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AN ENERGY-EFFICIENT QUALITY OF SERVICE (QOS) PARAMETER-BASED VOID AVOIDANCE ROUTING TECHNIQUE FOR UNDERWATER SENSOR NETWORKS

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ABSTRACT

Underwater sensor networks (UWSNs) have become among the most interesting research areas, since they open the door wide to researchers to conduct research in this field. There are so many issues in underwater sensor networks. The most serious issue is the void region that degrades the performance of networks. It is an issue, where a node doesn't have any forwarder node to forward the packets to another node. Here, the objective of this work is to avoid the void region. For the same purpose, this work proposes an algorithm named "An Energy-Efficient Quality of Service (QoS) Based Void Avoidance Routing Technique". The proposed work uses two-hop node information to avoid the problem of void region. This approach uses depth information, distance to next, holding time and residual energy as Quality of Service (QoS) parameters in order to find the best forwarder node to forward the data packets to their destination. The proposed algorithm has been implemented in MATLAB. Results show a better performance in terms of packet delivery ratio, energy tax and number of dead nodes as compared to Energy-Efficient Void Avoidance Routing Scheme for Underwater Wireless Sensor Network (E2RV).

KEYWORDS

Void avoidance, Sensors, Coverage, Connectivity, Surface station, Holding time, Quality of Service (QoS) parameters.

1. INTRODUCTION

Underwater Sensor Networks (UWSNs) are regarded among the favourable technologies for accumulating beneficial and valuable data from underwater seas. This technology mainly helps in assisting environmental predictions and military operations and comprises of underwater sensor nodes. One of the most challenging issues in underwater sensor networks is considering the demand and need to forward data packets with high packet delivery ratio and minimal energy consumption [1]-[2]. These sensor nodes are placed at water surface and at different depths of water. In Underwater Sensor Networks (UWSNs), the challenging task is to send data timely and efficiently because of the complex underwater environment. Radio signals are not fruitful in underwater environment because of radio signals' rapid attenuation in underwater environment [3]. So, acoustic signals are used for underwater communication. When data reaches a sink, then radio waves are used to forward data packets to the base station. In underwater environment, water current sensor nodes can move and change their position, which leads to a dynamic network topology. Apart from this, the links between sensor nodes are highly error prone due to path loss. There are some challenges related to acoustic communication as compared to electromagnetic waves, like: path loss, high error rate, propagation delay, lower bandwidth …etc. [4]-[5]. In acoustic communication, path loss can be defined by distance and frequency as:

$$P\_Loss\,(d,f) = P\ Loss_0\ d^k\ a\ (f) \tag{1}$$

where, d is the distance, f indicates the signal frequency, k is known as the spreading factor and the value of the spreading factor depends on the spherical factors and practical spreading. $PLoss_0$ signifies a constant and a (f) is the absorption coefficient as defined in [6]. The formula below is valid for high frequency.

$$10log_a(f) = 0.11f^2/(1+f^2) + 44 * f2/(4100 + f2) + 2.75 * 10^{-4}f^2 + 0.003 \tag{2}$$

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For low frequencies, the formula below is suitable.

$$10log_a(f) = 0.11f^2/(1 + f^2) + 0.011 * f^2 + 0.002 \quad (3)$$

In underwater communication, there are two types of noise; natural noise which can be generated by fish and tide rain and man-made noise that can be generated by ship movement. Delay is also a major challenge in underwater communication. Generally, the speed of acoustic waves is 1500m/s having a delay of 0.67s/km. Some parameters, like pressure, temperature and depth, affect the sound velocity in underwater communication. The formula below is used to calculate the velocity if pressure and temperature is known.

$$C = 1449.2 + 4.6T - 0.055T^2 + 0.00029T^3 + (1.34 - 0.010T)(S - 35) + 0.016d \quad (4)$$

Here, the temperature (T) is in centigrade (°C), S represents the salt in water in parts per thousand (‰), d indicates the depth which is calculated in meters and c is the sound velocity which is given in meter per second. The formula above is suitable for the following conditions [7]:

Routing depends on the selection of next forwarding node, which is the key component of Underwater Sensor Networks (UWSNs) having a direct and dominating effect on packet delivery ratio and energy consumption. Consequently, to resolve this problem, the research community decided to enhance the performance of Underwater Sensor Networks (UWSNs) [8]-[9]. Apart from this, underwater sensor networks also include some major challenges that are mentioned below:

- Sensor node deployment.
- Network connectivity.
- Limited energy.
- Low data rate due to acoustic communication.
- Large propagation delay.
- Unpredictable underwater environment.
- High equipment deployment cost.
- Unscalability.
- No interaction.
- Complicated design and network deployment.

1.1 Problems Related to Selection of Next Forwarding Node

The major issue in routing technique is the selection of next forwarding node [10]-[12]. This matter captivated researches to generate next forwarding node algorithms. Firstly, each of the source nodes selects a group of its neighbours. The selection of forwarder node is based on different parameters, such as physical distance, residual length and link quality. These forwarder nodes can hold data packets for some predefined time based on some different parameters, like: sound propagation speed, range of transmission, distance to elude redundant packet transmission and collision. The node having the least holding time will be selected as the best forwarder node which forwards data packets to another node or to the sink node. The removal of data packets from their buffers takes place if and only if a sensor node overhears the transmitted data packet. Otherwise, it waits till its holding time terminates to forward the data packet. Consequently, the aforementioned algorithms have a direct influence on energy consumption and packet delivery ratio.

The use of different parameters for the selection of next forwarding nodes results in a direct influence on the entire performance of routing protocols. The energy between the nodes is balanced by the use of residual energy metric. Another major metric that has a direct effect on upgrading the packet delivery ratio and minimizing energy consumption is link quality. The usage of depth metrics minimizes the consumption of energy, because the calculation of each node takes place locally. Physical distance can be measured using the beaconing messages assigned by the sink. Due to impotence of Global Positioning System (GPS) in underwater circumstances, identification of node location is costly using Global Positioning System (GPS). Consequently, it becomes important to derive and design an algorithm that selects the forward node based on multi-metrics, specifying energy-efficient and authentic forwarding nodes in order to minimize the consumption of energy, reduce traffic on the designated network and ensure the proper delivery of data packets [13]-[14].

One of the most major issues that came up on next forwarding node selection is communication void. The next problem arises due to the absence of neighbour nodes in the transmission range [15]-[16]. Since Underwater Sensor Networks (UWSNs) sustain from a sparse and dynamic network structure, such structure obtrudes a low packet delivery ratio, further reducing throughput because of shortfall of algorithms that look for the communication gap. Furthermore, the manoeuvre of weak void avoiding algorithms elicits high dissipation of energy. Terrestrial wireless sensor networks (TWSNs) do not support void handling algorithms in harsh conditions due to some precise features of UWSNs. Hence, avoidance of void nodes in the operation of selection of forwarding nodes is significant in order to refine and enhance the packet delivery ratio and fortify the delivery of data packets.

The next significant issue involves the selection of the shortest path and has a direct effect on transmission number, network lifetime and energy consumption. For minimizing retransmission and number of nodes stipulated to transfer data, selection of the node having a lower depth as compared to sender is a conventional method to handle this issue. The foremost shortcoming of this algorithm is that it completely relies on distance without considering any other parameters, such as link quality and residual energy. Therefore, it becomes significant to ensure path selection while choosing the next forwarding node. This results in minimization of total forwarded packets, vanquishing the irrelevant forwarding and compressing the total dissipation of energy.

