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Atomic-shaped efficient delay and data gathering routing protocol for underwater wireless sensor networks

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Abstract: High end-to-end delay is a major challenge in autonomous underwater vehicle (AUV)-aided routing protocols for underwater monitoring applications. In this paper, a new routing protocol called atomic-shaped efficient delay and data gathering (ASEDG) has been introduced for underwater wireless sensor networks. The ASEDG is divided into two phases; in the first phase, the atomic-shaped trajectory model with horizontal and vertical ellipticals was designed for the movement of the AUV. In the second phase, two types of delay models were considered to make our protocol more delay efficient: member nodes (MNs) to MNs and MNs to gateway nodes (GNs). The MNs-to-MNs delay in the network specifies how long is required for the selection of the next possible forwarders by eliminating the chances of backtracking and a higher number of association links. The MNs-to-GNs delay is considered to choose the path from a multipath environment that takes a minimum amount of time for sending the packet from its generation to destination node. For efficient data gathering, this new trajectory model creates the maximum possible GNs for the association of the MNs. Furthermore, our protocol, ASEDG, has been evaluated by using the aquasim network simulator (NS-2), and its results were compared with the already existing protocol, an efficient data gathering (AEDG) routing protocol. The simulation results show that the ASEDG performed better than the AEDG in terms of end-to-end delay and throughput.

Key words: Underwater wireless sensor network, routing protocol, autonomous underwater vehicle, delay-efficient, data gathering

1. Introduction

About 70% of the earth's surface is covered by water. Fast changes in technology have brought unique and better approaches for observing underwater conditions. Underwater wireless sensor networks (UWSNs) are precise enough for applications such as oceanographic data gathering, ocean sampling, assisted navigation, disaster prevention, oil and gas pipeline monitoring, and mine detection [1, 2]. Radio frequency (RF) signals are highly attenuated and easily absorbed in water so these signals do not propagate well in UWSNs. Therefore, acoustic communication is valuable due to its better data rates [3]. However, acoustic signals bring many design challenges like unwanted channel interference, which may occur over the network, and this may lead to a high amount of overhead due to the retransmission process of the data [4]. In UWSNs, other challenges include limited bandwidth, excessive propagation delays (propagation speed in water is lower than radio propagation speed), high error chances, high end-to-end delay, inefficient data gathering, short network lifespan, unending variations in network topology, and more power intake (sensors use battery power) [5, 6].

Most of the UWSN applications demand reliable data gathering and delivery where the dynamic and

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unpredictable underwater environment makes the routing task more challenging as compared to terrestrial networks [7, 8]. In traditional data gathering, there is a way to directly forward sensed data to a sink node in a multihop fashion. However, it takes a long route and there are more chances for the occurrence of energy hole problems [9, 10]. Mobile autonomous underwater vehicles (AUVs) have been critically observed to avoid this problem. They take data from the sensor nodes and send them to the sink by following the shortest path tree (SPT), and then return home [11]. Such vehicles come underneath the category of cellular robotics that have actuators, sensors, and on-board intelligence to enhance the productivity of data gathering with no human effort [12, 13].

In UWSNs, the process of data gathering holds the most important position [14]. Recent work shows that data collection with the help of an AUV minimizes the multihop data transmission, improving the energy efficiency in the UWSN [15]. For data collection, instead of visiting each node or cluster, the AUV visits only the selected nodes, called gateway nodes (GNs) or path nodes, to reduce the transmission power of the sensor nodes. The selection of GNs depend on the received signal strength indicator (RSSI) value of the hello packet (HP), the node position in the AUV region, and residual energy [16]. Furthermore, an association is made of the member nodes (MNs) with the GNs by using the SPT algorithm for flooding the data packets towards the GNs. When the GNs consume energy up to a certain threshold, a new node with higher residual energy from its neighbors is selected as the gateway node.

The path of the AUV has a significant role as the AUV must plan a path that maximizes the information collected and minimizes the travel time [17]. If there is no consistent movement of the AUV, it could have an effect on high packet loss and inconsistent energy consumption. Recent work shows that an elliptical-shaped trajectory provides the most favorable choice in terms of efficient data gathering, but more time is required for the association of those MNs that lie vertically in correspondence to the GNs and this leads to high end-to-end delay.

In this research work, we propose an efficient cooperative communication and data gathering routing protocol, ASEDG, which ultimately aims to reduce the high end-to-end delay. ASEDG performs its routing operations with the help of two elliptical-shaped trajectories, horizontal and vertical, that make an atomic-shaped delay model. It creates the maximum number of GNs and reduces the time required in the vertical association of the MNs with the GNs.

2. Literature review

In [1], the authors proposed an AEDG routing protocol that enhances network lifetime and throughput and reduces packet loss due to less energy consumption with the aid of the AUV, which takes data from GNs and forwards them to the sink. Rotating the AUV on the basis of residual energy additionally associates the minimum number of MNs with the GNs by using the SPT algorithm, which reduces the packet loss. The AUV moves on a suboptimal elliptical trajectory. The problem that remains unsolved is that the end-to-end delay of the AEDG is higher.

