Green-Centric Communication Void Avoidance for Underwater Wireless Sensor Networks

Umar Sani[1], Mohd Murtadha Mohamad[2]

[1]*School of Computing, Faculty of Engineering University Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia*
[2]*Department of Computer Science, Faculty of Science, Sokoto State University, PMB 2134, Sokoto, Nigeria*
email: murtadha@utm.my[2]

Abstract: Recently, there is rapid interest in the study of Underwater Wireless Sensor Network (UWSN), which is due to it verse applications such as pollution monitoring, seismic monitoring, equipment monitoring, disaster prevention, tactical surveillance, oceanography data gathering, and assisted navigation. Meanwhile, the realization of these applications is confronted with some underwater limitations namely, acoustic channel constraint, limited bandwidth, and water pressure. Several routing algorithms have been developed to achieve efficient data gathering. However, these algorithms are challenged with communication void problem. The communication void problem leads to packet drop/error and high energy consumption in the course of data packet forwarding. Therefore, in this paper, an improved communication void avoidance mechanism for UWSN has been proposed for handling void hole during data packet forwarding considering dislodgment of sensor nodes. The performance of the proposed mechanism has been evaluated against the adapted adjustment mechanism to confirm its benefit based on different data packet forwarding and energy efficiency metrics.

Keywords : Void hole, Communication void, Underwater wireless sensor network, Data forwarding, Energy efficiency

1. INTRODUCTION

The universe consists of seventy percent water of which ninety percent is of oceans. Thus, humans on earth cannot neglect the large quantity of water (Akyildiz et al., 2005). This has led to the exploration of water medium for gathering and sharing valuable information. The information dissemination employing UWSNs is considered as one of the promising technologies for underwater applications. The applications including pollution monitoring to the determination of natural disasters, oil exploration to aquaculture, submarine function, and climate monitoring (Vasilescu et al., 2005; Partan et al., 2007; Heidemann et al., 2012). In the underwater environment, radiofrequency waves cannot be used as a reliable communication medium. This is because radio frequency equipment depletes more energy by raising the attenuation factor. Generally, water becomes a conductor for radiofrequency waves when the frequency is low at the range of 30 to 300HZ (Latif et al., 2016; Manjula et al., 2011). Further, frequencies in the mention range call for the huge size antennas, which require high transmitting power for data dissemination. However, these prerequisites cannot be accomplished in UWSN. Therefore, radiofrequency waves are not suitable for UWSN. Furthermore, for a receiver and transmitter, the optical waves system requires extremely high precision on a solitary point (He et al., 2005). Nevertheless, sensor nodes are displaced from their positions due to water current. Summarily, the acoustic waves in UWSN must be used. However, the velocity of acoustic waves is 5 times lower than the velocity of radio frequency waves. In the comparison of the underwater medium (UWSN) with that of the terrestrial medium that is, Wireless Sensor Networks (WSN), the underwater medium is very challenging and unpredictable. Thus, the key variations of UWSN and WSN include low bandwidth, low data communication rate, high energy consumption, high environmental noise and interference, high dynamic topology change, and less propagation velocity (Felemban et al., 2006; Wei et al., 2010;).

The development of routing protocols is very essential in UWSN since it specifies the routing path for data from the source node, which is situated at the highest depth of the water to the sink node, which is situated at the surface of the water (Flury et al., 2008; Uichin et al., 2010). Meanwhile, the routing protocols are faced with several challenges related to underwater medium; for example, void hole and movement of sensors, high propagation delay, limited battery, noise, reliable packet delivery, and interference (Mateen et al., 2019). The underwater sensors have limited battery capabilities thus; judicious energy usage is a very important task that needs to be considered during the development of routing protocol. Since the batteries of the sensor node are situated in an underwater environment, which is very difficult to replace and has small energy storage capacity (Xie et al., 2006). Often, battery energy is depleted in the course of data transmission and reception. Efficient or judicious energy relies on many factors, for example, starting position and density of node and the deployment pattern of the nodes (Yan et al., 2008). Underwater sensor node deployment ought to be in one of the two forms namely, dense deployment and sparse deployment. Dense deployment often leads to a large number of sensors breakdown. The sparse deployment could result in the creation of a void hole due to the long proximity between nodes (Coutinho et al., 20018). A void hole is considered as a spot in the transmission coverage of a network in which node cannot discover or select a next neighbour or forwarder node towards the direction of a sink node. The situations that could lead to void hole include lack of neighbour node towards the direction of a sink node and dead node due to high energy usage.

