the velocity of 3–6 km/h [4] because of the water current. So, it is not possible to progress routing protocols which work with the whole topology. Moreover, underwater sensor node cannot be recharged or changed because of the harsh underwater environment. Underwater sensor node uses an acoustic modem whose propagation speed is 1500 m/s [5] to transfer data to each other. Our proposed routing protocol is devised by cogitating upon limited battery and limited bandwidth. Our proposed routing protocol provides shorter end-to-end delay and evades control packet to guide data packet to the destination entirely which hoards up huge amount of total energy. Information of control packet is incorporated in the data packet.

The rest of this paper is organized as follows. We describe related works in Section 2. Our proposed link expiration time aware routing protocol for UWSNs is presented in Section 3, and the simulation results are presented in Section 4. Finally, we conclude the paper in Section 5 along with future research direction.

2. Related Works

One of the primary topics for any network is routing, and routing protocols are regarded as an indictment of determining and preserving the routes. Most of the research works pertaining to underwater sensor networks have been on the issues related to the physical layer. On the other hand, routing techniques are a comparatively new arena of the network layer of UWSNs. Thus, providing an efficient

routing algorithm becomes a significant mission. Although underwater acoustic network has continued to be studied for decades, underwater networking and routing protocols are still at the infant stage of research. We have studied some routing protocols to shape our own routing protocol.

Vector-based forwarding (VBF) [5] guides the packet from the source to the destination. Packets are forwarded only by those sensor nodes that are within the range R of the vector. The forwarding process of VBF is thought to be a routing pipe (virtual pipe) between the source and the destination nodes. The energy of the network is saved because only the nodes that come across the forwarding path are involved in packet routing. It provides small data delivery ratio in sparse networks. Moreover, delivery ratio decreases when nodes are mobile and is sensitive to the routing pipe's radius. High communication time in dense network is needed, and multiple nodes act as relay nodes.

To reduce the high communication time and to handle node mobility, VBF routing protocol has been modified and proposed a hop-by-hop VBF (HH-VBF) [6] routing protocol. This protocol forms the routing pipe in a hop-by-hop fashion enhancing the packet delivery ratio significantly. It does not use a single virtual pipe, and each node forwards packet based on its current location. When a node receives a packet, it first holds the packet for sometime. Each node in the neighborhood may hear the same packet multiple times. Each node's overhearing the duplicate packet transmission to control the forwarding of this packet is allowed in HH-VBF routing protocol. In sparse networks, HH-VBF can discover a data delivery path as long as there exists one in the network. It also suffers from some disadvantages such as long propagation delay, high energy cost in dense networks, and being not efficient enough with node mobility.

In sector-based routing with destination location prediction [7], a node knows its own location and predicts the location of the destination node where the precise knowledge of the destination's location is relaxed by it. The sender determines its next hop using information received from the candidate nodes. It eliminates the problem of having multiple nodes acting as relay nodes. It does not require to rebroadcast the request to send (RTS) every time it cannot find a candidate node within its transmitting range. In SBR-DLP, node speed causes disconnections, and it gives relatively low PDR in sparse networks and has relatively high energy consumption in dense networks where it performs best but better packet delivery ratio when all nodes are mobile.

Distributed underwater clustering scheme (DUCS) [8] is an adaptive self-organizing protocol that forms clusters. It is considered that there are always data to be sent to the sink by the underwater sensor nodes and that power control can be used to adjust its transmission power. It tries to be adapted to the intrinsic properties of underwater environments and uses a continually adjusted timing advance combined with guard time values to minimize data loss and maintain communication quality. Nodes are organized into local clusters. One node is selected as a cluster head for each cluster. All data coming from noncluster head nodes are transmitted to their cluster head via a single hop. Data are received by the cluster-head node and transmitted to the sink (via the relays of other cluster heads) using multihop routing. DUCS incorporates randomized rotation of the cluster head among the sensors to avoid draining the battery of any underwater sensor in the network. As the number of the nodes decrease in the network, a slight decrease occurs in the number of data messages packet delivery ratio.

Multipath routing [9] is energy-efficient networks and overcomes long propagation delay and adverse link conditions. Depending on how the routes are selected, there is a strong likelihood of contention occurring among nodes that are on different routes but close to one another. The local sink connections are assumed to be via high-speed links, being wired to a buoy on the surface equipped with RF communications link or an undersea high-speed optical fiber. The ultimate goal of the underwater network is to ensure that data are delivered to one or more of these local sinks which collectively form a virtual sink. Connection is established through wire or optical fiber. Backup routes are created by deploying redundant nodes. Contention occurs among nodes due to redundancy.