In [4], the authors presented a distributed data-gathering scheme using an AUV for data gathering from a cluster-based UWSN. Instead of visiting each node or cluster, the AUV visits only the selected nodes, called path nodes, to reduce the transmission power of the sensor nodes. In [9], it was determined that mobility increases the sensing coverage area. In [15], the authors proposed the AUV-aided energy-efficient routing protocol (AEERP). This scheme employs GNs that rotate on the basis of their residual energy to enhance the network lifetime by reducing energy consumption, but it does not restrict the association of MNs with GNs and this becomes the reason for a high amount of energy consumption at the GNs; moreover, there are excessive possibilities of data losses at the GNs.

In [18], the authors presented an AUV-aided underwater routing protocol (AURP) for efficient data gathering and network maximization. This scheme uses multiple AUVs to transmit data to the sink, which minimizes the total number of data transmissions by relaying the data. It results in the maximum data delivery rate and efficient data gathering, and it minimizes the energy consumption. However, this technique uses fixed GNs to take the data from MNs; in this sense, the GNs use most of their energy in relaying the data and ultimately lessen the network lifetime and provide a low data delivery rate. In [19], a relative distance-based forwarding (RDBF) routing protocol was proposed to transmit data from the source to the sink, and which node becomes the forwarder depends on the idea of fitness.

In [20], a mathematical technique was proposed to calculate the distance between the nodes in the UWSN. In [21], a data-gathering scheme for hierarchical UWSN, which uses multiple AUVs to explore large-scale areas, was presented. These multiple AUVs form an intermittently connected multihop network through inter-AUV synchronization for forwarding data to the sink. In [22], the authors proposed an asymmetric link-based reverse routing protocol (AREP) in which each node maintains a routing table for storing information about neighbors to determine the link state as up or down.

In [23], a scalable and efficient data gathering (SEDG) routing protocol was proposed using AUVs to prolong network lifetime and take data from GNs. The SPT algorithm was used for MNs' association with GNs and minimizing the association time to reduce energy consumption. SEDG develops an elliptical trajectory for the movement of AUVs with the help of CDS. In [24], a channel aware routing protocol (CARP) was introduced that makes full use of link quality information for packet forwarding. It avoids loop-free routing and takes advantage of simple topology information to successfully route around void and shadow zones. In [25], a diagonal and vertical routing protocol (DVRP) was proposed for end-to-end delay in UWSNs. Packets are forwarded towards the sink by making a flooding zone angle. Sensors make local decisions on packet forwarding under the constraints of flooding angle and energy status of sensors.

In [26], an improved hydro cast was proposed, which deploys an AUV for data gathering. Routing takes place in a greedy multihop fashion to the sink by using the pressure level of sensor nodes. In [27], the authors addressed the problem of network lifetime by considering two basic elements: packet size and transmission power. They proposed a framework that jointly optimizes these two factors and increases the network lifetime by using integer linear programming. In [28], a new algorithm was proposed in which the AUV used Dubin curves to gather data from multiple targets located in a 3D environment. In the first step, it converts 3D targets into a 2D plane and designs a 2D path. In the second step, it converts the 2D path in the Dubin curve by using Euler rotation transformation into a 3D global coordinate system.

The path of an AUV plays a major role in data gathering processes as well as the energy consumption of sensor nodes. For different paths, there is no mechanism for an AUV to plan a path for data gathering processes by minimizing the energy consumption of nodes. To overcome this gap, an enhanced lawn mower pattern was proposed for AUV path planning and energy consumption of sensor nodes in [29]. In [30], the authors summarized the principles, advantages, and disadvantages of modeling and path search technologies for AUVs. Furthermore, they summarized the improvement methods of various technical shortcomings and improved the original methods.

3. Problem definition

For data transmission, most routing techniques propose a path that connects the source and sink (destination) nodes with the help of multiple intermediate sensor nodes. In these scenarios, there is a high probability of packet loss, node failure, high energy consumption, and inefficient data gathering. To overcome the probability of these issues, an AUV has been introduced in the routing techniques. For data gathering, the AUV moves in a predefined trajectory; in current scenarios, the most favorable choice for AUV movement is the elliptical trajectory when concerned about efficient data gathering, energy intake, and reliable delivery of data. However, there are some flaws in the trajectory itself and the procedure following it for the data gathering process.

1. One significant improvement is to introduce a new trajectory design process for the following reasons:
   (a) At the initial stage, there is unnecessary energy utilization of the sensor nodes for making connected dominant set (CDS) nodes.
   (b) Computational cost in terms of energy and time is high for sorting the CDS to design an elliptical shape.
   (c) Fixed-sized elliptical shapes have been used for different network area sizes.
2. The SPT is not applied at a specific region in the network, which causes backtracking and high delay in the MNs-to-GNs association.
3. Nodes that reside vertically at a higher distance in correspondence to the horizontal elliptical trajectory bring high end-to-end delay in the network.

4. System model

The general architecture of the network, node deployment pattern, design of the AUV path movement or trajectory, working principles, and constraints are discussed. Classification of the nodes depends on a few features, which are discussed in Table 1 as follows:

1. Member nodes (MNs).
2. Gateway nodes (GNs).
3. Autonomous underwater vehicle (AUV).

Table 1. Attributes of deployed nodes.