1.2 Underwater Sensor Network Architectures

1.2.1 1-D Architecture

In one-dimensional architecture, sensor nodes are individually deployed and equally responsible to sense data, process data and finally transmit data packets to the sink node or to the base station. For a particular time, the sensor node may float in underwater environment to sense the phenomena and then float again towards the upper direction to forward the sense data to the sink node or to the base station. Here, sensor nodes may communicate *via* radio frequency, acoustic or optical communication link [17].

1.2.2 2-D Architecture

In this architecture, nodes are placed in cluster form. Each cluster has one cluster head. Each cluster member senses the underwater phenomena and forwards the information to the cluster head. Now, the cluster head forwards information to surface buoyant nodes. Two types of communication take place in this architecture: horizontal communication link is used between cluster members and cluster head, while vertical communication link is used between cluster head and surface buoyant node. Nodes which are deployed in the depth can communicate with each other using acoustic communication and nodes which are placed at water surface can use radio communication. This type of architecture can be suitable for time-critical and delay-tolerant applications [18].

1.2.3 3-D Architecture

In this architecture, all sensor nodes are placed in cluster form and are anchored at different depth levels. Here, there are three types of communication scenarios that take place: first is intercluster communication among nodes, second is intracluster communication that means communication between sensor node and anchor node and third is communication between anchor nodes and buoyant nodes. Acoustic, radio frequency and optical links can be used by any type of communication.

1.4.4 4-D Architecture

It is a combination of mobile underwater sensor networks and 3-D underwater sensor networks (UWSNs). This architecture uses Remotely Operative Underwater Vehicles (ROVs). All anchor nodes send data packets to the Remotely Operative Underwater Vehicles (ROVs) and ROVs forward this data to the base station. It may be any vehicle, ship, robot, …etc. Each sensor node is able to send data to the Remotely Operative Underwater Vehicle (ROV) directly according to how close a sensor node is to the Remotely Operative Underwater Vehicle (ROV). The communication between Remotely Operative Underwater Vehicles (ROVs) and sensor nodes depends on the data and the distance between data. If a sensor node is near to the Remotely Operative Underwater Vehicle (ROV) node and has large data, then the sensor node can use radio link, while if the distance is far and the sensor node has small data, then the sensor node can use acoustic link [19]-[20].

1.3 Underwater Sensor Network Applications

Underwater Sensor Networks (UWSNs) cover many applications, like: water quality, water temperature, monitoring of underwater pipelines, environment, mine detection, disaster prevention, security, …etc.

Monitoring Applications: these applications refer to monitoring related to the environment, properties, characteristics and objects of interest under water. These applications are particularly related to monitoring of physical environment. These are further divided into three applications. First is monitoring **water quality:** water is one of the most valuable resources that are primary requirements for living under water and above water. So, it is necessary to monitor water. Second is monitoring the **habitat:** this application deals with the environment of living organisms. If considered under water, then it becomes more challenging due to underwater environment. Habitat monitoring if further divided into **reef**, **marine life** and **fish farm** monitoring. Third is monitoring the **underwater exploration:** this application refers to monitoring minerals available under water, like oil and gas. It is required to monitor underwater pipelines, because these pipelines are used for oil and gas. This application is further divided into **natural resource** and **pipeline and cable** monitoring. **Disaster Applications:** these applications are very critical, because they are very dangerous and may produce destruction on earth. Generally, disasters are unavoidable. This monitoring is related to events that aggravate water. Monitoring of **floods, volcanoes, earthquakes and tsunamis** comes under these applications. **Military Applications: t**hese are major applications of underwater sensor networks, where nodes are deployed to detect different features of military-related activities. Generally, Autonomous Underwater Vehicles (AUVs) are used to find submarines, secure ports, mines, …etc. Some sensing devices, like metal detectors and cameras, are equipped with AUVs for surveillance purposes. So, there are many potential scenarios, where (UWSNs) can be used. Here, Table 1. shows some major applications of underwater sensor networks.

Table 1. Underwater sensor network applications.

Application	Objectives	Category
Monitoring environment and geographical processes	i) Collecting information related to water. characteristics like: salinity, oxygen level and temperature. ii) Geographical processes include: earthquakes, tsunamis, floods and volcanoes.	Scientific
Counting or imaging animal life	Counting or imaging mammals, fish and microorganisms.	Scientific
Mine detection	Finding the location or position of specific mines in underwater environment.	Industrial, Military and Security
Minerals and oil extraction	First, finding the sources of minerals and oil and then installing the equipment in underwater environment to extract them.	Industrial
Monitoring underwater pipelines	Monitoring the underwater pipelines and providing immediate repairs.	Industrial
Offshore exploration	This application includes the exploration of unexpected regions.	Military and Security
Navigation	Providing accurate navigation to battle ships.	Military and Security
Communication	Providing communication between drivers and submarines.	Military and Security

2. PREVIOUS WORK

In [21], the authors have proposed an approach to overcome the problem of recovery and maintenance of the routing path. As a much less number of sensor nodes is needed to forward data, there is no need of sensor node state information. An interleaved and redundant path is used to send data from source to sink to overcome the problem of node failure and packet loss. In this approach, each node knows its location and the location of each data packet consists of the locations of all the involved nodes, like: source node, intermediate nodes and sink node. In this approach, a vector pipe is used to forward data from source to destination. Nodes that are near to this pipe are able to send data from source to sink. This approach reduces the network traffic and manages the topology. Like other approaches, this approaches has some drawbacks like that a virtual pipe can disturb the routing efficiency. It may be possible that if nodes become sparser due to water movement, it may be possible that a less number of sensor nodes will lie near or within the pipe or it may be possible that some paths will lie far from the pipe. In this situation, much less or no nodes are near to the virtual pipe, which results in low data delivery or no data delivery. Here, some nodes are involved again and again to send data, which results in more battery power consumption. Due to having a three-way handshaking nature, this approach has more communication overhead.

In [22], the authors have proposed a routing protocol to overcome the problem of continuous node movement. Sensor node uses dynamic addressing to resolve the problem of water currents. Due to this, the sensor node gets a new address based on a new position at a different depth level. According to this protocol, lots of sinks are fixed at water surface to collect data packets and some nodes are deployed at the bottom. Apart from this, the rest of nodes are deployed from bottom to surface at different-different levels. All nodes that are nearest to the surface have small addresses and become larger when the nodes float towards the bottom. This approach completes in two steps: first is to assign the dynamic addresses to the sensors node and second is to forward data using these dynamic addresses. These addresses are assigned by using hello packets that are generated by surface sinks. Each node tries to forward data packets to the upper direction in greedy fashion. The advantage of this protocol is that it does not require any special hardware or location information. Apart from this, it can handle the node movements. However, multi-hop routing problem still exists.

In [23], the authors have proposed Sector Based Routing with Destination Location Prediction (SBR-DLP) routing protocol. In this protocol, each sensor node knows its own location and guesses the destination node's location, where the precise information of the destination node's location is stored. All sensor nodes find their next hops using information received from the candidate nodes. This reduces the problem of multiple nodes that act as relay nodes. There is no need to rebroadcast the Request to Send (RTS). It is not possible to find the candidate node within the transmission range. Here, node speed causes disconnection, which results in low packet delivery ratio in sparse networks. If all nodes are mobile, then this protocol provides a better packet delivery ratio.