In H2-DAB [10], sink node broadcasts a hello packet, and the sensor node that receives the packet is assigned a Hop ID by incrementing the Hop ID existing in the hello packet of sink node. The packet-receiving node broadcasts the hello packet after updating the Hop ID of the received hello packet. In this way, sensor nodes are given a unique address from sink nodes to source node. When the packet is forwarded to the sink node, it searches for the sensor nodes with the smallest Hop ID. To forward a packet, this protocol utilizes only the hop count which is not a good indicator to forward packet because UWSN is an energy-constrained network. It does not guarantee the network living time because the same node can be chosen again and again to transfer a packet. Moreover, in this protocol, inquiry request and inquiry reply packets are to be exploited at the time of the forwarding of the data packets, which is costly in terms of delay and energy.

Depth-based routing (DBR) protocol [11] is an underwater sensor network routing protocol which is based on the depth information of each sensor. In this routing protocol, no complete dimensional information of the location of the sensor nodes is required, and it can manage a dynamic network. In DBR, to deliver a packet, it determines that the closer to the destination, the smaller the depth of the forwarding nodes, and to receive a packet, it compares between the depth retrieving of the previous hop and its receiving node's depth for the qualified candidates to forward the packet. DBR has good energy efficiency but not so much good performance for the dense network where it has significant end-to-end delay and high total energy consumption.

All of these discussed routing protocols for UWSNs are efficient and effective in their own ways. In this paper, we have developed a routing protocol to overcome the disadvantages of the vector-based routing protocol [11]. In DBR, the forwarding node takes the decision of packet forwarding based on only the depth which can make more forwarding nodes compatible to forward a packet because of the node's same depth. We introduce a novel technique by considering Bayes' theorem to assess the target node. In our forwarding technique, we use depth, residual energy, and the distance

from the forwarding node to the sending node as evidence. We calculate the link expiration time to handle node mobility between the two nodes.

3. The Link Expiration Time Aware Routing Protocol

In this section, we present our link expiration time aware (LETA) routing protocol in detail. multiple-sink underwater sensor network architecture has been applied in the proposed routing protocol. In this section, we have discussed about network architecture, protocol overview, and protocol design. Finally, we present the algorithm of the proposed routing protocol.

3.1. The Network Architecture. It is pointed out before that the multiple-sink underwater sensor network architecture [12] can be used by the proposed routing protocol, the link expiration time aware (LETA) routing protocol. Like DBR [11], it also takes advantages of the multiple-sink underwater sensor network architecture. An example of such networks is demonstrated in Figure 1. In this multiple-sink network, the water surface nodes that are called sink nodes are equipped with the modem that is capable of capturing both radio frequency and acoustic signal. The nodes that send and receive only acoustic signal are deployed in the underwater environment. Underwater sensor nodes with acoustic modems are placed in the interested 3D area, and each one of such nodes is assumed likely to be a data source. Underwater acoustic nodes can accumulate data and also assist to convey data to the sinks. When a sink node receives a packet from an underwater acoustic node, the sink node can converse with each other efficiently via radio channels. The protocol attempts to send a packet to any sink nodes on the surface because if a surface node receives a packet, it can send the packet to other sinks or remote data centers quickly due to the speed of radio frequency (with a propagation speed of 3×10^8 m/s in air) which is five orders of magnitude higher than sound propagation (at the speed of 1.5×10^3 m/s in water) [5]. Here, the protocol does not pay attention to the communication between the surface nodes. Instead, it tries to transmit a packet to a fixed surface sink and assumes that the packet reaches to its destination. The protocol has been built by considering the fact that every node knows its depth which is the vertical distance from the node's position to the surface and its position.

3.2. Overview of the Proposed Routing Protocol. The proposed protocol is divided into three phases named as selection of compatible forwarding node phase, routing table formation phase by the sending node, and target node selection phase by the sending node to send data packet. Each of these parts is discussed in this section.

3.2.1. Selection of Compatible Forwarding Node Phase. In this phase, most of the procedures are performed by the forwarding node. The sending node broadcasts a hello message named RREQ to discover its one-hop compatible forwarding node. Upon receiving the RREQ message of the sending node, the forwarding node estimates the probability of packet forwarding and packet discarding based on the depth difference of the forwarding node and the sending node, residual energy, and the distance from the forwarding node to the sending node. If the probability of packet forwarding is greater than that of packet discarding, the forwarding node responds to the sending node through RREP message incorporated its probability in the reply message.