Attributes	MNs	GNs	AUV
Modem	Acoustics	Acoustics	Acoustics, radios
Quantity	Larger	Smaller	Two
Info. sensing	Yes	Yes	No
Interacts with	MNs, GNs	MNs, GNs, AUV	GNs, Sink
Device mobility	No	No	Yes
Energy	Lesser	Greater	Not a constraint

5. Trajectory design

We have proposed a novel technique, atomic-shaped efficient delay and data gathering (ASEDG), a routing protocol for efficient data gathering and to minimize high end-to-end delay. Our protocol maximizes the amount of data gathered with the help of a maximum number of GNs and reduces the delay by using delay models.

5.1. Existing trajectory design

The existing elliptical-shaped trajectory or route for the movement of AUVs has been developed with the help of CDS nodes. The CDS is a set of dominator nodes in the network, which gives multiple paths towards the other nodes of the network.

When the CDS is established, the minimum spanning tree (MST) of the CDS is constructed. After construction of the MST, a Hamiltonian circuit (HC) is developed, which is a random trajectory for the movement of the AUV, as shown in Figure 1. The CDS does not give an actual image to develop an elliptical shape. These CDS nodes give a random trajectory, this random trajectory along with the HC is further refined into a circular trajectory, and that circular trajectory is converted into an elliptical trajectory. In this way, an elliptical shape is designed, which has no relation with the network area size. The case of an increase or decrease in network size, at which the ratio of the size of the ellipse varies, has not been addressed in existing work.

5.2. Atomic shape trajectory design

We have proposed a technique with horizontal and vertical elliptical trajectories. The idea of designing two trajectories has been taken from the atomic structure. Two AUVs are used for both elliptical trajectories. A considerable space is kept between them to eliminate the chances of collision. In contrast to the AEDG, a sensor node is placed in the center of the network by considering the area of the network. The center-positioned node is capable of designing differently sized elliptical horizontal trajectories by considering two variables, a (major axis) and b (minor axis). The X axis of the area helps to find the major axis of the elliptical shape and the Y axis helps to find the minor axis of the elliptical shape.

5.3. Defining major and minor axes

To decide the major and minor axes of the elliptical shape, we take the value of b static and draw multiple elliptical shapes as shown in Figure 2.

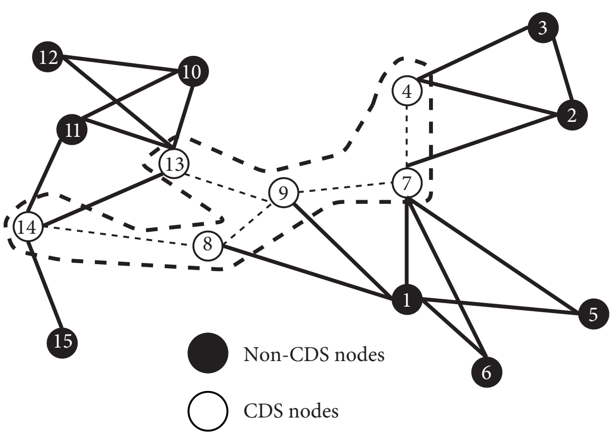

Figure 1. Trajectory of the AUV with HC.

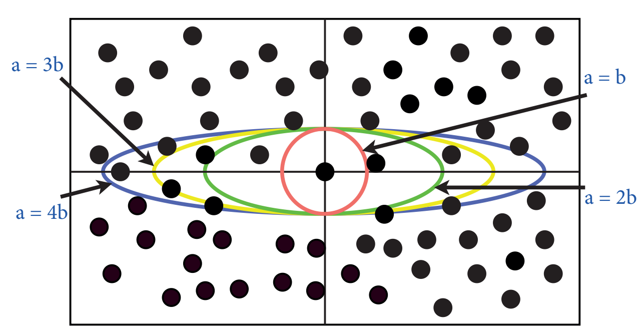

Figure 2. Multiple ellipses.

The procedure discussed above helped to develop the horizontal elliptical trajectory. The center-positioned node developed one more elliptical trajectory, but covering the same network area vertically and taking the values of major and minor axes of the horizontal elliptical trajectory, as depicted in Figure 3.

5.4. Atomic shape

If we take the major axis, b, as being equivalent to the minor axis, the shape creates a circle. If we take the major axis as twice that of b (minor axis), which is $2b$, the point where an ellipse is created does not vertically cover a sufficient area of the network so the distant nodes lying in the vertical region cannot be eligible to become GNs. However, by taking the major axis as thrice that of b, which is $3b$, it constructs a vertical ellipse that covers the appropriate vertical region of the network and selects the maximum number of distant nodes lying in the vertical region as GNs. If we take the major axis as $4b$ then the data gathering process slows down and an excessive number of GNs are made, which increases the energy consumption of the network; therefore, it is not taken.

We take the major axis $3b$, as it is thrice that of the minor axis, to construct a vertical trajectory that covers the optimal area of the network. The one optimal horizontal elliptical is when $a = 3b$. Multiple elliptical shapes are drawn against different values of b, as shown in Figure 4. For the selection of the optimal one, we have considered the horizontal distance covered by the ellipse. Since the horizontal distance of each ellipse was equal to $2a$, all of the ellipses' horizontal distances were compared with the center point of the network and the distance having the closest value to the center point was selected as the optimal one.