Underwater sensor nodes gather the needed information and forward the data packet to a next forwarding node which has required link quality and is close to a sink node (destination). A sink is considered as a node on the surface of the water. In the data packet forwarding process, the source nodes (highest depth node) creates data packets and communicate with its neighbours to determine the suitable candidate node (Wang et al., 2019). Then, the candidate neighbour node selects the next suitable candidate node from its neighbour and then forwards data packets towards that suitable candidate node (Kheirabadi et al., 2013). In order to select the optimal candidate node from a forwarding node, some decisive factors and routing concepts need to be considered. A number of void avoidance routing protocols have been suggested in the literature (Shin et al., 2012; Noh et al., 2013; Coutinho et al., 2016; Yu et al., 2016; Shah et al., 2018). However, these solutions have one limitation or the other, which leads to inefficient energy usage and/or poor data packet delivery. In our proposed Communication Void Avoidance (CVA) algorithm, the limitations of the existing void avoidance algorithm have been considered and addressed. The CVA algorithm considers the position changing of nodes due to water current, which determines the possible void hole before occurrence. The following are the contributions of this paper:

A proactive communication void avoidance algorithm based on position changes of a node.

An energy-efficient data packet forwarding algorithm considering the void avoidance concept

A link quality parameter based on hop count and residual energy of a node are considered.

A simulation and comparative result analysis of the proposed and benchmark algorithms are provided.

The rest of the paper is structured as follows. Section 2 presents a brief but comprehensive review of the related works. Section 3 presents the design and development of the communication void avoidance algorithm. Section 4 analyses the results of the performance evaluation. Section 5 concludes the paper.

2. RELATED WORKS

In this section, related works on communication void handling algorithms have been presented. A protocol named SPEED has been proposed for handling void hole by dropping the present packet and broadcasting a void message to all its neighbours. Afterward, the trapped node is kept away from the list of forwarding nodes. Void messages are continuously broadcasted until it receives a positive response from a node to discover an alternative route in order to achieve long time routing. The SPEED is centred on QoS-based protocol, which uses its geographic information to update the neighbour table in order to select paths during data packet forwarding (He et al., 2005). An alternative solution for handling a void hole based on geographic routing has been presented by (Liu et al., 2006). The solution employs virtual coordinate systems to select a reference point in the case of communication void occurrence. Further, the Manhattan distance concept has been used instead of Euclidean distance for determining the elevated value of the reference node. The virtual coordinate system algorithm enhances the connectivity and route quality, which addresses the localization errors. Distributed algorithms involving bound hole and tent rule has been introduced to rebuild and classifies the path when void occurs (Fang et al., 2006). The algorithms categorize the nodes into strongly stuck and weakly stuck, which is based on their availability of neighbour nodes and distance within the communication coverage. Thus, the tent rule algorithm determines the strongly stuck node, while the bound hole determines the weakly stuck nodes. However, all the aforementioned algorithms employ backpressure-aware or right-hand rule methods to conquer the communication void. A lightweight algorithm based on a geometric concept to determine potential forwarders for source node in the range of one-hop coverage from the void region. The concept reduces the number forwarders discovered initially in that area to divert the packet away from the void region. In an improved technique, a Vector-Based Void Avoidance (VBVA) algorithm has been proposed for handling communication void. It considers a 3-dimensional network in UWNS (Xie et al., 2009). VBVA works as an on-demand protocol that addresses communication void in ways namely, backpressure and vector-shift. Backpressure direct data packet backward to evade a concave void. The vector-shift is employed to direct the data packet beside the boundary of a void region. If there exists no void, the VBVA uses the Vector-Based Forwarding protocol (VBF) concept (Xie et al., 2006).