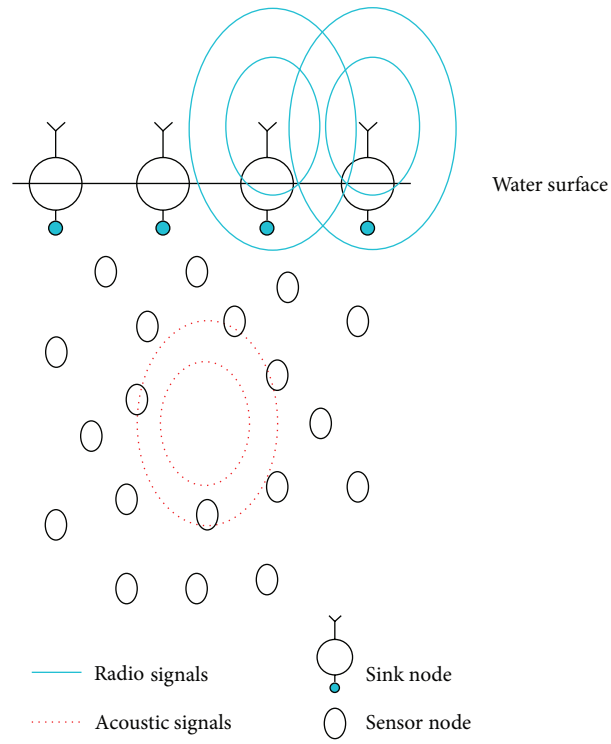

Figure 1: Multiple-sink underwater sensor network architecture.

3.2.2. Routing Table Formation Phase. After receiving RREP message from one-hop neighbor node, the sending node reckons the link expiration time with each compatible forwarding node. The sending node keeps the forwarding node in its routing table according to the decreasing order of the forwarding nodes' probability which means that the node with the highest probability is at the first position in the routing table and that the next highest is at the second position.

3.2.3. Target Node Selection Phase. After completing the formation of the routing table, the sending node picks up the forwarding node with the highest probability and corresponding to the link expiration time of the forwarding time in order to handle node mobility. The link expiration time is compared with the time to reach the packet to the forwarding node and return acknowledgment to the sending node from the forwarding node. If the link expiration time of the forwarding node exceeds the packet's reaching time and the acknowledgment's receiving time, then the forwarding node is chosen as a target node, and the packet is forwarded

Table 1: Route request message format.

Sender ID	Sender's location	Depth

Table 2: Route reply message format.

Forwarding node ID	Probability

Table 3: Data packet format.

Sender ID	Packet sequence number	Data

to the node. Otherwise, another node is chosen in the same way. If no node in the routing table is found as target node, then routing table is formed anew.

3.3. Protocol Design. Protocol design takes into account the packet format used by the proposed protocol, and the estimation of node's forwarding probability is performed in this section. The link expiration time for the forwarding nodes is estimated, and finally the proposed routing protocol algorithm is presented.

3.3.1. Packet Format. Two kinds of packets [13] are introduced in this protocol. Firstly, the sending node broadcasts a control packet named route request (RREQ) message to its neighbor within transmission range R in order to inform its neighbor of its location and depth. The route request message incorporates the sending node's ID, location, and depth that are used by the forwarding node to calculate its forwarding probability. The packet format of RREQ is illustrated in Table 1.

Other control packets include RREP message which carries the information of the forwarding node's probability to forward the packet and ACK which is used to confirm the packet received by the forwarding node. The RREP message is illustrated in Table 2.

Secondly, data packet is demonstrated in Table 3. The packet header consists of two fields: sender ID and packet sequence number and data. "Sender ID" is the identifier of the source node. "Packet sequence number" represents a unique sequence number that is assigned by the source node to the packet. Packet sequence number together with sender ID is required to differentiate between packets in later data forwarding.

3.3.2. Estimation of Node's Forwarding Probability. In this section, we have calculated the probability of forwarding packet and discarding packet of a node based on depth, residual energy, and distance from the forwarding node to the sending node. In order to calculate the probability, we use the Bayesian reasoning. We assume that the packet forwarding and packet discarding are two hypotheses, and three lines of observing evidence are the depth difference between the sending node and the forwarding node, the difference of current residual energy and the threshold residual energy of the forwarding node, and the distance from the sending node to the forwarding node.

Let H_1 = packet forwarding, H_2 = packet discarding, E_1 = depth difference between forwarding node and sending node, E_2 = difference of residual energy between current energy and threshold energy, and E_3 = distance between forwarding node and sending node