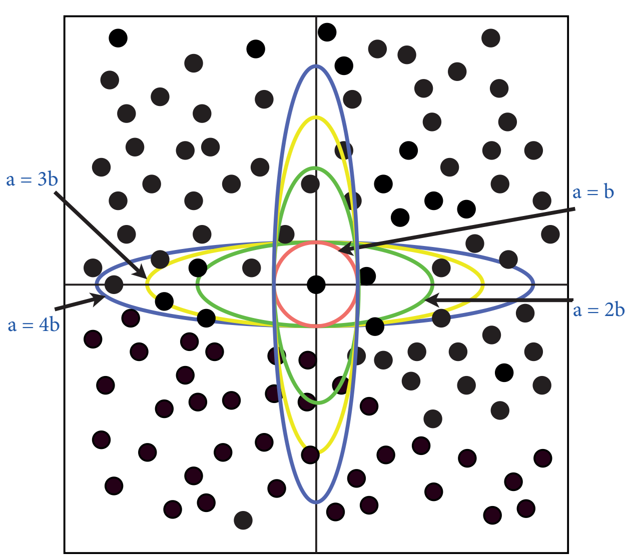

Figure 3. Atomic shape against multiple ellipses.

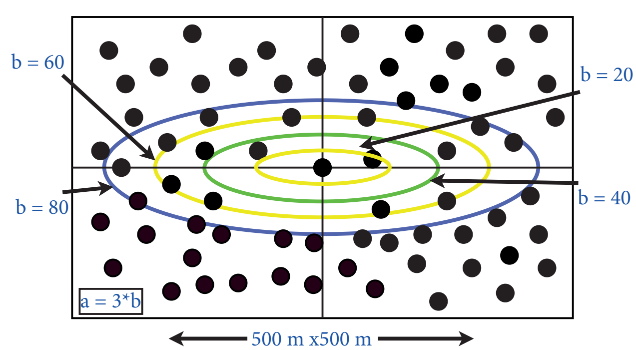

Figure 4. Selection of optimal ellipse.

In Figure 4, we have taken the area of $500 \times 500m^2$ and its center point is 250; therefore, it becomes optimal when $b = 40$ and $a = 120$. There exists a relation of 1 major axis being equal to 3 times the minor axis of the ellipse. From this ratio, the values of b and a are varied. For example, if the area will be 1000×1000 m^2, the values of b and a become 80 and 240, and if the area is $250 \times 250m^2$, b and a become 20 and 60.

6. Delay model

While designing a network, delay is an important performance characteristic to keep in consideration. Two types of delay are kept in consideration and their models are presented as well:

1. MNs to MNs,
2. MNs to GNs.

6.1. MNs to MNs

The delay of nodes in a network specifies how long the data packet takes to travel from one node to another node. If the next forwarder is far away or at a greater distance from the source node, it may be a cause of high delay among the nodes while forwarding. This high delay brings more chances of packet loss in a high ratio and more energy consumption over the nodes.

To overcome node-to-node delay, Algorithm has been proposed for the next forwarder selection in ASEDG. Since all of the nodes are position-aware and one node has been placed at center location in the network, that center node plays a vital role in selecting the next forwarder. By considering the location of the center node, a source node is able to decide the direction of the next forwarder node. The direction or location of the next forwarder can be determined by using Algorithm .

Algorithm Next forwarder selection.

Input: All nodes

Output: Determine next forwarder direction

Initialization :

$n = All\ \ Nodes$

$cx = Center\ \ node\ \ X - axis$

$cy = Center\ \ node\ \ Y - axis$

for $i = 1\ \ to\ \ n$ **do**

  $x = ith\ \ node\ \ X - axis$

  $y = ith\ \ node\ \ Y - axis$

  if $x \leq cx$ and $y \leq cy$ **then**

    Next forwarder $(x, y++)$,$(x++, y), (x++, y++)$

  else if $x \geq cx$ and $y \leq cy$ **then**

    Next forwarder $(x, y++)$, $(x--, y), (x--, y++)$

  else if $x \leq cx$ and $y \geq cy$ **then**

    Next forwarder $(x, y--)$, $(x++, y), (x++, y--)$

  else if $x \geq cx$ and $y \geq cy$ **then**

    Next forwarder $(x, cy--)$, $(x--, cy), (x--, y--)$

  end if

end for

In this algorithm, we divide the network into four quadrants. Whenever a node becomes a source node, it first draws a region horizontally and vertically in that quadrant along with the X and Y axes. The next forwarders must be residing in and at the boundary of the horizontal and vertical regions. For the selection of the next forwarders, a procedure is discussed in Algorithm. This will help us to reduce the delay that occurs due to the wrong selection of the next forwarders. The selection process of the nodes is also depicted in Figure 5.

The next forwarders will be selected and this process continues until all of the forwarders have reached the GNs. It is just like a tree topology, in which a source node acts as a root node and the next possible forwarders behave as child nodes. The GNs are playing leaf roles in this topology.

In Algorithm, n represents the total number of sensor nodes in the network and cx and cy represent the center node location. x represents the X axis and y represents the Y axis location of the source node. The center-positioned node divides the entire network into four regions.