Further, a pressure-based opportunistic, which uses pressure sensors to forward data from the source node to the sink (destination node) at the surface of the water has been proposed (Lee et al., 2010). Priority is given to efficient nodes to forward the packet based on the progress level of a node to reduce the number of packet transmission. Meanwhile, a 2-dimensional network structure is considered for evading void region. (Aissani et al., 2012) suggested a two-hop data packet forwarding strategy at the boundary, which traverses the shortest route towards the destination in the case of void occurrence. Further, a Void-Aware Pressure Routing (VAPR) in such a way that the nodes determine their 1-hop neighbour node by employing beaconing (Noh et al., 2013). The contribution of VAPR is twofold including opportunistic directional data packet forwarding and improved beaconing. The beaconing is employed for determining up or down direction for the potential next hop. Thus, based on the obtained direction the data packet is forwarded to the potential node upward/downward. It is a proactive strategy that matched a slow mobility environment. A Geographical and opportunistic Routing named GEDAR has been proposed for addressing communication void (Coutinho et al., 2016). By opportunistically routing packets to more than one sinks. In the presence of void, GEDAR switches to recovery mode in such a way that depth of the void node is adjusted to a new depth. The depth adjustment is regulated by the topology control mechanism in order to move the nodes in the void region to new depths to follow greedy forwarding. In (Yu et al., 2016), a The Division of Weighting Depth and Forwarding Areas (WDFAD) was proposed using the Depth Based Routing (DBR) protocol (WDFAD-DBR). The WDFAD-DBR minimizes the void hole by selecting the next forwarding node based on a weighting depth difference of two hops total. In this the probability of finding a void hole is therefore reduced considering not only the current depth but also the depth of the expected next hop. However, it may not be very useful to determine the depth of the predicted next-hop to predict the void hole, as the node could be displaced before a data packet is fully transmitted from a source node to the sink node. Therefore, a solution that addresses both the best-case and worst-case communication void scenarios based on node position change requires further investigation

3. COMMUNICATION VOID AVOIDANCE SCHEME

In this section, the complete design procedure of the proposed CVA algorithm is presented. It focuses on overcoming the void region in the data packet forwarding process, which improves the overall data delivery in a UWSN. The algorithm involves three stages namely information collection stage void avoidance phase and overall data packet forwarding stage, which is highlighted in Sections 3.1, 3.2, and 3.3 respectively.

3.1 Information Collection Stage

In this stage, every sensor node within the network finds its neighbour nodes by identifying and exchanging information within its network coverage area. Every node spreads a hello message to its neighbour vehicle. This is conducted periodically within a given time interval of one second to avoid message collision, which could lead to overhead. The hello packet is made up of three fields, namely depth value, residual energy, and sender ID. In network, every node that receives the hello packet extracts the information in it and contrasts its depth with that of the hello packet sender. If the information is received from a lower depth node, the information will then be saved to Table of Neighbour Information (TNI), otherwise the packets will be dropped. The weight of each node is measured based on the current residual energy. Also, there is a void alert packet, which is introduced to detecting void nodes in the trap area. See Fig.1 it illustrates the void scenario.

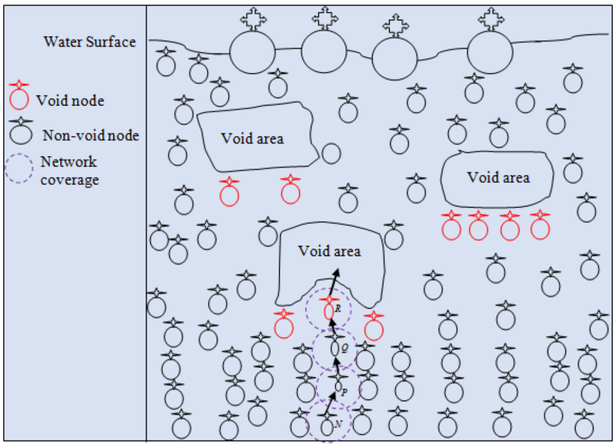

Fig 1. Illustration of Communication Void in UWSN

The void alert packet comprises two fields namely, Sender ID, and Void status. The Sender ID represents the ID of the void status signifies the type of void, void node, and trap node. The concept is in such a way that only void node create and broadcast void alert packet. If a normal node receives the packet, it immediately discards the void node in its TNI. Figure 2, Represents the void alert packet, which is used in the void avoidance stage.

SenderID	status

Fig. 2. Void Alert Packets

Considering Fig 1, the scenario of a communication void that leads to packet loss/drop is represented. Each node forwards the data packet to its lower depth neighbour node. From the figure node N attempt to transmit data to the destination node, which is the sink node. Thus, the node N inserts lower depth nodes ID according to their ranking into the Table of Neighbour Information. The Set N = {P, Q}, thus data packet is transmitted through P, Q. the Q is lower in rank than P. Once node P accepts data packet, it immediately updates it own forwarding set, namely, Set P = {Q, R} and then transfer the data packet. As seen in the figure, node R is in the network coverage of node Q. Node R is the node with the lowest depth from node Q. Since node R does not have any lower depth neighbouring node, say Set R = {}, then communication void occurs and packet are dropped.