In [24], the authors have proposed an energy-efficient fitness-based routing protocol which uses depth, residual energy and distance from the forwarding node to sink. The proposed protocol does not use the control packet, which reduces energy consumption and end-to-end delay. A fitness function is also calculated to determine the best forwarder. The achievement of the proposed protocol is that it increases network lifetime and reduces end-to-end delay.

In [25], the authors have proposed a routing algorithm that uses residual energy and depth variance for void avoidance. The proposed approach uses the two-hope node information to remove the void holes in the network. It also uses depth and remaining energy of the node to transfer data from source to destination. On the basis of depth difference, this approach finds the best node to forward data packets. This approach also calculates the packet holding time in the network for a particular node. The proposed approach reduces the overall energy consumption and increases the network lifetime by distributing loads. The proposed technique shows less energy consumption and improves the network lifetime and packet delivery ratio. It also reduces data duplicity, but this approach has a high delay, which is the disadvantage of the proposed approach.

In [26], the authors have proposed a routing protocol that considers the knowledge of node localization and merges it with the network coding to reduce duplicate data packet transmission and energy consumption. The best forwarder is selected based on its location information, which reduces high energy consumption. To overcome the duplicate problem, the network coding is attached with the packets. Here, using an acknowledgement message, the end-to-end delay is high.

In [27], the authors have proposed a balanced energy-efficient routing protocol based on circular network. This circular network is divided into ten circular regions known as sectors. This protocol uses two mobile sinks to collect data from the sectors, which means that one mobile sink is used for five sectors. The mobile sink moves in a circular fashion to collect data from the nodes. This process balances energy consumption and enhances data packet reception by the sink node. No priority is assigned to the location by the sink node. Instead of this, a fixed pattern for the movement is followed. Due to this, packet loss and delay increase. This protocol is not suitable for sparse environments when nodes are deployed so far from each other.

In [28], the authors have proposed a protocol for maximum network coverage. The protocol uses two mobile sinks to collect data from the sensor nodes. The sinks move in a circular fashion in the network, which helps balance energy consumption and reduce packet loss. The disadvantage of the protocol is that as the sink node is moving in a circular fashion rather than in the targeted areas, there may be some nodes in the targeted areas that have to send data. Due to this, packet dropping increases and delay also increases, especially in sparse situations.

In [29], the authors have proposed a routing scheme for underwater wireless sensor networks. The main objective of this scheme is to find the best forwarder node to forward data packets to node/sink node/base station. This scheme uses the concept of Time of Arrival (ToA) and range-based equations to locate the sensor node in a recursive manner in the defined network. After localization, residual energy and coordinate of sensor nodes are used to find the best forwarder node. This scheme avoids horizontal transmission of data to reduce end-to-end delay. It also avoids the problem of void nodes and increases the network throughput. The 2-hop concept is used for better acknowledgement. The simulation results show good results in terms of energy consumption, Packet Delivery Ratio (PDR), average hop count, average end-to-end delay and propagation deviation factor.

In [30], the authors have proposed a routing scheme to select the best forwarder node by avoiding void node, or void region. The functionality of this scheme depends on two special parameters named: energy and depth. This scheme avoids horizontal transmission of data packets. The node having large residual energy and multiple neighbours will be selected as the best forwarder node. This scheme also calculates the holding time to reduce duplicate packet transmission. This scheme uses the concept of 2-hop neighbours. The results show that this scheme achieves 15% Packet Delivery Ratio (PDR) and propagates 40% less copies of data packets. The proposed scheme also reduces energy consumption, which increases the overall network lifetime.

In [31], the authors have proposed a location based routing protocol known as Power-Efficient Routing (PER). The primary objective of the protocol is to tackle the problem of energy consumption in underwater environment. Here, ordinary nodes are randomly scattered in the underwater environment, while the sink node is placed at the center. Sensor nodes that are available at the bottom are known as the source nodes. This protocol consists of two modules, where the first module is known as forwarder node selector and the other is known as forwarding tree trimming mechanism. This scheme uses the three parameters: residual energy, angle between two neighbours and distance to select the forwarder node. The selection of forwarder node is based on fuzzy logic technique. The second module is used when the number of duplicate packets is greater than the defined threshold. This protocol performs better as compared to Vector-Based Forwarding (VBF), as Power-Efficient Routing (PER) uses 2-hop nodes during the forwarding process, while Vector-Based Forwarding (VBF) uses the flooding technique in its virtual shape.

In [32], the authors have proposed a protocol to tackle the problem of communication void. Vector-Based Void Avoidance (VBVA) is another escalation of Vector-Based Forwarding (VBF) and is supposed to be the foremost void avoidance protocol that gives 3D flooding procedures to deal with the issue of communication void. Absence of void area possesses the same functionality of these protocols. The principle dissimilarity between these protocols is that Vector-Based Void Avoidance (VBVA) imparts two 3D flooding mechanisms to handle the communication void; known as vector-shift and back-pressure mechanisms. In vector shift, data packets are routed to the forwarder node available in the boundary of the void region. There are two conditions of being void. If void is convex, data packets can route towards the destination, while in case of concave void, the vector shift mechanism does not work efficiently. This scheme uses the back pressure mechanism to route back data packets in order to avoid the problem of concave void. This scheme achieves a good performance in mobile underwater sensor networks.

3. PROBLEM STATEMENT

The most challenging issue of routing protocols is communication void. The presence of void may cause packet delivery in the routing time, which leads to data loss. When the sender node does not trace any neighbour node in its range of transmission, this issue arises. This problem occurs when a sender node does not have any neighbour node or forwarder node to forward data packets towards the direction of sink node or surface station. Whenever this type of situation occurs, it is necessary to have an alternative path to forward data packets; otherwise, data packets will be discarded, which affects the network performance in terms of data loss.

4. PROPOSED WORK

As a forementioned, nodes are originally positioned at the water surface and two-dimensionally connected network topology is formed and structured. Our elucidation fights vigorously to enlarge this two-dimensional network structure into the three-dimensional structure, so that the entire anticipated and sensed area of the three-dimensional network is increased and enhanced. Considering the elimination of coverage overlapping, the sensors that are nearer to each other are forwarded to distinct depths. The transmission of nearer sensors to distinctive depths facilitates the entire sensing coverage. Conversely, if the nodes are placed at a large distance to each other, the communication between them may be smashed and as a result, the ultimate network structure may possess internally disintegrated network segregation. Thence, it is of utmost significance to govern which conveyance linkage is to be safeguarded and which association and linkage may be shattered. Nevertheless, this issue is critical, conjecturing that the nodes are solely cognizant of the position of their one-hop proximate nodes. In our recommended algorithm, we assigned this significant charge to the surface station. Otherwise stated, the surface station will solely be accountable for the measurement of depth of every sensor in the mesh. The proposed work primarily encloses three important stages, which are:
1. Node Initialization.
2. Calculation of Depths of Nodes.
3. Distribution of Depths to Nodes.