The network region is divided into four quadrants; therefore, there exist four possibilities for the source node to create a path towards the receivers. Initially, the source node becomes aware of its current location and compares it with the centrally positioned aware node. In the second phase, it determines its boundaries by analyzing the center node position. In the third phase, a node sends the HP to neighbors and receives their acknowledgment that contains their location, too. The source node compares its location with the receivers' locations and selects the next possible forwarders. In all regions two conditions are imposed on the next forwarder; according to the first condition, they must reside between the source node's X and Y axis or at the boundary of the source node's X or Y axis; in the second condition, four possibilities are encountered as per the location of the source node. If a node appears in the first region, the next forwarder's X and Y axes must be greater than the source node's X and Y axes. In the second region, the next forwarder's X axis must be less and Y axis must be greater than the source node's X and Y axes. In the third region, the next forwarder's X axis must be greater and Y axis must be less than the source node's X and Y axes, and in the fourth region, the next forwarder's X and Y axes must be less than the source node's X and Y axis.

1. In the first region, $x \leq cx$ and $y \leq cy$.
2. In the second region, $x \geq cx$ and $y \leq cy$.
3. In the third region, $x \leq cx$ and $y \geq cy$.
4. In the fourth region, $x \geq cx$ and $y \geq cy$.

By applying these limitations, each region's node will be able to wisely choose the next forwarder.

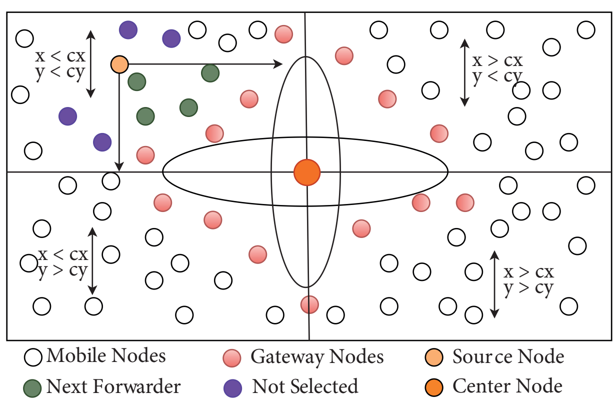

Figure 5. Next forwarder selection.

6.2. MNs to GNs

The MNs-to-GNs delay is considered to be the time taken by a packet from generation to destination (GNs). In a network, nodes are deployed in a high density area, which means there is a higher number of links created in the MNs' association with the GNs (described for MNs to MNs), which causes a distant communication, and it suffers from MNs-to-GNs delay. Creation of multiple links is also shown in Figure 6a. When the association time of the MNs with the GNs and the transmission distance are higher, MNs-to-GNs delay occurs. In the UWSN, there are many paths existing between the source node and destination node. By applying the next forwarder selection algorithm, paths are created in specific directions, which reduces the number of possible paths towards different GNs as shown in Figure 6b. Since our proposed trajectory is atomic-based it also creates GNs along its vertical trajectory. The nodes create paths towards both the horizontal and vertical trajectory GNs. Consequently, it reduces the delay that is caused due to the distant communication between the MNs and the GNs. MNs make paths towards multiple GNs. There are multiple paths existing towards the GNs and the SPT helps to find the one with the shortest distance. MNs compute their distances towards all possible GNs, and the MNs' associations get made by the SPT algorithm (Figure 6c).

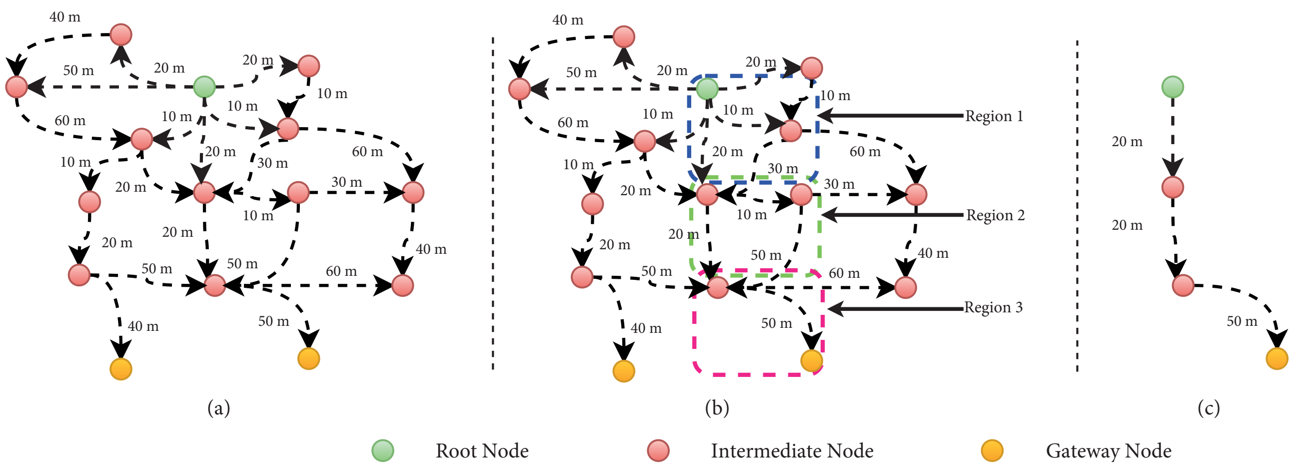

Figure 6. SPT applied (a) without algorithm 1, (b) with algorithm 1, (c) optimal path.