3.2 Void Avoidance Stage

The main aim of this stage is the creation of a strategy for avoiding the void area and trap nodes. Hence, avoid avoidance concept, which is centred on the energy efficiency of the sensor node has been developed. In this stage, the position changing of sensor nodes due to water current for estimating void node is highlighted. The position changing information is employed in the neighbour node selection process. There are two major scenarios in which void communication can occur. The first, are the nodes in the middle of the network and the second scenario, is when the nodes at the right and left edge of the network drift out of the network coverage of other nodes. In this solution, the assumption is that the inertial measurement unit is employed by each underwater sensor node. The inertia measurement unit can provide position changing information. Thus, it can be employed for void avoidance assessment.

The right and left edge nodes may easily drift away from the network that is, from other nodes within the network. The communication void avoidance strategy considers the edge nodes and maintains the possible void nodes in the routing table by verifying the inertia measurement unit's data of a neighbour and compare against the current information of that particular node. By so doing, the edge nodes are avoided in the case they are void nodes. For the middle nodes, each node verifies its neighbour table in a given interval of time. If there exists no neighbour node information in its table, then the node declares itself as a void node. It then broadcast a void alert to the nodes with higher depth (nodes below the void node). Every lower depth node that received the alert, verifies the sender's ID whether it is present in its TNI. If true, the nodes update the void status of the sender node in its TNI with the value implanted in the packet, otherwise, it drops the packets. Algorithm 1 presents the pseudocode for communication void avoidance.

From Algorithm 1, when sensor nodes have been displaced by water current, then the inertia measurement unit creates a signal that calls update beacon procedure, which is line 1 to 10. Firstly, it verifies whether the drift-ness or displacement D_{fN} has exceeded a given threshold $D_f N_T$, which is based on transmission coverage of the normal sensor node. Then the node forwards updated beacon to its neighbour nodes, which is line 3-7.

The neighbour nodes that received the beacon first verify if the packet is received from neighbour node with lower depth (node above). The beacon is now verified for position changing information and if the neighbour is drifted out of the coverage area of the current node, then it will update its neighbour table accordingly. If there exists an alternate path towards the sink node in the neighbour table, the alternate path can be employed for forwarding the data packet. Otherwise, the path is also path of the void region. In the present node neighbour table, if there exists no further path towards the sink, then it will forward void alert to higher depth node when the current node is in the middle. When the current node is at the edge of the network there might be no communication towards the other nodes within the network. But it will broadcast beacon to any node available to update then about the current situation. This update will cut-across the whole of the void region and nodes outside the void will become aware of the void region.

Algorithm 1: Void Avoidance Stage

Input: Position Changing Information (PCI)
Output: Update Beacon
1: **Procedure** UpdateBeacon (Bc)
2: **If** $D_f N > D_f N_T$ **then**
3: *Set* Pkt.PacketType ← UB
4: *Set* Pkt.ID ← ID_C
5: *Set* Pkt.Depth ← $Depth_C$
6: *Set* Pkt.PCI ← Drift Information
7: *Set* Void alert ← Trapped node
8: *Forward* Pkt to neighbour nodes
9: **End If**
10: **End Procedure**
Input: Update Beacon
Output: Update Neighbour Table, Forward Beacon Message, Avoid void node
11: **Procedure**ReceiveBeacon (*Pkt*)
12: **If** PacketType (Pkt) = UB **then**
13: **If** $Depth_C$ > Pkt.Depth **then**

```
                    If Neighbour is present in TNI then
                     If Pkt.PCI = Null then
                         Update TNI
                          If path towards sink at edge = False then
                              Set Pkt.ID ← ID_C
                              Set Pkt.Depth ← Depth_C
                              Set Pkt.PCI ← Null
                              Forward Pkt to Neighbour nodes
                          End If
                     Else
                           Compare Pkt.PCI with Neighbour Previous State
                           If D_f N > D_f N_T then
                               Update TNI
                               If Path towards sink at Mid = False then
                                   Set Pkt.ID ← ID_C
                                   Set Pkt.Depth ← Depth_C
                                   Set void alert ← Higher Depth Node (HDN)
                                   Forward Void alert to HDN
                               End If
                       End If
                End If
          Else
                Add Neighbour information in TNI
          End if
      Else
                Drop Pkt
       End If
   End If
End Procedure
```