$$
\begin{aligned}
P(H_1) &= \frac{1}{2}, \\
P(H_2) &= \frac{1}{2}, \\
P(E_1 \mid H_1) &= \begin{cases} \dfrac{d_f - d_s}{R} & \text{if } (d_f - d_s > 0), \\ 0 & \text{if } (d_f - d_s \le 0), \end{cases} \\
P(E_1 \mid H_2) &= \begin{cases} 1 - \dfrac{(d_f - d_s)}{R} & \text{if } (d_f - d_s \ge 0), \\ \dfrac{-(d_f - d_s)}{R} & \text{if } (d_f - d_s < 0), \end{cases} \\
P(E_2 \mid H_1) &= \begin{cases} \dfrac{E_r - E_r^{\text{th}}}{E_r^{\max} - E_r^{\text{th}}} & \text{if } (E_r - E_r^{\text{th}} > 0), \\ 0 & \text{if } (E_r - E_r^{\text{th}} \le 0), \end{cases} \\
P(E_2 \mid H_2) &= \begin{cases} 1 - \dfrac{E_r - E_r^{\text{th}}}{E_r^{\max} - E_r^{\text{th}}} & \text{if } (E_r - E_r^{\text{th}} \ge 0), \\ \dfrac{-(E_r - E_r^{\text{th}})}{E_r^{\max} - E_r^{\text{th}}} & \text{if } (E_r - E_r^{\text{th}} < 0), \end{cases} \\
P(E_3 \mid H_1) &= \begin{cases} \dfrac{D}{R} & \text{if } (D > 0), \\ 0 & \text{if } (D \le 0), \\ 1 - \dfrac{D}{R} & \text{if } (D \ge 0). \end{cases}
\end{aligned}
\tag{1}
$$

Now, we can calculate the probability of a node's forwarding packet and discarding packet by using the following conditional Bayes' theorem:

$$
\begin{aligned}
&P(H_1 \mid E_1E_2E_3) \\
&\quad = \frac{P(E_1 \mid H_1) \times P(E_2 \mid H_1) \times P(E_3 \mid H_1) \times P(H_1)}{\sum_{k=1}^{2} P(H_k \mid E_1) \times P(H_k \mid E_2) \times P(H_k \mid E_3) \times P(H_k)}, \\
&P(H_2 \mid E_1E_2E_3) \\
&\quad = \frac{P(E_1 \mid H_2) \times P(E_2 \mid H_2) \times P(E_3 \mid H_2) \times P(H_2)}{\sum_{k=1}^{2} P(H_k \mid E_1) \times P(H_k \mid E_2) \times P(H_k \mid E_3) \times P(H_k)}.
\end{aligned}
\tag{2}
$$

The forwarding node forwards the packet if $P(H_1 \mid E_1E_2E_3) > P(H_2 \mid E_1E_2E_3)$. The forwarding node discards the packet if $P(H_1 \mid E_1E_2E_3) < P(H_2 \mid E_1E_2E_3)$.

3.3.3. Reckoning the Link Expiration Time. The link expiration time of any two nodes means the duration of the connectivity of the two nodes within a fixed range R. Let n_1

and n_2 be two nodes within a fixed range R. These two nodes move in θ_1, ϕ_1 and θ_2, ϕ_2 directions in the three-dimensional space of underwater, respectively. Let their initial position be x_1', y_1', z_1' and x_2', y_2', z_2', respectively, after time t and their new coordinate will be x_1, y_1, z_1 and x_2, y_2, z_2, respectively. Suppose that they travel at the speed of v_1 m/s and v_2 m/s, respectively, and after time t, n_1 passes d_1 miter, and n_2 passes d_2 miter:

$$\begin{aligned} d_1 &= v_1 t, \\ d_2 &= v_2 t. \end{aligned} \tag{3}$$

New coordinates (with respect to old coordinates) can be calculated using the following formula:

$$\begin{aligned} x_1 &= x_1' + x_1 \\ &= x_1' + d_1 \sin\theta_1 \cos\phi_1 \\ &= x_1' + t\left(v_1 \sin\theta_1 \cos\phi_1\right), \\ y_1 &= y_1' + y_1 \\ &= y_1' + d_1 \sin\theta_1 \sin\phi_1 \\ &= y_1' + t\left(v_1 \sin\theta_1 \sin\phi_1\right), \\ z_1 &= z_1' \\ &= z_1' + d_1 \cos\theta_1 \\ &= z_1' + t\left(v_1 \cos\theta_1\right), \\ x_2 &= x_2' + x_2 \\ &= x_2' + d_2 \sin\theta_2 \cos\phi_2 \\ &= x_2' + t\left(v_2 \sin\theta_2 \cos\phi_2\right), \\ y_2 &= y_2' + y_2 \\ &= y_2' + d_2 \sin\theta_2 \sin\phi_2 \\ &= y_2' + t\left(v_2 \sin\theta_2 \sin\phi_2\right), \\ z_2 &= z_2' \\ &= z_2' + d_2 \cos\theta_2 \\ &= z_2' + t\left(v_2 \cos\theta_2\right). \end{aligned} \tag{4}$$

The distance between the two nodes at time t can be found as follows. Let

$$\begin{aligned} a &= \left(x_1' - x_2'\right), \\ b &= \left(y_1' - y_2'\right), \\ c &= \left(z_1' - z_2'\right), \\ e &= \left(v_1 \sin\theta_1 \cos\phi_1 - v_2 \sin\theta_2 \cos\phi_2\right), \\ f &= \left(v_1 \sin\theta_1 \sin\phi_1 - v_2 \sin\theta_2 \sin\phi_2\right), \\ g &= \left(v_1 \cos\theta_1 - v_2 \cos\theta_2\right). \end{aligned} \tag{5}$$

Table 4: Routing table for the proposed UWSNs routing protocol.