AP represents all the paths from the MN to different GNs.

$$n = AP \tag{1}$$

The call SPT is used on different paths to select the most optimal one in terms of shortest distance.

$$call - SPT(n) \tag{2}$$

The shortest path is a classic problem in graph data structures where the distance or weight of each edge is known. Assume that G is a graph where (V, E) are the vertex and edges in graph G. Assign every V a tentative distance. Set the initial node or source node as the current node and mark the rest of the nodes as unvisited. For the current node, consider all of the unvisited nodes and calculate their tentative distances. Compare the current distances with the calculated distances and assign the shortest distance value to every V. When all the neighbor nodes are considered by the current node, set them as visited. If the destination source is marked, set that as visited.

7. Simulation results

For the performance evaluation of ASEDG, we have tested it via aquasim NS-2 and compared its performance with the already existing AEDG routing protocol. The created environment for simulations is depicted in Table 2.

Table 2. Simulation settings.

Parameter	Value	Parameter	Value
Area	500 × 500, 1000 × 1000, 1500 × 1500 m^2	Nodes' dataset	100
Number of AUVs	2	Data packet size	1024 bytes
Communication medium	Wireless	Wireless channel	Radio and acoustic
Transmission range	120 m	Frequency	15 kHz
Energy	Energy model	Initial energy	1000 J
Transmission power	0.5 W	Receiving power	0.1 W
Idle power	0.008 W	Sleeping power	0.01
Nodes' mobility	Random and static	Network topology	2D

7.1. End-to-end delay

End-to-end delay depends on the transmission distance and transmission speed of the channel. The speed of the acoustic signal remained constant (1500 m/s), so it only depended on the transmission distances among the nodes. In the AEDG, the nodes were deployed in a high density area, which means that a higher number of links were created in the MNs' associations with the GNs, which caused a distant communication and it suffered from high end-to-end delay. For the MNs that were positioned vertically in correspondence to the horizontal elliptical trajectory, their association times with the GNs could be reduced to some extent. For this purpose, the ASEDG horizontal and vertical elliptical trajectories covered the maximum network area and created the maximum number of GNs. The time required for the associations of the vertically positioned MNs was reduced because of the creation of the GNs near the vertical elliptical trajectory. This caused a reduction in the end-to-end delay as compared to the AEDG.

7.2. Delay without nodes rotation

Figure 7 represents the average end-to-end delay of a network in a static environment. We have ignored the dynamic topology effect. In small areas, there is a higher collision rate of data packets that causes the retransmission of the same data packets towards the destination node. Therefore, there is a fluctuation as shown in Figures 7a and 7b. As the network size increases, the chances of packet collision are eliminated, which causes a constant delay, and the performances of both protocols are depicted in Figure 7c. ASEDG performs better than AEDG in different network areas and has less delay.

7.3. Delay with nodes rotation

Figure 8 shows the average end-to-end delay when the nodes are rotated. In this case, both protocols have higher changes in the values against the different iteration sets. From Figures 8a–8c it is not easy to decide which one is better in terms of the average end-to-end delay of a network. Therefore, we have taken the average of these 50 values and the results are shown in Table 2.

7.4. Network throughput

Throughput is defined as the successful packet delivery to the sink node. The number of packets delivered to the sink node is counted per second. In the AEDG and ASEDG, the nodes are alive for a longer period of time and the GNs rotate to enhance the stability of the network. In the AESDG, two elliptical trajectories result