3.3 Data Packet Forwarding Stage

The Data packet forwarding concept focusing on energy efficiency by avoiding void node has been presented. In the data packet forwarding process, the first stage is triggered in order to exchange information among sensor nodes within the network. A forwarding node attempts to select a void-free node while also considering the residual energy and hop count of the next forwarding node. Each forwarder node sort it TNI based on residual energy level and hops count by trying to evade the void nodes. Thus, the void-free node with the highest residual energy and lowest hop count of the list is selected. This is to balance the energy utilization of nodes within the network. This strategy is considered throughout the data packet forwarding stage from the highest depth node to the sink node. The step-by-step procedure of the stage is represented in Algorithm 2.

Algorithm 2: Data Packet Forwarding Stage
Input: Data to be forwarded
Output: Data Packet Forwarding

```
Procedure ForwardData (Data Pkt)
```

```
2.  If Neighbor information not exchanged then
3.   Call stage 1
4.  End If
5.  If PCI and void avoidance is required then
6.   Call Algorithm 1
7.  End If
8.  Set List ← Sort (TNI, Hop count, Descending)
9.  Set List ←Select (Nodes with Max Residual Energy (RE))
10. Select First/ Next Node in List
11. If node is void node then
12.       If no more nodes available then
13.    No possible path
14.       Else
15.      Select Next Node in List
16.      Goto step 10
17.    End If
18. Else
19.    Set Send Counter ←1
20.    Forward Data to Selected node
21.    If Send Counter = 3 then
22.      Goto Step 10
23.    Else
24.      Wait for Echo
25.      If No Echo Then
26.            Increment Send Counter
27.            Goto Step 20
28.      End If
29.    End if
30. End if
31. End Procedure
```

4. PERFORMANCE EVALUATION

In this section, the setup of the simulation and analysis of the results obtained have been presented. The CVA algorithm has been compared against Weight Depth Forwarding Area Division based on Depth-Based Routing (WDFAD-DBR) algorithm. Some experiments were carried out to assess the performance of the communication void avoidance algorithm. In the cause of the assessment, two evaluation metrics have been employed namely, Packet Delivery Ratio (PDR) and Total Energy Consumption (TEC). Each of the metrics has been plotted alongside different node densities and the number of void holes. PDR is considered as the ratio of the number of packets received by the sink node from the source node to the number of packets not delivered. The experiment is carried out considering node densities ranging from 100 to 500 nodes. While the number of void nodes is varied from 0 to 30 void holes.

The simulation framework for the implementation of the proposed algorithm is presented in this section. The implementation is carried out using AquaSim of NS-2 (Xie *et al.,* 2009). An AquaSim is a software tool that is usually used for simulating an underwater sensors communication over NS-2. It also works in parallel with the Communication Management Unit

(CMU) of wireless package. The AquaSim offers a more realistic and accurate simulation that mimics a real-life scenario. This is because the Media Access Control (MAC) protocol and the acoustic channel are provided in the MAC layer and physical layer of the AquaSim respectively. Similar to both VBF of Xie *et al.* (2009) and DBF of Yan *et al.* (2008), the AquaSim over NS-2 was employed as their simulator. Thu, AquaSim has been chosen for implementing the proposed algorithm based on the justification of previous literature.