4.1 Initialization Phase

This stage can be thought of as the starting setup stage. For the measurement of depths at the surface station, it is necessary to familiarize the surface station which the position of the sensors. When all the nodes are homogeneous and aimlessly dispersed at the surface of water in two dimensions, the sensors may not perceive the information regarding the location of the surface station. In this section or stage, a linked tree organization is devised, which is embedded at the surface station. The commencement of this stage takes place by transmitting a message known as Tree Request (TREQ). To answer this request, the one-hop neighbours dispatch a tree join report to their parent to form the connected tree and transmit a fresh Tree Request (TREQ) message to recognize the next hop neighbours. All the while, each of the nodes present in the network discovers its respective parent and children. After a linked tree structure is established, each node transmits its coordinates to their respective parents unassisted. The parent nodes then accumulate the coordinates received in the sub-tree in addition to their own coordinates. This accumulated list of coordinates is then forwarded to their parents. This activity and operation continue till the sink node acquires the coordinates of all sensors connected in the tree.

4.2 Depth Calculation

After the initialization phase, depth calculation method is invoked to calculate the depth for each node.

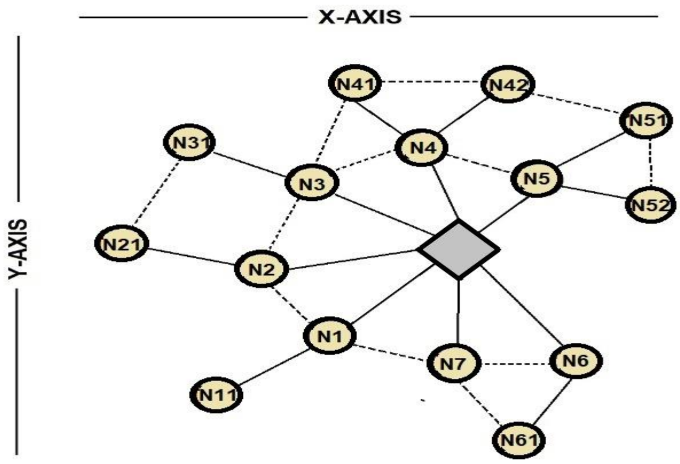

Figure 1. Nodes connected in 2-dimensional network topology.

The surface station is responsible for depth calculation till the first level. After this, the nodes at the first level are responsible for calculating depth for the next level. This process will continue till the last node of the list. Initially, all nodes are placed at the surface of water, where the z coordinate is assumed to be zero. Here, the surface station acts as a root and all other nodes will be left children or right children of the surface station. This process will make a connected tree structure and sensor nodes having highest depth will transfer their data to their upper nodes. Each upper node will act as a sub-root node for the same node. To calculate the sensor node depth, firstly the value of z coordinate for all sensor nodes is set to zero.

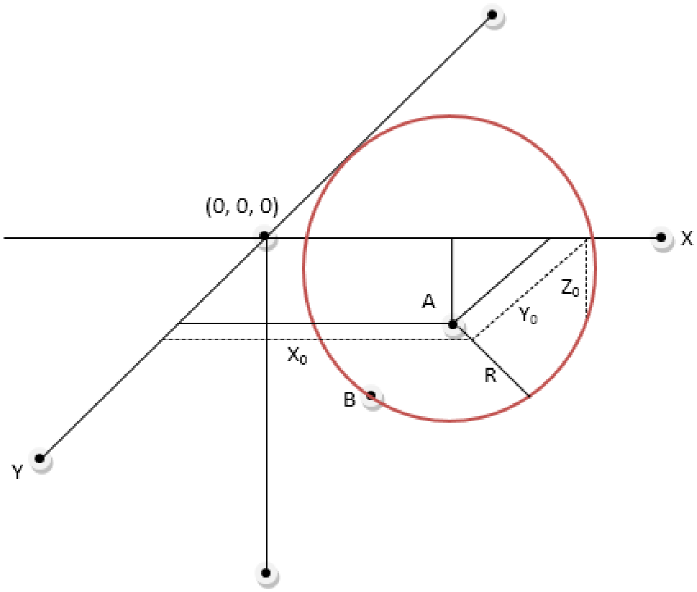

Figure 2. Deployment based on depth.

Here, R is the radius of the sphere and A is the center of the sphere. The coordinate of the surface station is A (x_0, y_0, z_0) and the coordinate of the sensor nodes is B (x, y, z). Initially, the value of z-coordinate for both surface station and sensor nodes is set to zero. The value of x- and y-coordinates for the sensor node B will remain the same when it will drift into the water, but the value of z-coordinate will change. The equations of the sphere are:

$$(x - x_0)^2 + (y - y_0)^2 + (z - z_0)^2 = R^2 \tag{5}$$

$$(z - z_0)^2 = R^2 - (x - x_0)^2 - (y - y_0)^2 \tag{6}$$

$$z = z_0 + [R^2 - (x - x_0)^2 - (y - y_0)^2]^{1/2} \tag{7}$$

Using Equations 5 and 6, we can calculate the value of z-coordinate for the respective node, where the value of z-coordinate can be determined with the condition that the value of x- and y-coordinates of sensor node B is known. During calculation of depth for a particular node, we need to check the closest node and calculate the depth of that node relative to the closest node in order to reduce the problem of overlapping.

4.3 Depth Distribution to Nodes

Till all the nodes are processed, the customized depth evaluation stage goes on. After quantifying the depths of all the nodes, it is necessary to acknowledge the nodes regarding their evaluated depths. This phase requires the use of a linked tree by the surface station, which is devised after the initialization phase. Fundamentally, the surface station transfers the computed depths of sensor nodes to their neighbours in two-dimensionally. This message is encountered by the children of surface station, which then transfers the same message to their children. This procedure steadily goes on till all the nodes acquire the information concerning their depths. The nodes start submerging their specified depths to accomplish the deployment process as soon as the message is forwarded to their children.

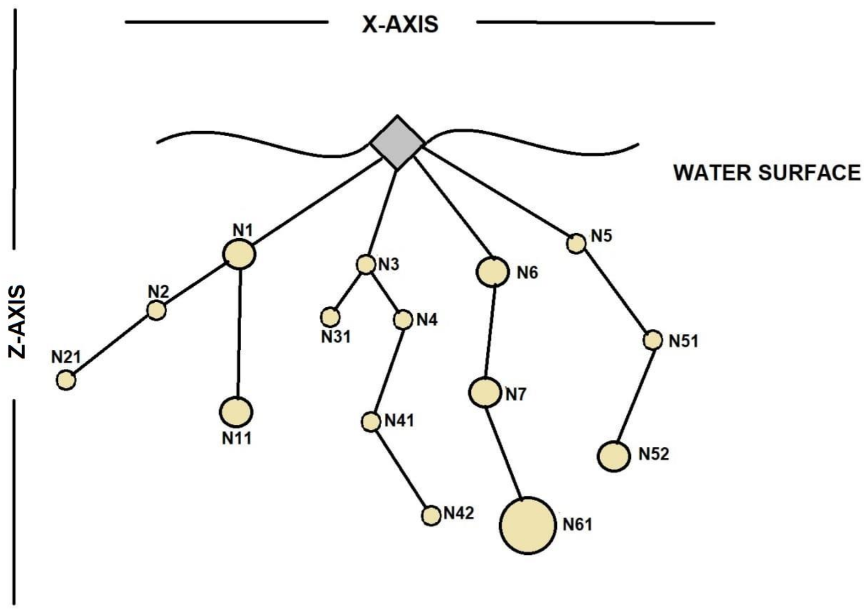

Figure 3. Nodes connected in 3-dimensional network topology.