Node	Forwarding probability	LET
N_1	FP(N_1)	LET_1
N_2	FP(N_2)	LET_2
N_3	FP(N_3)	LET_3
N_4	FP(N_4)	LET_4
N_n	FP(N_n)	LET_n

Now, the distance between the two nodes after time t can be calculated as follows:

$$\begin{aligned} D^2 &= (a + et)^2 + (b + ft)^2 + (c + gt)^2, \\ t^2\left(e^2 + f^2 + g^2\right) &+ t\left(2ae + 2bf + 2cg\right) + a^2 + b^2 + c^2 = D^2. \end{aligned} \tag{6}$$

Now, we assume that after time t the distance between these two nodes is R which is the transmission range. We can calculate the time t as follows:

$$\begin{aligned} t^2\left(e^2+f^2+g^2\right) &+ t\left(2ae+2bf+2cg\right)+a^2+b^2+c^2 = R^2, \\ t^2\left(e^2+f^2+g^2\right) &+ t\left(2ae+2bf+2cg\right)+a^2+b^2+c^2 - R^2 = 0. \end{aligned} \tag{7}$$

Again, let

$$\begin{aligned} m &= e^2 + f^2 + g^2, \\ n &= 2ae + 2bf + 2cg, \\ o &= a^2 + b^2 + c^2 - R^2. \end{aligned} \tag{8}$$

Now, it stands as follows:

$$\begin{aligned} mt^2 + nt + o &= 0, \\ t &= \frac{-n \pm \sqrt{n^2 - 4mo}}{2m}. \end{aligned} \tag{9}$$

3.3.4. Routing Table. Each node forms a routing table of three columns: candidate forwarding nodes, their corresponding probability, and link expiration time. Routing table of the proposed routing protocol is demonstrated in Table 4. Let the sender node be S, and let its one-hop candidate forwarding nodes be $(N_1, N_2, \ldots, N_n)$ within range R, and FP_n and LET represent the forwarding probability and the link expiration time between the two nodes, respectively.

3.4. The Routing Algorithms of the Proposed Routing Protocol. In this section, we design an algorithm for our proposed routing protocol. For each phase, a separate algorithm is implemented here. First, the algorithm for the forwarding node is illustrated in Algorithm 1. Second, the algorithm for routing table formation algorithm is given in Algorithm 2. Third, the packet forwarding algorithm for the sending node is shaped in Algorithm 3.

Require: RREQ message
Ensure: RREP message
(1) Extract RREQ message
(2) Calculate Probability of packet forwarding and discarding
(3) **if** $P(H_1 \mid E_1E_2E_3) > P(H_2 \mid E_1E_2E_3)$ **then**
(4) Send RREP message to the sending node
(5) **else**
(6) Discard the RREQ message
(7) **end if**

Algorithm 1: Algorithm for forwarding nodes.

Required: RREP message
Ensure: Routing table
(1) Broadcast RREQ message
(2) Extract RREP message
(3) Calculate LET (Link Expiration Time) for each forwarding node.
(4) Form routing table

Algorithm 2: Routing table formation algorithm of sending node.

4. Performance Evaluation

In this section, we evaluate the performance of the proposed UWSNs routing protocol and compare the performance of VBF [5].

4.1. Simulation Setting. All simulations are performed using the network simulator (ns-2) [14] with an underwater sensor network simulation package (called Aqua-Sim) extension. We performed simulations with a different number of sensor nodes (i.e., 25, 49, 100, and 225). The position of each node is generated randomly. Multiple sinks are randomly deployed at the water surface. Sink nodes are considered as stationary, while the sensor nodes are considered to be mobile at the speed of water current. In order to measure the performance of the proposed routing protocol, different speeds of water current are considered, and the minimum and the maximum speeds of water current are taken as 1 m/s and 10 m/s, respectively. In underwater environment, the sensor nodes move in random direction, and for easy simulation, we have defined the direction of each sensor nodes in 3D space randomly. We assume that control packets used in the protocol are much shorter compared to data packets. We define the energy consumed for each data packet to be 1 energy unit and for each *hello* packet to be 0.02 unit. The transmission range of the simulation is fixed to 250 m in all directions. The threshold energy of the sensor nodes is presumed to be 70 energy units. For the ease of simulation, the source node is chosen from the bottom of the taken 3D space. The same broadcast media access control (MAC) protocol as in [5] is used in our simulations. In this MAC protocol, when a node has a packet to send, it first senses the channel. If the channel is free, it continues to broadcast the packet. Otherwise, it backs off. The packet will be dropped if the maximal number of back offs has been reached.