The appropriate standard settings and parameters applied in the experiment are used based on the most applicable and accessible algorithms in order to test the proposed data communication algorithms. An inertia measurement unit was employed for calculation displacement acceleration as in (Tayyab et al., 2019). The underwater is generally considered as a 3-Dimensional architecture as employed in (Yan *et al.*, 2008; Wahid and Kim, 2012). The communication coverage of the sensor nodes has been set to 250m (Noh *et al.*, 2013). The random topology is made 5 times larger than the communication coverage of each node. Thus, the area is set as 1250 × 1250 × 1250m (Yan *et al.*, 2008). Various numbers of nodes ranging from 50 to 400 are used randomly in the simulated area. The vertical speed movement is set as 0m/s since it is negligible, while the horizontal speed movement is set as 0 to 3m/s (Wahid and Kim, 2012). The number of sinks deployed is based on the number of the sensor nodes in the network, which ranges from 3 to 7 sinks. The hello message periodic interval is set as 100s. The creation of a data packet by the source node at the application layer is in the size of 64bytes As in the case of Wahid *et al.* (2014). The bandwidth is 10kbps while the acoustic speed is 1500m/s as employed by Yan *et al.* (2008) and Noh *et al.* (2013). The overall initialized sensor node energy is 100j. The total energy consumption in idle, transmission, and receiving states is set as 0.01mw, 2w, and 0.75w respectively as used in Wahid and Kim (2012). The MAC protocol to broadcast is used in the MAC layer as a basic MAC protocol. The total duration of the simulation is set as the 1500s. In the estimation of results, the average of 50 runs is employed to achieve an accuracy as employed by Yan *et al.* (2008) and Noh *et al.* (2013). The void area is modelled by not placing node to certain areas of the network. Thus, having a void hole, this can be used to assess node entrapment. Meanwhile, Table 1 depicts the simulation parameters employed in the implementation of the proposed algorithms.

The benchmarking algorithm namely WDFAD-DBR is designed and developed using C++ programming language at the network layer of the AquaSim. The same programming language is employed for the proposed algorithms. Different simulation scenarios would be developed using the TCL programming language and executed. The results of the simulation would be generated from the trace files using AWK scripting language and the result is saved in text files. Afterward, the X-Graph and MATLAB are employed to generate the final results of the simulation from the extracted text files

Table 1: Simulation Parameters

Simulation Parameters	**Values**
Area of Deployment	1250 × 1250 × 1250m
Network Topology	Random
Number of Sink Nodes	3 to 7
Number of Nodes	50 to 400
The Transmission Range	250m
MAC Protocol	Broadcast Protocol
The Initial Energy	100J

The Communication Medium	Acoustic Waves
Th Bandwidth	10kbps
Velocity Signal	1500m/s
Horizontal Node Movement	0 to 3m/s
Vertical Node Movement	0m/s
Idle State Energy Consumption	0.01mw
Transmission State Energy Consumption	2w
Receiving State Energy Consumption	0.75w
Size of Data Packet	64 byte
Hello Message Interval	100s
Simulation Time	1500s
Number of Runs	50 times

4.1 Performance Metrics

In this section, the metrics employed for assessing the performance improvement attained in the proposed algorithm against the baseline algorithm has been presented. Packet delivery ratio and total energy consumption are the two metrics considered in this paper.

4. 1.1 Packet Delivery Ratio

Is the estimation of the ratio between the numbers of packets created at the source node and that of the number of packets successfully delivered to the sink node The mathematical formula employed to calculate PDR in terms of percentage is expressed in Eq 1.

$$PDR\% = \left(\sum_{i=1}^{50} \frac{PR}{PS} \Big/ 50 \right) \times 100 \qquad (1)$$

Where PS is the number of packets sent and PS is the number of packets successfully received, the value 50 is the number of simulations conducted, which the average is taken.

4. 1. 2 Total Energy Consumption

Total Energy Consumption (TEC) is the overall energy depleted by the batteries of each sensor node during idle, transmission, and receiving state. The underwater sensors use batteries as a source of energy for power. These batteries are limited in terms of capacity and they are not replaceable. The TEC is estimated using the energy model employed in VBF by Xie *et al.* (2009) as expressed in Eq 2.

$$TEC = \sum_{i=1}^{N+SN} E_{TEC_{Nodei}} \qquad (2)$$

Where N is the number of sensor nodes it denotes the number of sink nodes as SN and the $E_{TEC_{Nodei}}$ is the whole energy depleted by $Node\ i$.

4.2 Result analysis of CVA

In this section, the results obtained based on packet delivery ratio and total energy consumption are presented in graphical format an analysed. Subsection 4.2.1 and 4.2.2 represent the results discussion of packet delivery ratio and total energy consumption.