To demonstrate the functionality of the algorithm, let us examine the example in Figure 1. Initially, sensor nodes are placed randomly at water surface and form a two-dimensionally-connected tree. Figure 1 shows that nodes are connected in two-dimensional form. As the surface station has completed the initialization phase, this results in the formation of a connected tree, as shown in Figure 1, having solid lines and the propinquity of nodes that instigates the overlapping problem in two dimensions is shown by dashed lines in Figure 1. Firstly, the surface station exercises N1 and calculates its depth using Equation (7). The depth of N1 respective to the surface station is represented in Figure 3. Then, the algorithm appends N1 in the processed list and processes N2. As N2 is near to N1 in 2-dimensional framework, to reduce coverage overlaps, these nodes need to be settled down at different depths. Hence, the algorithm calculates the depth of N2 correlative to N1 and puts it at a deeper level. As connectivity of N1 is ensured in the previous iteration, connecting N2 to N1 ensures its connectivity as well. Correspondingly, the algorithm links N2 to the process list. Back to back, the algorithm works on N3, which is near to N2 in 2-dimensional framework and calculates its respective depth to the station. N2 and N3 are positioned at distinct depths, which again reduces the overlapping problem between them. This algorithm calculates the depth of N4, N5, N6 and N7 in similar fashion. N11 is processed after processing the first-hop neighbors in 2-dimensional fashion. As N11 possesses a single neighbor in 2D, it is directly connected to N1. Equivalently, the computation of depth of N21 starts in the upcoming iteration by linking it with N2. Then, the algorithm works on N31, where two choices are generated: 1. Connecting N31 with N21; 2. Connecting N31 to N3. Since both of the choices discard the feasible coverage overlap, the algorithm puts N31 nearer to the surface and links it to node N3. The algorithm then works on N41, N42, N51, N52 and N61 in the same fashion.

4.4 Selection of Best Forwarder

As we know, the selection of best forwarder candidate is one of the most important tasks in any routing technique. It is assumed in the proposed approach that each node knows the location of the surface station. In our proposed approach, the selection of best forwarder is based on certain metrics like: depth variance, distance and holding time. Whenever a node needs to send data, firstly, the sender node computes the value of fitness function, adds the value of this function to its own location coordinate and then broadcasts the data packets. Only one-hop neighbours can receive this packet and compute their fitness function value with the sender one. If the calculated value of fitness function is greater than the sender’s fitness function value that incorporates in the packet, it forwards the packet; otherwise, it discards it. There may be some situations where a more number of sensor nodes is involved to forward the data packet. To overcome this problem, this protocol calculates the holding time which is based on depth, residual energy and distance from the sender node to the forwarder node. The holding time may vary. The node having the less holding time forwards the packet, while the other nodes overhear the same data, avoiding the transmission.

Packet Format

A data packet consists of four fields as shown in Table 2.

Table 2. Packet format.

S_ID	P_SN	S_FV	S_L	Data

where, S_ID represents sender Id, P_SN is packet sequence number defined by sender node, S_FV is value of fitness function of sender and S_L represents the location of sender node.

Estimation of Fitness Function Value

A node having the greatest value of fitness function will be the best forwarder and the estimation of fitness function value is expressed in the following way:

$$f(n) = g(n) * h(n) \tag{8}$$

Calculation of g (n) Function

The calculation of g (n) function is expressed in the following way:

$$g(n) = Er(f) * depth\ (difference) * dsf \tag{9}$$

where, *Er(f)* represents the residual energy of the forwarding node, *depth(difference)* represents the difference of vertical differences from the forwarding node and the sending node to the surface and *dsf* is the distance from the sending node to the forwarding node.

Calculation of h (n) Function

The calculation of h (n) function is expressed in the following way:

$$h(n) = 1/\ dfd(node) \tag{10}$$

where, *dfd (node)* is the distance from the forwarding node to the destination node. Here, h (n) is estimated as the inverse of the distance from the forwarding node to the sink node, noting that less distance shows best node to forward the packet.

From the Equations 7 and 8, the fitness function stands in the following way:

$$f(n) = (Er(f) * depth(difference) * dsf)/\ dfd(node) \tag{11}$$

Estimation of Holding Time

To find the best forwarder, priority P will be assigned to these forwarders in order to forward data to the next forwarder. Remaining nodes that received the same packet will wait for a defined interval until they hear the same packet transmission from another node.

$$P = 1/\, g(n) \tag{12}$$

$$H_{Time} = [(1-((Er(f)/E))] * T_{Delay} * P \tag{13}$$

Here, H_{Time} = receiver's holding time, $Er(f)$ = residual energy, E = initial energy and T_{Delay} = predefined maximum delay.

At the point when a sensor node gets the data packet, it will look for the depth which is specified in the header of the data packet and then compare the depths. If it is situated at a higher depth, it will essentially discard the data packet. If it is located at a lower depth, it will calculate the distance from the source by using the concept of Time of Arrival (ToA). Distance between two nodes can be calculated by signal transmission time. Suppose t1 time is needed to send the packet and it reaches the destination at time t2 with velocity V, then the distance can be calculated as:

$$Dist\ to\ Next = V(t2 - t1) \tag{14}$$

Algorithm

1) *Source node is ready to send the data packet*
2) *Receiver node receives the data packet*
3) *If $R_{(Depth)} > S_{(Depth)}$*
   Where $R_{(Depth)}$: Depth of receiving node and $S_{(Depth)}$: Depth of source node
4) *Drop the data packet*
5) *else*
6) *Calculate the value of fitness function, set the priority and H_{Time} (Holding Time) for data packet*
7) *end if else*
8) *Extract the value of fitness function and calculate own fitness function value*
9) *If calculated value>extracted value then*
10) *Receive the data packet*
11) *else discard the packet*
12) *end if else*
13) *while(H_{Time} expires)*
14) *listen the channel*
15) *if same packet overhear then*
16) *discard the data packet*
17) *else*
18) *forward the packet*
19) *end if*
20) *end while*

4.5 Data Transmission

The proposed algorithm is designed to avoid horizontal transmission, which increases network lifetime and energy efficiency. Data transmission phase starts when a node has a data packet to send. The main objective is that the data packet should reach one of the sinks in multi-hop fashion. In the proposed approach, the number of acknowledgements per data packet may vary from zero to two hops based on the sender's and receiver's status. Here, zero-hop acknowledgement is used to control message transmission and end-to-end delay, while two-hop acknowledgement is used to handle the void node issue and improve the data delivery ratio. When a data packet is stuck in the communication void region, a control message-like acknowledgement is used to find another path for transmission. If two-hop acknowledgement is not received for any data packet, it is assumed that the data packet is stuck with the void node and then, a new path will be determined and the same data packet is sent with more hops. This process increases energy consumption, but also provides guarantee for successful data delivery. Let the initial energy of each node Eo which is equal to Emin +rand (Erand), where the value of Emin is 60j and that of Erand is 20j. This simulation uses the simplified energy consumption model to transmit the m bits at a distance of k meters. Energy consumption is presented as:

$$E\ tx\ (m\ ,k) = E\ elec * m + E\ am\,p * m * K2 \tag{15}$$

Here, Eelec is the energy required to transmit 1-bit data and Eamp is the acoustic wave attenuation coefficient or acoustic amplifier energy. To receive the m-bit data, energy consumption is presented as:

$$E\ r\ x\ (m) = E\ elec * m \tag{16}$$

The packet delivery ratio also plays an important role in data transmission. Suppose that k1 represents the data packets which are successfully received by the sink node 1, m is the number of sink nodes and n is the number of generated data packets, then packet delivery ratio is defined as:

$$P\ D\ R = (U^{m}{}_{i=1}\ \ Si)/n \tag{17}$$

According to the energy model, Table 3 shows the simulation parameters.