4.2. Performance Metrics. The following metrics are pointers used to appraise the performance of the proposed routing protocol.

(i) Network life time: network life time expresses the time that the energy of the first node in the network turns to be fully exhausted.

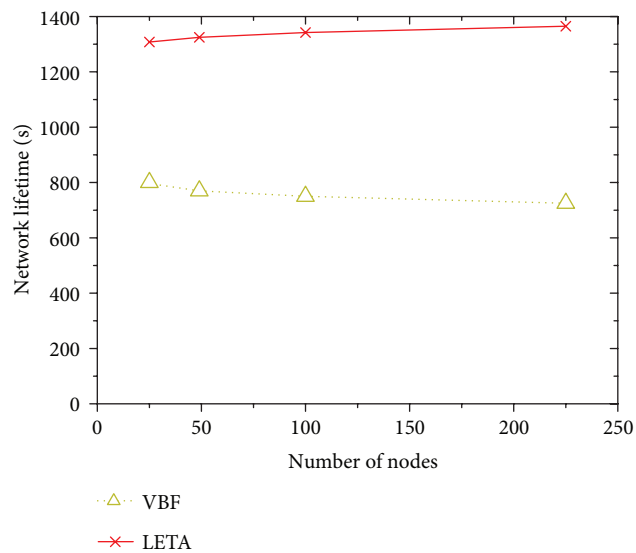

Figure 2: Comparison of network lifetime.

(ii) Total energy consumption: total energy consumption is computed through the total energy consumed in packet delivery including transmitting, receiving, and idling energy consumption of all nodes relaying the packet from the source node to the sink node in the network.

(iii) Average end-to-end delay: average end-to-end corresponds to the average time needed by a packet to go from the source node to any of the sinks.

(iv) Packet deliver ratio: packet delivery ratio is evaluated as the ratio of the number of distinct packet captured successfully by the destination node to the total number of packets spawned at the source node.

4.3. Result and Analysis. In this section, the result and the analysis of the simulation are discussed in detail.

4.3.1. Network Life Time. The network lifetime of LETA and VBF [5] in random topology is illustrated in Figure 2.

It is observed that LETA offers improved performance over VBF in the perspective of network life time. LETA exceeds the network lifetime of VBF because VBF always chooses the nodes within a fixed vector, and as a result, a senor node may be selected again and again to forward data.

Require: Data packet
Ensure: Packet forwarding & ACK
(1) Initialize $f \leftarrow False, ack \leftarrow False$
(2) **while** $i \leq n$ & $f = False$ **do**
(3) $N_{\text{Target}} \leftarrow N_i$
(4) **if** $T_{\text{LET}} \geq (2D/V)$ **then**
(5) Forward packet
(6) $f \leftarrow True$
(7) $i \leftarrow i + 1$
(8) **else**
(9) $i \leftarrow i + 1$
(10) **end if**
(11) **end while**
(12) Wait for $(2D/V)$
(13) **if** $ack = False$ & $i < n$ **then**
(14) *goto* (2)
(15) **else**
(16) Reform routing table
(17) **end if**

Algorithm 3: Packet forwarding algorithm.

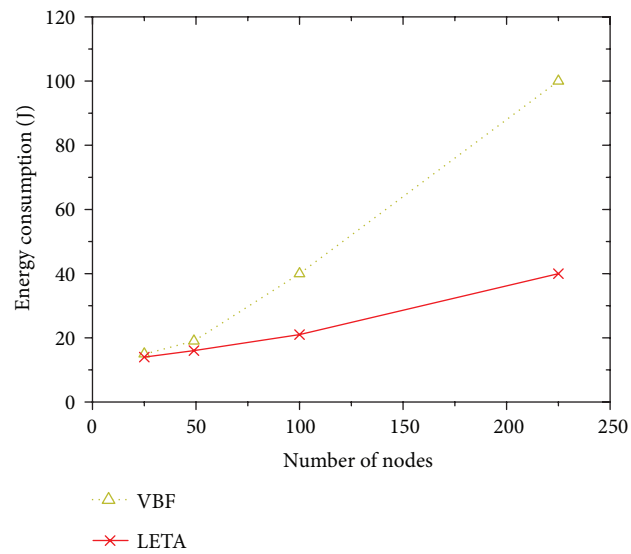

Figure 3: Comparison of total energy consumption of LETA with VBF.