4.2.1 Packet Delivery Ratio

The Packet Delivery Ratio (PDR) has been studied alongside the various node densities. It is a metric employed to evaluate the packets delivered successfully in contrast to the packet sent by the source node. It is calculated by running the simulation several times and taking the average, which is multiplied by 100 to get a percentage. The packet loss ratio is inversely proportionally to the PDR. The two expressions might be used interchangeably by different researchers. In Fig 3, the result shows that the PDR value increases as the number of nodes increase for both WDFAD-DBR and the proposed CVA algorithm. This is because the larger the number of nodes within the network the higher the possibility of selecting the next forwarder node. Thus, reducing the probability of packet loss due to non-availability of a node within the forwarding area. The proposed CVA algorithm achieved a higher packet delivery ratio compared to the WDFAD-DBR because it considers the position changing of nodes by employing an inertia measurement unit for earlier detection of nodes that have drifted away from their neighbouring node and the network entirely. The inertia measurement unit estimates the displacement of nodes at the extreme left and right side of the network and avoids selecting them as the next forwarding node. Hence, avoid the creation of a void region/node that could lead to packet loss during data packet transmission. The CVA algorithm achieves a 2.5% increase in packet delivery when the number of nodes is up to 500 nodes.

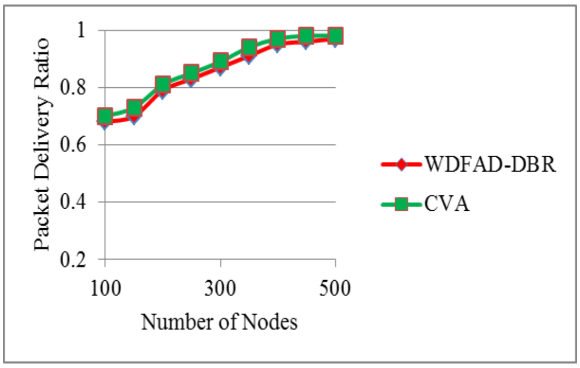

Fig. 4 Packet Delivery Ratio of Various Void Regions at 250 Nodes

In Fig 5, the results of the packet delivery ratio based on a different number of void regions have been studied. The number of nodes is fixed at 500, while the void region is varied from 0 to 30 with a range of 5 values intervals. The results obtained in Fig 5 are better when the nodes are 500 as compared to Fig 4 when the number of nodes is fixed to 250 nodes. The CVA algorithm also outperformed the WDFAD-DBR algorithm with a 7.1% increase in packet delivery when the number of nodes is 500 and the void region is considered.

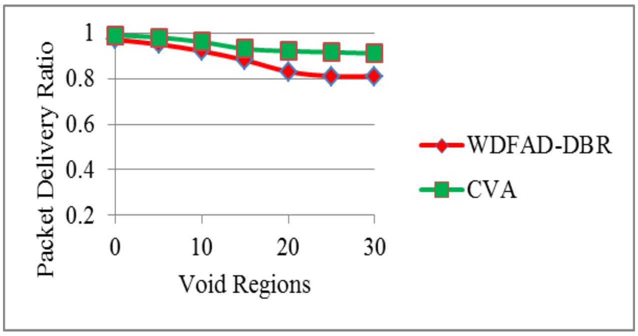

Fig. 5 Packet Delivery Ratio of Various Void Regions at 500 Nodes

4.2.2 Total Energy Consumption

In this subsection, the most important metric for evaluating the energy efficiency of an algorithm is the total energy consumption metric. It is employed to estimate the overall energy depletion of a node after a given period of data packet transmission. Therefore, the energy depletion alongside the various node densities and various numbers of void regions is shown in Figs 6, 7, and 8 respectively. The results of the proposed CVA algorithm against the baseline scheme namely WDFAD-DBR has been studied. The result studied is based on a different node and void region densities against the total energy depleted by the node densities. From Fig 6, the proposed CVA algorithm achieved lower energy consumption compared to the WDFAD-DBR algorithm. This is in connection with the earlier avoidance of void hole/region by employing the inertia measurement unit for estimating the displacement of node away from neighbouring nodes and the network. The earlier avoidance does not allow a forwarding node to forward the packet to avoid area hence, minimizes packet retransmission that could lead to higher energy depletion. The proposed CVA algorithm achieved as low as 28000 joules at an average when the number of nodes is 500, while the WDFAD-DBR attained 37000 joules at the same number of nodes. Consequently, the proposed CVA algorithm outperformed the WDFAD-DBR in terms of energy efficiency with a 19.3% decrease in TEC.