Table 3. Simulation parameters.

Parameter Name	**Parameter Value**
Water Surface	1000 * 1000 m
Depth of Water	2000 m
Ex	50W
Erx	158 mW
Number of Sensor Nodes	60-180
Acoustic Propagation Delay	1500 m
Ideal Energy	58 mW
Header Size	88 bits
Payload Size	576 bits
Neighbour Request	48 bits
Acknowledgement	48 bits
Data Rate	$16*10^3$ bits
Packet Generation Rate	0.2 packet/sec
Weighting Factor α	0.5 range (0,1)

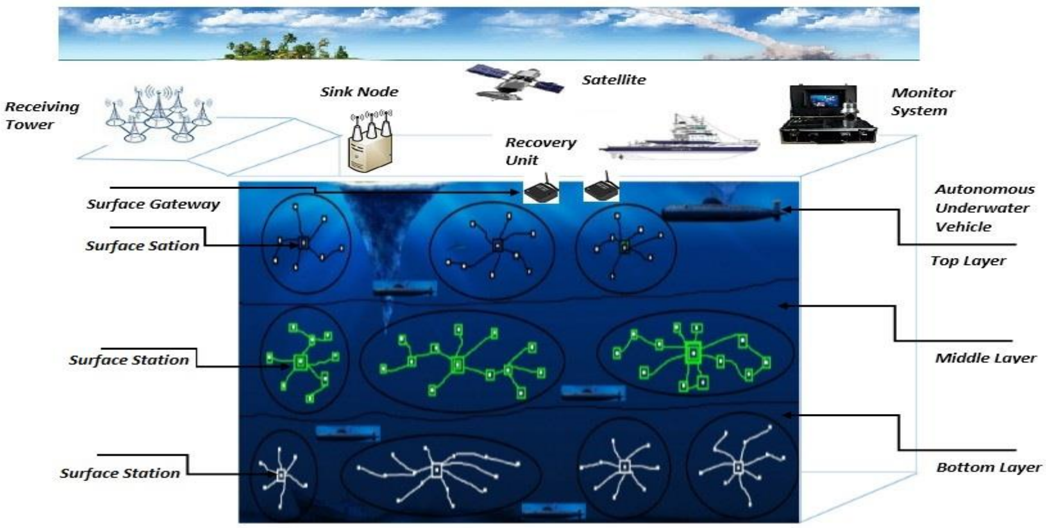

Figure 4. Proposed model for an underwater sensor network.

5. RESULTS AND ANALYSIS

The performance of the proposed algorithm is compared with that of the existing approach E2RV. The simulation is done on MATLAB. During simulation, this work considered a three-dimensional area of one kilometer in length and width and two kilometers in depth; i.e., Xmax=Ymax= 1 km and Zmax=2 km. In the simulation, a varying network is considered having 60, 90 and 180 nodes. It is also assumed that sensor nodes are homogenous in terms of transmission range that can vary from 600m to 1000m. Here, source nodes which are also known as data gathering nodes are placed at the bottom of water, while the sink node is placed at water surface. Remaining nodes are randomly deployed at different locations using depth distribution method between source nodes and sink node in the network. These nodes play an important role, as they act as data forwarder node or relay nodes.

In the trial of first simulation, 60 nodes are deployed in the network area randomly except the data source. In the next trial, 120 nodes are deployed, where the locations of the previous 60 nodes are unaltered and only the next 60 nodes are placed randomly in the network. In the proposed scheme, multiple sink nodes are placed at water surface to collect data from others nodes.

5.1 Packet Delivery Ratio

Packet delivery ratio is one of the important performance metrics of any routing or forwarding scheme. Therefore, this work analyzed the PDR performance metric of the proposed technique. The ratio of successfully received data packets by the sink nodes and the total generated packets by the source node is known as packet delivery ratio.

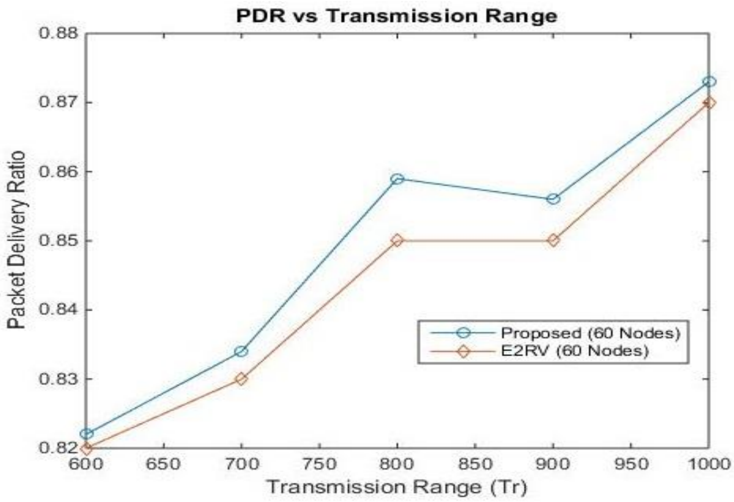

Figure 5. PDR *vs.* transmission range (at 60 nodes).

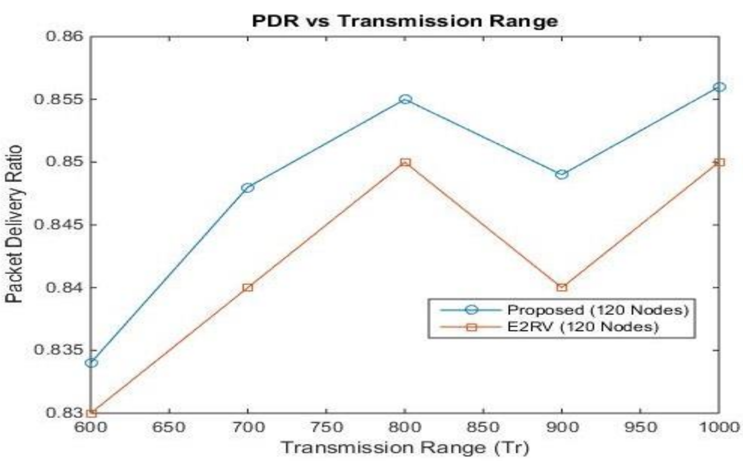

Figure 6. PDR *vs.* transmission range (at 120 nodes).

In case of a fixed network size (like 60 nodes, 120 nodes and 180 nodes) with varying transmission range, Figures 5, 6 and 7 show the improved performance as compared to the E2RV algorithm. As the total number of generated packets is directly proportional to network size, if the data packet generation is high, collision chances increase.