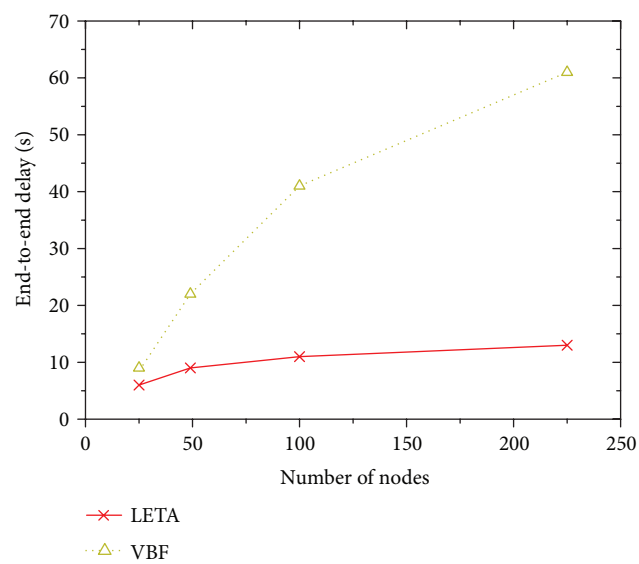

Figure 4: Comparison of average end-to-end delay of LETA with VBF.

Consequently, the energy of such nodes is exhausted fast, and these nodes' lifetime expires soon. On the other hand, LETA does not forward data to the sensor node in which residual energy is less than the threshold energy and always selects the sensor node with higher residual energy. It is a little chance for a senor node to go down its energy below threshold and dies. The control message hardly forces sensor nodes' energy to be exhausted. So, the network lifetime increases as the number of sensor node increases; in contrast, in case of VBF, if the number of sensor nodes increases, the network life time will decrease since with increasing the number of sensor nodes, more sensor nodes attend to forward data, and it is very chanceful for a sensor node to die at any time. Besides, VBF cannot avoid redundant packet transmissions. Most of the time, only one node in LETA forwards a data packet and thus saving energy, and it leads to improve the life time of the battery.

4.3.2. Total Energy Consumption. The comparison of the performances of LETA and VBF [5] in terms of energy consumption is illustrated in Figure 3.

It is seen that the proposed protocol consumes less energy than that of the VBF protocol. In LETA protocol, only one node takes part in forwarding packet. The forwarding node owns the title of the fittest node. As the sending node always gives the node with highest probability priority to forward packet, energy is much saved. On the contrary, in VBF more than one node attends in forwarding the same packet; as a result, higher energy is consumed in VBF protocol. In LETA protocol, the control packet is implied to find out the fittest node and to acknowledge the sender of its packet reaching to the forwarding node. These control packets consume a negligible amount of energy as they are used locally and when data packet is available to send. In VBF, three types of control packets are used: one is for fixing the destination and the other two are for packet forwarding. To fix up the destination, it has to flood the control packet which causes a lot of energy as the sender is deeper as it consumes more energy. In VBF, node mobility is not guarded; as a result, with the increase of nodes and node mobility, much energy is being consumed.

4.3.3. Average End-to-End Delay. In Figure 4, end-to-end delay of LETA and VBF [5] is shown, respectively.

LEAT always tries to send packet to the forwarding node which is near to the surface as the probability of forwarding packet is calculated based on the depth and the distance between the forwarding node and the sending node. On the contrary, in VBF, it takes much time to discover

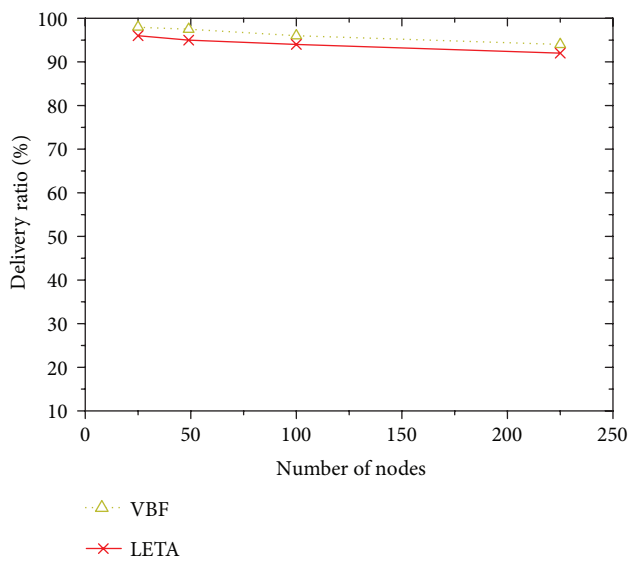

Figure 5: Comparison of packet delivery ratio of LETA with VBF.

the destination node and for the response to come from the destination node in VBF, so the average end-to-end delay in VBF is larger than that of LETA. As the velocity of water current increases, the end-to-end delay decreases as in both protocols. In LETA, there are a lot of forwarding nodes which are near to the surface to be chosen as target nodes. But in VBF, to handle node mobility, no direct technique is applied; as a result, less number of the forwarding nodes attend in forwarding packet with increasing node mobility, and it increases the end-to-end delay which is higher than that of LETA.