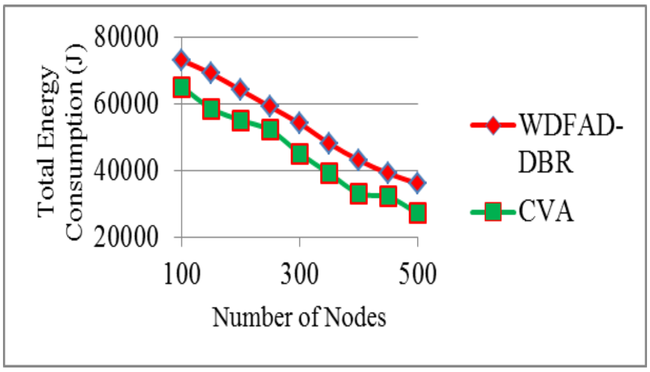

Fig. 6 Total Energy Consumption of Various Numbers of Nodes

In Fig 7, the results of the average total energy consumption against the various void regions have been observed. The density of the node considered is fixed to 250, while the void is varied between 0 to 30 void regions. From the result, a proportional correlation is observed between the energy consumption and void regions. Since there is no large holding time and depth adjustment, the CVA performs better than the WDFAD-DBR with a 21.6% decrease in TEC when the nodes are 250.

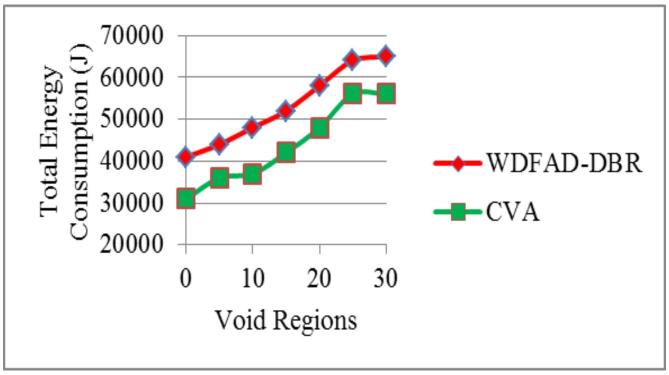

Fig. 7 Total Energy Consumption of Various Numbers of Void Regions at 250 Nodes

In Fig 8, the results of the average total energy consumption against the different void regions have been observed. The density of the node considered is fixed at 500, while the void is varied between 0 to 30 void regions. From the result, a proportional correlation is also observed between the energy consumption and void regions. Since there is no large holding time and packet retransmission, the CVA performs better than the WDFAD-DBR when the nodes are 500. Thus, the proposed CVA algorithm outperformed the baseline algorithm named WDFAD-DBR with a 19.2% decrease in TEC.

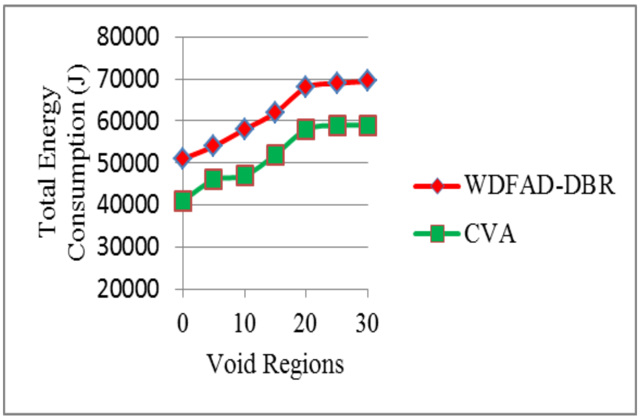

Fig. 8 Total Energy Consumption of Various Numbers of Void Regions at 500 Nodes

5. CONCLUSION

In this paper, a communication void avoidance algorithm in underwater wireless sensor networks has been proposed. The CVA algorithm focuses on determining node displacement before data packet transmission. Thus, this enabled early detection of potential void nodes during data packet forwarding. Further, the algorithm considered two metrics namely, residual energy and hop count for selecting an optimal node that serves a packet forwarder. The overall aim is to improve the rate of data delivery while less energy is depleted by the sensor nodes. Therefore, the performance of the proposed algorithm is assessed considering two metrics namely, packet delivery ratio and total energy consumption. In conclusion, the obtained results have proven that our proposed work can evade void, which in turn reduces the energy consumption and increases the packet delivery ratio in underwater wireless sensor communication.

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