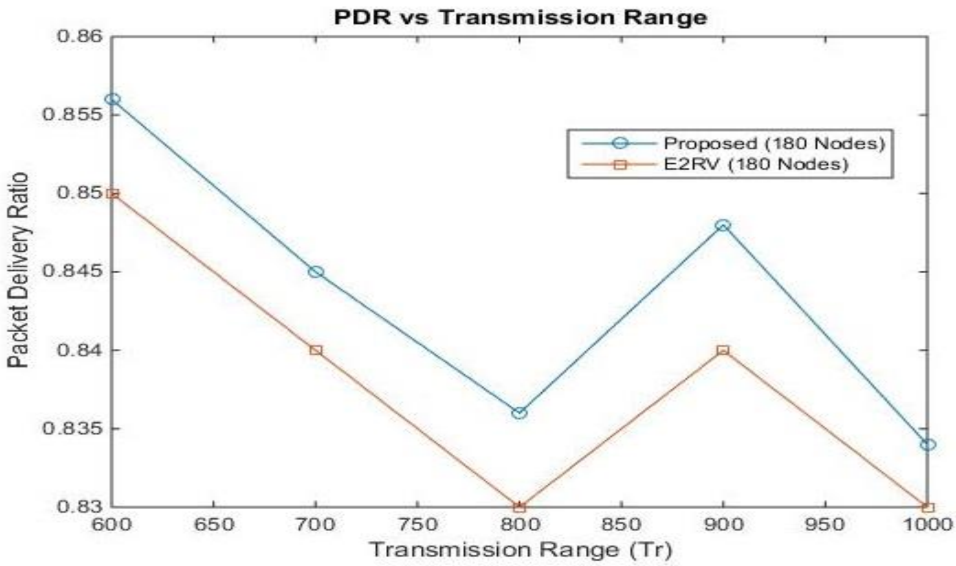

Figure 7. PDR *vs.* transmission range (at 180 nodes).

5.2 Number of Dead Nodes

A sensor node is said to be dead when the battery of the same node is completely used and no power is available to perform the task. The total number of dead nodes depends on the network size. As the network size increases, the number of dead nodes also increases due to the involvement of a large number of nodes to forward the packets. The simulation has been done for varying transmission range with fixed network size in terms of nodes, like 60 nodes, 120 nodes and 180 nodes, respectively. Figures 8, 9 and 10 show that as the number of nodes increases with network size, the number of dead nodes also increases. The reason is that data packet traffic significantly increases with network size.

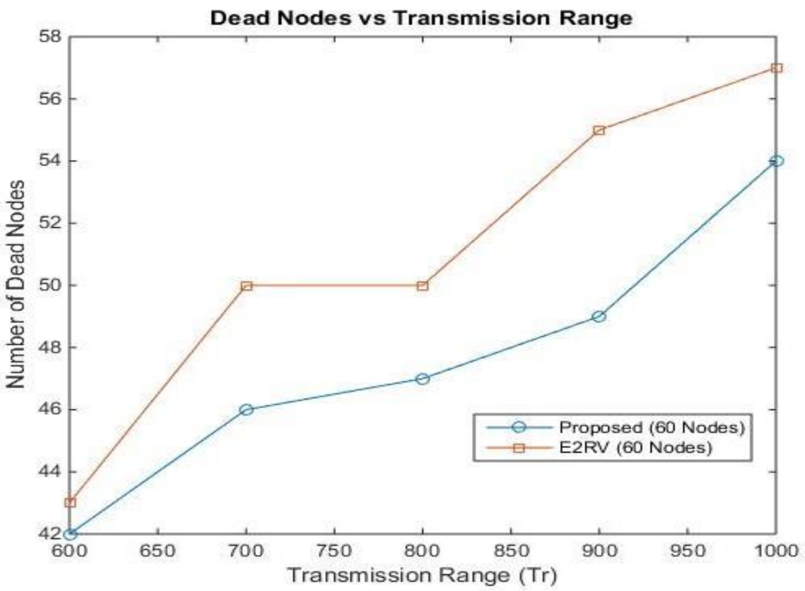

Figure 8. Dead nodes *vs.* transmission range (at 60 nodes).

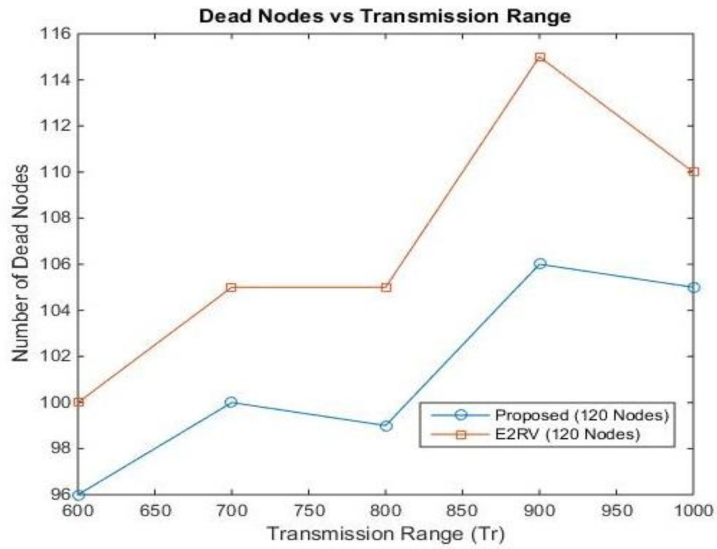

Figure 9. Dead nodes *vs.* transmission range (at 120 nodes).

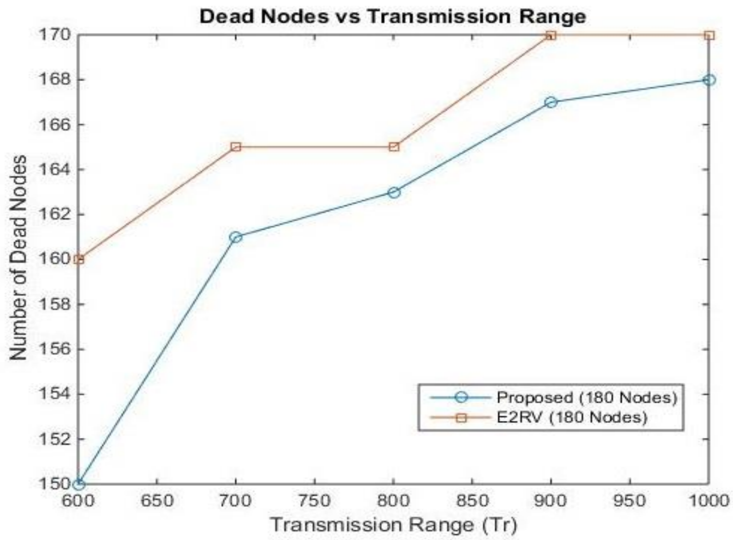

Figure 10. Dead nodes *vs.* transmission range (at 180 nodes).