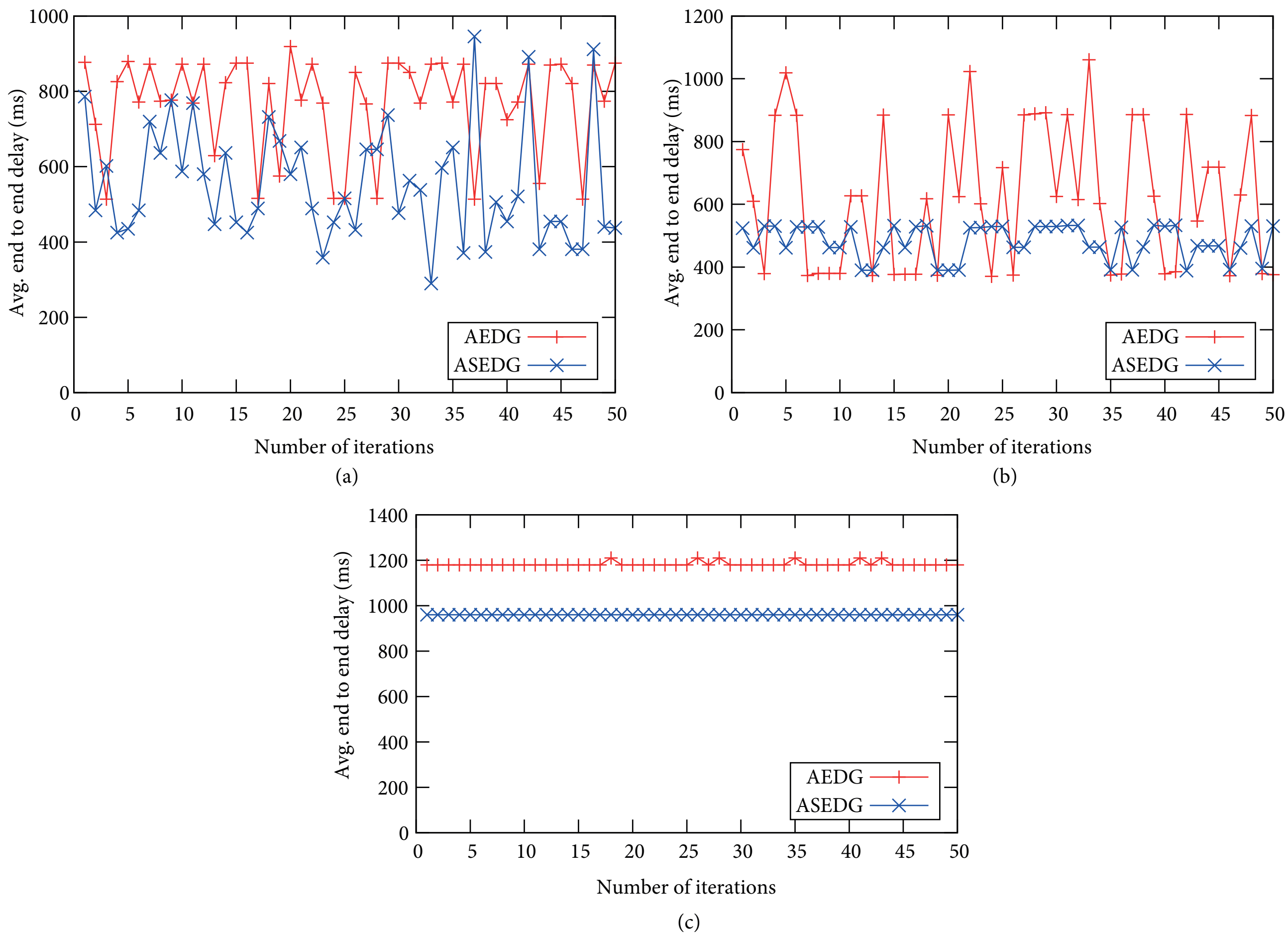

Figure 7. Average end-to-end delay of 100 static nodes in (a) 500 m × 500 m, (b) 1000 m × 1000 m, (c) 1500 m × 1500 m.

Table 3. Average end-to-end delay (ms).

Protocol	500 m × 500 m	1000 m × 1000 m	1500 m × 1500 m
ASEDG	623	566	408
AEDG	698	609	454

in the creation of more GNs, which cover the vertical and horizontal areas of the network to relay the data of the far-end nodes. This causes a decrease in the number of hops involved in the data forwarding process and also shortens the data transmission paths. Hence, shorter transmission paths reduce the chances of data collisions and information loss. Tables 3 and 4 show the packet transmission rates of the ASEDG and AEDG. The minimum and maximum number of packets per second are shown against these protocols. ASEDG has enhanced the successful packet delivery rate at the sink node because the nodes transmit the packets for a longer