4.3.4. Packet Delivery Ratio. Figure 5 shows the delivery ratio as the function of the number of nodes.

The delivery ratio of packet depends on how much reliable and robust the protocol is. The LETA is a reliable protocol as it is using acknowledgment packet which confirms a packet's successful receiving by a forwarding node, and it is robust because it floods control message locally. The packet delivery ratio of LETA is higher than that of VBF. Although in LETA, in most of the cases, only one node joins in packet forwarding, the packet delivery ratio is not below the expected level because the sender forwards the packet to the fittest node and waits for the acknowledgment. In VBF, only those nodes that are in the vector take part in forwarding packet; consequently, with the increasing of node mobility, the node can be out of the vector, and this effect reduces the packet delivery ratio in VBF.

5. Conclusion

In this paper, we introduce the link expiration time to handle node mobility and probability to select a node as forwarding node which is a novel technique. Acknowledgment packet is used in this protocol to ensure error-free date packet's receiving by the forwarding node. The protocol guarantees the maximum level of network life time and end-to-end delivery. In the future, we plan to adopt detour mechanism to avoid the void of zone and to develop better mobility handle method.

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References

[1] I. F. Akyildiz, D. Pompili, and T. Melodia, "Challenges for efficient communication in underwater acoustic sensor networks," *ACM Sigbed Review*, vol. 1, no. 2, pp. 3–8, 2004.

[2] J. Heidemann, Y. Li, A. Syed, J. Wills, and W. Ye, "Underwater sensor networking: research challenges and potential applications," USC/ISI Technical Report ISI-TR-2005-603, 2005.

[3] J. A. Rice, "Undersea networked acoustic communication and navigation for autonomous minecountermeasure systems," in *Proceedings of the 5th International Symposium on Technology and the Mine Problem*, 2002.

[4] L. Guo, P. H. Santschi, M. Baskaran, and A. Zindler, "Distribution of dissolved and particulate in seawater from the gulf of mexico and off cape hatteras as measured by sims," *Earth and Planetary Science Letters*, vol. 133, no. 1-2, pp. 117–128, 1995.

[5] P. Xie, J. H. Cui, and L. Lao, "VBF: vector-based forwarding protocol for underwater sensor networks," in *Networking 2006. Networking Technologies, Services, and Protocols; Performance of Computer and Communication Networks; Mobile and Wireless Communications Systems*, vol. 3976, pp. 1216–1221, 2006.

[6] N. Nicolaou, A. See, P. Xie, J. H. Cui, and D. Maggiorini, "Improving the robustness of location-based routing for underwater sensor networks," in *Proceedings of the OCEANS Europe*, pp. 1–6, June 2007.

[7] N. Chirdchoo, W. S. Soh, and K. C. Chua, "Sector-based routing with destination location prediction for underwatermobile networks," in *Proceedings of the International Conference on Advanced Information Networking and Applications Workshops (WAINA '09)*, pp. 1148–1153, IEEE Computer Society, May 2009.

[8] M. C. Domingo and R. Prior, "Design and analysis of a GPS-free routing protocol for underwater wireless sensor networks in deep water," in *Proceedings of the International Conference on Sensor Technologies and Applications (SENSORCOMM '07)*, pp. 215–220, IEEE, October 2007.

[9] Z. Zhou and J. H. Cui, "Energy efficient multi-path communication for time-critical applications in underwater sensor networks," in *Proceedings of the 9th ACM International Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc '08)*, pp. 221–230, May 2008.

[10] M. Ayaz and A. Abdullah, "Hop-by-hop dynamic addressing based (H2-DAB) routing protocol for underwater wireless sensor networks," in *Proceedings of the International Conference on Information and Multimedia Technology (ICIMT '09)*, pp. 436–441, Jeju Island, Korea, December 2009.

[11] H. Yan, Z. Shi, and J. H. Cui, "Dbr: depth-based routing for underwater sensor networks," in *NETWORKING 2008 Ad Hoc and Sensor Networks, Wireless Networks, Next Generation Internet*, vol. 4982 of *Lecture Notes in Computer Science*, pp. 72–86.

[12] W. K. G. Seah and H. X. Tan, "Multipath virtual sink architecture for underwater sensor networks," in *Proceedings of the OCEANS 2006 Asia Pacific Conference*, May 2007.

[13] M. Ayaz, A. Abdullah, I. Faye, and Y. Batira, "An efficient Dynamic Addressing based routing protocol for Underwater Wireless Sensor Networks," *Computer Communications*, vol. 35, no. 4, pp. 475–486, 2012.

[14] The Network Simulator NS-2, 2002, http://www.isi.edu/nsnam/ns/doc/index.html.