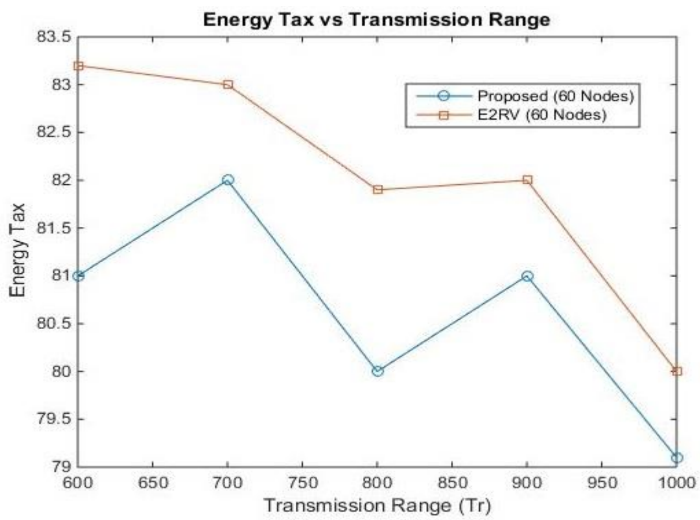

Figure 11. Energy tax *vs.* transmission range (at 60 nodes).

5.3 Energy Tax

The simulation to calculate energy tax has been done with varying transmission range and network size in terms of number of nodes. E2RV consumes more energy and has less packet delivery ratio. When the transmission range (Tr) is varying and network size is fixed, as shown in Figures 11, 12 and 13, respectively, the proposed approach shows good results in terms of energy tax. But, it is also seen that as the network size increases, energy tax slightly increases in both approaches. The reason behind this is that a large volume of energy is consumed to disseminate the large copies of data.

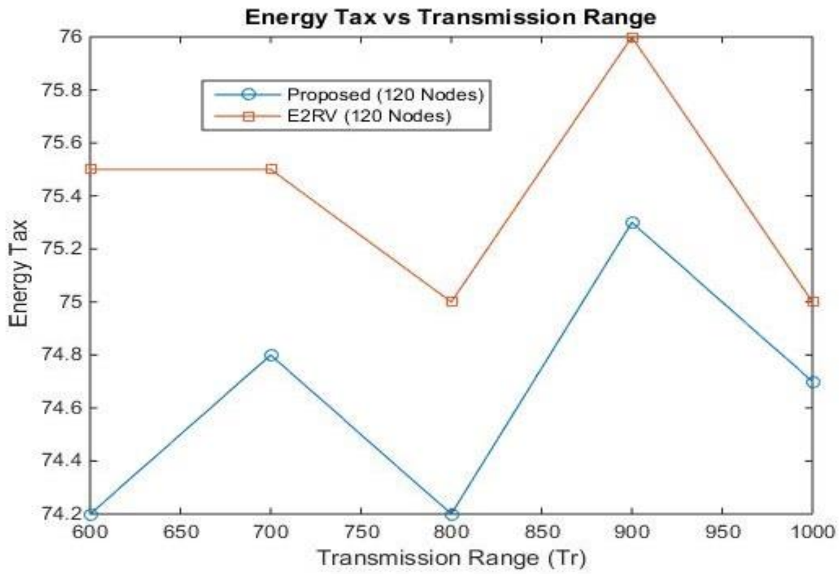

Figure 12. Energy tax *vs.* transmission range (at 120 nodes).

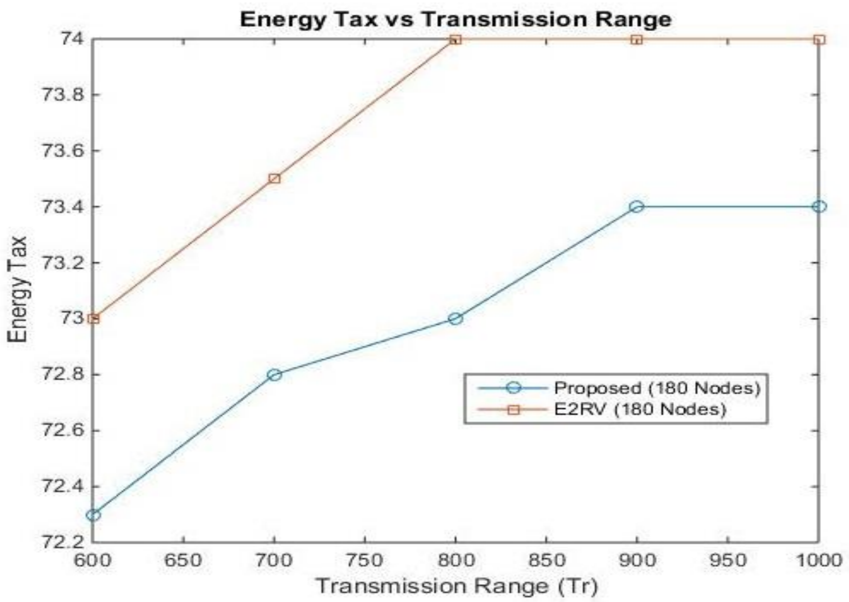

Figure 13. Energy tax *vs.* transmission range (at 180 nodes).

6. CONCLUSIONS

An energy-efficient Quality of Service (QoS) parameter-based void avoidance routing technique for underwater sensor networks has been proposed. In the proposed technique, initially nodes are randomly placed at water surface to form a two-dimensional network topology and a depth optimization technique is proposed here to compute the depth of each sensor node and then inform all the nodes of their optimized depths. By doing this, each node gets its depth and makes a three-dimensional network structure. A candidate forwarder selection method is also implemented here, which is based on fitness function, holding time, depth variance and distance …etc. In addition to this, the proposed work uses the concept of two-hop acknowledgement for successful delivery of data packets at the sink node. The proposed technique has been implemented in MATLAB, where comparison has been done with E2RV approach in terms of Packet Delivery Ratio (PDR), number of dead nodes and energy tax. The proposed approach improves Packet Delivery Ratio (PDR) and reduces the total energy consumption, which in turn decreases the number of dead nodes.

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ملخص البحث:

أصبحت شبكات المجسات تحت الماء أحد أكثر مجالات البحث إثارة؛ فقد فتحت الباب واسعاً أمام الباحثين لإجراء دراسات متخصصة في هذا المجال. والجدير بالذكر أن هناك العديد من المشكلات المرتبطة بشبكات المجسات تحت الماء، لعل من أبرزها منطقة الفراغ التي تحطّ من أداء الشبكة. وهي مشكلة تنطوي على عدم وجود أي عقدة ناقلة تنقل حزم البيانات من عقدة الى أخرى.

لذا يتلخص غرض هذا البحث في تجنب منطقة الفراغ. ولتحقيق ذلك الغرض، تستخدم هذه الدراسة تقنية فعالة من حيث استهلاك الطاقة، تقوم على عدد من متغيرات جودة الخدمة؛ من أجل تجنب الفراغ في شبكات المجسات تحت الماء. ولتجنب منطقة الفراغ في تلك الشبكات، تستخدم التقنية المقترحة معلومات العقد ذات القفزتين. أما منغيرات جودة الخدمة التي أُخذت بعين الاعتبار، فهي: الاحتفاظ، والطاقة المتبقية؛ من أجل إيجاد العقدة الناقلة المُثلى التي ستنقل حزم البيانات الى غايتها.

لقد طُبقت الخوارزمية المقترحة على "ماتلاب"؛ إذ بينت النتائج أداءً أفضل للتقنية المقترحة من حيث: معدل تسليم الحُزم، واستهلاك الطاقة، وعدد العُقد الميتة، وذلك بمقارنتها بالتقنية المسمّاة (E2RV) التي يشيع استخدامها في شبكات المجسات تحت الماء.