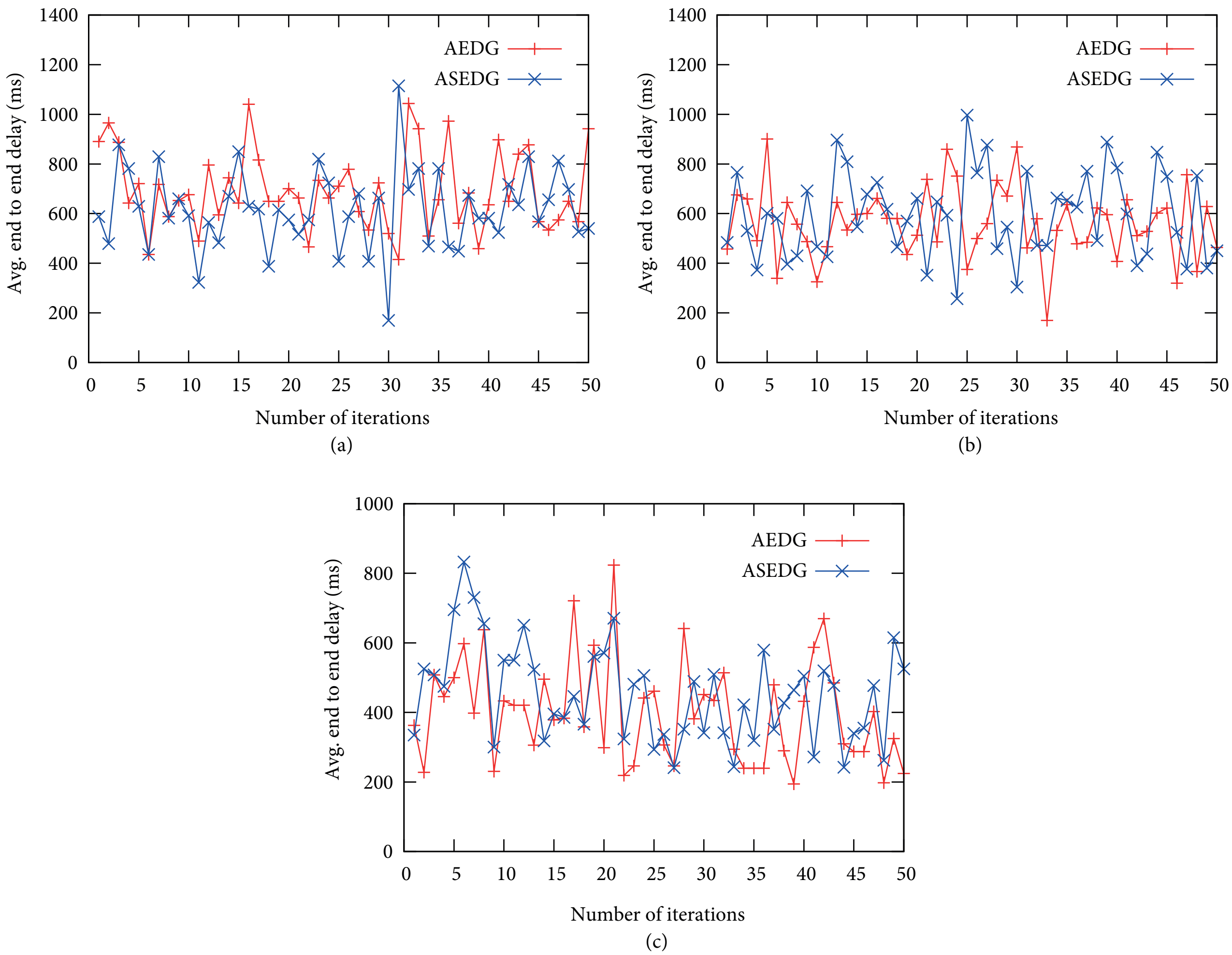

Figure 8. Average end to end delay of 100 mobile nodes in (a) 500 m $\times$ 500 m, (b) 1000 m $\times$ 1000 m, (c) 1500 m $\times$ 1500 m.

time period. Ultimately, the chances of packet losses are reduced and the successful delivery ratio is increased.

Table 4. Throughput without nodes rotation.

Area	AEDG Min	AEDG Max	ASEDG Min	ASEDG Max
500 m $\times$ 500 m	16	27	10	24
1000 m $\times$ 1000 m	10	20	7	15
1500 m $\times$ 1500 m	14	14	10	10

Table 5. Throughput with nodes rotation.

Area	AEDG Min	AEDG Max	ASEDG Min	ASEDG Max
500 m × 500 m	14	28	17	30
1000 m × 1000 m	11	24	11	23
1500 m × 1500 m	17	50	20	56

7.5. Energy Consumption

In the AEDG, the associations of the MNs with the GNs are optimal. The associations of the MNs with the GNs are minimum, so the maximum number of nodes remains alive in relaying the data. Hence, it increases the network lifetime. In the ASEDG, the maximum number of GNs is created and the maximum number of shortest paths is created in the associations of the MNs with the GNs, which causes more energy depletion at the GNs, hence reducing the network lifetime .

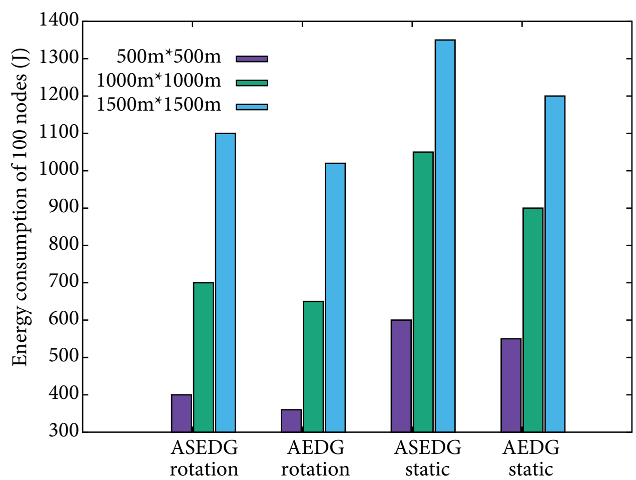

Figure 9. Energy consumption of network.

8. Conclusion

In this paper, we have identified the problem of data gathering in an inhospitable underwater environment and the solution has been provided in the form of a routing protocol to gather data efficiently. We have presented an AUV-aided delay and data efficient (ASEDG) routing protocol for UWSNs (see Table 6 for all acronyms). In UWSNs, there is a model for data gathering and a mobility model using a center-positioned node for the two suboptimal horizontal and vertical trajectories for the movement of the AUV. Besides addressing the problems of high end-to-end delay in the network, this protocol has achieved the performance targets for throughput in the network, balanced energy consumption, network lifetime, and end-to-end delay by means of simulations. The ASEDG has been evaluated by using NS2 and a simulation was performed to evaluate the performance

Table 6. List of acronyms

UWSN	Underwater wireless sensor network
ASEDG	Atomic-shaped efficient delay and data gathering
AUV	Autonomous underwater vehicle
AEDG	AUV-aided efficient data gathering
SPT	Shortest path tree
CDS	Connected dominating set
GN	Gateway node
MN	Member node
RSSI	Received signal strength indicator
AURP	AUV-aided underwater routing protocol
AREP	Asymmetric link-based reverse routing protocol
SEDG	Scalable and efficient data gathering
CARP	Channel aware routing protocol
DVRP	Diagonal and vertical routing protocol
AEERP	AUV-aided energy-efficient routing protocol
MST	Minimum spanning tree
HC	Hamiltonian circuit
NS-2	Network simulator
RF	Radio frequency
RDBF	Relative distance-based forwarding

of the proposed technique with the existing AEDG routing protocol, and our protocol achieved the targeted performance. Our results have proved that the ASEDG performs better than the AEDG in terms of data gathering and less end-to-end delay, but its energy consumption is higher than that of the AEDG because of a larger number of GNs.

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